COMMUNICATIONS

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Dear readers,

This volume of Communications, the scientific letters of the University of Zilina offers us briefly to present some projects and results of our university, its research teams, faculties and departments, institutes and centres over the past years.

The University of Zilina was established 60 years ago in Prague and after various organizational changes it became a full University in character, named since November 1996 the University of Zilina. Today the University of Zilina has approximately 1500 employees including 700 teachers, 200 researchers and 11500 students. The sixty years celebration is a good opportunity to look back and evaluate what we have done, but also what we can expect in the future. We are an educational institution with one of the longest traditions in the Slovak Republic. We have provided education and training based on the latest scientific knowledge, science and research in the broad international context, for young people under various political regimes. In the long run I consider this our advantage. It gave us a wider view, 'setback' and we can compare. Anyway, the pace of changes in the recent years has been amazing. Our core business is and will be the education and training based on excellent research with strong commitment to entrepreneurial environment. As a modern future-orientated research and educational institution we have developed cooperation with many partners' universities, research institutions and businesses or governmental and non-governmental institutions. The University of Zilina has promoted the improvement of education and research infrastructure and supported the integrated university-orientated approach to excellent research teams by the projects of university scientific park and research centre or centres of excellences.

The role of university is changing over time from students education and dissemination of scientific knowledge through creation and generation of new scientific knowledge and knowledge or technology transfer to the industry and creation of new business units with new products, new professions, to building the space or platforms for technology cooperation and exchange or open access to the scientific knowledge.

We are living in the era of many rapid changes and it is still accelerating; the economy is based on the gold of the modern age – knowledge. The knowledge and skills have become the global currency of the 21st century, knowledgeable and skilled people are the key to the future. Traditional structures are giving way to new models. Emerging technologies are reshaping industry. New economies are reshaping the patterns of international business, trade and international relations. The international relations among countries are being re-evaluated and re-formed. The relations among the academic research communities and commercial enterprises, relations among regions, cities etc. – all are evolving at an accelerated pace, responding to new opportunities and challenges, driven by explosive new developments in technology, new attitudes as a result of new levels of consciousness and awareness concerning the experience of life and a rising tide of human expectation.

I hope you will enjoy reading this issue of Communications as the contributions are presenting a range of ideas and focus on new knowledge and creativity.

Tatiana Corejova

COMMUNICATIONS

Jan Janech – Tomas Baca – Anton Lieskovsky – Emil Krsak – Karol Matiasko *

DISTRIBUTED DATABASE SYSTEMS AND DATA REPLICATION ALGORITHMS FOR INTELLIGENT TRANSPORT SYSTEMS

One can look at the vehicular ad hoc network (VANET) as at the source and storage of information useful for the safety, fluency and comfort of road traffic, which makes it a valuable tool for ITS. Our research is focused on data dissemination in VANET. We perceive the nodes of VANET as the nodes of a distributed database system (DDBS). As such they do not only store data but they also create new data. Normally, in the course of time the data lose their usefulness. The system we designed was tested by means of a computer simulation carried out by the simulation tool AdHocSim.FRI.

Keywords: *VANET, ITS, DDBS, simulation, data dissemination, AdHocSim.FRI, AD-DB.FRI.*

1. Introduction

The vehicular ad-hoc networks (VANETs) are the subset of mobile ad-hoc networks (MANET) with the differentiating quality based on vehicles being the network nodes. This means that how the node moves is affected by the traffic regulations. In a network like this each node plays the role of an end-system, as well as it behaves like a node that is capable of sending data into the environment, or communicating with the other nodes. The mobility of VANET networks and partial absence of a fixed infrastructure are what makes VANET attractive for time-critical applications. As the movement of on-board-unit nodes (*OBU*) is limited by traffic rules, *VANET* utilizes certain nodes called road-side-units (*RSU*) that are fixed to road-traffic infrastructure.

In our article we look at *VANET* as it is a distributed database system. In a distributed database system, data are often replicated. The aim of the replications is to improve the reliability and availability of the data throughout the whole network. In fixed networks, the replicas are often stored on the nodes that need them the most, in order to reduce the cost of the remote data access. However, in *VANET*, due to the excessive mobility of *OBU* nodes, this kind of solution is inadequate. The availability and reliability (consistency) of the data become an important problem. The fragmentation of the network and slow responses from some of the nodes in particular has an influence over the availability and reliability (consistency) of the data in VANET.

2. State of the Art

Besides our own *AD-DB .FRI* protocol described in Section 3, there is no other solution that would focus specifically on the *VANET* environment. On the other hand, there are some more general solutions for the *MANET*.

The *TriM* protocol [1][2] is the one of the first ones which attempted to solve the data distribution in *MANET* in a general way. It was developed as a part of a dissertation thesis at the University of Oklahoma [1]. It was designed mainly with the regard to energy consumption and the possibility of using three modes of communication [2]:

- Push mode – it represents sending the data via broadcast messages.
- Pull mode – it represents sending the data on the basis of a request.
- P2P communication – data request.

The protocol takes into account the distinction between two node types: *SMH* and *LMH*. A client or a small mobile host (*SMH*) is a node with limited computing resources, limited storage capacity, limited possibilities of communication and limited energy source. A server or a large mobile host (*LMH*), in contrast to *SMH*, has less limited resources. In the protocol, LMH is used as a database server.

The main disadvantage of the protocol is that it requires each server to have the same data [3].

The *HDD3M* protocol tries to fix the problems of the *TriM* protocol. Just like the *TriM*, it uses all of the three modes of communication. It tries to optimize their usage for the energy consumption. But, unlike the *TriM*, it provides the possibility of data fragmentation in the mobile *DDBS*, and it also deals with the data changes in the transactions [3].

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The *HDD3M* distinguish three types of nodes: a request node which sends queries to *DDBS*, a database node containing its own mobile database, and a database directory which contains the information about the fragment location in the distributed database. The database directory is also responsible for receiving and processing the queries from the individual nodes.

However, the problem of these protocols is that they focus primarily on the minimum consumption. This is an important feature to have for the general *MANET*, but at the same time it constitutes an obstacle in the deployment in the *VANET* environment. There are many restrictions for the systems operating in *VANET* but the limitation of the energy source or computing power is not one of them.

3. The concept of the AD-DB .FRI database system

With the classical distributed databases, it is necessary for each node to know about all of the other nodes, as well as about the distribution of the data on them. This information makes it possible to execute distributed queries. The query node needs to know whom to send which parts of the query. The information about the data distribution in the system is stored in so called Global Directory/Dictionary (*GD/D*) [4].

If we try to transfer this principle into the *VANET* environment, we will find out that it is impossible [1][5][6]. The individual nodes of the network are not aware of each other, and it is even technically impossible to guarantee constant possibility of their mutual communication.

The only way how to use the distributed database systems in the *VANET* environment is to replace the *GD/D* by a different principle. In *VANET*, every node is familiar with only its immediate surroundings. Therefore, making any queries in such environment is remarkably limited. The only nodes we can require data from are those within the communication range of the query node. That is why the virtual node-clusters are naturally created in the system. They can communicate with each other and pass on the data between each other.

Therefore, our solution is to restrict the possibilities of making queries only to the nodes accessible within a cluster, and to introduce a new notion – Cluster Directory/Dictionary (*CD/D*). The *CD/D* contains information about the distribution of just the data accessible in the current cluster. But, to simplify the system, this catalogue never exists as one whole. Each of the nodes remembers only a part of it, concerning the fragment of the distributed database handled by the node in question. Also Ozsu and Valduriez [4] describe this method as one of the ways of storing *GD/D*.

Our *AD-DB .FRI* system develops this idea even further. The *CD/D* does not get folded even when a query is being carried out. Instead, the query is sent to all nodes neighboring to the query node. The data nodes which receive the query decide on their own, on the grounds of their part of the *CD/D*, whether to send any data to the query node. This way, most problems caused by the introduction of the distributed database system in the *VANET* environment are solved. The query execution process does not depend on whether the query node can communicate and who with. The only thing that changes is the set of data which the node receives as a reply. Therefore, the *AD-DB .FRI* system is possible to use only in case it does not matter that completed data are not the reply. Thanks to using the specialized *OSACP* protocol (see Section 4), the system even enables processing incomplete data in case the connection between the data node and query node is interrupted during sending the reply.

By means of the principle described above, the *AD-DB .FRI* enables to use two querying methods, according to the communication mode being used: the pull method and the push method.

3.1 Pull method

A query node sends a query packed as a broadcast message. Each data node which receives the query checks whether it has the requested data or their part. If it does, it sends the answer to the query node in the form of the unicast message. In case it could respond to the query only partly, it informs so in its reply, and says specifically which part of the query it was able to process. The query node waits for the response for a specified period of time, and then it starts processing the replies. If it receives partial responses, it tries to interconnect them by the operations which remained unexecuted in the query.

The principle is illustrated in Fig. 1.

3.2 Push method

A data node in regular intervals sends responses to a pre-programmed query, bundled with the query itself, in the form of a broadcast message. If any of the nodes receives this response, it checks if it needs the given data, and if it does, it processes them.

The principle is illustrated in Fig. 2.

4. Object Structure Aware Communication Protocol (OSACP)

The *OSACP* is an application level communication protocol. It is designed to provide the communication layer for the *AD-DB .FRI*. It is supposed to transfer large messages with a well-defined internal object structure that is known equally to both, the sender and the receiver of the message. The protocol follows the philosophy of *AD-DB .FRI* that the query node does not expect and does not require to receive complete responses from all data nodes in *VANET*. Instead, it tries to put together as much valuable information as possible from the data that it has managed to receive at a given moment.

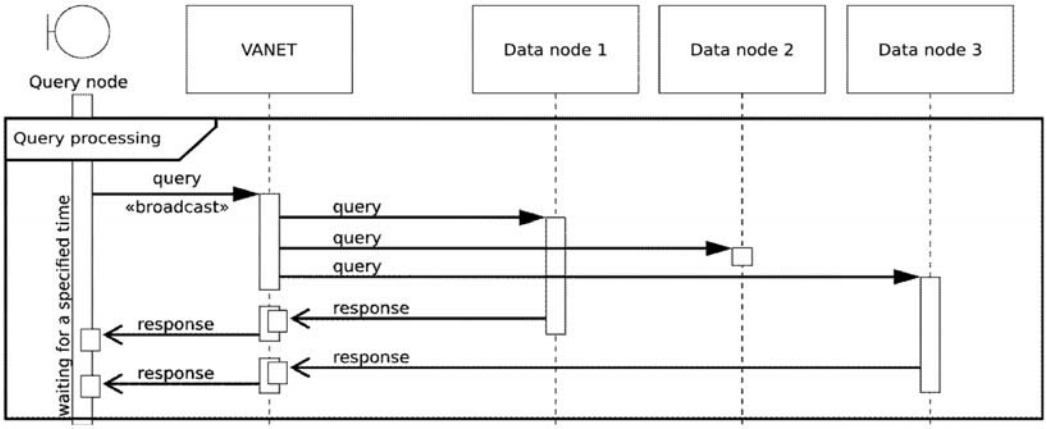

Fig. 1 PULL method

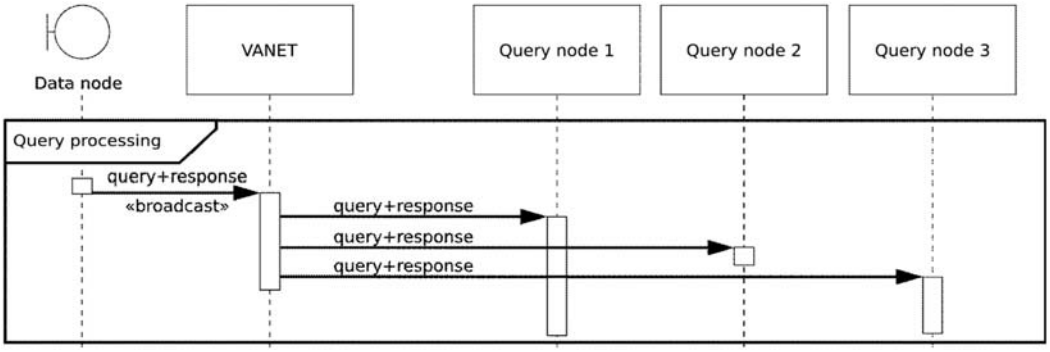

Fig. 2 PUSH method

The endpoint-to-endpoint communication service is provided by the User Datagram Protocol (*UDP*) protocol, which runs atop Internet Protocol version 6 (*IPv6*). We have experimentally compared it with the Transmission Control Protocol (*TCP*), the only other available alternative, in the simulation of *AD-DB .FRI* in *VANET* and we discovered that the UDP outperforms the *TCP* in efficiency and the total amount of useful data delivered [7][8][9]. Since neither the sender nor the receiver is informed by the *UDP* on the successfulness of a datagram delivery, it is up to the *OSACP* to deal with losses, duplications and changed order in the delivery of datagrams by itself. Moreover, the network communication between two arbitrary endpoints in *VANET* is frequently short-lived, and its interruptions are often irreparable. Therefore, the *OSACP* handles any interruption as a standard situation, and not an error.

Any message transmitted by the *OSACP* is expected to have an object structure with one major object that directly or indirectly refers to all of the other objects of the structure. If any object in the original structure is referenced to more than once, then, before the message is sent, all but one reference are replaced by the virtual

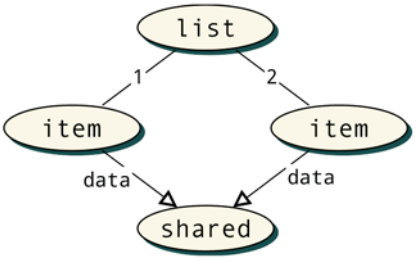

Fig. 3 Object structure with references forming a cycle

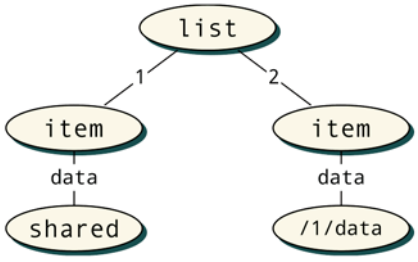

Fig. 4 Object structure with replaced reference by new Address object

Address objects. Afterwards the message takes up a tree structure, in which the main object is in the root of the tree. Then we assume that every node in the tree carries enough data to make its contents at least partly meaningful even without the data stored in its child nodes. On the other hand, its data are not expected to make any sense without the context of the data stored in its parent nodes. Practically, the elementary values (numbers, texts, etc.) are stored in the leaf nodes. The non-leaf nodes represent complex objects composed of the references to other objects, and thus they create a multi-level tree structure.

```
ROOT ::= LIST[65535] of Person;

Person ::= SEQUENCE {
   id       INTEGER {1 .. 1000000},
   name     STRING[20],
   surname  STRING[20],\
   shared   POINTER to STRING[65535]
}
```

Fig. 5 Sample declaration of an object structure

Both, the sender and the receiver of the message are expected to share the same declaration of the transported object structure. The declaration specifies the class of the main object, the list of its attributes, their classes and so on. The declarations are either hard-coded or derived from their previous communication, e.g. it is possible to derive the declaration of database response from a database query. Using the declaration enables the communication protocol to recognize the object structure.

Messages are expected to be relatively large, hence, inevitably fragmented, so that every fragment fits into one datagram. Depending on the momentary network state, any fragment may get lost during the transmission, therefore every fragment has to be processable independently on the other fragments. That is why the *OSACP* inserts an identifier of the message as a whole into every fragment. The identifier, among other things, matches the transmitted object structure within the message to its declaration. Every fragment also contains its identifier within the message, composed of the relative address of first leaf node encoded in the given fragment. Furthermore, every fragment contains the data from the tree-root node, as well as the data from the parent nodes for every node which is transferred in the given fragment. Although it may seem that this would cause too much redundancy, we believe that most of the non-leaf node data are possible to derive from the declaration, and that is why it is not necessary to transfer them within the fragment.

Our data-encoding was inspired by the *ASN.1 DER*, which uses the *type-length-value* triplet for every object of the object structure. The *OSACP* uses the declaration of the object structure which already contains the information about the type and length of most of the objects. The length is not clear only in cases of collections and texts, and the type is ambiguous only rarely.

Thanks to the identifier of the message and the identifier of the fragment, the declaration of the object structure can be assigned to the received message. It is possible to create the skeleton of the message from the declaration. Consequently, the skeleton of the message gets filled in by the receiver with the data received in the individual fragments. Should any datagrams not be received properly, then the skeleton of the message is not filled in completely, yet, because its missing parts are explicitly denoted, the message-receiving process is able to recognize them.

5. Replication algorithms

The application usage of the technologies mentioned so far (Pull, Push, *AD-DB .FRI, OSACP*) is applied namely with distributing the data in the Ad-Hoc network. Since our work deals with the data distribution in the Ad-Hoc network of *VANET* type, we can also speak of the data replication in *VANET*. Therefore, replication algorithms for *VANET* which would use the mentioned technologies are required.

Due to the specific attributes of the *VANET* (frequent changes of the network topology, high node mobility etc.), we designed a series of our own algorithms, to add up to the existing ones.

5.1 Skip Copy algorithm

It is a replication algorithm designed for the *MANET* networks but, of all generally known algorithms, it meets the *VANET* network needs the best. Skip Copy algorithm [10] functions as follows: it provides sending data only up to a certain distance from the source node (Position parameter and Hop parameter). The data replicas are not created on all of the neighboring nodes but only on each nth node determined by Skip parameter.

The main advantage of this algorithm is that it is not necessary to keep the chart of the information on the neighboring nodes.

5.2 AORPlD algorithm

The Active *OBU* Replica Pull Dissemination algorithm (*AORPlD*) is based on Pull method mentioned in Section 3.1. It functions as follows: after a query is sent out, the node waits for an established period of time (timeout) for the reply. When the reply comes, the query node matches it to the sent query. After the given time limit expires, the node ceases to expect any replies, and considers the query processed.

5.3 AORPsD algorithm

The Active *OBU* Replica Push Dissemination algorithm (*AORPsD*) as the method of the data replication in the *VANET* network, using *AD-DB .FRI*, also enables mobile nodes to function as replication nodes. *AORPsD* runs in two threads. The first one

runs in *RSU* and *OBU*, and it is in charge of distributing data into the network using Push method, according to Section 3.2. The second one runs only in the *OBU* nodes, and takes care of processing the replicas [11][12].

5.4 SPA algorithm

The Simple Pulling Algorithm (*SPA*) principle of the replication algorithm is based on the fact that the *OBU* nodes in *VANET* do not try to behave like replication nodes. Their aim is to satisfy only their own queries. All they try to do is to update the replicas they are interested in in the given time. Doing so, they do not try to extend their local DB by the data (replicas) which could have some meaning to them in the future. Each node in the network owns its own local DB over which it implements local queries.

5.5 IRA algorithm

The Independent Replication Algorithm (*IRA*), unlike *SPA*, also thinks of creating the replicas of the data *OBU* currently does not need. In established intervals, each *OBU* in *VANET* sends the information about the content of its local *DB*. On the basis of the information the other *OBU*s in the network do the update of their databases. The remarkable difference between the *IRA* and *SPA* algorithms is that the node, while using *IRA*, always does a query on its local *DB*, and gets the result immediately.

5.6 DRA algorithm

This algorithm combines the good properties of both SPA and the IRA algorithms. The first part of this algorithm is based on SPA algorithm. Second part is realized by IRA algoritm.

It means, that decision to realised IRA algorithm is conditioned by request creation on OBU side.

5.7 PDDA algorithm

The Push Different Data Algorithm (*PDDA*) distributes data by means of Push method only. At first, the *RSU* nodes distribute data over the environment. Consequently, the *OBU* nodes distribute the data that they own but they did not acquire them from the environment. Therefore, the distributed data are different from the ones the current *RSU* distributes. The aim of this algorithm is to achieve a balanced information status in the *VANET*.

6. Simulation experiment

The goal of the simulation experiment was to implement a data replication in *VANET* using the described technologies and designed algorithms. The simulation experiments were implemented by means of the *AdHocSim.FRI* tool.

When assessing the simulation experiments, we followed two values:

- Satisfaction with the data a node needed in a given moment. We modeled the satisfaction with the data by means of so called L-function [13]. (later data meant higher satisfaction)
- The volume of the transmitted data, the load on the transmission channel of the *VANET* respectively.

The simulation scenario for all algorithms was identical. The *OBU* units that receive information from other *OBU* and *RSU* units, come into the road network. The information is received on a request from a particular *OBU*. The behavior of the *OBU* and *RSU* units is specifically determined by the replication algorithm.

6.1 The simulation tool AdHocSim.FRI

AdHocSim.FRI [7][14][15] is a discrete event simulation tool specialized on the simulation of deployed applications within the *VANET* environment. It contains the model of road traffic, models of *WAVE DSRC, IPv6, TCP, UDP* protocols and the model of an on-board computer with an operating system embedded in cars. It is implemented in Python, and the simulations are defined in Python as well [7][14][15].

6.2 Results

Implementing the simulation experiments brought the following results: from the viewpoint of the satisfaction with the data, the algorithms *DRA* and *PDDA* proved themselves to be the most successful (see Fig. 6–7).

It is important to note that the related algorithm (IRA and DRA) have quite different results. Satisfaction of DRA algorithm is higher than satisfaction of algorithm IRA. It means, that higher satisfaction is not achieved by more frequent iterations of IRA algorithm. Higher satisfaction is achieved by using the algorithm in "the right time", that is, when the request on the OBU is created.

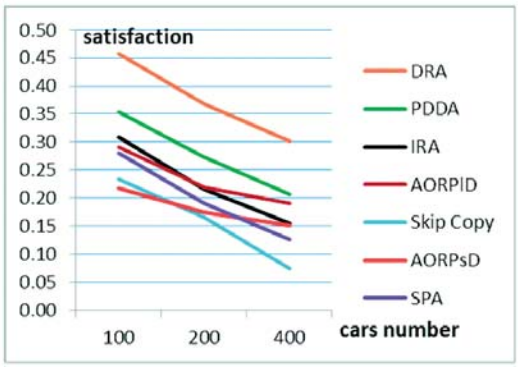

Fig. 6 The relation between the satisfaction and the number of cars in the simulation for the individual replication algorithms

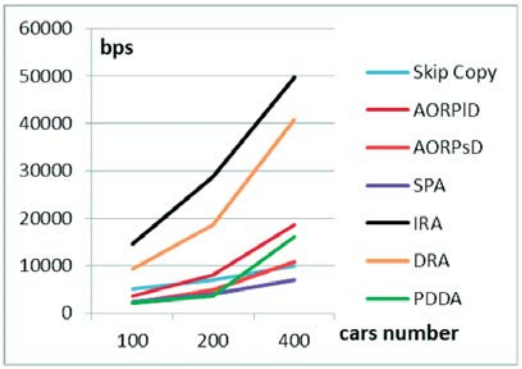

Fig. 7 The relation between the volume of the transmitted data and the number of cars in the simulation for the individual replication algorithms

As Fig. 7 shows, from the viewpoint of the network load, the algorithms *SPA* and Skip Copy achieved the best results.

From the viewpoint of the network is also important, that related algorithms (IRA and DRA) have also different results. We can see, that not only satisfaction but also number of transmitted data is better during using DRA algorithm than using IRA algorithm. These results means, that DRA algorithm is much better for data replication than IRA algoritmh.

But, it is clear from the results that it is impossible to say unequivocally which of the algorithms is better. Therefore, to get an over-all evaluation, it is necessary to define the way of using the data and the requirements on the replication algorithm. As far as volume-demanding replications are concerned, and the critical point is minimizing the transmitted data, it is possible to use the *SPA* algorithm or the Skip Copy algorithm. But if the goal is to maximize the satisfaction, the *DRA* and *PDDA* algorithms achieve better results.

7. Conclusion

Our article presents the on-going research focusing on improving the quality of *ITS* by means of the communication of close participants of road traffic through *DDBS*. The system we suggest to use is based on the *AD-DB .FRI* database system which communicates with the *OSACP* protocol. Over these, we designed several algorithms ensuring the data replication between the individual nodes. To compare those, as well as for the entire research, we used the computer simulation carried out by the *AdHocSim.FRI* tool.

Within the on-going research, we would like to concentrate on several areas. At the network level, it is the experimental verification, if the *OSACP* protocol will achieve higher efficiency, if it uses the Stream Control Transmission Protocol (*SCTP*) instead of the *UDP* for the communication between the end-nodes. The *AD-DB.FRI* system offers some space in the area of the optimization of the database query processing, and also in securing the communication channel. We will also continue to develop new algorithms for data distribution. One of our visions, conditioned, however, by the availability of hardware, is also implementing the described experiments in the real *VANET* environment, and not just by means of the computer simulation.

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Stefan Badura – Stanislav Foltan – Martin Klimo *

FUZZY LOGIC NETWORKS FOR SPEECH RECOGNITION

This paper proposes a massive fuzzy logic network which can be considered as a novel model of pattern classification network. Our approach introduces fuzzy logic circuits fulfilling the function of a binary classifier at first, which are connected into fuzzy logic networks with fuzzy flip-flop circuits as memories. Genetic programming is used as a circuit designing method. In order to establish design methodology, experiments aimed at testing the suitability of fuzzy logic operation sets, fitness functions and parameters of genetic algorithm were carried out. From trained circuits a hierarchical layered structure is built, where single layers consisting of given circuits are contextually dependent. Experiments with fuzzy logic circuits and fuzzy flip-flop network show some valuable results especially in the task of audio and visual speech recognition.

Keywords: *Fuzzy logic, speech recognition, genetic programming, binary classifier, memristor, lip-reading, structure, network.*

1. Introduction

Speech is the most natural form of human communication. No wonder that with the development of technology, a man has come with an idea to communicate with the machine or a computer. Since then, the history of speech recognition started [1]. Initially, it was recognition of isolated words, later the development of systems recognizing continuous speech. All these systems are based on the acoustic representation of speech [2]. Many approaches exist also for visual speech recognition. Most of them use artificial neural networks (ANN) or hidden Markov models (HMM). Recurrent neural networks are often used for time series recognition. If we consider just visual speech recognition, then in [3] authors recognize silence and vowels, where an Elman topology of ANN is utilized and that is constructed from 3 layers. In [4, 5, 6] a time delay NN (TDNN) is used. In [7] a modified TDNN is introduced for the same purpose. Many researchers resorted to the hidden Markov model (HMM) since it performs well also in audio speech recognition [7, 8, 9].

In recent years, some works describing the recognition from an entirely different perspective appeared. This is a view of the brain response to the received perception. In late 2008 work describing the recognition of simple black and white images based on the brain activity, scanned by functional magnetic resonance imaging (fMRI) was published [10]. In 2011, scientists from UC Berkeley announced reconstruction of the video [11]. In early 2012 work describing the reconstruction of audio perception [12] was published. Inspired by these publications we attempt to simulate the activity of the nervous system and we try to design which is suitable for audio or visual speech recognition.

We propose a novel network model where we combine fuzzy logic circuits with a fuzzy flip-flop memory described in [13]. Our goal is to interconnect two class classifiers into a robust network that can be considered as a universal multiclass classifier for dynamic data. Hierarchical organization and layered structure introduce a contextual modeled system which is not difficult to understand and which provides suitable abilities for a general task of speech recognition. Speech is a non-stationary process; our goal is to model this property using mentioned memories and fuzzy logic memories.

This paper is organized as follows. The second part describes initial identification of simple speech features in the input signal. This identification is realized in a form of binary classifiers that decide whether there is a specific feature detected at the input or not. The classifiers are represented by fuzzy logical functions where their output's values correspond to the level of the fired feature. The third part presents a hierarchical structure of the network which is responsible for identification of larger units of the input signal (time sequence). The fourth part describes briefly inputs used for the network evaluation. The fifth part describes some results and the final part concludes this paper.

2. Fuzzy logic circuits

The structure of the logical function representing a single classifier is designed by means of genetic programming [14], and it consists of different sets of fuzzy logical functions where some of them allow even hardware implementation with memristors [15, 16].

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The example of an individual is shown in Fig. 1. The structure of the chromosome for this individual can be encoded to string "0(1(2(.3),.248)),0(1(.72),.40)))))", where in this example "0" represents function NOT, "1" – MIN, "2" – MAX, ".XYZ" – XYZ-th value of input spectrum, ")" – creation of left child node, ")" – termination of a sub-tree and transition to the parent, and "," – creation of the right child node.

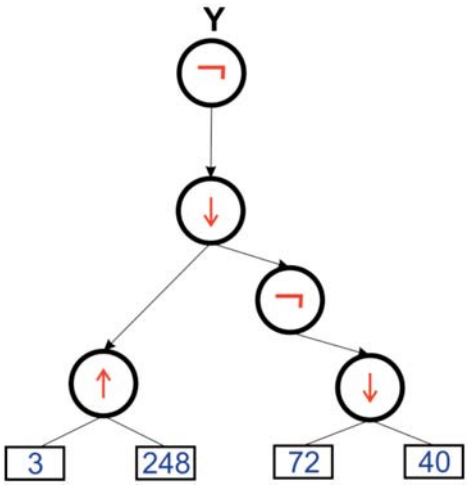

Fig. 1 This image shows an example of generated structure and its prescription can be written as: Y=NOT(MIN(MAX(spectrum[3]; spectrum[248]), NOT(MIN(spectrum[72]; spectrum[40]))))

2.1. Fuzzy logical operations

For realization of a decision process we use a fuzzy logical function. There are many types of fuzzy logic, like Zadeh logic, probabilistic logic, and Lukasiewicz logic. Since there is no clear answer to which of these is the most appropriate representation of human reasoning, we formed several different sets of logical operations consisting of each of these three logics. Valuable results were obtained by means of these two sets of functions:

Zadeh logic:

$$F_{AND}(x,y) = \min(x,y)$$

$$F_{OR}(x,y) = \max(x,y) \tag{1}$$

Lukasiewicz logic:

$$F_{\rightarrow}(x,y) = \min(1 - x + y,1) \tag{2}$$

The advantage of Zadeh logic over remaining logics lies in the possibility of hardware implementation with memristors. In our experiments we used Lukasiewics's logic for the network design evaluation. Zadeh's logic was left for further investigation.

2.2. Mechanism of individual's evaluation

The individual's evaluation is based on the output of the logical function for any input sample. Fig. 2 illustrates histograms of output values divided into 101 bins; approximated by A) Gaussian functions and by B) fuzzy-like functions, where T1 is the lowest output value for the sample of class i and T2 is the

$$T = \frac{T1 + T2}{2}$$

highest output value for the sample of class *j*.

The sample is considered as correctly recognized at A) if

$$f(x_i; \mu_i; \sigma_i^2) > f(x_i; \mu_j; \sigma_j^2),$$

or

$$f(x_j; \mu_i; \sigma_i^2) < f(x_j; \mu_j; \sigma_j^2), \tag{3}$$

where

$$f(x;\mu;\sigma^2) = \frac{1}{\sqrt{2\pi\sigma^2}} e^{\frac{-(x-\mu)^2}{2\sigma^2}}. \tag{4}$$

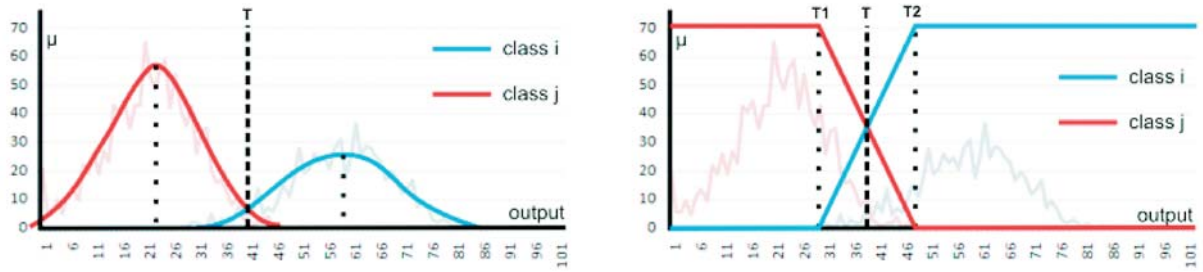

Fig. 2 Image on the left shows histograms of output values approximated by Gaussian functions and image on the right shows histograms of fuzzy-like functions

The sample is considered as correctly recognized at B) if $f(x_i) > T$, or $f(x_j) < T$.

Our aim is to find out a logical function which recognizes correctly as many input samples as possible. To meet this objective, we use the following fitness functions:

1) The first fitness function tends to make output values (see Fig. 2 histograms) the most distinguishable by increasing the distance between the outputs of each class:

$$F_1 = \mu_i - \mu_j \tag{5}$$

where μ_i is the mean of class i outputs and μ_j is the mean of class j outputs.

2) The second fitness function corresponds to the total probability of a correct recognition:

$$F_2 = \left(\frac{|good_i|}{|N_i|}\right)\left(\frac{|N_i|}{|N_i + N_j|}\right) + \left(\frac{|good_j|}{|N_j|}\right)\left(\frac{|N_j|}{|N_1 + N_j|}\right) \tag{6}$$

where $|good_x|$ is the number of correctly recognized samples from class x and $|N_x|$ is the size of class x.

3) The third fitness function maximizes the number of true positives and minimizes the number of false negatives:

$$F_3 = \frac{2 * P * R}{P + R} \text{ where } P = \frac{N_{correct}}{N_{detect}},\ R = \frac{N_{correct}}{|N|} \tag{7}$$

where $N_{correct}$ is the number of correctly recognized samples from class i, N_{detect} is the number of all samples detected as i, and $|N|$ is the size of class i.

3. Hierarchical network design

In the previous section we described the basic principle of training and evaluation of single circuits (structures). In this section we propose a hierarchical network's model. The proposed network is aimed to be used in the speech recognition task, deeper description can be found in [17].

The topology consists of 2 layers where each layer has its purpose, see Fig. 3.

- *The 1st layer* – this layer tries to indicate simple properties. In the task of lip reading one property could be, e.g., the mouth's position (open-close position).
- *The 2nd layer* – this layer tries to consider time dependence of detected properties.

Both layers consist of trained fuzzy logic circuits. Each structure is trained on one property against other properties as it was described in the previous section.

As it was already mentioned, the first layer tries to indicate some properties. In our case we define property as a number of a single cluster. A set of vectors from training samples, which will be introduced in the 4th section, is grouped with Ward method into several clusters. Then each cluster represents one property. The number of groups was chosen as 15 (see the dendogram in Fig. 4 for given input data) where a slice for 15 groups is shown.

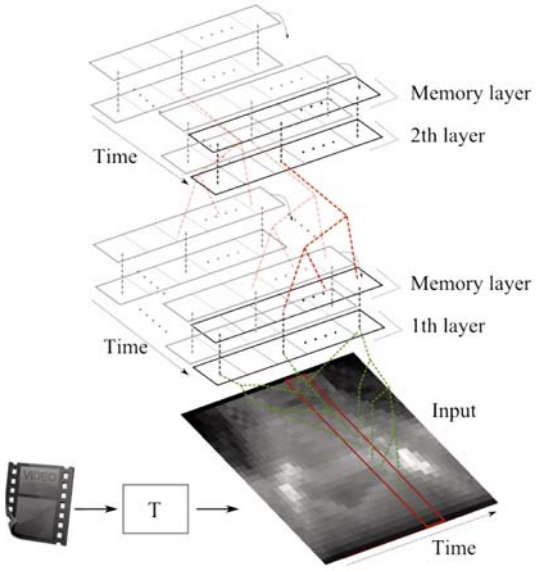

Fig. 3 General network model. Layer 1 and 2 consit of trained structures; the block T presents an image transformation into feature space

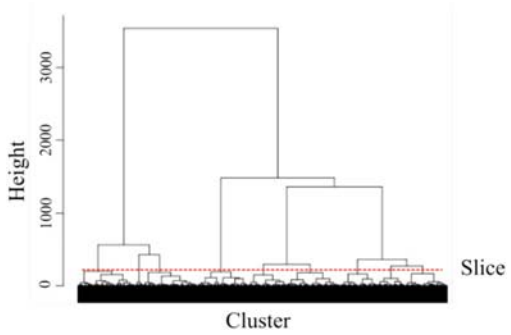

Fig. 4 Dendogram for input data obtained with Ward clustering method; the count of chosen clusters is decided based on a slice. In our case we use 15 clusters

The 1st layer consists of 15 structures where each structure is trained for one property (one data cluster). Structures for the second layer are trained for the output values of the first layer. We are using 23 vowels in our experiments, so the 2nd layer is generated from the structures trained on output sequences from the first layer for each vowel. The topology of the second layer is more complicated than the first layer, but the training principle of the second layer is very similar to the first one. The difference is in an objective

function where it is evaluated after a time period for one vowel when training structures.

3.1. Memory

Memory is an important part when the time dependence of input data is modeled. In [13] a fuzzy flip-flop that provides abilities for sequential remembering of the input signal was presented. If a signal is close to value 1, the flip-flop can remember its value – it is excited. If a higher signal is proposed for a longer time period, the output stays excited also for a longer time. In our experiments we used basic flip-flop as it is shown in Fig. 5.

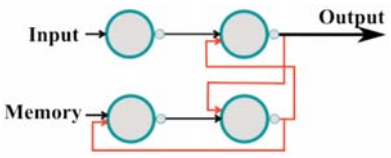

Fig. 5 Basic flip-flop used as memory designed from NAND fuzzy logic operation

Above each of the two introduced layers; a memory layer can be placed, which is designed from fuzzy flip-flops. As it was already described, the basic idea behind the memory is as follows: if the signal is high enough (close to 1) for a longer time period, the memory supports it and if it is not strong enough, the memory suppresses it. Using the memory serves also for modeling the time dependence. From other point of view at memory it can be said; that memory enlarges the gap between stronger and weaker signals. In our experiments we use basic flip-flop memory as Fig. 4 shows. The main goal of using the memory is to provide ability for continuous speech recognition. We are interested in the state of the network after a time period. Structures, which are strongly fired, are indicating inputs for which they were trained. In next experiments the memory is placed just above the second layer. We executed experiments without using memories also. In this case we do not consider the time dependence and the results are as expecting less satisfied.

4. Used inputs

In our experiments two datasets were tested. The first dataset is used for the logic circuits evaluation and the second one is used for the hierarchical structure verification. The database of spectra was created in our department from audio recordings of the Slovak book "Cukor a sol'", written by Keleova and Vasilkova, published by Ikar, Bratislava, 2004. At the recording, the book was read by one woman (sampling rate 22050Hz, 16 bit per sample, mono), the position of each phoneme was marked, and spectrum of the window (512 samples) centered on the mark was computed by means of R-software (functions *spec.pgram()* and *log10()*). The final spectrum is represented by 256 values. The database consists of more than 133000 samples of 60 phonemes. At current experiments, 1000 randomly selected spectra of each vowel (a, e, i, o, u) are used. This database is referred as db1 in proposed experiments.

A set of vowels extracted from video sequences is used as inputs for the lip reading task. The feature extraction process is shown at the flow chart in Fig. 6. Fig. 7 shows an example of an extracted feature for different video sequences. Median sieves are used for scale, space invariant feature extraction. Each column in each image in Fig. 7 represents the feature vector extracted from one video frame..

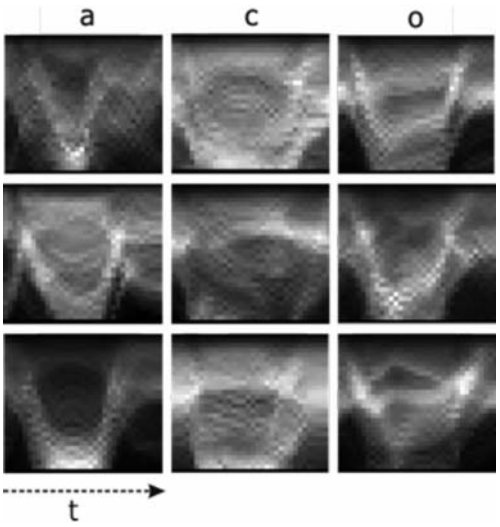

Fig. 7. An example of extracted features for the process of lip-reading. Columns in each image represent feature vector extracted from one frame of video sequence for vowels "a,c,o".

This database is referred as db2 in our experiments.

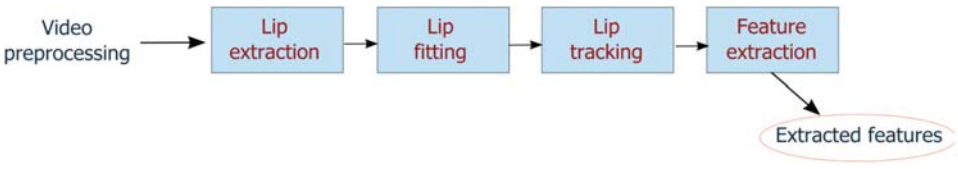

Fig. 6 Flow chart for the feature extraction process; the input is a video sequence; lips are extracted in the first frame; the lips'model is found (the lip fitting process) in next step; the 3th phase represents the lip's tracking system and the final stage is the process of feature extraction

5. Experiments

For the logic circuits' evaluation, a set of experiments was executed which is described in next text. All the experiments were tested on the audio database, referred as db1.

5.1. Expriments with audio

The experiment is focused on the accuracy of recognition when pairs of phonemes were used. In all the scenarios 1000 vs. 1000 samples of phonemes, divided with ratio 7:3 into a learning/test set were used. The total number of binary classifiers at each scenario was 10 (a/e, a/i, a/o, ..., o/u). Table 1 contains the results of this experiment. It is visible that the best accuracy was obtained with Lukasiewicz logic (L6), and it was around 93% no matter which fitness function was used. The results achieved with Zadeh logic (L2) were approximately at the same level with any fitness function.

Results obtained from the recognition between pairs of phonemes; F1, F2 represent fitness functions and L2, L6 are logics which were used — Table 1

	a	e	i	O	u	L: μ(S)	T: μ(S)
F_1L2	87.1%	77.4%	87.6%	84.9%	85.2%	84.5%	83.4%
F_1L6	95.5%	92.8%	96.8%	95.2%	92.2%	94.5%	93.1%
F_2L2	89.8%	84.0%	92.7%	84.1%	86.8%	87.5%	83.5%
F_2L6	95.6%	92.5%	98.5%	96.1%	94.8%	95.5%	93.0%
F_3L2	92.3%	83.3%	89.3%	86.1%	84.9%	87.2%	83.6%
F_3L6	97.0%	93.2%	96.5%	95.3%	94.9%	95.4%	92.7%

5.2. Experiments with video

For the evaluation of the network design we processed a series of experiments with the lip reading data (referred as db2). A database of Slovak vowels was collected for our purposes. Together, a set of 23 different vowels was recognized and each vowel was recorded 54 times. Before experiments the whole dataset was divided into training and testing subsets with the ratio 6:4. All the structures at the first and the second layer were trained for the first subset. The Ward's clustering algorithm was used for defining properties at the first layer. This method labels time rows of each feature vector with a group number, which represents an interesting property. Together 15 different labels (groups) were used in proposed experiments. For evaluating of the vowel recognition, two different objective functions were examined:

- U1 – the cumulative objective function (sum of values in time).
- U2 – this function takes the value in the last considered time.

When using U2 function, another parameter was examined, and it was the fall time (the fall time is time where the network is feeded by 0 values as inputs). Table 2 shows some experimental results of these experiments.

Experimental results - positive recognition rates in % for different settings and objectives functions of given network design; rows present results depending on the fall time, U1, U2 are objective functions used for results evaluation. — Table 2

Memory	0.05		0.15		0.25	
Fall time	U1	U2	U1	U2	U1	U2
0	16.41	14.16	15.84	12.90	18.51	12.34
5	16.41	14.16	16.54	14.58	18.51	13.74
10	16.12	15.28	16.83	14.02	17.67	12.34
15	16.12	14.58	17.11	14.44	17.25	10.93
50	16.12	15.00	16.97	6.45	17.67	4.347

6. Conclusion

In this paper a novel approach for speech recognition was introduced. It shows a good behavior for the task of lip-reading. The final result obtained from experiments were around 18–19% for a positive vowel recognition which is considered as satisfied because it shows good behavior for sequential remembering of time values. For an effective lip reading task it must be enhanced in the future.

Interesting results were obtained when the memory was used. In the experiments it was shown that using memories leads to the modeling of dynamic properties in the input signal. Future experiments should cope with the memory itself and its structure because the memory does not consider time occurrence of excitation in the described experiment. Other experiments which can be executed can concentrate on the objective function in the training phase, especially for the second layer. The future work can be directed to increasing the number of recognized classes (consonants), the recognition of speech for different speakers, and for the proposal of a strategy for the recognition of larger units of speech (i.e. words). At the level of logical circuits' training a different logic can be tested for example as it is shown in [18].

It is important to say that the aim of this paper was not to present a perfect speech recognition system. The traditional methods of speech recognition are much more sophisticated and successful. Unlike the traditional methods, the main advantage of proposed approach lies in its possibility of hardware implementation (which as far as we know has not been presented so far). As it is suggested in the paper, this is possible by using memristors.

Acknowledgment

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FUTURE AIRPORTS DEVELOPMENT STRATEGIES

Air transport was traditionally highly regulated, fragmented and protected. With European air transport market deregulation in the mid 1980s also airports could respond to new factors. Methodology developed within the FAST project analyzed evolution of airport strategies potential in the forthcoming decade in the frame of new airport typology reflecting different strategies depending on the airport size, market type and market potential.

Keywords: *Airport development, airport strategies, deregulation.*

1. Background

The last decade in the European air transport market was characterized by air transport deregulation which resulted in the appearance and growth of the low cost airlines segment which characterizes a prominent share of intra-European market today [1]. Another significant advancement was the change in the airports management. Many airports transformed from public to private ownership. In the new environment airports could play a more active role in the air transport industry. They improved their attractiveness and competitiveness [2], [3], [4]. Many of secondary airports have developed more active strategies towards airlines and, in particular, toward low cost carriers.

Airlines' strategies are those more explored. However, airport strategies and their future development are one of the main drivers of traffic evolution [5]. The airports are no passive players and their strategies have significant impact on airline behavior and route structure. This paper describes new trends in airport strategies and how they are adopted by airports.

The paper analyzes potential progress of airport strategies and provides some answers to questions relating to stakeholders and clients (airlines and passengers) needs. However, there are no universal strategies feasible for any airport but it depends on the airport characteristics. [6] This reality led us to build an innovative typology of airports aimed at three elements: airport size, potential for growth in capacity and potential in demand.

Long term traffic forecasts are stable and promising for the air transport sector [6]. The principle question at the airport level is the capability to receive increasing number of passengers in the future, i.e. its capacity to grow. This element will characterize the possible evolution/adaptation of recourses to a general increase of demand. The role of the third element, airport actual size, is to take into account the existing situation of an airport. This allows us to reflect the past strategies of a given airport.

Based on this typology and the generic strategies defined we outlined the future strategies available to a given airport.

This methodology was developed within the FAST project funded by EUROCONTROL in 2008–2009. The results [7], [8], [9] were illustrated by an application to Bordeaux airport in France. After the end of this project, it is interesting to observe and compare the strategy developed by the airport, with the analysis made in the FAST project.

2. Methodology

2.1 Airport strategies

2.1.1 Airport customers and revenues

Airports are typical service organizations [10]. From the aeronautical perspective, the main airport clients are airlines of all types: traditional airlines, low cost carriers, but also cargo/freight airlines and integrators. Airports provide them with infrastructure (e.g. runways, taxiways, aprons, terminals) and services (e.g. refueling and handling). Services can be provided directly by the airport, or subcontracted to private companies. Passengers are considered to be especially airline clients but they are also direct clients of airports as they must be processed before/after their flight. The range of non-aeronautical services depends on the airport size and type and they usually include shops, restaurants and bars providing services to the passengers, visitors and employees and bringing revenues to the airport. Needs and wants of airport customers can be conflicting: for example, passengers prefer short connections times

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between flights, while shop keepers would prefer passenger long dwell times in the terminal to increase their sales potential.

The revenues of an airport are usually split into aeronautical revenues and non-aeronautical revenues [11]. The aeronautical revenues are linked with the aeronautical activities of passengers and aircraft, and the non-aeronautical revenues are all other revenues. However, these can be further split into two groups: revenues from service providers located at an airport, providing services either to the airlines or to the passengers; and revenues from activities the airport has diversified in order to use its expertise [12]. Those could be for example consultancy or management services. The strategies of specialization will aim at developing the aeronautical revenues, whereas the strategies of diversification will have the objective of increasing the non-aeronautical revenues.

2.1.2 Strategies of specialization

Strategies of specialization are focused to develop airport aeronautical activities. Some could be related to aeronautical infrastructure, while others will aim to increase service levels, or improve the communication or marketing towards clients [13].

Concerning the airport infrastructure, examples are:
- Increase of the runway capacity by extending the existing runway and/or building a new runway and/or other investments in the airport movement areas (for example taxiways system completion, apron expansion).
- Investment in passenger terminal capacity by building a new terminal, extending existing ones or processing technology improvements.
- Investment in freight terminal capacity by improving technology, building a new terminal or extending existing ones.
- Investment in a low-cost terminal to enable differentiation of the airport service level quality.

Strategies of specialization centered on quality improvement can include:
- Improvement of airport accessibility via bus shuttles, car parking, road and/or rail infrastructure (which often requires financial support from the region, town, etc.).
- Investment in terminal infrastructure to improve the efficiency of aeronautical services (e.g. luggage transfer and passengers flows).
- Development of intermodality with a high-speed rail interconnection (which requires financial support from the country, region, town, etc.).

Finally, policies towards customer could include:
- Development of commercial policies to airlines (e.g. lower passenger taxes to airline opening new lines, reaching a certain level of traffic at the airport, lower taxes on subsidized routes and lower taxes for transit passengers).
- Investment in publicity, communication and marketing towards airlines (market research, advertisement) or towards passengers (advertising the region's attractiveness, ...).

2.1.3 Strategies of diversification

A diversification strategy of a company consists in developing activities not related to the core businesses. This strategy can result in reduction of a firm's exposure to a risk. Indeed, if its core business is affected by a crisis, the company can still generate profits through different strategy. For airports, strategies of diversification aim to develop the non-aeronautical activities. They are considered increasingly important to stabilize and balance the airport economy.

These diversification strategies mainly aim at:
- Improving the financial results by increasing non-aeronautical revenues with the development of commercial activities.
- Diversifying the financial risks by investing in other airports or other economic sectors.
- Finding a way to allocate the airport's capital elsewhere than in the airport capacity when the potential of capacity growth of the airport is low.
- Offices or land rental.

The most common diversification strategy is the development of commercial activities by increasing the areas for shops, restaurants, car rentals, etc., at the airport. The strategy of diversification concerns the development of services to the airport passenger independently of the airlines (lounges, wireless internet, trip planner websites...) [14]. The objective is to increase revenues and to indemnify the loyalty of passengers toward airports. This type of strategy improves revenues, but does not reduce the risk exposure, as the revenues are still closely linked to the number of passengers attracted by the airlines. In case of a traffic decrease, these revenues will also be impacted. These strategies are applicable to any airport, even small ones. Other strategies of diversification of midsize or large airports consist in selling the airport know-how to other airports by developing consultancy or management services. Airports can also invest in other airports or other economic sectors. [15] These last strategies of diversification however require financial resources and are therefore generally developed only by large airports.

2.2 Typology of airports

The strategies available to a particular airport depend on its characteristics not only in terms of current traffic, but also considering the airport potential with respect to capacity and demand [16], [17], [18]. The current situation of an airport in terms of passenger throughput or cargo volume is not necessarily the best indicator of what the airport could become in 10 or 20 years. Some airports have grown massively in the past 10 years while others have not. Analyzing the future evolutions of airport strategies therefore requires us to confront the information on the airport traffic forecasts with other elements.

We are interested in identifying the characteristics of an airport in terms of its potential: what can explain why a given airport will develop, while another will not? We are looking at airports from

the point of view of traffic evolution. To be able to grow, an airport needs to have 'good characteristics' in terms of supply (mainly capacity) and demand.

2.2.1 Airport capacity

For a midsize or large airport the most important parameter is always the runway capacity which limits the traffic volume in peaks. This should be linked with apron capacity, the passenger or freight terminal capacity, but also airport surface access infrastructure in case of large airports. Indicators of the airport potential for growth in capacity relate to the current runway system, apron and terminal capacity but also to their possibility of future extension.

2.2.2 Airport demand

In order to grow, an airport should have spare capacity, to accommodate more flights and/or more passengers or cargo, but it would be of no benefit if there is no demand. Indicators of the potential for growth of the airport in terms of demand are based on passenger numbers on incoming/outgoing segments of the market. Some airports have mostly incoming passengers, leisure or business, because of some attractiveness of the area. Others have mostly outgoing passengers and this has to do with different factors, linked to population wealth in the region (depending on an adequate supply of flights at the airport). Some airports are hubs and have an important proportion of connecting passengers for whom the region around the airport will be unimportant. Last, cargo demand will have different requirements. Overall indicators of the potential for growth in demand relate mainly to intrinsic characteristics of the airport region [19].

2.2.3 Airport typology

All indicators of the airport potential for growth in capacity and demand can then be used to develop a typology of airports that will be used as a basis for the FAST project. In addition to the potential for growth in capacity and demand the analysis of the possible strategies takes into consideration the airport size according to the ACI airport size typology:

- Small size for airports with no more than 5 million passengers a year.
- Medium size for airports with more than 5 million passengers a year and fewer than 10 million passengers a year.
- Large size for airports with more than 10 million passengers a year.

Our typology of airports is therefore based on three parameters: the airport size determined by number of passengers, the level of potential for growth in capacity and the level of potential for growth in demand. Both levels of potential for growth are decomposed into low, medium and high potential levels. Fig. 1 illustrates this three dimensional typology with examples of airports.

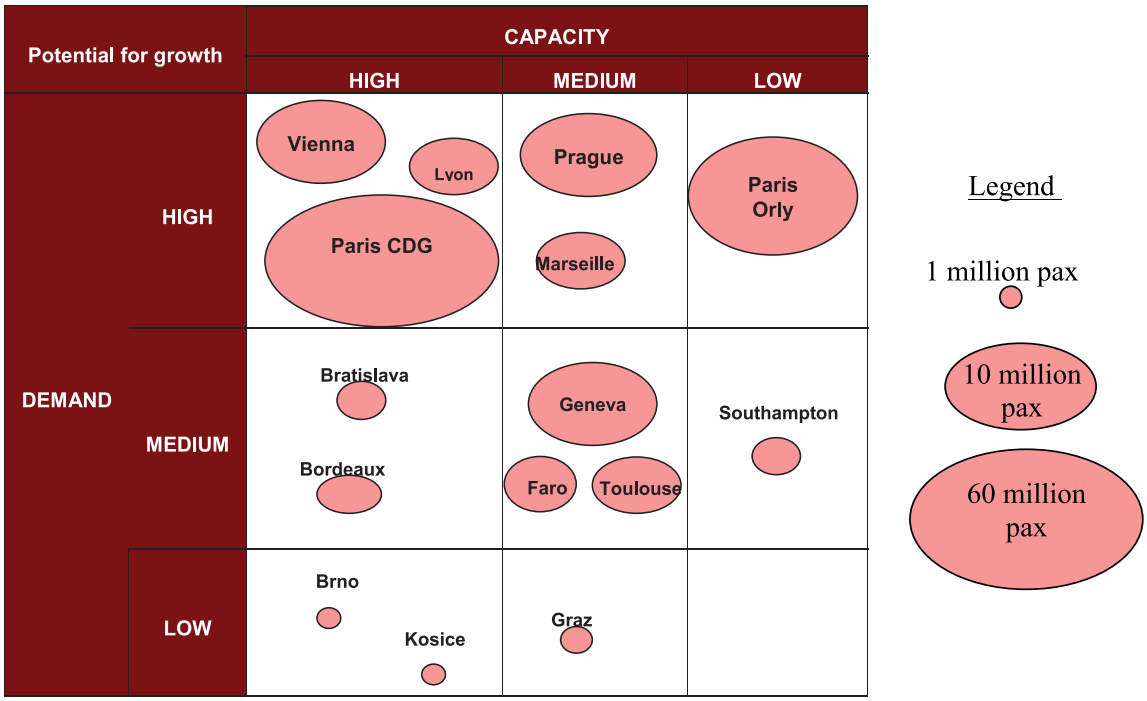

Fig. 1 Illustration of the three dimensional airport typology
Source: FAST project, EUROCONTROL CARE INO project, March 2009

3. Strategic alternatives and future network

3.1 Method of identification of strategic alternatives

To identify the strategic alternatives for a particular airport and to make predictions about its future route network evolution can be broken down as follows:

- Analyses of the past strategies of the considered airport.
- Identification of the future strategic alternatives of the analyzed airport according to its position in our typology of airports.
- Identification of a reference airport which has developed past strategies similar to the future strategies of the considered airport.
- Analysis of the past route network evolution of the reference airport following the strategy it developed.
- Use of this past route network evolution of the reference airport to make predictions about the future route network evolution of the analyzed airport.

3.1.1 Past strategies

The future strategic alternatives of an airport are closely related to the strategies it developed in the past. These past strategies were influenced by the airport characteristics and environment. It is therefore essential to analyze the past strategies of an airport before being able to identify its future strategic options.

3.1.2 Future strategies by airport type

The future strategies that can be developed by an airport will first be significantly dependent on its type. As an example, a medium sized airport with spare capacity will not behave in the same way as a large airport with runway capacity constraints [20]. The situation in terms of demand will also condition the type of passengers the airport plans to attract (local or foreign? business or tourists?) but also airline type (traditional or low cost) (see Fig. 2) [21], [22], [23]. Besides the type of the airport the degree of development of these strategies will be strongly linked to the level of competition with other airports, the level of congestion of the airport but also to the airport ownership and management and the limits of regulation of the airport [24], [4], [25].

Our method of identification of the possible strategies of an airport therefore comprises three steps: We first identify all the possible strategies of specialization for particular type of airport, then all the possible strategies of diversification. Finally, we refine these strategic options (specialization and diversification strategies) with other factors: capacity constraints, competition level, regulation type, airport status. As a result, we identify the airport objectives and strategic options at a five to eight year time horizons.

<table>
<tr><th colspan="2" rowspan="2">Potential for growth</th><th colspan="3">CAPACITY</th></tr>
<tr><th>HIGH</th><th>MEDIUM</th><th>LOW</th></tr>
<tr><td rowspan="3">DEMAND</td><td>HIGH</td><td>- Accessibility improvement
- Commercial policies to airlines (reduced fees on hub traffic)
- Investments in communication and marketing
- Investment in passenger and/or freight terminal capacity
- Investment in a low-cost terminal
- Investment in runway capacity
- Investment in infrastructure for efficiency
- Development of intermodality</td><td>- Accessibility improvement
- Commercial policies to airlines (incentive fees to use large aircraft)
- Investments in communication and marketing
- Investment in passenger and/or freight terminal capacity
- Investment in a low-cost terminal</td><td rowspan="2">- Accessibility improvement
- Commercial policies to airlines (incentive fees to use large aircraft)</td></tr>
<tr><td>MEDIUM</td><td>- Accessibility improvement
- Commercial policies to airlines (reduced fees on hub traffic)
- Investments in communication and marketing
- Investment in passenger and/or freight terminal capacity
- Investment in a low-cost terminal
- Investment in runway capacity</td><td>- Accessibility improvement
- Commercial policies to airlines (reduced fees on traffic volume)
- Investments in communication and marketing
- Investment in passenger and/or freight terminal capacity
- Investment in a low-cost terminal</td></tr>
<tr><td>LOW</td><td colspan="3">- Accessibility improvement
- Commercial policies to airlines (reduced fees on traffic volume)
- Investments in communication and marketing</td></tr>
</table>

Fig. 2 Strategies of specialization by airport type
Source: FAST project, EUROCONTROL CARE INO project, March 2009

4. Conclusion

Airports are essential actors in the air transport market with a growing role, market stabilizing effect and independence in strategic decision-making. Analyzing the impact of future airport strategies on the evolution of the airport route structure is significant and could give important clues as to the direction of future development of the industry.

This paper describes some aspects of the FAST project, which developed a new methodology for identification of the future airport strategies that can be applied to any European airport. In particular, we demonstrated that while strategies of diversification are often considered the preserve of large firms, they have been successfully applied by (and should be considered by) rather small airports to stabilize their economy in the years of crises.

The future airport strategies should also put more stress on avoiding so called 'curb-to-curb' approach. Airports should be viewed as integral part of the regional, national or international transport infrastructure rather than being perceived as an isolated transportation system. Quality of airport ground access/egress and level of airport integration into ground transport network significantly influences its competitiveness, operations and capacity.

The study researched few airports only. The methodology could be extended and refined by including more detailed parameters and could be extended to all airport types. Airports in the new European member states could give us different strategic options, but also to airports with overlapping catchment areas as well as to the competing hubs, low cost 'pseudo hubs' or complementary airports in case of multi-airport systems and/or complementarity between hub and secondary airports could be researched.

The relevance of the results of our methodology was confirmed by the Bordeaux airport strategy. In June 2009, three months after the end of the FAST project, Bordeaux Merignac airport decided to build a low-cost terminal of 4,000m² which opened in May 2010. This strategy was fully in line with the results we obtained for Bordeaux airport: attracting additional low-cost and securing the loyalty of passengers in expectation of strong future competition with the high-speed train in 2016.

Three years after the opening of the Billi, the low-cost terminal, this strategy reveals successful since the airport traffic already increased by 1 million passengers since 2010, while the impact of the high-speed train competition in 2016 is expected to reduce the airport traffic by 800,000 passengers.

To reach the final objective of getting one additional million passengers by 2016, the airport plan to enlarge by 2,000m² the Billi terminal from 2013.

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REGIONAL DIMENSIONS OF KNOWLEDGE PROCESSES IN THE SECTORS OF TRANSPORT AND LOGISTICS AND ICT IN THE ZILINA REGION

The paper presents the results of the APVV project - Regional dimensions of knowledge economy, which was solved in the Department of Communications, Faculty of Operation and Economics of Transport and Communications, University of Zilina during 2008 – 2011. The paper briefly describes logistics sector and ICT sector in the Zilina region and their knowledge management. Significant results of the project were achieved through knowledge biography, which maps creation, processing and dissemination of knowledge. Based on this methodology the case studies in selected logistics and ICT enterprises in the Zilina region were created. The results of sectoral analysis and knowledge biographies of enterprises resulted into finding that knowledge is the most strategic "material"; learning is a critical process for maintaining competitiveness of enterprises and that relevant aspects together create key mechanism for regional differentiation.

Keywords: *Knowledge economy, knowledge processes, knowledge biography.*

1. Introduction

Knowledge economy is economy based on the ability to produce, use and disseminate new knowledge. It is a collective process with many participants within enterprises, and also from narrower or wider environment of enterprise, with knowledge [1]. Within researching regional dimension of these processes we can see different symptoms and identify a new type of gap, which lies in low ability of regions (as systems of interconnected entities) to adapt to economic changes. The REDIPE project – Regional dimension of knowledge economy (APVV-0230-07) was coordinated by the University of Economics in Bratislava, Faculty of National Economy, Department of Public Administration and Regional Development; and the University of Zilina, Faculty of Operation and Economics of Transport and Communications, Department of Communications was a project partner. The main aim of the project was to explore regional aspects of knowledge economy from different points of view and to set recommendations for implementation of development policy in regions. During solving the project, the research team achieved deeper understanding of knowledge creation and dissemination processes in specific regions; decision-making and planning processes at regional and national levels were improved and obtained knowledge was implemented into education activities at the University of Zilina. Within this project, for the first time in Slovakia, knowledge economy on regional level with application methodology based on multidimensional analysis of sectors and regions in order to identify key instruments of the knowledge economy development in regional context was explored. Based on empirical research, new information referring to behaviour of enterprises in connection to creation, processing and dissemination of knowledge was achieved. So far, this type of research had absented, thus it was not possible to diagnose and compare process of developing knowledge economy at micro level within selected sectors, as well as make a comparison with similar processes abroad [2].

2. The main goals

The main goal of the paper is to provide brief results of the REDIPE project – Regional dimensions of knowledge economy. The intermediate goal of the paper is to provide results of the sectoral analysis of two selected sectors, as well as the introduction of a specific research method, based on the enterprise knowledge biography. There are also two case studies in the paper. These case studies document the way of knowledge diagnostics, knowledge processing and knowledge dissemination in enterprises in the regional, national and international contexts.

3. Methodology – sectoral analysis in a selected area and knowledge biography

As mentioned above, the paper presents the result of the REDIPE project to which a selection of methods also corresponds. In order to meet aims of the paper, it was considered to be a primary research whose results allowed to create SWOT analysis of selected sectors in terms of knowledge economy. For monitoring knowl-

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edge dynamics in selected enterprises specific methodology based on qualitative research processed as knowledge biographies of enterprises was applied. The aim of the knowledge biographies creation is to analyse knowledge dynamics and its connections within the enterprise and between enterprises themselves and to understand the complex of events, participants and flows which create knowledge dynamic, which is necessary for ensuring a change of the product, process and organization [3].

Methodology of knowledge biography lies in the following six steps:

I. Finding a suitable candidate for knowledge biography – it means selection of a sufficient number of enterprises with territorial knowledge dynamics as suitable candidates for creating knowledge biography; identification of innovative and strategic changes at the enterprise level.
II. Establishing initial contact (initial meeting) – the aim is to create foundation for the future cooperation in order to obtain general information about the enterprise, its innovation activities and links to the region.
III. Initial verbal interview with a representative of the enterprise – for gathering information necessary for knowledge biography. The obtained data include the main participants, milestones and barriers of knowledge processes. This creates "story of development process of enterprise realized through creation, processing and dissemination of knowledge", defining types of knowledge, proximities, internal and external links.
IV. The second interview in the enterprise – is based on deepening understanding of knowledge dynamics in the enterprise; subsequently a first draft of network map resulting from the results of interviews and other data obtained during the previous steps is created. The interview includes questions about time and content focus of change, internal and external participants of change, initiators of change and also about the way of knowledge transfer into the enterprise.
V. The interview with external participants of knowledge dynamic of enterprise – in order to create comprehensive case study, where respondents are customers, suppliers, institutions of supporting infrastructure, public administration, members of clusters, etc., who were important partners in the innovation process and affect the innovation process in the enterprise [3].

For evaluation of knowledge biography and creation of the knowledge model several types of maps were created:

a) Map of milestones in the creation, processing, utilization and dissemination of knowledge in the enterprise – is created based on the information included into knowledge biography of the enterprise. Horizontal division identifies the location where the processes of creation, processing, utilization and dissemination of knowledge (internal or external) were realised and a vertical division represents various phases of knowledge process. The time indicated in the map reflects a difficulty of meeting different stages of knowledge process in the enterprise.
b) Map of knowledge processes in the enterprise – describes participants of the process of creation, processing, utilization and dissemination of knowledge throughout the life of knowledge and innovation. It is created in relation to particular horizontal and vertical fields of the map (the example of the map is illustrated in Fig. 1).
c) Time-spatial map of knowledge processes in the enterprise – is produced using 3D presentation and represents a time and spatial map of relations and processes in knowledge management (the example of the map in a selected enterprise is shown in Fig. 2) [3].

4. Results

4.1. Framework characteristics of the ICT sector in the Zilina region in the area of creation, processing and dissemination of knowledge

Experts and founders of the major enterprises of the ICT sector in the Zilina region have previously worked at the VUVT Zilina. The main customers of ICT enterprses in the Zilina region are not only from the Zilina region, but also from outside the region. In terms of a geographic market definition, the market is described by the ICT enterprises as global. The global market definition implies major suppliers from the region and outside the region. The 90% of respondents think that the main impulse to innovation is a customer. A significant importance is attributed by ICT enterprises to informal relationship. Regional cooperation is mainly reflected in the ICT cluster [4]. The brief SWOT analysis of ICT sector in the Zilina region, which resulted from the performed sectoral analysis, with highlighted strengths and weaknesses, opportunities and threats is in Table 1.

4.2. Framework characteristics of transport and logistics sector in the Zilina region in the area of creation, processing and dissemination of knowledge

Enterprises draw inspiration for creation, processing and dissemination of knowledge mainly from neighbouring regions, with which they cooperate and have good relationship. Participation in professional events, literature and membership in professional organizations also contribute to creation and processing of knowledge. In comparison with the 90's of the last century, it appears that the area of knowledge dissemination has been influenced mostly by entry of enterprises with foreign participation in a logistics sector [5]. They bring inspiration for change, capital and knowledge (for example about new management systems, etc.). In national as well as regional contexts enterprises were profiled, which can be considered as leaders in processing and dissemination of knowledge (e.g. Logisped, Cargo, etc.). Development in the sector was also influenced by differences in legislation and technological level of providing services. In transport and logistics sectors, there is an intense competition and the market is highly fragmented. The process of creating preconditions for realization the knowledge process, associated with creation of innovation in transport and logistics sector does not have significant particularities compared to other sectors [6].

SWOT analysis of ICT sector in the Zilina region Tab. 1

Strengths	Weaknesses
- Skilled labour force (transport, communications, postal sector, ICT sector, logistics) - High concentration of IT professional labour force - Creativity – new original ideas - Know-how – essential for the regional development - Network of good class suppliers with high value added for customers - Region is defined as the centre of "IT brains"	- Insufficient know-how of professional and general public in the area of ICT cluster research - Inconsistent employees (do not think as a customer) - Hierarchy of power can be felt in the sector of ICT - Short product life
Opportunities	**Threats**
- The existence of the University of Zilina – Professional employee development at the University of Zilina for the ICT sector - Arrival of new investors - In general – tendency of young people to achieve success - General tendency of industry to expanse - The growth of e-business at the market - Encouraging the EU to integrate the ICT sector and to formalize the clusters - Software development solutions worldwide as an example of the best practice	- Sensitivity of the sector to the economic situation - An increase of management at humanities universities in the Slovak Republic – poor functional education system at the Slovak universities (lack of practice) - Rapid and intense development (outside the region) in the ICT sector - Strong competitive environment in the area of ICT Small national market – low market potential

Source: [4]

SWOT analysis of transport and logistics sectors in the Zilina region Tab. 2

Strengths	Weaknesses
- Quick establishment of enterprises in the labour market - High flexibility of enterprises in the transport and logistics sectors - Modern rolling stock - Transition to corporate social responsibility	- Lower level of employees' motivation to influence their passive approach to work - Inefficient and unsystematic fight with competition
Opportunities	**Threats**
- Geographic location of the region - Workforce skilled enough in the labour market, possibility for permanent education - Creation of appropriate conditions by the state for business in the transport and logistics sectors - Pan-European and global levels of know-how in the sector - High customer loyalty in the transport and logistics sectors - Cheap workforce in the region - Support of the development of integrated transport system by national and regional governments, - Growth in demand for transport and logistics services	- Pressure from customers on quality of services, - Lack of transparency between orders of the services provided - Existing competition in national and international contexts in the transport and logistics sectors - Passive attitude of employees - Increasing input prices - Negative effects of weather on businesses in the transport and logistics sectors

Source: [7]

The brief SWOT analysis of transport and logistics sector in the Zilina region, which resulted from the realized sectoral analysis, with highlighted strengths and weaknesses, opportunities and threats is pictured in Table 2.

Sectoral analysis in the Zilina region was a base for creating case studies. Within them knowledge biographies for selected enterprises were created. Examples of these studies from both sectors are in the subchapters 4.3 and 4.4.

4.3 Case study of Scheidt & Bachmann Slovakia s.r.o.

The enterprise Scheidt & Bachmann Slovakia s.r.o., is a related enterprise managed by two commissioners. General agreement between the controlling enterprise and related enterprise Scheidt & Bachmann Slovakia, s.r.o., can be defined as an essential specification of mutual cooperation. The price of ordered solutions is bargained individually with a controlling enterprise for every single order. Initially, the controlling enterprise defines the project problems and then managers from the related enterprise appraise the

time and a number of developers needed for the project. Indeed, negotiations regarding the price are not concluded with the first proposal. The payments for the finished projects are paid out only after the projects are finished. The time needed for the project realization varies. The simplest project requires a couple of weeks but some others take up to a few years. Therefore, the related enterprises realize a number of various projects at the same time. Despite the fact that Scheidt & Bachmann Slovakia s.r.o. finances the research activities, the enterprise does not have its own research departments.

During the development employees often have to face problems for solving of which they need more other professionals. In this case Scheidt & Bachmann Slovakia s.r.o. assigns the problem tasks to additional subjects, particularly to the University of Zilina. There are four independent divisions in this enterprise. These divisions develop, produce and distribute systems for car parks (parkings) and relax centers, systems for railway security devices, systems for passenger care, systems for petrol station, etc.

At the beginning the enterprise profile graded as "a softwarehouse" for all four divisions. After some time the enterprise strategically increased its range of activities and created a division of operation devices. Scheidt & Bachmann Slovakia s.r.o. also specializes in control software development for products of a parent firm. Transport means are more and more intelligent, their software is becoming more and more difficult and it takes some functions which were previously done mechanically. The enterprise Scheidt & Bachmann Slovakia s.r.o. employs 2000 employees. Within this number there is 1200 employees in the parent firm and in its daughter firm, Transport systems Scheidt & Bachmann, s.r.o., Zilina it employs 200 employees. The enterprise Scheidt & Bachmann Slovakia s.r.o. is a member of ICT cluster. In the 70's the enterprise produced mechanical printers for the city buses [8].

Contemporary printing and encoding device for transportation tickets presents an innovation of the former printer. The innovation represents an **electronic system** which expanses product features of the former printer. The main reason regarding this shift leans on technical development (technological changes) that affected the product innovation pressure. Whereas the innovation was affected by technical development, marketing research was not realized. The main innovator in the innovation was the top management of Scheidt & Bachmann Slovakia s.r.o. The innovation was funded from the enterprise financial resources. The enterprise Scheidt & Bachmann Slovakia s.r.o. did not apply for public funds (grant, project).

Phase 1: *Commencement of the idea, characteristic of features of a new (innovated) product, selection of a convenient partner, assignment of the project to the university of Zilina (January – February 2006)* – the leader of the innovation was the management of Scheidt & Bachmann Slovakia s.r.o. The management of Scheidt & Bachmann Slovakia s.r.o., the chief of development department and the chief of production participated in the innovation. There was no need to hire and train new employees in the first phase.

Phase 2: *Development of the initial prototype, completed draft of hardware (6 months), draft of design, development of software (4 months)* – The development department participated in the innovation. No additional employees were needed. In the period of March – December 2006, the University of Zilina – the external enterprise was involved into this process. The cooperation rate during the innovation process was regular and intensive. The University of Zilina brought know-how needed for the software and hardware development to the innovation process. We can state that the importance of cooperation between the University of Zilina and Scheidt & Bachmann Slovakia s.r.o. was significant because the University of Zilina offered the hardware and software to the innovation process. Without this contribution the innovation process could not be realized. The cooperation with the University of Zilina developed on the base of several years of relationship with the university of Zilina and Scheidt & Bachmann Slovakia s.r.o. The relationship was based on specialists' education and students' study stays. The University of Zilina brought knowledge when creating the hardware and software and it also provided place and equipment because Scheidt & Bachmann Slovakia s.r.o. could not offer such facilities for the realization of the change [9].

Phase 3: *Development of the second prototype* (2007) – this phase, in comparison with the previous one, differs in the period of time of the realization which was the period from January – December 2007. The leader of the third phase was also the enterprise Scheidt & Bachmann Slovakia, s.r.o., particularly its development department. There was no need to hire some additional employees. The University of Zilina took part in the innovation process, again. The cooperation rate during the innovation process was regular and intensive. The development of the second prototype proceeded the same way as the development of the first prototype in the first phase.

Phase 4: *Project talks with customers, final product marketing (2008, 2009)* – this phase was performed via meetings between the enterprise and customers when the final product and its benefits and properties were presented to customers. This activity was managed by the employees responsible for marketing of the enterprise.

Phase 5: Batch production (2010) – a final phase was managed by the production department of Scheidt & Bachmann Slovakia, s.r.o. New employees were hired, including graduates from the University of Zilina. The innovation process as a whole was finished and no innovation extension came into consideration. New employees were trained by Scheidt & Bachmann Slovakia, s.r.o. The knowledge gathered within this project was disseminated via the presentation of Scheidt & Bachmann Slovakia, s.r.o. The project was presented at significant national and international conferences, congresses and extra lectures at the University of Zilina [10].

The main hypothesis, which was defined as the statement is as follows: *"forwardness of enterprise in the area of* ***creation, processing, exploitation and dissemination of knowledge*** *is heavily influenced by internal and external factors, related to sector characteristic,* **all**

approved by research through the case study. Despite all this, the enterprise does not play a significant role in the region."

Specific hypotheses

I. The process of creation, processing, utilization and dissemination of knowledge in enterprises is not realized purposefully and co-ordinately. The case study **did not approve** this hypothesis.
II. Innovation process within enterprises is characterized mainly by absorption, combination and knowledge usage, created elsewhere. The hypothesis within this case study **was approved.**
III. The process of creation, utilization and dissemination of knowledge is characterized by a low rate of cooperation and knowledge supporting usage already created in regions. The hypothesis within this case study **was not approved**.
IV. Lack of financial funds poses a barrier against creation, gathering and dissemination of knowledge. The hypothesis within this case study **was not approved**.
V. In general, the state does not donate enterprises with the state funds. The case study **approved** this hypothesis [10].

4.4. Case study of Slovenska posta a. s. (Slovak Post, Inc.)

Slovenska pošta, a. s., is a leading provider of modern communication, distribution and payment services in the domestic market with already created logistic conditions for running business in central and eastern Europe. Innovation explored and solved within the project was based on the fulfillment of aims leading to the systematic quality improvement throughout the project "Service Level Agreements". The project deals with the permanent improvement of quality regarding international and inland first class letters. The main impulse for these changes was quality imbalances at international and inland levels. The project as a whole was aimed at customer's consolation and enterprise stabilities in the already competitive market. The innovation development was funded by Slovenska posta, a. s., no other donations were applied.

The solution is innovative in the fact that through the "statement" we shifted the fulfillment of quality to an employee because this employee might be a kind of a potential source of a poor quality. The main principle was to find the method to fulfill the quality standard. So, for instance, if the quality standard has to be fulfilled at 96% as a whole and the time for mail delivery is kept, then the logistics department must achieve the standard of 98.5%. The main impulse for the change was the appearance of variation in quality at international and national levels in the area of correspondence. The inspiration for the change was the fact that customers compare the quality of service of Slovenska posta, a. s. with other postal service providers and Slovenska posta, a. s. has to succeed in the competition [10].

Time and content development of the innovation process proceeded in three main phases listed below.

Phase 1: *It represented a creation of the idea, creation of steering committee for service quality assurance, work team for service quality secure* (2006). In this phase, the innovation was managed by the top management of SP, a.s. The innovation carried out the following external and internal studies aimed at the service quality provided, among others, by the University of Zilina. Into the innovation process the whole enterprise SP, a. s. was involved, particularly all top directors from all the departments. The education of employees was provided by the enterprise. Two external companies participated in the innovation process: the Austrian Post – an international transit region, the Hungarian Post (Budapest); the level of participation was determined according to the process demands. These external movers found their place by exposing the innovation principle and presented a significant support for carrying it out. The additional aspects that significantly affected the innovation process were: the change of customers' behaviour and important technological changes in a postal sector, these aspect have occurred t in the recent years.

Phase 2: *Solution statement* – created the first version of the "Service Level Agreements" project, regarding first class international and domestic intercourses in the year 2008. Both the steering committee and work team were set up to maintain the service quality. Two external companies participated in the innovation process: the Austrian Post – an international transit region, the Hungarian Post (Budapest), the level of participation was determined according to the process demands.

Communication throughout the process was irregular. The innovation process affected the entire trend in the field of postal services, which aimed to improvement of service quality.

Phase 3: *Additional development of product* – this phase presents the updating for the years 2009 up to 2010 and still running in the year 2009. A change in this phase was managed by the top management with participation of all the subjects. There was no additional need for external partners. The innovation process continually affected the steadily changing behaviour of customers towards the improvement of service quality, technological changes, global trends regarding competition in the liberalized postal market.

Nowadays, the project is being periodically updated. Recently, the project "Service Level Agreements" was accepted in the service for EPG, EMS-MS. A further extension of the project will take place only in the future [10].

Fig. 1 presents the chart of knowledge processes within the enterprise.

The main hypothesis: *"Forwardness of enterprise in the branch of creation, handling, utilization and spreading of knowledge is heavily influenced by internal and external factors, related with sector characteristic,* all **approved** by case study. Despite all this, the influence of regional dimension was not recognized.

Specific hypotheses:

I. Creation, processing, utilization and dissemination of knowledge within the enterprises is not realized purposely and coordinated. The case study **did not approve** this hypothesis.

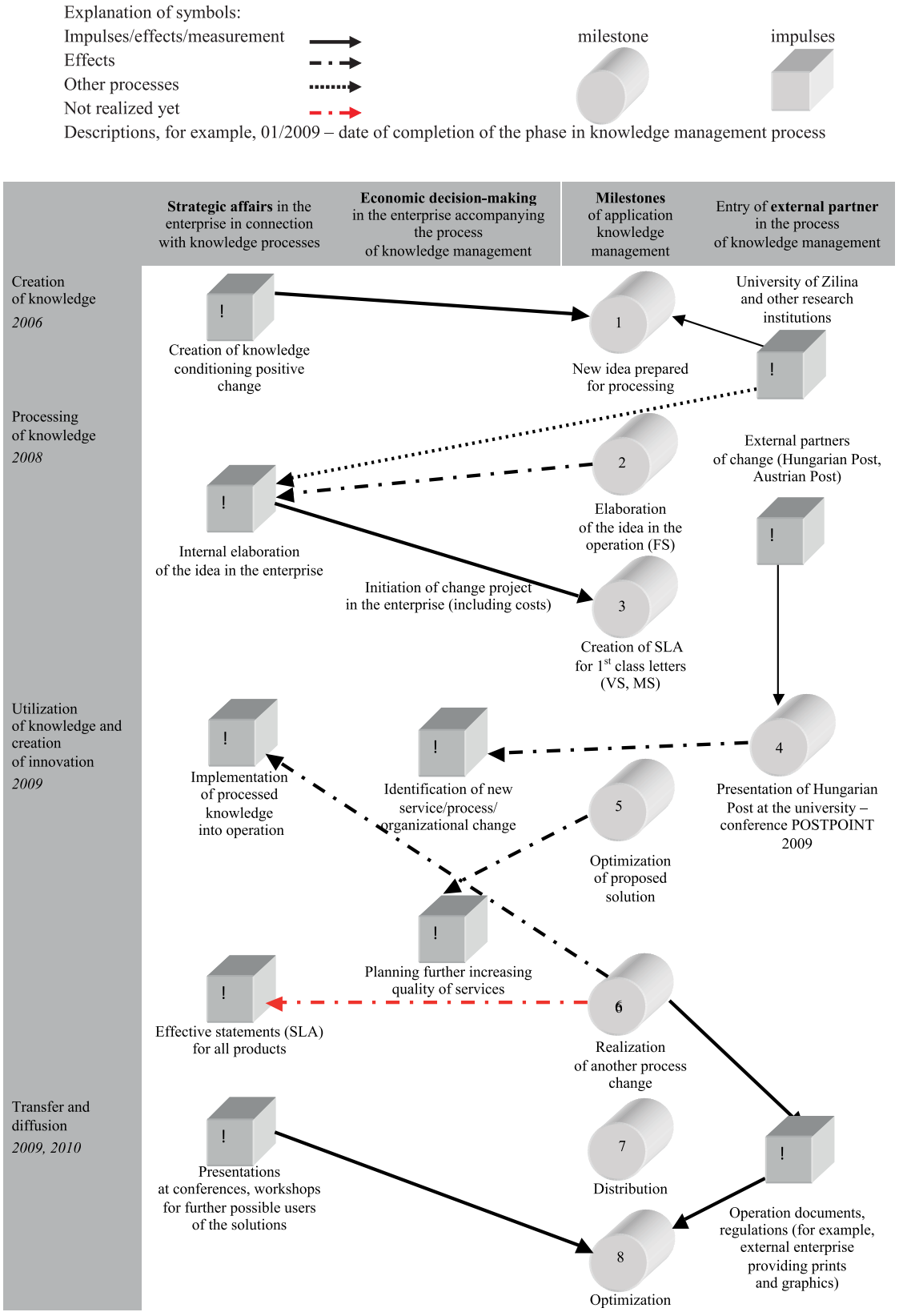

Fig. 1 Map of knowledge processes in Slovenska posta, a. s. [10]

II. Innovation process within the enterprises is characterized mainly by absorption, combination and knowledge usage, created elsewhere. The hypothesis within this case study **was approved**.

III. Creation, utilization and dissemination of knowledge is characterized by a low rate of cooperation and knowledge supporting the usage already created in the regions. The hypothesis within this case study **was not approved**.

IV. Lack of financial funds poses a barrier against creation, gathering and dissemination of knowledge. The case study **did not approve** this hypothesis.

V. In general, the state does not donate the enterprises during creation, processing, using and dissemination of knowledge. The case study **did not approve** this hypothesis, but it neither denies it, because the enterprise did not ask for donation during the project realization [10].

ilarities in the time parameters of the knowledge management process.

5. Discussion and conclusion

Technological know-how is considered as a major factor in a long-term growth and prosperity of enterprises, regions and countries. The project REDIPE presents the way of realization of the knowledge diagnostics, the knowledge processing and the knowledge dissemination. The mechanism of diagnostics, processing and dissemination in enterprise innovation processes are different in each region. There are different conditions under which diagnostics, processing and dissemination take place in each region. The research in the Žilina region was focused on examining the impact of the regional environment (in the area of knowledge) in the inno-

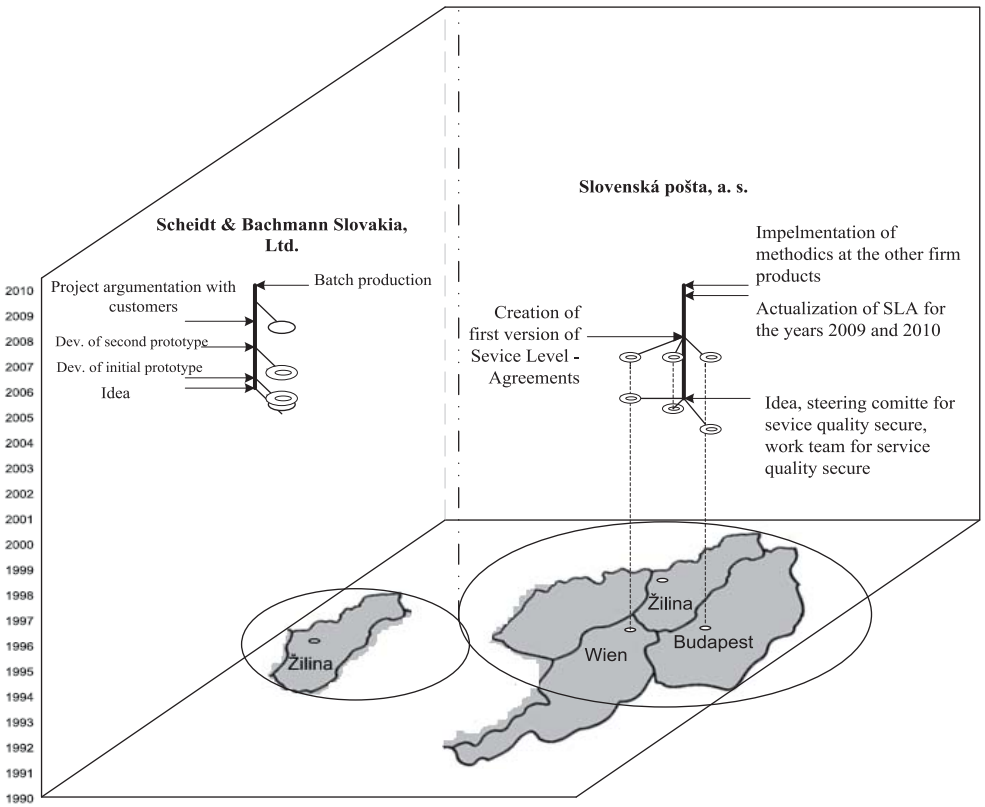

Fig. 2 Time-spatial map of knowledge processes in Scheidt & Bachmann Slovakia, Ltd., and Slovenska posta, a. s. [10]

Fig. 2 presents a time-spatial map of knowledge processes in selected enterprises from the ICT sector of transport and logistics sector.

As we can see from the time special knowledge maps, there are obvious differences between the enterprises in the spatial scope of creation, processing and dissemination of knowledge and simvation process of the enterprises in the ICT sector and transport and logistics sectors.

As the research shows, both sectors were affected by the knowledge-based processes in their enterprises' history. As an example, the economic dimension of the ICT sector is shown in Fig. 3, from which it is clear how the sector has evolved from the year 1980 to the present.

Based on the results the following can be stated: "Creation, processing and dissemination of knowledge is not a simple and automatic process. Knowledge is generated collectively. Within this process interaction and exchange of ideas take place among participants. It is also confirmed that the creation and dissemination of knowledge in space require financial expenses following from the interaction of participants. Economic activities are concentrated in space because within the sectors observed in the Zilina region, imitation and mutual studying occur more often and faster. It is obvious that under such conditions the enterprises cannot be considered as single units, but they are closely connected with other firms (suppliers, competitors), customers, private and public organizations. Firms in both sectors combine sources inside a firm (education, research and development) with acquisition of external sources of knowledge. It is evident that the relation of external and internal knowledge differed in the subject sector. It depended on

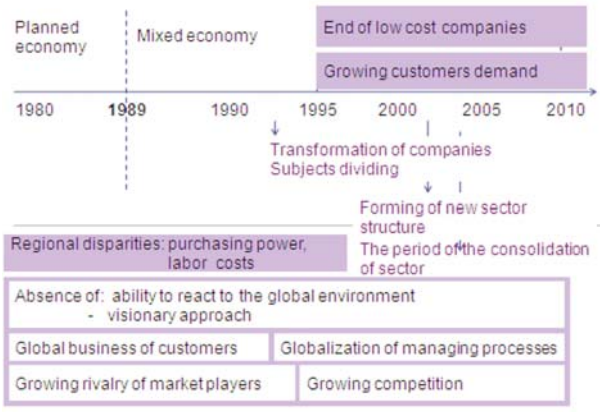

Fig. 3 Economics dimension of the Zilina Region research in ICT sector [4]

expenses to get external knowledge. The firms preferred an inter-enterprise knowledge creation.

Finally, we can state that the concept known as an "innovative milieu" is characteristic for most enterprises of transport, logistics and ICT sectors in the Zilina region. It means that the enterprises do not innovate separately, but they are part of the environment where they are established and this environment influences them significantly. The sense of the REDIPE project was to identify the key regional participants whose activity and interaction contribute to innovation performance of the Zilina region. The research of the creation process, processing and dissemination of knowledge also pointed out the concentrated relationships between commercial and academic sectors. For all regions, as well as for the Zilina region applies that for the future success of sectors in the region it is necessary to identify new directions for development, strategic partners, and to the maximum possible extent commercially evaluate new knowledge.

Achieving the objectives of the research determined the fact that the REDIPE project has got its continuation within the project "Creative economy − regional and national economic conditions and incentives − KRENAR", approved for solving during the next years by the Slovak Research and Development Agency. All the participants of the REDIPE project are going to take part in the KRENAR project.

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7/KS/2012 Kreativna ekonomika a jej uplatnenie v Zilinskom regione.

2/KS/2012 Realizacia a kooperacia na uskutocneni komplexu vyskumnych aktivit vo vybranej sfere sluzieb – faza 2.

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Juraj Muzik – Karel Kovarik – Dana Sitanyiova *

MESHLESS ANALYSIS OF AN EMBANKMENT USING LOCAL GALERKIN RADIAL POINT INTERPOLATION METHOD (LGRPIM)

The paper deals with use of the meshless method for slope stability analysis. There are many formulations of the meshless methods. The article presents the Local Galerkin Radial Point Interpolation method (LGRPIM) – local weak formulation of the equilibrium equations. The main difference between meshless methods and the conventional finite element method (FEM) is that meshless shape functions are constructed using randomly scattered set of points without any relation between points. The shape function construction is the crucial part of the meshless numerical analysis in the construction of shape functions. The article presents the radial point interpolation method (RPIM) for the shape functions construction. The numerical example of the slope stability was calculated using meshless computer code and compared with FEM results.

Keywords: *Meshless, radial point interpolation method, numerical methods, slope stability.*

1. Introduction

The investigation of soil behavior through the field observations or laboratory modeling is usually expensive and time-consuming [1]. So it is profitable to develop numerical solutions which may be used to predict the load-deformation characteristics and the stability of the soil structures [2]. The most popular method for numerical analyses in geotechnical engineering is the finite element method [3]. Although finite element method – FEM is widely used, there are some deficiencies such as the discontinuity of stresses on element boundaries or low accuracy at large deformation analysis. The mentioned shortcomings are mainly related to the mesh definition.

Therefore, the new families of numerical methods independent of mesh are applied to the geotechnical problems – the slope stability analysis in this article. These new families of numerical methods are widely named as meshless methods.

In this article, the elasto-plastic analysis of soil slope structure using the Local Galerkin Radial Point Interpolation method (LGRPIM) is presented. LGRPIM is the "true" meshless method based on the local weak-formulation of the equilibrium equations [4]. The Radial point interpolation method (RPIM) is used to construct shape functions. The system of equations has been derived and the computer code developed. The validity has been investigated by solving an example and the result comparison is provided at the end of the article.

2. Meshless shape function construction

The crucial part of meshless methods is the construction of the shape function used to approximate the unknown field function [3]. These shape functions are locally supported, because only set of field nodes in a small local domain are used in the construction of shape function. In contrast with FEM, where the shape func-

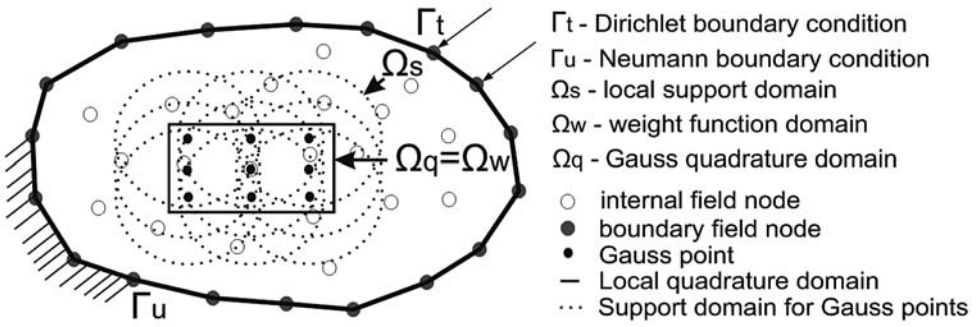

Fig. 1 A problem domain and boundaries modeled using LRPIM

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tion is based on nodes with defined relationship (elements), the meshless shape function is based on the group of nodes arbitrarily scattered within the support domain [5]. There are many techniques used to construct meshless shape functions. The point interpolation method (PIM) and radial point interpolation method (RPIM) are presented.

2.1 Point interpolation method – PIM.

The polynomials have been used as basis functions for interpolation in various numerical methods such as FEM. In FEM the interpolation process is based on connected elements without gaps or overlaps. In PIM, the interpolation is based on small portion of nodes around the desired point, forming the local support (Fig. 1) [5]. Support domains of different points can overlap each other. The continuous function $u(\boldsymbol{X})$ (displacement function) can be expressed around point $\boldsymbol{X}$ as

$$u(\boldsymbol{X}) = \sum_{i=1}^{n} p_i(\boldsymbol{X}) a_i = \boldsymbol{P}^{\boldsymbol{T}} \boldsymbol{a} \tag{1}$$

where $p_i(\boldsymbol{X})$ is polynomial function of $X = [x,y]^T$, n is count of nodes in support domain of point $\boldsymbol{X}$ and a_i is suitable coefficient of the basis function. Unknown coefficients ai in Eq. 1 can be obtained by setting the $u(\boldsymbol{X})$ to be nodal displacement at n nodes of the support domain. This can be written using matrix notation as:

$$\boldsymbol{U}_S = \boldsymbol{P}_m \boldsymbol{a} \tag{2}$$

where $\boldsymbol{U}_S$ is the vector of nodal displacement,

$$\boldsymbol{U}_S = [u_1 \;\; v_1 \;\; u_2 \;\; v_2 \;\; \ldots \;\; u_n \;\; v_n]^T \tag{3}$$

and $\boldsymbol{a}$ is the vector of unknown coefficients

$$\boldsymbol{a} = [a_1 \;\; a_2 \;\; a_3 \;\; \ldots \;\; a_n]^T \tag{4}$$

and P_m is polynomial moment matrix

$$\boldsymbol{P}_m = \begin{bmatrix} 1 & x_1 & y_1 & x_1y_1 & \ldots & p_m(\boldsymbol{X}_1) \\ 1 & x_2 & y_2 & x_2y_2 & \ldots & p_m(\boldsymbol{X}_2) \\ 1 & x_3 & y_3 & x_3y_3 & \ldots & p_m(\boldsymbol{X}_3) \\ \ldots & \ldots & \ldots & \ldots & & \ldots \\ 1 & x_n & y_n & x_ny_n & \ldots & p_m(\boldsymbol{X}_n) \end{bmatrix} \tag{5}$$

considering $m = n$ one can assume that the inversion of moment matrix $\boldsymbol{P}_m^{-1}$ exists and the unique solution for coefficients a can be obtained as

$$\boldsymbol{a} = \boldsymbol{P}_m^{-1} \boldsymbol{U}_S \tag{6}$$

It has to be noted that the coefficients a are constants even if the point of interest $\boldsymbol{X}$ changes, as long as the same set of nodes is used in the interpolation, because the $\boldsymbol{P}_m$ is matrix of constants for given set of nodes.

Substituting Eq. 6 into Eq. 1 gives

$$u(\boldsymbol{X}) = \boldsymbol{P}^{\boldsymbol{T}}(\boldsymbol{X}) \boldsymbol{P}_m^{-1} \boldsymbol{U}_S = \sum_{i=1}^{n} \varphi_i u_i = \boldsymbol{\Phi}^{\boldsymbol{T}}(\boldsymbol{X}) \boldsymbol{U}_S \tag{7}$$

where $\boldsymbol{\Phi}(\boldsymbol{X})$ is the vector of PIM shape functions defined by

$$\boldsymbol{\Phi}^{\boldsymbol{T}}(\boldsymbol{X}) = \boldsymbol{p}^{\boldsymbol{T}}(\boldsymbol{x}) \boldsymbol{P}_{\boldsymbol{m}}^{-1} = \left[\phi_1(\boldsymbol{X}) \;\; \phi_2(\boldsymbol{X}) \;\; \ldots \phi_n(\boldsymbol{X})\right] \tag{8}$$

The derivatives of the shape functions can be easily obtained because PIM function is of polynomial form. The I-th derivative of PIM shape functions can be written

$$\boldsymbol{\Phi}^{(I)}(\boldsymbol{X}) = \begin{bmatrix} \phi_1^{(I)}(\boldsymbol{X}) \\ \phi_2^{(I)}(\boldsymbol{X}) \\ \ldots \\ \phi_3^{(I)}(\boldsymbol{X}) \end{bmatrix} = \frac{\partial^I \boldsymbol{p}^{\boldsymbol{T}}(\boldsymbol{X})}{\partial \boldsymbol{X}^I} \boldsymbol{P}_{\boldsymbol{m}}^{-1} \tag{9}$$

The shape functions constructed by PIM have the Kronecker delta function property, which allows the simple imposition of essential boundary conditions as in conventional FEM [6].

2.2 Radial point interpolation method – RPIM

The PIM is accurate and easy to use. However, an inappropriate choice of polynomial basis or the improper position of nodes inside the support domain near $\boldsymbol{X}$ results in singular matrix $\boldsymbol{P}_m$ [6]. Several strategies have been proposed to overcome this problem. Using radial basis functions (RBF) is one of the best solutions to guarantee the invertibility of $\boldsymbol{P}_m$ [5]. There are various classes of functions such as multi-quadratic, Gaussian or Logarithmic that can be used as RBF. Multi-quadratic is one of the most popular radial function [5] and it is defined as

$$R_i(\boldsymbol{X}) = (r_i^2 + \varepsilon^2)^q \tag{10}$$

where r_i is the distance between the desired point ($\boldsymbol{X}$) and the field node $i(\boldsymbol{X}_i)$ defined simply as 2D Euclidean distance

$$r_i = \sqrt{(x - x_i)^2 + (y - y_i)^2} \tag{11}$$

Constants ε and q in Eq.10 are constants that depend on the type of problem. For the solid mechanics the suggested values are 1.42 and 0.98 for ε and q, respectively [3].

The RPIM interpolation augmented with polynomials can be written as

$$\begin{aligned} u(\boldsymbol{X}) &= \sum_{i=1}^{n} R_i(\boldsymbol{X}) a_i + \sum_{j=1}^{m} p_j(\boldsymbol{X}) b_j = \\ &= \boldsymbol{R}^{\boldsymbol{T}}(\boldsymbol{X}) \boldsymbol{a} + \boldsymbol{p}^{\boldsymbol{T}}(\boldsymbol{X}) \boldsymbol{b} \end{aligned} \tag{12}$$

where $R_i(\boldsymbol{X})$ is the radial basis function (RBF), n is the number of RBFs, $p_j(\boldsymbol{X})$ is polynomial basis function, m is number of polynomial basis function, a_i and b_j are interpolation coefficients. In order to determine a_i and b_j a support domain is formed for the point of

interest at X, and n field nodes are included in the support domain. Interpolation coefficients can be determined by enforcing Eq. 12 to be satisfied at these n nodes surrounding the point of interest X. This leads to n linear equations, one for each node. The equation system in matrix form can be expressed as

$$\boldsymbol{U}_S = \boldsymbol{R}\boldsymbol{a} + \boldsymbol{P}_m\boldsymbol{b} \tag{13}$$

where $\boldsymbol{U}_S$ is the vector of displacement function values, the RBF moment matrix is

$$R = \begin{bmatrix} R_1(r_1) & R_2(r_1) & \dots & R_n(r_1) \\ R_1(r_2) & R_2(r_2) & \dots & R_n(r_2) \\ \dots & \dots & \dots & \dots \\ R_1(r_n) & R_2(r_n) & \dots & R_n(r_n) \end{bmatrix} \tag{14}$$

and the polynomial moment matri is

$$\boldsymbol{P}_m^T = \begin{bmatrix} 1 & 1 & \dots & 1 \\ x_1 & x_2 & \dots & x_n \\ y_1 & y_2 & \dots & y_n \\ \vdots & \vdots & \ddots & \vdots \\ p_m(x_1) & p_m(x_2) & \dots & p_m(x_n) \end{bmatrix} \tag{15}$$

the vector of RBF interpolation coefficients is defined as

$$\boldsymbol{a}^T = [a_1 \quad a_2 \quad \dots \quad a_n] \tag{16}$$

And the vector of polynomial interpolation coefficients is defined as

$$\boldsymbol{b}^T = [b_1 \quad b_2 \quad \dots \quad b_n] \tag{17}$$

However, there are $n + m$ variables in Eq. 13. The additional m equations can be added using the following m constraint conditions.

$$\sum_{i=1}^{n} p_j(\boldsymbol{x}_i)a_i = \boldsymbol{P}_m^T\boldsymbol{a} = j = 1, 2, \dots, m \tag{18}$$

Combining Eq. 13 and Eq. 18 yields the following set of equations in the matrix form expressed as

$$\tilde{\boldsymbol{U}}_S = \begin{bmatrix} \boldsymbol{U}_S \\ \boldsymbol{0} \end{bmatrix} = \begin{bmatrix} \boldsymbol{R} & \boldsymbol{P}_m \\ \boldsymbol{P}_m^T & \boldsymbol{0} \end{bmatrix} \begin{bmatrix} \boldsymbol{a} \\ \boldsymbol{b} \end{bmatrix} = \boldsymbol{G}\boldsymbol{a}_0 \tag{19}$$

where

$$\boldsymbol{a}_0^T = [a_1 \quad a_2 \quad \dots \quad a_n \quad b_1 \quad b_2 \quad \dots \quad b_n] \tag{20}$$

$$\tilde{\boldsymbol{U}}_S = [u_1 \quad u_2 \quad \dots \quad u_n \quad 0 \quad 0 \quad \dots \quad 0] \tag{21}$$

Because the matrix $\boldsymbol{R}$ is symmetric, the composed matrix $\boldsymbol{G}$ will be also symmetric. Solving the equation system (19), we obtain

$$\boldsymbol{a}_0 = \begin{bmatrix} \boldsymbol{a} \\ \boldsymbol{b} \end{bmatrix} = \boldsymbol{G}^{-1}\tilde{\boldsymbol{U}}_S \tag{22}$$

Equation (12) can be subsequently rewritten as

$$\boldsymbol{u}(\boldsymbol{X}) = \boldsymbol{R}^T(\boldsymbol{X})\boldsymbol{a} + \boldsymbol{p}^T(\boldsymbol{X})\boldsymbol{b} = \begin{bmatrix} \boldsymbol{R}^T(\boldsymbol{X}) & \boldsymbol{p}^T(\boldsymbol{X}) \end{bmatrix} \begin{bmatrix} \boldsymbol{a} \\ \boldsymbol{b} \end{bmatrix} \tag{23}$$

Using equation (22) we can obtain

$$\mathbf{u}(\boldsymbol{X}) = \begin{bmatrix} \boldsymbol{R}^T(\boldsymbol{X}) & \boldsymbol{p}^T(\boldsymbol{X}) \end{bmatrix} \boldsymbol{G}^{-1}\tilde{\boldsymbol{U}}_S = \tilde{\boldsymbol{\Phi}}^T(\boldsymbol{X})\tilde{\boldsymbol{U}}_S \tag{24}$$

and finally the RPIM shape functions corresponding to the nodal displacements vector $\boldsymbol{\Phi}(X)$ are obtained as

$$\begin{aligned} &\tilde{\boldsymbol{\Phi}}^T(\boldsymbol{X}) = \begin{bmatrix} \boldsymbol{R}^T(\boldsymbol{X}) & \boldsymbol{p}^T(\boldsymbol{X}) \end{bmatrix} \boldsymbol{G}^{-1} = \\ &= \begin{bmatrix} \phi_1(\boldsymbol{X}) & \phi_2(\boldsymbol{X}) & \dots & \phi_n(\boldsymbol{X}) & \phi_{n+1}(\boldsymbol{X}) & \phi_{n+m}(\boldsymbol{X}) \end{bmatrix} \end{aligned} \tag{25}$$

$$\boldsymbol{\Phi}^T(\boldsymbol{X}) = \begin{bmatrix} \phi_1(\boldsymbol{X}) & \phi_2(\boldsymbol{X}) & \dots & \phi_n(\boldsymbol{X}) \end{bmatrix} \tag{26}$$

Then the displacement function approximation can be written using the RPIM shape functions and nodal displacements

$$\boldsymbol{u}(\boldsymbol{X}) = \boldsymbol{\Phi}^T(\boldsymbol{X})\boldsymbol{U}_S = \sum_{i=1}^{n} \phi_i u_i \tag{27}$$

and the I-th derivatives of displacement function $u(X)$ are easily obtained as

$$\boldsymbol{\Phi}^{(I)}(\boldsymbol{X}) = \begin{bmatrix} \dfrac{\partial^I \boldsymbol{R}^T(\boldsymbol{X})}{\partial \boldsymbol{X}^I} & \dfrac{\partial^I \boldsymbol{p}^T(\boldsymbol{X})}{\partial \boldsymbol{X}^I} \end{bmatrix} \boldsymbol{G}^{-1} \tag{28}$$

Note that $\boldsymbol{R}_0^{-1}$ usually exists for arbitrarily scattered nodes. In addition, the order of polynomial used in RPIM shape functions is relatively low. Therefore, there is no singularity problem in the RPIM as a small number of nodes is used in the local support domain [7].

3. Weak formulation of the equilibrium equations

The LGRPIM uses the local weighted residual formulation of the equilibrium equations rather than the global energy principle to create the discretized equation system. The compatibility of the shape functions in whole domain is not required as long as the field approximation is continuous at any point in the local quadrature domain. In other words the LGRPIM method only requires the local compatibility in the local quadrature domain. The RPIM shape function formulated in previous chapter satisfies all these requirements, in addition to its delta function property.

3.1 Local weighted residual formulation of the equilibrium equations.

The general local weighted residual form defined over local quadrature domain Ω_q bounded by Γ_q has following matrix form [5]

$$\boldsymbol{K}_I\boldsymbol{u} = \boldsymbol{f} \tag{29}$$

where $\boldsymbol{K}_I$ is the matrix called nodal stiffness matrix for the I-th field node, which is computed using following formula

$$\boldsymbol{K_I} = \int_{\Omega_q} \boldsymbol{V_I^T D B} d\Omega - \int_{\Gamma_{qt}} \boldsymbol{W_I^T} n \boldsymbol{D B} d\Gamma - \int_{\Gamma_{qu}} \boldsymbol{W_I^T} n \boldsymbol{D B} d\Gamma \quad (30)$$

and the $\boldsymbol{f_I}$ is a nodal force vector with contribution from the body forces applied in the model domain, and the tractions applied on the natural boundary

$$\boldsymbol{f_I} = \int_{\Omega_q} \boldsymbol{W_I^T b} d\Omega + \int_{\Gamma_{qt}} \boldsymbol{W_I^T} \bar{t} d\Gamma \quad (31)$$

The terms $\boldsymbol{W}$ and $\boldsymbol{V}$ in the previous definitions is the weight function matrix and weight function derivatives matrix respectively [6], used to smear the numerical residuals over the local quadrature. In equation (30) $\boldsymbol{D}$ represents the matrix of elastic constants, $\boldsymbol{B}$ is the strain-displacement matrix, $\boldsymbol{n}$ is matrix containing the components of the unit outward vector on the domain boundary, $\boldsymbol{t}$ is the traction defined on the domain boundary and b is the body force.

The weight function W definition used in this article follows the rectangular shape of the quadrature domain. Cubic spline type weight function was defined as follows [5]

$$W(x - x_i) = W_{ix}(x - x_i) W_{iy}(y - y_i) = W(r_{ix}) W(r_{iy}) \quad (32)$$

$$r_{ix} = \frac{\left\| x - x_i \right\|}{d_{sx}} \quad r_{ix} = \frac{\left\| x - x_i \right\|}{d_{sx}} \quad (33)$$

where d_{sx} and d_{sy} is the size of the local quadrature domain.

$$W(r_{ix}) = \begin{cases} \frac{2}{3} - 4r_{ix}^2 + 4r_{ix}^3 & r_{ix} \le 0.5 \\ \frac{4}{3} - 4r_{ix} + 4r_{ix}^2 - \frac{4}{3} r_{ix}^3 & 0.5 \prec r_{ix} \le 1 \\ 0 & r_{ix} \succ 1 \end{cases}$$
$$W(r_{iy}) = \begin{cases} \frac{2}{3} - 4r_{iy}^2 + 4r_{iy}^3 & r_{iy} \le 0.5 \\ \frac{4}{3} - 4r_{iy} + 4r_{iy}^2 - \frac{4}{3} r_{iy}^3 & 0.5 \prec r_{iy} \le 1 \\ 0 & r_{iy} \succ 1 \end{cases} \quad (34)$$

Assembling the nodal stiffness matrices into a global stiffness matrix based on node numbering, the global equation system is obtained. The global stiffness matrix is asymmetric, which makes the computation more expensive than conventional FEM [4]. For numerical example in this article the Gaussian elimination solver was used to solve global equation system [8]. Because the analysis of the soil models using the elasto-plastic models needs the nonlinear solution scheme, the modified Newton-Raphson scheme was adopted for solving the models. The nodal loads are generated from the self-weight of the slope body and redistributed over the model nodes. Once the plastic flow occurs, the stresses are computed using elasto-plastic matrix (Eq. 36) and the unbalanced forces are redistributed over adjacent nodes. This process is repeated until there is no unbalanced force or maximum iteration count was achieved.

3.2. Elasto-plastic constitutive equations

In elasto-plastic analysis, the incremental stress-strain relation is as follows [5]:

$$d\boldsymbol{\sigma} = \boldsymbol{D}_{ep} d\boldsymbol{\varepsilon} \quad (35)$$

where $\boldsymbol{D}_{ep}$ is elasto-plastic matrix. In this article, the Mohr-Coulomb yield function was used as the most popular yield criterion used in soil mechanics.

$$F = \sigma_m \sin\varphi + \bar{\sigma}\left(\frac{\cos\varphi}{\sqrt{3}} - \frac{\sin\theta \sin\varphi}{3}\right) - c\cos\varphi \quad (36)$$

where c and φ means the cohesion and internal friction angle respectively. The quantities σ_m, σ, θ represents the stress invariants in the principal stress space. The plastic potential equation is similar to the yield function (Eq. 36), except that instead of internal friction angle the dilatation angle - ψ is used.

4. Numerical example of the slope stability computation

The LGRPIM model has been verified with the computation of the slope stability problem. Because there is no exact analytical solution of this kind of problem, the model of the embankment slope was calculated using conventional finite element code for geotechnical problems - PLAXIS and the Janbu's limit equilibrium method (LEM) implemented in GeoStudio 2003. Figure 2 shows the geometry and dimensions of the slope model and parameters for the Mohr-Coulomb elastoplastic model are presented in Table 1. The model represents simple homogenous slope body with "roller" essential boundary condition on left and right boundary ($u_x^r = u_x^l = 0$) and fixed ($u_x^b = u_y^b = 0$) movement at the model bottom.

The result of the slope stability analysis is *FS* - factor of safety and the shape of the failure in the slope body. Factor of safety (FS) in numerical analysis is defined as the strength reduction factor (SRF) which represents the boundary between stable and unstable state of the model. In the case of the limit equilibrium methods (Janbu), the factor of safety is defined as the ratio between active (moving) and passive (resisting) forces along the slip surface.

To perform the integrations for the local weak-form, local quadrature domains are needed. The local quadrature domain is simple rectangular domain which is easy to handle. The size of the quadrature domains used in LGRPIM implementation is $r_{qx} = r_{qy} = 3.75$. The quadrature domain needs to be divided into 4 subdomains to ensure accuracy of the solution. Each partition contains 16 Gauss points [5]. The support domain used to construct RPIM shape functions has circular shape with radius $r_s = 3.75$. The cubic spline function (34) is used as the test function for the LGRPIM.

The Mohr-Coulomb model was used in PLAXIS computation as well as in the analysis performed using LGRPIM. The Janbu's limit equilibrium method is also using the Mohr-Coulomb strength

criterion for stability analysis. The result of the LGRPIM analysis showing the slope failure (Fig. 2) and plastic flow vectors (Fig. 3) at the $FS = 1.63$.

Soil parameters used in the numerical study [1] Table 1

Soil parameter	Value	Soil parameter	Value
γ – volumetric weight	20 [kNm^{-3}]	φ – friction angle	20 [°]
E – Young modulus	100000 [kPa]	c – cohesion	15 [kPa]
ν – Poisson ratio	0.3 []	ψ – dilatation angle	0 [°]

The parametric study with varying slope inclination angle (β – Fig. 2) was also performed to show how the factor of safety (FS) will develop. Parametric study was performed using LGRPIM, FEM and Janbu's limit equilibrium method. The result (Fig. 5) indicates close agreement of LGRPIM with FEM and Janbus's method for presented slope stability problem.

The relative difference of the computation results performed by LGRPIM against the FEM code are shown in the Table 2. The safety factor was developing similary with maximum overall difference 9.64%.

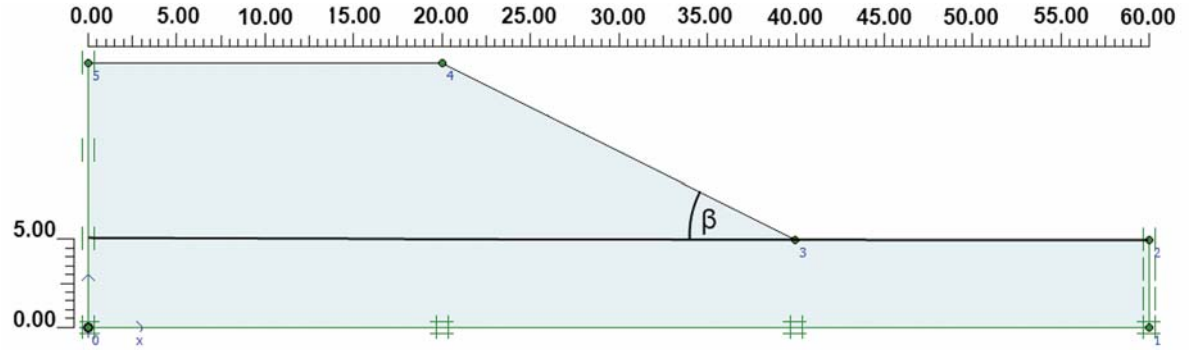

Fig. 2 Embankment slope geometry and dimensions (in meters) used for numerical study

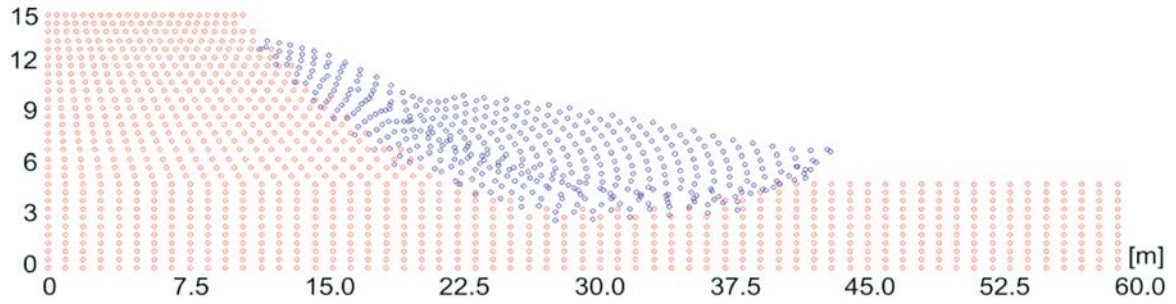

Fig. 3 The slope failure at the FS ≡ SRF (strength reduction factor) = 1.63 computed using LGRPIM

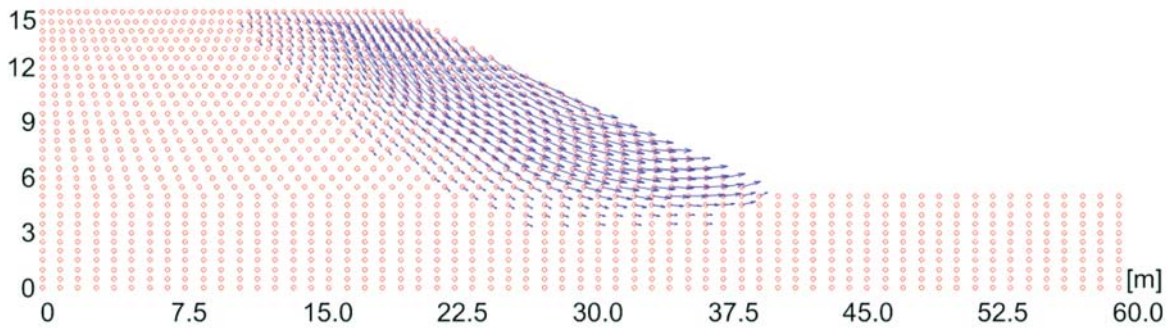

Fig. 4 Plastic flow vectors at the FS ≡ SRF (strength reduction factor) = 1.63 computed using LGRPIM

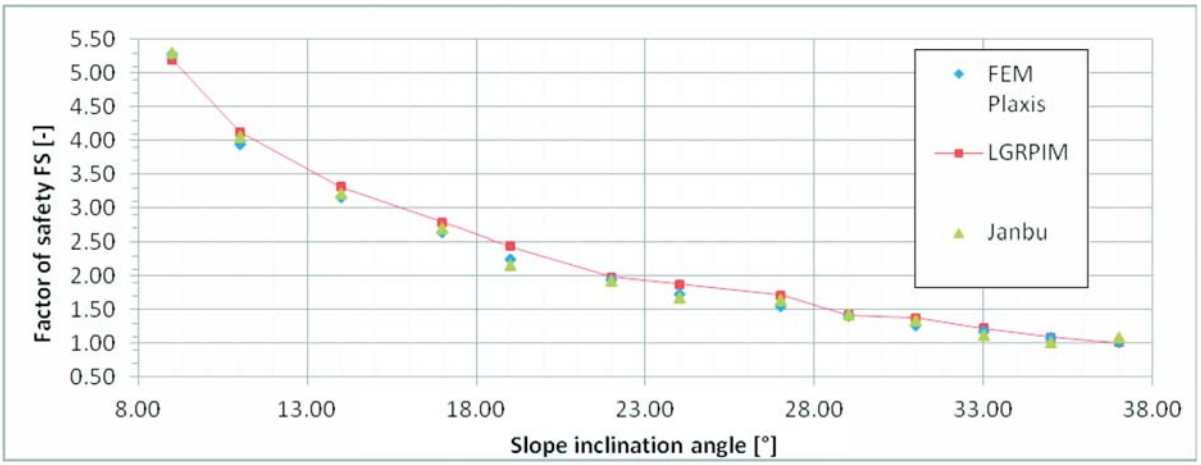

Fig. 5 Factor of safety variation with slope inclination angle

Factor of safety variation with inclination angle — Table 2

Slope inclination [°]	Factor of safety FS [-]			LGRPIM – FEM Difference [%]
	FEM	LGRPIM	Janbu	
9.0	5.278	5.197	5.069	1.53
11.0	3.950	4.128	3.820	4.31
14.0	3.158	3.315	3.077	4.74
17.0	2.632	2.784	2.557	5.46
19.0	2.241	2.438	2.186	8.08
22.0	1.952	1.988	1.911	1.81
24.0	1.726	1.881	1.698	8.24
27.0	1.547	1.712	1.528	9.64
29.0	1.400	1.426	1.389	1.82
31.0	1.272	1.378	1.274	7.69
33.0	1.176	1.225	1.177	4.00
35.0	1.090	1.094	1.095	0.37
37.0	1.019	1.014	1.024	0.49

5. Conclusion

In this paper the application of the radial basis point interpolation method (RPIM) as an local weak formulated meshless method (LGRPIM) for the elasto-plastic analysis of slope structure. There is no need of mesh in the traditional sense and the shape functions are based on nodes. This method uses rectangular local quadratures with 4 sub-domains and 16 Gauss points per subdomain for numerical integration. The results of the analyses with the LGRPIM, FEM and LEM show very good agreement with each other. Hence the result of the parametric study presented in Figure 5 shows very good agreement with the results of the FEM and LEM result. This can be a positive outlook for the application of meshless methods in slope stability analysis. However, as the present study is the first one in this category, it is too soon to conclude generally, and more theoretical and experimental research is needed.

Acknowledgements

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Jan Bencat – Krzysztof Stypula *

BUILDINGS STRUCTURE RESPONSE DUE TO RAILWAY TRAFFIC

The free-field dynamic response at the distance and dynamic response of building structures due to railway traffic calculation procedures is described in this paper. The viscoelastic halfspace model is used both for evaluation of the track-soil interaction forces as well as for prediction of the ground-borne vibrations spectral functions at the distance. In the next step these functions are applied for building structure dynamic response calculation via relevant computational building structure model.

Keywords: *Microtremor, railway traffic effects on structures, prediction dynamic half space and structures response models, in situ experimental tests, spectral analysis.*

1. Introduction

The growing traffic volume, the higher population density and the diminishing distance between the track and the structure can be considered to be responsible for increasing vibration nuisance due to railway traffic. Therefore, the development and validation of a numerical prediction model for traffic induced vibrations in buildings is treated in many works. Empirical models show a close relationship to a set of experimental data but the application of the model is limited to similar conditions. Also these models do not always provide insight in the influence of specific parameters. Numerical models allow the influence of various parameters to be investigated but a validation of the model with experimental data is required to verify the underlying theoretical assumptions. Even though the validation focuses on traffic induced vibrations, the numerical prediction model can be generally applicable to other types of vibration sources [1]. The dynamic train-track interaction is a coupled problem, contrary to vehicle-road interaction problems, that requires the simultaneous solution of the equations of motion of the train and the track. The train-track interaction forces due to the track unevenness are computed using a flexibility formulation. A two-dimensional linear vehicle model with a limited number of DOF is coupled to a linear elastic longitudinal invariant track model, which allows a solution of the equations of motion in the frequency-wavenumber domain [2]. The transfer functions between the track and the soil and the computed interaction forces are used to compute the response at any arbitrary point in the free field [3-5]. Finally, the building structure dynamic response at the distance calculation is performed using half - space output data (PSD, time history) as the input data into the building structure foundations [6].

2. Track model description – numerical approach

A numerical prediction model for ground-borne vibrations due to railway traffic on ballasted track requires the modelling of several components, as indicated in Fig. 1. This paper presents a numerical prediction model which calculates the ground-borne vibration level due to railway traffic in two steps. The first step determines the dynamic track-soil interaction forces using a detailed train model and the dynamic behaviour of the layered spring-damper system and the through-soil coupling of the sleepers are accounted for the soil model [7-9].

The prediction of the ground-borne vibration level at the distance in the second step is based on the viscous-elastics soil model [1, 2, 10, 11, 12].

The vehicle car-body, the bogie and the wheelset are modelled as rigid bodies connected by springs and dampers, Fig. 2e. The wheelset is connected to the rail with a linearized Hertzian spring. The rail is modelled as a hinged Rayleigh beam with rotational inertia. In the track model the rail is supported discretely by sleepers modelled as rigid bodies with spring-damper systems representing the railpads. The sleeper is modelled as a short Rayleigh beam resting on flexural mass layer supported by discretely Pasternak spring-damper systems representing the elastic and attenuation characteristics of the railway ballast and substrate soils. As a result, the model evaluates the track-soil interaction forces in terms of the spectral density function which is often calculated as the statistical description of the rail roughness function [13]. This calculations followed by a second step in which the spectral density of the level of ground-borne vibrations is determined by FRF

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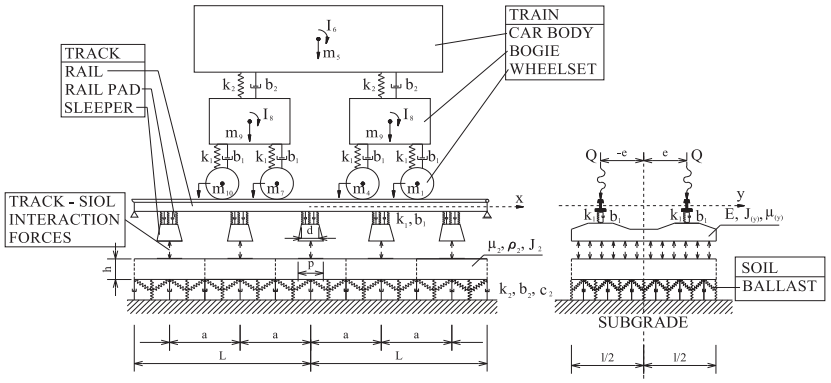

Fig. 1 Components of the train–track–soil system

between track and unbounded soil. Proposed prediction theoretical model for vertical track vibration numerical program consists of three parts:

- model of vehicle
- model of train–track interaction
- model of track (sleepers/ballast and subsoil).

The frequency characteristics method (input–output) was used for calculation modelled feedback linear dynamic train–track–soil system parameters, Fig. 2g (program *Interaction*). Final products of the numerical calculations are: vehicle, rail, sleeper, railpads and ballast frequency response functions (also sleepers deflection and bending moment in time domain) using spectral density functions (SDF) of the rail roughness used by railway operators or experimentally measured in situ for case study. An important example of non–linear behaviour is the wheel–rail contact but also the railpads and the suspension of the train can deflect in a non–linear manner. Nevertheless the results presented in this study are limited to linear analyses. Also in this model is accepted symmetrical dynamic response of the sleepers to longitudinal axis of the track (rail roughness coherence function for left and right rail is equal to ≈ 1).

2.1 Track model

The track model commonly found in the literature represents the rail as infinite Timoshenko, Euler or Rayleigh beam [7–9] on a continuous uniform support, Fig. 2a. The beam is taken as uniform flexural rigidity *EI*, rail mass per unit m_r and distributed sleeper mass m_s. The railpad stiffness and viscous damping constant per unit length are taken to be k_1 and b_1, respectively; the corresponding parameters for ballast are k_2 and b_2. An harmonic point force $p(t) = P \cos \omega t$ is assumed to run at constant velocity v along the rail. The FRF of the track excited to a harmonic force for proposed prediction model are discussed in this section. The track model consists of two parts: (i) model of sleeper with ballast and subballast, Fig. 2b and (ii) track model (rail supported discretely by sleepers modelled as rigid bodies with spring–damper systems representing the railpads), Fig. 2c, d.

Finally, the solution for FRF of the linear dynamic system model, e.g. in which on input are rail roughness ξ and on output are wheel forces Q, enable calculations of the interaction matrix FRF according to scheme as shown in Fig. 2g. The dynamic displacement of the wheel z is defined by $z = \xi + v + \eta$, where ξ represents rail roughness, v – rail vertical deflection and η – wheel and rail contact deformation in contact location.

The track irregularities are great source of the track and vehicles dynamic excitations. Such excitation arises from discrete irregularities such as wheel flats and rail joints as well as periodic irregularities such as corrugation of the railhead. It is assumed that excitation of the track arises from a wheel passing over a sinusoidal irregularity on the rail head, (Fig. 2f). The stochastic theory analysis [3] enables to define irregularities by PSD function by $S_{\xi}(\Omega) = A\Omega^{-a}$ where A and a are empirical (experimental) constants. The distance x is used as the independent variable to define $\xi(x)$.

2.2 Calculation of track component arbitrary FRF

The frequency response function of arbitrary dynamic system part is calculated by rule of *FRF* summing as follows $W_O^I = W_{O1}^I \,.\, W_{O2}^{O1} \,.\, W_{O3}^{O2} \,.\, \ldots\ldots\ldots W_{Oi+1}^{Oi} \,.\, \ldots\ldots W_O^{On}$. The same way is used for summing of the arbitrary FRF matrix. E.g. consider a dynamic system with a defined input rail roughness ξ producing a defined output sleeper deflection v_2, then the FRF is given by [13]:

$$W_{v_2}^{\xi} = W_Q^{\xi} \,.\, W_{Q_1}^{Q} \,.\, W_{v_2}^{Q_1}$$

2.3 The response of track resting on a continuous rail supports

An advantage of the continuous track model (Fig. 2c,d) is that enables for arbitrary track variables to calculate [13]: FRF, input spectra and standard deviation of the track dynamic response parameters – dynamic forces Q, Q_1, Q_2, dynamic deflections v_1, v_2, wheel centre dynamic displacement z and dynamic bending moment in rail and sleeper. As an example in Fig. 3 is plot of numerical

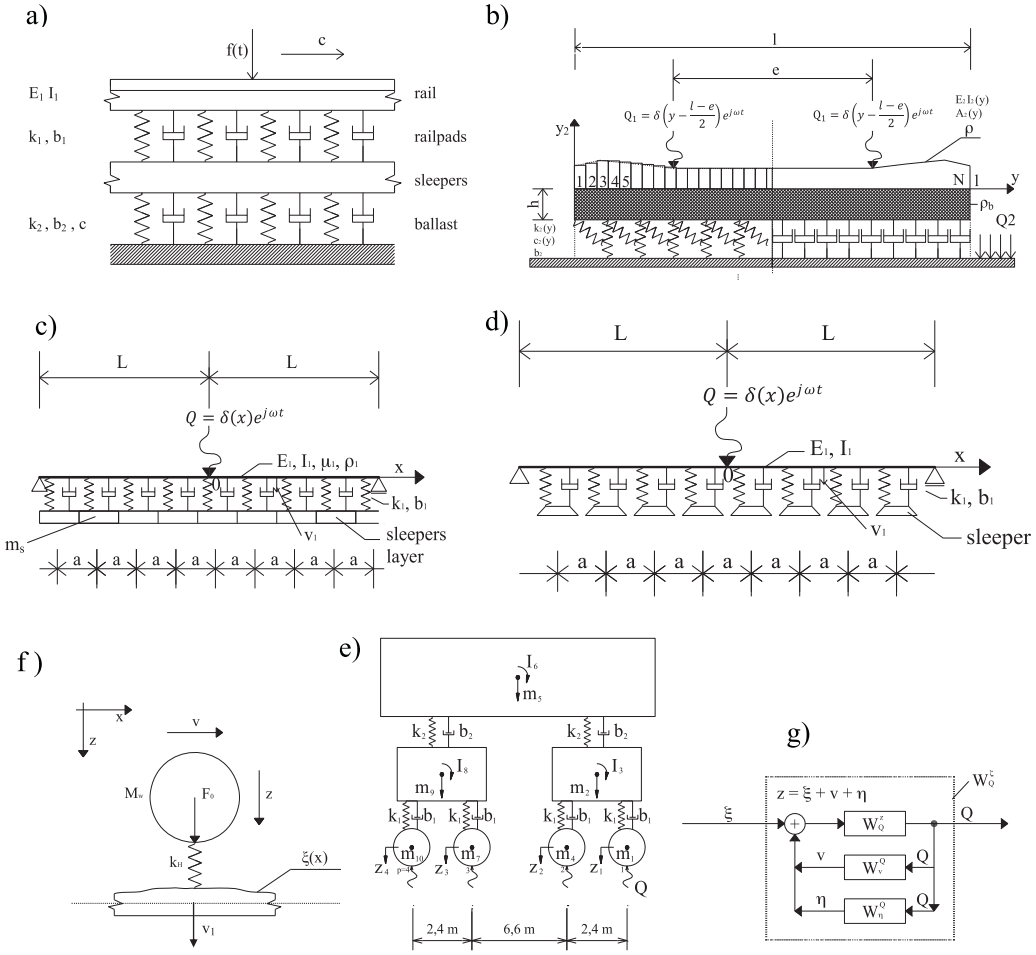

Fig. 2 The railway components model for numerical analysis

calculations results for vertical track receptance of rail deflection v_1 due to wheel contact forces Q.

Parameters used in calculation:

Sleeper SB8: $k_2 = 49.40$ MPa; $b_2 = 0.023$ MPa.s; $c_2 = 0$; $h = 0.45$ m; $a = 0.55$ m; $\rho_b = 0.0017$ Mkg.m^{-3}.
Rail R65: $L = 12.12$ m; $k_1 = 217\,000$ MPa; $b_1 = 0.037$ MPa.s; $E = 210\,000$ MPa; $I_1 = 3.6.10^{-5}$ m^4; $m_r = 65$ kg.m^{-1}.

Vehicle: SKODA E 699; 10 degree of freedom; 4 axles; $k_H = 1{,}5.10^9$ N.m^{-1}; mass of axle:1250 kg; mass of bogie: 4750 kg; mass of body casing: 23.500 kg; bogie inertia moment: $5.5.10^3$ kg.m^2; bogie casing inertia moment: 5.10^5 kgm^2; $k_1 = 7.266.10^5$ N.m^{-1} spring stiffness: $k_2 = 9.5.10^6$ N.m^{-1}; $k_1 = 7.266.10^5$ N.m^{-1}; spring damping: $b_1 = 7.37.10^4$ N.m^{-1}; $b_2 = 3.68.10^4$ N.m^{-1}; axle base: 2.8 m; bogie base: 10.3 m.

From proposed model it is possible to calculate also sleeper dynamic deflection and acceleration PSD as the input spectra $S_{v_2v_2}(f)$ or PSD $S_{\ddot{v}_2\ddot{v}_2}(f)$ into the ballast and roadbed, see Fig. 4. To predict the level of ground vibration in the vicinity of railways it needs to calculate the response spectrum at distance point on the surface of a linear viscous – elastic half space $S_{ww}(f)$ via the frequency response function (FRF) – $H_{ik}(f)$ of the ground by a method involving integral transform [3].

3. Prediction models for ground vibration propagation

3.1 The analytic–experimental approach

The analytic–experimental approach proposes the test and the theory data combination to calculate the prediction level of ground vibration. In this process as an input signal can be used accelerations spectra (or spectral densities) derived from experimental data bank for authorized railway category with corresponding rail profile or accelerations spectrum $\bar{S}_{\ddot{w}\ddot{w}}(f)$ measured at the nearest ground point to the track for individual case study. The frequency response function (transfer function) of the ground can be derived via experimental impulse seismic method (ISM) or cross–hole test

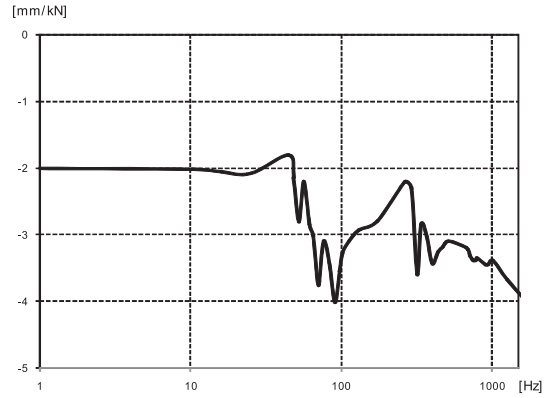

Fig. 3 The vertical track receptance of v_1

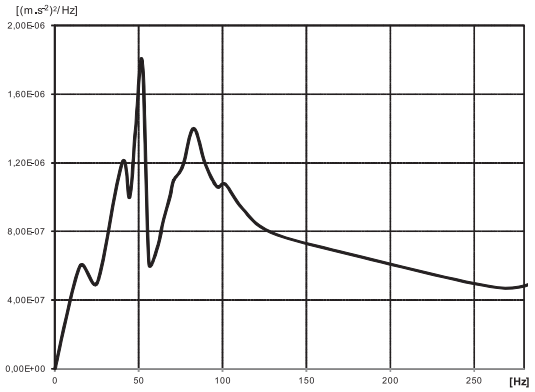

Fig. 4 The input PSD $G_{\ddot{v}_2\ddot{y}_2}(f)$

data [14], from which elastic and attenuation parameters of the ground can be obtained [1,6], too. The measuring output response acceleration spectrum at the distance $S_{ww}(f)$ due to input accelerations spectrum $\bar{S}_{\ddot{w}\ddot{w}}(f)$ the FRF-H(f) can be derived, by equation [3], (see also Fig. 6)

$$S_{\ddot{w}\ddot{w}}(f) = \left|H(f)\right|^2 S_{\ddot{w}\ddot{w}}(f)$$

3.2 In - situ soil dynamic parameters tests

Experimental tests at nearby building IBM region. To calculate prediction vibration level and dynamic response for projected new building in a new railway line area it was needed to know the building site soils dynamic parameters values and FRF. Therefore the in situ ISM tests in the IBM *Data Centre building* site were performed. The building site is situated in the same area in which the new *Trans European Network* (*TEN-T*) line is projected, too. After the both structures erection the distance between them will be approximately 20 m. Hence the prediction of building vibration level and response spectra due to operating trains was required.

The building site is situated on level ground (sandy loam — 3.5 m and gravel sand —12.0 m). This permits the ground to be modelled as a damped, viscoelastic half space. The viscoelastic model of soil simulation using the complex modulus conception $E^* = E(1 + \delta_E)$ and $G^* = G(1 + \delta_G)$ respectively, offers a very good approach [2, 11] to the actual soil behaviour (E, G and $\delta_E \approx \approx \delta_G$ are real and imaginary components of complex modulus). The *Raleigh's and shear waves propagation velocities* v_R in half space in this form are analysed in [6, 12]. The experimental tests for the purpose of the evaluation of elastic and attenuation soil parameters are described in reference [6]. The *IBM* building site layout and accelerometers and impact loading positions (I_i) during the experimental tests are shown in Fig. 5.

The impulse test results are as follows:

- $v_R = 145.10$ ms^{-1}; $\delta_G = 0.117$; $E_0 = 109.20$ MPa; $G_0 = 41.10$ MPa,
- the ISM test No. 5 spectral analysis results are plotted in Fig. 6

The calculation includes data: $\lambda_R = 9.2$ m, (*Raleigh's waves length*); $\rho = 1950$ kg.m^{-3}, (*soil mass density*); $\alpha = 0.0398$ m^{-1}, (*the attenuation coefficient obtained by standard deviations* $\sigma(0)$, $\sigma(y)$ *of displacement amplitude vibration at the distance* l_0, l_y *from source of excitation using the displacement power spectral densities* $G_{ii}^{(0)}$ and $G_{kk}^{(y)}$).

3.3 Vibration propagation process experimental spectral analysis

An experimental study of ground vibration transmission from a railway was carried out in the same region as the impact tests, adjacent to the *ZSR* railway line *Bratislava - Vienna*, track No. 1 (No. 2) in the town district *Bratislava Trnavka*. The object of the experimental measurements was to find: spectral characteristics of the vibration components of the track near region soils by the accel-

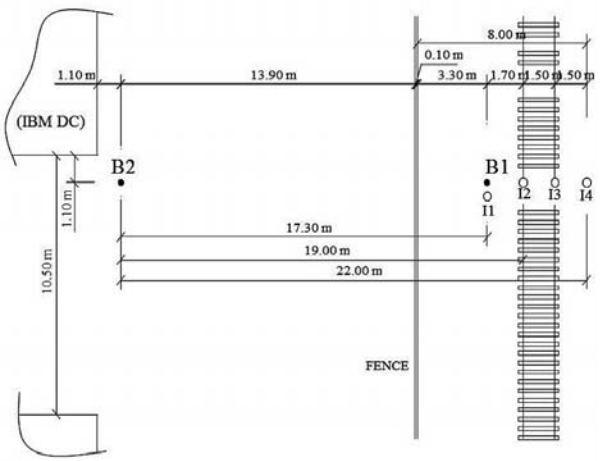

Fig. 5 Accelerometers and ISM (I1- I4) positions and projected building and railway site layout

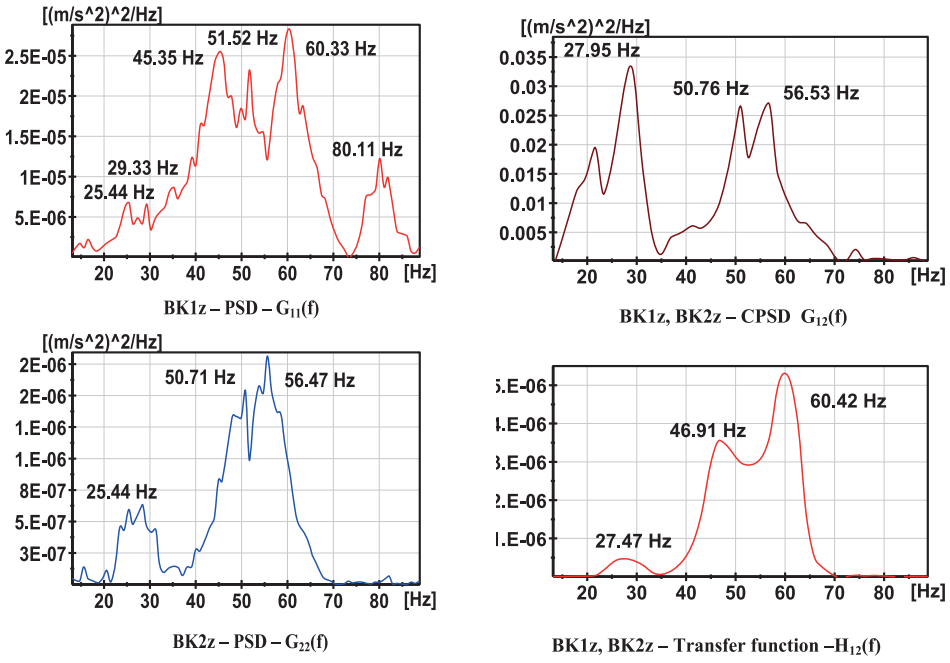

Fig. 6 The ISM5 test spectral analysis results at points B1 and B2

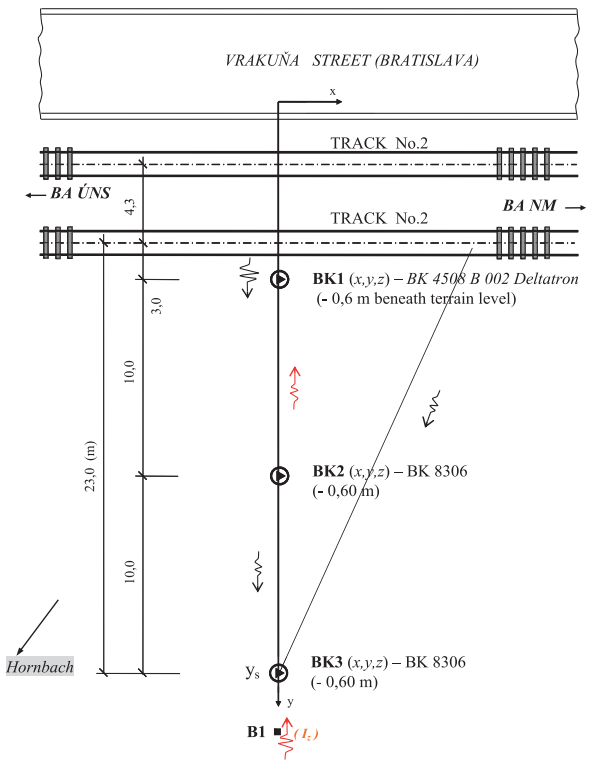

Fig. 7 The pickups and DLP positions in track region

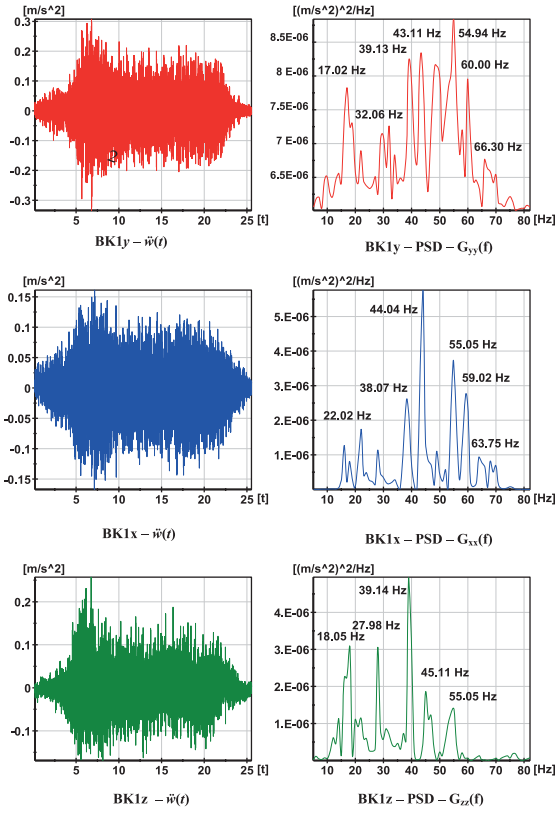

Fig. 8 The accelerations time histories and PSD at point BK1

eration power spectral densities $G_{ii}(f)$, $G_{kk}(f)$, $G_{ik}(f)$. The pickups positions are shown in Fig. 7. The roadbed and ground accelerations of the vibrations were recorded using a portable notebook computer with *NI* software and hardware facilities. The test experimental procedure in details is described in [6]. As an example of the train induced vibrations accelerations spectral analysis results (PSD) in the ground at measured point BK1 are plotted in Fig. 8.

4. Dynamic response of the building structure prediction

To calculate the prediction vibration level and structure dynamic response of the projected new building structure situated at the nearest area of the projected new railway line it was needed to know the building site soils dynamic parameters, site geological medium FRF and also the representative input accelerations spectra similar to expected real train spectra in future traffic [6]. For calculation of expected structure dynamic response it was used: (**i**) PSD – $G_{ii}(f)$ of ground acceleration at the track nearest region (Fig. 7) with similar geological medium data as site medium (ZSR – railway line Bratislava – Vienna, track No. 1 (No. 2) in the town district Bratislava Trnavka) as input spectra (see Fig. 8), (**ii**) The halfspace transfer function $H_{ik}(f)$ of the building site geological medium obtained by ISM tests (Fig. 6) and (**iii**) project of building structure. The response PSD – $G_{kk}(f)$ of the halfspace point at the projected structure foundations location were calculated and plotted, (Fig. 11).

In the next step these spectra were used as the input spectra for the expected building structure dynamic response calculation due to train. The dynamic response of the building structure numerical calculation was carried out by the *Visual Fea* program package.

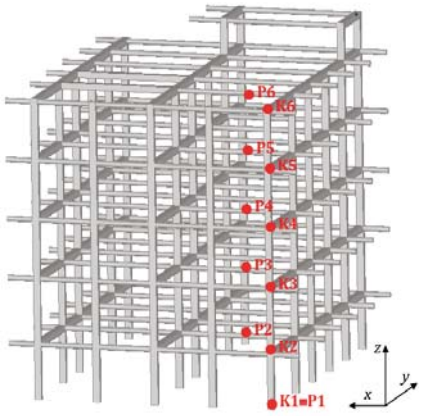

Fig. 9 FEM model render

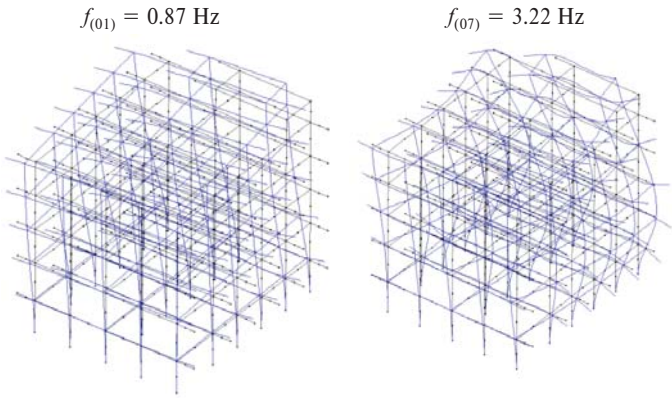

Fig. 10 Structure natural modes

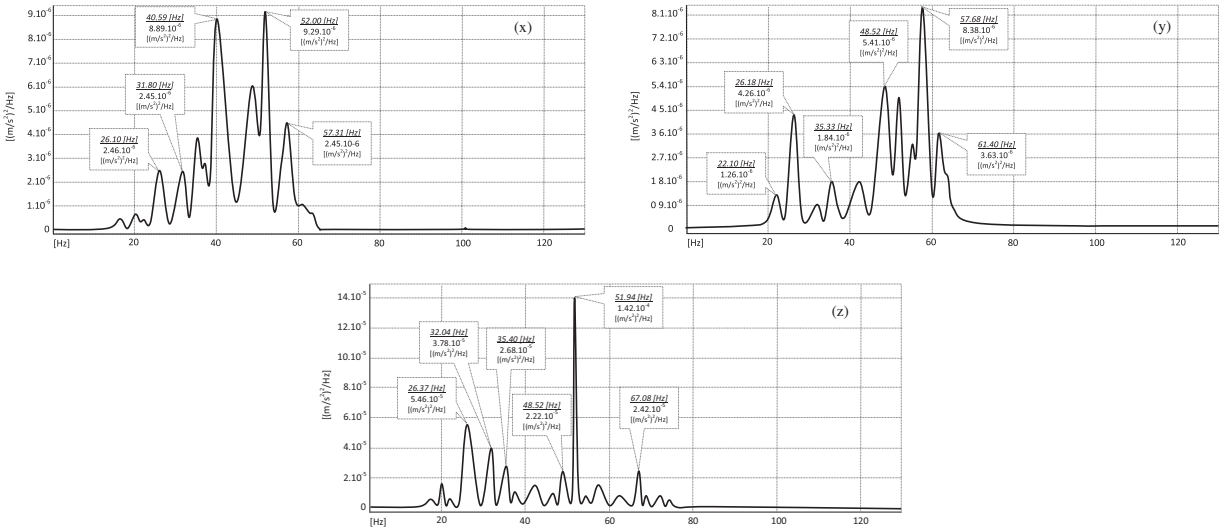

Fig. 11 The input acceleration PSD – $G_{11}(f)$ to foundation at point K1/10 – 130 Hz

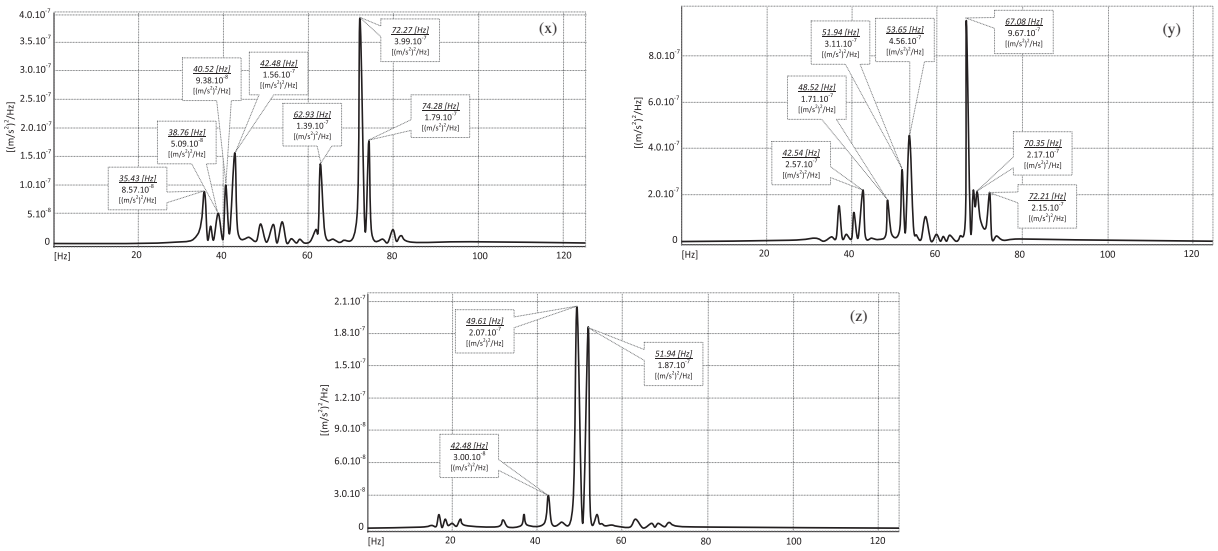

Fig. 12 The response acceleration PSD - $G_{66}(f)$ of roof at point K6/10 - 130 Hz

The calculated values of natural frequencies and natural modes were applied for the building structure dynamic response calculations. The structure FEM model render and natural modes examples are shown in Figs. 9 and 10. Also the building structure dynamic response calculations were carried out in frequency domain. The spectral analysis was divided into two parts: low frequency band (0 – 10 Hz) and higher frequency band (10 – 130 Hz).

The *low frequency band spectral analysis* gives the basic natural frequencies vibration rangewhich enables to predict possible resonance effects of structure vibration due to traffic. Because of the vibration sensitive technologies installing in the *IBM DC* building the power spectral densities are determined in the structure relevant points (over columns and in the middle of beam spans) for the structure dynamic response considering in the range of frequency band 10 – 130 Hz. The *higher frequency spectral analysis band* is mainly required for vibration level assessment on monitored frequency according to the *IBM Corporate Standard C-S1-9711-002*, 1990-03 requirements. The accelerations PSD and displacements *extreme* and *RMS values* were numerically calculated at selected render points (K1...K6, P1...P6) in the three vibration directions *x,y,z*. The results of the *IBM D*C building structure dynamic response calculations are presented in detail by Bencat [6]. The adequate input load acceleration PSD - $G_{11}(f)$ into the foundation structure (render point K1) for *x, y* and *z* vibration direction are plotted in Fig. 11 and the response acceleration PSD - $G_{66}(f)$ of the building roof structure (render point K6) is plotted in Fig. 12.

5. Conclusions

Based on the results presented in this paper the following conclusions can be drawn:

- *The numerical prediction model* can account for many parameters of the train-track-soil interaction problem. Final products of the numerical calculations are vehicle, rail, sleeper, railpads and ballast frequency response functions using spectral density functions of the rail roughness. To predict the level of ground vibration in the vicinity of railways it needs to calculate the response spectrum at distance point on the ground surface $S_{ww}(\omega)$ via the FRF - $H_{ik}(f)$ of the ground by a method involving integral transform.
- *The numeric - experimental prediction model.* The numeric-experimental approach process proposes the test and the theory data combination to calculate the prediction level of ground vibration.
- *The frequency response function* - $H(f)$ of the ground for the case study was derived via experimental impulse seismic method - ISM test data, from which elastic andattenuation parameters of the ground were obtained, too.

The calculation results of the predicted IBM Data Centre building dynamic response using relevant input experimental data as the case study example are introduced, too. The relevant calculated data values following from spectral and amplitude analysis of the predicted building dynamic response (spectral picks limit, vibration levels, etc.) were compared with relevant standards prescription values and criteria (*IBM Corporate Standard C-S1, Slovak Standard STN 73 0036, STN EN 1998 - 1/NA/Z1 (EC8), etc.*). From these comparisons it follows that all standards prescription values and criteria in future will be fulfilled.

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We kindly acknowledge the research project *VEGA, Nr.G1/0169/12* granted by *Scientific Grant Agency of the Slovak Republic Ministry of Education*. We should also like to thank the *Civil Engineering Faculty - University of Zilina* for additional feed in this field research activity.

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PROJECT SPENS – SUSTAINABLE PAVEMENT FOR EUROPEAN NEW MEMBER STATES

This paper represents the main results of work package 5 of the SPENS project (Sustainable Pavements for European New Member States) that was focused on assessment of the impact of roads on the environment and where the Faculty of Civil Engineering of University of Zilina was the most active and closely cooperated with CDV.

Collaborative international project was focused on particulate matter (PM) production due to mechanical abrasion of road pavements. PM (and noise emission) was captured next to roads with different pavement types (stone mastic asphalt and asphalt concrete) by middle volume samplers with consequent gravimetric analysis of each exposed filter. The content of organic and inorganic pollutants fixed to PM was determined to characterise the PM composition. Dust fall measurements including mass and chemical composition determination in road tunnels with different pavements (cement concrete and asphalt concrete) were done to determine the pavement abrasion contribution to overall PM emissions in tunnels.

Keywords: *Roads, traffic volume, environment, particulate matter /PM/, traffic noise.*

1. Project introduction

The Faculty of Civil Engineering, University of Zilina, Department of Highway Engineering was involved in solution of the Project SPENS – Sustainable Pavements for European New Member States supported by the Sixth Framework Programme within priority 1.6.2 Sustainable Surface Transport. The objective of the SPENS research project was to develop appropriate tools and procedures for the rapid rehabilitation of road pavements especially in the EU new member states using materials and methods that would behave satisfactorily in a typical climate, have an acceptable environmental impact, be easy to incorporate within existing technologies and be cost-effective and easy to maintain. In the period of September 2006 to August 2009 partners including VTI Sweden, CDV Czech Republic, ZAG Slovenia, Arsenal Austria, KTI Hungary, IBDiM Poland, DDC Consulting & Engineering Ltd. Slovenia, Ferriere nord S.p.A. Italy, FEHRL Belgium cooperated in the performance of laboratory and field tests of asphalt materials, as well as in the evaluation of the impact of roads on the environment. The research work was organized into four technical work packages (WP).

2. State of the art

Air pollution related to transportation is one of the most discussed issues within the context of negative impacts on the environment at present. Combustion processes are the reason of exhaust gas emissions that contain hundreds of chemical compounds in different concentrations contributing to the greenhouse effect and often with toxic, carcinogenic or mutagenic effects on organisms including humans [1], [2]. Particularly PAHs and POPs belong to the most dangerous ones that originate due to fuel combustion [3]. However, pollutant emissions, especially particulate matter (PM), could be also related to non-combustion processes such as resuspension or mechanical abrasion of particles during the interaction between tires and road pavement. Mechanically separated particles from the pavement (asphalt particles, soil dust etc.) especially on damaged roads, abrasion of tyres and brake-shoe lining, particles of chemical (mineral salt) and inert (gravel, sand, slag) materials for road maintenance in winter season and carried materials falling off are the significant sources of overall PM air pollution [4], [5]. All of these particles quickly settle on road surface near their sources due to their size and get again into the air due to turbulent flow initiated by vehicle movement and wind blow. Resuspension due to road transport contributes particularly to an increase of total suspended particles (TSP) and PM_{10} fraction [6] and depends on specific local conditions such as road surface, vehicle speed and weight and air humidity. Resuspended dust is hazardous due to its enrichment by risk compounds that are emitted by other anthropogenic sources [7], [8], [9]. Inorganic particles are generated mostly due to abrasion of cement concrete pavement [10]. These particles also represent 90 % of particles from asphalt pavement abrasion [11]. It is assumed that aggregates generated due to wear of road pavement are composed mostly of Al, Si, Ca, Mg, C and Na, or K in the forms of their oxides. Other metals represent other sources such as mechanical abrasion of car bodies and vehicle other parts (Cu, Sn, Cr, Pb, Cd, As, Sb), mechanical abrasion of brake shoe lining (Cu, Sb, Ba) [12] and catalytic converters (Pt. Pa, Rh) [13].

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Increasing traffic volumes on the European road network are directly related to increasing annoyance of the population due to noise, which is a huge problem throughout the EU. To achieve road traffic noise abatement not only with passive measures, like noise barriers, but by reducing noise emissions at the source, it is necessary to assess the influence of pavements on the noise emission process and to make use of low-noise pavements. The paper describes results of measurements carried out according to the method of comparing traffic noise on different road surfaces for various compositions of road traffic for the purpose of evaluating different road surface types.

3. Methods

3.1 PM and dust fall sampling and analyses

Two methods were chosen to evaluate the contribution of road pavement abrasion to air pollution by particulate matter – active PM sampling on common localities and passive measurements of dust fall in road tunnels. It is assumed that contribution of PM from non traffic sources is insignificant comparing with emissions from traffic in tunnels.

PM were captured on different filter types using middle volume samplers LECKEL MVS6 (Sven Leckel Ingenierbüro, Germany) with consequent gravimetric analysis on Mettler-Toledo MX5/A microbalance (Mettler-Toledo GmbH, Switzerland) of each exposed filter to determine PM concentrations. Two localities in Zilina city area, Slovakia next to roads with different types of pavements were chosen. D1 highway in Predmier with traffic intensity of 28,000 vehicles per 24 hours with Stone Mastic Asphalt SMA represents the first one and urban through-road I/18 in Zilina – Mostna Street with traffic intensity of 25,000 vehicles per 24 hours with Asphalt Concrete AC was the second one.

Dust fall measurements were realized in road tunnels with different pavements that are the components of Prague city ring, Czech Republic. Mrazovka tunnel with traffic intensity of 42,400 vehicles per 24 hours with Asphalt Concrete (AC) road pavement and Strahovsky tunnel with traffic intensity of 44,500 vehicles per 24 hours with cement concrete (CC) road pavement. Sampling devices for dust fall measurements were placed near the tunnel centre, 4 sedimentation glasses in each tunnel tube with the neck diameter of 90 – 200 mm and high 145 – 400 mm filled with the mixture of 250 ml distilled water and 25 ml izopropanol. Sampling interval was 28 days due to regular tunnel cleaning procedure. Captured sample of dust fall was for determination of overall content of inorganic compounds burned in 710 °C [9]. Partial pressure of CO_2 above $CaCO_3$ is in this temperature approximately 4 kPa and $CaCO_3$ is not significantly decomposed in this temperature. Chemical composition of burned residuum thus represents aggregates used in road pavement.

Subsequent chemical analyses were proceeded to determine the content of selected metals using inductively coupled plasma mass spectrometry (Thermo Scientific X series 2, Thermo Electron Limited, United Kingdom) and polyaromatic hydrocarbons (PAH) using gas chromatography-mass spectrometry (Shimadzu QP2010, Japan) and to find out the differences in composition of PM originated due to vehicles operation on roads with different pavements.

3.2 Measurement of the influence of road surfaces on traffic noise.

Traffic noise measurements were performed by using Statistical Pass-By-Method (SPB) that is described in the ISO 11819-1 standard [14]. It provides a method to determine an index which can be used to compare the noise emission impact of different road

Vehicle categories in ISO 11819-1 Table 1

Category	Typical examples		Minimum number of pass-bys
1) cars	2 axles, 4 wheels Passenger cars		100
2a) dual-axle heavy vehicles	2 axles, more than 4 wheels Light trucks, buses		30 (2a + 2b = 80)
2b) multi-axle heavy vehicles	Heavy trucks More than 2 axles		30 (2a + 2b = 80)

surfaces by measuring vehicle pass-bys at the roadside. The SPB method is based on the measurement of the maximum A-weighted sound pressure levels of a statistically significant number of individual vehicle pass-bys (Table 1) together with the vehicle speeds. Specific measurements of A sound levels LA were conducted by a sound analyser NOR-121 (Norsonic, Norway – ID 31211) accuracy Class 0. The sound analyser was prior to each set of measurements calibrated by a microphone calibrator NOR N-1251 (Norsonic, Norway – ID 31069), accuracy Class 1. Applied measuring string of noise emissions and pollution had separate verification for own sound level meter, measuring microphone Nor-1225 (Norsonic, Norway – ID 48045), one-third-octave filters, acoustic calibrator. Velocity measurements were realised by a speed radar gun Bushnell Speedster (Table 1) and meteorology conditions by a Wireless weather station - WS 888 set (Table 1).

The passing vehicles were classified into one of three vehicle categories and one of three reference speeds was chosen according to the average operating speed of the road (Table 2).

A regression line of the maximal A-weighted sound pressure level versus the logarithm of speed was calculated for the pass-bys of every category (Fig. 1).

This regression line was then used to determine the average maximum A-weighted sound pressure level L_{veh} at the reference speed. The L_{veh} of the three vehicle categories ($L_{veh,1,regression} \equiv L_1$, $L_{veh,2a,regression} \equiv L_{2a}$, $L_{veh,2b,regression} \equiv L_{2b}$) can be combined to give a single index called SPBI (Statistical Pass-By Index) which is indicative of the influence of the road surface on the noise emission of a mixed vehicle collective.

$$SPBI = 10 \cdot \log\left[W_1 \cdot 10^{\frac{L_1}{10}} + W_{2a} \cdot \left(\frac{v_1}{v_{2a}}\right) \cdot 10^{\frac{L_{2a}}{10}} + W_{2b} \cdot \left(\frac{v_1}{v_{2b}}\right) \cdot 10^{\frac{L_{2b}}{10}}\right] \quad (1)$$

where:

- $SPBI$ – the Statistical Pass-by Index, for a standard mix of light and heavy vehicles
- L_1, L_{2a}, L_{2b} – the Vehicles Sound Levels for vehicle categories 1, 2a, 2b (Fig. 1),
- W_1, W_{2a}, W_{2b} – the weighting factors which are equivalent to the assumed proportions of vehicle categories in the traffic (Table 2)
- v_1, v_{2a}, v_{2b} – the reference speeds of individual vehicle categories (Table 2).

Reference speeds and weighting factors (W_x) in the different road aped categories Table 2

Vehicle category		Road speed category					
		Low		Medium		High	
Name	No.	Ref. speed [kph]	W_x	Ref. speed [kph]	W_x	Ref. speed [kph]	W_x
Cars	1	50	0.900	80	0.800	110	0.700
Dual-axle heavy vehicles	2a	50	0.075	70	0.100	85	0.075
Multi-axle heavy vehicles	2b	50	0.025	70	0.100	85	0.225

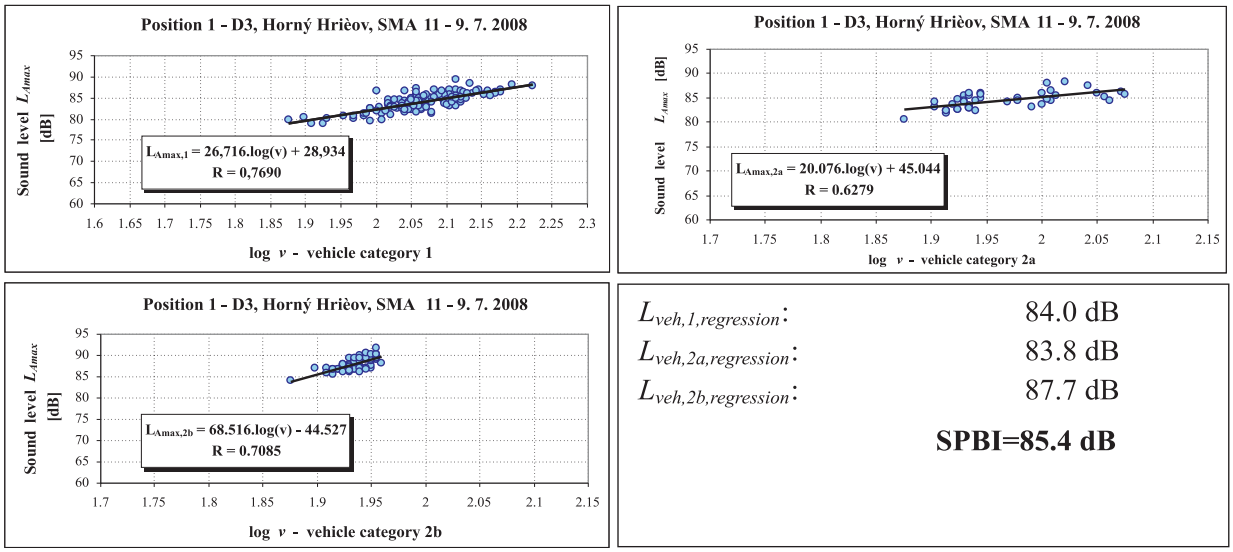


Fig. 1 Regression lines for Position 1

4. Results and discussion

4.1 PM and dust fall measurements

It is assumed that inorganic particles originated by abrasion of cement-concrete pavements consist mostly of coarse PM fraction. The share of this coarse fraction on total PM_{10} concentrations was higher at sites with asphalt concrete (AC) surface at the city ring (approximately 48 %) than its share in stone mastic asphalt (SMA) – 35 to 40 %. This was confirmed during both sampling campaigns (Fig. 2). $PM_{1.0}$ fraction was generally predominant in both campaigns at both sites that indicate the origin of more particles due to combustion processes. These results also indicate higher production of coarse PM fraction due to abrasion of asphalt concrete.

Chemical composition of captured PM separate fractions was analysed. Content of selected elements representing sources related to mechanical abrasion of particles, such as Zn, Sb, Cu, Ba and others, were determined in both coarse and fine PM fractions.

Elements concentrations were higher in both PM fractions at sites with AC pavement in both sampling campaigns, except K and Pb in the second measuring period in autumn. Elemental composition of PM_{10} fraction in summer sampling campaign is shown in Fig. 3 and indicates higher production of PM due to abrasion of AC pavement (Ca, Mg content) or due to abrasion of tyres (Zn content) during the interaction with AC pavement.

$PM_{2.5}$ fraction was also measured and content of Polyaromatic Hydrocarbons (PAH) was determined (see Fig. 4). 18 PAH were analysed in accordance with US EPA list of importance including Benzo[a]pyrene and Dibenz[a,h]anthracene as the most harmful compounds and Coronene as the fuel combustion in vehicles engines indicator. Higher PAH concentrations were determined during the autumn sampling campaign on both localities but there were found no statistically significant differences between localities. So small amount of PAH during the summer campaign could be caused by the PAH occurrence mostly in the gaseous phase due to higher temperatures.

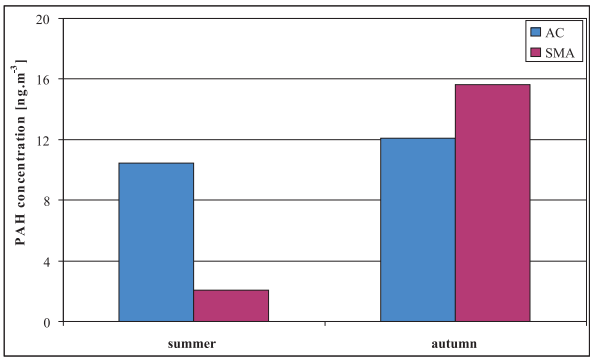


Fig. 4 PAH content in $PM_{2.5}$ fraction

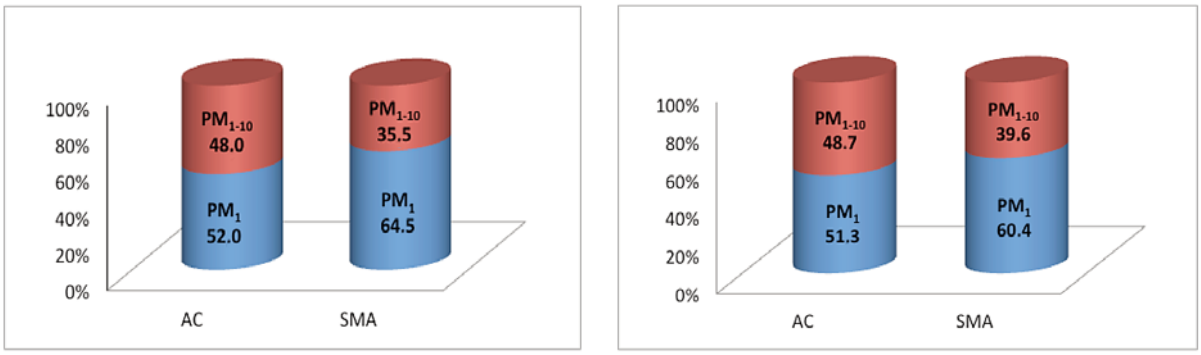


Fig. 2 The share of PM fractions (summer and autumn sampling campaign)

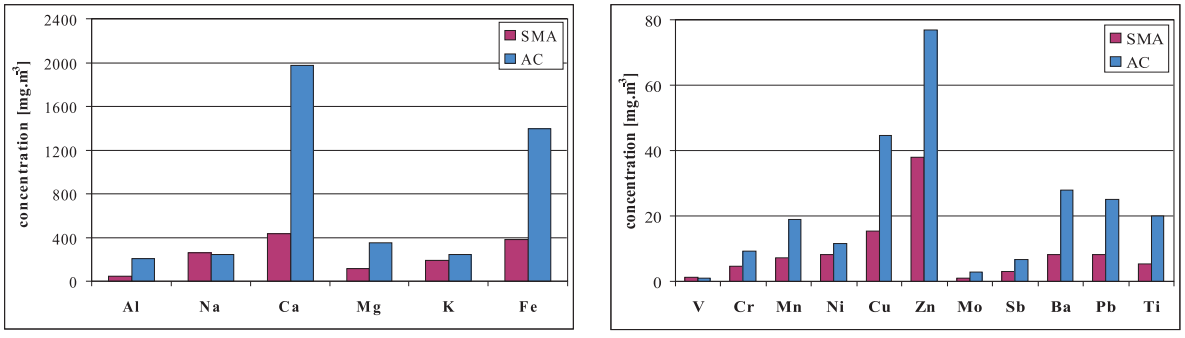


Fig. 3 Content of selected elements in summer sampling campaign - macro components in the left graph, micro components in the right graph

Dust fall measurements Table 3

Tunnel	Pavement	Slope	Dust fall inorganic share	Dust fall organic share	Dust fall total	PAH summ	Dust fall organic share	PAH share from organic dust fall
			g.m^{-2}				%	
Strahovsky	Cement Concrete	decreasing	1449.9	261.5	1711.4	6.69	15.3	2.56
		increasing	247.6	74.1	321.7	0.91	23.0	1.23
Mrazovka	Asphalt Concrete	decreasing	946.6	188.5	1135.2	5.88	16.6	3.12
		increasing	91.2	39.7	130.9	1.26	30.3	3.17

Higher amount of dust fall was determined in the tunnel with cement concrete (CC) pavement that indicates more intensive abrasion of this type of pavement (Table 3). This is in accordance with the previous results from PM measurements next to the roads with different pavement types. However, higher amount of dust was measured in the downward-sloping tube of both tunnels. The share of inorganic content in dust fall in the downward sloping tube was about 84 % whereas in the upward sloping tube of the tunnels it was about 60 % of dust fall. Also the share of PAH on organic dust fall was smaller. The reason could be a higher PM production because of brake shoe lining wear during more intensive braking.

Selected elements contents were also determined in dust fall in both tunnels. There was found no statistically significant correlation between the tunnels or more precisely between the pavement types (see Fig. 5). The only correlation was determined for the content of Ba between the decreasing and increasing tubes of both tunnels namely its concentration was higher in the downward sloping tube. This element was mostly originated due to brake lining abrasion so the interpretation of this fact could be more intensive vehicle braking.

4.2 Noise results

During TUZA research activities of the SPENS project SPB measurements were carried out according to the ISO 11819-1 standard on 4 measuring positions (Fig. 6) and results are presented in Figs. 7 and 8.

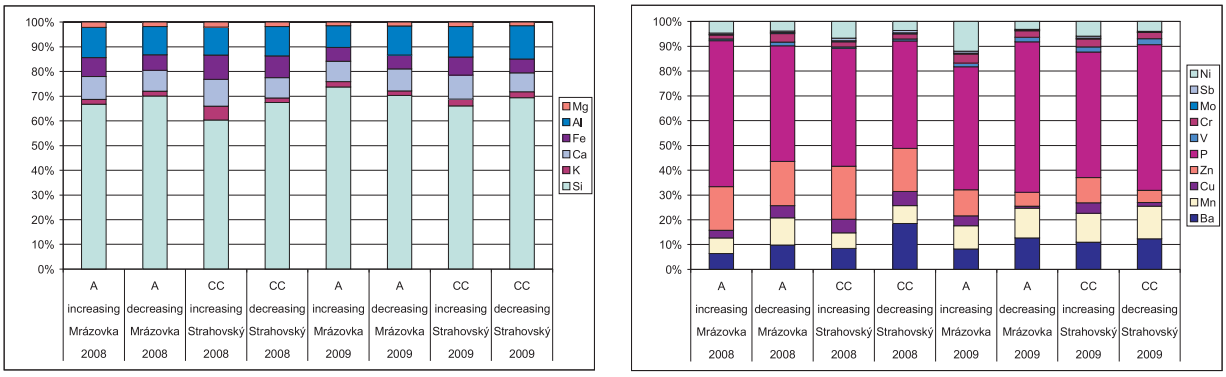


Fig. 5 Comparison of macro element concentrations on the left graph and comparison micro element concentrations on the right graph

Fig. 6 Views of the measuring position 1 – 4 around Zilina

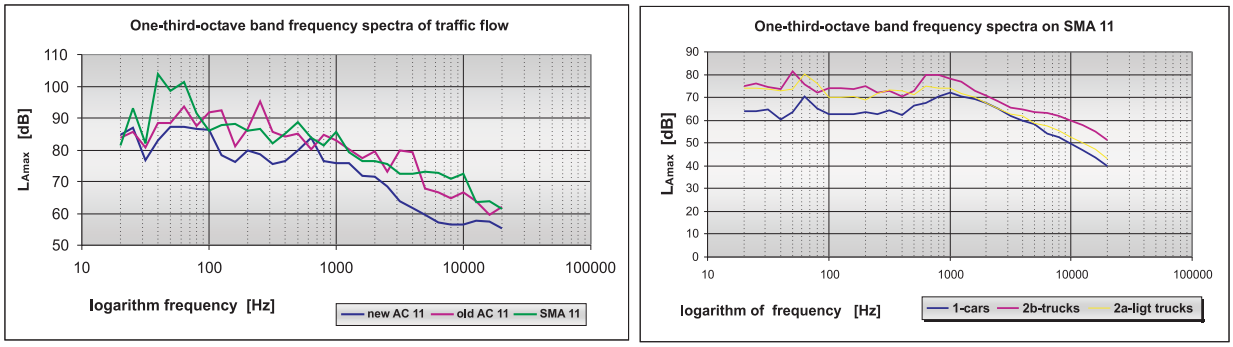
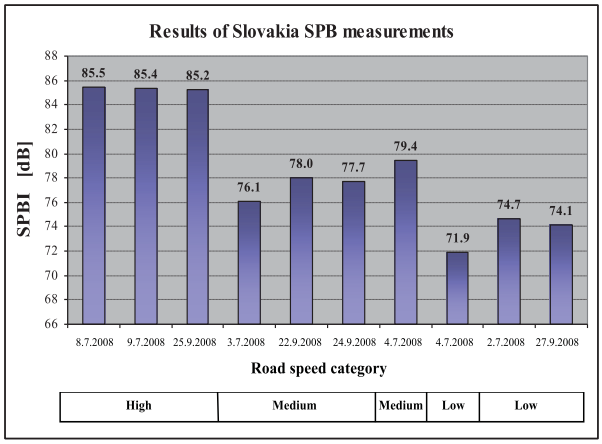


Fig. 7 Examples of one-third-octave band frequency spectra - normally evaluated L A(max), 15min of traffic flow



Position 1 - highway D1, Horny Hricov - SMA 11 PmB (polymer modified bitumen) - pavement 2 years old	Position 3 - road 1st class, Dolny Hricov - AC_O 11 - 15 years old
Position 2 - road 1st class I/18, Dolny Hricov - AC_O 11 - pavement realized 18.6.2008	Position 4 - road 3st class, Bytca - SMA 11 - 4 years old

Fig. 8 Results of Slovakia SPB measurements obtained during TUZA research activities of SPENS

5. Conclusions

PM measurements performed in Slovakia on localities with different road pavements, asphalt concrete and stone matrix asphalt indicate a higher production of coarse PM fraction due to abrasion of asphalt concrete pavement. These particles contain more Ca, Mg and Fe from abrasion of pavement but they also contain Zn originated probably due to abrasion of tyres.

Dust fall measurements in road tunnels in the Czech Republic indicate a higher production of particles due to abrasion of cement concrete pavement comparing with dust production in the road tunnel with asphalt concrete pavement. The share of inorganic content in dust fall in the downward sloping tube was about 84 % whereas in the upward sloping tube of the tunnels it was about 60 % of dust fall. This indicates higher PM production due to brake shoe lining wear during more intensive braking and is supported by a higher content of Ba in this tunnel tube.

The differences in SPBI of old and new AC for a medium road speed category were about 3 dB and the differences in SPBI of SMA (4 year old) and new AC for a low road speed category were about 2.5 dB. The average reduction of noise pollution in external environment in the pavement vicinity at level 3 dB corresponds with the decrease of traffic intensities from 1000 to 500 veh./hr. Slovakian experts recommended that before and after larger pavement reconstructions it is greatly convenient to perform measurements of the influence of road surfaces on traffic noise by means of the SPB method. The reference temperature needs to be implemented in relevant laws, standards and guidelines and results of traffic noise monitoring should be corrected to the reference temperature.

According to the authors the presented facts can help to fill the next premise for an environmental correct design and maintenance of pavements. The pavements have to be designed, constructed and maintained in such a way as to meet the requirement the environmental protection, such as noise reduction at wheel rolling [15].

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Tomas Lovecek – Jozef Ristvej – Katarina Kampova – Juraj Vaculík – Roberto Gamboa – Adam Zagorecki *

PORTAL OF SECURITY AND SAFETY ENGINEERING AS A TOOL TO INCREASE THE SUSTAINABLE DEVELOPMENT OF HIGHER EDUCATION IN SECURITY IN THE EUROPEAN UNION AND BEYOND

In this article we describe a project "Competency Based e-Portal of Security and Safety Engineering" - eSEC portal approved by The Education, Audio-visual and Culture Executive Agency (EACEA), developed in the period between 10/2009 and 10/2012. The eSEC portal is one of 10 centralised multilateral projects approved in 2009 by EACEA and only one with the University of Zilina as a coordinator, with total budget 356.138 Euros. The EACEA is responsible for the management of certain elements of the EU's programs in the fields of education and culture. The idea for the eSEC project originated from the demand to increase the quality of education in the field of security and safety. One of the key problems of the education is disparity between the knowledge received from educational institutions and the practical requirements. It is necessary to redefine how students are prepared for the challenges of the labour market: identifying competencies that are currently in demand and how it would be possible to link the educational systems of various institutions more efficiently. The aim of the eSEC project was to develop the competencies of students, teachers, researchers and professionals working in the field of security and safety, within the EU and the world. To achieve these objectives, an electronic portal was developed at www.esecportal.eu. The portal was launched in May 2012, hopefully starting the way to become an established and well known Internet portal on the security and safety education.

Keywords: *Competency Based e-Portal, Security Education, eSEC.*

1. Introduction

The eSEC project originated from the identified need to increase the quality of education in the field of security. Based on experiences from eastern and middle Europe, one of the key problems of the education is disparity between the knowledge received from educational institutions and the practical requirements. That is the reason why it is necessary to focus more on the way in which the participants of Lifelong Learning Programs (LLP) can be prepared for the challenges which emerge from the labour market, which competencies are required and how it would be possible to link the educational systems of various institutions more efficiently. Therefore, the aim of this project was to develop and increase the competencies of students, teachers, research personnel and professionals from EU countries who work in the field of security.

To achieve the project's objectives, an electronic portal eSEC was developed. The portal is intended to support its users in acquiring new competences. One of practical contributions of the eSEC is ability to define individualised study plans that may exploit the available exchange programmes offered by European universities and consequently to obtain competences in practice, wherever it is mostly suitable. The eSEC portal also provides information on the availability of current grants and studentships that are consistent with the chosen study plan and this information are provided to the user in an individualised form (also see [1] and [2]).

Since the eSEC users are intended to be mainly students, teachers, academics, and professionals with an interest in the field of security engineering, eSEC creates a link between the educational providers and the professional community for whole of EU.

2. Portal – outcomes and results

The eSEC portal consists of several modules which reflect the requirements of the stated partial objectives as follows (see Fig. 3):

Main Modules:
- Competency Based Creation of the Curriculum,
- Subjects,
- Scholarships Agencies,
- Glossary of Terms,
- Blogs,

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- Forum,
- Resources,
- Student Projects,
- Calendar of Events,
- Labour Market,
- The European Journal of Security and Safety,

Other parts:
- Comments and Suggestions,
- Web Search,
- Project Partners.

Module Competency Based Creation of the Curriculum is the main module in the framework in which the users can choose the required competences that they wish to acquire in the areas of security and safety. The module provides a space for creating a study plan which may include various programmes, subjects, seminars and actions organised at the EU universities. This module also provides information about available scholarship programmess or grants that are related to the created study plan.

The Module Subject is designed to provide study subjects and study programmes focused on the problems of security and safety, offered by the European higher education institutions. Once a user is logged in, it provides customised offer based on the user's country highlighting local offers in the first place.

The Module Scholarship Agencies provides the users with information about scholarship programmes.

Module Glossary of Terms allows browsing an electronic dictionary of terms in the twelve defined fields of security and safety. Currently it consists more than 500 terms in 6 languages.

The "Blogs about Security and Safety" and *"Forum"* modules are designed to create a space for communication among project stakeholders and for publishing ideas related to the security and safety.

Module Resources is focused on innovative methods in education supporting creativity and active approach to education and training in the field of security and safety. It enables the stakeholders to share audio-visual presentations, lectures, field trips, practical workshops, measurements and other sources.

Module Student Projects provides tools for publishing and comparing students' works. It is intended to contribute to a deeper perception of the solved problems by the students. It is a space where the individual student can share the already acquired knowledge with other students or professionals.

Module Labour Market provides job offers in the field of security and safety within Europe. It allows for publishing professional CVs of the job applicants.

The Module Calendar of Events enables the portal users to know about the prepared events related to security and safety, mainly in the EU framework.

Last but not least, from the point of view of the project goal, is the module European Journal of Security and Safety (EJSS – http://www.esecportal.eu/journal). EJSS is a new online European scientific journal, primary source of peer-reviewed research articles in all fields connected with security and safety. EJSS publishes peer-reviewed research articles, book reviews, news and communications, opinions from researchers and practitioners. The EJSS has ISSN 1338-6131 and several papers were already published. For details see Fig. 4.

The eSEC portal's goal is not only to collect all content in the field of security and safety but it is intended to provide links to other Internet sources related to the scope of interest. The Module Web Search serves this purpose. The user has an option, based on the entered competence, to browse and search in the databases, e.g. Open iCoper Content Space, Scientia or Google Scholar.

These elements of the portal (modules and parts) bring significant improvement for students' learning process and the users can benefit in both academically and later professionally. Students have opportunity to compare study programmes and requirements at different institutions, in scientific and professional environment. Teachers are able to get feedback from professionals, colleagues and students. In longer perspective the eSEC portal is expected to contribute to the users' attractiveness at the labour market. It should be achieved by directly highlighting competencies required by employers and matching them with the opportunities available for students on the portal and that may not be part of the local educational system (for more also see [3]).

Educational institutions can offer their courses and capabilities to the target groups, whereas, commercial and government organisations can provide the contents for individual modules (documents, articles, blogs, etc.) and therefore affect the curricula. At the same time these organisations have a possibility opportunity to obtain and improve their own expertise and training (for more also see [4] and [5]).

Figure 1 shows the first version of the portal at the beginning of the project. Figure 2 shows the beta version of the portal. The beta version was used just for the testing. Figure 4 is the final version of the eSEC portal. Figure 5 presents the logo of eSEC portal and the project. The link of the portal follows Fig. 5.

In the first part of the eSEC project the main focus was on learning the best practices in the area of portal development and competencies in areas of security. Several documents were produced by the consortium to prepare the grounds for the future eSEC portal. At that stage of the project several outcomes and results were produced: European Basic Security and Safety Glossary of Terms including 500 terms from the field of security and safety. The glossary was created within the frame of the Competency Based e-portal of Security and Safety Engineering project (www.esecportal.eu). The glossary was translated into six languages (Czech, English, French, Italian, Portuguese and Slovak).

One of the outputs of the project was preparation of the eSEC Best Practices conference in Zlin (http://esec.utb.cz/), on 18 March

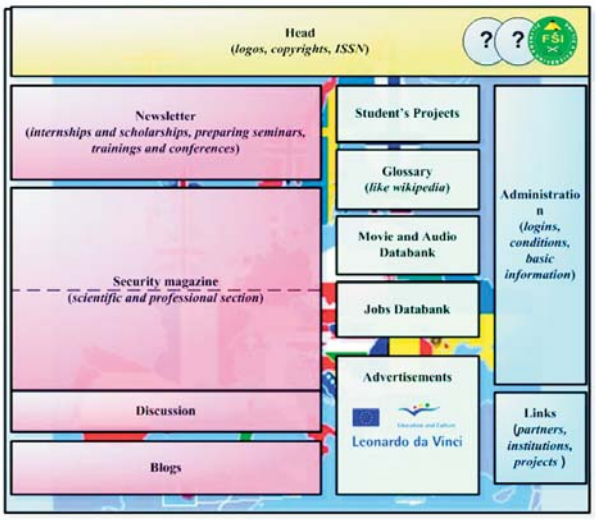

Fig. 1 eSEC Portal Structure, first idea

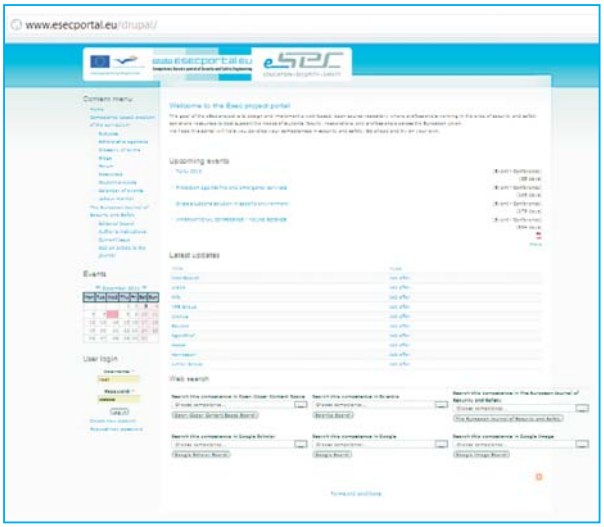

Fig. 2 Beta Version of the eSEC Portal

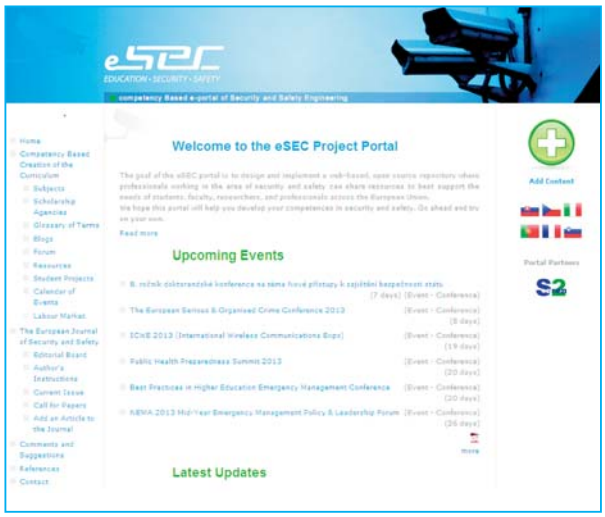

Fig. 3 Final version of the eSEC Portal

Fig. 4 eSEC Journal - European Journal of Security and Safety

EDUCATION • SECURITY • SAFETY

Fig. 5 eSEC Portal Logo

http://www.esecportal.eu/journal/

2010, which brought together 157 participants from 7 European countries (Czech Republic, Poland, Slovakia, Slovenia, Portugal, Ukraine, Russia).

Academic papers related to eSEC presented at conferences:

- Best Practices conference of eSEC portal project in March 2010,

- ISCRAM conference 2010 presented the eSEC project May 2010,
- International Conference on Computer Simulation in Risk Analysis and Hazard Mitigation, Algarve, Portugal in September 2010,
- Several papers were presented during the conference Policing in Central and Eastern Europe in Slovenia.

Participation in these events allowed the consortium to obtain very useful feedback for development of the portal and its data content, and contacts for future cooperation.

The project consortium also participated in the following events:
- ITEC – Defence Training and Simulation Conference and Exhibition, London, May 2010,
- Conference Crisis Situations Solutions in Specific Environment, Slovakia, June 2010,
- Conference Open Source Systems for Education, Research and IT 2010, Slovakia, July 2010.

The mentioned Best Practices conference and several workshops (one in Slovakia, security and safety engineering within defined countries in Europe, in October 2010; and two in Portugal, April 2010 Civil Protection, prevention and society and November 2010 Tecnicos de Proteccao Civil – Presente e Futuro) were prepared to receive not only the best practices, but also to increase the discussion for future directions for the project development and the preparation of the portal. At that stage the Glossary of Terms within 12 fields of security was finalised, which were also the 12 main fields of the portal:
- Economic Security,
- Energy Security,
- Environmental Security,
- Fire Protection,
- Industrial Security,
- Information Security,
- International Security,
- Civil Protection,
- Occupational and Health Safety,
- Protection of Persons and Property/ Private Security,
- Public Security,
- Transport Infrastructure Security.

A key document was also prepared, the Analysis Study (for more see [6]), which included analyses of the environment in individual regions, analysed by partner organisations of the eSEC project focused on the competences required by practice and academic society in the field of security and safety. A part of that document was the analysis of potential eSEC users' structure and their requirements, the structure and representation of expected target groups the portal users: students, teachers, academics, and professionals.

The document provided analysis of requirements for interactivity, user-friendly extremity, graphical surroundings and multimodality of eSEC portal's modules in relation to the expected target groups' skills. The document included analysis of eSEC portal's modules content based on required competences and the users' structure, which defined the need of individual modules focused on the identified 12 fields of security. In the conclusion of this document there were defined basic security and safety competencies within the fields according to Best Practices Conference of eSEC, the questionnaire of the Analysis Study and also formal and informal discussions during project implementation, with support of several communication channels.

Once the portal was launched the project consortium achieved its most important goal: to create the initial portal content which was hoped to bring wider community attention and thus lead to sustainability of the eSEC portal in the future. The project partners attempted to the maximal possible extent to create initial content which was as complete as possible (see Table 1).

The eSEC portal was also disseminated in several workshops, conferences and exhibitions organised by the consortium or where the partners were present, in the Check Republic, France, Germany, Ireland, Italy, Portugal, Russia, Slovakia, Slovenia, UK, ...

3. Contribution to EU policies

The eSEC project contributes to addressing the following EU policies:

1. The development of the high-quality life-long education and it supports high performance efficiency, innovations at the European dimension in the systems and procedures in the area of security and safety especially through an open access system that allows academics and professionals for accessing, creating and modifying broad information on different aspects of security and safety.
2. The eSEC project supports the European space of the life-long education on basis of linking the education of the European Professional community in the area of security and safety. In the framework of the portal it offers a space for linking educational institutions with practitioners from industry and government. The portal offers information from the area of security and safety to all stakeholders without any restriction.
3. The eSEC project through its key output – the eSEC portal – contributes to disseminating information about relevant opportunities for the life-long education which are available throughout the member states, in particular on the basis of the modules created – e.g. Competency Based Creation of the Curriculum and Scholarships Agencies.
4. The eSEC project helps to support creativity, competitiveness, employment and development of the entrepreneurial spirit based on creating an environment that supports achieving competences in the area of security and safety both directly through the resources available at the portal and indirectly through the advisory process. Making the Competency Based Creation of the Curriculum aimed at particular competences, information about the scholarships abroad as well as the job offers in the area of security and safety where the employer requires certain competences from the student belong to the area of consultancy. The project increases the chance of finding a job by the portal users as it directly links competences required by employ-

Figures of eSEC portal content Table 1

eSEC portal content	Description	Figures	
Subjects	The module is designed to publish subjects and study programmes focused on various aspects of security and safety.	Subject	>2630
		Country	>26
		Universities	>174
Scholarship Agencies	This module is designed to provide information about scholarship programmes and grant opportunities.	Organisations	>150
Glossary of Terms	The Glossary of Terms is an easy way to browse an electronic dictionary of terms in the twelve defined fields of security and safety.	Terms	>500
Resources	This module is focused on innovative methods in education supporting creativity and active approach of users to education and trainings in the field of security and safety. It enables the user to access audio-visual presentations from lectures, excursions, practical workshops, and other sources.	Audio-visual presentations from lectures, excursions, practical workshops and other sources	>920
Student Projects	In this module view, compare, or publish students' works, which have gained a prominent position in students competitions focused on research and development activities within partners universities.	Student Projects	>190
Calendar of Events	The module provides information about upcoming events within the field of security and safety.	Upcoming events	> 200
Labour Market	The module lists job offers in the field of security and safety within the EU along with the functionality to publish professional CVs of the job applicants.	Job offers	>300
		Employee's offers	>40
The European Journal of Security and Safety	European Journal of Security and Safety (EJSS) is European scientific journal, a source of peer-reviewed research articles in all fields related to security and safety.	Articles	>2
References	Official support letters of eSEC portal from stakeholders.	Certificates	>5

ers and those competences the student can acquire using the portal.
5. The eSEC project contributes to increasing popularity of the life-long education for people of all age categories through the free access to a great number of scientific and professional information from the area of security and safety.
6. The eSEC project supports collaboration and contributes to the quality of education and professional training in the area of security and safety in the EU. It is achieved through enabling collaboration between educational institutions and professionals in the EU.

The eSEC project contributes to fulfilling the following EU objectives:

1. The eSEC project supports the personal development of the eSEC portal users. It increases their chance to find a job and the participation in the European labour market based directly on providing the educational resources published at the eSEC portal and indirectly by providing information where and how the related competences can be gained and implemented.
2. The eSEC project is intended to increase mobility for the university students in the area of security and safety. With the use of the Mobility module, the students can learn about opportunities to study abroad.
3. The eSEC project increases and improves the collaboration between educational institutions, industry, government and public sector and other relevant organisations in whole Europe in the area of security and safety. This collaboration should be increased by sharing information through the portal and by exchange of students between universities.

The eSEC project contributes to fulfilling the following EU priorities:

1. The eSEC project supports the education and development of the teachers' skills through the eSEC portal that enables effective use of their time. The portal offers useful information and resources related to various areas of security and safety and it creates a platform for scientific collaboration, but also addressing practical problems from these areas.
2. The eSEC project contributes also to the development of the professional skills based on the market demand by linking the practitioners with educational institutions. The eSEC portal facilitates the flow of ideas between the professionals and the academia and naturally building bridges between these two communities, encouraging the practitioners to develop their skill sets and making the teachers and students aware of the current market requirements leading to more agile professional workforce.

4. Conclusion

In this paper we discussed the portal for sharing information knowledge in field of security and safety that is intended for students, teachers and professionals. Among the benefits of the portal are: the centralisation of multiple resources at a single location, facilitating information and knowledge sharing, evaluation of published articles, advertising and promoting seminars and conferences, creating a common place for blogs related to security and safety, publishing student works, etc. It allows for searching information about scholarships, internships and possible work vacancies in fields of security and safety. These phenomena are more discussed within [7] and [8]. Another contribution of the eSEC portal is the specialised glossary of the security, safety and crisis management terms, with interactive search in six languages.

At a more abstract level, the eSEC-portal is intended to bridge the practitioners' community with educational institutions. It does so at the regional level but as well throughout all EU countries. For the future it is expected that the reach of the portal will be beyond the EU and should cover the rest of the world. The eSEC-portal has become a centralised source of information in the field of security and with the intention to respond quickly to labour market demands through linking interested industries and agencies with current and prospect students. The development of the eSEC-portal is intended to contribute to increased participation in the lifelong education of people of all age categories by allowing access to information for all registered users regardless of the age and socio-economic background, in accordance with the rules for web application creation with the support of people with specific needs (also recommended to see [9], [10], [11], [12] and [13]).

A multilateral project eSEC – Competency Based e-portal of Security and Safety Engineering was submitted within the framework of Erasmus (Modernisation of Higher Education) and was focused on supranational cooperation among educational institutions and professionals, in the field of security and safety in the EU.

The official launch of the eSEC portal was on May, 30, 2012 at the Dissemination Conference of eSEC Portal, at the University of Zilina, in Zilina, Slovakia and the official opening on September 12, 2012 in Paris, France, at the last partnership meeting during the duration of the project.

The plans for the Future of the eSEC portal:

- encouraging involving the greatest possible number of stakeholders,
- keeping in contact with regular stakeholders' activities which should ensure that the eSEC portal content is regularly up-to-date,
- regular updating of the existing content and uploading of the new content,
- adding new modules based on the users' requirements (e.g. connection to the social networks, new e-learning tools, etc.),
- connecting the eSEC portal to other portals, networks and consortiums dealing with the issues of security and safety,
- encouraging involving the users on the creation of content, not only the partner institutions of the original project, but also the cooperating institutions of the individual project partners and other institutions, individual students, teachers or professionals,
- extending the collaboration with the partner institutions,
- addressing potential supporters, partners and sponsors.

The project consortium believes that the eSEC-portal will become an established and well known Internet portal in security and safety education, fulfilling the main objectives of the project.

Acknowledgments

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Katarina Holla – Katarina Kampova – Andrea Peterkova – Andrew Collins *

COMPLEX MODEL OF RISK ASSESSMENT OF INDUSTRIAL PROCESSES MOPORI

Modern day society wants to create optimal living conditions for its citizens and to ensure constant sustainable development. This objective cannot be achieved without reaching the required level of perceived security in complex. One of the areas that threaten the lives and property of people and are harmful for the environment is the anthropogenic crisis phenomena, which also include industrial accidents. Prevention of these accidents and subsequent reaction are the key issues considering adjustment of the level of security not only for the citizens of Slovakia, the European Union but also worldwide. The article focuses on the problem of prevention and the way how to deal with the issue in the Slovak Republic as well as on the fulfilment of the requirements in this field which emerge from our membership in the EU. The Faculty of Special Engineering at the University of Zilina deals with partial issues which are necessary to be solved by the approved project APVV – 10 Complex model of risk assessment of industrial processes. Partial results of the project, which is in the second year of its solution, are listed in the text below.

Keywords: *Major industrial accidents, prevention, SEVESO directive, risk assessment and treatment, MOPORI, model.*

1. Current state of the problem and the benefits of the outcomes of the project solved

Several threats both of antropogene or natural character affect people in the current world. And just the industrial accidents which threaten not only people but also the property and the environment belong among these antropogene phenomena. The European Union attempts to control these most dangerous EU enterprises (which have at disposal hazardous substances) through the adaptation of the SEVESO directive. This directive was called after a major industrial accident which happened in an Italian town SEVESO in 1976 [1], [2]. These enterprises are called SEVESO establishments and are classified according to the amount of the hazardous substances to lower tier and upper tier and currently there are approximately 10,000 companies of this type [3]. In spite of all the measures, the major industrial accidents as Bhopal, Schweizerhalle, Enschede, Toulouse and Buncefield claimed even after adopting this directive a lot of lives, damaged the environment and cost the member states lots of millions of EUR [4], [5]. Figs. 1 and 2 show a twelve-year overview according to the classification type and the number of events.

The Slovak Republic as a member of the EU also solves the problem of the major industrial accidents prevention. The basic legal document which transposes directive SEVESO II into our legal environment is Act No.261/2002 Coll. of Laws – law on the prevention of major industrial accidents, as amended, and other two implementing decrees [6].

Fig. 1 Events types in eMARS 2001-2012

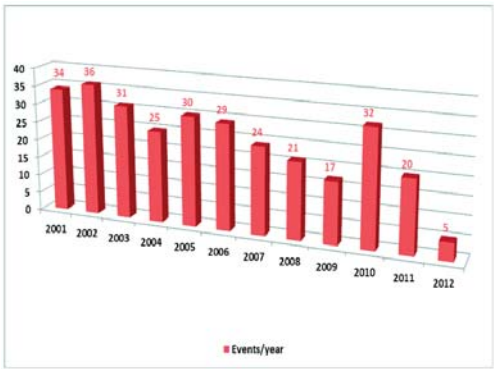

Fig. 2 No. of events 2001- 2012
(Source: https://emars.jrc.ec.europa.eu/)

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There are several problematic areas in this field. In 2008, The European Virtual Institute for Integrated Risk Management made a questionnaire study, the purpose of which was to obtain information about the transposition requirements of the directive SEVESO II in all the member states. At the same time, it obtained information about and its general advance, practical experience with the use of weaknesses and problems associated with its practical implementation, efficiency of its implementations and its impact on the competitiveness of European industry. Consequently, the member states were asked to react by improving the form of this directive.

The Results of the survey are as follows:

- In some areas, the respondents themselves see the opportunity to elaborate further supporting documents, whereby the point with the highest priority is the area of risk assessment and treatment.
- The area of concern is non-universality of the risk assessment approach, lack of the criteria to quantify the risks and the methods, tools and data used for implementation of the procedures.
- Many companies elaborate qualitative rather than quantitative analysis, which can conceal a higher level of uncertainty of the results.
- An approach to the risk assessment should be synchronized in accordance with the Directive SEVESO II on the one hand and the legal norms in the field at particular country on the other [7].

Selected findings from the survey indicate insufficient or formal approaches to the risk management within selected enterprises, and thereby confirm the possibility of elimination of the deficiencies by correct, system and mainly live approach of the subjects to the risk assessment and treatment.

As results from the mentioned research, one of the most problematic areas in the sector of the prevention of the major industrial accidents is to assess and treat risks. This issue is not appreciated by the laic general public as well as by the expert public at the time when there is no accident in a long-term. However, in case it occurs, the loss of human lives and material values prove to everyone that the issues related to the prevention of this type of accidents are necessary. It is also necessary to address number of demands related to dysfunction of the risk management system in a given subject. These dysfunctions could occur either due to poor coordination of particular activities within the prevention or by inappropriate reaction to the resulting accident. The causes of these types of accident are various and in most of the cases it is possible to talk about formally elaborated system of risk assessment and treatment. It means that the complex interconnection is not secured considering the system, organizational, personal, technical or material aspects [3].

It is just this crucial topic of assessment and treatment of risks which is the main problem being solved within the project APVV 0043 – 10 Complex model of risk assessment of industrial processes

2. Resources and results of the Project APVV 0043 – 10 Complex Model of Risk Assessment of Industrial Processes

Project with the title "Complex Model of Risk Assessment of Industrial Processes" (thereinafter MOPORI) originated due to the requirements to create a simple and system approach to risk assessment and management. The main objective of the project is *to increase a security level of industrial enterprises - "Seveso establishments" in the Slovak Republic* by creating a complex model of

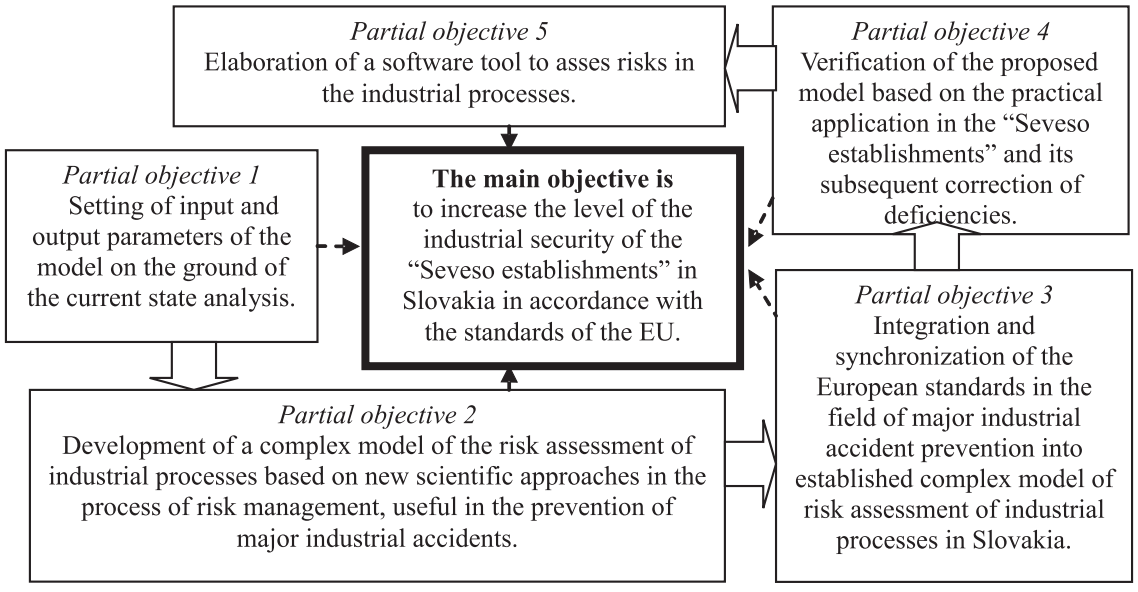

Fig. 3 The main objective and the partial objectives of the project

risk assessment of industrial processes with the use of quantitative methods and by its synchronization with the standards of the EU and their subsequent application in Slovakian conditions.

Duration of the project "MOPORI" is in the time interval 5/2011 – 4/2014. Throughout its duration, the project was given the main objective as well as the partial objectives whose interaction can be seen in Fig. 3.

Accomplishment of the main declared objective of the project MOPORI is ensured by creating eight work packages [8], which are designed in accordance with the general project and implementing phases of the project management. The titles of the work packages are listed below:

- PB0 Management of the project
- PB1 Complex analysis of the current state of the problem solved
- PB2 Development of a complex model of the risk assessment of industrial processes
- PB3 Application of the European standards in the field of major industrial accident prevention into the complex model of the risk assessment of industrial processes in Slovakian conditions
- PB4 Verification of the complex model of the risk assessment of industrial processes in practice
- PB5 Elaboration of a software tool to assess the risks of the industrial processes in Slovakian conditions
- PB6 Popularization of the project results
- PB7 Use of the project results

To support the project solution in addition to the clearly set work packages and activities, a council of experts has been nominated within the packages that composes of the representatives of selected target groups, namely:

- "Seveso establishments".
- Assessors: RISK CONSULT, s.r.o. (Ing. Jan Kandrac, CSc., Ing. Marek Kandrac – experts for prevention of major industrial accidents).
- Evaluators: Representatives of the Ministry of Environment of SR – Department of environmental risks and biosafety.

3. Results achieved within the time horizon of the project MOPORI

The above-described main objective of the project MOPORI – *increase of the security level of industrial enterprises - "Seveso establishments" in SR*, is achieved within the project by completion of the partial objectives which create conditions for its fulfilment. Partial objectives are met by the project team that is comprised of experts from the practice and scientific researchers from the ZU. Currently, it is possible to present these partial outputs from the individual defined work packages as follows:

The first partial objective "Setting of input and output parameters of the model on the ground of the current state analysis" creates conditions to fulfil another objective to design a model of risk assessment of the industrial processes by means of:

- Needs analysis following the lessons learnt from the major industrial accidents prevention in SR and EU.
- Analysis and synthesis of the conclusions of the survey performed among the SEVESO establishments.
- Stakeholders' workshops.

The table listed below presents an overview of the major industrial accidents in the time period 2003–2011. The importance of this overview is in the analysis "lessons learnt" from these unwanted events. This analysis also created one of the assumptions to define input and output parameters of the proposed model in the partial objective 2.

Based on the analysis of major industrial accidents (see Table 1) main causes of this type of event were identified.

The analysis "lessons learnt" was subsequently amended by the survey which focused on the issues of major industrial accidents and the fulfilment of the requirements valid for the SEVESO establishments in the Slovak Republic with an emphasis on the implementation of the risk assessment and treatment. The questionnaire was sent to all SEVESO establishments in Slovakia (80) while the backflow was more than 50%. The project team considers this backflow as a success which was conditioned by the long-term and intensive communication not only of the project team from the university environment but also by the use of contacts from the institutions involved in the project MOPORI. Based on a survey conducted by the questionnaire method several facts were detected out of which we choose the most important and relevant to the proposed model:

- Inconsistency of the used approaches and methods of risk assessment and treatment of industrial processes whereby there is missing possibility to compare results (different algorithms of the approaches based on the economic potential of the subject).
- Inadequate conditions for the application of the quantitative procedures for the risk assessment and treatment.
- The lack of explanatory documents and methodologies for processing the required source data necessary for the documentation in question.
- Inconsistency in an approach to assess risks of the natural character considering the ambiguity of data and criteria for their assessment.
- The lack of knowledge on new approaches to the latest technical and technological development in the field of major industrial accident prevention.

Another approach to achieve this objective was a personal contact with selected stakeholders, which was arranged during the created workshops. In the workshops, creation of the model and the definition of the input and output parameters were the primarily addressed issues. The added value of these workshops was to identify perspectives on the problem solved form various points of view. The Ministry of Environment as a competent authority sees the main problem in the quality of the elaborated documents submitted by the SEVESO establishments. Processors of the security documentation, whether internal or external, do not have required qualification, experience and frequently they are given incomplete materials form the SEVESO establishments. The outcomes of the workshops were processed as a ground for creation of a model of

Major industrial accidents in the Slovak Republic in the time period 2003 – 2011 [9] Table 1

Name of the enterprise	Date of the event	Place and type of the event	Cause
DUSLO, a.s.	24.7.2010	Office building (production of ammonia) 1236, Sala technical failure, explosion, fire	Flange leak on a high pressure synthesis gas distribution
Novacke chemicke zavody, a.s.	28.9.2005	Novaky, company area, ethylenehydrin operation, human error	Welding and ignition of the explosive blend from the weld joint
U. S. Steel Kosice, s. r. o.	28.9.2005	The energy division, energy media operation, technical failure, explosion, fire	Damage and subsequent breakage of the end of the shaft inside the wheel of the centrifugal pump type A-CB 185/4-7,2 Nr. 1.
U. S. Steel Kosice, s. r. o.	16.11.2006	Company area – technical failure	Power failure and subsequent failure of technological and security equipment of the company

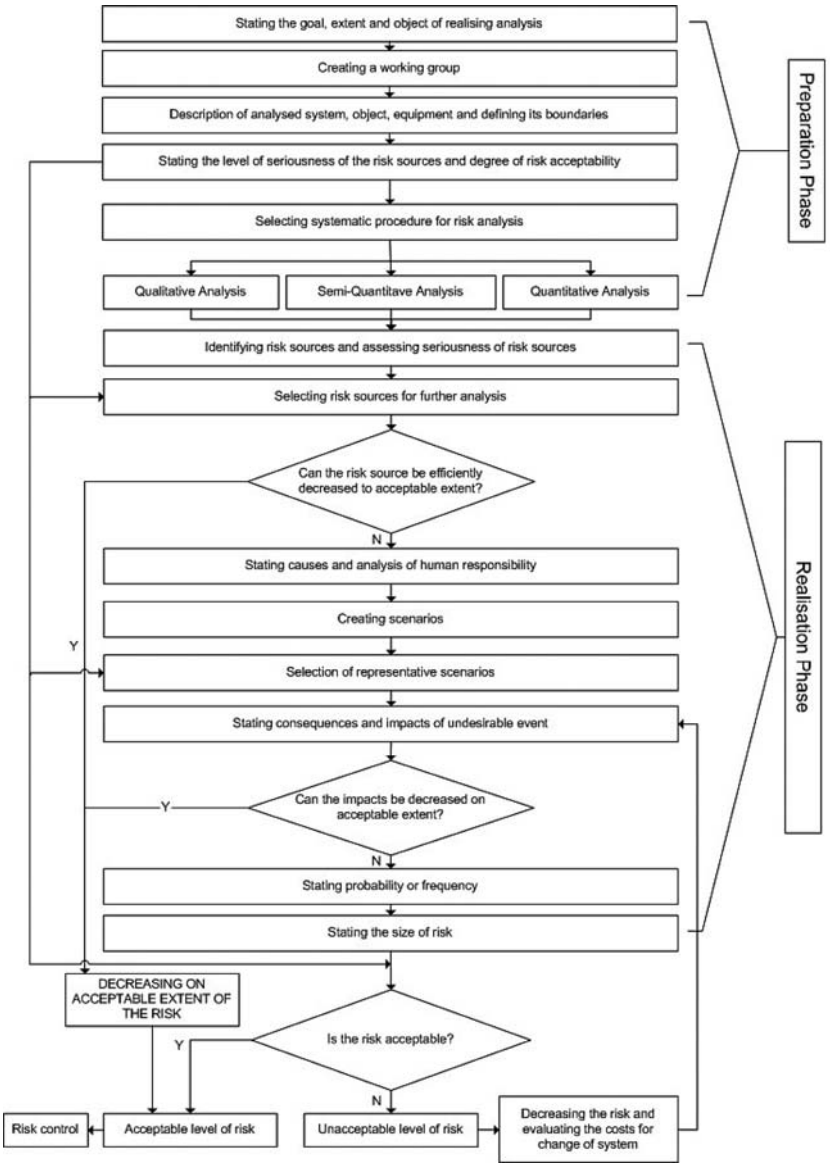

Fig. 4 Model of risk assessment of industrial processes

risks assessment and treatment of industrial processes, and together with the individual contributions from the participating stakeholders they were compiled in an electronic anthology that was published on CD. The project website is the main dissemination channel to spread the results of the workshops.

The three basic approaches (analysis of lessons learnt, questionnaire survey and stakeholders workshops) contributed to the solution of the partial objective *"Setting of input and output parameters of the model on the ground of the current state analysis"* and created a primary source of information for the design of the model, which forms the main output of another project objective *"Development of a complex model of the risk assessment of industrial processes based on new scientific approaches in the process of risk management useful in the major industrial accidents prevention".*

Based on the observed assumptions and analysis of the approaches currently in use as well as of the modern ones a model of risk assessment of industrial processes has been proposed and designed which will be verified by practical application in two of the "Seveso establishments". The verification of the accuracy of the proposed model is planned for the next year of the project. The verification should enable the incorporation of the deficiencies of the designed model so that the proposed model could be correct from the viewpoint of the usability by the stakeholders. Consequently, an efficient software tool to assess the risks in industrial processes could be created. This tool should remedy the deficiencies associated with the errors in assessment and management of risks that has been partially described in this article.

The model shown in Fig. 4 was created as a basic algorithm for risk assessment and management in the field of major industrial accident prevention within this project and is also useful for other types of accidents in industrial plants. Formalizing the approaches and pointing out the link between individual phases and steps of the created model is one of the key positives of the model [9, 10].

4. Plans for the future within MOPORI

Considering the continuation of the project, the project team has defined the essential activities and tasks associated with the fulfilment of the defined partial objectives of the project, namely: Based on the established model of risk assessment of industrial processes, an integration of currently valid as well as newly-formed approaches in the project will be implemented to achieve its complexity. Two representative models will be established, one will have a character of a deterministic approach and the other of a probabilistic approach [11].

Established model and the application of the currently valid approaches and methods into particular phases and steps will create a prerequisite for its verification in two of the SEVESO establishments. Negotiations are currently underway with several companies. The model will be applied into use by two experts for major industrial accidents prevention from the University of Zilina and two employees of the company Risk Consult who are involved in the project. Due to the use of two different approaches within the model, it will be possible to compare the results of the application not only between the companies but also between the different approaches established. Based on this, new conclusions will be determined and so will, consequently, advantages and disadvantages of the application of the complex model.

The next planned step is to create a software tool for risk assessment in the industrial processes. Following the verification of the model in practice, deficiencies of the complex model will be eliminated and a software tool will be created and recommended for use by the companies in the Slovak Republic [12,13].

5. Conclusion

In addition to the main outputs that have been mentioned above, the project team produces other outputs while achieving the partial objectives of the project. The main ones include dissemination activities on conferences within the Slovak Republic, the European Union but also in the USA or Canada. Next year, the first monograph will be published in the field of the problem solved with the title "Prevention of major industrial accident" necessary to improve the learning process on the issues in question at the FSI. In like manner, the finances of the project are also used to increase the competences of individual members of the research team – to become a proficient specialist to prevent major industrial accidents, an emergency technician or an OSH technician. In addition to these results, this year a new project was submitted to 7Framework programme SEC-2013-1 with a title Industrial Accidents Prevention Stakeholders Platform – INFORM. More information on the activities of the project is available on the project website http://mopori.blogspot.sk/.

Acknowledgements

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SURFACE AND SUBSURFACE RESIDUAL STRESSES AFTER MACHINING AND THEIR ANALYSIS BY X-RAY DIFFRACTION

Process specifications and working procedures widely used by the aerospace and automotive industries require surface analysis by machining and specify the process parameters such as type, destructive measuring or simulations. Destructive measuring or simulation carried out in order to optimise and later to verify the process parameters are a very indirect way of measurement. While they are performed on simulation only similar in composition and elastic properties to that of the actual part to be machined, they almost never match all the important conditions of the process such as the shape of the real part or the residual stress prior to the treatment. Consequently the residual stresses and their depth distribution after the machining may differ very significantly from those required by the technologist. The only reliable way to verify that the operation has produced the desired effect is to actually measure the stresses in the machined component.

Keywords: *Surface, residual stresses, X-ray diffraction, machining.*

1. Introduction

Residual stresses are an integral part of manufactured workpieces, whether they are introduced deliberately, as a part of the design, as a by-product of a process carried out during the manufacturing process, or are present as the product of the component's service history. Residual stresses are additive with the stresses existing in the workpieces as a result of service loads. Clearly, they may be considered beneficial to the workpieces and therefore desirable, they may be irrelevant and can be ignored, or they are a potential detriment to the workpieces and their continued service life. Given an adequate history, the magnitude of residual stresses in parts that are in service can be considered as indicators of the workpiece's deterioration [1].

Obviously, to realize the benefits of understanding the residual stresses in parts and structures, tools are needed to measure them. Several techniques are available, with varying degrees of sophistication. Some of them are rather limited in their application, but one stands out as having widespread applications and being readily available.

X-ray diffraction is applicable to crystalline materials, which include virtually all metals and their alloys, and most ceramic materials. It is a non-destructive detection technology in many applications, and is widely accepted by the engineering community, being the subject of SAE and ASTM publications, which provide reliable sources of information on methods to ensure repeatability and reliability in the results of measurements. Because individual measurements are non-destructive, they can be replicated to demonstrate their statistical reliability.

This article will look closely at the methodology of residual stress measurement by X-ray diffraction, explore the characteristics of measurements performed using modern X-ray methods, and offer a few practical examples [2].

2. Principles of X-Ray Diffraction Stress Measurement

Macroscopic stresses, which extend over distances that are large relative to the grain size of the material, are of general interest in design and failure analysis. Macroscopic stresses are tensor quantities, with magnitudes varying with direction at a single point in a component. The macroscopic stress for a given location and direction is determined by measuring the strain in that direction at a single point. When macroscopic stresses are determined in at least three known directions, and a condition of plane stress is assumed, the three stresses can be combined using Mohr's circle for stress to determine the maximum and minimum residual stresses, the maximum shear stress, and their orientation relative to a reference direction. Macroscopic stresses strain many crystals periodically in the surface. This periodical distortion of the crystal lattice shifts the angular position of the diffraction peak selected for residual stress measurement [1].

Microscopic stresses are scalar properties of the sample, such as percent of cold work or hardness, which are without direction

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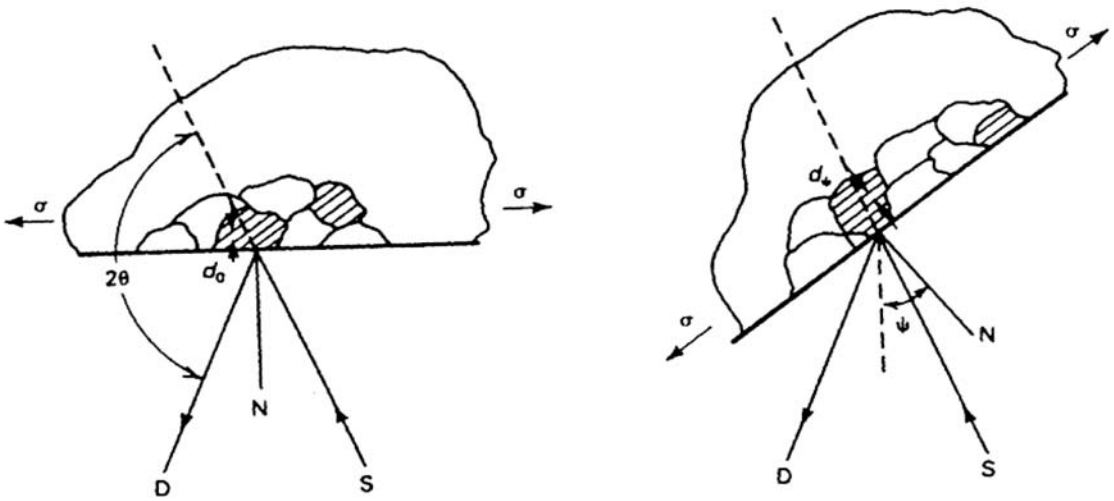
and result from imperfections in the crystal lattice. Microscopic stresses are associated with strains within the crystal lattice that traverse distances on the order or less than the dimensions of the crystals. Microscopic stresses change within the crystal lattice, altering the lattice spacing and broadening the diffraction peak. Macroscopic stresses and microscopic stresses can be determined individually from the diffraction peak position and breadth [1].

Figure 1 describes the diffraction of a monochromatic beam of X-rays at a high diffraction angle 2θ from the surface of a stressed sample for two orientations of the sample relative to the X-ray beam. The angle ψ, defining the orientation of the sample surface, is the angle between the normal of the surface and the incident and diffracted beam bisector, which is also the angle between the normal to the diffracting lattice planes and the sample surface [3].

Diffraction occurs at an angle 2θ, which is defined by Bragg's Law: $n\lambda = 2d \sin \theta$, where n is a number denoting the order of diffraction, λ is the X-ray wavelength, d is dimension of the lattice spacing of crystal planes, and θ is the diffraction angle. For the monochromatic X-rays produced by the metallic target of an X-ray tube, the wavelength is known to 1 part in 105. Any change in the lattice spacing d results in a corresponding shift in the diffraction angle 2θ. Figure 1a shows the sample in the $\psi = 0$ orientation. The presence of a tensile stress in the sample results in a Poisson's ratio contraction, reducing the lattice spacing and slightly increasing the diffraction angle, 2θ. If the sample is then rotated through some known angle ψ (Fig. 1b), the tensile stress present in the surface increases the lattice spacing over the stress-free state and decreases 2θ. Measuring the change in the angular position of the diffraction peak for at least two orientations of the sample defined by the angle ψ enables calculation of the stress present in the sample surface lying in the plane of diffraction, which contains the incident and diffracted X-ray beams. To measure the stress in different directions at the same point, the sample is rotated about its surface normal so that the direction of interest coincides with the diffraction plane. Because only the elastic strain changes the mean lattice spacing, only elastic strains are measured using X-ray diffraction for the determination of macroscopic stresses. When the elastic limit is exceeded, further strain results in dislocation motion, disruption of the crystal lattice, and the formation of microscopic stresses, but no additional increase in macroscopic stress. Although residual stresses result from non-uniform plastic deformation, all residual macrostresses remaining after deformation are necessarily elastic.

The residual stress determined using X-ray diffraction is the arithmetic average stress in a volume of material defined by the irradiated area, which may vary from square centimetres to square millimetres, and the depth of penetration of the X-ray beam. The linear absorption coefficient of the material for the radiation used governs the depth of penetration, which can vary considerably. However, in iron, nickel, and aluminium-based alloys, 50% of the radiation is diffracted from a layer approximately 0.005 mm deep for the radiations generally used for stress measurement. This shallow depth of penetration allows determination of macro and microscopic residual stresses as functions of depth, with depth resolution approximately 10 to 100 times that possible using other methods. Although in principle virtually any interplanar spacing may be used to measure strain in the crystal lattice, the availability of the wavelengths produced by commercial X-ray tubes limits the choice to a few possible planes. The choice of a diffraction peak selected for residual stress measurement impacts significantly on the precision of the method. The higher the diffraction angle, the greater the precision. Practical techniques generally require diffraction angles, 2θ, greater than 120° [4].

Plane-stress elastic model X-ray diffraction stress measurement is confined to the surface of the sample. Electropolishing is used



a) *b)*

(a) out rotation $\psi = 0$. (b) angle of rotation $\psi = \psi$ sample rotated through some known angle ψ, D – detector: S – source; N – normal to the surface.

Fig. 1 Principles of X-ray diffraction stress measurement [3]

to expose new surfaces for subsurface measurement. In the exposed surface layer, a condition of plane stress is assumed to exist. That is, a stress distribution described by principal stresses σ_1 and σ_2 exists in the plane of the surface, and no stress is assumed perpendicular to the surface, $\sigma_3 = 0$. However, a strain component perpendicular to the surface ε_3 exists as a result of the Poisson's ratio contractions caused by the two principal stresses (Fig. 2) [5].

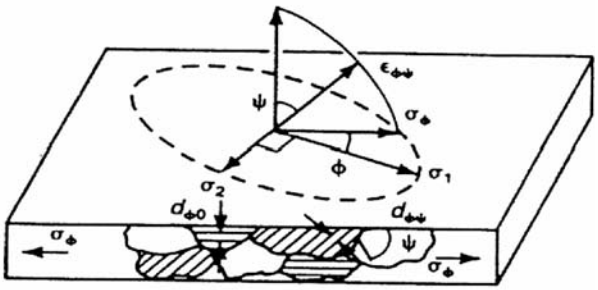


Fig. 2 Plane-stress elastic model [3]

The strain, $\varepsilon_{\varphi\psi}$ in the direction defined by the angles φ and ψ is:

$$\varepsilon_{\varphi\psi} = \left[\frac{1+\nu}{E}\left(\sigma_1\alpha_1^2 + \sigma_2\alpha_2^2\right)\right] - \left[\frac{\nu}{E}\left(\sigma_1 + \sigma_2\right)\right] \quad (1)$$

where E is the modulus of elasticity, ν is the Poisson's ratio, and α_1 and α_2 are the angle cosines of the strain vector:

$$\alpha_1 = \cos\varphi \sin\psi$$

$$\alpha_2 = \sin\varphi \sin\psi \quad (2)$$

Substituting for the angle cosines in Eq. 1 and simplifying enables the strain to be expressed in terms of the orientation angles:

$$\varepsilon_{\varphi\psi\phi\psi} = \left[\frac{1+\nu}{E}\left(\sigma_1\cos^2\varphi + \sigma_2\sin^2\varphi\right)\sin^2\psi\right] - \left[\frac{\nu}{E}\left(\sigma_1 + \sigma_2\right)\right] \quad (3)$$

If the angle ψ is taken to be 90°, the strain vector lies in the plane of the surface, and the surface stress component, σ_φ is:

$$\sigma_\varphi = \left(\sigma_1\cos^2\varphi\right) + \left(\sigma_2\sin^2\varphi\right) \quad (4)$$

Substituting Eq. 4 into Eq. 3 yields the strain in the sample surface at an angle φ from the principal stress σ_1:

$$\varepsilon_{\varphi\psi} = \left[\frac{1+\nu}{E}\sigma_\varphi\sin^2\psi\right] - \left[\left(\frac{\nu}{E}\right)\left(\sigma_1 + \sigma_2\right)\right] \quad (5)$$

Equation 5 relates the surface stress σ_φ, in any direction defined by the angle ψ, to the strain, $\in$, in the direction (φ, ψ) and the principal stresses in the surface. If $d_{\varphi\psi}$ is the spacing between the lattice planes measured in the direction defined by φ and ψ, the strain can be expressed in terms of changes in the linear dimensions of the crystal lattice:

where d_0 is the stress-free lattice spacing. Substitution into Eq. 5 yields:

$$\frac{d_{\varphi\psi} - d_0}{d_0} = \left[\left(\frac{1+\nu}{E}\right)_{(hkl)}\sigma_\varphi\sin^2\psi\right] - \left[\left(\frac{\nu}{E}\right)_{(hkl)}\left(\sigma_1 + \sigma_2\right)\right] \quad (6)$$

where the elastic constants $(1 + \nu/E)_{(hkl)}$ and $(\nu/E)_{(hkl)}$ are not the bulk values but the values for the crystallographic direction normal to the lattice planes in which the strain is measured as specified by the Miller indices (hkl). Because of elastic anisotropy, the elastic constants in the (hkl) direction commonly vary significantly from the bulk mechanical values, which are an average over all possible directions in the crystal lattice. The lattice spacing for any orientation, then, is:

$$d_{\varphi\psi} = \left[\left(\frac{1+\nu}{E}\right)_{(hkl)}\sigma_\varphi d_0\sin^2\psi\right] - \left[\left(\frac{\nu}{E}\right)_{(hkl)}d_0\left(\sigma_1 + \sigma_2\right) + d_0\right] \quad (7)$$

Equation 7 describes the fundamental relationship between lattice spacing and the biaxial stresses in the surface of the sample. The lattice spacing $d_{\varphi\psi}$, is a linear function of $\sin^2\psi$.

The intercept of the plot at $\sin^2\psi = 0$ is:

$$d_{\varphi 0} = d_0 - \left(\frac{\nu}{E}\right)_{(hkl)}d_0\left(\sigma_1 + \sigma_2\right) = = d_0\left[1 - \left(\frac{\nu}{E}\right)_{(hkl)}\left(\sigma_1 + \sigma_2\right)\right] \quad (8)$$

which equals the unstressed lattice spacing, d_0, minus the Poisson's ratio contraction caused by the sum of the principal stresses. The slope of the plot is:

$$\frac{\partial d_{\varphi\psi}}{\partial\sin^2\psi} = \left(\frac{1+\nu}{E}\right)_{(hkl)}\sigma_\varphi d_0$$

which can be solved for the stress σ_φ:

$$\sigma_\varphi = \left(\frac{E}{1+\nu}\right)_{(hkl)}\frac{1}{d_0}\left(\frac{\partial d_{\varphi\psi}}{\partial\sin^2\psi}\right) \quad (9)$$

The X-ray elastic constants can be determined empirically, but the unstressed lattice spacing, d_0, is generally unknown. However, because $E \gg (\sigma_1 + \sigma_2)$, the value of $d_{\varphi 0}$ from Eq. 8 differs from $d0$ by not more than ± 1%, and σϕ may be approximated to this accuracy using:

$$\sigma_\varphi = \left(\frac{E}{1+\nu}\right)_{(hkl)}\left(\frac{s_1 - s_2}{2R}\right)\left(\frac{\cot\theta}{\sin^2\psi_1 - \sin^2\psi_2}\right) \quad (10)$$

The method then becomes a differential technique, and no stress-free reference standards are required to determine d_0 for the biaxial stress case. The three most common methods of X-ray diffraction residual stress measurement, the single-angle, two-angle, and $\sin^2\psi$ techniques, assume plane stress at the sample surface and are based on the fundamental relationship between lattice spacing and stress given in Eq. 7 [6].

The single-angle technique, or single-exposure technique, derives its name from early photographic methods that require a single

exposure of the film. The method is generally considered less sensitive than the two-angle or $\sin^2\psi$ techniques primarily because the possible range of ψ is limited by the diffraction angle 2θ [7].

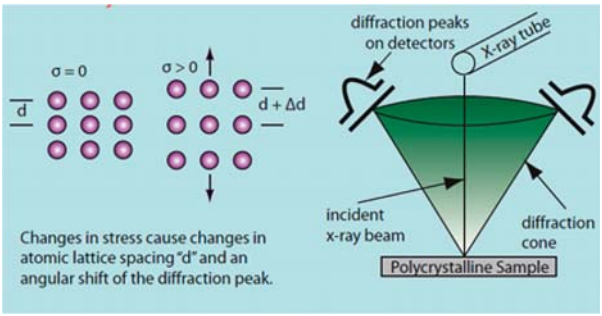


Fig. 3 Basic geometry of the single-angle technique for X-ray diffraction residual stress measurement [4]

Figure 3 shows the basic geometry of the method. A collimated beam of X-rays is inclined at a known angle, β, from the sample surface normal. X-rays diffract from the sample, forming a cone of diffracted radiation originating at point 0. The diffracted X-rays are recorded using film or position-sensitive detectors placed on either side of the incident beam. The presence of a stress in the sample surface varies the lattice spacing slightly between the diffracting crystals shown at points 1 and 2 in Fig. 3, resulting in slightly different diffraction angles on either side of the X-ray beam. If detector $S1$ and detector $S2$ are the arc lengths along the surface of the film or detectors at a radius R from the sample surface, the stress is:

$$\sigma_\varphi = \left(\frac{E}{1+\nu}\right)_{(hkl)} \left(\frac{s_1 - s_2}{2R}\right)\left(\frac{\cot\theta}{\sin^2\psi_1 - \sin^2\psi_2}\right) \qquad (11)$$

The angles ψ_1, and ψ_2 are related to the Bragg diffraction angles θ_1, θ_2, and the angle of inclination of the instrument, β, by:

$$\psi_1 = \beta + \theta_1 - \frac{\pi}{2} \quad \text{and} \quad \psi_2 = \beta + \theta_2 - \frac{\pi}{2} \qquad (12)$$

The precision of the method is limited by the principle that increasing the diffraction angle 2θ to achieve precision in the determination of lattice spacing reduces the possible range of $\sin^2\psi$, lessening sensitivity. The single-angle technique is generally not used, except for film and position-sensitive detector apparatuses designed for high-speed measurement [7].

3. Quantitative and Qualitative Stress Analysis

The conventional way of measuring the surface residual stresses is X-ray diffraction (XRD). This is a well-established quantitative, absolute method and provides accurate stress values. In machined components the beneficial maximum compressive stresses are beneath the surface and thus to verify the result of the machining, evaluation below the surface is necessary. The measurement depth of the XRD method is limited to a few microns. To measure the subsurface stress by XRD requires successive electrochemical removal of material and repeated XRD measurements. Such a procedure is acceptable for laboratory evaluations on selected samples. Difficult to reach areas such as holes, fillets or roots of gears form an additional difficulty. The XRD is nevertheless irreplaceable in obtaining the true and complete picture of the effects of machining. Particularly, very steep stress gradients after machining of very hard steels are well resolved by this technique. It ought to be mentioned here that, in addition to the stress profile, also the effects of plastic deformation, work hardening or softening of the machined surface can be illustrated and quantified by the XRD measurement (Fig. 4).

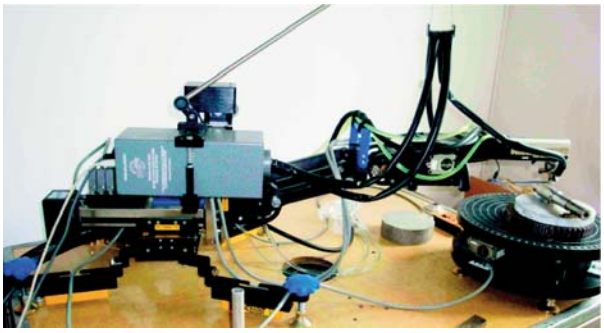


Fig. 4 Measurement system for residual stresses in X-ray diffraction

4. Material and experimental technique

Experimental studies were made on a high carbon rolled steel bar (60 mm diameter and 500 mm long). The chemical analysis of the steel conducted on a direct reading spectrometer determined its chemical composition as: 1.14% C, 0.46% Mn, 0.16% Si, 0.11% S and 0.04% P. Round slices cut from the steel bar were shaped as shafts (59 mm × 150 mm) by subsequent machining. The thickness of samples subjected to inhomogeneous plastic deformation were approximately 30 mm, whereas those subjected to thermal and phase transformation were approximately 15 mm. All these samples were made free from residual stresses by annealing them in a muffle furnace as follows: heating rate, 165 °C.h^{-1}; soaking time, 1 h; soaking temperature, 850 °C; cooling rate, 30 °C.h^{-1} (Fig. 5 and Fig. 6).

Residual stress measurements were made on five machined samples, three samples having thermal residual stresses and two samples having thermal and phase transformation stresses. The specimens were carefully prepared and made free from scale and dirt. Clamping of the samples to the work holder was done with chuck tightening to avoid their sliding during the experiment. Residual stresses were measured in the area located at the middle, e.g., at l/2 length in all the samples. The residual stresses were measured on the X-ray diffractometer using the strain flex X-ray analyzer.

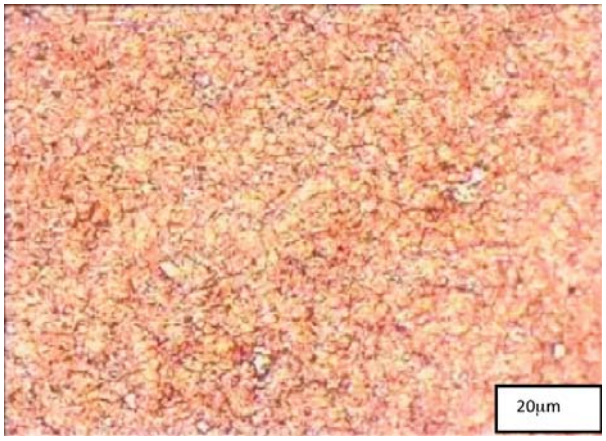


Fig. 5 Microstructure result of specimen, etching Murakami

Fig. 6 Thorns on rolling bearing rings

From the theory of elasticity the relationship between residual stress (σ) and strain (ε) on the specimen surface under plane stress is given by the Bragg equation, $\lambda = 2d \sin\theta$, relating incident X-ray wavelength (λ), lattice interplanar spacing (d) and diffraction angle (θ).

Determination of the magnitude and direction of the maximum residual stress created after machining is posssible to measure by X-ray diffractometry. The direction of maximum residual stress, that is, the most tensile or least compressive, is assumed to occur in the cutting or grinding direction during most machining operations. This is frequently the case, but the maximum stress often occurs at significant angles to the cutting direction. Furthermore, the residual stress distributions produced by many cutting operations, such as turning, may be highly eccentric, producing a highly tensile maximum stress and a highly compressive minimum stress [8].

The residual stress field at a point, assuming a condition of plane stress, can be described by the minimum and maximum normal principal residual stresses, the maximum shear stress, and the orientation of the maximum stress relative to some reference direction. The minimum stress is always perpendicular to the maximum. The maximum and minimum normal residual stresses, shown as σ_1 and σ_2 in Fig. 2, and their orientation relative to a reference direction can be calculated along with the maximum shear stress using Mohr's circle for stress if the stress σ_φ is determined for three different values of φ [9].

To investigate the minimum and maximum normal residual stresses and their orientation produced by turning of samples, X-ray diffraction residual stress measurements were performed in the longitudinal, 45°, and circumferential directions at the surface and at subsurface layers to a nominal depth of 0.1 mm, exposing the subsurface depths by electropolishing complete cylindrical shells around

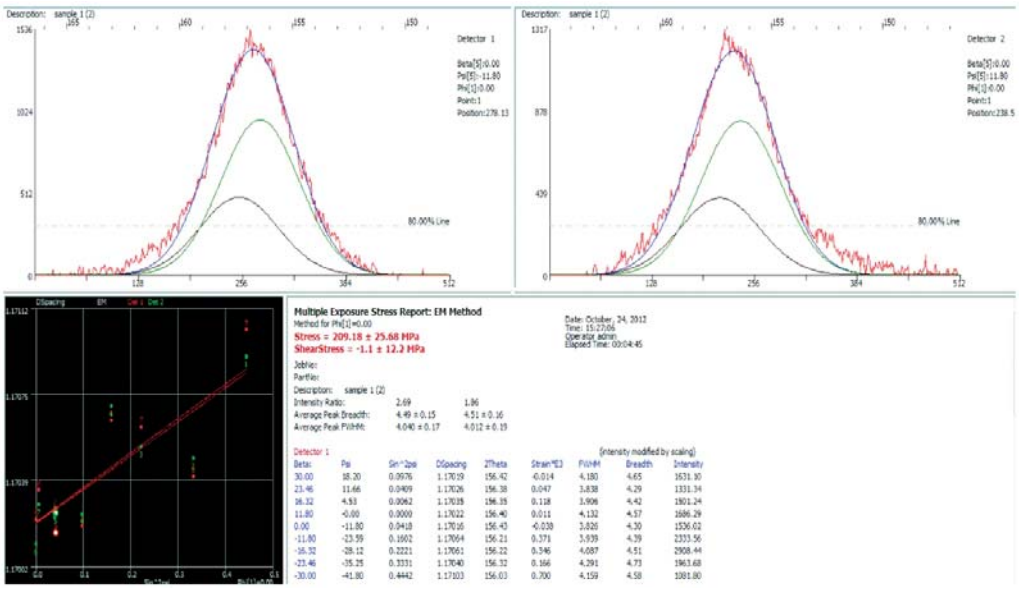


Fig. 7 Residual stress analysis of calculations with WINXRD 2.0

the cylinder. The cylinder was nominally 59 mm in diameter and uniformly turned along a length of several inches. The irradiated area was limited to a nominal height of 1 mm around the circumference by 2.5 mm along the length [10]. Measurements were conducted using a Cr Kα (420) two-angle technique, separating the Kα_1 peak from the doublet using a Cauchy peak profile (Fig. 7).

The measurements performed independently in the three directions were combined using Mohr's circle for stress at each depth to calculate the minimum and maximum normal residual stresses and their orientation defined by the angle φ, which was taken to be a positive angle counterclockwise from the longitudinal axis of the cylinder. Figure 8 illustrates the results, showing the maximum and minimum principal residual stress profiles and their orientation relative to the longitudinal direction. The maximum stresses are tensile at the surface, in excess of 140 MPa, dropping rapidly into compression at a nominal depth of 0.005 mm. The maximum stress returns into tension at depths exceeding 0.025 mm and remains in slight tension to the maximum depth of 0.1 mm examined. The minimum residual stress is in compression in excess of −480 MPa at the turned surface and diminishes rapidly in magnitude with depth to less than −138 MPa at a depth of 0.013 mm. The minimum stress remains slightly compressive and crosses into tension only at the maximum depth examined. The orientation of the maximum stresses is almost exactly in the circumferential direction (90° from the longitudinal) for the first two depths examined. For depths of 0.013 mm to the maximum depth of 0.1 mm, the maximum stress is within approximately 10° of the longitudinal direction.

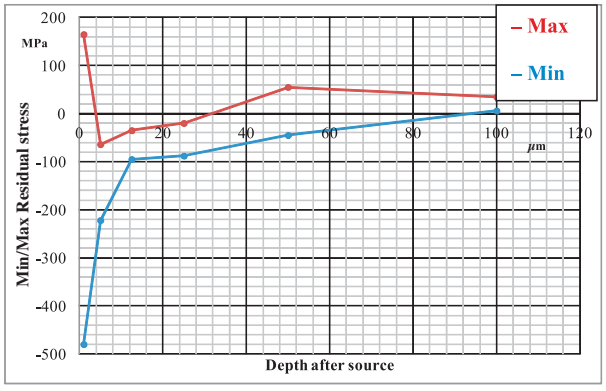


Fig. 8 Minimum and maximum principal residual stress profiles and their orientation relative to the longitudinal direction in a turned sample

5. Experimental Results and Discussion

To measure the residual stresses, we began by placing the parts on a pad measuring system. The detector arm focused on the unit area measured (Fig. 9). Stresses were measured in the axial and radial direction components. After preparing the parts the X-ray apparatus began to emit and X-rayed the previously selected point in the part. The device measured the stress to a depth of 12μm in the range of angles around 123° – 171° [11]. Then the computer formulated the results as graphs, which calculated the residual values for shear and residual stresses, which were then processed into tables.

Fig. 9 Focusing the machine on the component

Turning Roughing Operation when using a cutting speed of v_c = 100m.min^{-1} a measurement was made of the axially compressed nature of the residual stress, whose value hovered around −360MPa, and the radial residual stress in the application of the same cutting speed showed a value of −175MPa pressure of the same character. With increasing cutting speed there was a reduction of the residual stresses in the axial and radial directions. With a value of v_c = 150m.min^{-1} the tension in the axial direction compared with v_c = 100m.min^{-1} reduced by 40%, while in the axial direction it decreased by 30%. When using v_c = 200m.min^{-1} the tension in the axial direction when applied to the values of v_c = = 100 m.min^{-1} decreased by 50%, while in the radial direction there was a change to tensile stresses of pressure and a change of 250% (Fig. 10).

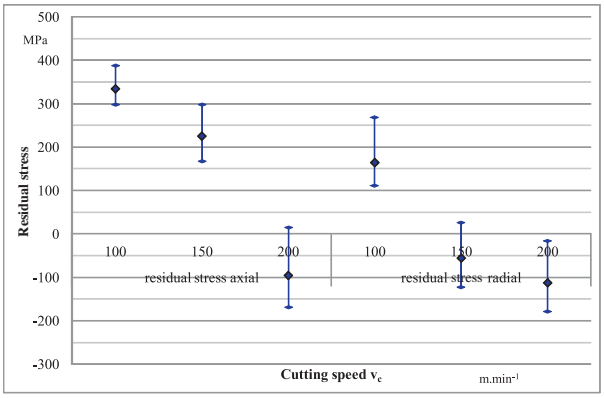


Fig. 10 Graph of residual stresses in turning roughing

The turning operation was complete when the residual stress nature of the pressure had been finished in all cases. When using a cutting speed of $v_c = 100$ m.min^{-1} the value of the measured axial tension corresponded to a voltage of -850MPa, whereas the radial residual stress when applying the same cutting speed showed a value of −580MPa. With a cutting speed of $v_c = 150$ m.min^{-1} the tension in the axial direction increased by 2% compared with $v_c = 100$ m.min^{-1} whereas in the radial direction the tension increased by 20%. When using $v_c = 200$ m.min^{-1} the tension in the axial direction when applied to the values of $v_c = 100$ m.min^{-1} increased by 250%, whereas in the radial direction of the residual stress it increased by 25% (Fig. 11).

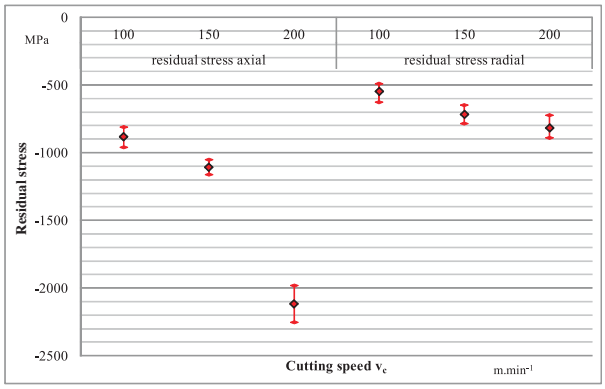


Fig. 11 Graph of residual stresses in turning finishing

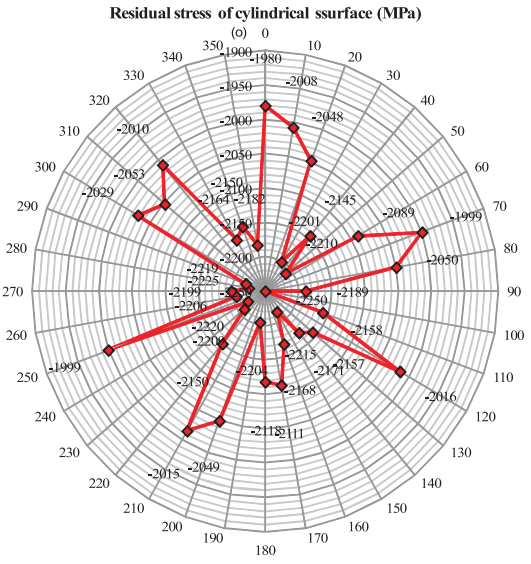


Fig. 12 Graph of residual stresses in polar coordinates when turning finishing with cutting speed $v_c = 200$ m.min^{-1}

That component is used as rolling tool that operates its surface on material to a ductile strength. In places where there is tensile residual stress, there is a negative effect on the functional area components. They have a great impact on the spread of cracks in components. Compressive stress occurs because the distances between the atoms themselves are very small, so they tend to associate and act against cracks in the workpiece. The compressive stress should not reach high values, for example, 2 GPa when in the surface can give rise to crevices and cracks. The optimal value of the residual stress varies in the range of 500–700 MPa. Residual stresses in a given case should not exceed 1000 MP, and the most extreme value for steel is 2550 MPa. In this experiment, the residual stresses in some places were evaluated as 2 GPa. Such a large residual stress was caused by previous use of the rolling thorn, which created great forces that had a large impact on the results of the measurements of residual stresses in this experiment (Fig. 12).

The results appear to indicate that stresses within approximately 0.013 mm of the sample surface are dominated by machining, which resulted in a maximum stress direction essentially parallel to the cutting action. At greater depths, the stress distribution may be governed not so much by the machining as by stresses that may have been present due to forging or heat treatment.

6. Conclusion

Distributions of residual stresses on the surfaces and along the depth of the machining steel samples have been presented. The stress distribution for the sample with the cylinder sample is characterised by compressive stresses on the surface and by tensile stresses in the subsurface. Residual stress distributions for samples with a circular surface are more complicated.

Conclusions about reversing of compressive residual stress on the surface of the sample to compressive and tensile stress in the depth made by analysis of equilibrium equations have been confirmed experimentally.

This work is related to the project with the University of Zilina, 2009/2.2/04-SORO OPVaV number (26220220101), and named “Intelligent system for non-destructive evaluation technologies for functional properties of components of X-ray diffractometry”. The main objective is to transform the new non-destructive technologies for knowledge transfer to industry practice in the evaluation of functional properties of the surface and subsurface layers of non-destructive techniques.

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INTELLIGENT MANUFACTURING SYSTEMS IN CONCEPT OF DIGITAL FACTORY

This paper deals with selected areas of concept of Zilina Intelligent Manufacturing System (ZIMS), which is developed by the Faculty of Mechanical Engineering in collaboration with CEIT and other faculties of the University of Zilina. Main research areas realized in the framework of ZIMS cover the basic processes in the entire product lifecycle from beginning to end (PLM - Product Lifecycle Management). In this paper two of these areas will be described - manufacturing system design using progressive digital technologies and utilization of automation and robotics in intelligent manufacturing systems.

Keywords: *Intelligent Manufacturing Systems, Zilina Intelligent Manufacturing System, robotics, simulation, virtual 3D models, optimization of production systems.*

1. Introduction

Nowadays companies must be sufficiently flexible with respect to increasing diversity and changes in customer requirements and needs, so that they can stay competitive in the current dynamic and turbulent environment. The time becomes a key factor, what is reflected in the need for constant shortening of product innovation cycles and consequently in the need for shortening of processes and systems innovation cycles [1]. Intelligent Manufacturing Systems represent the actual answer to the solution of the above mentioned problems.

Intelligent Manufacturing Systems are socio-economic systems with the ability to autonomously identify system changes and impulses from the environment, their causes and to use the obtained knowledge for self-learning, adapting and responding to all changes of the surrounding environment in a way similar to human response.

The implementation and operation of intelligent manufacturing systems requires highly qualified specialists able to design and to apply new methods and technologies based on artificial intelligence and utilization of progressive digital technologies, able to increase the quality, flexibility and efficiency of designed manufacturing systems [2].

The concept of Zilina Intelligent Manufacturing System (ZIMS) developed by the University of Zilina in collaboration with CEIT solves several research areas:

- Intelligent Manufacturing Systems
- Digital Factory Technologies
- Design and simulation of manufacturing processes and systems
- Virtual and augmented reality technology
- Virtual design and testing of products
- Bionics and bionics principles exploitation
- Reverse engineering and Rapid Prototyping
- Holonic production control
- Intelligent transportation and handling systems
- Artificial Intelligence
- Automation and Robotics

2. Methodology of interactive manufacturing systems design

At the University of Zilina a new approach to manufacturing systems' design was developed within the framework of the ZIMS and the concept of digital factory. This new approach is based on using of progressive technologies like reverse engineering, 3D modeling, interactive design and augmented reality.

The manufacturing system design process is carried out in the following phases (Fig. 1):

1. Preparation and analysis of input data:

The main source of information for manufacturing system design is the database of data from a design and technological preparation of production. The data for a design of production layout shall include the information on:

- products which are going to be produced in the production system (types of products, bills of material, part design parameters, production volumes planned, etc.)
- their production processes (manufacturing and assembly processes, technologies, time standards, etc.)

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- resources to be used for their production (machinery, equipment, tools, personnel, transportation and handling equipment etc.).

Key outputs from the input data analysis have to provide an overview of the planned material flow in the production system (material flow analysis) and total need of resources required for implementation of the planned production (production system capacity dimensioning). These data sets form the basis for a proper layout design (optimal layout of machines with respect to material flow) and time plan (balancing the production performance of individual workstations) of the future production system.

2. 3D objects preparation:

Design and visualization of the production system in a digital environment requires the preparation of 3D models for all components which the production system consists of (production machines and equipment, transport and handling equipment, handling units, storage facilities, auxiliary equipment, etc.). The methodology uses three basic approaches to obtain 3D objects:

- Using the existing model libraries of available software solutions
- Acquisition of new 3D models by using reverse engineering methods – 3D laser scanning (see chapter 3)
- Creation of new models using CAD software (AutoCAD, Microstation, CATIA, etc.)

3. Manufacturing system modeling:

The phase of modeling production system (see Chapter 4), includes the design of initial layout which represents the ideal layout of workstations in the production system with regard to the transport relations between workstations and design of a real layout that takes into account all the real constraints in the production system, resulting from respecting the building construction solution, existing engineering networks, links to the logistic chain of the company and service processes.

4. Manufacturing system optimization and visualization:

The interactive design approach is used to optimize a layout configuration (see Chapter 5) which allows monitoring and evaluating of the implemented changes in the production layout immediately after their realization. For this serves a set of analytical tools to help the projection team in determining and evaluating changes. For the interactive visualization and designing of the production system its own solution represented by a planning projection table is used. This table is complemented by a 3D visualization using augmented reality technologies.

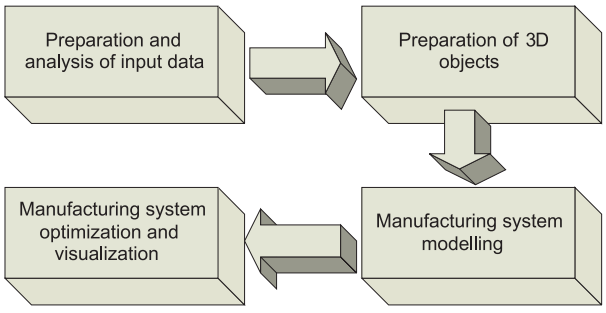


Fig. 1 Methodology of interactive manufacturing system design

3. Virtual 3D models preparation by using reverse engineering methods

In the process of reverse engineering a real object is transformed by the digitization into the computer model. In the case of a manufacturing systems design, 3D digitizing is used for creating models of the production system components (DMU – Digital Mock Up), as well as for digitization of an entire production area (FMU – Mock Up Factory). Digitization technology is based on the use of 3D scanners [3]. Obtained data from the scanner are further adjusted by software and the result of these changes is a computer model of the object.

The methodology for creating 3D models of machines and equipment by 3D scanning is divided into four successive phases:

1. Preparatory phase of 3D laser scanning process consists of:
   - selection of real object needed for solution of the problem
   - collection of data about a scanned object (object photo-documentation, drawings documentation of the object, technical documentation)
   - Scanning plan preparation (preliminary positions of the scanner at the scanning process and positioning of reference points needed for the scanning process)

2. 3D laser scanning phase consists of:
   - proper deployment of reference points and suitable location for the scanner
   - connection of the scanner with the software equipment and setup of parameters
   - launch of 3D laser scanning

3. Phase of editing scanned data:
   - import of 2D panoramic photos
   - marking references in 2D panoramic photos
   - creation of 3D point cloud model
   - modification of the model and filtering

4. Phase of editing and modeling scans in CAD system:
   - import data into the CAD program
   - creation and editing of polygonal network model
   - redrawing of polygonal network into the 3D model

4. Production system modeling

In the first phase of modeling the production system an ideal layout of workplaces is designed. In the ideal layout the real space requirements of workplaces, input – output points of the production system or other constraints (e.g. space restrictions) are not taken into account. To create the ideal layout a heuristic algorithm is used. During the optimization process this algorithm minimizes the total transport capacity calculated as the sum of the Euclidean distance and intensity of transport between all workplaces.

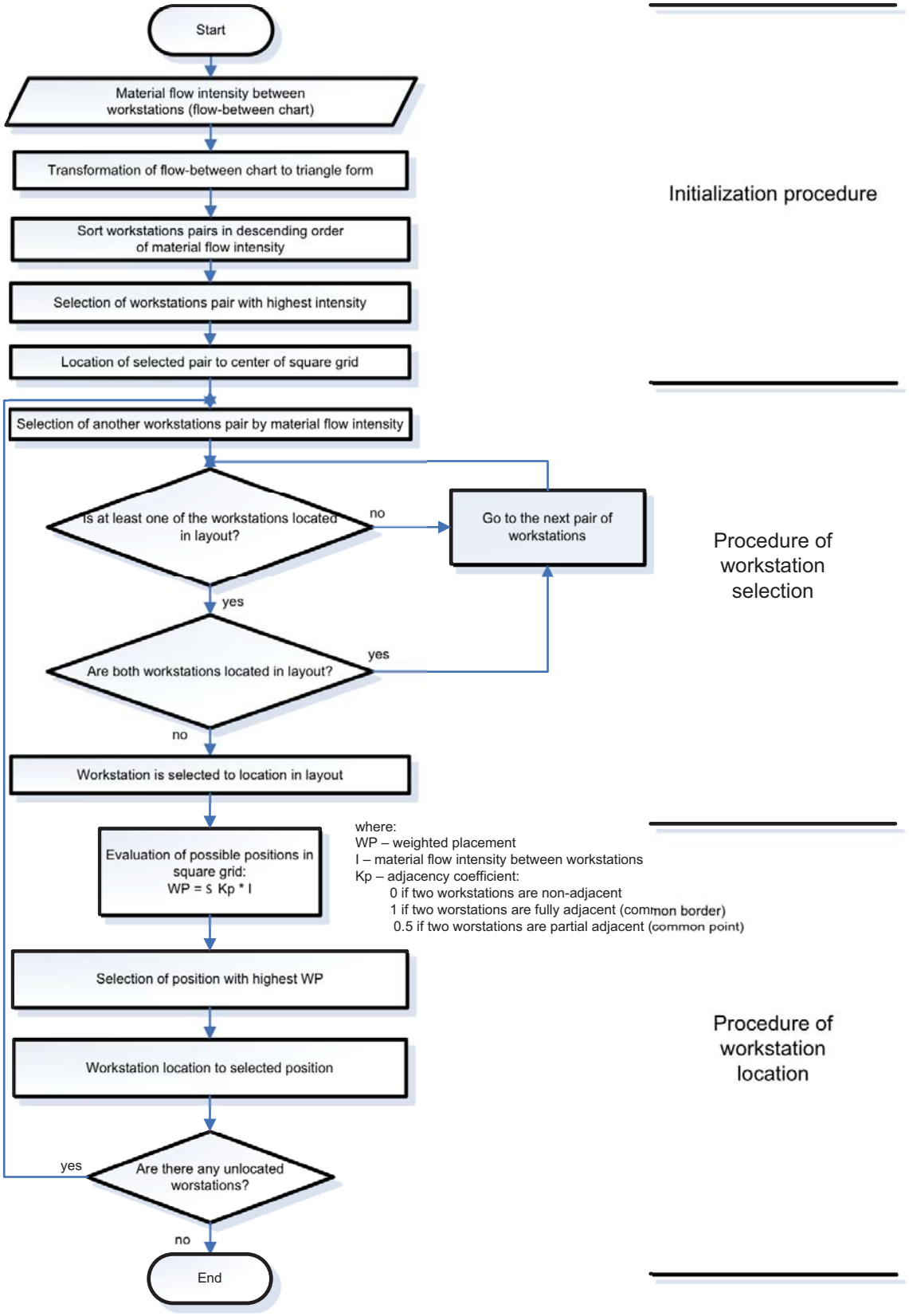


Fig. 2 The algorithm of the ideal layout design

The algorithm is divided into 3 phases (Fig. 2):

1. Process initialization: Includes processing the input data in the form of a checkerboard table of transport relations, sorting of workplaces pairs (sort from the highest to the lowest transport intensity) and the selection and placement of pairs with the highest intensity into the layout.
2. Workplace selection procedure: Serves for selection of a workplace that will be in the next step assigned to the workplace already placed into the layout.
3. Workstation placement procedure: It serves for a suitable selection of a position of a chosen workplace in the layout considering earlier placed workplaces and relevant transport relations.

In the second phase of modeling the ideal layout is transformed into real (Figs. 3a and 3b), and respects:

- real shape and dimensions of the machine / workplace and workplaces operating areas (represented by 2D / 3D model),
- basic material flow in the production hall and its connection to the material flow between different halls (input, output, stores location),
- transport and material handling needs (handling units in production, transport network and streets dimensioning, cranes paths, etc.),
- placement of building elements (columns, walls) and permanent installations (electricity, industrial gas stations, etc.).

5. Optimization and visualization of production system

For the purpose of the layout optimization the approach of interactive team layout design is used which uses as a technical resource its own concept of the projection planning table [4] which has been designed in two technical variants:

1. Projection planning table based on the principle of bottom projection of the image on the semi-transparent surface and interactive control of the objects on the screen using the eBeam system (Fig. 4a).
2. Projection planning table using touch screen (Fig. 4b).

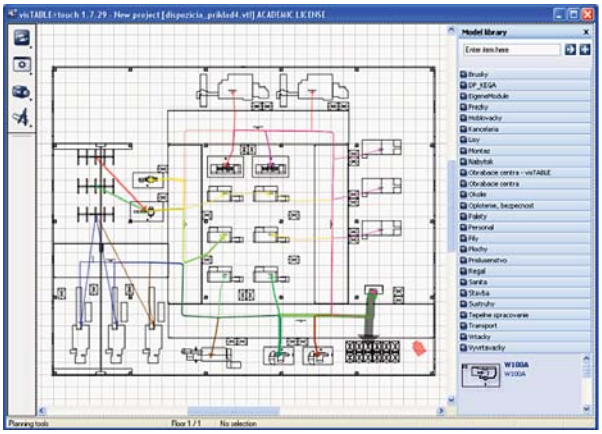
Decisions about changes and adjustment of the layout are realized by a projection team using basic analytical tools which enable continuous evaluation of the consequences of the decisions made by the team on parameters of the production system:

- Sankey diagram
- I – D diagram (Intensity – Distance diagram)
- calculation of the overall transport performance
- triangular method
- analysis of safety equipment service areas
- analysis of safety of operating areas and equipment

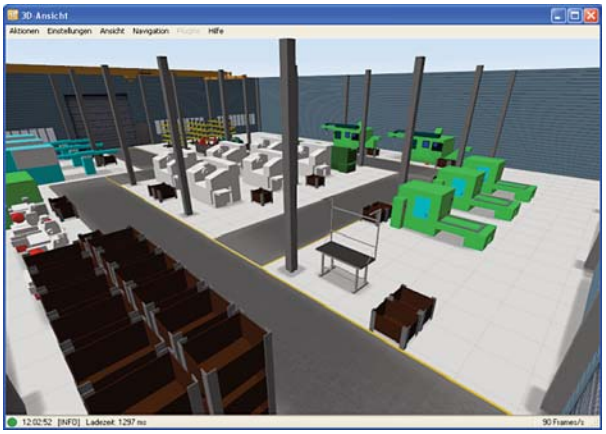
Visualization of the projected production system in the 2D view on the area of the projection planning table is accompanied by a 3D visualization using augmented reality technologies [5, 6] which add selected virtual elements / objects into the real environment. Technology of the projection planning table is supplemented by AR virtual 3D models of various elements of the production system and the models of workplaces in the 2D layout serve as markers (signs which identify the correct position and orientation of each 3D object) (Fig. 5a). In the final phase AR technology is also used for visualization of the production system in the real environment of the production hall (Fig. 5b).

6. Application of industrial robots within the factories

Industrial robots have a distinct set of capabilities that allow them to perform in industrial environments while also distinguishing them from other specialized robots. A network of complex mechanical gestures, triggered by sensors and computer software enables industrial robots to perform a wide range of tasks: spot and arc welding, picking up and clamping activities, clamping for machining, and the transfer and manipulation of parts are all common applications for industrial robots. As European economies start to recover from the recession, manufacturing companies are seeking ways to ramp up production in a flexible way. One option is to use industrial robots which are now more cost-effective both



a) 2D layout



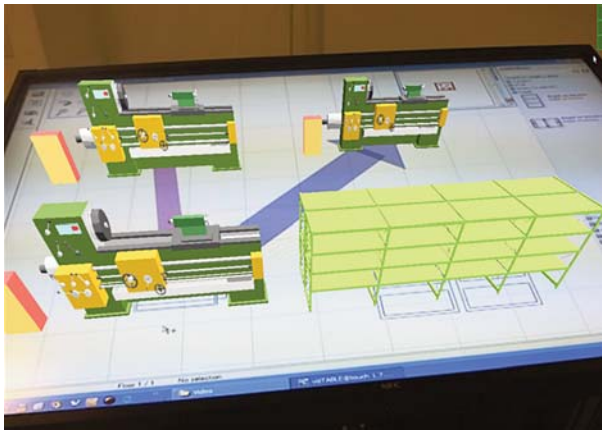
b) 3D layout

Fig. 3 Real layout of manufacturing system

a) Planning table with down projection

b) Planning table with multitouch display

Fig. 4 Variants of the projection planning table



a) Planning table

b) Real production hall

Fig. 5 Layout visualization using augmented reality

to purchase and to implement, thanks largely to programming software that is more engineer-friendly.

In field of industrial robots several trends are visible as, for example:

- application of force/torque sensors,
- modular and reconfigurable structure of robots for specific applications,
- increasing of ratio between robot's weight and payload,
- robots are able to carry heavy objects (car chassis),
- special robots for service operations,
- automated assembly and control operations (KUKA Sensibot),
- specialization and differentiation of robots,
- higher resistance within environment with specific conditions (water, dust, etc.),
- grasping of randomly placed objects by machine vision systems,
- cooperation of multi-arm systems,
- system integration (robot with camera system, robot mounted on mobile platform),
- application of robots for technological operations as machining, etc.

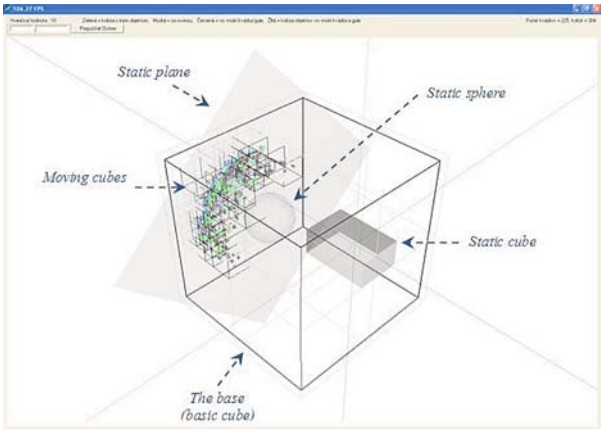
For industrial automation the *four main types of robot* are Cartesian (gantry) robots, SCARA types, anthropomorphic robots that typically have five or six axes, and Delta (parallel kinematic) types. SCARA still leads in the electronics sector, but the speed of the standard arm has improved to rival that of SCARA now. A Cartesian robot more closely matches the motion of a human arm where manual tasks need to be automated. The capabilities of industrial robots can be increased by peripheral devices as feeders, belt conveyors, camera systems, systems for automatic tool changing, index tables etc. [7]. Nowadays the robots have improved properties as higher speed, precision, rigidity, payload and efficiency.

With robots now being simpler to integrate, there is increasing competition among manufacturers to add functionality so they can offer increasingly sophisticated systems. An example is the integration of a vision system into the control system of each

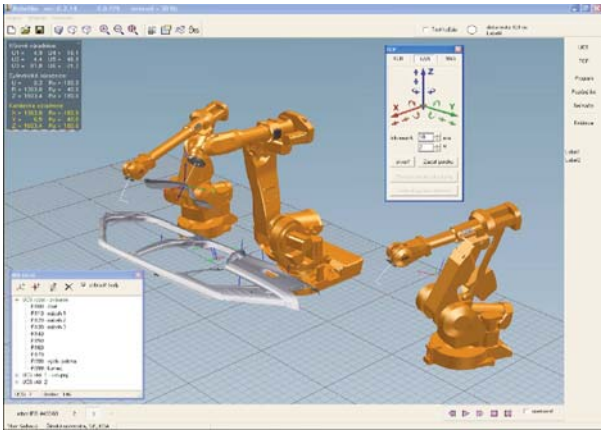
a) Application of delta robot for assembling of electronic device

b) Control system include the Vision Tool and so-called teach-pendant

Fig. 6 Application of delta robot FANUC M1-iA with integrated vision system



a) Principle of anti-collision system (Department of Automation and Production Systems) [9]



b) Simulation software for collision detection of robotized workplaces within 3D space

Fig. 7 Designed simulation software for collision detection within 3D space

FANUC robots. The designers of robotic cells are pushed to integrate more processes and solve them by only one robot. It means that the robot should have more end-effectors. The best solution is the system of automatic tool changing controlled by pneumatic or electric fixation units (for example made by co. SCHUNK, ATI Automation, etc.).

The Delta robot FANUC M-1iA (Fig. 6a) is a novel lightweight robot for electronics, measuring device and other precision industries [8]. This robot provides a higher productivity for assembly and picking applications, a lightweight mechanism with better cycle times and a unique 6-axes parallel link arm mechanism that allows automate difficult tasks such as complex insertion, gluing and more. The compact and intelligent controller integrated iRVision (Fig. 6b) which can locate and check work pieces for flexible parts feeding applications and other intelligent tasks. This vision system allows four possible processes: normal 2D Vision, depalletizing 2.5 D Vision (includes a calculation of Z-height and some special depalletizing functions), 2D Multiview Vision and Visual Line Tracking 2D Vision. The task of keyboard assembling the numbers of a sloping keyboard is an example of real application.

6.1. Collision detection, prediction and avoiding

Because of still quite a high price of robotic devices, the recent industrial robots are able to modify the realized trajectory and this way to avoid collision with any object within the workspace (Fig. 7a). This avoiding process is done during its movement thanks to application of appropriate sensors and control system. Their deployment is particularly suitable for the tasks which require immediate correction of the track in response to a sudden, not expected changing of the real working environment.

Under the term "anti-collision control system" we understand any software, hardware, seeking to avoid collisions on real machines. In general these systems can operate in two modes [9]:

Off-line mode – in this case we apply the specialized simulation software (for example: simulation software shown in Fig. 7b). There is created or loaded a 3D virtual model of handling device, end-effector, manipulated objects, peripheral devices and any other components placed in the real robot workspace. The control system must continuously detect the collisions during the run of simulation. If there arise any collisions the simulation software shows them. Then the operator can modify the original program and repeat the loop until a collision-free trajectory is obtained.

On-line mode – is an active approach. Directly during the robot movement the control system tries to avoid a collision with any objects in real time. In this case it is necessary to have enough numbers and appropriate types of sensors. The best way is to combine several different types of sensors as, for example, tactile sensors, ultrasound or infrared sensors and cameras. On-line systems don't need the model of environment and they can work with or without the model.

7. Mobile robotics and its integration within the factories

A separate area in robotics called mobile robotics was established during the last period. This area is focused on the development of suitable mobile robotic devices, methods, special algorithms and finding their appropriate application in real world. Generally, the mobile robot (MR) is a complicated mechatronic cognitive system. Selection of appropriate navigation method in the workspace is one of the fundamental problems which is solved by the design process of all mobile robots [10].

The reasons for mobile robots development and their application are, for example, safety level of processes, exploration of unknown terrain, inaccessibility and unavailability, reliability. Increasing the safety level of processes, reliability and continuous growing of production efficiency are also the very important reasons for their application in industry. They can be applied as a main transport system within the factory, they can co-operate with standard industrial robots in robotic cells and they can be used also as cleaning or other kind of service devices. According to their application they have different level of autonomous behavior. In the highest level we can speak about autonomous mobile robots (AMRs). Each AMR is composed of a mechanical subsystem (undercarriage), a sensoric subsystem (internal and external sensors), a control subsystem (control of all subsystems of AMR), a communication subsystem (data transfer and communication with operator). With respect to the possibility to execute and record the realized trajectory, it is necessary to create a suitable mathematical description of the mobile robot, movement method and model of environment.

Examples of mobile robots applied in the industrial environment are represented by a mobile robot OmniMove with a mounded robotic arm made by co. KUKA, robotic system AutoStore (made by co. Swisslog) for manipulation within the warehouse, mobile robot equipped with omnidirectional wheels Vetex, etc.

7.1. Control system suitable for mobile robots in industry

The control system together with control algorithms are the basic parts of all mobile robots. The hardware of control system must be able to process any input information from the sensoric, communication and navigation subsystem in qualitative and quantitative meaning too. The main control program or some subroutines must handle with raw data – their preprocessing, analyzing and finding of adequate reaction of actuators (actuated wheels and actuated technological tools). The mobile robot autonomy significantly affects the final configuration of the designed control system. Roughly speaking, the mobile robot control system can be based on:

- personal computer,
- industrial computer (IPC – Industrial PC) or
- microcontroller.

The control system based on a standard personal computer is not very suitable for mobile robots applied in a factory [10]. This kind of applications requires the control system with some special characteristics (resistance to different temperature, humidity, dust and vibrations, electric noise, etc.). All these requirements and some others can be met using the control system based on IPC or based on the microcontroller (for example Atmel AT MEGA). For exploring the surrounding environment the system of proximity sensors is the most common. Tactile sensors are used only as a backup safety element to activate the emergency stop. Only the combination of different processing methods and the application of various types of sensors can increase the quality of output information.

7.2. Navigation of mobile robots

By robot navigation within a space with obstacles, the goal is to find a collision-free path of a robot from the starting to the target (goal) position. Navigation strategies can be classified into several groups from the viewpoint of a method of sensors' data processing, representation and type of environment and level of path planning. At the bottom is the pure reactive control oriented only on obstacles avoidance when the nearest space surrounding

the robot is scanned. Next level is local navigation which solves also localization. When the robot knows the environment and has its own map, we can speak about a global navigation (Fig. 8). In this case the robot can find the path between two or more points located somewhere in the map. There are many approaches depending on types of obstacles, dimensionality of the space and restrictions for the robot movements. Among the most frequently used are roadmap methods (visibility graphs, Voronoi diagrams, RRT, case-based reasoning, A* algorithm, etc.) and methods based on a cell decomposition. A common feature of all these methods is the generating of trajectories composed of line segments.

Industrial environment can be classified as difficult due to a wide range of disturbing elements – dust, electric noise, etc. The connection with the human operator can be lost. In these cases the robot should have its own map and find the right way by itself.

8. Unconventional mechanisms for robots and machine tools

Even though the high-speed integrated spindles and linear motors make it possible to reach the highest cutting velocities and feed rates for HSC (High Speed Cutting) applications, the practice all utilizations of these parameters is limited by mechanical problems of machines. With respect to these limits of machine tools and robots with conventional serial kinematics, it appears better to use for HSC or high speed manipulation just the machines with parallel or hybrid kinematic structure. These mechanisms are characterized above all by higher stiffness and higher dynamic parameters (thanks to the reduced moving mass). Few years ago the research group at the University of Zilina started to deal with this area. During this period the research group designed some construction concepts of mechanisms based on a PKS (parallel kinematic structure – Figs. 9a and 9b) and different kinds of simulation software (Figs. 10a and 10b) for these types of mechanism [11].

One of the well-known fully parallel manipulator in general is called Hexapod. Hexapod known also as Stewart platform is a multi-axis machine capable of full six degrees of freedom (DOFs) motion plus spindle rotation at the tool head. Among these advantages, higher structural rigidity along with a large payload capability and high speed motions it will be capable for high speed and high accuracy machining or manipulation. The designed machine tool can work in a fully automated regime.

9. Multi-software platform for multibody systems synthesis

The problem during the production machine synthesis solving is to find the suitable construction and the corresponding suitable parameters of the mechanism (i.e. materials, dimensions of body shapes and cross-sections, algorithms for the movement controlling, etc.). The parameters must fulfill some functional and technological requirements. These requirements may relate only to the position of the mechanism elements. In this case we call it the geometrical synthesis. In the other cases we must deal with the velocity and acceleration requirements. The methods solving these problems are within the scope of kinematics synthesis.

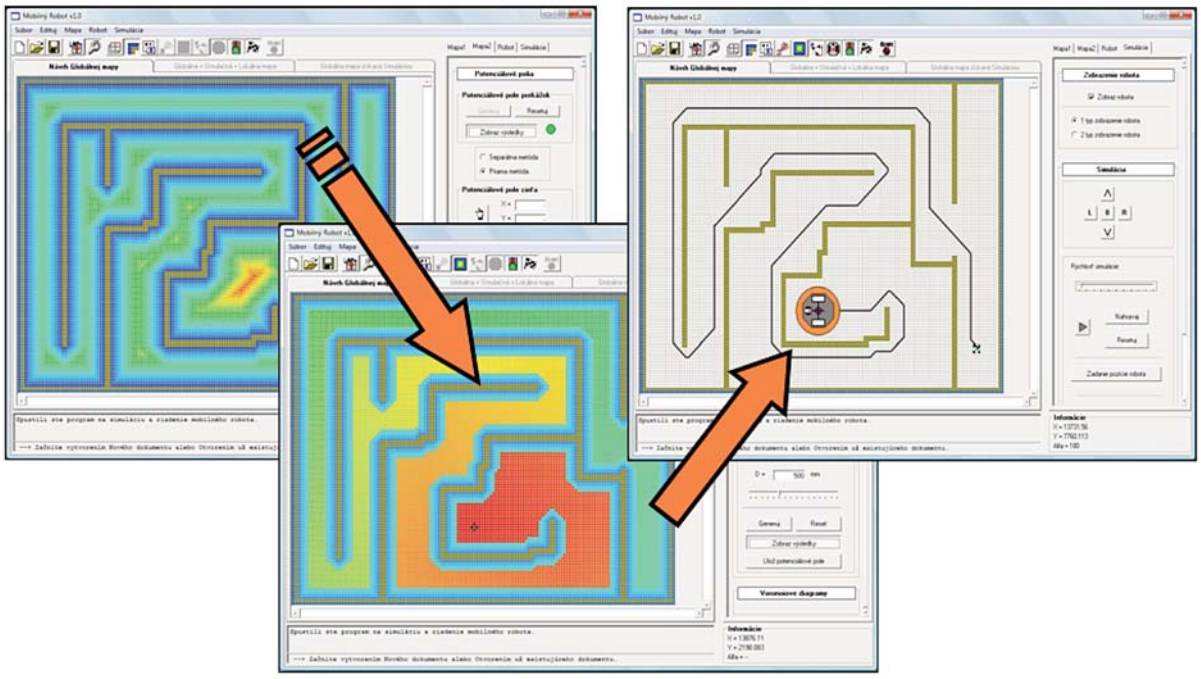
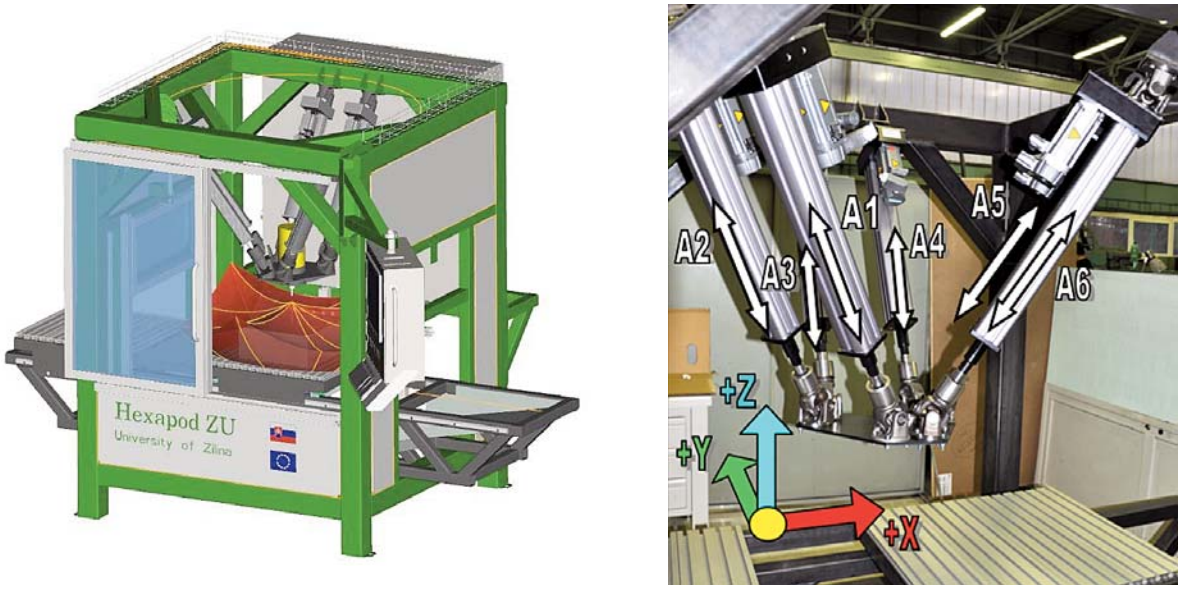


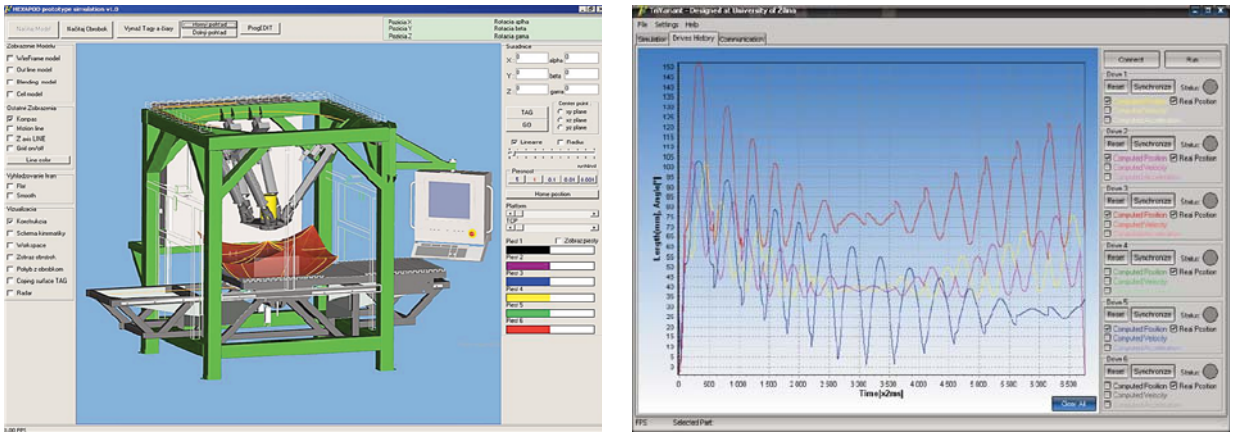
Fig. 8 The method of global navigation (simulation SW Mobile Robot designed at the University of Zilina).



a) The design of machine based on parallel kinematic structure used for high-speed machining or manipulation

b) The actuators, moving axis (A1 to A6) and Co-ordinate system (X, Y, Z) of hexapod mechanism

Fig. 9 Mechanism with high-speed parallel kinematic structure designed at the University of Zilina [11]



a) Main screen of simulation software designed for control of mechanism with PKS

b) The output ramp of acting values obtained from mathematical model of mechanism with PKS

Fig. 10 Simulation software designed for control of mechanism with PKS (University of Zilina)

The dynamical requirements (i.e. balancing, reaction forces reduction, motion irregularity reduction, required motion properties, etc.) are solved by dynamic synthesis [12]. The area of mechanisms synthesis was primarily defined as a relationship between the input and the output (1:1). However, this area is more complicated for the production of machine mechanisms and it covers the whole mechanics and the control area. The solutions can be characterized as multiple inputs – outputs (M:N). Therefore, it is needed to extend the traditional mechanic techniques by the techniques focused on the general design theory [13].

9.1. Files preparation for the kinematics synthesis of the solid system virtual prototype

The solution objective is to design and implement the algorithm of the evaluation of the operating gear parameters from the mechanical properties view [14]. The approach is based on the solution of the fixed solid system (FSS) virtual prototypes by means of the computer simulation using the kinematics and optimization [15]. There is tendency to eliminate the time-consuming analyses so that the program interconnection of the ADAMS and MATLAB

systems will be designed and implemented. For the inverse kinematics problem solving the virtual prototype (VP) manipulator robot was chosen.

9.2. Virtual prototype preparation in the ADAMS/View environment

The particular elements of the manipulator robot were designed in the ADAMS/View environment. Kinematic scheme of the manipulating equipment has four movement degrees of freedom (Fig. 11). Quantity "*v*" is speed of motion and quantity "*ω*" is speed of angle.

During the creation of virtual prototypes the models in the ADAMS environment are saved in various file formats according to their purposes. The manipulator robot was created in the binary file format (model.bin). This database contains the information about the working space configuration, all properties of one or more models and the analyses and the simulations results too. The binary format allows the quick writing and loading of the data and it can be transferred between computers with the different operating systems, but it does not allow their reading and editing.

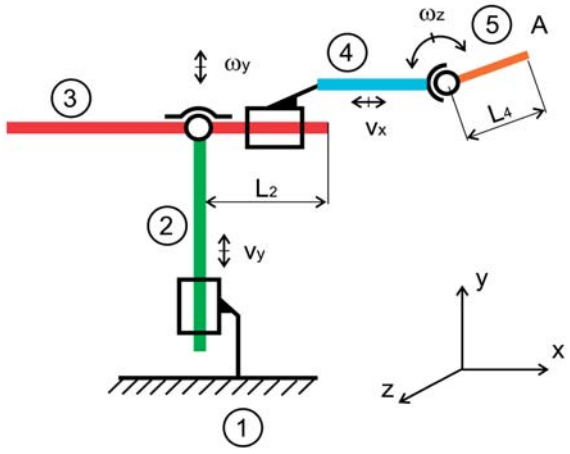


Fig. 11 Simulation model of industrial robot with serial kinematics

9.3. Inverted kinematics problem

The inverted kinematics problem solves the suitable input kinematics parameters multibody of the systems (MBS) for obtaining the described movement [16]. Assuming the stepping motor realistic usage with a step of 5 degrees, all the working positions of the manipulator robot endpoint "A" are mapped (Fig. 12). The point "A" has a screw as the prescribed trajectory. From the obtained working position map the coordinates of those points were chosen which correspond with the prescribed trajectory in the best way and which meet the condition of the continuous movement MBS at the same time.

The input kinematics parameters ensuring the given element prescribed movement MBS are the solution results. Their number depends on the solution step size. Parameter "*r*" is the minimal distance of the solved point from trajectory. The element lengths were changed from the original $L_2 = 500$ mm and $L_5 = 200$ mm to the optimal ones by the coordinate parametrizing of the markers. The optimal values of the manipulator robot element lengths are: $L_2 = 515.92$ mm, $L_4 = 191.85$ mm (Fig. 11). The genetic algorithm method was used. The objective function value was a numerical zero. In order to obtain the continuous movement the optimal length values was used in the program *opt_uhl.m* (calculation scheme is shown in Fig. 13).

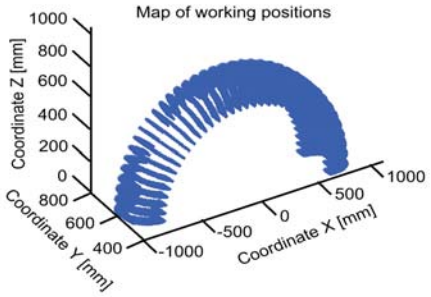


Fig. 12 Point "A" - map of working positions

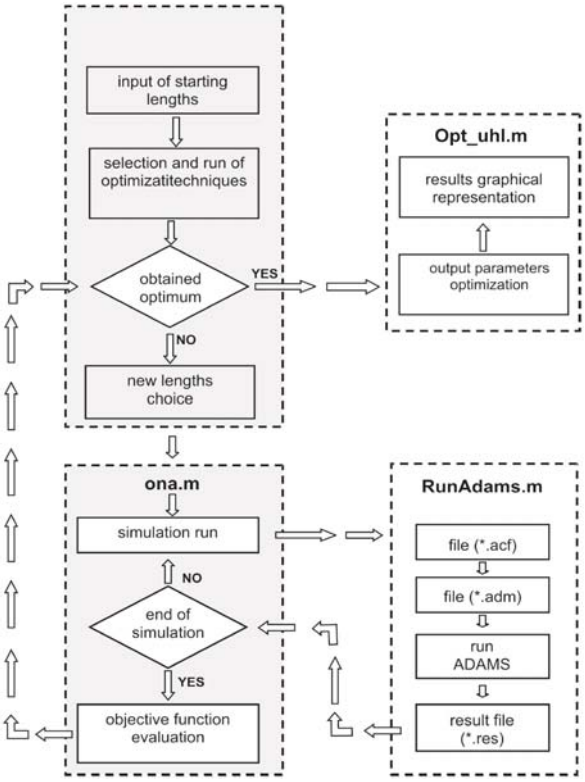


Fig. 13 Graphical representation of the inverted kinematics problem solution

10. Conclusions

The concept of Zilina Intelligent Manufacturing System (ZIMS) covers the basic processes in the entire product lifecycle from beginning to end – PLM (Product Lifecycle Management) as well as PDM (Product Data Management). An example is the design of manufacturing systems by using progressive digital technologies and utilization of automation and robotics in intelligent manufacturing systems and many others. By these progressive technologies the development and product costs can be reduced, product quality and performance improved, and time-to-market reduced too. A very useful tool is a concurrent product design, prototyping and manufacturing, as well as worker training. This approach can be achieved by effective data analysis, visualization, off-line and on-line simulation, advanced interaction and presence within the virtual environment, ergonomics analysis, and collaborative decision-making. The concept ZIMS described in this paper includes all mentioned above.

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Milan Vasko – Ardeshir Guran – Lenka Jakubovicova – Peter Kopas *

DETERMINATION THE CONTACT STRESS DEPENDING ON THE LOAD RATE OF THE NU220 ROLLER BEARING

The purpose of this paper is to present the impact magnitude of the load rate of the roller bearing at mutual slewing of roller bearing rings to the process of contact stresses in rolling element. The roller bearing satisfies prescribed basic static load capacity if it is loaded by the maximum specified load only in the radial direction according to the ISO / TS 16281. The basic static radial load capacity of the cylindrical roller bearing determines the maximum loading for which there is no plastic deformation in the raceways yet. However, the real roller bearings are not loaded only in the radial direction in practice. During operation there exists a mutual slewing of the roller bearing rings. This leads to a change in the conditions of contact and contact stresses. The analysis of the mutual influence of these two parameters was made using finite-element software ADINA.

Keywords: *Roller bearing, rating life, contact mechanics, Hertz contact stress, FEM, computational analysis, stress analysis, ADINA.*

1. Basic static load capacity of the cylindrical roller bearing

If the static loads are acting on the rolling elements and raceways of bearings, permanent deformations are rising and they will increase with loads enlarging. It is difficult to determine the degree of deformation arising in the test of bearings at specific conditions. It is therefore necessary to develop a different method for determination of suitability of the selected bearing. Based on the experience an international technical standard (Technical specification: Rolling bearing – Methods for calculating the modified reference rating life for universally loaded bearings) was established [1, 2].

The total permanent deformation of 0.0001 diameter size of rolling elements in the most loaded contact zone of rolling elements and the raceway in many cases of the mounting does not effect the subsequent impairment of bearings function [3, 4]. The deformation arises from an equivalent load which is equal to the calculated bearing load capacity.

Radial static load for different types of bearings is:
- 4600 MPa – for two-row self-aligning ball bearings,
- 4200 MPa – for all other ball bearings,
- 4000 MPa – for all cylindrical roller bearings (roller, needle, spherical, tapered) which correspond to computational contact stresses in the centre of the most loaded contact zone of rolling element with the raceway.

The static central load is:
- 4200 MPa – for axial ball bearings,
- 4000 MPa – for all axial cylindrical roller bearings (roller, needle, spherical, tapered).

Basic radial static load capacity C_{or} for the roller bearings is [1]

$$C_{or} = 44\left(1 - \frac{D_{we} \cdot \cos\alpha}{D_{pw}}\right) i Z L_{we} D_{we} \cdot \cos\alpha\,, \qquad (1)$$

D_{we} – roller diameter applicable in the calculation of load rating,
D_{pw} – pitch diameter of roller elements,
Z – number of rolling elements,
L_{we} – effective roller length.

The main focus of this article is to analyze roller bearings stresses by Finite Element Method [5]. The outer and inner ring of a cylindrical roller bearing will be slewed against each about the specified angle $\varphi = 0', 2', 4', 6', 8'$ (Fig. 1).

The safety coefficient f_s represents a degree of safety against too high plastic deformations at the rolling elements contact points [6]. If the bearings have easy and especially silent rotation, they require the high value of safety coefficient

$$f_s = \frac{C_{or}}{P_{or}}, \qquad (2)$$

f_s = 2.5 to 4 – for extremely high requirements,
f_s = 1.2 to 2.5 – for high requirements,
f_s = 0.8 to 1.2 – for normal requirements,
f_s = 0.5 to 0.8 – for low requirements.

P_{or} is the static equivalent radial force in Newtons. Especially high safety factor is required for structures that have higher requirements for safety (bearings used in wind turbines, lifts gearboxes, wheels for railway carriages, etc.) [7, 8]. The roller bearing load

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represents 0.25 to 1 times the basic static load capacity of the bearing, i.e. rate of load $f_F = 0.25$ to 1. The results for the load rate $f_F = 1$ will be referred in this article [9]. Finally, the results will be evaluated in cooperation of both applied parameters.

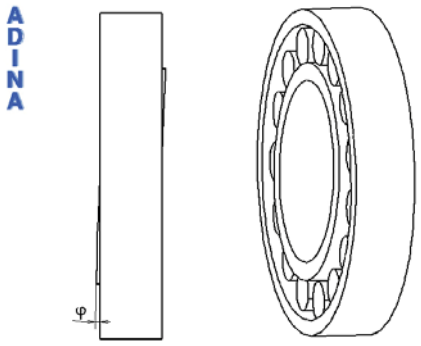

Fig. 1 Mutual slewing of the roller bearing rings together with rolling elements

2. Calculation of logarithmic roller profile and basic static radial load capacity

If a purely cylindrical roller is loaded, edge stresses will occur, which can substantially exceed the calculated Hertzian pressure. Therefore the rollers are usually profiled; they are produced to the roller bearing with logarithmic profile or "KB" profiles [2, 10].

In our case, the profile of a roller bearing element is logarithmic [11]. For rollers having a length $L_{we} \leq 2.5D_{we}$ a stepwise defined profile function $P(x_k)$ is

$$P(x_k) = 0.00035D_{we} \cdot \ln\left[\frac{1}{1-(2x_k/L_{we})}\right], \tag{3}$$

where x_k is x-coordinate from the center of roller. The analysis of the mutual influence of load rate and slewing of roller bearing rings was made for the NU220 single row cylindrical roller bearing.

By substituting the basic bearing dimensions into equation (1) the value of the basic radial load capacity $C_{or} = 300848$ N is obtained. FE calculations were made for the rate of load $f_F = 1$, therefore the applied loading radial force from equation (2) is $P_{or} = 300848$ N.

3. Preparation of a model for FE analysis

A quarter of the roller bearing model was built for the purposes of the analysis. FE software ADINA was used for FE analysis. In the model, the profile of the roller bearing element is logarithmic. Eight-node quadratic elements were used to create a finite element mesh for the FE model (Fig. 2). The mesh size was 2 mm in meshing of the model. The higher mesh density was used in the

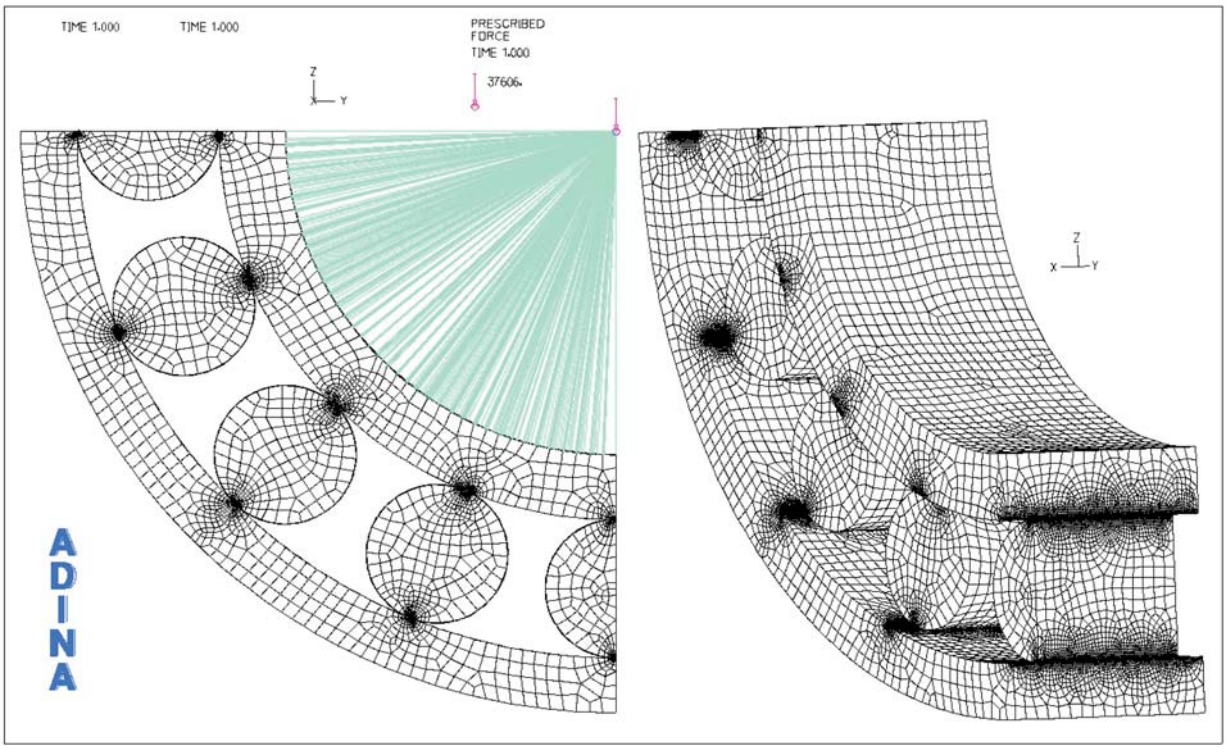

Fig. 2 FE model created by software ADINA

inner and outer rings contact point of rolling elements [12]. At least 6 elements on the contact ellipse width were used.

According to [13], the width of the contact ellipse is $b = 0.74 \cdot \cdot 10^{-3}$ m. The isotropic linear elastic material was used ($E = 2.11 \cdot \cdot 10^5$ MPa, $\mu = 0.3$) [14]. The shaft was replaced by constrains. The non-linear contact problem was solved by Full-Newton iteration method.

4. Stress-strain FE analysis

Stress state is evaluated in the most loaded element of the roller bearing (on the surface of contact area). *P*1, *P*2 and *P*3 stresses are evaluated at gradual slewing of the roller bearing rings, angle $\varphi = = 0'$ to $8'$ [15]. The step is $\Delta\varphi = 2'$.

The maximum value of *P*3 stress at the angle $\varphi = 0'$ is 3808 MPa and at the angle $\varphi = 8'$ it is 4220 MPa. The increase in the value of *P*3 stress is 10.82%. Table 1 shows a gradual increase in the value of *P*1, *P*2 and *P*3 stresses at gradual slewing of roller bearing rings. The load rate $f_F = 1$. The increase in the maximum value of stress is quadratic [16, 17].

The maximum contact stresses at the point of contact on the roller surface were evaluated. However, the maximum stress arises below the surface of the roller and its size is 4000 MPa. This is in accordance with the values prescribed by the norm.

Maximum contact stresses at the point of contact on the roller surface at gradual slewing of roller bearing rings, $f_F = 1$ Table 1

Angle φ	P1 stress [MPa] - [%]	P2 stress [MPa] - [%]	P3 stress [MPa] - [%]
0′	−2010 (0%)	−3040 (0%)	−3808 (+0%)
2′	−2024 (+0.69%)	−3080 (+1.32%)	−3840 (+0.84%)
4′	−2060 (+2.48%)	−3160 (+3.95%)	−3935 (+3.34%)
6′	−2100 (+4.47%)	−3270 (+7.56%)	−4100 (+7.67%)
8′	−2140 (+6.46%)	−3390 (+11.5%)	−4220 (+10.82%)

The stresses at slewing of roller bearing rings by the angle $\varphi = 0'$ and $\varphi = 8'$ are shown in Figs. 4 and 5.

The bearing is loaded with the maximum allowable static load. We can see the formation of edge stresses in Figs. 4 and 5. They are greater at slewing of roller bearing rings by the angle $\varphi = 8'$. In this case the permanent plastic deformations arise in the bearing. This is unwanted effect for the safe bearing run in practice.

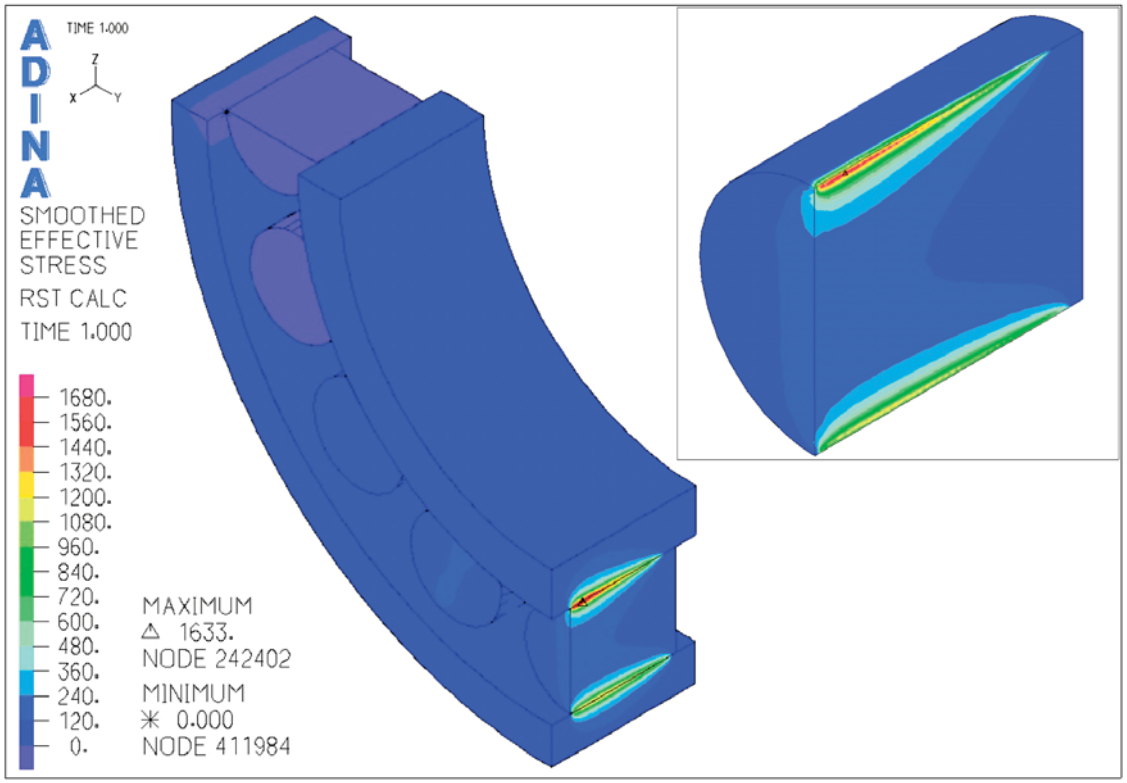

Fig. 3 Effective stress, load rate $f_F = 0.25$, angle $\varphi = 8'$

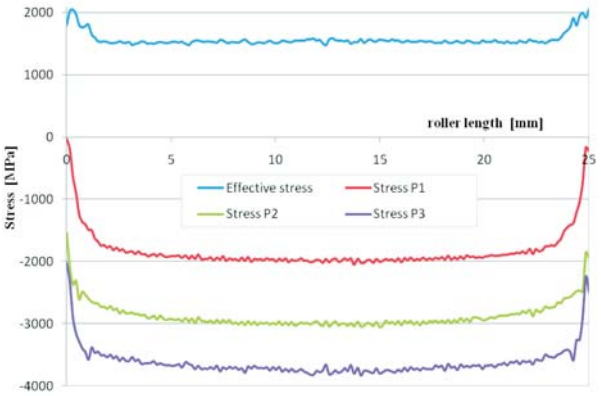

Fig. 4 Stresses at slewing of roller bearing rings by the angle $\varphi = 0', f_F = 1$

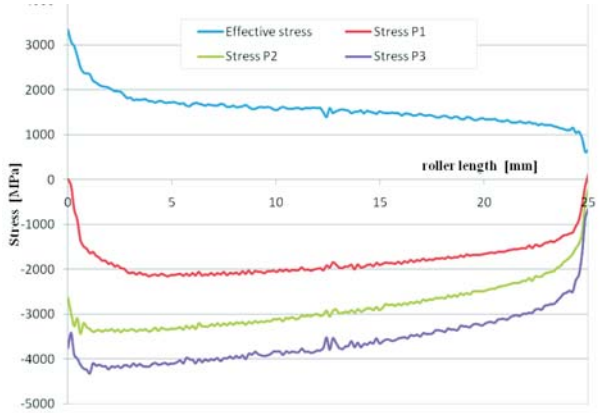

Fig. 5 Stresses at slewing of roller bearing rings by the angle $\varphi = 8', f_F = 1$

The *P*1, *P*2 and *P*3 stress at gradual slewing of roller bearing rings by the angle $\varphi = 0'$ to $8'$ are shown in Figs. 6 to 8.

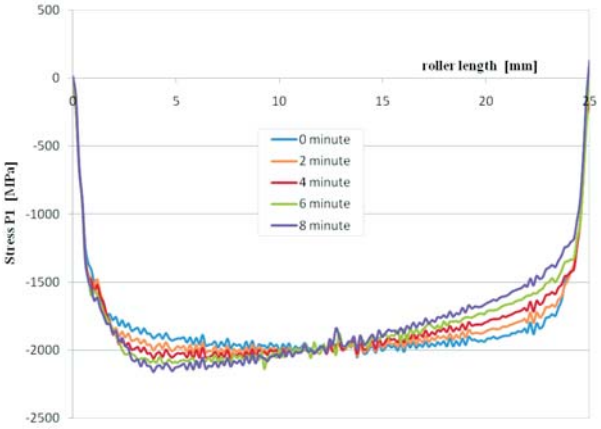

Fig. 6 P1 stress at gradual slewing of roller bearing rings by the angle $\varphi = 0'$ *to* $8', f_F = 1$

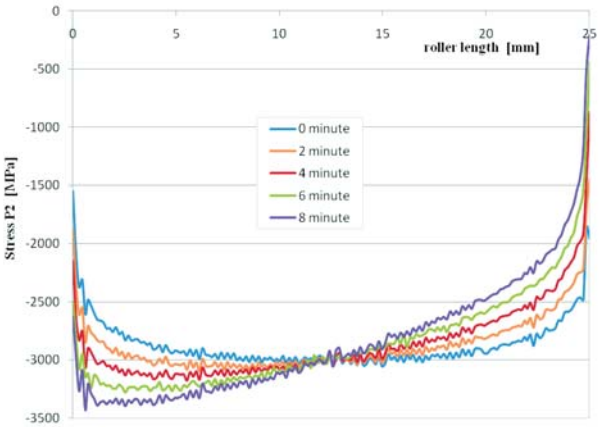

Fig. 7 P2 stress at gradual slewing of roller bearing rings by the angle $\varphi = 0'$ *to* $8', f_F = 1$

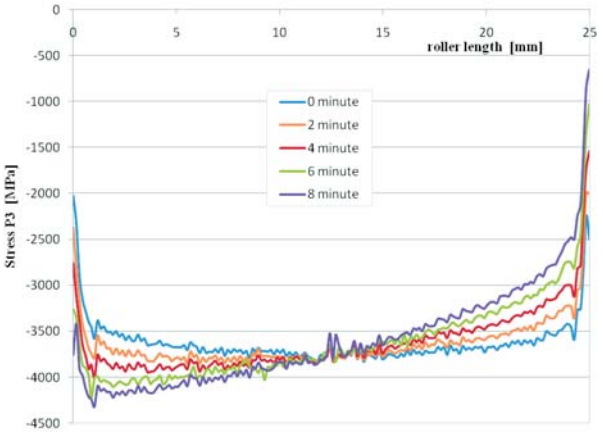

Fig. 8 P3 stress at gradual slewing of roller bearing rings by the angle $\varphi = 0'$ *to* $8', f_F = 1$

The maximum stresses on the roller will be analyzed in the next section. The dependence between the load rate and slewing of roller bearing rings is shown in Fig. 9. In this figure, the values of the slewing angle were approximated by the polynomial of 3rd degree and load rate values were approximated by the polynomial of 2nd degree.

In the equation (4) is the consequential polynomial which describes the entire surface of stresses. RMSE represents the root mean squared error or standard error. A value closer to zero indicates a fit that is more useful for prediction; for our resultant polynomial it takes the value of 30.42.

For the loaded roller bearing with similar dimensions the increase of contact stress *P*3 can be estimated by the polynomial function mentioned above.

Fig. 10 shows the Mohr's circles at gradual slewing of roller bearing rings by the angle $\varphi = 0'$ to $8'$ and the rate of load $f_F = 1$.

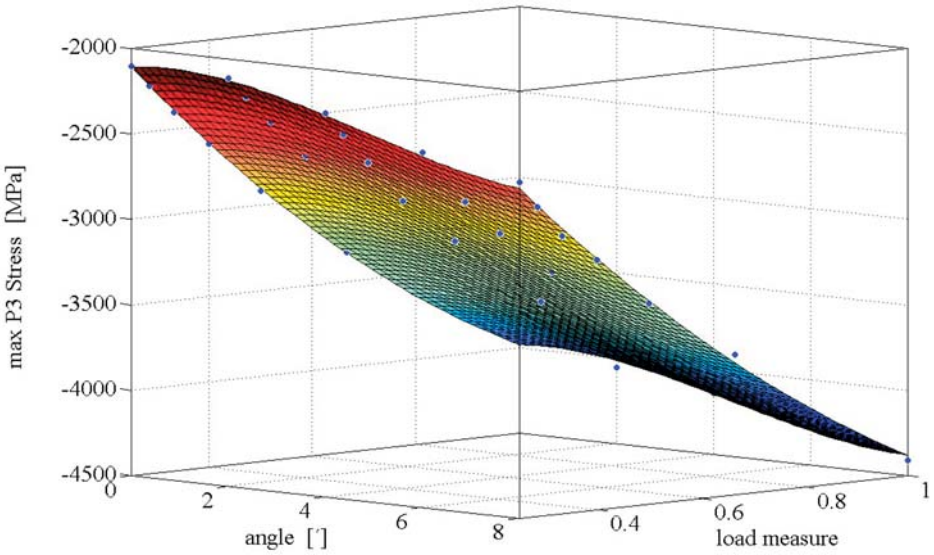

Fig. 9 P3 stress (contact stress) at gradual slewing of roller bearing rings by the angle φ = 0′ to 8′ and at gradual change of load rate f_F = 0.25 to 1

$$\left[-1146\ \ 31.95\ \ -4177\ \ -27.37\ \ 24.35\ \ 1341\ \ 1.851\ \ 3.11\ \ -30.43\right]\cdot\begin{bmatrix}1\\ \varphi\\ f_F\\ \varphi^2\\ \varphi f_F\\ f_F^2\\ \varphi^3\\ \varphi^2 f_F\\ \varphi f_F^2\end{bmatrix} = P3 \tag{4}$$

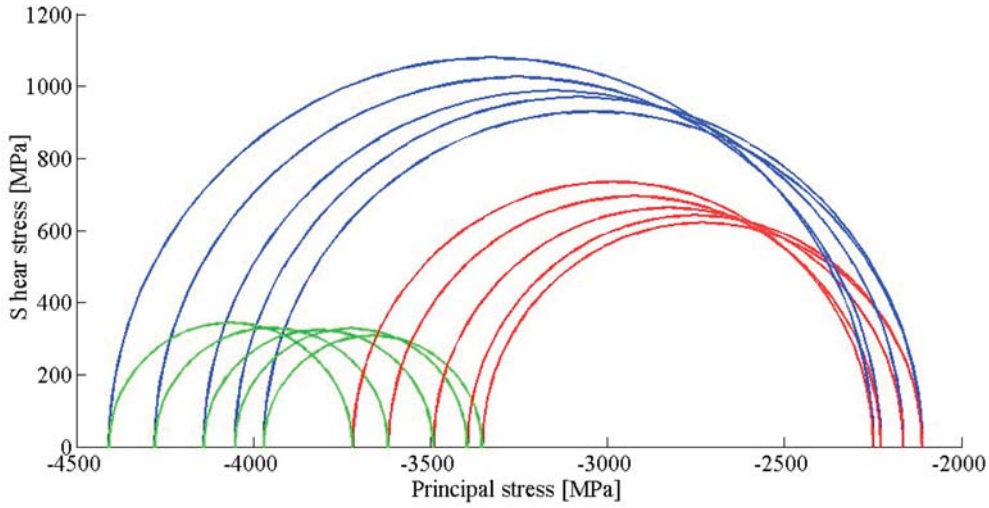

Fig. 10 Mohr's circles at gradual slewing of roller bearing rings by the angle φ = 0′ to 8′, the load rate f_F = 1

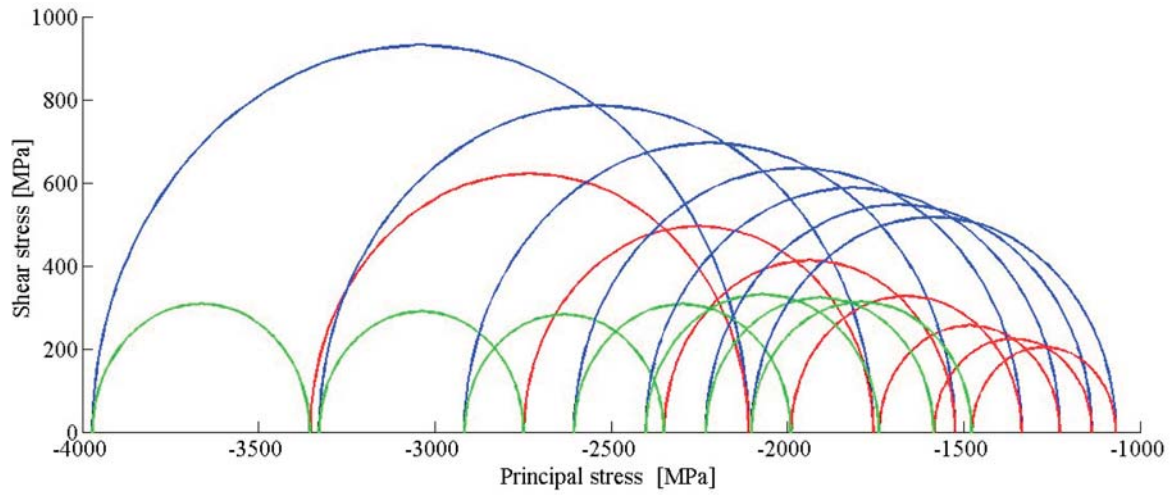

Fig. 11 Mohr's circles at gradual change of load rate f_F = 0.25 to 1, the slewing of roller bearing rings by the angle $\varphi = 0'$

Fig. 11 shows the Mohr's circles at gradual change of load rate f_F = 0.25 to 1 and the slewing of roller bearing rings by the angle $\varphi = 0'$.

5. Conclusion

The paper deals with the magnitude of the contact of roller bearing rings mutual slewing to the process of contact stresses in rolling elements. This mutual slewing of the bearing roller rings leads to a change in contact stresses and conditions of contact.

If the bearing is exposed to the high load which makes slewing of roller bearing rings during the operation, it is necessary to reduce the loading. The loading reduction will ensure that the load does not exceed the maximum allowed values specified by the norm and there will be no plastic deformations of rolling elements on the raceway.

The main goal of this article was to analyze roller bearings stresses by FEM. For the analysis of this problem we used the finite-element program ADINA. The set of calculations in the gradual change of load rate f_F were realized with the various values of the slewing of roller bearing rings.

Acknowledgements

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Robert Hudec – Ladislav Janousek – Miroslav Benco – Pavol Makys – Vladimir Wieser – Martina Zachariasova – Matej Pacha– Vladimir Vavrus – Martin Vestenicky *

STRUCTURAL HEALTH MONITORING OF HELICOPTER FUSELAGE

The helicopter design is a challenging experience for fatigue concern as it is subjected to a very wide range of low- and high-frequency load cycles per flight, much more than a fixed wing aircraft. Structural Health Monitoring (SHM) seems to have capability in helping to reduce the maintenance and operational costs, which are about 25 percent of the direct operating cost of the helicopter, thus playing an important role especially in the case of the ageing helicopters. In fact, the damage tolerant design approach makes the fatigue resistance evaluation not only a safety issue but also a maintenance related concern. The work presented in this paper is a part of an international research project HECTOR (HElicopter fuselage Crack moniToring and prognosis through On-board sensoR network), founded by the European Defense Agency (EDA) and supported by 10 EDA Member States: Cyprus, France, Germany, Greece, Hungary, Italy, Poland, Slovakia, Slovenia and Spain.

Keywords: *HECTOR, Structural Health Monitoring, smart sensors, helicopter.*

1. Introduction: The HECTOR project overview

The project consortium was coordinated by Politecnico di Milano and it was comprised of universities: Politecnico di Milano, University of Zilina, AGH University of Science and Technology, non-governmental laboratories: Laboratory of Technology & Strength of Materials – University of Patras, a research entity: Consorzio Milano Ricerche, as well as from industrial partners: AgustaWestland, Vitrociset and a small-medium enterprise: Stiftelsen SINTEF. Thus, five European countries participated in the project realisation: Greece, Italy, Norway, Poland, Slovakia.

The Faculty of Electrical Engineering, University of Zilina had an important role in the project. It was included in five of six work packages (WP), while leading one of the most important WP4: Study and development of real-time SHM techniques for helicopter fuselage. Researchers from five departments of the faculty participated on R&D activities related to the project.

The aim of HECTOR was to increase the systems availability by directly monitoring the damage while it is propagating inside the structure. The concept is based on the System Health Monitoring (SHM) concept. In this way it would be possible to get real time knowledge about the damage situation, thus setting a Condition Based Maintenance (CBM) [1].

The helicopter tail structure is presented herein as a good candidate for the application and testing of the SHM system [2, 3]. The main reason is the criticality of the region, where the torque generated by the tail rotor to balance the rotation induced by the main rotor is undergone. In particular, the attention was focused over some simplified reinforced panels, well suited to indicate the general behaviour of the entire structure and particularly adapt for the safe and early application on board of the machine [4, 5]. The calculated strain distribution across an entire fuselage from finite element methods is shown in Fig. 1.

The idea was to update the scheduled maintenance intervals according to the actual condition of the structures. However, this is not an easy task, as it is governed and influenced by many variables, each one characterised by a stochastic distribution. In particular, the key factor is the disposal of detection and monitoring systems as reliable as possible, on the basis of which all the machine stops can be optimised in order to maximise the machine availability with the minimum loss of reliability, thus conjugating safety with economics [1].

2. System overview

Figure 2 shows basic structure designed for the SHM of helicopters. In general, the overall concept of the system consists of two main hardware parts, namely:

- On-board unit (helicopter side):
  - Smart Sensors' communication network placed in the helicopter's fuselage,
  - Main control unit including the communication link HW between the helicopter and the ground operator's tablet,

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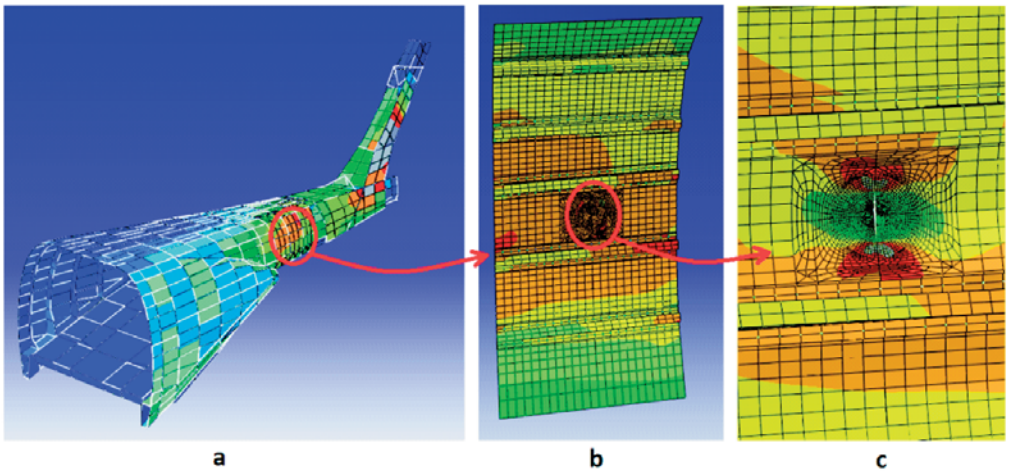

Fig. 1 Calculated strain distribution across an entire fuselage from finite element methods a) General model of the entire rear fuselage b) Submodel for the most stressed zone, with crack modelled inside c) Crack model

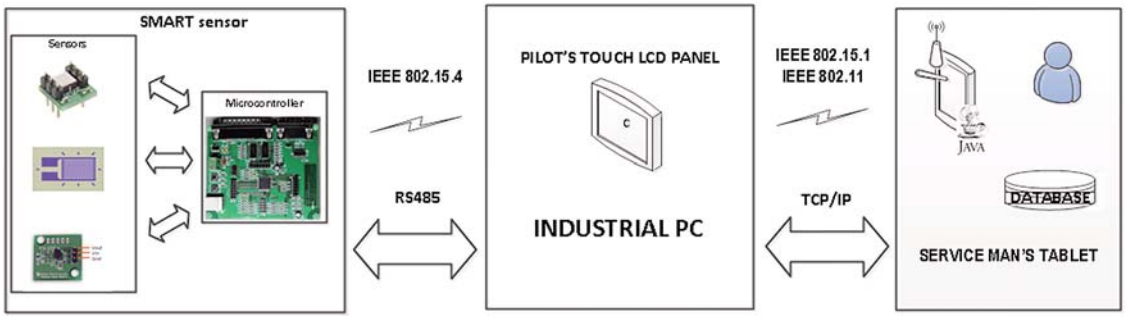

Fig. 2 Designed SHM system structure

- Maintenance unit (service side):
  - Serviceman's tablet or other kinds of handheld devices.

And two main software parts:
- GUI (Graphic User Interface) at helicopter side:
  - signal pre-processing, enhancement and feature extraction block,
  - simple crack prognosis block,
- GUI at the service side:
  - feature extraction and signal classification block,
  - detailed crack prognosis block,
  - database block.

3. The Sensor Network definition

The basic premise of most damage detection methods is that damage modifies the stiffness, mass, or energy dissipation properties of a system, which in turn alter the measured dynamic response of the system. Environmental and operational variations, such as varying temperature, moisture, and loading conditions affecting the dynamic response of the structures again will complicate the interpretation of possible damages.

The ideal sensor for the purpose of damage detection should have the following properties:
- be sensitive to the measured property,
- be insensitive to any other property,
- does not influence the measured property,
- be linear over the expected range of the measured property.

There are several available sensing principles for reading mechanical properties. These range from the well-established strain gauges to innovative and so far unproven technologies like, for example, sensing devices based on nano-technologies. Based on available knowledge, literature and information from vendors the following sensor candidates were evaluated in this study: strain gauges, crack gauges, eddy current sensors, fibre-optic sensors, potential drop, MEMS devices and mechanical wave-based sensors including general piezoelectric sensor systems, ultrasonic, Lamb waves and acoustic emission. Three among the most innovative and relevant for the current purposes are described hereafter.

The goal of an extended smart sensor system should be to provide an early warning that material fatigue is under development. The focus is thus on strain sensors since formation of cracks usually follows from excess strains. While there are several methods for measuring strains, the most common is to use a strain gauge, a device whose electrical resistance varies in proportion to the amount of strain in the device. The most widely used gauge is the bonded metallic strain gauge. The implementation of strain gauge sensors is shown in Fig. 3.

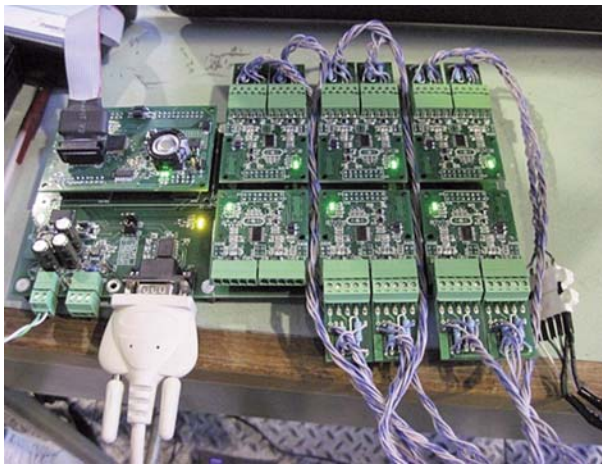

Fig. 3 HECTOR Smart Sensor, Base board, DSC board, 6x ADC modules

A system based on fibre Bragg gratings (FBGs) is again a strain sensing system which can be made capable of displaying a strain map in the structure. These sensors, easily and economically embeddable into the laminates without significantly affecting the mechanical properties of the hosting material, have several advantages such as: light weight, low power consumption (less than 1W is required to power the filter and the SLED optical source), immunity to electromagnetic interference, long lifetimes and high sensitivity. They don't need initial and in-service calibrations and are affected by very low signal drop. From an economic point of view, because of their diffusion and industrialisation, also the costs are by far reduced. Last but not least, comes the multiplexing option, or the possibility to photowrite more FBGs inside one optical fibre, thus becoming particularly attractive for damage location identification through the analysis of the whole FBG network reflected spectrum. The continuous improvements concerning the operating range of such sensors [6], would make possible their utilisation also in the harsh environments typical for the helicopters. It is also possible to correlate the effects of various damages (mainly cracks and delaminations) on the reflection spectrum of the embedded FBG sensor [7]. However, there are some challenges that must be addressed in order to construct a system based on FBG sensors from a practical point of view. First of all, an optical fibre for sensor purpose in which a Bragg grating is inscribed consists of the circular glass fibre surrounded by a thin and hard protective coating like, for instance, polyamide.

The SMART Layer® developed by Acellent Technologies, Inc. is also presented as a valid alternative for monitoring the structural integrity of composite and metal structures. It consists of an array of networked piezoelectric sensors embedded in a thin dielectric film, eliminating the need for each sensor to be installed individually. A pre-defined diagnostic signal can be transmitted by one of these sensors. It then travels through the structure under investigation as surface acoustic waves and is picked up by the neighbouring sensors. Each sensor can function both as an actuator and as a detector, creating a multitude of actuator-sensor pairs. By looking at the modulation of the transmitted signal, information about the structural health of the object can be extracted. Information about parameters such as loading, delamination, crack initiation and growth as well as corrosion can be deduced. The SMART Layer technology has been tested in monitoring the health and condition of diverse structures ranging from aircraft and rotorcraft to pipelines, bridges, wind turbines, automobiles etc. This technology seems to be a very promising candidate for helicopter SHM, but further tests are needed in order to prove the long term stability and airworthiness of the sensors.

4. The communication system

The main objective of the designed SHM system was to develop the hardware and software solutions for the real-time monitoring of the structural integrity of helicopter fuselage.

The communication system is capable to deliver measured data from the sensors to the access points for further processing. The problem related to communication systems was classified as follows.

- Which technology (wired or wireless) would be convenient for data transport? Wired technology seems to be a good choice, but there are problems to be solved (e.g. reliability of physical connection among sensors, lots of wires, etc.). Besides, there is a possibility to enhance the connectivity reliability by using both technologies (wired – main, wireless – secondary).
- There were problems in the wireless solution to be solved.
  - Radio wave propagation in closed metal environment concerning signal attenuation, time dispersion of the signal.
  - Signal frequency selection in other to avoid mutual interference to/from other communication systems.
  - Communication technology selection based on wireless standard for indoor and outdoor communication.
  - Network topology selection, etc.

The communication technology and the standards selection for communication infrastructure are pointed out in Fig. 4. There are two main technologies to be used for indoor communication – CAN bus for wired solution and IEEE 802.15.4 (ZigBee) for wireless communication. To deliver collected data to service side, the IEEE 802.15.1 (Bluetooth), IEEE 802.15.4 (ZigBee) or IEEE 802.11a, g, b (WiFi) were taken as possible candidates.

Problem connected with radio wave propagation in closed metal environment is due to the almost ideal wave reflection from a con-

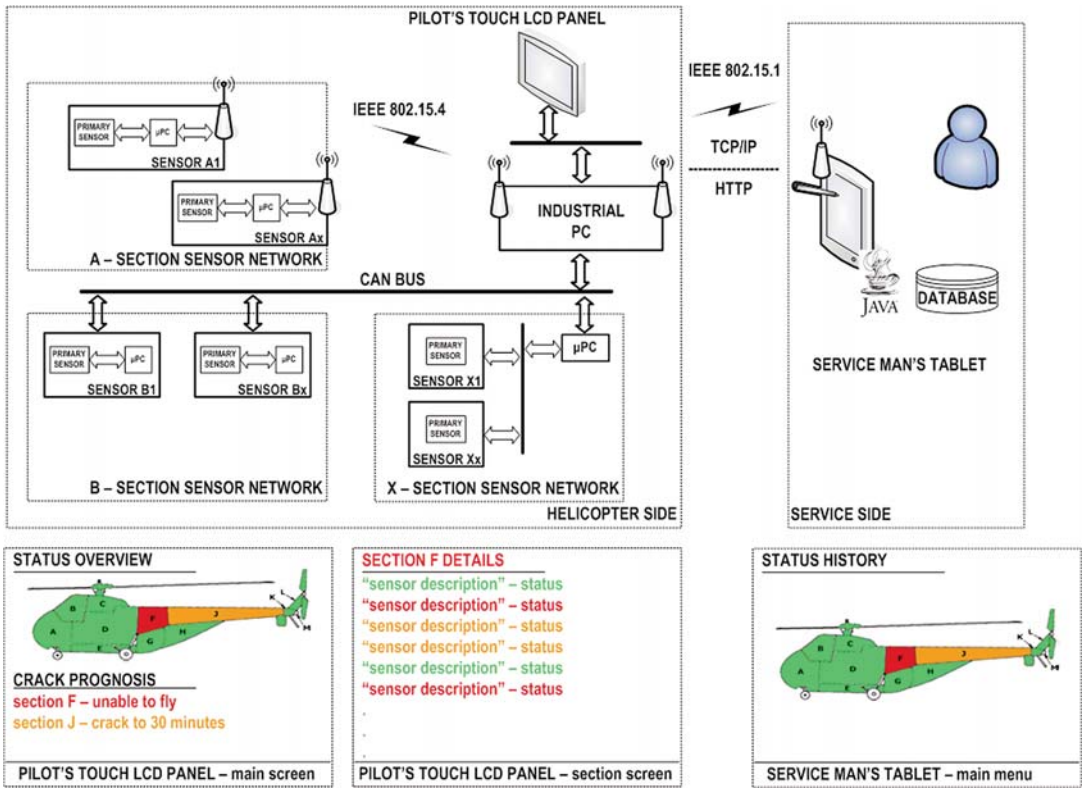

Fig.4 The principal block diagram of communication concept

ductive plate. The result is the signal propagation only through holes or apertures in metal plates as shown in Fig. 5.

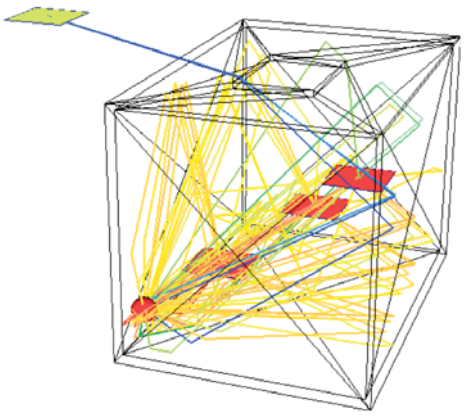

Fig. 5 Signal propagation through aperture in a conductive material

Signal propagation in such an environment may be roughly described through the following formula:

$$L(d) = L(d_0) + 10 \cdot \alpha_0 \cdot \log(d) + n_w \cdot L_w$$

where $L(d)$ is the signal attenuation (in dB) in distance d, $L(d_0)$ is signal attenuation in a reference distance (1 m), α_0 is the path-loss exponent, n_w represents the number of obstacles, L_w is the obstacle attenuation. This expression doesn't take into account the signal reflection from walls. For precise evaluation of signal attenuation it is commonly used the ray tracing method [8], which was also used for the investigated simulation (Fig. 5).

From Fig. 5 (red ball is transmitter, red squares and green square indicate receivers) it is obvious that the signal transmitted by transmitter is able to propagate outside the cube only following one path through the aperture (blue line), while other paths (yellow and green lines) are blocked. Signal attenuation becomes high outside the cube (changing squares colour from red to green). In conclusion, to deliver radio signals in metal conducting materials with barriers it is possible only by convenient arrangement of transmitters and receivers.

Indoor wireless communication system was proposed to be based on the IEEE 802.15.4 standard. Two different device types can participate in an IEEE 802.15.4 network; a full-function device (FFD) and a reduced-function device (RFD). The FFD can operate in three modes serving as a personal area network (PAN) coordinator, a coordinator, or a device. An FFD can talk to RFDs or other FFDs, while an RFD can talk only to an FFD. An RFD is intended for applications that are extremely simple, such as a light

switch or a passive infrared sensor; they do not have the need to send large amounts of data and may only associate with a single FFD at a time. Consequently, the RFD can be implemented using minimal resources and memory capacity. Depending on the application requirements, an IEEE 802.15.4 network may operate in either two topologies: the star topology or the peer-to-peer topology.

In the star topology the communication is established between some devices and a single central controller, called the PAN coordinator. A device typically has some associated application and is either the initiation point or the termination point for network communications. A PAN coordinator may also have a specific application, but it can be used to initiate, terminate, or route communication around the network. The PAN coordinator is the primary controller of the PAN. All devices operating on a network of either topology shall have uniquely 64- bit addresses. The PAN coordinator might often be mains powered, while the devices will most likely be battery powered. Applications that benefit from a star topology include home automation, personal computer (PC) peripherals, toys and games, and personal health care.

The peer-to-peer topology also has a PAN coordinator; however, it differs from the star topology in that any device may communicate with any other device as long as they are in range of one another. Peer-to-peer topology allows more complex network formations to be implemented, such as mesh networking topology. Applications such as industrial control and monitoring, wireless sensor networks, asset and inventory tracking, intelligent agriculture, and security would benefit from such a network topology. A peer-to-peer network can be ad hoc, self-organizing, and self-healing. It may also allow multiple hops to route messages from any device to any other device on the network.

Up to now some proposals and simulations were prepared with IEEE 802.15.4 (ZigBee) standard as solution for indoor wireless propagation. Several topologies for wireless networks have been compared – Star, Clustered star and Clustered star bus shown in Fig. 6, discarding Peer-to-Peer topology because of problems with radio signal transmission through apertures in structures. Instead, star topology was simulated with hybrid link connection – wired solution for connection among coordinators and PAN coordinator and wireless connection for individual networks belonged to coordinators. The division of the whole network to several sub-networks helped to avoid problems with propagation of radio signal through metal apertures in indoor environment.

5. SHM implementation

In this section the On-Board and the Maintenance Units software applications are presented. These software applications cover on the one hand visualisation of crack detections and propagation and on the other hand they prepare basic database structures for storage of all data from sensors which can be downloaded whenever it is necessary.

The On-Board Unit interface allows data acquisition from various Smart Sensor Units and stores them in a database. Collection and storage is going on at regular intervals. Communication with sensor networks is done through MODBUS protocol over RS485 network. The time intervals are adjustable, however, there are some theoretical limits. For demonstration purposes a period of 1 second was selected. It is obvious that this value is far above the real possibilities of the used network and the database subsystem. This is the main task of this application. Another task of the

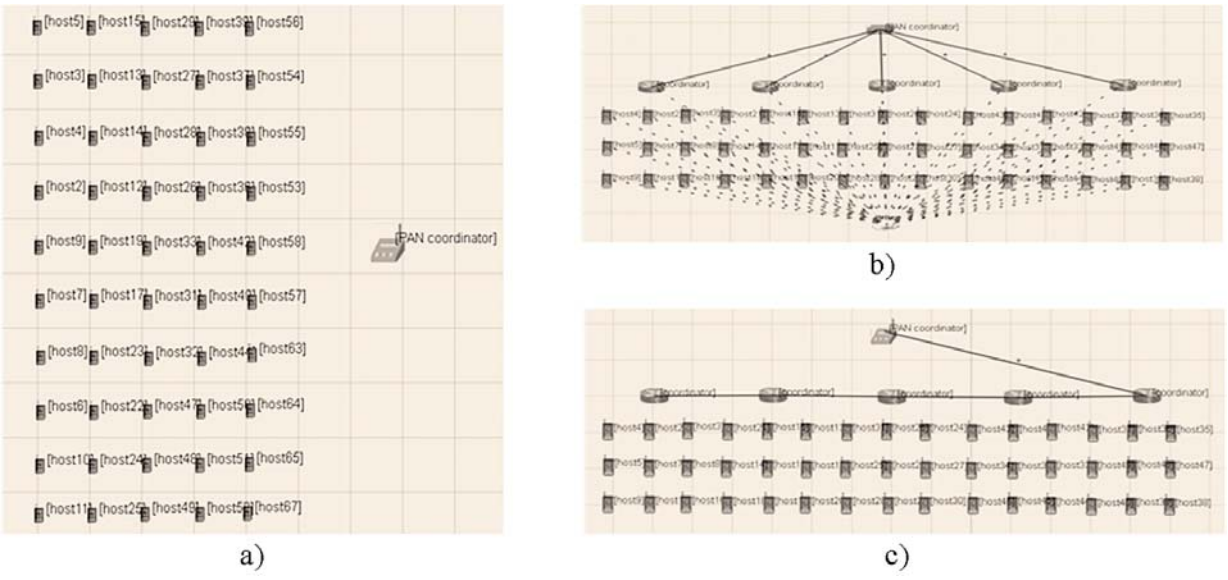

Fig. 6 Sensor network topology scenarios: Star (a), Clustered star (b), Clustered star bus (c)

application is a visual representation of the state of a helicopter tail. The visual representation is for simplicity done using three states. These three states are presented as a change of colour of the helicopter tail in the picture inside the application GUI, depending on whether the part is intact or not. The green colour means that it is not damaged. The orange colour represents that there is already some damage in the part, however, the operation is still safe as shown in Fig. 7. The red colour means that the damage is already serious and the helicopter should land as soon as possible.

The Maintenance Unit provides deeper diagnosis and prognosis in the SHM system. The communication is managed by a standalone application and provides full access to establishing and closing communication channels between the On-Board Unit and the Maintenance Unit. The data transfer is made of stream of pre-processed readings from sensors. Connection is established and communication executed after successful mutual authentication and authorization. After terminal connection, the sensor data are transferred only in one way with continuous depositing in the database.

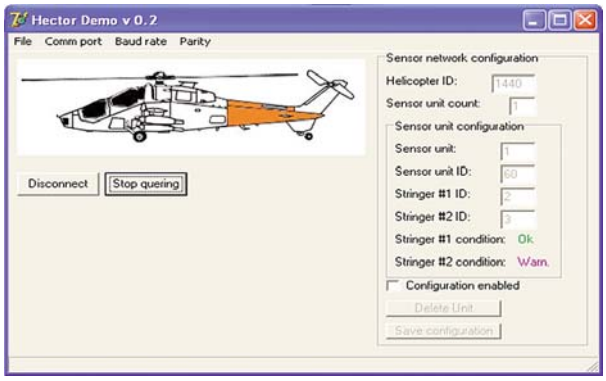

Fig. 7 Graphic user interface for On-Board Unit

The JAVA platform was chosen for this application. The main advantage of this programming language is multiplatform use (the application is runnable on all operating systems with Java runtime) [9]. The communication with SQL database is also provided by standard library the Java Database Connectivity (JDBC). The system contains four function blocks; the graphical interface for data visualisation and application control, the communication unit for the communication with On-Board Unit, the database unit for data storing and access control and data processing unit for the diagnosis and prognosis. The Maintenance interface is shown in Fig. 8.

6. Conclusion

The System Health Monitoring is the next future key factor of all the cutting edge structures, in particular concerning helicopters and going ahead tiltrotors. The raw instruments such as sensors, algorithms and stress analysis implemented into a compact functioning SHM system were studied and laboratory tested in this project. In this paper, the short system overview was presented. Analyses of sensor network definition and network communication were described. Finally, the visualisations for the On-Board and the Maintenance Units were shown. The future task is to improve analytical and laboratory based studies to set-up innovative SHM technology for helicopter applications, taking into consideration the main characteristics such as high frequency vibratory loads, different load manoeuvres, missing of pressurisation in the fuselage, etc. of this very complex machine.

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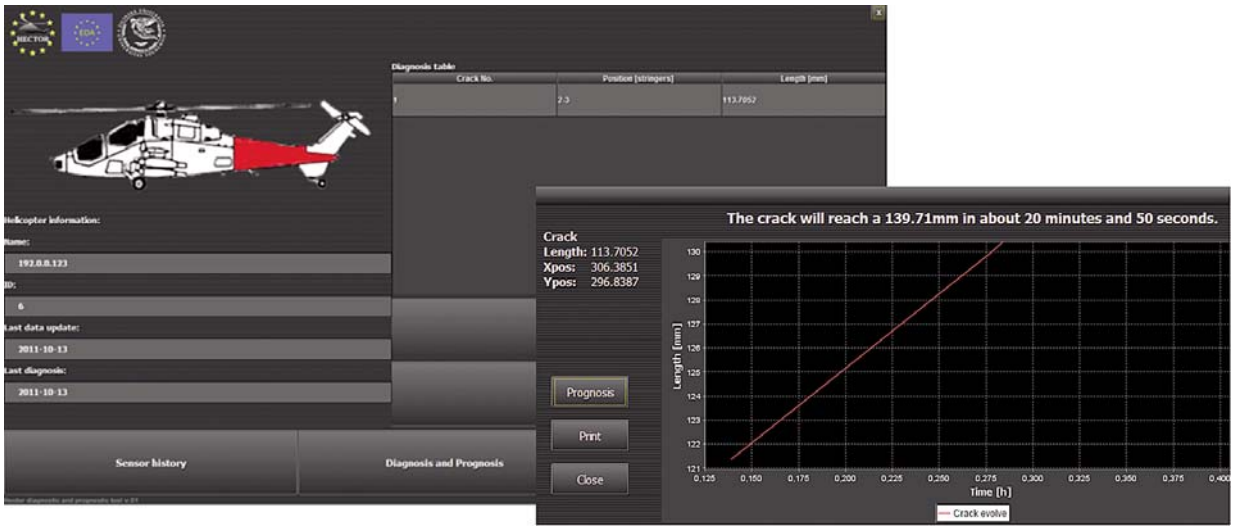

Fig. 8 Graphic user interface for Maintenance Unit

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Ladislav Janousek – Mihai Iulian Rebican – Milan Smetana – Tatiana Strapacova – Anton Duca – Viera Pernisova *

RECENT INNOVATIVE SOLUTIONS IN EDDY CURRENT NON-DESTRUCTIVE DIAGNOSIS

Recent innovative solutions in eddy current non-destructive evaluation of conductive materials are reported in the paper. Two main areas influencing reliability and preciseness of real cracks diagnosis are discussed. Advances in sensor technology are concerned at first. Innovative sensor design allowing sensing all the three spatial components of the perturbation electromagnetic field is presented. A novel approach for automatic diagnosis of real cracks from two-dimensional eddy current response signals is then introduced. The tabu search is applied for the three-dimensional reconstruction of partially conductive cracks.

Keywords: *Non-destructive evaluation, eddy currents, sensors, diagnosis.*

1. Introduction

Many structures require periodical inspection to keep safety, reliability as well as quality of various processes. It is especially crucial in areas where possible damages could lead to high economic and/or environmental losses, such as nuclear, petrochemical and transportation industries.

Recent trends in maintenance are embracing the so-called damage tolerance approach, wherein an element is actively used up to a certain point, beyond which the structural integrity of a structure could be affected. Replacement is thus performed at the end of the element service life, which helps in decreasing operating costs of the whole system, while keeping required level of safety, reliability and quality.

Modern approaches in the maintenance such as System Health Monitoring and Condition Based Maintenance come out from the damage tolerance approach. Degradation detection of a construction element must be accompanied by interpretation of the measured data in order to estimate the extent of the degradation and to predict its future development in consequence. The first two phases are inherently associated with Non-Destructive Evaluation (NDE) of materials. Enhancing NDE methods is therefore very important for accomplishing their challenging missions.

Different physical principles are utilised for the NDE of materials. Eddy current testing (ECT) is one of the widely utilized electromagnetic methods. It originates from the electromagnetic induction phenomena and the principle of ECT underlies in the interaction of induced eddy currents with structure of an examined body [1]. There are many advantages such as high sensitivity for surface breaking defects, high inspection speed, contact-less inspection, versatility, maturity of numerical means that account for continuously enlarging application area of the ECT even for biomaterials inspection [2]. However, in contrast to the simplicity of the method, recent trends in NDE open several challenging issues.

ECT is a relative method and the inverse problem is ill-posed [3]. Therefore, evaluating dimensions of a detected defect from ECT response signals can be quite difficult [4]. ECT instruments provide raw data with limited or absent capability of interpreting quantitatively the data [5]. Typically, evaluation relies on calibrated curves measured on pre-fabricated etalons and on the skills of an operator. Recently, the progress in powerful computers has allowed developing of automated procedures to make decisions. Quite satisfactory results are reported by several groups for automated evaluation of artificial slits [4] and even for several parallel notches [6]. However, evaluation of real cracks, especially stress corrosion cracking (SCC), from ECT response signals remains still very difficult. Many unsatisfactory results are reported when the automated procedures originally developed for non-conductive cracks are employed in the evaluation of SCCs. It is stated that one of the possible reasons is lack of sufficient information [4].

The authors have been working in the field of eddy current non-destructive evaluation for a long period. Their current activities are focused especially on enhancing information level of sensed data as well as on their correct and reliable interpretation. The paper addresses two important aspects in the light of the state-of-art. Advances in the sensor technology are discussed at first. Innovative solution of ECT probe providing possibility to detect all the three spatial components of the perturbation electromagnetic field is introduced in the next section. Interpretations of sensed data are

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analysed in consequence. A novel approach for diagnosis of real cracks from eddy current testing response signals is proposed. The tabu search is applied for the three-dimensional reconstruction of partially conductive cracks. Uniqueness of the proposal lies in the utilization of two-dimensional response signals for the three-dimensional inversion. Moreover, all the three spatial components of the perturbation electromagnetic field are taken as the response signals in order to tackle severe problem connected with diagnosis of partially conductive cracks.

2. Advances in sensor technology

ECT probes are one of the most important elements in NDE, because they transfer information between an ECT instrument and a conductive object through the induction coupling. An optimal ECT probe should assure [7]:

- high sensitivity to expected defects,
- high probability of detection of expected defects,
- possibility to distinguish parameters (location, dimensions, etc.) of expected defects.

Exciting coil(s) of ECT probe should thus induce eddy currents with high density and such distribution that the eddy current vector lines are significantly perturbed when a defect is in presence. The detection element should assure that maximum of the perturbation electromagnetic field is sensed.

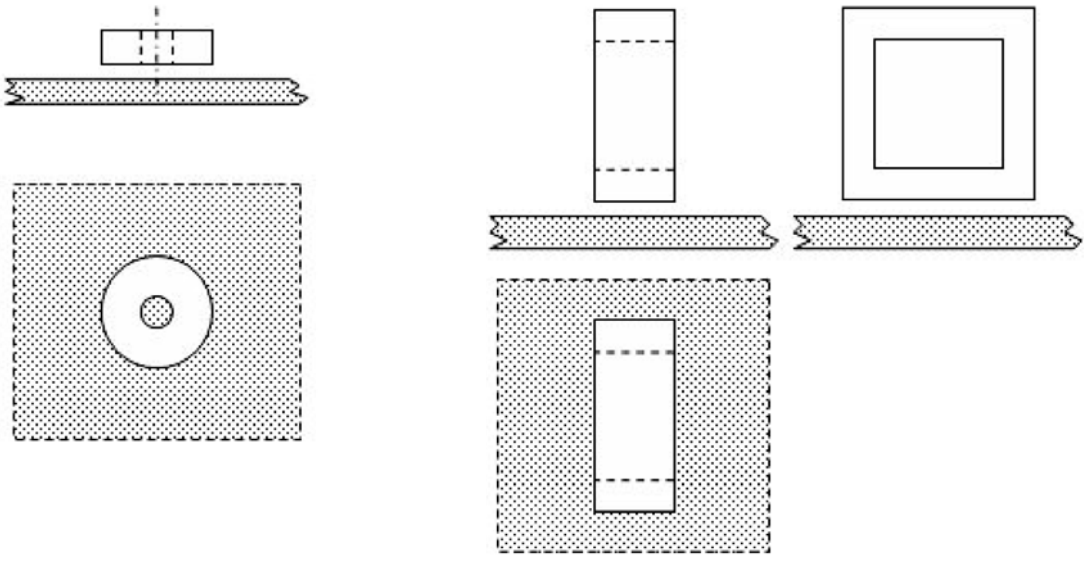
An exciting system of ECT probes is usually made of inductance coils. Properties of the system depend on number, shape, configuration, orientation, dimensions and connections of exciting coils. Due to simplicity of analysis, synthesis, construction and production usually exciting coils of a circular shape or a rectangular one as shown in Fig. 1 are used to build up the ECT probes. They can be oriented normally (Fig. 1a) or tangentially (Fig. 1b) regarding the surface of a tested body. The shape and the orientation of exciting coil(s) determine distribution of the eddy current density vector in a tested body. The normal coils induce circular-like distribution of eddy currents and the tangential coils induce eddy currents with so called uniform distribution; however, the later exhibit directional properties.

There is one particular disadvantage of the ECT originating from its principle. Eddy currents are quite dense at a surface of a conductive material and they decay almost exponentially going inside the material due to the well known skin-effect. According to the electromagnetic field theory, the distribution of eddy currents along material depth depends mainly on a testing frequency and the electromagnetic parameters of a material as it is given by the well known equation for the standard depth of penetration:

$$\delta = \frac{1}{\sqrt{\pi f \mu \sigma}}, \tag{1}$$

where δ [m] is the standard depth of penetration, f [Hz] is the inspection frequency, μ [H·m^{-1}] and σ [S·m^{-1}] are the magnetic permeability and the electric conductivity of the inspected material, respectively. However, there are much more parameters with substantial influence on this distribution under real conditions, such as shape of coils, their dimensions, configuration of inspection, material thickness, etc.

Influence of the parameters defined above on the eddy current attenuation in a conductive material has been analyzed. The analyses have been carried out in order to optimize exciting coils for a new design of ECT probe with optimal features. There are especially two parameters of a circular exciting coil oriented normally



a) normally oriented circular coil *b) tangentially oriented rectangular coil*

Fig. 1 Basic shapes and orientations of exciting coils

regarding a material surface (see Fig. 1a) that substantially influence the eddy current attenuation in the material: 1) outer radius of the coil; 2) clearance between the coil and the material surface, so called lift-off [8].

Particular results of the investigations are shown in Fig. 2 for a plate made of SUS316L with a thickness of 10 mm and the electromagnetic parameters $\sigma = 1.35{\cdot}106\ \mathrm{S{\cdot}m^{-1}}$ $\mu_r = 1$. Cross section of the coil winding is adjusted to $1 \times 1\ \mathrm{mm}^2$. Attenuations of the eddy current density absolute value along the material depth for coils with different radius are shown in Fig. 2a. The dependences are shown in normalized values for the frequency of $f = 1$ kHz and the lift-off $lf = 0.5$ mm. Black dotted line denoted as "theory" is calculated according to:

$$J_{ez} = J_{es} e^{-\frac{z}{\delta}}, \tag{2}$$

where J_{ez} [A·m^{-2}] is the absolute value of eddy current density at distance z [m] from boundary between the air and the conductive material and J_{es} [A·m^{-2}] is the absolute value of eddy current density at the material surface, δ [m] is the standard penetration depth given by (1). Influence of the lift-off on the eddy current profile along the material depth direction for the same frequency is shown in Fig. 2b. It is obvious from the presented results that the attenuation of eddy current density strongly depends on the coil diameter as well as on the lift-off. However, these influences gradually vanish with increasing ratio between the plate thickness and the standard depth of penetration. It should be noted that larger coils and/or larger lift-offs provide deeper penetration of eddy currents inside a material and thus it would provide better resolution. However, sensitivity can be decreased. Sophisticated design of the exciting system requires therefore appropriate compromise to reach essential performance of an ECT probe.

Detection elements of conventional ECT probes are usually made of inductance coils. However, recently, magnetic sensors based on either Hall effect, Anisotropic-Magneto-Resistance (AMR), Giant-Magneto-Resistance (GMR) effect, or Fluxgate magnetometers have been successfully used for crack detection in ECT [9].

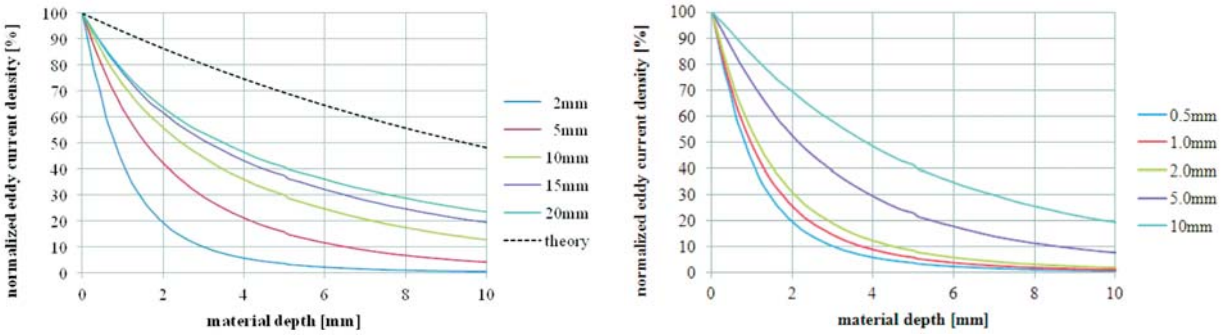
The most common Fluxgate sensor consists of two coils wrapped around the high-permeability ferromagnetic core. Magnetic induction of the core is changed by the presence of an external magnetic field. A driving signal is applied to one of the coils and the measured signal is taken from the second one. Changes in core permeability affect the measured signal as its amplitude variations.

AMR sensors usually consist of four ferromagnetic resistor stripes connected in Wheatstone bridge. Changes of magnetic resistance due to applied magnetic field can be up to 3%. AMR sensors offer small size and noise sensitivity.

GMR sensors use the phenomenon of large magnetic field dependent changes in resistance in thin ferromagnetic/nonmagnetic metallic multilayer structures. Comparing to small changes of resistance in AMR, GMR material can achieve about 10% – 20% changes in resistance. The resistance of two thin ferromagnetic layers separated by a thin nonmagnetic conducting layer can be altered by changing the moments of the ferromagnetic layers from parallel to anti-parallel. Layers with parallel magnetic moments will have less scattering at the interfaces, longer mean free paths, and lower resistance. Layers with anti-parallel magnetic moments will have more scattering at the interfaces, shorter mean free paths, and higher resistance.

Among these, the magneto-resistive (MR) sensors offer a good trade-off in terms of performance versus cost. They have small dimensions, high sensitivity over a broad range of frequency (from hertz to megahertz domains), low noise; they operate at room temperature, and are inexpensive. It has been demonstrated that ECT probes with MR sensors perform better than the ones with inductance sensing coils for low-frequency applications, e.g. when detecting deeply buried flaws. This is because the electromagnetic sensors are sensitive to the magnitude of the magnetic field. In the case of inductive-based probes, the output voltage is proportional to the time variation of the magnetic field; therefore, their sensitivity is reduced at low frequencies.

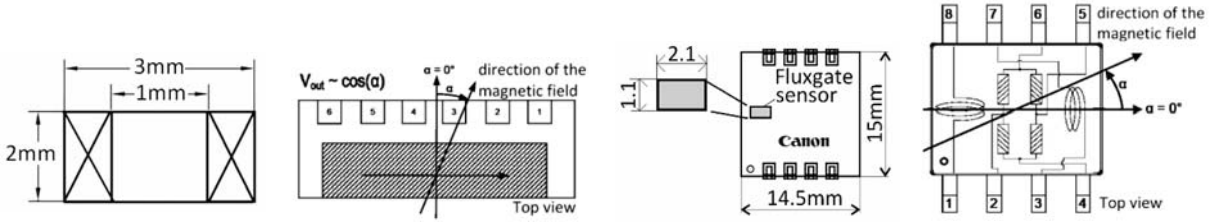
The authors have analyzed properties of various sensors in order to design a novel ECT probe [10], [11]. Especially, perfor-



a) influence of the coil radius, lf = 0.5 mm

b) influence of the lift-off, $r_c = 2$ mm

Fig. 2 Attenuation of eddy current density in normalized values along material depth, f = 1 kHz



a) inductance coil *b) GMR sensor (Sensitec)* *c) Fluxgate sensor* *d) AMR Sensor (Sensitec)*

Fig. 3 Sensors layout

mances of GMR, AMR and Fluxgate magnetic sensors and of an inductance coil, shown in Fig. 3, were compared under the same conditions based on numerical simulation as well as experimental measurements.

The results presented in [10], [11] proved that the magnetic sensors provide very similar resolution comparing to the inductance coils; however, they offer much better sensitivity especially for low frequency applications.

Common eddy current probes are designed in such a way that they sense only one component of the perturbation electromagnetic field. Usually, the most significant component is used for the evaluation. However, curved paths of eddy currents provide more information in principle.

Several studies of authors focused on enhancing information level of eddy current testing signals [12], [13]. The original idea is based on sensing of all three spatial components of the perturbation electromagnetic field. The studies have revealed that the uncertainty in cracks' evaluation is reduced when the enriched information is utilized for the purpose.

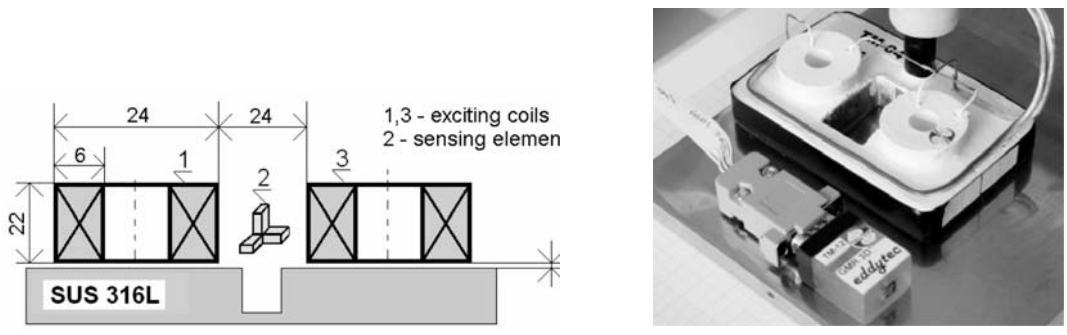
A novel ECT probe has been designed accounting for increased information level of response signals according to the previous works shortly introduced above. Layout of the probe together with its photo is shown in Fig. 4.

The probe consists of two circular exciting coils positioned apart from each other and oriented normally regarding the surface of an inspected material. The circular coils are connected in series but magnetically opposite to induce uniformly distributed eddy currents in the specimen. A detection system of the probe is composed of three GMR sensors oriented along three axes perpendicularly to each other. The detection system is located in the centre between the exciting coils to gain high sensitivity as the direct coupling between the exciting coils and the sensors is minimal at this position. The following section presents innovative solution for automatic diagnosis of real crack employing the new probe.

3. Advances in automatic diagnosis

The progress in powerful computers has allowed developing of automated procedures to provide diagnosis of cracks from ECT response signals. Two approaches are utilized for the purpose in general: 1) deterministic and 2) stochastic [4], [6].

Usually, one dimensional signal gained by scanning just above an indicated crack along its length is taken as an input to the evaluation procedure. Mostly, three variables of the defect are estimated, its depth, length and position of its centre, while a profile, a width and the electromagnetic parameters of the defect are adjusted in advance. The deterministic methods are the model based. They



a) layout and dimensions *b) photo*

Fig. 4 Novel ECT probe

work according to the difference minimization between measured and simulated signals. The process is iterative and therefore large number of forward simulations is required. The stochastic approaches simulate the mapping between eddy currents signals and defect profiles based on many known datasets. So called evolution algorithms, for example neural networks, genetic algorithms, are utilized for the inversion.

The authors have already developed an algorithm for reconstruction of multiple slits from ECT response signals by means of a stochastic optimization method, such as tabu search [6]. The reconstruction of multiple slits was done in three-dimensions. Therefore, the scheme is also appropriate for reconstruction of a partially conductive crack, when its width as well as its partial conductivity have to be considered as variable.

This section presents a novel approach for automatic diagnosis of real cracks proposed by the authors using the new probe presented above. The tabu search is applied for the three-dimensional reconstruction of partially conductive cracks. Uniqueness of the proposal lies in the utilization of two-dimensional response signals for the three-dimensional inversion. Moreover, all the three spatial components of the perturbation electromagnetic field are taken as the response signals in order to tackle severe problem connected with diagnosis of partially conductive cracks. Effectiveness of the proposal has been studied by numerical means at first and particular results are presented here.

A plate specimen having the electromagnetic parameters of a stainless steel SUS316L is inspected here. The specimen has a thickness of 10 mm, a conductivity of $\sigma = 1.35$ MS/m and a relative permeability of $\mu_r = 1$. A single surface breaking crack appears in the plate. It is modelled as a structure having different electromagnetic properties from the base material. Configuration of the plate (region Ω_0) with the crack (region Ω_1) is shown in Fig. 5. The crack region Ω_1 ($22 \times 2 \times 10$ mm^3) is uniformly divided into a grid composed from $n_x \times n_y \times n_z$ ($11 \times 5 \times 10$) cells defining a possible crack geometry. The dimensions of each cell are $2.0 \times \times 0.4 \times 1.0$ mm^3.

The new eddy-current probe, shown in Fig. 4, is employed for the near-side inspection of the plate. Two-dimensional scanning, so called C-scan, is performed over the cracked surface with a lift-off of $l_f = 1$ mm. The real and the imaginary parts of the output

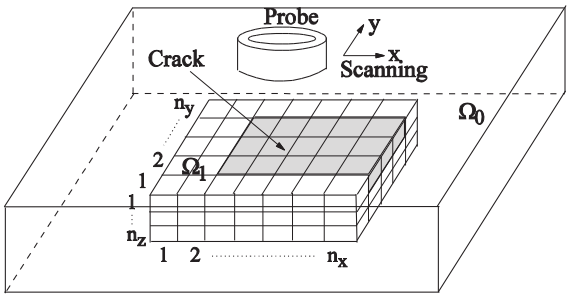
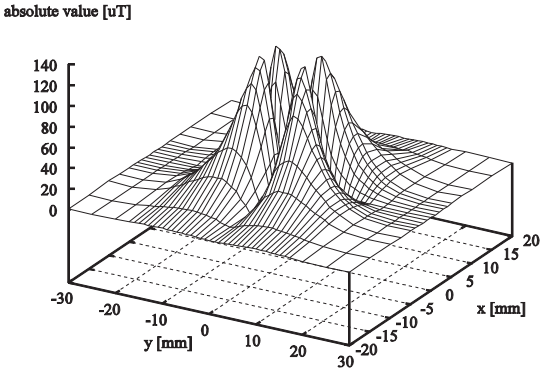
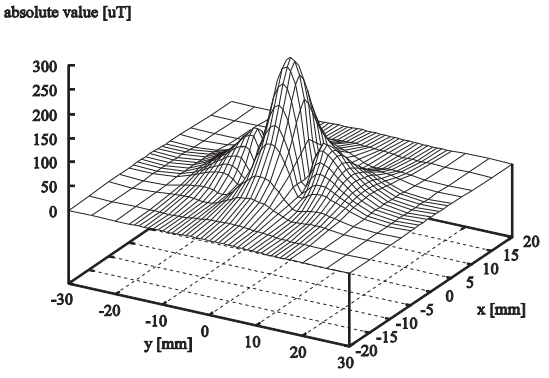


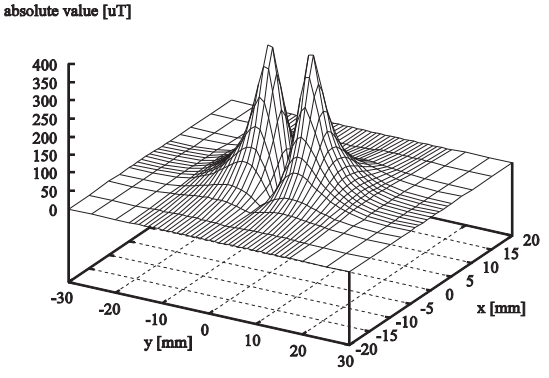
Fig. 5 Configuration of plate specimen with crack region



a) x-component B_x



b) y-component B_y



c) z-component B_z

Fig. 6 Absolute values of the sensed magnetic flux density vector B vs. probe position, $l_c = 10$ mm, $d_c = 5$ mm, $w_c = 0.2$ mm, $\sigma_c = 0\%$ of σ

voltages from all three GMR sensors corresponding to three spatial components of the perturbation electromagnetic field are sensed and recorded during the inspection. Example of crack signatures is shown in Fig. 6. Dependences of the three spatial components of the perturbation magnetic flux density vector on the probe position are displayed. The signals correspond to a crack of the cuboid

shape with a length of l_c = 10 mm, a depth of d_c = 5 mm, a width of w_c = 0.2 mm and its partial conductivity is adjusted to σ_c = 0% of the base material conductivity σ. The crack is oriented along the y-direction in the 10 mm thick SUS316L plate.

A database approach for fast-forward computation of the ECT response signals due to multiple cracks is used in this paper [6]. The database is designed for a three-dimensional defect region and not as usually for a two-dimensional one where a crack width is considered as fixed. Thus, the ECT response signals can be simulated also for partially conductive cracks with variable width using the same database generated in advance. The area of the simulated two-dimensional ECT signals has surface dimensions of 100 × 28 mm^2. The number of scanning points in the two directions is 50 and 70, respectively.

Tabu search is employed for the three-dimensional diagnosis of a detected crack [6]. Three-dimensional model of the crack is shown in Fig. 7. The crack depth is considered as variable along the crack length. The crack parameter vector c consists of n_x + 3 integers, $c = [iz_1, iz_2, ..., iz_{nx}, iy_1, iy_2, s]$, where iz_k, $k = 1, n_x$ is the number of cells of the crack along the crack depth, iy_1 and iy_2 are the indices of the first and last cells of the crack along the width direction, and the crack partial conductivity is expressed as σ_c = s% of the base material conductivity σ.

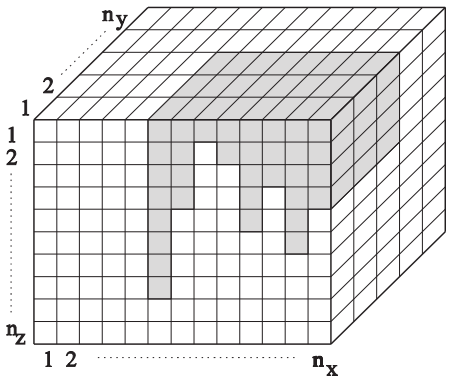
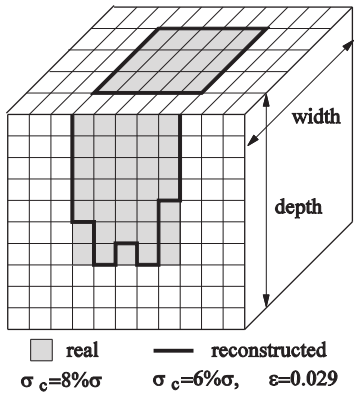
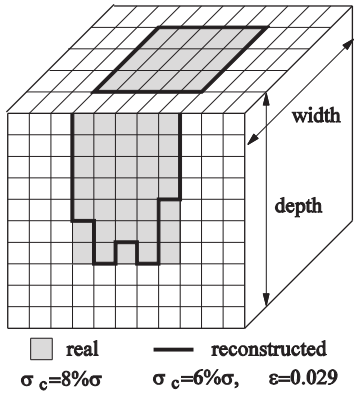


Fig. 7 Three-dimensional model of partially conductive crack

Figure 8 shows results of three-dimensional diagnosis of two partially conductive cracks when the crack model shown in Fig. 7 is employed for the inversion. In this case two profiles of a crack are considered. The first crack has the cuboid shape and its true parameters are as follows: length l_c = 10 mm, width w_c = 1.2 mm, depth d_c = 7 mm and partial conductivity σ_c = 8% of the material base conductivity σ. The result of reconstruction is shown in Fig. 8a). As it can be observed the crack is precisely localized and also its length and width are exactly estimated. The depth profile does not perfectly copy the true one. However, the maximum depth is accurately assessed. A crack with elliptical profile is also reconstructed. The crack opening has a value of w_c = 0.4 mm, its surface length is l_c = 14 mm, the maximum depth is d_c = 4 mm and the crack's partial conductivity is adjusted to σ_c = 8% of the base material conductivity σ. The reconstruction result is shown in Fig. 8b). The crack width and its surface length are accurately assessed. The estimated crack position is minimally shifted (0.4 mm) in the crack width direction comparing the true position. The maximum depth is slightly overestimated of 1 mm.



a) cuboid shape of crack



b) elliptical shape of crack

Fig. 8 Results of partially conductive cracks' reconstruction

The presented results proved effectiveness of the proposed novel approach of three-dimensional diagnosis of partially conductive cracks. ECT response signals gained during C-scan together with acquiring all three spatial components of the perturbation electromagnetic field significantly improve the preciseness of inversion process using tabu search stochastic method.

4. Conclusion

The paper focused on recent R&D activities in the field of eddy current non-destructive evaluation of conductive materials. Two innovative solutions providing more reliable diagnosis of real cracks from eddy current response signals were presented. A new design of eddy current probe allowing sensing three spatial com-

ponents of the perturbation electromagnetic field due to a crack was introduced. A novel approach for three-dimensional diagnosis of partially conductive cracks was proposed consequently. The tabu search stochastic method was employed for the reconstruction from eddy current response signals gained during two-dimensional scan of the probe. The presented results proved that the proposed approach allows quite precisely reconstructing three-dimensional profile of a partially conductive crack even with elliptical shape together with its partial conductivity.

Further work of the authors will concern especially experimental verifications.

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Zuzana Malacka *

OSCILLATORY PROPERTIES OF THE SOLUTIONS OF FIRST ORDER LINEAR NEUTRAL DIFFERENTIAL EQUATIONS WITH "MAXIMA"

In this paper we consider a neutral differential equation with "maxima" of the form

$$\left[x(t)+p(t)x(\sigma(t))\right]+q(t)\max_{[t-\alpha,t]}x(s)=0$$

We obtained sufficient conditions for oscillation of all the solutions when $t\to\infty$.
Keywords: *Neutral equation, delayed argument, oscillation.*

1. Introduction

We consider a first order linear neutral functional differential equation of the form

$$\left[x(t)+p(t)x(\sigma(t))\right]+q(t)\max_{[t-\alpha,t]}x(s)=0\,,\ t\geq t_0 \qquad (1)$$

Let the following conditions regarding functions p, σ, q be always assumed to hold:

$t\to\infty$

$p:[t_0,\infty)\to R$ is continuous (2)

$\sigma:[t_0,\infty)\to R$ is continuous and stricly increasing,

$$\lim_{t\to\infty}\sigma(t)=\infty,\ \alpha\in R,\ \alpha>0 \qquad (3)$$

$q:[t_0,\infty)\to(0,\infty)$ is continuous,

$$q(t)\neq 0,\ \int_0^\infty q(t)dt=0 \qquad (4)$$

Differential equations with maxima are special type of differential equations that contain the maximum. Though differential equations with maxima are often met in applications, the qualitative theory of these equations is relatively little developed. The existence of periodic solutions of these equations is considered in [1]. Our aim is to obtain new sufficient conditions for the oscillation of all the solutions of equation (1). By the solution of equation (1) we mean a continuous function $x:[t_x,\infty)\to R$ such that $x(t)+p(t)x(\sigma(t))$ is continuously differentiable and $x(t)$ satisfies equation (1) for all sufficiently large $t\geq t_x$. The vanishing solutions of all large t will be excluded from our consideration. The solution of (1) is called oscillatory if it has arbitrarily large zeros in $[t_x,\infty)$ and it is called nonoscillatory otherwise. The nonoscillating solutions of (1) are characterized as being eventually positive or eventually negative. Let us define the function

$$z(t)=x(t)+p(t)x(t-\tau), \qquad (5)$$

where $t-\tau=\sigma(t)$. Then, from equation (1) we get

$$z'(t)+q(t)\max_{[t-\alpha,t]}x(s)=0\,. \qquad (6)$$

The following lemmas will be useful in the proof of the main results. Lemmas can be found in [2, 3].

Lemma 1.1 *We consider equation*

$x'(t)=p(t)x(t-\tau)=0,\ t\geq t_0$

In addition to (2) let us suppose that $p(t)>0$, $\tau>0$, $(\sigma(t)<t)$ and

$$\lim_{t\to\infty}\int_{t-\tau}^{t}p(r)dr>\frac{1}{e}\,.$$

Then the following statements are true: the inequality

a)

$x'(t)+p(t)x(t-\tau)\leq 0$

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has no eventually positive solution,
b)

$$x'(t) + p(t)x(t-\tau) \geq 0$$

has no eventually negative solution, or inequality
c)

$$x'(t) - p(t)x(t-\tau) \geq 0$$

has no eventually positive solution,
d)

$$x'(t) - p(t)x(t-\tau) \leq 0$$

has no eventually negative solution, and
e)
the following equation

$$x'(t) - p(t)x(t-\tau) = 0$$

has only oscillatory solutions.

Lemma 1.2 *Let the conditions (2) - (4) hold. Then the following statements are true:*

a)If $p(t) \leq -1$ and
(i) $x(t)$ is an eventually positive solution of (1), then the function $z(t)$ is an eventually decreasing function and $z(t) < 0$ eventually,
(ii) $x(t)$ is an eventually negative solution of (1), then the function $z(t)$ is an eventually increasing function and $z(t) > 0$ eventually.

b)If $-1 \leq p(t) \leq 0$ and
(i) $x(t)$ is an eventually positive solution of (1), then the function $z(t)$ is an eventually increasing function and $z(t) > 0$ eventually,
(ii) $x(t)$ is an eventually negative solution of (1), then the function $z(t)$ is an eventually decreasing function and $z(t) < 0$ eventually.

2. Main results

Theorem 2.1 *Let conditions (2) - (4) hold and* $p(t) \equiv 0$. *Then all the solutions of equation (1) are oscillatory.*

Theorem 2.2 *Let conditions (2) - (4) hold,* $p(t) \leq -1$ *and* $\tau > \alpha$. *Next, let the following condition hold*

$$\liminf_{t\to\infty} \int_{t-\tau+\alpha}^{t} \frac{q(s)}{\max\limits_{u\in[s-\alpha,s]}\{-p(u+\tau)\}}ds > \frac{1}{e}. \tag{7}$$

Then all the solutions of equation (1) are oscillatory.

Proof. Let us suppose that equation (1) has a nonoscillatory solution $x(t)$. Let $x(t) < 0$. From Lemma (1.2) we have that $z(t) > > 0$. Then, from (5) we get the inequality

$$z(t) < p(t)x(t-\tau)$$

from which we have

$$x(t) < \frac{z(t+\tau)}{p(t+\tau)}$$

and, finally

$$\max_{[t-\alpha,t]} x(s) \leq \max_{[t-\alpha,t]} \frac{z(s+\tau)}{p(s+\tau)}. \tag{8}$$

Next, from Lemma (1.2) we know that $z(t)$ is an eventually increasing function, then for sufficiently large t we have

$$z(t+\tau-\alpha) \leq z(s+\tau),\ \ s \in [t-\alpha, t]$$

Then

$$\max_{[t-\alpha,t]} \frac{z(t+\tau-\alpha)}{p(s+\tau)} \geq \max_{[t-\alpha,t]} \frac{z(s+\tau)}{p(s+\tau)}$$

and

$$\max_{[t-\alpha,t]} \frac{-z(t+\tau-\alpha)}{-p(s+\tau)} \geq \max_{[t-\alpha,t]} \frac{z(s+\tau)}{p(s+\tau)}$$

From the last inequality and (8) we can deduce that

$$\max_{[t-\alpha,t]} x(s) \leq \frac{-z(t+\tau-\alpha)}{\max\limits_{[t-\alpha,t]}\{-p(s+\tau)\}}. \tag{9}$$

Then from (6) and from (9) it follows that only the positive function $z(t)$ satisfies the inequality

$$z'(t) - \frac{q(t)}{\max\limits_{[t-\alpha,t]}\{-p(s+\tau)\}} z(t+\tau-\alpha) \geq 0 \tag{10}$$

But from (7) and from Lemma (1.1) it follows that the last inequality (10) has no positive solutions. The contradiction obtained shows that equation (1) has no negative solutions, which is a contradiction.

Let $x(t) > 0$ From Lemma (1.2) it follows that $z(t) < 0$ As above, we obtain the estimate

$$\max_{[t-\alpha,t]} x(s) \geq \frac{-z(t+\tau-\alpha)}{\max\limits_{[t-\alpha,t]}\{-p(s+\tau)\}} \tag{11}$$

Then from (6) and from (11) it follows that only the negative function satisfies the inequality

$$z'(t) - \frac{q(t)}{\max\limits_{[t-\alpha,t]}\{-p(s+\tau)\}} z(t+\tau-\alpha) \leq 0 \tag{12}$$

But from (7) and from Lemma (1.1) it follows that the last inequality (12) has no negative solutions. Hence equation (1) has no positive solutions, which was a contradiction.

Then all the solutions of equation (1) are oscillatory.

Theorem 2.3 *Let conditions (2) - (4) hold,* $-1 \le p(t) \le 0$ *and* $\alpha \ge \tau$. *Next, let the following condition hold*

$$\liminf_{t\to\infty} \int_{t-\tau}^{t} q(s) \max_{u\in[s-\alpha,s]} \{-p(u)\} ds > \frac{1}{e} \tag{13}$$

Then all the solutions of equation (1) are oscillatory.

Proof. Let us suppose that equation (1) has a nonoscillatory solution .

1) Let $x(t) > 0$ From Lemma (1.2) we have that $z(t)$ is a decreasing function and $z(t) > 0$. Then $z(t) < x(t)$ and

$$\max_{[t-\alpha,t]} z(s) < \max_{[t-\alpha,t]} x(s).$$

With regard to (6) from the last inequality we get

$$z'(t) + q(t) \max_{[t-\alpha,t]} z(s) \le 0.$$

Since $z(t)$ is a decreasing function, then we obtain

$$\max_{[t-\alpha,t]} z(s) = z(t-\alpha).$$

Therefore, the positive function $z(t)$ satisfies the inequality

$$z'(t) + q(t) z(t-\alpha) \le 0 \tag{14}$$

In view of

$$\max_{[t-\alpha,t]} \{-p(u)\} \le 1$$

then from (13) and from Lemma (1.1) it follows that inequality (14) has no positive solutions. The contradiction obtained shows that equation (1) has no positive solutions.

2) Let $x(t) < 0$ From Lemma (1.2) we have that $z(t)$ is an increasing function and $z(t) < 0$. From the definition of $z(t)$ the inequalities follow

$$x(t) < -p(t) x(t-\alpha) < -p(t) z(t-\alpha).$$

$$\max_{[t-\alpha,t]} x(s) < \max_{[t-\alpha,t]} \{-p(s) x(s-\alpha)\} < \max_{[t-\alpha,t]} \{-p(s) z(t-\alpha)\}.$$

With regard to (6) from the last inequality we get

$$z'(t) + q(t) \max_{[t-\alpha,t]} \{-p(s) z(t-\alpha)\} > 0. \tag{15}$$

From (13) and from Lemma (1.1) it follows that inequality (15) has no negative solutions, which was a contradiction.

Then all the solutions of equation (1) are oscillatory.

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OPTIMISATION OF THE PROCESSES OF WRITTEN HERITAGE PRESERVATION AND DIGITISATION

The Memory of Slovakia Centre of Excellence (MSCOE) is a project of the University of Zilina, under the scientific and organisational auspices of the Faculty of Humanities implemented from 2010 until 2013. The paper contains information about the project, some outcomes and specialisation of scientific and innovation activities. It describes priorities for research and innovation in the MSCOE, especially optimisation of mass digitisation technology, integrating processes of mass digitisation and conservation of textual materials and optimisation of linguistic solutions in mass digitisation and the best possible preparation of digital content for use.

Keywords: *Mass Digitisation, Mass Conservation, Mass Deacidification, Mass Sterilisation, Memory of Slovakia Project, Text Analysis, Knowledge Mining.*

1. The Memory of Slovakia Centre of Excellence

The predominant orientation of Centres of Excellence (COE) in Slovakia since 2008 has been research into new technologies and procedures. The COEs which have been founded are focused mainly on the following areas: technology, medicine, biology, ecology, theoretical computer science, veterinary medicine, social sciences (linguistics).

Among all COE projects approved between 2008 and 2010 the "Memory of Slovakia" Centre of Excellence (MSCOE) is the only one which is primarily focused on the documentation and preservation of cultural heritage. Besides pursuing the general mission of Centres of Excellence, such uniqueness dictates the need for a specific approach to formation of the centre, and formulation of its basic documents as well as profiling the priorities for research, development and innovation in the context of European efforts to promote Europe's cultural and creative industries and the European Commission's Digital Agenda [1], [2], [3].

The Memory of Slovakia – the National Centre of Excellence for Research, Preservation and Accessibility of Cultural and Scientific Heritage (MSCOE) is a project of the University of Zilina. The Slovak National Library in Martin is a partner of the project. The Project is being implemented from September 9th, 2010, until August 31st, 2013 (36 months). The project budget is 4,033,864.35 Eur. On the part of the University of Zilina, the Memory of Slovakia project is supervised by the Faculty of Humanities, the Department of Mediamatics and Cultural Heritage, and the Slovak National Library in Martin is the project partner.

We expect that in 2013 the partners involved will consider various alternatives for integrating the Memory of Slovakia COE and the infrastructure procured into the system of research and development components of the University of Zilina, as well as the potential of research, innovation and organisation of science represented by the MSCOE.

The strategic goal of the project is create the MSCOE for research, preservation and access of cultural and scientific heritage with internationally recognised scientific results. Specific goals of the project are: a) to create the centre of excellence and its formal structure, b) to build ICT infrastructure and complete instrumental equipment of the centre, c) to achieve important scientific results in research, preservation a presentation of cultural and scientific heritage.

2. Strategic Priorities of the MSCOE

1. Identification of the best available technologies in the area of digitisation, optimisation of the methods and tools for mass digitisation, quality control of digitisation, optimisation of transfer of huge amount of data, long time data preservation.
2. Identification of the best available technologies in the area of mass conservation of the books and archive material and integration of processes of mass digitisation and mass conservation of the written heritage.
3. Optimisation of the access to the digital content, creation of the experimental base for availability of scientific and educational content.

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Overview of implementation of the project activities Table 1

Item number	Activity name	Progress expressed in %
Main activities		
1.1	Establishment of the Centre of Excellence for research, preservation and presentation of cultural heritage	100%
1.2	Creation of strategy for long-term sustainability of the Centre, coordination of activities, dissemination of the research results	80%
2.1	Procurement, installation and commissioning of the instruments and equipment for the Centre	90%
2.2	Procurement, installation and commissioning of ICT	90%
3.1	Research and development of techniques for access to digital content and techniques of scientific communication	50%
3.2	Research in the area of restoration, conservation and preservation of cultural heritage objects	65%
3.3	Basic research of historical books and collections	70%
Support activities		
Project management		65%
Publicity and awareness-raising		65%

4. Building of the experimental mobile data centre (multi CPU HPC cluster, tiered storage (FC, SATA, Tape), high speed SAN and LAN environment.
5. Research and development of techniques for access of digital content and scientific communication.
6. Research in the area of restoration, conservation and preservation of cultural heritage objects.
7. Basic research of historical books and collections.

3. Implementation of the project activities and available infrastructure (10/2012)

The overview of the project activities implementation is in following Table 1.

Important preliminary results of infrastructure building are illustrated in the next tables: overview of costs in the years 2010 – 2012 [Table 2], mobile data centre components [Table 3], software available for the project purpose [Table 4], installed scanners [Table 5], and list of expected specialised equipment [Table 6].

Overview of costs Table 2

Item	Price
Total project price	3 486 950 €
Mobile data centre	2 735 000 €
Scanners	252 975 €
Specialised equipment	201 100 €
Common ICT equipment	137 750 €
Other	160 125 €

Mobile data centre Table 3

Blade server	• IBM Blade server • 16 blades (32 processors) • divided into 2 physical blocks, each by 8 blades • 2x LAN port (metallic) • 2x SAN port (optic)
Tape library	• robotic, high speed • 4 x LTO5 tape drives with optical connection • 600 LTO5 tapes included • total capacity cca 900 TB
Disc array	• SAN Pillar axiom storage system • 9,6TB - high speed FC discs • 32TB – mass storage SATA discs • HW RAID 0,1,5,6
Hierarchical storage management (HSM)	• incremental backup management • synthetic backup management • VMware and vStorage integration • Backup management thru SAN and LAN
Connectivity	• metallic LAN • optic LAN

Software Table 4

VmWare vSphere	• virtualisation software for Blade server
RedHat Enterprise Linux	• primary operating system
Windows 2008 Server	• secondary operating system
ScanFlow Advanced (ScanGate)	• digitalization workflow software
MediaInfo MIRV	• digital content publishing software
ABBY OCR server	• server-based OCR solution

Scanners Table 5

Treventus	• bound books automated scanning • V-type scanner with book cradle • up to 2 000 pages per hour
BookEye	• bound book binding • flatbed manual scanner • up to 1 500 pages per hour
XinoScan	• simple pages • up to 300 pages per minute

Specialised equipment Table 6

Lux meter	• light intensity measurement
Digital stereomicroscope	• physicochemical properties research of selected materials carriers
Spectrometer	• paper whiteness changes measurement • paper color changes measurement
XRF analyser	• multi elemental analysis of elements from Mg up to U • qualitative analysis of paper document elements • quantitative analysis of paper document elements
SurveNir system	• non-destructive measurement of selected paper document properties

4. Future strategy and perspectives of MSCOE

The priority of the MSCOE in 2013 and the following years is to establish a worksite with expertise in the areas of optimisation of digitisation processes, conservation, preservation, text analysis and knowledge mining.

The MSCOE project is constructed in such a way that it should support the major areas of research in the field of library and information science, mediamatics, mediology and cultural heritage. In accordance with that and with the main research directions the work plan will be organised along these areas of R&D in the following research topics:

Topic 1 is aimed at optimisation of mass digitisation technology

Topic 2 is aimed at integrating processes of mass digitisation and conservation of textual materials.

Topic 3 is aimed at optimisation of linguistic solutions in mass digitisation and the best possible preparation of digital content for use.

5. Area of optimisation of mass digitisation processes (Topic 1)

During the last years, researchers in MSCOE participated significantly in the application of knowledge in practice. By linking the academic sector and one of the leading national memory institutions – the Slovak National Library (SNL) in Martin it was achieved that the SNL started building capacities and infrastructure for mass digitisation of written and printed cultural heritage. Within the relationship among the MSCOE and the National Library and other institutions and systems in the fields of science, research, culture and education, the MSCOE represents a research and experimental base. It is a platform for searching and testing the best available solutions. The combination of research and innovation activities under MSCOE was of key significance especially for the National Library.

The SNL has been awarded the national project (DL&DA) financed from EU structural funds and implemented in 2012 – 2015, with a budget of 49.6 M € and going to produce over 2.8 mil. digitised library & archival objects which amounts to over 270 mil. pages to be selected, treated in mass sterilisation & deacidification, scanned, processed digitally, including image treatment, OCR etc. Within the DL&DA project, the SNL has to create 78 new positions, including researchers, technicians, chemical technologists, mass digitisation and conservation specialists etc. The DL&DA project in figures: Daily production of 43 TB (terabyte), transfer 6 GB (gigabyte) of data per second, digitisation of 2 800 000 objects (270 000 000 pages, represent 17 PB of data, 2 working copies require about 34 PB (petabytes) of data, daily production of 43 TB (terabyte) and need to transfer 6 GB (gigabyte) of data per second [4].

The objectives of Topic 1: support of the research in the field of mass digitisation and digital content reuse through exchange of know-how and experience with partners; recruitment of experienced researchers; specialist dissemination and outreach to innovation capacity building activities. Affordability, widespread availability of tools and services for releasing the economic potential of written library and archival cultural heritage in a digital form and for adding value to the cultural content in an educational, scientific and leisure context. The objectives also include a wider range of users of cultural resources in diverse real and virtual contexts, as well as considerably altered ways of experiencing culture in more personalised and adaptive interactive settings.

All processes of mass digitisation have to be constantly optimised in order to a) increase performance, b) reduce costs, c) identify critical points, d) ensure sustainability, e) improve availability of digital content to people.

Research and similar activities in the DL&DA project are not supported, and, therefore, the optimisation activities must be addressed with regard to the best practices in the MSCOE Project which represents fulfilment of the strategy for preservation and accessibility of documents held in libraries and archives, but not exploited sufficiently for the need of Slovak and European citizens in the interest of overall economic and cultural growth.

The methodology and management of digitisation technology is based on two essential systems: the logistic system which monitors and controls the flow of analogue documents in the digitisation process, and the work flow engine, which is a management system designed on the basis of the SOA/BPM principles, which controls the digitisation itself, interacts with the logistic system,

staff, as well as each automated technological step. Technologically, the digitisation process is supported by cutting-edge HW technology (IB, disk arrays, strong CPU processing), which is technologically prepared for handling large amounts of data. Our calculations show that the financial costs of digitising one page will be 0.20 EUR, which includes complete cleaning, chemical treatment, logistics, technologies, overhead, staff, infrastructures, sterilisation and digital content preservation.

The project's ambition is to demonstrate that these costs are essentially lower than those in similar projects in the EU and the USA. Despite the positive figures indicated, we still see possibilities for optimising the entire process. It has been proven through simple simulations of technological processes that for the given large amount of content to be digitised any minor enhancement in technology has got a great performance and costs impact on the overall result. It proves to be inevitable to optimise the logistics of paper document flow, to maximise the usage of technological elements, and to minimise the load on data concentrators and digital archiving space, as each repetition of processes and operations increases enormously the requirements for logistics, professional staff and digitisation costs.

Next works in the area of optimisation of mass digitisation processes will be led by:

1) Technological part: 2) Organisation and logistics, 3) Management and digital content organisation and reuse

Indicative list of Topic 1 objectives:

1. Optimisation of logistics and flows of printed material with respect to minimal movements between technological steps.
2. Optimisation of technological steps to reach the maximal usage of each technological element and minimise costs.
3. Optimisation of digitised data transfers between technological steps to achieve a better processing performance.
4. Introduction of further automated points of quality control with respect to minimise retries and achieve better quality near-to-actual-technology step and minimise unnecessary material movements.
5. Integration of all in-digitalisation-needed technologies into pluggable SOA/BPM based logistics and workflow system to maximise overall automation and minimise human intervention. Also to propose a reference model with industry SOA/ESB standards for inter-process communication and industry standard-based BPE/BPM workflow management system for use by any entity planning or carrying out mass digitisation projects.
6. Optimisation of acquisition, collecting, managing, long-term archiving of digital content, webharvesting, webarchiving.

The strategy development in Topic 1 is evaluation of the state-of-art and trends and new middle term strategy in mass digitisation in Slovakia. High level scientific awards and competitions consist in the implementation of: a) benchmarking of the world best available software and technologies b) accredited quality control testing and certified quality assurance c) implementation and validation of control methods of quality. The project benefits from expertise accumulated in the projects like IMPACT, Europeana, MINERVA etc.

6. Area of conservation and preservation (Topic 2)

A MSCOE researcher has knowledge of the newest technologies and best solutions in the field of mass conservation and digitisation, which will be applied in the project.

In the field of conservation and long-term preservation of analogue media, in 2012-2015 the SNL plans to implement within the DL&DA project the excellent results from the KNIHA SK *Project Preservation, Stabilisation and Conservation of Traditional Carriers of Information in the Slovak Republic* under the state basic research plan [5]. Besides solving technological and scientific issues, the benefit of the project was also in implementing the procedures of a scientific collaboratory [6].

The essential requirements for selecting a system and technology for conservation are contained within the criteria. In the public procurement process, the project will also take into account the *criteria and requirements for technology directly related to the conservation-based preparation of documents for digitisation.* Under the DL&DA project, the complete best available technology of Papersave Swiss (app. 10 mil. €) will be implemented by the SNL in 2013 under the DL&DA project, to be maintained at least until 2020. The SNL as a research partner of the KNIHA SK task possesses the results which can potentially improve the best available Papersave Swiss technology multiple times.

Objectives of Topic 2: Support of research in the field *of mass conservation and preservation (deacidification) sterilisation* through exchange of know-how and experience with partners; recruitment of experienced researchers; specialist dissemination and outreach to innovation capacity building activities. Specific subtopics for research and innovation are focused on the following two areas: 1) Implementation of industry SOA/ESB standards as described in Topic 1 for conservation and preservation technologies with producer's participation to achieve integration with industry standard BPM based workflows and logistics systems. 2) Sterilisation, conservation and digitisation – internal logistics optimisation with respect to achieve optimal performance and usage of these technologies. 3) Conservation – chemical process optimisation with respect to a short treat cycle.

The DL&DA project's goal is to: a) improve technological and technical equipment of laboratories, conservation and preparation worksites for professional treatment, conservation and restoration of items and special collections (library, archival, ...) in a close relationship with the information and communication infrastructure for acquiring, processing and protecting the content; b) implementation of the research results in the field of mass deacidification of ligno-cellulose-based information carriers in heritage institutions, which are directly connected with digitisation.

The potential MSCOE project main partners are Nitrochemie Wimmis AG (Papersave Swiss), the Slovak University of Tech-

nology, BelNovaman International Ltd., and Groupe Eurofins, the Swiss National Library. Transfer of know-how and technology from Nitrochemie and Slovak University of Technology will take place in accordance with the existing agreements (secrecy agreement and business contract between the SNL and Nitrochemie). The SNL also uses know-how within the KNIHA SK research consortium, which includes the Slovak University of Technology, Slovak Academy of Sciences (the Institute of Polymers), and the Slovak National Archives. Preservation of archival and library collections pertains to the main tasks of archives and libraries throughout the world.

Unfortunately, the SNL currently does not employ a new generation of experts in the field of mass conservation of written cultural heritage. This is an opportunity for the MSCOE project. Since 2006 the SNL has been building its Integrated Conservation and Digitisation Centre (ICDC) as its present-day organisational unit.

The ICDC concentrates the following activities: a) mass digitisation and digital archiving of cultural heritage materials; b) conservation (i.e. cleaning, restoration, mass sterilisation, deacidification, lyofilisation) of paper-based library and archival documents; b) research, development and education in the above areas especially under the auspices of the MSCOE.

It is, therefore, necessary to implement the MSCOE project and thus support the building of capacities in research, development and education and to set up the open cooperation in the EU.

Thanks to the effective link established between the academic sectors with cultural heritage sectors the unique approach was conceived which has enabled the development of the DL&DA national project. The uniqueness of the approach rests in mass industrial digitisation and mass industrial conservation *as one integrated technological and functional system.* Such approach is rare on both European and global scale.

7. Area of text analysis and knowledge mining (Topic 3)

The objectives of activities under this topic are: support of research in the field of text analysis and knowledge mining as a component of mass digitisation and digital content reuse through exchange of know-how and experience with partners; recruitment of experienced researchers; upgrading and acquisition of research equipment; specialist dissemination and outreach to innovation capacity building activities.

The outcome of this topic includes affordability, widespread availability of tools and services for releasing the economic potential of cultural heritage in a digital form and for adding value to cultural content in the educational, scientific and leisure context., and a wider range of users of cultural resources in diverse real and virtual contexts and considerably altered ways of experiencing culture in more personalised and adaptive interactive settings.

Upon completion of the national DL&DA project, the Slovak National Library will hold about 270 million pages of text in a digital form. Topic 3 goal is to implement new experiences and trends in working with extensive masses of digital texts. New world's trends show that the digitisation process is not the end of the process, but only its beginning.

Additionally, in presentation of the original content the information society requires options which emerge with the introduction of Web 2.0. For example, this concerns enriched content and supporting context, fostering multilingualism (which means that the original content is viewable and searchable through translation to other languages), and offering web links to already existing knowledge. This information is to be generated directly from the original text, it is not changed, but supplemented in combination with knowledge databases. These requirements also result from the Memorandum of Europeana member libraries as regards the methods of presenting digitised content.

Topic 3 is focused on supporting research using advanced methods of text analysis and natural language processing specialised in the Slovak language. The activities include pre-processing, classification, categorisation, clustering of text and knowledge extraction from source texts aimed at assisting the SNL in making decisions concerning text processing methods applied in mass digitisation processes (structural analysis, metadata assignment, tokenisation, lemmatisation, classification, clustering). There will be clear benefits of this interaction in the fact that currently, researchers concerned with linguistics, artificial intelligence, cybernetics, library and information science have not cooperated so far at a national level, and the national text digitisation project gives them a unique opportunity to apply theoretical knowledge into production practice to the users' benefit.

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Peter Fabian – Juraj Gerlici – Jaroslav Masek – Peter Marton *

VERSATILE, EFFICIENT AND LONG WAGON FOR INTERMODAL TRANSPORT IN EUROPE

This contribution describes the efforts of the multidisciplinary team of University of Zilina in answering the EC FP7 Call for project proposals FP7-SST-2010-RTD-1 SST.2010.2.1-1: Fast implementation of innovative/effective rail technologies to improve rail freight services. The results of the project "VEL-Wagon - Versatile, Efficient and Long Wagon for Intermodal Transport in Europe", approved under the grant No. 265610 should be a key milestone for the efficiency of intermodal freight wagons, since it demonstrated that fewer elements and less dead weight can result in the same or even better transport output, saving material, energy, environment and thus provide more efficient means for transport.

Keywords: *Rail freight, intermodal transport, wagon concept development, multipurpose wagon platform, longer and lighter wagon, dead weight reduction, efficiency of wagon use, capacity increase, market needs.*

1. Introduction

The objective of the EC FP7 2010 Call [1] in Area 7.2.2.1-Logistics and intermodal transport was to improve transport efficiency between and within different modes while recognising their complementarities within a transport system. It included activities for the development of high quality logistics, covering all transport modes. Intermodality in passengers and freight was addressed by activities including seamless and competitive solutions, and, integration of transport hubs (terminals, stations, ports, etc.) in all transport modes.

Among the expected impacts among others was also:

- Maximisation of the cargo capacity of vehicles and vessels within intermodal door-to-door transportation routes,
- Optimisation of logistics services, transportation flows, terminal and infrastructure capacity within European and global supply chains.

The aim of the research under the sub-topic SST.2010.2.1-1-"Fast implementation of innovative/effective rail technologies to improve rail freight services", was to develop technologies and solutions to improve competitiveness of rail freight.

To fulfil these expectations, a project consortium, led by the Technical University of Berlin (TUB) and including participants from the Royal Institute of Technology in Stockholm (KTH), University of Zilina (UNIZA) and Tatravagonka Poprad (TVP), was formed. The proposed project with the name concerned the design of a versatile platform element for a multipurpose function and intermodal use that could bring an important gain of flexibility, accessibility and efficiency of rail freight services.

It investigated the current status of the European freight railway market and, more importantly, it took a look at the trend thereof and its associated logistics. In synchronisation, a wagon engineering activity was launched, for determining the final costs of a solution matching the market requirements.

The project with the name "Versatile, Efficient and Long Wagon for Intermodal Transport in Europe" and acronym "VEL-WAGON" (2011–2012) examined the limits of light wagon construction and the future infrastructure response to the everyday-more-challenging railway traffic (www.vel-wagon.eu). The investigation was initiated with concrete wagon concepts to be examined, namely, 4-axle rigid platforms of 24.384 m to 27,432 m (80ft to 90 ft) length. The outcome was a compromised solution between economic aspects and technical constraints.

2. The analysis

The project was targeting the above mentioned concepts by analysing the future necessities on light and versatile wagons that will deploy better performance and quality to compete against the road. The basic idea of VEL-Wagon was that in the future longer loading surfaces without interruptions, as well as more capable platforms with higher axle loads and with lower loading heights will be necessary to increase the capacity of the freight railway transportation. This can be understood as the current trend follow

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up of enlarging the vehicles of other means of transportation like the Jumbo and Giga-liners trucks.

VEL-Wagon pursued strongly the knowledge expansion in the following subjects:

- Future rail-road intermodal transportation market in Europe, especially when it comes to the utilisation of intermodal transport units (ITU) and freight wagons.
- Future wagonload transportation market in Europe, especially when it comes to conventional wagonloads and freight wagons utilisation.
- Infrastructure limitations, technical and economic, to extended wagon lengths, axle loads and loading gauges. In that context to identify and assess infrastructure capacity enlargements, implications of axle load increases, study suitable corridors and areas of influence of VEL-Wagon.
- Wagon enlargement possibilities, especially when it comes to length between bogie pivots, length between pivots and couplers, loading height and loading gauge for ITUs (also semitrailers) and conventional units, tare weight, heavy solicitations on frame as well as dynamic and static properties of such wagons.
- Economic equilibrium between wagon capacity increase, infrastructure requirements and freight market.

Regarding its effect on the infrastructure and operations, it should contribute to reduce the energy consumption per transported TEU, not only because of offering better loading factors but because of employing less deadweight and fewer axles, approximately 17% saving on energy consumption against a reference case, saving on maintenance (due to reduced number of axles) and reducing the noise emission (due to reduced number of axles).

2.1. Constraints on VEL-WAGON design

The use of large-sized wagons has a long tradition in the rail transport but nevertheless the application of large-scale container wagons for intermodal transport is not as widespread, as it would be appropriate. One of the regions, most strongly represented in the use of large-scale wagons in the world is the North America. In Europe, due to the differences in regulations in particular countries, as well as differences on the regional level, the use of proven solution is very difficult [2].

The specific requirements of different scenarios of the utilisation and technical constraints on the proposed VEL-WAGON output were summarized as follows – Table 1.

It was concluded that the challenging situation from a technical point of view commences from 80ft onwards.

An initial analysis of the loading cases, comparing the articulated version of 24.384 m (80 ft) wagon against non-articulated version of the same length yields led to the proposition of VEL-WAGON technical concept. The benefits of the proposed solution over different modalities are depicted in Fig. 1.

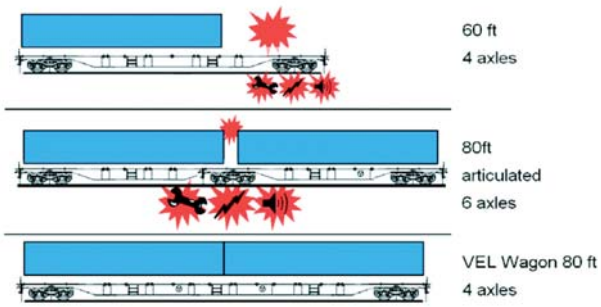

Fig. 1 Benefits of non-articulated VEL-WAGON concept over other possible technical solutions (Source: TVP [3])

Main advantages and disadvantages of competing types of design are summarized in Table 2.

Critical points of VEL-wagon design. (Source: TVP[3]) Table 1

Critical points of VEL-Wagons design				
Wagon lenghth	24,384 m (80 ft)		27,432 m (90 ft)	
Parameter	Advantage	Disadvantage	Advantage	Disadvantage
Sag of car body		+		++
Self-frequency of car body (frame)		+		+++
Kinematics outline (reduction Ec)	+			+
Profile of railway	+		+	
S-curve transition	+			+
Safety – quasi-static conditions Y/Q = 1.2		+	-	++
Safety – during operation Y/Q = 0.8		+	-	++

Non-articulated and articulated wagon's properties summarization (Source: TVP[3]) Table 2

VEL-Wagon 24.384 m (80 ft)-non-articulated	Articulated 24.384 m (80 ft) wagon
Advantages: - lower tare mass - fewer bogies - effective for light transports 6.096 m (20ft), 9.144 m (30ft) and 12.192 m (40ft) units	Advantages: - big mass loading capacity, i.e. high load limit - technical and design parameters - effective for loading by all 6.096 m (20ft) and 12.192 m (40ft) units
Disadvantages: - low mass loading capacity - inefficiency for heavy 6.096 m (20 ft) units, mainly up to 22 t - many design challenges - structural strength, - sag of skeleton wagon, - natural frequency of vertical bending oscillation	Disadvantages: - higher tare mass - higher investment cost - inefficiency for loading by light 6.096 m (20ft) units and in combination with 9.144 m (30ft) and 12.192 m (40ft) units

2.2 Market analysis

The volume of transported freight with the use of intermodal traffic is increasing, needing additional capacity and investment in additional cars. Transport of semitrailers by rail is also on its increase, so there is also need for additional pocket wagons, handling standard semitrailer length of 13.6 m to 13.7 m. The use of longer containers of 12.192 m (40ft) and 13.716 m (45ft) of length is also increasing, so there is a growing need for the use of additional wagons, capable of their transport. The length of 13.716 m (45ft) does not fit with the more common lengths of 6.096 m (20ft) and 12.192 m (40ft), but it closely matches 13.7 m.

Thus, there is a need for new pocket wagons able to carry 13.7 m semitrailers as well as 12.192 m (40ft) and 13.716 m (45ft) containers and swap bodies.

After analysing the needs of intermodal traffics (hinterland and continental), it can be concluded that an 24.384 m (80ft) container wagon for ISO-containers and swap bodies would offer an important improvement in terms of logistics and energy efficiency [4].

Longer loading lengths – 25.908 (85ft) and 27.432 m (90ft) – could have an advantage too, but only if the 45ft unit is widely introduced and if it dominates in intermodal traffics, which is not the current case. A revision of this issue has to take place in approximately 5 years.

On the other hand, an 24.384 m (80ft) pocket wagon is an interesting solution for continental transports.

It would target mainstream traffic flows with great diversity on unit types, including semitrailers. However, the available solutions in the market [5] for the transportation of only semitrailers would offer a better performance at this time. This issue together with the 13.716 m (45ft) unit issue, have to be re-examined in about 5 years.

Hence, a 24.384 m (80ft) wagon without pocket, suitable only for the transportation of containers and swap bodies, could be more competitive than other wagons in its market range.

3. Design and modelling of VEL-WAGON

As a result of the above mentioned analysis and simulations, the final variant of the VEL-WAGON parameters was chosen [6] and used for design of the model and its static and dynamic evaluation. This 4 – axle freight wagon for transportation of ISO containers and swap bodies – meets description TSI-WAG, valid regulations UIC, agreement on the reciprocal use of freight wagons in international traffic AVV (RIV), ERRI recommendations and EN standards. The wagon is suitable for transport of ISO containers 6.096 m (20ft), 7.9248 m (26ft), 9.144 m (30ft), 12.192 m (40ft) and 13.716 m (45ft) according to UIC 592-2, class 1 and swap bodies 12.192 m (40ft) according UIC 592-4.

The requirements specified in previous sections led to the design with geometric parameters of the wagon shown in Table 3:

Geometric parameters of VEL-WAGON (Source [6]) Table 3

Length over buffers	25 940 mm	Draw gear height from top of rail	1 005 +10-0 mm
Loading length	24 700 mm	Wheel base of bogie	1 800 mm
Pivots Distance	18 000 mm	Gauge of track	1 435 mm
Lading height	1 090 mm	Wheel diameter	920 mm
Buffer axis height	1 025 +10-0 mm		

Weight parameters of the proposed wagon are as follows:

Mass of unoccupied coach – 21.5 t ± 3 %, maximum mass of occupied coach 90 t, maximum mass of load 68.5 t, maximum axle load 22.5 t.

The considered **speed parameters** are as follows:

Highest construction speed 120 km/h, highest operating speed for the weight of 20t / axle – 120 km/h, highest operating speed for the weight of 22.5t / axle 100 km/h.

The 3D model of the proposed wagon design is shown in Fig. 2.

The model was used for extensive static and dynamic testing, which confirmed the feasibility of the proposed parameters and design.

3.1 Static analysis

The results of static analysis proved that the designed construction meets the EN 12663-2 technical requests. The virtual simulation tests (described in detail in [6]) were performed – Fig. 3:

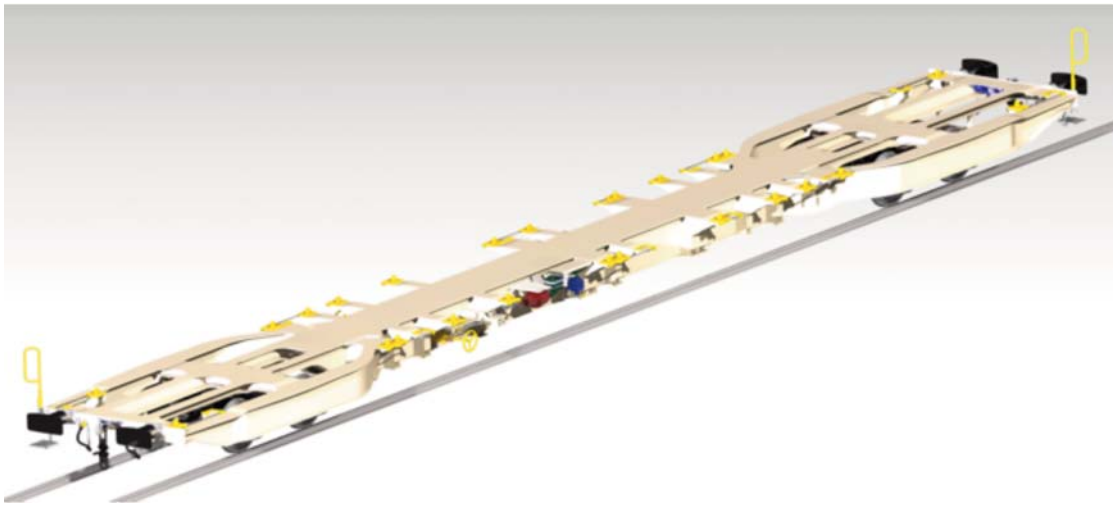

Fig. 2 VEL-WAGON 3D model used for modelling and simulations (Source [6])

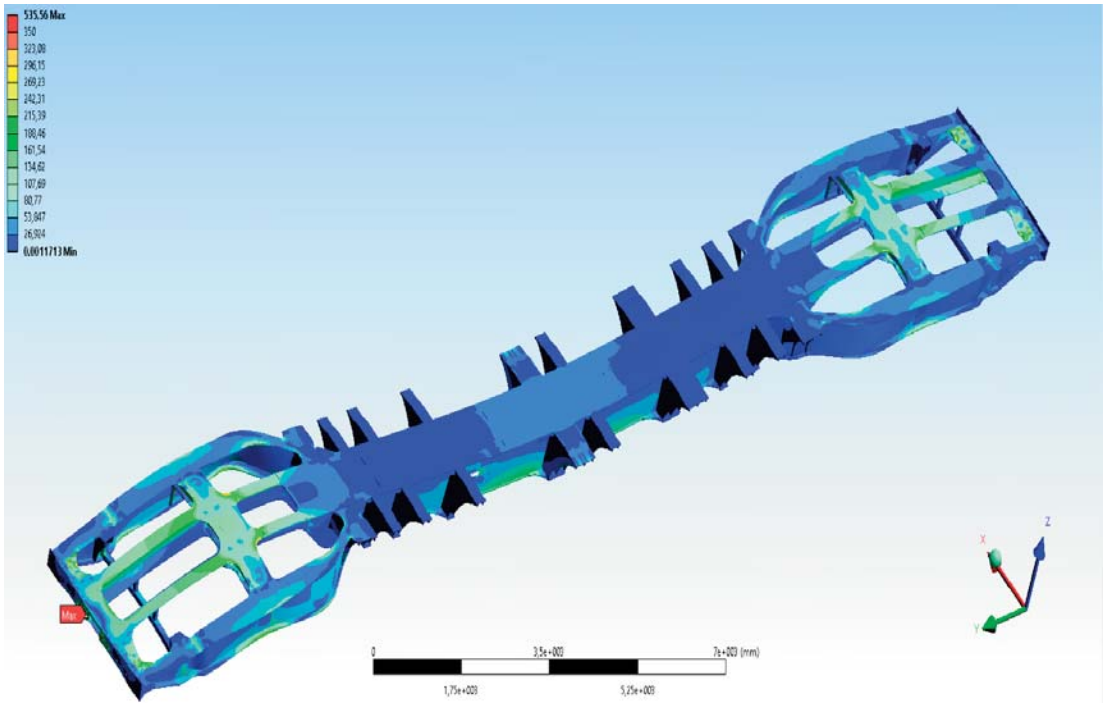

Fig. 3 Reduced stresses distribution in the wagon model (Source [6])

a. Modal analysis.
b. Wagon torsional stiffness computation.
c. Maximum vertical load force.
d. Wagon rising on one side – in the determined points.
e. All wagon rising.
f. Load combination- Press load in buffers and vertical load (loaded wagon).
g. Load combination- Pull load in coupling device and vertical load (loaded wagon).

In the first case, the eigenfrequency and eigenshapes (eigenvalues) were evaluated in the case, when the vehicle is bound with the bogie by means of ball pins and flexible sliding shoes. In the second case, the bogie torsional rigidity was investigated. This parameter has an important influence on the safety against derailment when the vehicle enters the track in a radius. This rigidity is relatively high which is caused by a closed design of a main wagon slide sill. The evaluated stresses exceed the permitted values only in some of the metal plates' connections which is caused by the local computational model mesh formulation or by the sharp edged crossing between plates. In the case of the real wagon production intention, it is recommended to pay increased attention to these spots from the point of view of production background (material quality, technology of welding, or parts connection) and so on. The results prove that the vehicle design meets EN 12663-2 requirements.

3.2 Dynamic evaluation

The dynamics analysis was performed in accordance with the technical parameters for two track sections in Cerhenice railway test track circuit. In the first case, the track with 450 m radius (see Fig. 4) was used and in the second case the straight track and the velocity of 100 km/h were considered.

The geometric characteristics of railway wheel-set and track (Equivalent conicity and Delta-R function) were evaluated for the profiles contact couples S1002 for wheel, UIC60 and R65 rail with inclinations of 1:20 and 1:40 (straight track) and for the profiles contact couples S1002 for wheel, S49 rail with inclinations of 1:20 and 1:40 (radius R450 m).

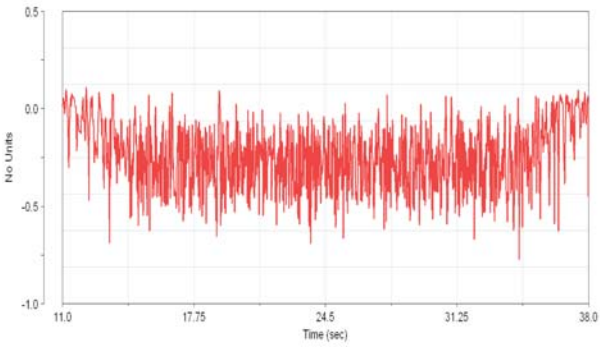

Fig. 4 Safety against derailment - curve - first wheel-set - R = 450m (Source [6])

The geometric characteristics analysis for both cases was completed with the Equivalent conicity and Delta–R function characteristics set for different gauges values (in the interval of 1432–1448 mm).

In order to analyse the safety against derailment, the accelerations, wheel vertical forces and leading lateral forces values were evaluated. In both cases, the safety against derailment values were in the interval of safe operation.

4. Conclusions

The performed simulations of the proposed VEL-Wagon use for the freight train composition instead of currently used wagons show that an 24.384 m (80ft) VEL-Wagon for intermodal transport can lead to better loading factor of trains (10% more TEU per length (vs. REF due to better arrangement of units).

The use of fewer axles per length implies:
- less energy consumption (decreased rolling resistance, less deadweight),
- less maintenance,
- less noise (fewer axles with increased axle load),
- better aerodynamics (fewer bogies and fewer gaps between containers),
- lower cost per transported unit load that is also a prerequisite for higher market share for intermodal transport.

The potential market of VEL-Wagon embraces the whole European Intermodal Market (Container transport and Swap Body transport) and part of the conventional railway freight market, the one dedicated to the light products.

A similar innovative wagon produced by Tatravagonka Poprad was implemented by METRANS, an intermodal and railway company which already bought an important batch of wagons. These units are however not the full version of VEL-Wagon, just a commercial application of its partial results.

VEL-Wagon implies a challenge for the technology because it opens the door for more capable wagons with lower tare and higher speed. It represents a gain in loading factors and a better arrangement for diverse and multiple loading schemes of containers and swap bodies. It is a wagon that is adapted better to the trend of having lighter containers, more prone to be volumetric loads than dense loads. Finally, it represents a challenge for the regulations, specifically when it comes to the certification of new wagons, whose dimensions go beyond the standards regulated by the norms. As the trends in the waterborne-, air- and road transport show, the vessels, planes and road vehicles tend to grow in size, so it can be expected that also longer, more capable wagons will be needed in the future.

The results of the project were submitted to the contest at the Green Corridors Day in Sweden among 31 contestants. VEL-Wagon was chosen by the Jury and on 12. 12. 2012 received from

Fig. 5 Best Green Corridor Project Award

the Swedish Traffic Administration Trafikverket the award as the Best Green Corridor project – Fig. 5.

Acknowledgement

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Pavol Kohut – Gustav Kasanicky *

EVALUATION OF CRASH TESTS OF THE INSTITUTE OF FORENSIC ENGINEERING, UNIVERSITY OF ZILINA, AIMED AT EES

For the proper analysis of traffic accidents it is important to properly evaluate the deformation work of a vehicle deformation based on the extent of damage of the vehicle. The Institute of Forensic Engineering, University of Zilina, made a series of vehicles crash tests focused on the evaluation of the vehicle deformation work. The article focuses the on evaluation of the vehicle deformation work or of the EES (energy equivalent speed) and comparison of stiffness tests of cars (production year around 2000) and older generation of vehicles (which were subject of tests - Crash tests DSD LINZ 1996).

Keywords: *Crash test, deformation work, EES (energy equivalent speed), deceleration, deformation depth, stiffness.*

1. Preface

The Institute of Forensic Engineering, University of Zilina, made in the course of 2012 a series of 5 vehicles crash tests focused on the evaluation of the vehicle deformation work, or of the EES of a vehicle, upon its impact with a fixed, non-deformable barrier with a full overlap.

2. Conditions of crash tests

2.1. Crash vehicles

For crash tests we used 5 vehicles with the age structure shown in Table 1. By yellow colour is highlighted a period when a given type of vehicle was produced, and by a red dot is marked the production year of the vehicle used in the crash test.

Photo documentation of individual vehicles before relevant crash test, including Euro NCAP evaluation of a given vehicle, is shown in Fig. 1.

2.2 Crash barrier

In the crash tests the vehicles were accelerated to the impact velocity by the Mercedes trailer and a pulley system, and they crashed into a solid concrete barrier of weight 10,000 kg (see Fig. 2).

But the given weight of the barrier was not sufficient to ensure a condition that no significant displacement of the barrier occurs, and therefore, the barrier was fixed using a blade of a recovery tank of weight 35,000 kg (see Fig. 3).

Age composition of vehicles — Table 1

	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005
Nissan Primera							●						
Renault Laguna							●						
Renault Scenic							●						
Audi A6								●					
Honda Accord									●				

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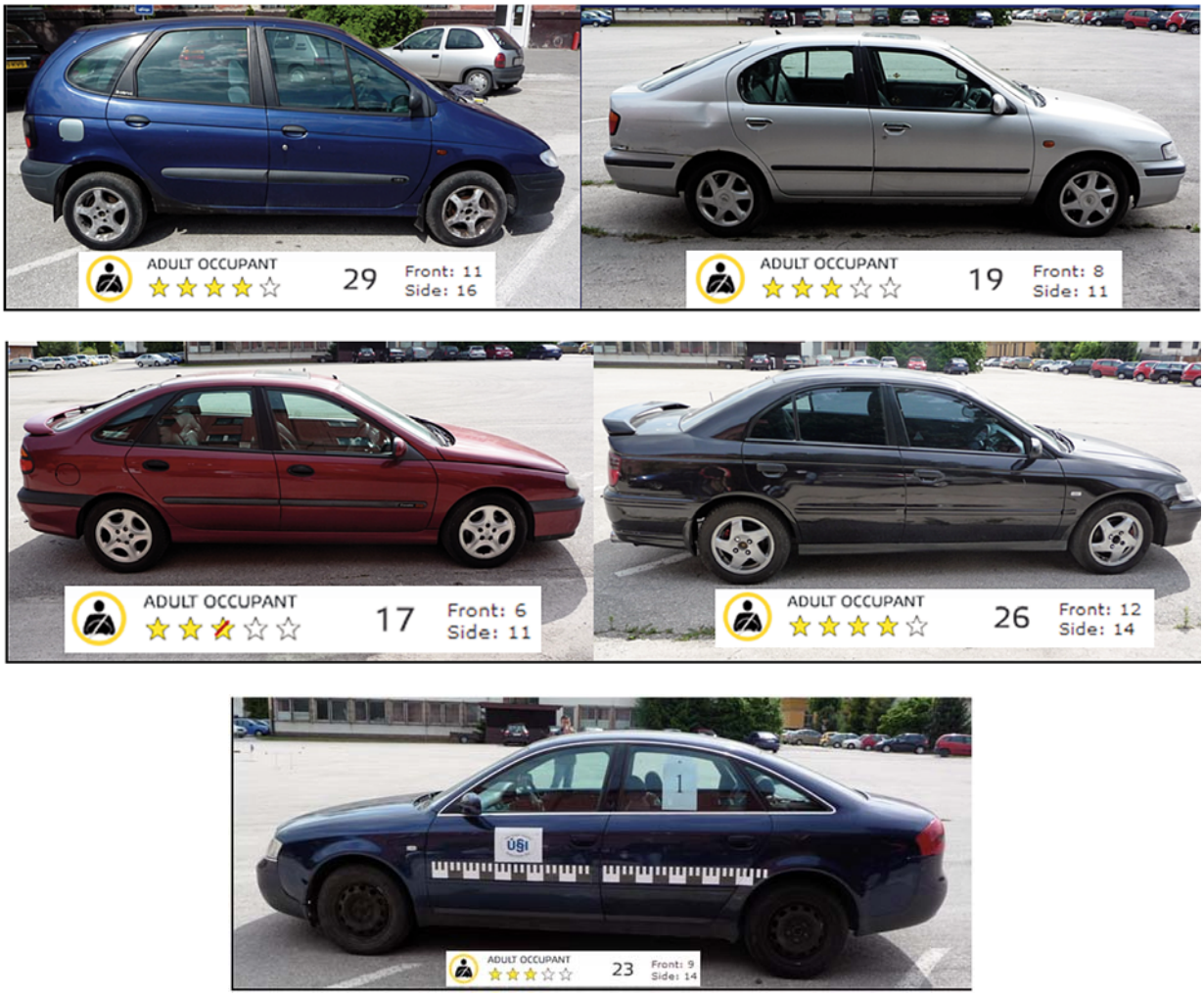

Fig. 1 Photo documentation of passenger cars (before crash test)

Fig. 2 Concrete solid barrier

Fig. 3 Recovery tank

3. The results of crash tests

The following photos show (Figs. 4, 5, 6, 7 and 8) the damage to the vehicles after given crash tests, while in the description of the photo is always included the EES value, corresponding to the given damage.

Fig. 4 Damage of the car Nissan Primera (EES = 54 km/h)

Fig. 5 Damage of the car Renault Laguna (EES = 62 km/h)

Fig. 6 Damage of the car Renault Megane Scenic (EES = 72 km/h)

Fig. 7 Damage of the car Honda Accord (EES = 58 km/h)

Fig. 8 Damage of the car Audi (EES = 18 km/h)

The course of a vehicle deceleration was captured by the crash meter, while the time-depending course of Renault Laguna vehicle deceleration is shown in Fig. 9.

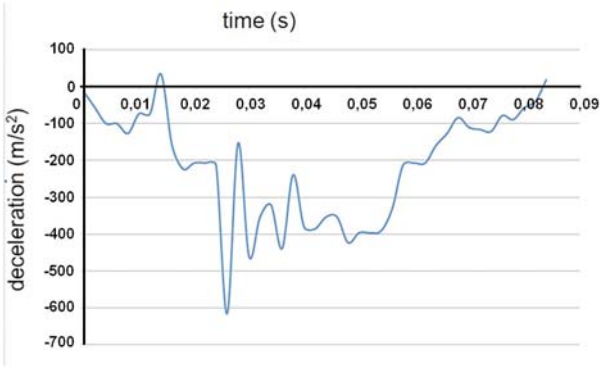

Fig. 9 Time – deceleration diagram

In Fig. 9 above is recognizable considerable oscillation caused by the natural frequency of the measuring device, by a fixing method of the measuring device, as well as by the oscillation of the measuring point (trunk floor of the vehicle) during the impact. For further evaluation it was therefore necessary to filter out the resulting oscillation, and thus the time-depending course of deceleration of the given vehicle was obtained (for each vehicle). In Fig. 10 the filtered course for Renault Laguna vehicle is shown.

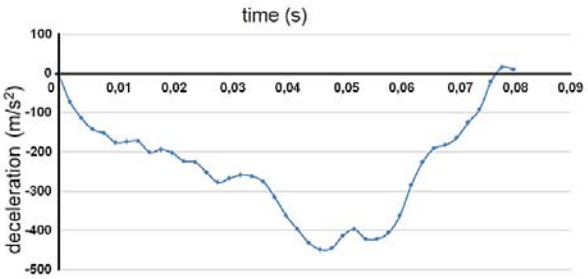

Fig. 10 Time - deceleration diagram (Renault Laguna)

The time-depending course of deceleration was integrated according to the following formula:

$$v = \int_{t_0}^{t_1} a(t)dt$$

where: $a(t)$ – time-depending course of deceleration.

By the mentioned integration the time-depending course of the velocity was obtained. This course was consequently integrated by the following formula:

$$s = \int_{t_0}^{t_1} v(t)dt$$

where: $v(t)$ – time-depending course of the velocity.

Consequently, from the obtained data of the path and deceleration a path-deceleration diagram was constructed (during the tests). In Figs. 11, 12 and 13 the individual diagrams for the tested vehicles are shown. For Renault Megane Scenic vehicle, the crash meter broke down and the correct record was not captured.

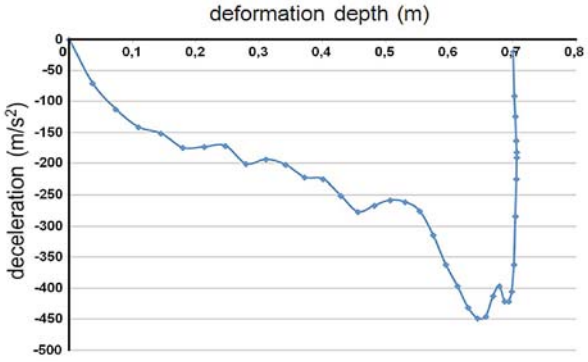

Fig. 11 Deformation depth - Deceleration diagram (Renault Laguna - EES = 62 km/h)

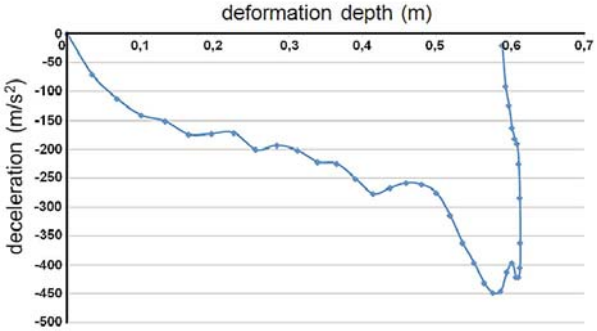

Fig. 12 Deformation depth - Deceleration diagram (Honda Accord - EES = 58 km/h)

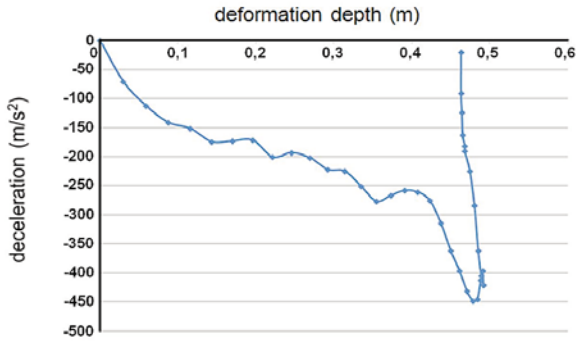

Fig. 13 Deformation depth - Deceleration diagram (Nissan Primera - EES = 54 km/h)

In all three diagrams the course of deceleration depending on the deformation depth can be divided into three approximately linear areas with characteristic points A and B (see Fig. 14).

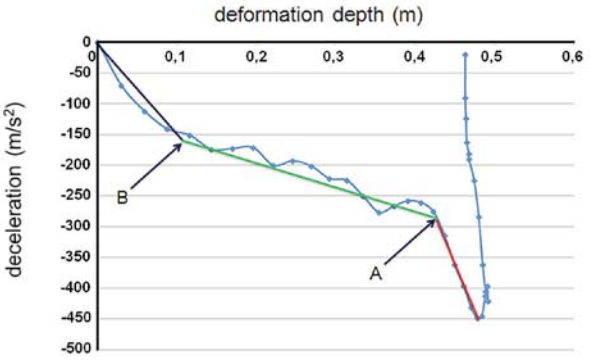

Fig. 14 Deformation depth - Deceleration diagram (Nissan Primera - EES = 54 km/h)

From a comparison of the diagrams follows:

1. The position of point B (approximately 0.1 m and 150 m/s^2) is almost identical for all three vehicles (Nissan Primera, Honda Accord and Renault Laguna).
2. The position of point B in terms of achieved deceleration (approximately 300 m/s^2) is almost identical.
3. The position of point B in terms of deformation depth is similar for the vehicles Honda Accord and Renault Laguna (about 0.53 meters), and different in comparison to the vehicle Nissan for about 0.43 m.

For comparison of the presented diagrams with an older generation of vehicles an analogous procedure with 4 crash tests of a Ford Escort vehicle was performed. It was executed by the company DSD LINZ (Austria) in 1996 [1]. The given courses and impact velocity for a given crash test are shown in Fig. 15.

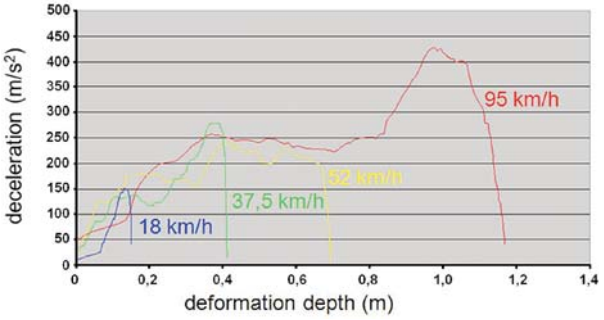

Fig. 15 Deformation depth - Deceleration diagram (Ford Escort - DSD LINZ 1996)

From the comparison of deceleration courses depending on the deformation depth for the vehicles Ford Escort (year of man-

ufacture about 1986) versus crash tests performed by the Institute of Forensic Engineering, University of Zilina (see Fig. 16) it can be stated that for the vehicles produced around 2000, there is almost a linear increase between the points marked as A and B. Consequently, from point B there is a significant increase of deceleration which means a significant increase of stiffness at the deformation depth of 0.5 m.

For the vehicles Ford Escort an area could be identified where the deceleration was almost constant within a relatively large range of the deformation depth. Such effect was not detected for the vehicles tested by the Institute of Forensic Engineering, University of Zilina. A significant increase of deceleration (and hence stiffness) for the vehicles Ford Escort occurs only at the deformation depth of about 0.85 m.

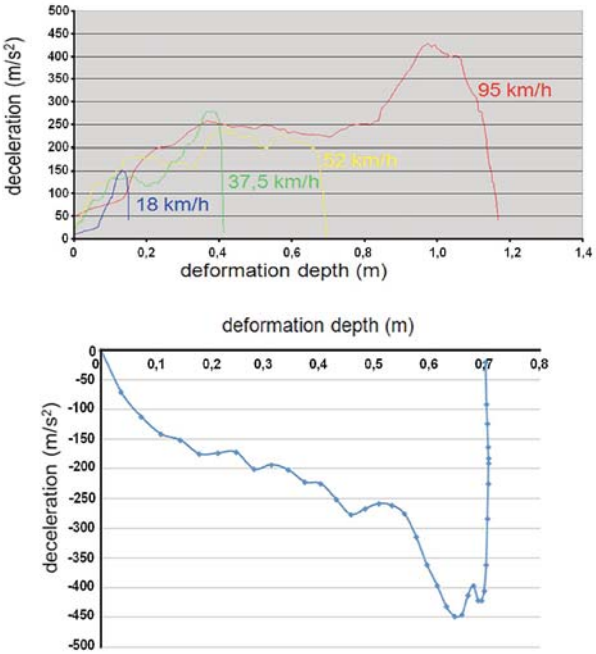

Fig. 16 Comparison Deformation depth – Deceleration diagrams of cars Ford Escort (Crash tests DSD LINZ 1996) and Renault Laguna (Crash tests Institute of Forensic Engineering, University of Zilina 2012)

4. Conclusion

From the tests performed it is concluded that for the newer generation of vehicles – production year around 2000 it will be more difficult to properly identify the EES of the given vehicle (under conditions where EES exceeds 50 km/h) versus the older generation of vehicles (which were subject of tests – Crash tests DSD LINZ 1996). This is due to the significantly different course of deceleration and, therefore, also due to the course of stiffness of vehicles, at crash velocities above 50 km/h. Such difference is evident also from the comparison of the extent of damage, as shown in Fig. 17.

Fig. 17 Comparison damage of cars Ford Escort (Crash tests DSD LINZ 1996) and test car Nissan Primera (Crash tests Institute of Forensic Engineering, University of Zilina 2012) [2]

The significant difference between the vehicles Ford Escort and vehicles tested by the Institute of Forensic Engineering, University of Zilina is reflected also in terms of dependency of a shorter wheelbase and impact velocity (see Fig. 18).

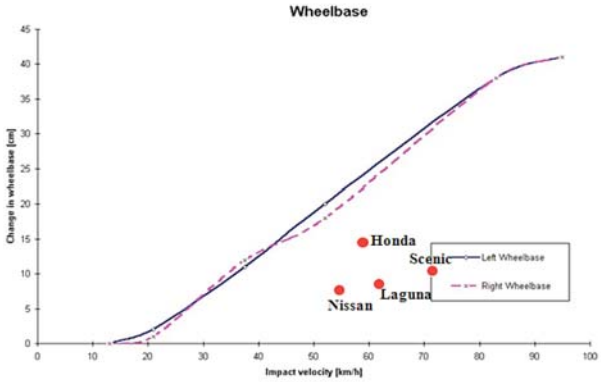

Fig. 18 - Comparison Change in wheelbase for cars Ford Escort (Crash tests DSD LINZ 1996) and for test cars Honda Accord, Nissan Primera, Renault Laguna and Renault Megane Scenic (Crash tests Institute of Forensic Engineering, University of Zilina) [2]

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[2] CD DSD LINZ, 1996.

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PHYSICOCHEMICAL PROPERTIES OF WATER COURSES IN TATRA NATIONAL PARK

The aim of this study is to present an informative overview of the physicochemical properties of a representative sample of water courses located within Tatra National Park. The water quality of 28 selected water courses was monitored at altitudes from 639 to 2002 m a.s.l. Water temperature, pH, conductivity, concentrations of total dissolved solids, salinity and dissolved oxygen were measured from June to October 2010. The concentration of dissolved oxygen ranged from 5.90 to 16.46 mg/l, conductivity ranged from 5.30 to 282.60 μS/cm and pH averaged 7.25. An inverse relationship was found between nitrate and altitude as well as between conductivity and altitude. Measurements were consistent with the rating for very pure water. The results obtained serve as initial findings and form the basis for further biotic monitoring of water quality in the Tatra Mountains.

Keywords: *Physicochemical, Tatra Mountains, water courses, water quality.*

1. Introduction

The habitats of Tatra National Park (TANAP) have undergone significant environmental impacts, especially in the last decade. A storm in 2004 caused substantial damage to forest stands. Changes in vegetation cover, including deforestation, usually result in disruption of biochemical cycles, hydrology and ecology in terrestrial and aquatic environments [1].

Surface water courses are a very important component of mountain environments. Their properties reflect both natural and anthropogenic processes [1, 2]. Climate, geology, topography as well as soil and vegetation cover are some of the main factors affecting water quality [3, 4]. Contrary to lowlands, where the vertical flow of nutrients in the soil-plant-atmosphere system predominates, the system in mountains depends more on various phenomena mutually interconnected to altitude [5].

Changes in the retention potential of subalpine areas have an indirect impact on other physicochemical parameters of mountain streams. In recent years there has been a significant loss of water run-off volume at some locations, especially in summer months. This situation has a direct impact on the climate of the locations. Globally, we can expect a trend towards a gradual increase in ambient temperatures in mountainous areas. High mountain ecosystems represent unique areas for the detection of climate change and the assessment of climate-related impacts [6]. Climate change associated with global warming is more pronounced at higher elevations [7]. The main ecological driving force is climate, with temperature and duration of snow cover as key factors [8]. Changes in air temperature can extend the length of the average annual growing season [9] and can also cause a shift in phenology [10].

The characteristic features of well-functioning landscapes are effectively operating nutrient cycles, balanced drainage conditions and minimal losses of nutrients by transport. The basic parameters for evaluating function and surface temperature oscillations are the quality of surface water run-off and its dynamics. These parameters can be considered as integral values where the values of spatial distribution and temporal variability are reflected in the key functional processes occurring in the biocenosis and their interaction with the environment [11]. Physicochemical parameters of water quality status reflect natural and anthropogenic changes in conditional land use [1].

The chemistry of surface water is very variable. Rainfall and snow have a considerable impact on stream water chemistry. Streams formed mainly by rainwater have a low content of soluble substances [12]. Human activities (combustion, traffic, emissions from agricultural and industrial plants) have a marked influence on atmospheric pollution and cause different types of environmental stress. They have a negative influence on human health as well as forest, soil, surface and groundwater quality.

The aim of this study was to obtain an informative overview of physicochemical properties of individual water courses located within TANAP in order to define their water quality. Spatial monitoring enabled us to compare water quality between streams independent of inter-annual fluctuations. The data obtained will serve as the basis for further studies. Subsequent, continuous monitoring of water courses within TANAP will provide a view of the dynamics

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Fig. 1 Selected water courses in the Tatra National Park

of changes in the selected parameters according to anthropogenic impacts and climate change.

2. Material and methods

Study area

The Tatras are the highest mountains in the Western Carpathians and lie on the border between Slovakia and Poland. The southern part reaches into the Sub-Tatra Basin and northern part into the Sub-Tatra Trough. The High Tatra Mts. represent a typical fold mountain range composed of igneous rock [13]. The geology of the study area is based on crystalline bedrock. The Tatra Mts. contain significant biotite tonalities and granodiorites, locally porphyritic and also porphyritic granodiorites and granites [14]. The Western Tatra Mts. contain a significant amount of metamorphic rock (gneiss and mica schist) in addition to granodiorite [15]. The massif of the Tatra Mts. forms a European watershed [16]. The River Vah, rising in the Tatra Mts., flows to the Black Sea via the Danube, while the Poprad and Dunajec Rivers flow towards the Baltic Sea. Vegetation in the alpine zone of the Tatras is dominated by meadows with patches of dwarf pine (Pinus mugo) and, above the upper tree line at 1800 m a.s.l., a higher percentage of bare or lichen-covered rocks [17]. The area generally falls into the cold mountain zone with average temperatures <10 °C in June. The lower parts and submontane areas belong to the lower mountain zone, with average temperatures of 12 – 16 °C. Annual precipitation ranges from 600 mm in foothills to over 2000 mm at the highest altitudes [18].

Sampling

The research was carried out during the vegetation period, from June to October 2010. During this period, 28 water courses were monitored in TANAP. Samples were taken from four sites along an altitudinal gradient from montane up to the alpine region, 639 - 2002 m a.s.l. The following water courses were monitored in the east of the High Tatras: Biela voda (BIVO1-6), Javorinka (JAV1-6), Biela (BIE1-5), Kezmarska Biela voda (KBV1-5), Skalnaty potok (SKA1-5), Maly Studeny potok (MSTU1-4) and Velky Studeny potok (VSTU1-3) – which converge to form Studeny potok (STU4-6), Slavkovsky potok (SLA1-4), Velicky potok (VEL1-5), Batizovsky potok (BAT1-4), Velky Sum (VSUM1-3), Poprad (POP1-5), Mlynica (MLY1-5), Biely Vah (BVA1-4) and Beliansky potok (BEL1,2). In the west, the following water courses were selected: Tichy potok (TICH1-4) and Koprovsky potok (KOP1-4) – which converge to form the Bela (BELA1, 2), Kamenisty potok (KAM1-4), Bystra (BYS1-4), Rackov potok (RAC1-5), Jamnicky potok (JAM1-3), Smrecianka (SMR1-4), Jalovecky potok (JAL1-4), Suchy potok (SUCH1-4), Latana (LAT1-3), Rohacsky potok (ROH1-4) Studeny potok (STU) and Bobrovecky potok (BOB1-4) (Fig. 1). The selected water courses are described in [19, 13] and [20]. Each sampling site was fixed by GPS (WGS84 system, Decimal Degree Format).

At each sampling site, physical parameters such as pH (YSI pH100, YSI Inc., Ohio, USA), water temperature, conductivity (COND), concentrations of total dissolved solids (TDS), salinity (YSI EC300, YSI Inc., Ohio, USA) and dissolved oxygen (DO) (YSI DO200, YSI Inc., Ohio, USA) were measured in “in situ”

conditions. Current weather, bank characteristics and potential sources of pollution were also recorded.

The following sources of pollution was detected in the selected areas of water courses:

Biela voda (BIVO1-6) – tourism, cottage
Javorinka (JAV1-6) – tourism, village Tatranska Javorina, logging
Biela (BIE1-5) – logging, Strednica ski resort, hotel Magura, cottages, village Zdiar
Kezmarska Biela voda (KBV1-5) – cottage at Zelene pleso, tourism, logging
Skalnaty potok (SKA1-5) – Encian hotel, ski resort TMR, logging, build-up area
Studeny potok (STU4-6) – Tery cottage, Zbojnicka cottage, tourism,
Slavkovsky potok (SLA1-4) – tourism, logging, build-up area
Velicky potok (VEL1-5) – Sliezky dom hotel, tourism, build-up area
Batizovsky potok (BAT1-4) – cottage, logging, buid-up area
Velky Sum (VSUM1-3) – logging, build-up area
Poprad (POP1-5) – Popradske pleso hotel, tourism, agriculture, build-up area
Mlynica (MLY1-5) – tourism, Strbske pleso, agriculture, build-up area
Biely Vah (BVA1-4) – tourism, agriculture, build-up area
Beliansky potok (BEL1,2) – tourism, Tri studnicky cottage, logging
Tichy potok (TICH1-4) – tourism, Podbanske village
Koprovsky potok (KOP1-4) - tourism
Bela (BELA1, 2) – build-up area, agriculture
Kamenisty potok (KAM1-4) – tourism, cottages
Bystra (BYS1-4) – tourism, cottages
Rackov potok (RAC1-5) – tourism, build-up area
Jamnicky potok (JAM1-3) - tourism
Smrecianka (SMR1-4) – Ziarska cottage, tourism, build-up area, logging
Jalovecky potok (JAL1-4) – tourism, build-up area
Suchy potok (SUCH1-4) – cottage, Liptovske Matiasavce village
Latana (LAT1-3) – tourism, cottages
Rohacsky potok (ROH1-4) – Tatliakova cottage, Spalena ski resort
Bobrovecky potok (BOB1-4) – tourism, cottage, logging

Air temperature was measured at approximately 1 m above ground.

Similar chemical parameters were determined. Water was collected from the middle of the stream depth using sterile polyethylene bottles (500 ml). Conservation and transportation of samples were performed according to [21].

Laboratory analyses

Concentrations of ammonium ions (NH_4^+), nitrate (NO_3^-) and chloride ions (Cl^-) were determined colorimetrically (YSI 9500 Photometer, YSI Inc., Ohio, USA). Total hardness (chelatometric titration) and chemical oxygen demand (COD) (manganometric titration) [22] were determined in the laboratory by titration. All chemical parameters were determined within 24 hours. All statistical analyses were performed with Statistica 8 software.

3. Results

Dissolved oxygen was found to range from 5.90 mg/l to 16.46 mg/l and oxygen saturation from 45.70 to 122.63%. The lowest value of DO was measured in Batizovsky stream (sampling site BAT1) and the highest in Biela (sampling site BIE6). DO decreased with increasing elevation. Concentrations began to decline as the water temperature rose (Fig. 2).

pH values were between 6.16 and 8.54. Most water courses had a close to neutral pH. Only two streams, Biela and Suchy potok, had an alkaline character (>8). pH was inversely proportional to elevation (Fig. 3).

Conductivity ranged from 5.30 to 282.60 µS/cm, with an average of 36.3 µS/cm. However, in most water courses CON was <96 µS/cm. A CON value greater than 100 µS/cm was found in two streams: Biela (100.80 – 149.80 µS/cm) and Suchy potok (195.50 – 282.60 µS/cm). An inverse relationship between altitude and conductivity was apparent (Fig. 4).

The water courses under study were generally very soft (e.g. Skalnaty potok, Studeny potok, Biely Vah, Smrecianka, Kamenisty potok etc.) or soft with a transition to medium hard water at a lower altitude with active anthropogenic activities (Biela, Bobrovecky potok, Javorinka). Suchy potok in the Western Tatras had moderately hard water.

COD concentration in most water courses did not exceed the limit of 3.00 mg/l. Water samples from streams flowing through areas with anthropogenic activity had COD concentrations above 3.00 mg/l: Skalnaty potok 3.71 mg/l (736 m a.s.l.), Slavkovsky potok 3.81 mg/l (676 m), Velicky potok 4.51 mg/l (689 m), Batizovsky potok 3.95 mg/l (749 m), Mlynica 3.60 mg/l (859 m).

The limit value for ammonium ions (NH_4^+) in surface water is set at 1.00 mg/l. Our measurements of NH_4^+ did not exceed this limit, with observed values ranging between 0.00 and 0.37 mg/l. The concentration of NH4+ did not exceed the value of 0.10 mg/l in most water courses, although higher concentrations were observed in three streams: Skalnaty potok (SKA2) 0.21 mg/l, Batizovsky potok (BAT4) 0.23 mg/l and Velicky potok (VEL1) 0.37 mg/l. No relationship between ammonium and altitude was observed (Fig. 5).

Measurements of nitrate anions ranged from 0.42 to 4.34 mg/l. The highest value was observed in Mlynica stream (859 m a.s.l.) and the lowest value in Kamenisty potok (1633 m). The mean concentration was 1.17 mg/l. A positive correlation was found between TDS and concentration of nitrate ions. There was an inverse relationship between nitrate and elevation (Fig. 5).

Measurements of chlorides ranged from 0.00 to 4.70 mg/l, with a mean of 0.50 mg/l. The highest value was found in Mlynica. Zero values of C^- anions were observed in the following water courses: Bielka (953 m a.s.l.), Velky Sum (1109 m), Poprad (1267 m), Mlynica (1488 m), Kamenisty potok (1633 m), Rackov potok

Comparative measurements of physicochemical properties of Tatra streams in alpine and pine habitats (2010 year) Table 1

ID	Collection date	T of water [°C]	pH	ORP [mV]	COND [µS/cm]	TDS [mg/l]	salinita [ppt]	dissolved oxygen [mg/l]	dissolved oxygen [%]	COD_{Mn} [mg/l O]	$CaCO_3$ [mg/l]	[°dH]	NO_3 [mg/l]	NH_4 [mg/l]	Cl [mg/l]	altitude [m asl]
JAV1	15.6.2010	2.5	6.92	302	9.9	11.8	0.0	12.54	91.5	1.066	5.305	0.297	0.945	0.02	0.2	1885
MSTU1	30.6.2010	6.4	6.46	304	5.3	5.4	0.0	11.64	94.6	1.440	3.336	0.187	1.116	0.00	1.0	2002
MSTU2	30.6.2010	10.0	6.48	292	5.8	5.4	0.0	10.37	92.0	1.333	5.338	0.299	1.037	0.00	0.6	1939
VEL1	6.7.2010	4.1	6.49	316	5.8	6.4	0.0	12.66	95.9	0.613	5.004	0.280	1.037	0.37	1.2	1947
BAT1	8.7.2010	4.8	6.16	299	6.2	6.6	0.0	5.90	45.7	0.080	3.003	0.168	0.859	0.00	0.4	1893
MLY1	12.7.2010	6.8	6.99	300	10.1	10.1	0.0	11.02	90.3	0.720	6.673	0.373	1.546	0.03	0.6	1892
JAV2	15.6.2010	3.7	6.73	294	11.8	13.3	0.0	12.79	95.3	0.587	7.006	0.392	0.799	0.01	0.2	1601
JAV3	15.6.2010	5.4	7.19	270	14.7	15.2	0.0	12.44	98.4	0.933	10.339	0.578	0.882	0.01	0.1	1514
BIVO1	27.6.2010	5.6	6.90	300	10.7	11.3	0.0	12.69	96.8	0.960	3.336	0.187	0.882	0.00	0.3	1637
KBV1	28.6.2010	6.9	6.65	298	6.3	6.4	0.0	11.66	96.0	0.800	5.338	0.299	0.619	0.04	0.3	1560
KBV2	28.6.2010	5.3	6.87	285	9.5	10.0	0.0	12.28	96.4	0.773	6.673	0.373	0.911	0.04	0.5	1529
SKA1	29.6.2010	11.0	6.46	295	7.5	6.6	0.0	9.99	90.7	0.533	4.337	0.243	0.713	0.09	0.2	1745
VSTU1	1.7.2010	9.6	6.42	304	6.5	6.1	0.0	10.50	91.9	0.960	5.338	0.299	0.638	0.03	0.3	1746
VSTU2	1.7.2010	10.4	6.65	310	7.0	6.4	0.0	10.33	91.7	1.093	5.672	0.317	0.855	0.03	0.5	1603
VEL2	6.7.2010	9.4	6.76	314	7.7	7.2	0.0	10.73	93.2	2.400	7.339	0.411	0.899	0.08	1.0	1664
POP-H2	10.7.2010	7.2	7.30	282	16.5	16.5	0.0	11.69	96.1	0.507	12.010	0.672	1.032	0.03	0.1	1505
MLY2	12.7.2010	12.7	7.12	352	12.8	11.1	0.0	9.88	92.1	0.533	8.841	0.495	1.648	0.01	0.4	1685
BVA1	13.7.2010	5.9	6.62	348	10.6	10.9	0.0	11.55	93.0	0.373	5.672	0.317	1.201	0.00	0.2	1836
SMR1	22.7.2010	6.7	7.25	268	20.2	20.2	0.0	11.62	95.0	0.373	15.013	0.840	0.501	0.01	0.1	1631
KAM1	3.8.2010	6.5	7.01	280	14.5	14.5	0.0	12.39	100.1	0.693	10.009	0.560	0.421	0.01	0.0	1633
BYS1	11.8.2010	9.6	6.83	272	22.8	21.7	0.0	10.66	94.3	1.253	18.516	1.036	0.607	0.01	0.4	1774
BYS2	11.8.2010	11.2	7.42	252	23.6	21.0	0.0	10.91	99.1	1.867	17.515	0.980	0.908	0.01	0.3	1547
RAC1	17.8.2010	4.7	7.20	237	25.3	27.0	0.0	13.13	102.1	0.613	19.350	1.083	0.851	0.05	0.0	1648
JAM1	17.8.2010	6.4	6.85	236	19.3	19.7	0.0	12.24	99.4	1.760	13.178	0.737	0.536	0.03	0.4	1654
TICH1	21.9.2010	3.2	6.45	228	14.7	16.6	0.0	14.25	106.4	1.253	11.210	0.627	0.465	0.01	0.2	1532

Comparative measurements of physicochemical properties of Tatra streams in montane habitats in 2010 Table 2

ID	Colection date	T of water [°C]	pH	ORP [mV]	COND [µS/cm]	TDS [mg/l]	salinita [ppt]	dissolved oxygen [mg/l]	dissolved oxygen [%]	COD_{Mn} [mg/l O]	$CaCO_3$ [mg/l]	[°dH]	NO_3 [mg/l]	NH_4 [mg/l]	Cl [mg/l]	altitude [m asl]
BIE1	24.6.2010	5.9	8.31	288	100.8	104.3	0.1	11.90	97.8	1.200	86.408	4.835	0.513	0.01	0.1	1344
BIE2	24.6.2010	6.4	8.36	258	110.8	11.6	0.1	11.92	97.7	1.573	91.413	5.115	1.068	0.00	0.1	1128
BIE3	24.6.2010	6.1	8.31	237	126.8	130.4	0.1	12.36	101.9	1.627	109.095	6.104	2.255	0.01	0.1	988
BIE4	24.6.2010	6.3	8.23	230	134.7	137.3	0.1	12.90	102.5	1.707	114.433	6.403	2.437	0.01	0.3	975
BIE5	24.6.2010	7.6	8.35	224	149.8	146.5	0.1	12.82	101.9	1.813	121.106	6.776	2.580	0.03	0.8	914
JAV4	15.6.2010	7.5	7.01	280	13.9	13.7	0.0	12.21	98.5	1.093	9.675	0.541	0.546	0.00	0.1	1255
JAV5	15.6.2010	7.3	7.77	273	76.0	77.4	0.1	12.05	99.1	1.440	64.389	3.603	0.936	0.01	0.2	1059
JAV6	21.10.2010	3.3	8.43	202	31.8	35.3	0.0	14.93	112.2	0.693	100.788	5.639	0.997	0.01	0.3	951
BIVO2	27.6.2010	7.9	6.96	280	14.4	13.0	0.0	12.02	98.7	0.960	8.007	0.448	0.970	0.00	0.3	1397
BIVO3	27.6.2010	8.1	7.17	267	14.8	14.2	0.0	11.48	96.3	0.880	8.675	0.485	0.988	0.00	0.5	1208
BIVO4	27.6.2010	10.2	7.72	253	47.1	42.8	0.0	11.73	104.2	1.253	35.031	1.960	1.094	0.00	0.1	1007
BIVO5	21.10.2010	5.3	7.60	262	32.0	33.5	0.0	13.97	109.9	1.360	54.748	3.063	1.125	0.01	0.0	953
KBV3	28.6.2010	7.3	7.05	273	10.9	10.7	0.0	11.69	96.6	0.880	7.674	0.429	1.068	0.03	0.3	1305
KBV4	28.6.2010	8.9	7.80	257	45.9	43.4	0.0	11.60	99.5	1.040	34.697	1.941	1.152	0.03	0.2	1010
SKA2	29.6.2010	7.3	6.85	295	11.7	11.6	0.0	11.78	97.7	0.987	6.673	0.373	1.019	0.21	0.7	1331
SKA3	29.6.2010	9.1	6.99	283	14.9	14.0	0.0	11.31	97.8	0.987	10.009	0.560	1.574	0.10	1.4	1135
SKA4	29.6.2010	18.8	7.56	257	28.2	20.9	0.0	9.00	95.9	2.613	16.014	0.896	0.549	0.09	0.4	928
MSTU3	30.6.2010	7.8	6.68	283	8.9	8.7	0.0	11.30	94.6	1.733	5.338	0.299	0.864	0.00	0.3	1486
MSTU4	13.10.2010	4.7	6.54	203	9.9	10.6	0.0	13.64	106.0	0.400	7.206	0.403	1.218	0.01	0.5	1311
VSTU3	1.7.2010	8.8	6.94	301	11.4	10.8	0.0	11.44	97.1	0.880	8.007	0.448	1.050	0.00	0.1	1363
VSTU - STU4	1.7.2010	8.2	6.83	286	10.5	10.2	0.0	11.80	99.3	0.880	10.676	0.597	1.094	0.03	0.3	1314
STU CS5	14.10.2010	2.5	6.99	282	10.6	12.1	0.0	15.57	114.2	1.334	11.210	0.627	1.754	0.01	0.2	928
SLA1	2.7.2010	5.8	6.87	298	17.5	18.1	0.0	12.36	98.1	1.147	14.680	0.821	0.948	0.00	0.3	1252
SLA2	2.7.2010	8.5	7.18	310	18.1	17.4	0.0	12.33	105.1	1.253	16.682	0.933	1.032	0.00	0.1	1028
SLA3	2.7.2010	9.1	7.11	344	19.3	18.0	0.0	11.63	101.1	1.253	11.677	0.653	1.156	0.00	0.3	973
VEL3	6.7.2010	9.8	6.65	309	8.4	7.8	0.0	10.68	93.7	1.493	8.340	0.467	0.979	0.01	0.9	1461
VEL4	14.10.2010	6.3	6.84	241	11.1	11.2	0.0	13.37	108.2	1.440	8.007	0.448	1.373	0.03	0.6	990
BAT2	8.7.2010	8.0	6.20	303	7.0	6.8	0.0	10.47	88.0	0.427	3.503	0.196	0.957	0.00	0.1	1401
BAT3	8.7.2010	10.2	6.65	298	7.5	6.8	0.0	11.00	97.8	0.507	4.504	0.252	0.988	0.00	0.1	1130
VSUM1	9.7.2010	4.9	6.45	286	15.2	16.3	0.0	12.88	99.9	0.667	9.008	0.504	1.790	0.00	0.8	1481
VSUM2	9.7.2010	6.7	7.02	301	17.2	17.3	0.0	12.48	101.9	0.907	9.175	0.513	0.815	0.01	0.6	1191
VSUM3	9.7.2010	9.4	7.10	319	18.4	17.4	0.0	11.85	102.4	1.600	9.341	0.523	0.784	0.00	0.0	1109
POP-K1	10.7.2010	9.9	6.48	295	12.0	11.0	0.0	10.42	91.9	0.267	8.007	0.448	1.050	0.01	0.1	1464
POP3	10.7.2010	9.0	7.16	282	15.8	14.9	0.0	11.62	97.0	0.720	11.343	0.635	1.072	0.01	0.0	1267
POP4	10.7.2010	11.6	6.90	343	17.4	15.4	0.0	10.80	98.6	0.880	11.510	0.644	1.192	0.01	0.4	1195
MLY3	12.7.2010	11.4	7.04	295	12.6	11.1	0.0	10.22	93.2	0.613	9.175	0.513	1.050	0.00	0.0	1488

Comparative measurements of physico-chemical properties of Tatra streams in submontane habitats and agricultural land in 2010 Table 3

ID	Collection date	T of water [°C]	pH	ORP [mV]	COND [µS/cm]	TDS [mg/l]	salinita [ppt]	dissolved oxygen		COD_{Mn} [mg/l O]	$CaCO_3$ [mg/l]	[°dH]	NO_3 [mg/l]	NH_4 [mg/l]	Cl [mg/l]	altitude [m asl]
								[mg/l]	[%]							
BIE6	21.10.2010	3.1	8.54	205	31.8	35.7	0.0	16.46	122.6	1.813	155.936	8.725	1.453	0.05	0.8	832
KBV5	13.10.2010	4.2	7.65	229	64.5	70.2	0.0	15.16	115.6	1.200	52.346	2.929	0.983	0.04	1.1	679
SKA5	13.10.2010	3.9	7.27	134	31.1	34.0	0.0	14.99	114.4	3.707	29.526	1.652	1.652	0.03	1.0	736
STU6	13.10.2010	6.4	7.44	169	20.4	20.5	0.0	13.98	113.1	1.307	18.316	1.025	1.533	0.03	0.3	719
SLA4	13.10.2010	7.4	7.60	179	39.8	39.0	0.0	13.72	113.9	3.813	29.526	1.652	2.135	0.03	2.0	676
VEL5	13.10.2010	6.4	7.58	180	33.0	33.4	0.0	13.67	110.9	4.507	42.537	2.380	1.883	0.08	1.8	689
BAT4	13.10.2010	6.9	7.30	101	29.5	29.5	0.0	13.48	110.2	3.947	21.319	1.193	0.629	0.23	1.1	749
POP5	14.102010	2.9	7.06	269	16.9	19.0	0.0	15.17	112.3	1.040	15.213	0.851	1.413	0.01	0.8	816
MLY5	14.10.2010	3.9	7.75	222	32.0	34.9	0.0	14.73	112.4	3.600	45.239	2.531	4.335	0.03	4.7	859
BVA4	14.10.2010	3.9	8.02	213	32.2	35.0	0.0	15.17	115.4	2.827	51.545	2.884	2.188	0.09	3.6	783
SUCH3	21.7.2010	13.7	8.44	258	252.3	211.6	0.2	10.67	101.9	1.387	179.657	10.052	2.549	0.05	1.5	735
SUCH4	21.7.2010	15.7	8.12	275	282.6	224.5	0.2	9.68	97.2	1.627	169.147	9.464	2.348	0.09	0.6	639
JAL4	23.7.2010	13.6	7.52	366	30.7	25.6	0.0	10.63	102.2	0.987	17.515	0.980	0.882	0.04	0.1	862
BYS4	11.8.2010	11.8	7.19	249	33.6	39.4	0.0	11.51	105.8	2.213	23.520	1.316	0.820	0.04	0.5	862
RAC5	17.8.2010	10.2	7.04	243	31.8	29.0	0.0	11.55	102.3	1.520	18.516	1.036	1.369	0.03	0.3	791
BOB3	14.9.2010	7.7	8.52	221	159.3	155.3	0.1	13.32	111.3	1.040	124.809	6.983	2.275	0.03	0.5	882
BOB4	14.9.2010	8.4	8.40	197	169.8	162.5	0.1	12.90	109.6	0.853	134.417	7.521	2.188	0.03	0.5	845
BELA2	14.10.2010	6.5	7.87	229	36.4	36.6	0.0	14.09	114.4	1.013	33.529	1.876	0.864	0.03	0.5	697

(1648 m) and Bobrovecky potok (1178 m). A slight negative correlation was observed between chlorides and altitude (Fig. 5). The observed values for each parameter in all water courses for which measurements were obtained are shown in Tables 1–3.

4. Discussion

Dissolved oxygen is the limiting factor for life of various aquatic organisms. It affects the majority of biochemical processes and is

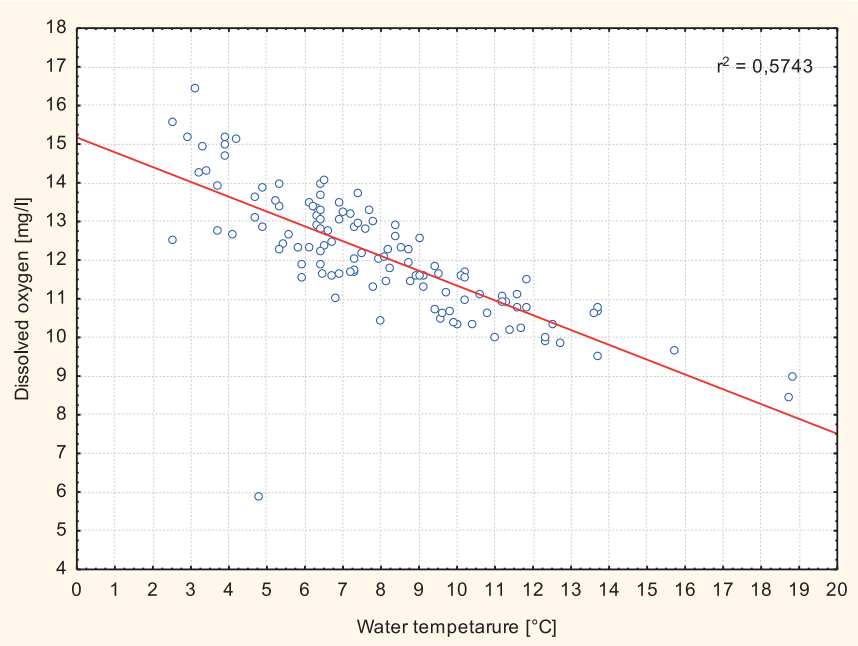

Fig. 2 Relationship between temperature and dissolved oxygen

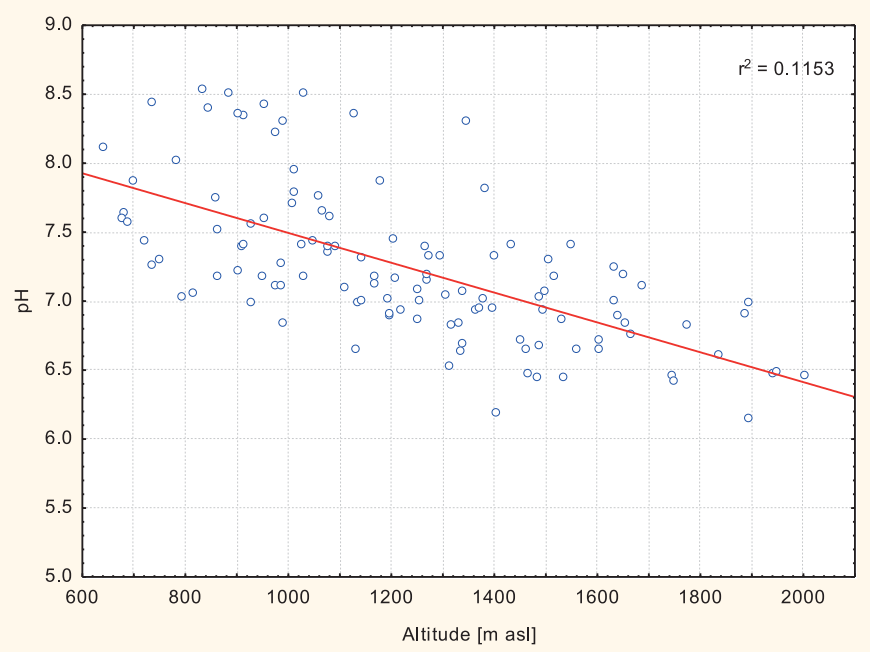

Fig. 3 Relationship between pH and altitude

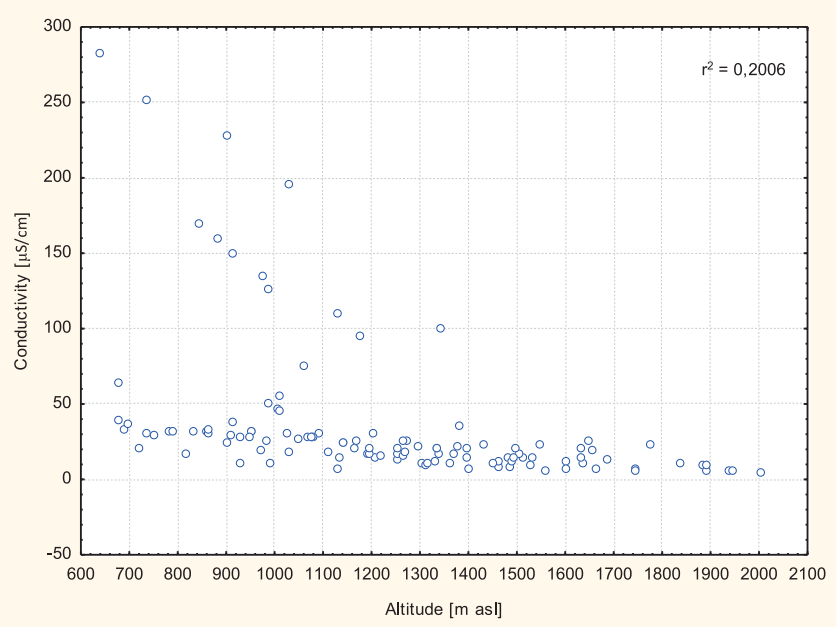

Fig. 4 Relationship between conductivity and altitude

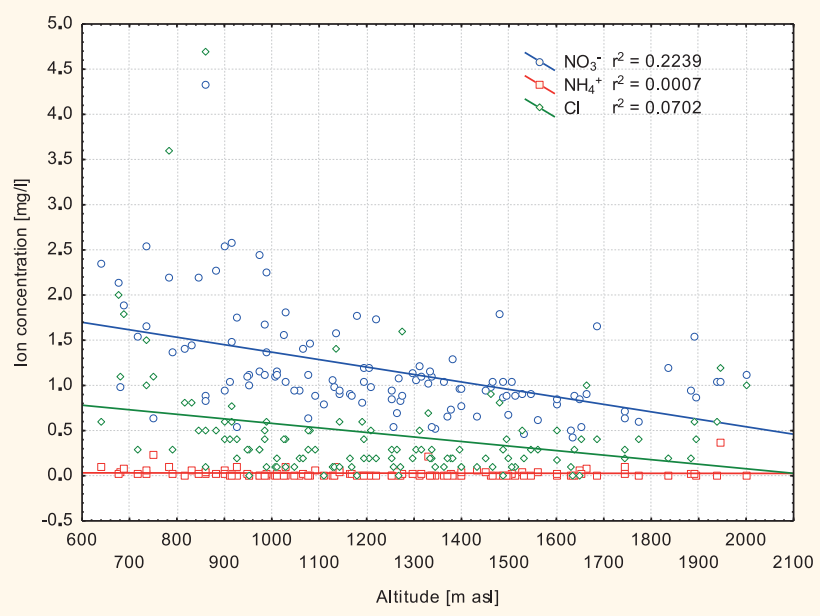

Fig. 5 Relationship between ion concentration (Cl^-, NH_4^+, NO_3^-) and altitude

an important indicator of purity. In flowing water, oxygen of atmospheric origin prevails [23]. Under normal conditions the amount of oxygen varies between 7 and 14 mg/l [24]. Our study found concentrations from 5.90 to 16.46 mg/l.

Dissolved oxygen decreases with increasing water temperature [25]. However, although water temperature decreases with increasing elevation, only a weak relationship ($r^2 = 0.1637$) was observed between DO and elevation (Tab. 1–3). The concentration of DO tended to increase up to a certain elevation, but beyond this limit it showed a negative correlation. The relationship between DO and elevation can probably be explained by the diminishing amount of oxygen produced by photosynthesis. The concentration of DO in the water is dependent on atmospheric pressure, sunshine, subse-

quent algal photosynthetic activity and respiration of all organisms [23]. As our results confirm, DO is affected to a large extent by water temperature (Fig. 2). The majority of these factors are limited at higher elevations.

The pH of stream water affects the solubility of a spectrum of components and consequently their availability to aquatic organisms [26, 2]. Krno [24] observed that pH in natural flowing water reaches values of 6.3 – 8.5, which is very similar to those observed in our study. Other authors [27] observed an average pH value of 7.67 in Tatra water courses. pH is affected by the geological environment, acid rain [25], geochemical reactivity of rocks and the length of time that water is in contact with rock [2]. The highest pH was recorded on a bedrock of sandstone and conglomerates (BIE6). The lowest pH was measured on granodiorite bedrock (BAT1). Comparing the pH between altitudinal vegetation stages, water was more acidic in coniferous forests (1250 – 1550 m a.s.l.) than in deciduous and mixed forests (200 – 1300 m). Spruce stands, in particular, caused higher acidity of the environment [28]. The lowest pH was observed in the highest streams. It is generally known that pH decreases with increasing elevation [2].

Conductivity provides information about the concentration of dissolved compounds, particularly inorganic compounds (salts of ammonium, calcium, potassium, sodium, sulphate, chloride, phosphate) [23]. Higher COND indicates higher ion content of dissolved solids in water. COND very significantly depends on water temperature and on the level of anthropogenic load. The occurrence of pollutants in a water course increases the degree of presence of cations and anions in the water. High COND values are a symptom of the presence of anthropogenic load [25]. COND in Tatra water courses ranged from 5.30 to 282.60 μS/cm, with an average of 36.30 μS/cm.

Total hardness is caused by divalent and polyvalent cations dissolved in water, among which calcium and magnesium ions predominate. Calcium concentration in surface waters corresponds closely to bedrock type [29]. The water courses included in our study were generally very soft, which is probably mainly due to the soil structure (crystalline basement of the Tatras). The highest concentrations of Na, Mg and Ca ions and thus the highest hardness were measured on limestone-granite bedrock. Changes in forestry negatively affect aquatic ecosystems. These changes reduce the concentrations of basic cations, which can affect the hardness of water. Naturally soft water contains less than 50.00 mg/l of total dissolved solids, is low alkaline and a pH is in the acidic range [30]. In addition to the bedrock type and anthropogenic activities including not only tourism but also deforestation and urbanization, Ca and Mg ions can reach the water by wastewater pollution or from the atmosphere.

Chemical oxygen demand (COD) is used to estimate organic pollution. This may be of natural origin (extracts from leaching of organically rich soils, decomposition of animal and plant bodies) or of artificial origin, which may indicate leakage of toxic chemicals such as pesticides and fertilizers. COD concentration in most streams did not exceed 3.00 mg/l, which is the limit for drinking water [31]. Higher concentrations were measured in water courses flowing through areas with anthropogenic activity.

Ammonia nitrogen ($N\text{-}NH_4^+$) is present in all surface water, both in water polluted by anthropogenic activity as well as in streams with only background levels, where its source is atmospheric deposition [32]. Ammonium ions (NH_4^+) in excess of the limit values can indicate faecal contamination, but may be of geological background. Combined with the increasing content of nitrite and higher levels of organic matter (CHSKMn), it signals contamination by fresh animal waste [31]. The amount of ammonia is influenced by many factors, but is most affected by temperature. Several studies indicate that the concentration of ammonia decreases in winter (November, December) and is highest in summer (July and August) [33, 34, 35]. The release of ammonia can also be associated with organic matter mineralization [36], or assimilated by plants and organisms to produce nitrate [37]. Values of ammonia may affect the concentration of pH, thus pH is higher as the concentration of ammonia increases [34]. In surface water, the concentration of NH_4^+ normally ranges up to 1.00 mg/l [38, 39]. We observed a concentration of NH_4^+ in selected Tatra water courses of between 0.00 and 0.37 mg/l.

Nitrates (NO_3^-), similar to ammonium ions, are present at low levels in almost all surface water. Greater concentrations are subject to anthropogenic impacts [39]. Nitrate, as well as other anions, decline with increasing altitude [40, 37] because they are more diluted due to more precipitation and increasing rainfall and run-off. This observation is consistent with our measurements, where decreasing altitude raised nitrate concentration, which was highest in bedrock of limestone and conglomerates. The main source of nitrate is atmospheric deposition or decomposition of organic matter in soils [2, 41]. Ground water, which is passed along to surface waters, can also be a source of nitrates [36]. Nitrates are a major source of nutrients for vegetation [39]. Nitrogen is an important biogenic element and is one of the limiting nutrients. However, beside adverse physiological effects, its excess also leads to quite substantial acidification of the environment. In natural waters, nitrate concentrations vary depending on the growing season [24].

Chloride concentrations in surface water in mountainous conditions are dependent only on their concentration in precipitation, in which most of the chloride is formed by marine aerosol formed mainly by sodium chloride. Altitude is another determining factor, because rainfall and run-off increase with higher total precipitation and decreasing temperature, so that the concentration of chloride in surface water is close to the concentration of precipitation (bedrock is not the source) [2]. We did not observe this trend in the streams of TANAP, where no relationship was observed between chloride concentration and altitude.

5. Conclusion

The aim of this study was to test the quality of surface water in a representative sample of 28 water courses in Tatra National

Park. On the basis of one-shot monitoring, during which we measured water temperature, pH, conductivity, salinity, concentrations of total dissolved solids, dissolved oxygen, Cl^-, NH_4^+, NO_3^-, CHSKMn and total hardness, we obtained informative data on water quality. The results obtained were consistent with the rating for very pure water. Results from these sites will form the basis for further monitoring of water quality in the Tatra Mountains.

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MULTIMEDIA TEXTBOOK: GERMAN FOR MECHANICAL ENGINEERING

In our presentation we would like to inform about the international project DEUMA called "German for Mechanical Engineering". This project was supported by the European Union as part of LEONARDO DA VINCI II program in which 11 partners from 5 countries participated. The aim of the project was to create a multimedia textbook of technical German language that would be designed especially for students of Faculties of Mechanical Engineering as well as for other students of German language with the focus on its use in the field of professional engineering. DEUMA teaching materials are modern multimedia language tools helping to improve professional German language knowledge in the field of mechanical engineering for Czech, Slovak and French students, teachers and practitioners in the field. The Internet and CD ROM versions enable both self-study and "blended learning" as a combination of classroom teaching and e-learning.

Keywords: *Mechanical engineering, multimedia textbook, technical German language, e-learning, blended learning, Internet and CD ROM versions.*

1. Introduction

Computers, Internet, e-mail, multimedia, e-learning, blended learning etc. Those are the terms which definitely belong to our common life today. The times, when Johannes Gutenberg (1438) invented book-printing and the mankind was looking forward to the end of the era when the access to the written word was dedicated only to the small amount of people who were able to get in touch with these documents, were over. If we observe this situation from the present point of view we can say that J. Gutenberg made a revolution in the field of information technology. But who will recall those times when today we are the witnesses of the fact that majority of people who were just recently great enemies of modern technologies reach for computers which make their work easier and, at the same time, more effective. The situation in the production of textbooks for foreign language learning is similar.

Classical, printed textbooks for foreign language learning are gradually supplemented by multimedia courses on DVD, CD, or by their shortened versions on the Internet. In our contribution we would like to inform you about the *first multimedia textbook of German language* for the needs of students and professionals working in the field *of mechanical engineering* which appeared in our book market by the end of 2005. From the present point of view we are not talking about a new release in the right sense of the word but about a release verified by several years of practice. It is known to all involved German teachers, mainly to those teaching at technical universities, that textbooks for professional teaching of German language are mostly outdated, their choice is very limited, in other words, there is just a small amount of convenient textbooks which comply with the criteria laid on the modern textbook of German language for professionals. Those were the impulses and at the same time the reasons why we decided to participate in the international project in the framework of the program EU *Leonardo da Vinci II*. The Project was approved by the European commission in 2001 bearing the name *Deutsch im Maschinenbau (DEUMA)* with allocated number CZ/01/B/F/LA-134057 and its implementation was carried out in the period from 1 November 2001 to 31 October 2004. 11 various organisations from 5 different countries were engaged in the Project, 5 partners were from the European Union.

To the partner organisations that were *directly* involved in the preparation, development and didactic, methodical and professional adaptation of the textbook belonged:

1. *Brno University of Technology - Faculty of Mechanical Engineering*
2. *VŠB - Technical University of Ostrava*
3. *Chambre de Commerce et d'Industrie du Jura, France*
4. *The University of Zilina - Department of Foreign Languages, now Institute of Foreign Languages*

Those responsible for language and professional-didactic consultancy were:

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Goethe-Institut Inter Nationes Praha, Technische Universitat Wien a Universitat Tubingen, where the software with the title Telos Language Partner Pro 4.00 was produced. This software became the basis for the multimedia processing of the textbook DEUMA. Those whose main task was the practical evaluation and testing of processed thematic areas and their modules in teaching practice were: *S.A. ROBERT BOSCH, (France), SEM Drasov Siemens Electric Machines, Ltd. and TOS Kurim, a. s.* All partner institutions that participated in this project as the authors of the textbook also contributed to the validation and testing along with their students.

The project aimed to:

a) create a multimedia textbook of specialized German language for the professional area of mechanical engineering and thus fill in the gap in the book market with multimedia textbooks of German professional language;
b) combine classical learning of German language with new technologies, support learners' activities in pursuance of individual studies (CD-ROM and web) with interconnection to Tele Tutoring via the Internet;
c) broaden, deepen and strengthen language skills of Czech, French and Slovak learners who use this multimedia textbook with the aim to improve their flexibility and versatility in the European labour market;
d) choose more widely designed topics that can be used effectively to support learning of professional German also at other faculties, other types of schools and educational facilities or at various professional language courses.

2. Structure of textbook

The textbook contains ten topics focused on the issues of mechanical engineering in the broader professional context. It can be found in two versions – 4 pieces of CDs and in a shortened form as a web version which can be found on **http://www.uni-tuebingen.de/ael/deuma/deuma_overview.htm.** The main topics that we chose after extensive discussions with experts are : mathematics, physics, materials, connecting elements, parts of machines – bearings, parts of machines-gear units, parts of machines-pistons and cylinders, apparatuses, devices, and tools, two final topics represent *technical dialogues.* The first final topic is dedicated to telephone conversations, making contacts, discussions about production problems, finding solutions to problems, management programs, construction of machines etc. The second final topic deals with discussions about projects, missing technical documentation, product development, prototypes etc.

Each topic consists of a greater amount of modules and each module develops the main theme. As an example we introduce the topic *Mathematik.* It consists of *7 modules: 1. Numeric fields; 2. Counting with natural numbers; 3. Equations; 4. Basic concepts from geometry; 5. Triangle, rectangle, circle; 6. Geometric solids; 7. Pyramid, cylinder, cone, sphere.*

Each module contains:

- input text with video,
- exercises focused on listening and reading comprehension of the text,
- lexical exercises practising professional vocabulary,
- grammar exercises taking into account morphological and syntactic phenomena encountered in the text,
- description of communicative approaches used in the module with the practical use of grammar and structures which students have to master in order to communicate correctly.

The input text or input dialogue is designed to introduce students to the professional problems of carefully sought and selected current professional topics. Videos of each lesson are visual and sound representation of the professional text, or of the dialogue. It appears on the monitor simultaneously in a written form on the right side of the animation. When working with the text we can use all the options which the multimedia processing offers us. We can listen to the text with or without visual support, we can record and listen to ourselves, we can delete the text and record our reproduction, we can act as a partner in a dialogue, in case of not understanding the text we can click on the translation etc. The text is followed by a number of exercises focused on all four language skills – reading, writing, listening and speaking. For navigation reasons the structure is uniformed, clear and we must adhere it in particular topics and modules. This uniformity of processing creates advantage for the learner but disadvantage for the authors of the textbook who are to some extent forced to follow up the pre-programmed templates, types of exercises and the overall structure of all modules. Regarding the choice of exercises, we decided to use mainly these types of exercises:

to practise comprehension of a heard and read text:

- choosing the correct sequence of particular parts of the text (with sound),
- linking the parts of sentences (with or without sound),
- deciding correct – incorrect (true – false) (with or without sound),
- multiple-choice exercises (with or without sound),
- drag & drop exercises (with or without sound).

to practise vocabulary:

in the beginning of each section which is dedicated to practise vocabulary, there is a list of vocabulary that contains unknown words from the input text. The words are not arranged in alphabetical order but in the order they appear in the text and most of the time also in short passages from the text. This section provides many options how to practise given vocabulary. There are exercises of the type: matching the terms with definitions, drag and drop exercises with moving objects, exercises with gaps for filling in special terms, formation of antonyms, compound words, formation of new words with the help of prefixes and suffixes, superior and inferior terms etc.

to practise grammar:

in this section those grammar phenomena are taken into account and practised with which students have the biggest difficulties. For example: articles, prepositions, comparison of adjectives, nouns, irregular conjugation of verbs, passive voice, attribute, word order

in the main and subordinate clauses, usage of infinitive with "zu", infinitive constructions etc.

to practise communicative activities:
the exercises in this section provide students with necessary instructions which language means they should use in order to be able to express their ideas on given topics aptly and promptly. In our textbook the multimedia teaching templates are accessible either in the learning system (Lernmodus) or in the processing system (Bearbeitungsmodus).

Lernmodus is dedicated to individual learning. Bearbeitungsmodus was designed with the aim to enable further processing of the given exercises and tasks by changing a text, picture and also audio material. The program Bearbeitungsmodus allows us to form also internal dictionaries and to connect them with various modules. The last two communicatively oriented topics *Technical dialogues* form a separate part to practise dialogues. Through these dialogues students learn how to lead business and technical meetings with German speaking partners in a better, quicker and more effective way.

Multimedia software *Telos Language Partner* includes the following pre-programmed multimedia templates:
- templates for videos,
- templates for text,
- templates for drag and drop exercises,
- templates with gaps for missing words,
- templates for multiple-choice exercises,
- templates for lexical, grammar, professional and other supplementation.

We incorporated already mentioned professional texts into the templates which were processed from the point of view of methodology and didactics very carefully and the texts were transformed into different types of exercises.

To facilitate the work with the multimedia textbook, we provided integrated assistance to students within the program but also the printed user's manual was published in Czech, Slovak and French language.

Additionally, we processed a detailed curriculum how to utilize the textbook at the faculties of mechanical engineering of the participating states. This new integrated didactic – technological concept that mutually connects individual learning with the aid of computer and multimedia textbook also with Tele Tutoring via the Internet, was very successfully tested in terms of pedagogical practice at 7 faculties of mechanical engineering in Slovakia, France and in the Czech Republic as well as at 11 secondary schools specializing in mechanical engineering in the mentioned countries.

Although the textbook is intended to be used first of all in class, we have evidence that students work with the mentioned textbook also outside the class in order to achieve permanent and prime professional language competences.

The results gathered from both planned and random surveys show that our multimedia textbook is useful and helpful to all those who decided to learn from it. DEUMA and its authors received on 26 September 2003 the Award from the European Commission and the Ministry of Education of the Czech Republic – *European Language Label 2003*.

3. Place of multimedia textbooks in teaching foreign languages, their advantages and disadvantages

In the future no school, no school facility no matter how demanding the study will be, will not be able to ignore multimedia textbooks because the whole world, the whole human society is very closely and firmly connected with new information technologies. On the other hand, however, the publishers of classical books and educators who prefer a printed form of textbooks should not be afraid of the fact that multimedia textbooks will replace traditional textbooks and that they will even replace the teacher. It is absolutely clear that the role of a teacher and the form of interaction teacher-student will always change in the scope of teaching. Present-day extensive discussions on the merits of multimedia textbooks, on their efficiency in the foreign language learning rather than using traditional textbooks in a written and printed form, which in the opinion of some teachers encourage the students to converse more, this fact leads us to the conclusion that if we consider a multimedia textbook it is about the communication of human being with the computer. That apparently does not correspond with the current life situations. Objectively, we believe there are still just a few studies dealing with the influence of multimedia language programs on the learner's success. Different types of research and comparative studies show that there is 30-33% more stimulation to learn when using multimedia activities. On the other hand some other studies indicate either a very small or even no difference in efficiency of foreign language learning between the classical learning activities and those supported by multimedia. However, the objectivity of these comparative studies and research of efficiency is being discussed among experts because there are no generally valid instruments to measure efficiency and accurately defined comparative criteria of success in foreign language learning. It is actually the reason why success in learning and efficiency cannot be objectively measured.

In the context of a rather limited opinion poll carried out on a sample of 154 students we came to the conclusion that all the participants welcomed the use of multimedia programs in foreign language learning. The students believe that their main advantages over the traditional textbooks are: self-activity in learning, they can determine the order of exercises and tasks themselves, choose topics themselves, test themselves and view the evaluation, test results are stored in the computer after they exit the program, multimedia processing offers variety of special functions – translation of texts, of technical terms, instructions for grammar exercises, practising those grammar structures which occur in professional texts, they practise the language within the framework of forum, they advise each other and help each other when solving problems etc. Whatever the conclusions of these discussions are, we, the teachers of foreign languages can only welcome any teaching aid which will make our work more effective.

Of course, we have to define precisely the target group, i. e., for whom the specific textbook is intended. The situation is different, for example, in courses for adults who are generally less proficient and flexible when using the computer the multimedia textbooks can cause stress and anxiety in students or create psychological barriers. In our university practice we become witnesses of the fact that students got very quickly used to the omnipotent medium – the computer. They even work very willingly with multimedia language programs and they prefer them to other sources of learning. They complete all the tasks which are somehow connected with computer or the Internet which are being assigned to them responsibly and in time. That was also the main reason which led us to the decision, in absence of literature, to compile the multimedia textbook instead of a traditional one.

For illustrative purposes we present several examples to illustrate the structure, content and processing of the multimedia textbook DEUTSCH IM MASCHINENBAU – Fig.1.

Content of the book:

Deutsch im Maschinenbau

Ein Produkt des Leonardo-da-Vinci-Projektes DEUMA

→ Impressum → Systemvoraussetzungen → Lernhilfe: CZ - D - F - SK
→ realONE PLAYER → Acrobat Reader → Kurskonzept → Rahmencurriculum

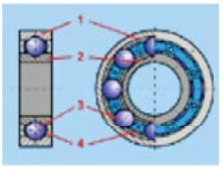
Thema 1		MATHEMATIK	→ M1 Zahlenbereiche → M2 Rechnen mit natürlichen Zahlen → M3 Gleichungen → M4 Grundbegriffe der Geometrie → M5 Dreieck, Viereck, Kreis → M6 Körper → M7 Pyramide, Kegel, Zylinder, Kugel
Thema 2		PHYSIK	→ M1 Einheiten → M2 Bewegungen von Körpern → M3 Kreisbewegung und Drehmoment → M4 Reibung → M5 Druck
Thema 3		WERKSTOFFE	→ M1 Werkstoffeinteilung → M2 Werkstoffeigenschaften → M3 Stahlherstellung
Thema 4		VERBINDUNGS-ELEMENTE	→ M1 Stoffschlüssige Verbindungen → M2 Schrauben und Gewinde → M3 Welle-Nabe-Verbindungen → M4 Dialog zu Verbindungselementen
Thema 5		LAGER	→ M1 Gleitlager → M2 Walzlager → M3 Lagergestaltung und -berechnung → M4 Lagerherstellung

Fig. 1 The structure, content and processing of the multimedia textbook Deutsch im Maschinenbau

Demonstration of a practical guide of how to work with the multimedia textbook DEUTSCH IM MASCHINENBAU

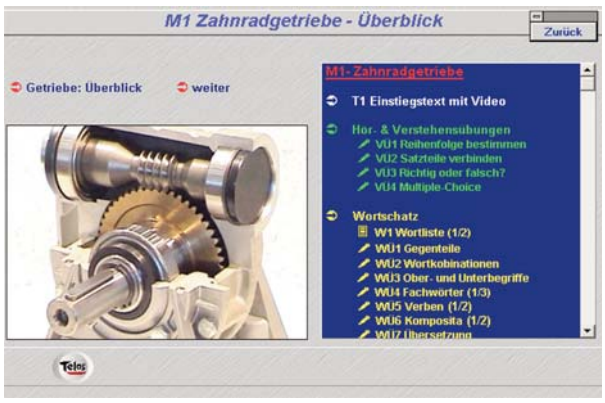


Fig. 2 Gear drive [1]

Start every new activity by going to ***the outline of topics/Themenuberblick*** *– Fig. 2 and choose one of the modules. From the introduction page of the module/****Moduluberblick*** *there is an access to the particular parts of the learning module (Lernmodul). In addition, you can find a reference to the link* ***Lernhilfe/help****, which will provide you with valuable didactic instructions for each type of task.*

With the help of button **Telos** you can get to the content and any part of the chosen module can be accessed.

Work with video

First of all you must become familiar with the video in order to understand the content of the video well – Fig. 3.

Watch and listen to the video, look up the unknown words and practise chosen grammar structures.

Tasks

1st step: listening to the dialogue

- First, watch the video **without the support of the written text** – Fig. 4. Delete the text by clicking on delete button /Losch-Button . Listen to the text and try to understand as much as possible.
- You can control the video with the help of buttons on the control sound panel below the window with video.

Fig. 3 Content [1]

Fig. 4 Text and video [1]

play the video

stop the video

pause

move the video forward or backward.

2nd step:

- Refresh the text once again and watch the video. Shift the button with eye on grey field and the text is displayed again.
- Look up the unknown words in the appropriate dictionary.
- Open the notepad (by clicking on Notepad in menu Extras) and write down new words or word collocations.
- Use Back-Button Zurück / to return to the beginning.

Work with dialogue

Dialogue exercises are led by participants of the dialogue to drill their roles and expression in the flexible combination of listening, reading and speaking.

Fig. 5 Dialogue [1]

Tasks

1st step: listening to the dialogue

- Delete the text of the dialogue (by shifting the button for delete to a situation picture), then listen to the dialogue or its parts once or more times (shift the reproduction button to a situation picture or to some text fields) and try to understand as much as possible.
- Refresh the text again (by shifting button with eye to a situation picture). Listen to the dialogue again and use the written text as the aid for understanding – Fig. 5.

2nd step: looking up

- Look the unknown words up in the appropriate dictionary.
- Open the notepad (by clicking on Notepad in the menu Extras) and write down the new words or word collocations.

3rd step: listening and recording

- Repeat the parts of the text and record yourself (shift the button with recording to the text).
- Compare your recording with the model (alternately shift the button with model and the button of a learner over a text field).

If you are not satisfied with your performance repeat the recording.

4th step: writing

- Delete the text of the dialogue (shift the button to a situation picture). Listen to a part of the dialogue and write it down as a dictation into the appropriate field.
- Compare your text with the original (shift the button for solutions to the text).
- Delete parts of the dialogues or the whole dialogue (shift the delete button to the text field or to any head of the speaker in the picture) and try to write down the text by heart without repeated listening.

5th step: role game

- Choose one role in the dialogue (shift the recording button to selected head of the person on the situation picture) and record yourself.

- Listen to your recording (shift the reproduction button of the learner  to the situation picture).
- Compare your recording with the model.
- Repeat the dialogues until you are satisfied with your performance.
- Delete the text of the dialogue and repeat it again.

4. Conclusion

We are convinced that our multimedia course will be very useful for those who will use it to improve their language and communication competencies in the field of mechanical engineering. We are grateful to the European Union for the fact that variety of its programs are oriented on modernisation and increasing the efficiency of learning/teaching foreign languages and in our case on the modernisation of learning/teaching the professional German language. We must be aware of the fact that modern foreign language teaching requires also quality, creative and committed teachers, pleasant atmosphere in the classroom and many other additional activities [2]. Thorough preparation for the modern knowledge society requires, on the one hand broad knowledge of our students in the field of foreign languages and on the other hand, from our side, it means from the side of foreign language teachers, introduction and utilisation of new modern didactic methods which support the autonomy of students in learning and they place them as active members of the learning process into the centre of foreign language education. The use of our multimedia textbook for learning/teaching German professional language contributes to this fact. We must not forget that even the most perfect technique, multimedia programs and textbooks are not able to substitute either the teacher, or the teaching process. The role of the teacher is changing when multimedia language courses are being used – teachers become more navigators, presenters or tutors of their students. We wish us and also our potential students who choose to learn professional German for mechanical engineering from our multimedia textbook a lot of success, joy and enthusiasm in their studies.

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[1] Telos Language Partner – Benutzerhandbuch und Materialien zum Projekt DEUMA.
[2] KRALOVA, Z.: Vyucovanie cudzojazycnej vyslovnosti [Teaching Foreign Language Pronunciation], Cudzie jazyky a kultúry v modernej skole (Foreign Languages and Cultures at Modern School), Brno : Masarykova univerzita, 2009, pp. 183–197, ISBN 978-80-210-4974-1

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1. Submitted papers must be unpublished and must not be currently under review for any other publication.
2. Submitted manuscripts should not exceed 8 pages including figures and graphs (in Microsoft WORD – format A4, Times Roman size 12, page margins 2.5 cm).
3. Manuscripts written in good English must include abstract and keywords also written in English. The abstract should not exceed 10 lines.
4. Submission should be sent: By e-mail – as an attachment – to one of the following addresses: komunikacie@uniza.sk or holesa@uniza.sk (or on CD to the following address: Zilinska univerzita, OVaV – Komunikacie, Univerzitna 1, SK-10 26 Zilina, Slovakia).
5. Uncommon abbreviations must be defined the first time they are used in the text.
6. Figures, graphs and diagrams, if not processed in Microsoft WORD, must be sent in electronic form (as JPG, GIF, TIF, TTF or BMP files) or drawn in high contrast on white paper. Photographs for publication must be either contrastive or on a slide.
7. The numbered reference citation within text should be enclosed in square brackets. The reference list should appear at the end of the article (in compliance with ISO 690).
8. The numbered references (in square brackets), figures, tables and graphs must be also included in text – in numerical order.
9. The author's exact mailing address, full names, E-mail address, telephone or fax number, the name and address of the organization and workplace (also written in English) must be enclosed.
10. The editorial board will assess the submitted paper in its following session. If the manuscript is accepted for publication, it will be sent to peer review and language correction. After reviewing and incorporating the editor's comments, the final draft (before printing) will be sent to authors for final review and minor adjustments
11. Submission deadlines are: September 30, December 31, March 31 and June 30.

WARNING

The articles by Martin Katuscak on page 73, Milan Konvit on page 76, and Martin Konvit on page 80, published in the Communications – Scientific Letters of the University of Zilina journal, volume 2012, No. 1, were the outputs of their research tasks under the project "Memory of Slovakia: National Centre of Excellence in Research, Preservation and Accessibility of Cultural and Scientific Heritage".

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