Stanislav Beroun and the team *

VEDECKOVÝSKUMNÁ ČINNOSŤ KATEDRY STROJOV PRIEMYSLOVEJ DOPRAVY NA FAKULTE STROJNÍCKEJ TECHNICKEJ UNIVERZITY V LIBERCI V OBLASTI VOZIDLOVÝCH MOTOROV

SCIENTIFIC-RESEARCH ACTIVITY OF THE DEPARTMENT OF TRANSPORT MACHINES, FACULTY OF MECHANICAL ENGINEERING – TECHNICAL UNIVERSITY OF LIBEREC AT THE FIELD OF THE VEHICLES ENGINES

Príspevok ukazuje výsledky vedeckovýskumných prác a vývoja plynových vozidlových motorov (pre autobusy a nákladné automobily), zaoberá sa technickým riešením konverzie pôvodných naftových motorov do zážihovej verzie. V článku je uvedené porovnanie emisných vlastností nových plynových motorov a pôvodných naftových motorov tak z hľadiska súčasnej legislatívy, ako aj s ohľadom na hygienicky najrizikovejšie zložky výfukových emisií.

The paper shows the technical solutions and the results of the research works, connected with the conversion of Diesel engines to spark ignition (SI) gas fuelled engines for the vehicles. The attention is paid to the comparision of the exhaust pollutions from the gas fuelled engines and from original diesel engines.

Introduction

The Department of Transport Machines was founded in 1956 (with the original title Department of Piston Machines). Since 1956 the technical and scientific know-how of department workers has gradually advanced, and at the same time the quality of technical equipment of the laboratory had increased as well. The new laboratory for teaching (practical lesson, theses), research, development and testing of internal combustion engines was finished in 1966, and since 1968 the department laboratory has been authorised as the State Testing Laboratory for Internal Combustion Engines (1993 – Accredited Testing Laboratory No. 1043).

At present the Department of Transport Machines leads the technical education of specialists in designing of motor vehicles (university bachelor's, master's and doctorate studies). The department staff consists of two professors, four associate professors, four lecturers, four doctors and students and four experts (technical, administrative, production). The department cooperates with partner departments from Czech Technical University of Prague, Technical University of Brno and Faculty of Transport in Pardubice.

The scientific research activity of the department has a few courses:

- The research of internal combustion engines (ICE), ecological characteristics of vehicle engines and the development of a gas motor.
- The strength and tension analyses of designing groups and parts (for example tension analyses of superstructure boxes for special lorries).
- The hydrostatics transmissions and hydrostatics mechanisms for transport and power working machines (wheeled loaders, lifting trucks).
- The technical diagnostic methods: the measurement of the noise and vibration.

The main scientific research of the department is orientated to the field of internal combustion engines (ICE). The Department of Transport Machines has a large laboratory with 10 test benches for scientific research and testing work on ICE. The laboratory has necessary testing apparatus and devices. The department laboratory of ICE solves complicated engineering problems of investigation and research specialization (namely problems about mixture creation, combustion processes and exhaust emissions of gas fuels, including H_2). In this field the department laboratory has great experience with solving various thermodynamics and combustion problems in engine cylinder with the measuring of exhaust emissions (both gases and particles pollutants according to ECE 49). The department laboratory also cooperates with

* **Prof. Ing. Stanislav Beroun, CSc.; Ing. Ladislav Bartoníček, CSc.; Doc. Ing. Josef Laurin, CSc.; Doc. Ing. Lubomír Moc, CSc., Ing. Celestýn Scholz, Ph.D.**
TU of Liberec, Hálkova 6, 461 17 Liberec I, Czech Republic,
Tel.: ++420-48-5353143, Fax: ++420-48-5353139, E-mail: stanislav.beroun@vslib.cz

specialized chemical (hygienic) laboratories on the monitoring of the most dangerous exhaust emissions [9,10].

During 1993 – 2000 the department research and test laboratory converted a few diesel engines into gaseous (LPG, CNG) SI engines. The selected characteristic parameters of gaseous SI engines from Department of Transport Machines – Technical University of Liberec (the design conversion, research and optimizing works) are shown at Tab. 1. All of these gaseous engines were authority tested and have an authority document from testing laboratory ECE (E8), certifying their power and pollutant properties. The shown gas engines are produced in a smaller series: towns Most and Litvinov (North Czech region) operated 85 city buses with gaseous engines type 1-LPG, town Havirov (Northern Moravian region) operated 35 city buses with gaseous engines similar to type 2-CNG (lower power alternative without intercooler), a few gas engines type 3-CNG are operated at transport enterprise ČSAD-BUS Česká Lípa (North Czech region) and the gas engines of types 4-CNG, 5-CNG and 6-CNG are operated in Slovak Republic.

Tab. 1

Engine	1-LPG $\lambda >> 1$	2-CNG $\lambda >> 1$	3-CNG $\lambda >> 1$	4-CNG $\lambda = 1$	5-CNG $\lambda = 1$	6-CNG $\lambda = 1$	EURO II / III
V [dm^3]	11.95	11.95	11.95	3.59	3.59	11.95	-
ϵ	10.8	10.4	11.5	10.5	10.5	12	-
P_E [kW]	180	175	210	58	65	170	-
p_e [MPa]	1.11	1.00	1.21	0.72	0.88	0.90	-
P_M [g/kWh]	0.03	0.02	–	–	0.01	–	0.15/0.1
NO_X [g/kWh]	3.72	5.15	3.45	0.51	0.22	0.79	7.0/5.0
HC [g/kWh]	0.26	0.95	0.94	0.16	0.11	0.23	1.1/0.7
CO [g/kWh]	0.55	0.28	0.23	0.65	0.49	0.35	4.0/2.5
CO_2 [g/kWh]	780	640	625	800	770	680	-

Tab. Note: - exhaust emissions in [g/kWh] according to ECE 49
- types 1-LPG, 2-CNG and 3-CNG turbocharging with intercooler and catalyser
- typ 4-CNG natural aspirated with catalyser [7]
- typ 5-CNG turbocharging without intercooler and with catalyser [7]
- typ 6-CNG natural aspirated with catalyser

Technical solutions of the gas fuelled engines for the road vehicles

For higher power gaseous SI engines ($p_{eMAX} > 1$ MPa) using the conception $\lambda >> 1$ in alternative turbocharging-intercooler with total (max) efficiency about 38 % accessible [1,5,6], for lower gaseous SI engines power ($p_{eMAX} <$ MPa) suitable conception is $\lambda = 1$ [7]. The gaseous SI engines for extremely lean combustion are furnished with a richness control system on the load: the solution ensures both very good operating properties (acceleration, running fuel consumption), and very low exhaust pollutions [1,5,6]. The schematic layout drawing of gaseous SI engines types 1-LPG, 2-CNG and 3-CNG are shown in Fig. 1, the characteristic course of control mixture richness on engine load is shown in Fig. 2. For combustion process optimization for these engines a few procedures were applied for analysing significant parameters variability of work cycle and it was confirmed that the mean indicated pressure variability (VARpi) reduction is for engine efficiency increasing and for emission reduction especially unburned hydrocarbons. It was also confirmed that the very lean mixtures combustion is connected with variability increasing. A significant effect of the combustion chamber form on pursued parameters variability of work cycles was proved [8].

The great influence on combustion process has the combustion chamber form. Pressure indication proves the VARpi reduction by turbulent specific intensity (squish swirl) in combustion chamber increasing and the considerable reducing of unburned hydrocarborn was achieved.

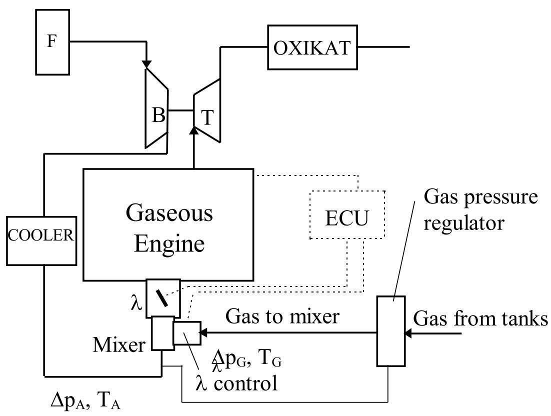

Fig. 1.

Fig. 1: Schematic drawing of gaseous SI engine and its facilities for conception $\lambda >> 1$; mechanical/pneumatic or electronic lambda regulator (regulation of the richness of the mixture) into the input of gas before the mixer, providing for a continuous

leaning of the mixture in dependence upon the filling pressure of the supercharging, starting from the idle run of the motor, through a partial loading until the area of the full load of the engine in the interval of lambda 1.0 ÷ 1.50. The course of the momentous characteristic in the area from the middle r.p.m. upwards is provided for by a mechanical & pneumatic corrector, which closes the throttle valve gradually with dependence upon the filling pressure of the supercharger or by system "waste-gate". This solution suppresses an undesirable increase of torque moment in the regimes of 100 % load of the motor at the r.p.m. above 1400 – 1500 1/min, and torque moment of the engine is regulated gradually to a value allowing it to reach the necessary nominal output of the engine.

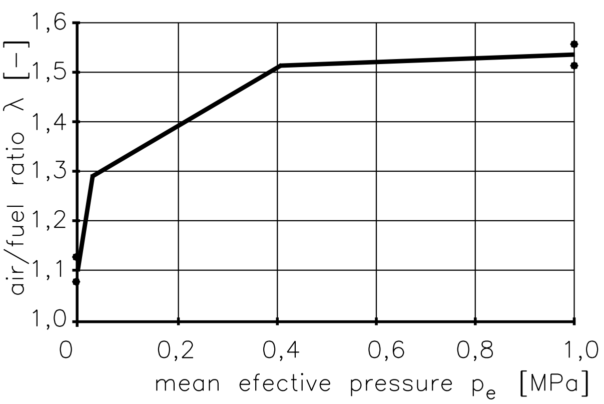

Fig. 2. Characteristic course of control mixture richness on engine load

An important role in the course of the combustion of the cylinder charge is exerted by the motion condition of the mixture in the combustion chamber. Both the velocity of the flame propagation and the mass velocity of the mixture combustion increase considerably in cases when the combusting mixture is in a condition of an intense whirling (turbulence).

The level of turbulence in the engine cylinder depends partly upon the design arrangement of the inlet valves (the whirling of the contents by the transverse "tumble" whirl, and the tangential "swirl" movement of the cylinder charge); an important effect upon the turbulent whirling of the contents of the combustion chamber is effected by the radial "squish" whirling produced during the compression stroke (in particular, in its end) by the displacement of the parts of the charge from the edge sections of the cylinder into the combustion chamber. The intensity of the radial "squish" whirling is then dependent upon the design solution (shape, size and location) of the combustion chamber.

An intensive whirling of the charge in the combustion chamber of a piston engine is applied with the compression ignition engines in particular; however, the "whirling" combustion chambers appear ever more often with the spark ignition engines. During the development of the bus gas engines in the Department of Transport Machines of the Technical University of Liberec (conversion of the original diesel engines LIAZ), the improvement of their energy, performance and ecological parameters has been related mainly with the design modifications of the combustion chamber in the engine piston [3,4,6].

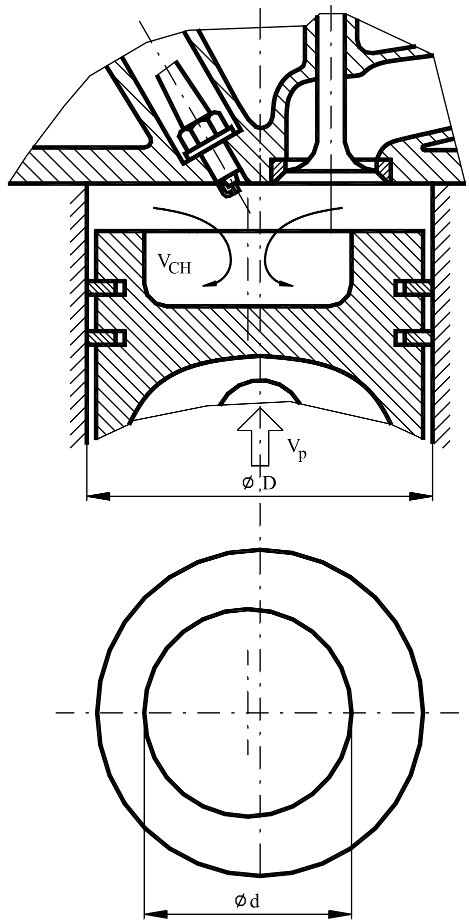

Fig. 3. Drawing of the cylinder unit with a high-turbulence combustion chamber

In fig. 3 is a simplified drawing of the basic layout of the cylinder unit of a bus gas engine: above piston is scheme of the radial flow of the mixture delivered into combustion chamber. The energy of turbulence Q in the combustion chamber is determined by the radial velocity w_r, at which a part of the mixture is pressed out from the edge zones of the cylinder into the inside volume above the combustion chamber and inside it, and by the mass quantity m of the part of the charge of the cylinder transferred radially. The calculation of the turbulence energy can be effected with a sufficient accuracy in compliance with the simplified Pischinger's model.

The combustion chambers of the gas motors (employing both LPG and CNG) are designed as "very whirling" (of the Heron type), with a reduced inlet section and a minimum interstice between the cylinder head and the piston in TDC: the summary energy of the turbulence has been increased several times throughout this design. The new execution of the combustion chambers has allowed an increase the compression ratio by approximately 2 units. The reduction of height of the uncovered (and intensively cooled) wall of the cylinder above the piston in TDC has somewhat reduced the "extinguishing" zones, and consequently (including the effect of the turbulence evidently as well), the concentrations of not combusted hydrocarbons in the exhaust gases at the outlet of the engine have dropped (a drop amounting up to 50 %).

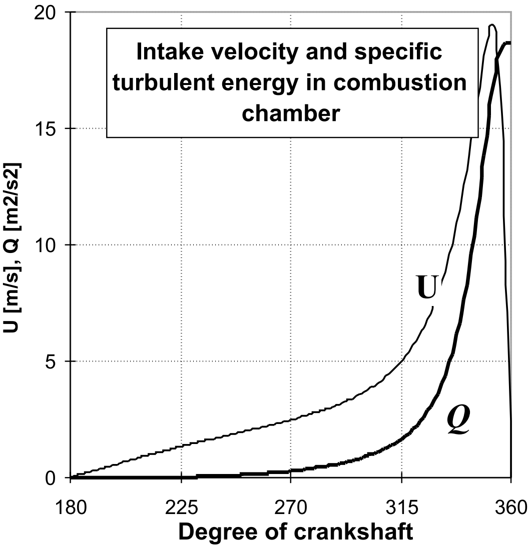

Fig. 4.

Fig. 4: The courses of the radial velocity w_r/n (U) and the specific energy of the turbulence Q for the combustion chamber "whirling" concept ($\epsilon = 11{,}6$) at nominal regime ($n = 2000$ 1/min, $p_e = 0{,}88$ MPa). The total specific turbulence energy Q at TDC is comparable with the specific turbulence energy in the combustion chamber of the original diesel engine ($Q_{DIESEL} = 23{,}5\ m^2s^{-2}$).

Pollution parameters of gas-fuelled engines

The basic ecological parameters of gas-fuelled engines are shown in Tab. 1. In the gaseous SI engines types 1-LPG, 2-CNG and 5-CNG were performed (besides prescribed test emissions), and the emissions properties measured essentially wider range than the laws determine. The attention was paid to the identification of various organic matter groups in exhaust gases. The same research was performed on the original diesel engines of their gaseous alternative (1/2-DE, 5-DE). The selected results of this research work are shown in Fig. 5, 6 and 7.

The measured results definitely show the gaseous SI engines as an ecological friendly drive for motor vehicles. The gaseous SI engines against original diesel engines have more than 10x lower particular matter (PM) emissions. The considerable difference is at hygienic very risky injurants, polycyclic aromatic hydrocarbons (PAH) and their cancer derivates (PAHkarc) from gaseous SI engines and diesel engines: the gaseous engines have these pollutants more than 10x lower then diesel engines. The PAH emissions are in exhaust gases included in both free (gaseous) form, and connected on PM: the research shows, that the portion PAH on PM depend on total PM emissions from engine. The PM emissions from gaseous engines contain only about 10 % total PAH emissions, PM from diesel engines contained as much as 50 % total PAH emissions. Considering, PM emissions represent a great hygienic risk in atmosphere (breathing) and gaseous SI engines have an ecological effect as more as shown in emissions values of individual exhaust injurants.

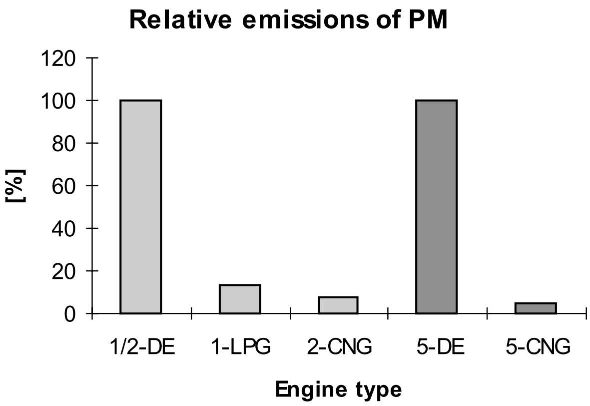

Fig. 5.

Fig. 5: Diesel engines 1/2-DE and 5-DE fulfill the emissions regulation EURO II. Emissions measuring and evaluating practiced at regimes by procedure ECE 49.

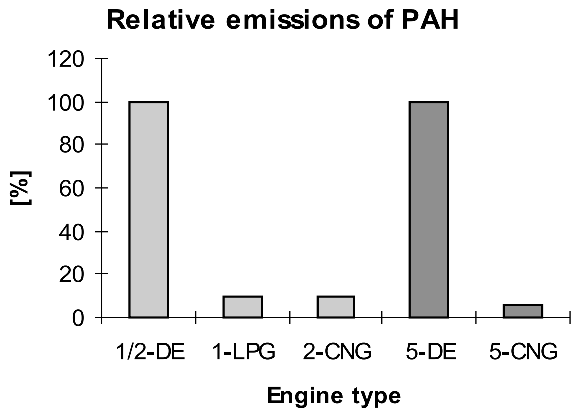

Fig. 6.

Fig. 6: PAH emissions contain 3 – 7 nuclear polyaromatic hydrocarbons. The samples from exhaust gases were caught by special pack, filters, adsorption substances in glass tubes and condensed matter (after sample freezing) for chemical analysis at special laboratory of organic chemistry [2,9,10]. Measuring and evaluating of PAH were practiced at regimes by procedure ECE 49.

Conclusion

The piston combustion engines have reserves, concerning the increase of their efficiency, performance and emission parameters.

The theoretical and experimental research show that in addition to new design solutions, the possibilities of improvement must also be looked for in the processes of the mixture production and its combustion. A controlled combustion employing a high turbulence in the combustion chamber offers a way to increase the efficiency of the operating circulation of the engine and to reduce the production of harmful substances. The gas engine may be the example: the well effected conversion of the town transport bus to gas driven, based upon the up-to-date knowledge of technical solution possibilities and arrangements in the gas-driven engine, its fuel system and the additional or complementary equipment, constitutes an important contribution to the reduction of the burden of the operation of engine vehicles upon the environment.

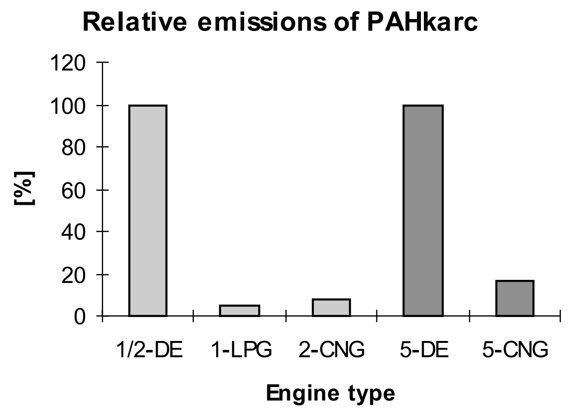

Fig. 7.

Fig. 7: PAHkarc contains emissions of benzo(a)anthracen, benzo(k)fluoranten, benzo(a)pyren, dibenzo(a,c)anthracen and indeno(1,2,3-cd) pyren. Measuring and evaluating of PAHkarc practiced at regimes by procedure ECE 49 [2,9,10].

From the point of view of ecological contributions of the gas-driven transport vehicles to the reduction of the burden upon the environment in town agglomerations, it is necessary to point out the importance of the conversion of the town transport buses (however, the municipal and other utility vehicles for the town service as well): compared with the vehicles with diesel engines, the gas-driven vehicles exert without any doubt a positive effect upon the quantity of emitted NO_X, CO, particles, aldehydes and polycyclic hydrocarbons. Compared with diesel engines, the emissions of harmful particles of the gas engines are 10 times lower, approximately; there is also an important difference in the emissions of the most harmful organic components – with the gas engines, the emissions of the polycyclic aromatic hydrocarbons (the most dangerous emission from the hygienic point of view) are also 10 times lower than with a diesel engine.

Acknowledgements

This article was compossed as summary of the research works of Department of Transport Machines in frame-work of Project No. LN00B073, supported by the Ministry of Education of Czech Republic.

References

[1] BARTONÍČEK, L., BEROUN, S.: *Lean mixture combustion at gas fuelled (CNG) spark ignition engines*. Motor vehicles on CNG. Piešťany, 1999 (Slovakia republik – in Czech).

[2] BEROUN, S., BLAŽEK, J., POSPÍŠIL, M.: *Emission of solid particulates and unburned hydrocarbons by diesel and gas engines.* Motorsympo 99, Brno 1999 (in Czech).

[3] BEROUN, S.: *Ecological effect of gas fuelled vehicles engines.* MOTOAUTO 99. Plovdiv, Bulgaria, 1999.

[4] BEROUN, S. and collective.: *Ecological contributions of the conversion of the automobile transport to gas drive.* Technical reports of the project S 401/220/005/96, SM 353/98, SM 364/00, KSD TU of Liberec (In Czech).

[5] BEROUN, S., BARTONÍČEK, L., SCHOLZ, C.: *Gas fuelled engines and their pollutions parameters.* Gas Engines 2000. Czestochova, Poland, 2000.

[6] BEROUN, S.: *Importance of the combustion chamber form for the quality of the gas engines.* MOTAUTO 2000, Sofia, Bulgaria 2000.

[7] LAURIN, J., MOC, L.: *AVIA engines on CNG.* XXIX. Conference Departments of internal combustion engines on Slovakia and Czech technical universities. Bratislava 1998 (Slovakia Republik – in Czech).

[8] SCHOLZ, C.: *Combustion variability of spark ignition engines.* Dissertation work, Technical university of Liberec, 1998 (in Czech).

[9] ŠEBOR and the team: *Influence of the fuel sort and the composition of the motor fuel on the exhaust pollution from the engines.* Technical report, Department of Petroleum Technology and Petrochemistry, Chemical Technology University of Prague, 1997. (In Czech).

[10] ŠEBOR and the team: *Influence of the fuel sort and the composition of the motor fuel on the exhaust pollution from the engine of the light lorries.* Technical report, Department of Petroleum Technology and Petrochemistry, Chemical Technology University of Prague 1998. (In Czech).