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UPGRADING OF THE SINGLE POINT LASER VIBROMETER INTO A LASER SCANNING VIBROMETER

The paper proposes a construction design of measuring device for fast and reliable non-contact modal analysis of object surfaces which cannot be measured using classical methods. The design combines conventional non-contact laser interferometer with an active optics module to be able to measure multiple points in a rapid sequence. The paper briefly discusses all the key constructional components and describes in detail the system functional layout. It also introduces the experimental measurement of a HV transformer under operation to demonstrate the system functionality.

Keywords: *modal analysis, laser, doppler, vibrometry, measurement, prototype*

1. Introduction

The method of Laser Doppler Vibrometry (LDV) has been widely used in medical [1, 2] or engineering applications involving the non-contact vibration [3-7] and can be also adopted for electrical engineering, especially when contact with the measured surface is not possible, such as measuring machines under operation, measuring of hot surfaces or surfaces which are under high voltage operation [8, 9].

However, since most single point LDV systems are only capable of sensing data for one point at a time, performing modal analysis to obtain an operational deflection shape tend to be quite long process. This problem is even more difficult for bigger structures or for structures with low natural frequencies, such as aircraft, space structures or civil structures, which would require more measurement points and excessively longer testing time if a single point LDV were used [10-12].

There are several types of laser-scanning vibrometers available on the market that can measure multiple points simultaneously, but their cost is too high. Only a few literature sources deal with its own vibrometer design whereas the most relevant work to this issue has been published in [13]. Here, the authors introduced a design of three-dimensional vibration measurement system consisting of one laser scanning vibrometer, one CCO camera and one laser scanner. Though it can measure the shape and vibration of the tested object at the same time, it is still expensive.

This paper describes the unique device developed to measure vibration for fast and reliable modal analysis of facial surfaces. Measurement of vibration via LDV has been used as the instrument of choice when contactless measurement and measurement with high spatial detail is required. The proposed vibrometer construction allows us to redirect the laser beam via computer controlled mirrors to acquire data for predefined matrix of measurement points. Moreover, it upgrades the single-point vibrometer into the fast programmable 2D fullfield vibration scanner [14, 15].

2. Construction design

The proposed measuring device, seen in Figure 1, exploits the benefits of a functional connection of the conventional non-contact laser interferometer (PDV 100) and the active optics with the fast steering mirrors. The interferometer generates laser beam which is sequentially redirected via the computer controlled mirrors in a predefined pattern. This solution enables us to perform multi-point measurements in a rapid sequence, having no back effect on the tested object. In addition, it will considerably simplify either the operational deflection shape (ODS) or the modal analysis of complicated 3D objects. The influence of the varying deflection angle of the laser beam pointing the measurement locations can be reduced using the proper software

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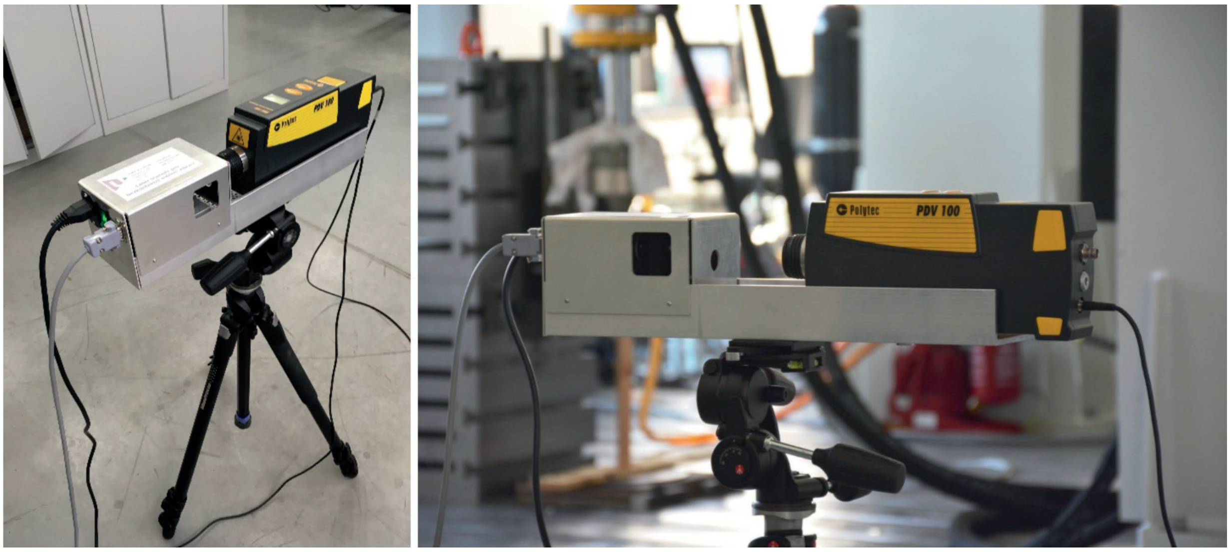

Figure 1 *LDV with XY scan head*

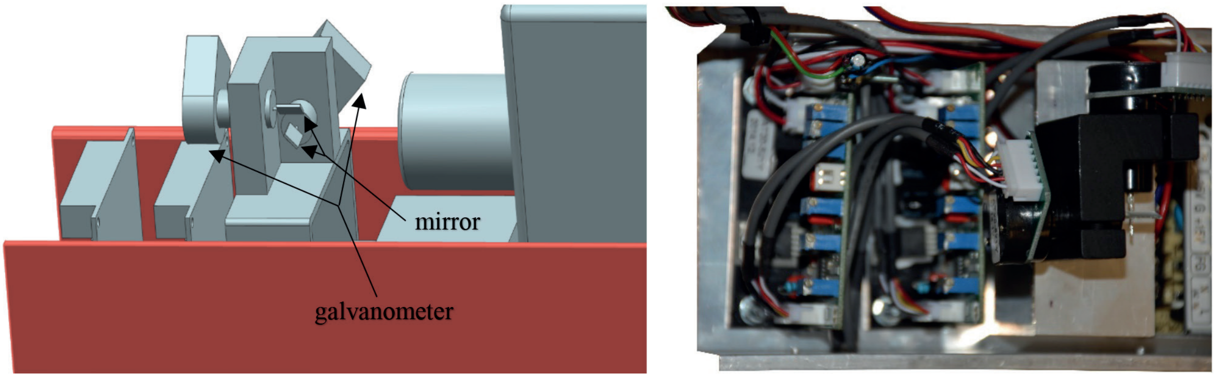

Figure 2 *Detailed 3D mechanical model of the measuring system with the LDV (left), inside view of the mirrors with galvanometer and control electronics (right)*

compensation, but if the testing object is far enough, it would be neglected.

The laser deflecting module (see Figure 2) is based on the principle of galvanometer with special mirrors mounted on its axes. In this case, we adapted the mechanism of the low-cost X-Y GALVO scanner, commonly used in the field of entertainment electronics for sweeping and rendering the laser beam patterns. In order to prevent any laser beam disturbance, the mirrors should provide high reflectivity and low roughness. The mechanism is driven by electronics, sometimes called DC servo, giving us very fast and accurate dynamic response of the deflection module measured in both axes. All the components are assembled together on a mutual chassis made up of structural AL profiles, forming a compact device suitable for practical application.

Figure 3 shows an input control console, based on a single-board microcomputer, using an intelligent graphical display to show either the relevant communication data or the main systems settings. The controller is based on the Arduino Esplora programmable array, including control buttons, joystick for the laser beam control and local storage to store programmable data for further re-editing or resetting the measurement sequence. The control console is mounted into a compact plastic chassis printed by a 3D printer.

The measured data are processed using the PULSE^{TM} analyses system developed by BK Company [16]. The system is extended with our own software routine to perform the modal analyses and includes measurement card with accessories that processes the signals from the LDV and the auxiliary reference sensor. The overall specification of developed measuring device may be listed in Table 1.

3. Experiment

For the functional demonstration, the operational deflection shape of a 22 kV transformer, with 1000 kVA of rated power, was made. The transformer was partially loaded during the test and was located in the HV transformer cell behind a barrier (see

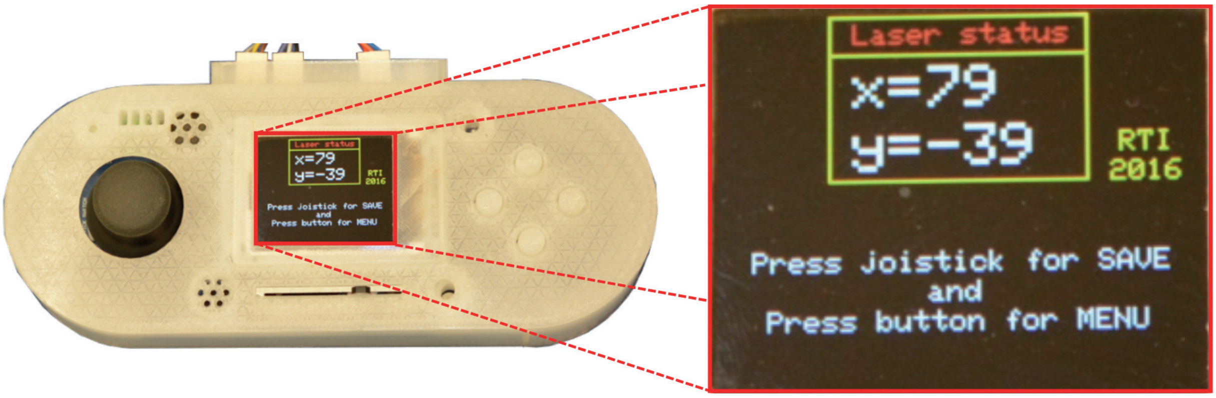

Figure 3 *The control console with Arduino Esplora for XY scan head*

Figure 4 *Tested HV transformer; without the safety barrier (left), measuring points programming (right)*

Table 1 Proposed device specification

Parameter	Values	Additional Notes
Input resistance	200 kΩ	differential
Signal input voltage	± 5 V	
Input voltage requirements	+ 15 V/1.0 A and - 15 V/0.6 A	
Operating temperature range	0 ÷ 50 °C	
Operational optical angle	± 30 degrees	max
Scanner speed	>15 kpps	30 kpps, ± 20° optical
Mirror dimensions (width, height, thickness)	7 mm, 11 mm, 0.6 mm	wide wave-length

Figure 4). Our goal was to demonstrate the strong advantage of the proposed system laying in possibility to measure under conditions when the testing operator has no direct access to the tested object. Thus, it is particularly relevant to the application where there is no possibility to measure using classical contact methods (like accelerometers) due to the high voltage, high temperature or other possible reasons.

The testing procedure may be understood from Figure 5. The required *x*- and *y*- positions of the laser beam are considered as inputs to the CPU (Arduino Esplora). This command is set using the joystick and then it is sampled by an 8-bit A/D transducer. Data are further processed by the predefined algorithm, but they could be additionally modified or manipulated. Up to 256 x 256 pixels (measuring points) can be uploaded into the internal or external storage (micro SD card). Then, the sequence of stored points can be recalled and executed by defined scanning speed. At the output of the CPU, two signals corresponding to the *x*- and *y*- positions are generated by the PWM modulation. Since the control unit for the galvanometer requires a DC signal fluctuating in the range of 0÷5 V, a low-pass filter is applied at the output of

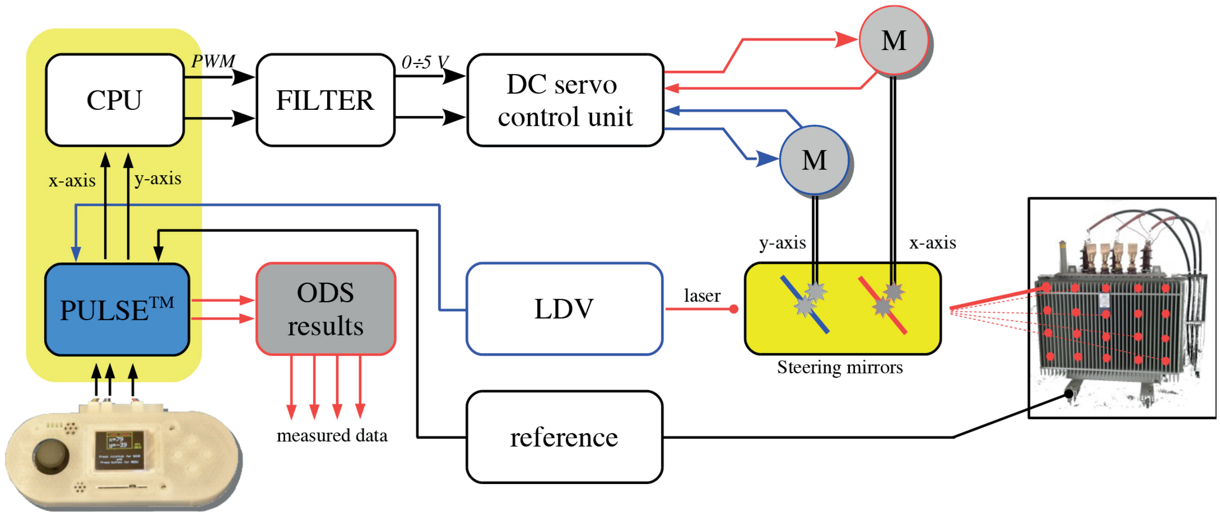

Figure 5 Block diagram of the measuring procedure

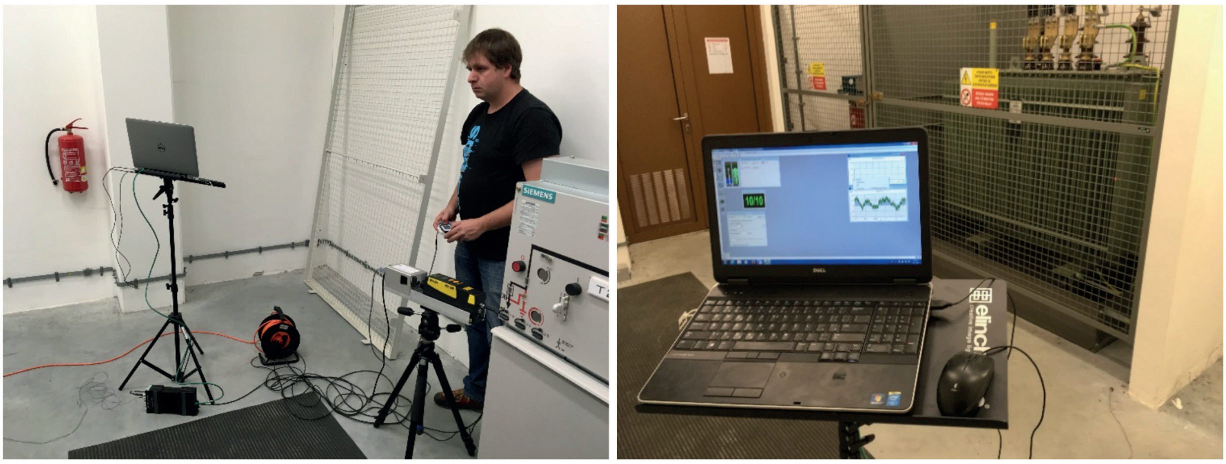

Figure 6 Experimental setup; the programming procedure (left), calibration (right)

the CPU. This regulation is highly accurate and quick enough to provide precise mirror adjustments according to set commands.

The measuring mechanism is driven by the PULSE™ system extended with our own SW routine for data processing. It continuously collects data from the LDV and the reference sensor, needed for the proper system synchronization. Based on these data, the operational deflection shape, corresponding to the evaluated vibration, is calculated.

Figure 6 shows the situation during the measurement. On the left-hand side, the procedure of programming is seen, the right-hand side shows the preparatory measurement and the system calibration.

The resulting vibration map measured on the transformer is seen in Figure 7. The results show that the proposed constructive solution of the testing device is fully functional and it is also suitable for the non-contact vibration sensing. As a consequence, the device upgrades a common single point vibrometer into the full-filed vibrometer, which can visualize either the Eigen modes or the operating deflection shapes of any tested object.

4. Conclusion

The experimental measurement has proven good operability of the proposed laser-scanning vibrometer even in an industry application. Due to the fact that the design combines conventional non-contact laser interferometer with a low-cost X-Y GALVO scanner, primary designated to the field of entertainment electronics, we have achieved significant financial savings while maintaining very good operational usability. The vibrometer can measure multiple points in a rapid sequence and hence it will find its purpose especially when measuring either the Eigen modes or the operating deflection shapes. Moreover, the measurement is non-contact and therefore it has no feedback effect on

***Figure** 7 Measured ODS results mapped onto the transformer*

a tested object. This may also be beneficial for testing objects operating under high voltage, high temperature or being otherwise inaccessible. The bottle neck seems to be ensuring proper surfaces reflection together with manual focusing of laser beam between measured points. There is also the need of dedicated analysis hardware and software tool to display results. For field measurement it is recommend a dust protection because dust can damage the functionality of the mirror based optical system.

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