Increasing the efficiency and flexibility of laboratory testing with virtual instrument techniques

Roland Pawliczek [1,a] *

[1]Faculty of Mechanical Engineering, Opole University of Technology, Mikolajczyka 5, 45-271 Opole, Poland

[a] r.pawliczek@po.edu.pl

Keywords: Measurements, Control System, Virtual Instrument, Graphical Programming Environment

Abstract. This paper presents an upgrade of the functionality and modernization of the laboratory testing process using virtual instruments. A case study of airflow laboratory stand for air velocity profile determination and the fatigue testing on the MZGS100 stand shows the applications, where standard sensors and transducers are used as measuring devices. The article focuses mainly on DAQ (Data Acquisition) measurement techniques, where at present the USB communication method is very widely used. The main advantage of the system is the so-called open user interface, which is software developed according to the researcher's own algorithms. The developed software is just this virtual instrument, and the graphical programming environment is used as an effective tool to build the program. Virtual instrumentation based laboratory equipment present cost-effective, compact, and user-friendly human-machine interfaces for the measurement and laboratory equipment control.

Virtual instrumentation

It is a well-known fact that any scientific activity that requires experimental validation is associated with measurements and measuring devices. Measuring physical quantities requires systems equipped with sensors that convert these parameters into current quantities, and appropriate transducers that process the measured signals and present measurement results. Existing computer techniques also make it possible to transmit data to workstations and process them further using additional tools, software etc. This basic structure of measuring systems is called a "traditional" measuring device (Fig.1).

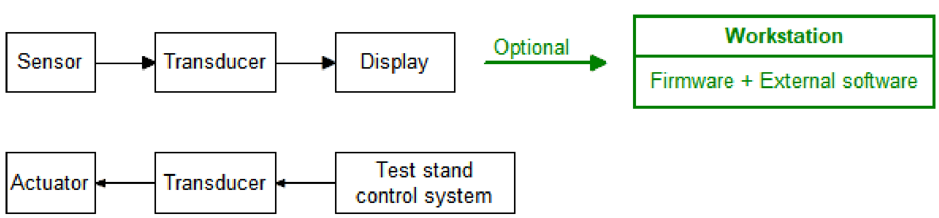

Fig. 1. Traditional measuring device.

The most significant disadvantages of this system are the impossibility to observe non-measurable (indirect) quantities and the need for additional calculations in post-processing; the user has no influence on the structure of the measurement system. By default, the control system of the test stand is independent of the measurement system.

Hence, the main idea for "virtual instruments" is to create a so-called open user interface for software performing data acquisition, processing them according to required algorithms and presenting them in a readable form (e.g., graphs).

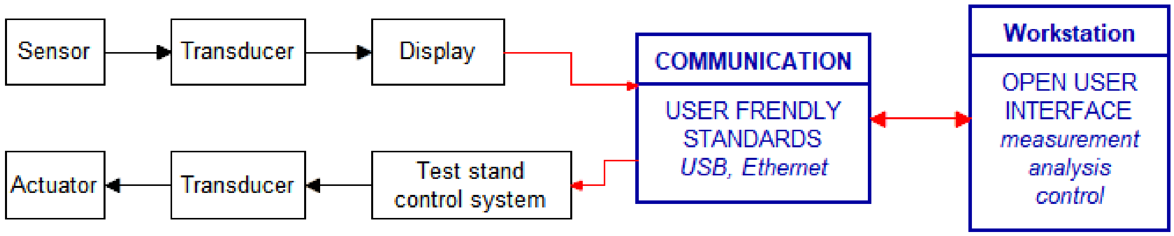

Fig. 2. The idea of virtual instrument.

In this case, actual existing sensors and transducers are used, it is necessary to provide data transfer communication (e.g., USB, Ethernet) and provide a programming environment to create custom programs for data acquisition (DAQ) and analysis. As shown in Fig. 2, it is also possible to integrate measurement and control devices into a single virtual instrument. The flexibility universality of this method favours applications in various fields: mechanical engineering [1, 2], electrical engineering [3] as well as medical science [4, 5], for example. Widespread measurement data transfer (communication) standards make measurement (control) system components easily accessible, where engineers/researchers who are not specialists in the development and programming of measurement systems can carry out integration and IT handling of such systems.

Despite this, most often these DAQ systems are used for basic tasks like monitoring and collecting data from measurement systems. Meanwhile, these environments provide a wide of possibilities for data analysis, from determining parameters by indirect methods and their monitoring during the test, statistical analysis or determination of systems characteristics and also the design of control systems for test equipment [6-10]. For higher expectations in data acquisition and processing, complex so-called real-time techniques are offered. The CompactRIO controllers and field-programmable gate array (FPGA) systems makes it easier for engineers to develop embedded applications designed to control and monitor industrial systems [11, 12]. As it is a hardware component, the system works extremely fast.

The purpose of this overview paper is to discuss the application of the idea of virtual instruments in the development of custom test stands using examples of laboratory tests, where measurements and analysis are performed simultaneously and the data is used in the control process.

Data Acquisition (DAQ) systems

Data acquisition is the process of measuring real-word physical parameters and convert them into digital form that can be manipulated and analysed by a computer technics. Due to the need to program and analyse calculations for data, PC-based measurement structures are found in laboratories. Standard I/O modules like PCI, PCIe or USB and Ethernet can be used. They differ mainly in the speed of data transmission. Easy of use and sufficient performance for typical measurement tasks have made the USB and Ethernet standards very popular recently. One advantage is the mobility of workstations based on laptops, for example. For the applications described in this article, external USB I/O hardware and National Instruments transducers used as:

- NI9205 Module with counter input channels to control the turbine flowmeter,
- NI9237 Strain/Bridge Input Module for handling strain gauge systems and load measurement,
- NI6001 Multifunctional I/O Module, where digital I/O have been used to turn drives on and off and control limit switches, and analog outputs controlled the inverter,
- NI9217 Module for temperature measurement,
- NI9203 Module to serve the absolute pressure transducer, differential pressure transducer, barometer,
- NI9265 Module to control the electric motor rotation,

- NI9403 Module with digital input/output channels to control the stepper motor and limit sensors.

Some of them functioned grouped in a dedicated CompactDAQ cDAQ9172 chassis. The cDAQ system is an extension and facilitation of communication in case of using more measuring DAQ modules.

Standard USB 2.0 Hi Speed is applied, which for small power consumable systems can supply up to 5.25V and 5mA maximum. In this case, it is possible to collect analogue input/output signals with sampling rate 3.2MS/s and update rate 1.6MS/s respectively, digital signal with frequency up to 10MHz.

Virtual instrument programming - graphical programming environment

As mentioned earlier, an essential element of the so-called virtual instruments is an open user interface. Solving the software problem of data acquisition, processing and presentation (e.g., tables, graphs) is the user's task. Custom software allows you to apply your own algorithms for conducting research, processing data, including consideration of physical quantities measured by indirect methods. The difficulty here is knowledge of the programming language. In the case of text-based, highly sophisticated languages like C and its variants, knowledge of syntax, formulating text commands can be very time-consuming and the procedures for communicating with measurement equipment require a lot of experience on the part of the programmer. Supporting engineers and scientists with little programming experience are graphical programming environments. Supporting engineers and scientists with little programming experience are graphical programming environments (e.g. DASYLab, nCode, Matlab SIMULINK or NI LabVIEW). These languages characterized by the fact that the program is created as *a data processing scheme* and built in this form in the workbench (Fig. 3).

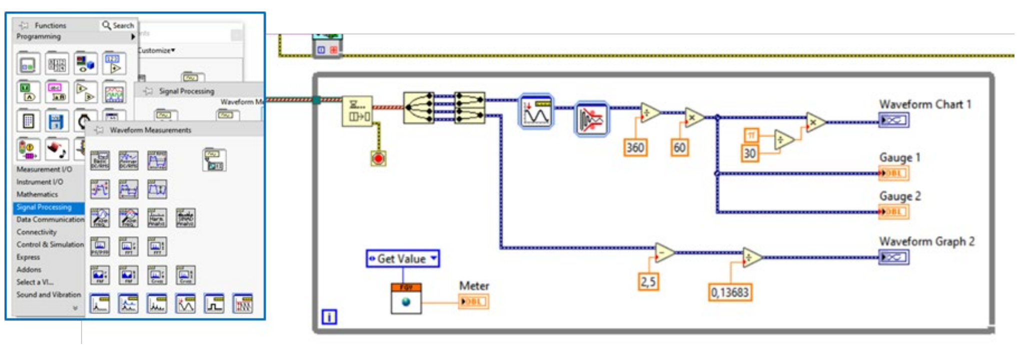

Fig. 3. Functions library (palette) and graphical code of the data flow scheme (NI LabVIEW).

Graphic icons on Figure 3 represent functions and data. They have so-called terminals, to which lines (wires) are connected. The lines represent the flow of data and the direction of flow is strictly defined. A major simplification is defining functions using configuration windows. The user can create his own functions, so-called subroutines. The LabVIEW environment appears to be uniquely advanced in this area: it addresses a variety of engineering issues in measurement programming, data analysis, computer simulation or even machine control systems.

In addition to the graphic code, the user can develop a screen on which the user will communicate with the software (Fig. 4). Again, the user has a library of elements ready to use.

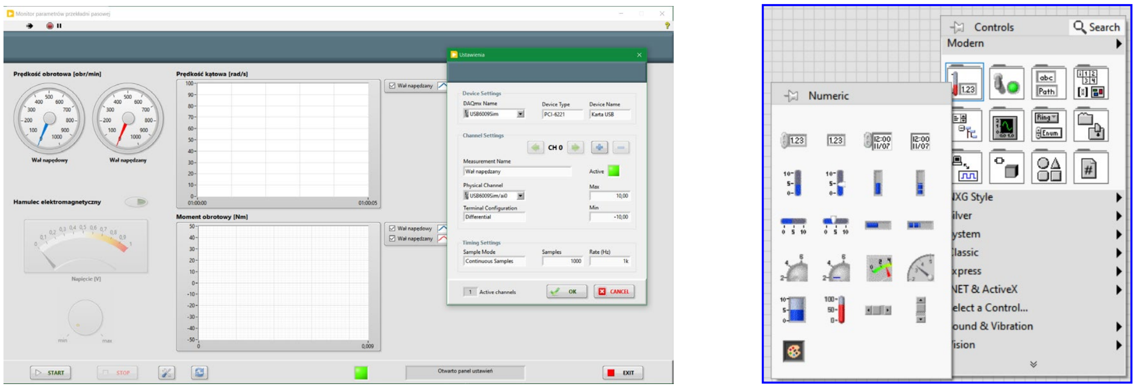

Fig. 4. Front Panel – user interface and screen component library (NI LabVIEW).

Air flow laboratory – case study

The airflow laboratory located at the Opole University of Technology conducts research in the area of phenomena accompanying the flow of air in pipes (Fig. 5a). The size of the gas stream, along with temperature and pressure, are the basic parameters of the operation of such systems. There is a need to study new designs of measuring elements for these phenomena: the presented stand serves, among other things, for this purpose [1, 8, 10]. According to the scope of the study, it is necessary to control the current parameters of the airflow in the pipe. For this purpose, the test stand is equipped with suitable sensors such as a temperature sensor (Fig. 5b), a flow meter (Fig. 5c) or a pressure sensor (Fig. 5d) used for indirect measurement of the jet velocity. The tests have been carry out for different levels of airflow speed. This can be achieved by controlling the speed of the blower drive with an electric motor controlled by an inverter.

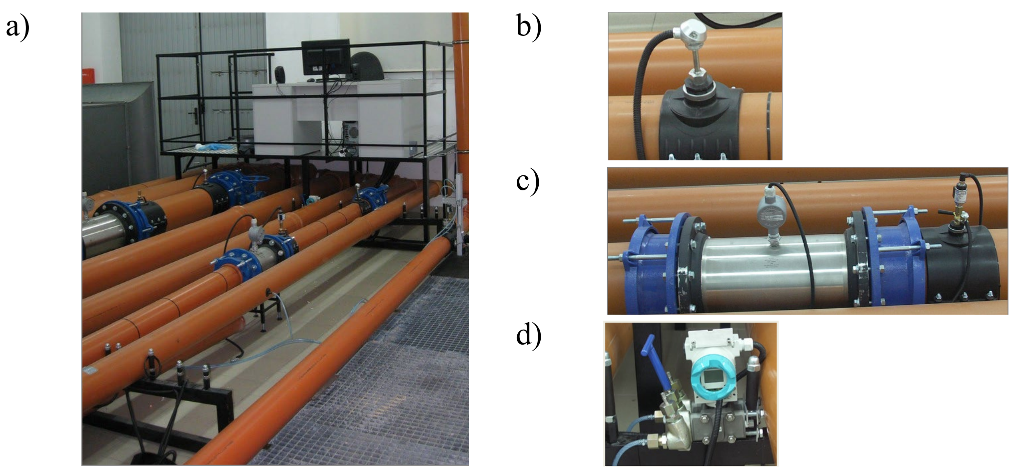

Fig. 5. General view of the stand and example sensors.

In addition, in order for the determination of the air velocity profile in the pipe cross-section to take place automatically the pressure sensor (Prandtl tube) was moved and positioned in the pipe using a linear module with a stepper motor (Fig. 6).

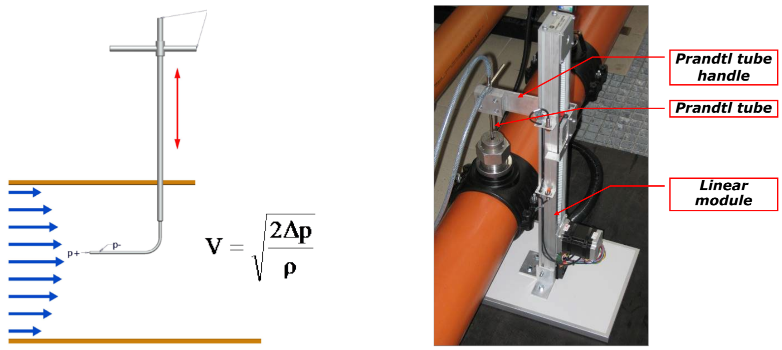

Fig. 6. Measurement of the profile of the air stream velocity.

Both measurements of airflow parameters such as temperature and pressure, positioning of the Prandtl sensor to study the velocity profile, and controlling the blower rotational speed (RPM) have been integrating in a dedicated virtual instrument (Fig. 7).

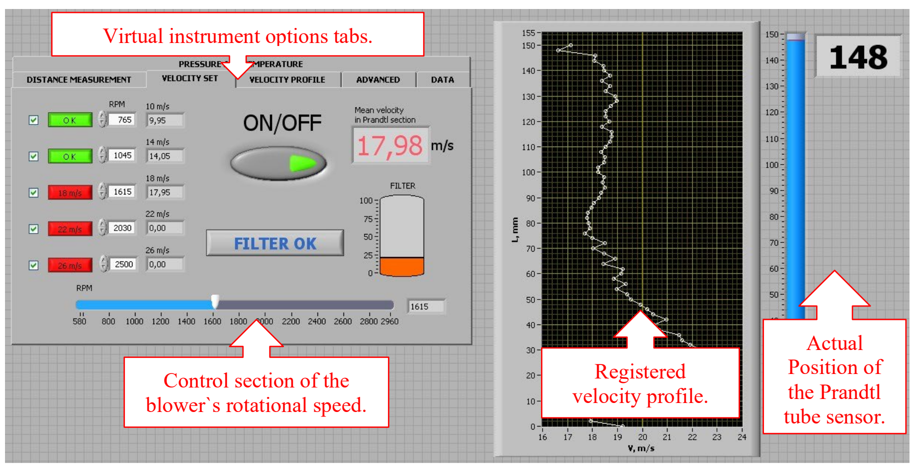

Fig. 7. Virtual instrument for airflow laboratory stand.

As a result, an integrated, completely automatic test and measurement stand has been obtained. The modifications made have resulted in the following functional advantages:

- automatic measurement of the velocity profile of the air stream for different velocities of the jet in the pipe,
- fully monitored and controlled parameters of the air stream in the pipe,
- reduction in the duration of measurements,
- increasing the repeatability of the measurement parameters with controlling and sustaining pre-set values during the test,
- increased resolution of velocity profile measurements.

MZGS fatigue test stand – case study

The MZGS100 fatigue test stand [13] (Fig. 8) was developed for fatigue tests of specimens made from constructional materials subjected to combined bending and torsional loading [14].

The specimen is loaded with moment caused by force applied to the load lever. A rotating disk on which unbalanced weights are placed generates a cyclically time-varying force. As the disk rotates, a centrifugal force B is generated, which, with the help of a link, is transmitted to the beam. An AC motor drives the disk where for rotational speed management the controller with LG iC5 inverter is applied. An additional spring actuator allows a mean load to be achieved. From a mechanical point of view, the machine is a second-order oscillating object.

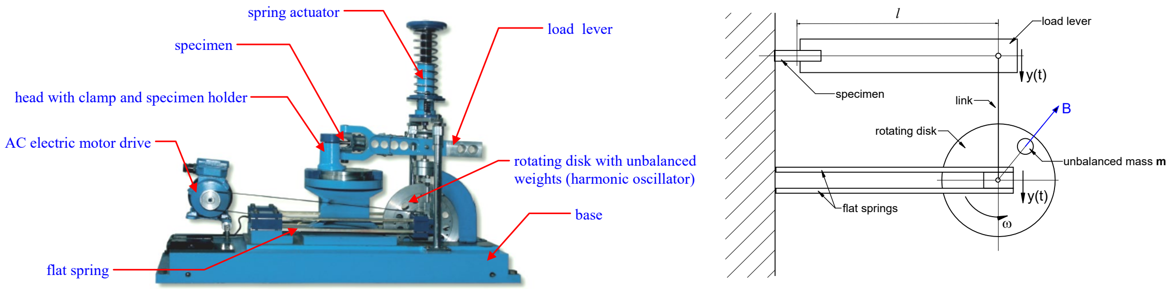

Fig. 8. Overall view of the MZGS100 stand and its scheme [13].

The original design was primarily used to determine the fatigue limit and fatigue properties in the so-called high-cycle fatigue range. Only elastic deformation of the material occurs here, and for proper operation of the stand, it was enough to properly select the weight (base on determined characteristic) and control the speed of the electric motor. The functionality of the machine is strongly limited, and any change in load requires stopping the test and manually changing the operating parameters. Expanding the scope of testing for the area of low-cycle fatigue testing requires controlling test parameters. It is necessary to measure specimen load and displacement. The possibility of changing the load amplitude during operation requires changing the value of the centrifugal force - the speed of the electric motor must be controlled (Fig. 9).

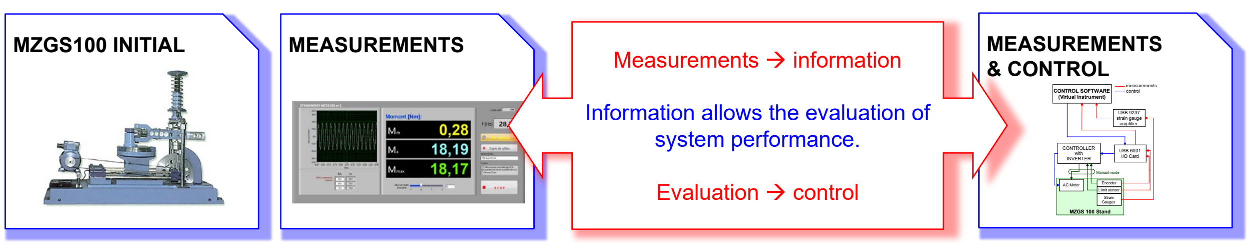

Fig. 9. System development.

Strain gauge sensors act as a load (resultant moment) sensor, elastic deformation of the springs is scaled to measure the displacement of the beam and an encoder integrated with the disk is used to measure the speed of the drive (Fig. 10).

The 4-channel USB 9237 strain gauge amplifier has been use to acquire the signal from the strain gauges. Measurement of the encoder signal was implemented using the counter input of the USB 6001 module. At the same time, the digital outputs of this module controlled the start/stop AC motor connectors of the LG iC5 inverter and the analog output of USB 6001 managed its speed control connectors. Figure 11 shows an example of the screen of the measurement section of a dedicated measuring virtual instrument and an excerpt from the graphical code (schematic) of data processing. During the measurement, it is possible to monitor the accuracy of the drive operation and the current state of the test parameters, observe the time waveforms of load and deformation, the graph of the so-called hysteresis loop is presented as an indirect diagram from the measurement results. Information about test parameters, fragments of data history are saved in the local disk automatically.

a) b) c)

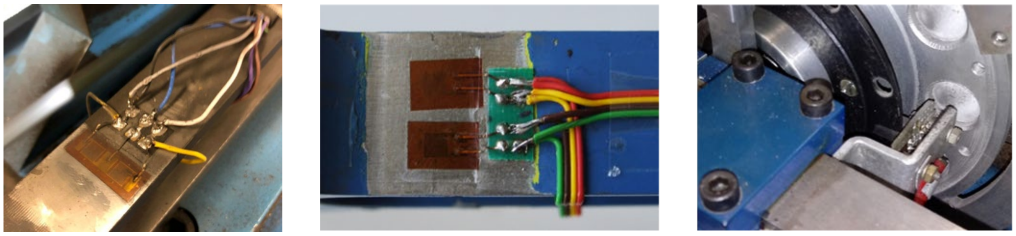

Fig. 10. Sensors: Strain gauges a) on the spring, b) on the beam, c) rotary encoder.

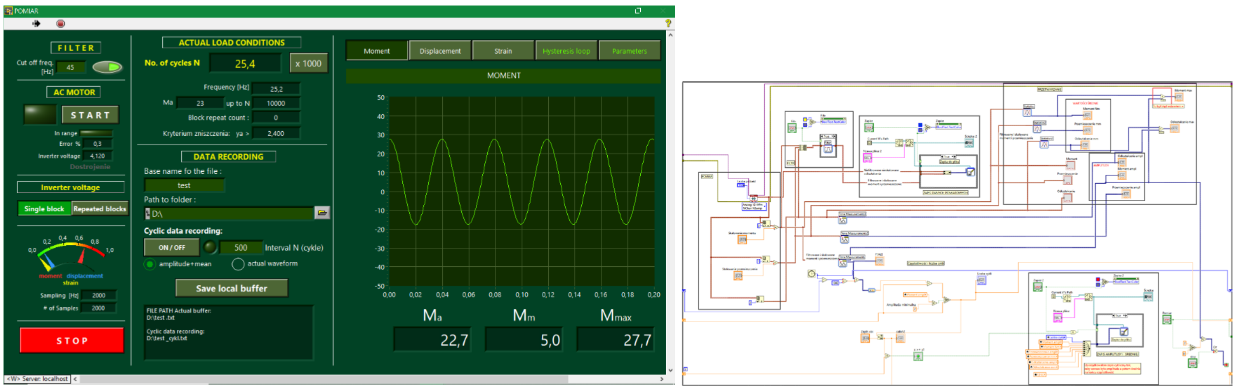

Fig. 11. Virtual instrument for MZGS100 control: measurement module and example of graphical code of the program.

The modifications made have resulted in the following functional advantages:

- configuration of sensors and measurement modules at the control program level,
- full management and control of the parameters of the fatigue test and their sustainment over time,
- performing fatigue tests for both load amplitude and displacement amplitude control,
- automatic load change during tests according to a pre-set sequence of moment amplitude (block load),
- saving data according to user settings,
- control of limit states and automatic shutdown when critical values of operating parameters are exceeded.

Summary

The idea of virtual instrumentation makes available solutions that are effective alternatives to traditional measurement systems. It can be used as a complement to the measurement systems of commercial measurement systems and is an excellent tool for building control and measurement systems for custom laboratory stands. The main advantages of virtual instruments can be drawn as:

- the hardware configuration (e.g. DAQ I/O cards) can support different laboratory stands and tasks as long as the sensor signals meet the data acquisition system's requirements,
- the open user interface allows you to create dedicated programs that process data according to custom (researcher`s) algorithms, especially for physical quantities that are not measurable (indirect quantities),
- both measurements of quantities from the experiment and control of test bench operation can be integrated into the virtual instrument,
- the user can effectively introduce into the existing systems both new measurement equipment and new program elements measurement and control programs,

- the ability to apply any data processing algorithms within the virtual instrument allows to analyse data on the fly without post-processing calculations.

The presented examples of applications of virtual instruments confirm the possibility of their wider use than just for data acquisition from measuring instruments. The virtual instrumentation based laboratory equipment present cost-effective, compact and user-friendly human-machine interfaces for the measurement and laboratory equipment control.

References

[1] M. Kabaciński, R. Pawliczek, Mechatronic concept for airflow test laboratory equipment, Solid State Phenomena, 220-221 (2015) 445-450. https://doi.org/10.4028/www.scientific.net/SSP.220-221.445

[2] R. Pawliczek, P. Soppa, Measurement and control system for analysis of the operation of the stepper motor, Solid State Phenomena 260 (2017) 113-126. https://doi.org/10.4028/www.scientific.net/SSP.260.113

[3] X. Pei, Virtual instrument based on electronic and electrician's experiment teaching laboratory design, Procedia Computer Science 183 (2021) 120-125. https://doi.org/10.1016/j.procs.2021.02.039

[4] I. Beriliu, H. Falota, Virtual Instrumentation Based Equipment for Bio-medical Measurements, Journal of Electrical and Electronics Engineering, 2 (2009) 155-158.

[5] K. Swain, M. Cherukuri, S.K. Mishra, B. Appasani, S. Patnaik, N. Bizon, LI-Care: A LabVIEW and IoT Based eHealth Monitoring System. Electronics 10 (2021) 3137 https://doi.org/10.3390/electronics10243137

[6] F.J. Jimenez, A.M. Gonzalez, L. Pardo, M. Vazquez-Rodriguez, P. Ochoa, B. Gonzalez, A Virtual Instrument for Measuring the Piezoelectric Coefficients of a Thin Disc in Radial Resonant Mode, Sensors, 21 (2021) 4107. https://doi.org/10.3390/s21124107

[7] M. Almaged, J .Hale, Virtual Instruments Based Approach to Vibration Monitoring, Processing and Analysis, Int. Journal of Instrumentation and Measurement, 4 (2019) 9-16.

[8] M. Kabaciński, R. Pawliczek, Fully automated system for air velocity profile measurement, The Archive of Mechanical Engineering, 59(4) (2012) 435-451. https://doi.org/10.2478/v10180-012-0023-0

[9] R. Pawliczek, Modernization of the fatigue test stand control system using the idea of a virtual instrument, 15th Int. Conference Mechatronic Systems and Materials (Bialystok, Poland), IEEE Xplore (2020) 1-6. https://doi.org/10.1109/MSM49833.2020.9201702

[10] M. Kabaciński, R. Pawliczek, Investigation of vibration effect in measurement system for air flow phenomena in large pipelines, Measurement Automation Monitoring, 62(3) (2016) 96-99.

[11] G. Rata and M. Rata, A solution for study of PID controllers using cRIO system, 9th Int. Symposium on Advanced Topics in Electrical Engineering (ATEE), Bucharest, Romania, 2015, pp. 121-124. https://doi.org/10.1109/ATEE.2015.7133685

[12] I. Moreno-Garcia et all, Real-Time Monitoring System for a Utility-Scale Photovoltaic Power Plant, Sensors 16 (2016) 770. https://doi.org/10.3390/s16060770

[13] H. Achtelik et al., Non-standard fatigue stands for material testing under bending and torsion loadings, AIP Conference Proceedings, 2029 (2018) 020001. https://doi.org/10.1063/1.5066463

[14] K. Kluger, R. Pawliczek, Assessment of Validity of Selected Criteria of Fatigue Life Prediction, Materials (MDPI), 12(14) (2019) 2310. https://doi.org/10.3390/ma12142310