MULTITERMINAL CYLINDER PRESSURE MONITORING-DIAGNOSTIC SYSTEM OF NATURAL GAS MOTOR COMPRESSORS OF GMVH TYPE IN KRIO ODOLANÓW

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Abstract

The paper characterises the current state of development and use of equipment and monitoring-diagnostic systems of engine cylinders and reciprocating compressors. It has presented a prototype system for monitoring and diagnostics of motor compressors of GMVH type natural gas installed in the Krio Company in Odolanów. The system monitors on-line 5 stands of motor compressors. Simultaneously 12 engine cylinders and 6 compressor cylinders of each motor compressor are indicated - a total of 90 cylinders. Driven by the need to reduce the number of monitors in the control room, a principle to operate the system through one monitor with the capability of immediate switching-off of a monitored motor compressor has been adopted. A charts menu provides for simultaneous on-line observation of the work of all the cylinders of a selected motor compressor. For each cylinder of both engine and compressor, against the background of the average from 16 runs and average for the cylinder's unit there are presented a few indicator diagrams, which allows for observation of the variability of a cylinder's work, which in a spark-ignition engines can be significant. Values of main parameters of the cylinder's work are presented in tables and bar charts. These include: the maximum pressure of combustion and compression as well as average indicated pressures. The indicated powers are determined for the engine and compressors and a mechanical efficiency of the unit. The fiber-optic "Optrand" sensors have been used for indication, mainly to meet the need of spark-safety requirements. For the measurement of pressure, 12-bit converter cards of own construction have been applied. Values of pressure have been sampled with angle axis pulses 0.5° crankshaft rotation. Ethernet connections were applied to transfer data between the pumping station and control room. The study characterises the main conclusions arising from past experience of system use.

Keywords: *cylinder pressure monitoring system, natural gas motor compressors*

1. Introduction

At present the Polish gas system uses a large number of GMVH-type motor compressors, which play an important role in ensuring the uninterrupted supply of gas. A large number of such motor compressors are operated in the U.S.

Originally accepted operation periods of numerous compressors have already been exceeded bringing significant savings. This has been achieved through appropriate use, an accurate planning and consistent implementation of the repair plan, as well as consistent modernisation and prevention of machinery failure. In Poland, for the past 15 years, Zamtech and other companies have implemented the broad programme of automation and introduction of control systems into power generators, signalisation and visualisation of motor compressor's work in the country's largest gas pumping stations [6]. Visualisation systems include low-frequency parameters of motor compressors, their rotational speed, the installation parameters of engines and compressors, parameters of gas transmission installation, start and stop processes and motor processor's fixed work.

The idea of building a system monitoring and diagnosing the work of cylinders of engines and compressors was born as early as 1998 [7]. On behalf of the Zamtech Company a conceptual design of this system was developed. The first prototype system was implemented in 2008. A number of practical application experiences were obtained.

2. The equipment and systems monitoring the work of engine cylinders and reciprocating compressors for practical application

Since the beginning of reciprocating machines use, indicator diagrams have provided the basic source of information on their adjusted parameters, load and technical condition. For indication of reciprocating machines fitted with indicated valves, mechanical indicators were and are still used, produced and marketed, for example, by firms such as Lehman & Michels GmbH and Friedrich Leutert GmbH & Co.KG. Mechanical indicators are still used in shipbuilding. Due to their high dependability and operational reliability even when the electronic indicators are installed, they can be used for control measurements in cases of suspected malfunction of electronic devices.

On-line systems that support all of the engine cylinders are expensive and hampered by unreliability problems relating primarily to sensors. Hence the creation of numerous designs of pressure analyzers and electronic indicators for portable use. Such devices usually have function of engine peak meters and waveforms recorders. Advanced analysis of indicator diagrams can be generally implemented on a PC or laptop with the use of specially designed software.

One of the first providers of portable electronic indicators was the Kistler Company, which currently offers engine peak meters Type 2516A10 and 2515.

A similar portable engine peak meter-recorder (PMI system) with software to analyse the diagrams on the PC is also marketed by MAN&BMW. The Lehmann & Michels Company offers several varieties of electronic indicators. In the case of PREMET C indicator [10], high resolution colour screens enable display of waveforms and bar charts. In addition, the TDC reference signal is registered, which allows an estimate of the average value of the indicated pressure. It should be stressed that in order to determine the exact value of the average indicated pressure, it is necessary to indicate in the function of crank angle, and it is necessary to set the piston TDC on the indicator diagram with an accuracy not less than ± 0.3° of crankshaft rotation (recommended ± 0.1° crankshaft rotation).

Electronic indicators and portable cylinder pressure analyzers were not the first electronic devices to indicate reciprocating machinery. The first were cylinder pressure analyzers, also known as MIP-Calculators, used in real-time monitoring and diagnostic systems.

The first electronic, computer pressure combustion analyzers were developed and marketed by a Norwegian Company Autronic and by ABB Company in the seventies of last century for stationary applications in the monitoring and diagnostic systems of marine engines. From their inception in engines of ships and land stations over 1,500 systems with the Autronic analyzers were installed. Currently, the fifth version of the Company's analyzers (analyzers NK-200) is offered by the Norwegian Company Kongsberg. Most commonly in shipbuilding, the pressure analyzer (MIP-calculator) type NK-5 was used, which became the model for the later construction of other manufacturers.

Pressure analyzers play not only the role of indicators, but in general also measure the pressure in the injection ducts, charge air pressure and rotational speed. Indicator diagrams may be presented collectively, comparatively to their average or sometimes, in comparison to the standard charts. Parameters read from the indicator diagrams are monitored in the form of tables or bar charts in various forms.

Marine engine manufacturers MAN & BMW and Wärstilä market their own construction monitoring and diagnostic systems. Continuous engine monitoring systems on the basis of the analysis of indicator diagrams are also now offered by Kistler and AVL, well-known producers of piezoelectric pressure sensors. Membrane strain gauge sensor of their own design features a German Company, Imes [8], which also offers an indicator (engine peak meter) [2] based on this sensor and offers the opportunity to build this system on-line.

ABB, which had previously offered the Cyldet analyzer and system with a sensor of their own construction, now offers a modern system of monitoring and diagnostic called Cylmate with a new type of pressure sensors, also their own, patented by ABB, construction [3]. The Company stresses the extended measurement durability of pressure sensors estimated at a year or even more of continuous operation without losing the precision parameters, which permits the creation of reliable parameter trends providing a source of diagnostic information. However, sensors are characterised by their large dimensions and weight. This system is designed for monitoring cylinders of low-speed engines of large power.

3. Construction of analyzers and systems created and used in Poland

The first own construction electronic indicator was marketed by the Lehmann & Michels Company in 1983. Also at that time the Maritime Institute in Gdansk in cooperation with the Marine Fisheries Institute in Gdynia produced the first national portable pressure analyzer, referring to the concept of Autronic's NK-2 analyzer. The next design was the analyzer ACS-4 (Fig. 1a), developed in 1987 by a team from the Naval Academy and Institute of Marine Fisheries. Over 20 of these analyzers produced by DEMPOL [9] were used on Polish merchant and navy ships. ACS-4 Analyzers in addition to cylinder indication and determining typical parameters, showed the average cylinder indicated pressure, and the indicated powers, as well as measured vibrations acceleration enveloping, used to control the operation of the injection systems and valve timing.

Analyzers ACS-4 were based on microprocessor technology and tube monitors. The following versions of pressure and vibration analyzers, developed by the paper co-author M. Łutowicz, EngD within the research work conducted in the Naval Academy, were based on computer technology [4]. The first one, analyzer MA-2, was built on the basis of a PC where a traditional monitor was used. The contemporary designs of portable pressure analyzers include pressure analyzer MA2000 (Fig. 1b) [5]. Consecutive versions have been created and used.

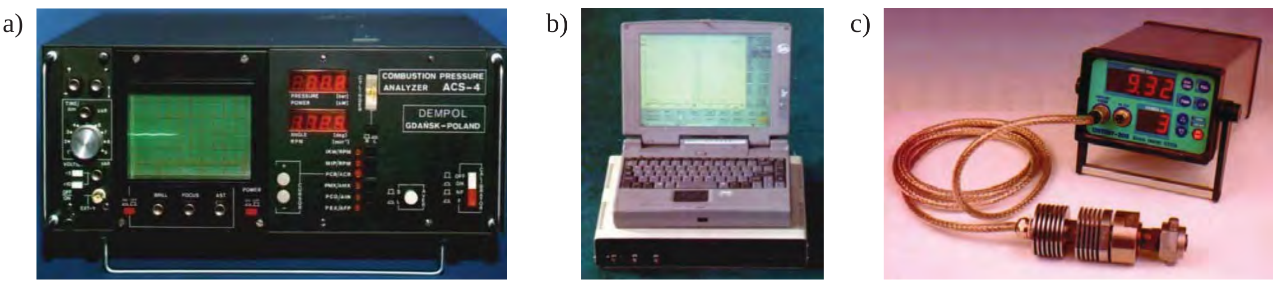

Fig. 1. Portable pressure analyzers developed and applied in Poland: a) – ACS-4 analyzer, b) – MA2000 analyzer, c) – UNITEST 203 analyzer

The analyzers are built in the form of a peripheral to a laptop. The engines of Polish Navy ships and merchant ships have been systematically diagnosed by the use of an analyzer of this type. They were also used to indicate motor compressors in gas pumping stations. A notable national achievement was the use of several electronic indicators UNITEST-203 (Fig. 1c) and UNITEST-205 on board ships, produced by UNITEST [1], a Company cooperating with the Maritime Academy. These analyzers have functions of engine peak meters and recorders of indicator diagrams. The advanced processing and visualisation of diagrams can be performed on a computer of any type []. Today, the UNITEST Company abandoned the production of indicators resulting from the high cost of servicing in all maritime countries. The Company focused on the production of control simulators for training crews in the field of engine room operation as well as production of specialised software.

The only Polish development of a stationary diagnostic-monitoring on-line system is worthy of mention; the primary designer and software developer of this system was also the author of the paper, M. Łutowicz EngD. Four such systems have been applied on large bulk carriers of the French Company Louis Dreyfus to monitor the main propulsion engine Sulzer 6RTA76 [5]. Indicating all the engine cylinders, measuring vibrations acceleration on all the cylinders, measuring pressure in the fuel injection system on a selected engine cylinder (Fig. 2), data processing, visualising waveforms of pressures and vibrations acceleration enveloping, setting the average cylinder pressure, the presentation of parameters values as tables and bar charts are done in on-line mode at high angular resolution of 0.1° crankshaft rotation.

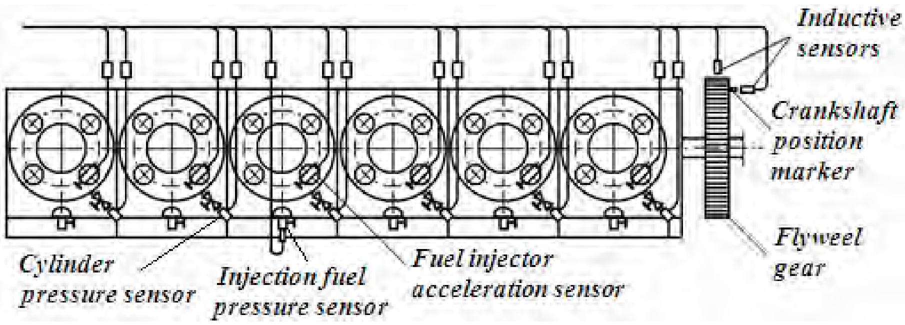

Fig. 2. The scheme of measuring unit of monitoring-diagnostic system used on four bulk carriers to monitor the main propulsion engine Sulzer 6RTA76

Inductive sensors (Fig. 2) were used in the system of angular axis generator and to identify the positions of GMP cylinders.

In order to ensure high resistance to vibration and shock a PC of own design was used (Fig. 3), based on standard cards of the standard features. Specialised cards of converters, amplifiers, angular axis generator, data bus were of own construction.

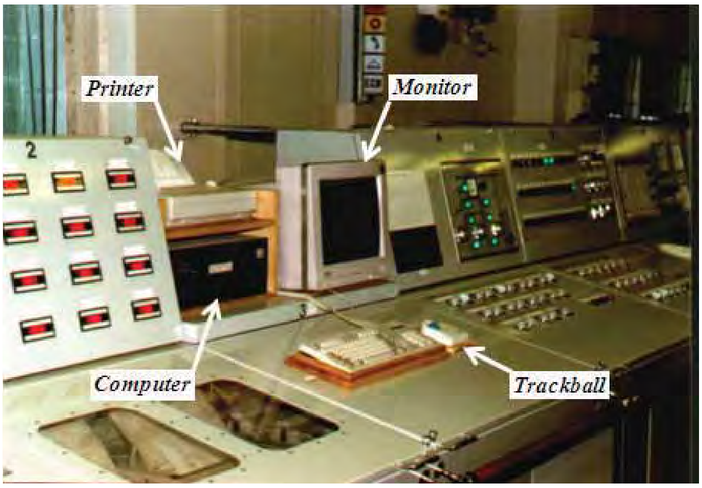

Fig. 3. Hardware of monitoring-diagnostic system on an operator desktop on bulk carrier

The on-line indicator diagrams were presented for cylinders and averaged for the engine, pressure waveforms in the fuel injection system and vibrations acceleration enveloping, and what was a novelty at that time, pressure speed rise (first-order derivatives) diagrams were determined programmatically. At that time only the Kistler Company in their electronic indicator offered to designate the maximum value of pressure speed rise, the value of which was probably hardware designated. Also on-line average indicated pressures were determined the maximum combustion pressure and compression of all cylinders that could be displayed in the form of bar charts and tables, also on-line.

High performance measurement, data processing, rich menu of visualisation of waveforms and parameters, a unique application of the vibration put the developed system in first place among existing competition. The foreign companies expressed great interest in the system, but due to procedural difficulties the works were discontinued.

4. Cylinder pressure monitoring – diagnostic system of natural gas motor compressors type GMVH in KRIO Company in Odolanów

The system covers five motor compressors of GMVH type (Fig. 4).

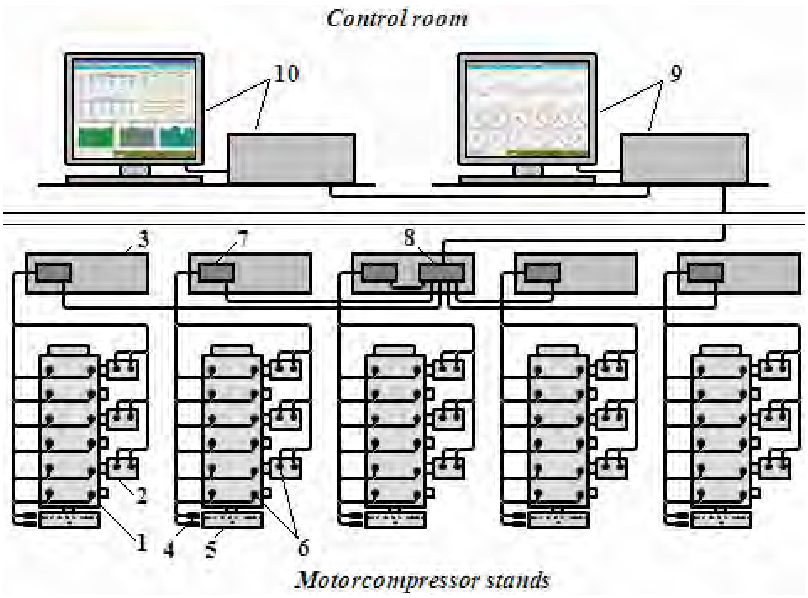

Fig. 4. Scheme of monitoring and diagnostic system of five motor compressors in Odolanów KRIO: 1 – 12-cylinder gas engine, 2 – Two-cylinder natural gas compressor, 3 – Measuring-controlling equipment cabinet, 4 – Induction sensor, 5 – Flywheel with angle and position markers, 6 – Cylinder pressure sensors, 7 – Unit (card)of measuring microcomputer, 8 – Unit (card) data concentrator and Ethernet connection, 9 – Computer stand for cylinder pressure visualisation, 10 – System control and supervision console of pumping stations (visualisation of low frequency processes)

In total, in on-line mode, 90 cylinders are indicated: 60 engine cylinders and 30 compressor cylinders. For GMVH motor compressors assumed sampling angular resolution of 0.5° crankshaft rotation and 12-bit amplitude resolution. Assuming that the maximum speed of the unit amounts up to 330 RPM, the maximum pressure sampling frequency for each cylinder is 4 kHz, for the purposes of visualisation and determination of the average indicated pressure it is an absolutely sufficient frequency. The upper frequency of signal transmission range for the used Optrand sensors is 5 kHz.

Each motor compressor is supported by one unit of measuring microcomputer 7 (Fig. 4) of own design, which in addition to the angular pulses generator, consists of three integrated circuits of analogue-digital converters 12bit/200 kHz, each operated by a microprocessor. Samples of pressure are writing down to memory in DMA mode. Each memory is sufficient for data recording of 8 channels during 17 revolution of crank shaft. Additional microprocessor in each unit by programming realization of the circuit PLL duplicates pulses from ignition system in order to timing and control of measurements and data transmission to data concentrator 8 (Fig. 4). One unit can handle up to 24 channels with sampling frequency up to 25 kHz in each channel. With 18 channels, sampling frequency is 33,3 kHz per channel. The need to develop their own measuring microcomputer unit was dictated by the lack of suitable products on the market. Currently, another version of a universal measuring microcomputer has been developed.

Measurement data transmission between the compressor room and the console in the control room is via Ethernet network (Fig. 4), which gives substantial savings in wiring and lowers the level of interference. In the case of the Krio the greatest distance between the motor compressor stands and the control room is over 100 m and the total intensity of measuring data amounts to 356,4 thousand 12-bit samples per second.

5. The functions of the monitoring-diagnostic system

The analyzer software is divided into menus (screens). System maintenance screens are not available to users. Given the need to observe the existing desktops monitoring the work of pumping station and motor compressors based on low-frequency parameters one desktop monitoring a selected motor compressor was considered adequate.

Main menu (Fig. 5) presents on-line the main indicator diagrams of all engine cylinders and the compressor indicator diagrams of the selected unit.

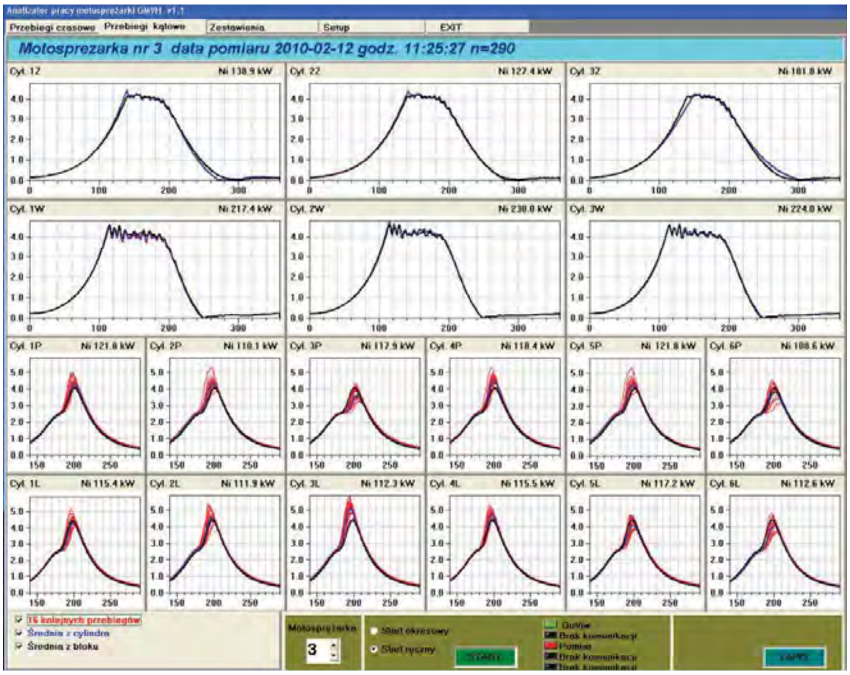

Fig. 5. Main menu of pressure analyzer of GMVH motor compressor monitoring-diagnostic system, presented in on-line mode

A simultaneous presentation of eight consecutive diagrams, averaged diagram for a cylinder and an averaged diagram for an engine or compressor allows an operator immediate assessment of an observed cylinder.

The values of key parameters, such as the maximum combustion pressure and average indicated pressure may be presented on-line in a different menu in the form of bar charts (Fig. 6). The indicated powers of engines, compressors, and the indicated efficiency of units are stated.

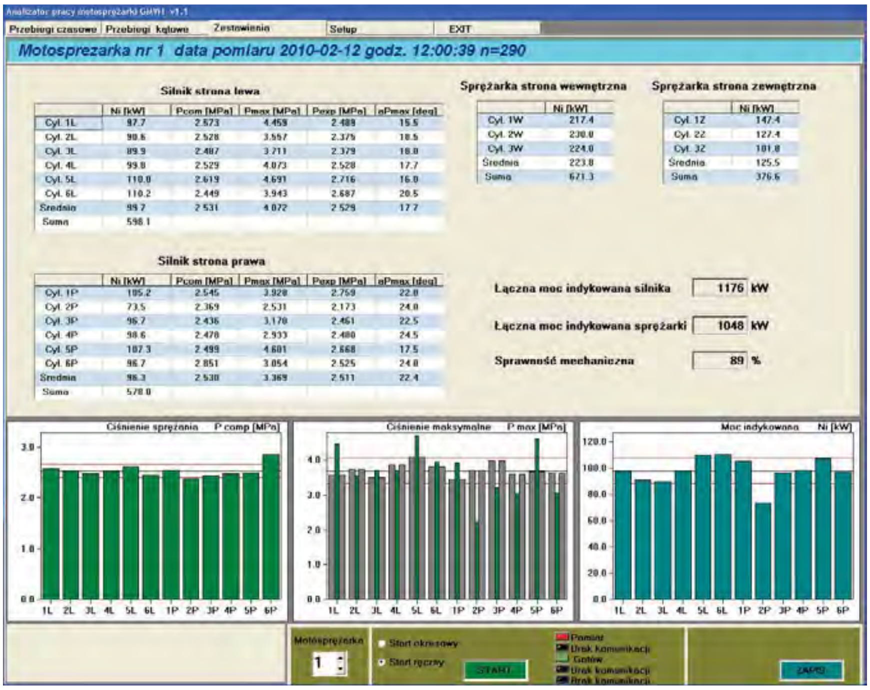

Fig. 6. Presentation of tables and bar charts of parameters on the monitor screen of GMVH motor compressor monitoring-diagnostic system

The possibility to transfer data between the above system and the existing monitoring system of low-frequency parameter has been provided, which allows for presenting bar charts of certain parameters also in this system, and especially gives the possibility to create trends of selected parameters.

6. Summary and conclusions

The above mentioned monitoring – diagnostic system is a prototype devise. There are no ready solutions to this kind of system.

For almost every new type of object, its specificity requires adjustment of hardware and software to system requirements.

Experience resulting from use of the system has proved the system construction concept and development.

There were disturbances in the measuring process caused by pollution of the pressure sensors on the engines and reliability issues of one of the standard (purchased) elements of Ethernet. The works on removal of these inconveniences are being carried out.

Reliability of measurement sensors is crucial for the credibility of parameter’s trends which are essential in the diagnostics of changes in technical conditions of such devices.

References

[1] Gałecki, W., Tomczak, L., *Indykowanie okrętowych silników spalinowych*, Akademia Morska w Gdyni, Gdynia 2002.

[2] Imes newsletter, No 1, February 2010, www.imes.de.

[3] Karlsson, L., Sobel, J., *Stroke by stroke measurement of diesel engine performance on board*, Paper No. 23, 24th Cimac Congres in Kyoto, Japan 2004, Lars.o.karlsson@se.abb.com.

[4] Łutowicz, M., Polanowski, S., Wójtowicz, R., *Mikrokomputerowy analizator przebiegów okresowych silnika spalinowych*, praca własna AMW pod kierunkiem S. Polanowskiego, AMW, Gdynia 1987.

[5] Łutowicz, M., Polanowski, S., Żuralski, C., *Uniwersalny analizator do pomiarów i diagnostyki maszyn*, Przegląd Mechaniczny, 1992.

[6] Moskal, S., Czerwiec, S., Kłos, M., *Doświadczenia eksploatacyjne TJO Jarosław po modernizacji układu sterowania motosprężarek GMVH*, II Małopolska Konferencja Energetyczna JARGAZ 2001, Przemyśl – Krasiczyn 2001, http://www.zamtech.com.pl/referat.pdf.

[7] Moskal, S., Polanowski, S., *Koncepcja systemu monitorująco-diagnostycznego bazującego na ciśnieniach cylindrowych i drganiach dla motosprężarek typu GMVH*. Materiały III Krajowej Konferencji Naukowo-Technicznej Diagnostyka Procesów Przemysłowych, Jurata 1998.

[8] Neumann, S., Bienwald, M., *High temperature – and intelligent pressure sensors based on thin-film technology including modular electronic concepts for closed loop control on gas engines*, CIMAC 2007.

[9] Polanowski, S., Wójtowicz, R., *Analizatory firmy DEMPOL – charakterytyka i możliwości ich diagnostycznego wykorzystania*, Zeszyty Naukowe Politechniki Świętokrzyskiej, Mechanika, Nr 42, Kielce 1988.

[10] PREMET C (www.lemag.de).