

PRELIMINARY EVALUATION OF EFFECTIVE VIBRATION ANALYSIS FOR THE FAULT DIAGNOSIS OF NATURAL GAS ENGINE-DRIVEN COMPRESSOR

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Abstract

In this paper were presented results of preliminary research of the fault diagnosis of natural gas engine-driven compressor by vibration analysis. Natural gas engine-driven compressors are heavily exploited during delivering natural gas to the transmission network of Poland. Every failure brings about interferences to gas system, furthermore it causes notably cost of maintenances. The major failures are piston seizures and overly level of vibration causes by exceedingly wear, an unbalanced engine after repairs and dry friction. During research investigated three natural gas engine-driven compressors. Acceleration of engine cylinders was measured in cylinder axis and perpendicularly axis and acceleration of compressor cylinders, engine fundament and gas receiver in three axes. Results obtain during investigation of engine cylinders one gas engine-driven compressor collates with results of validation of engine cylinders after their stripping. Preliminary results of investigation indicate proper trend to set up diagnostic symptoms. It was found that for increasing of information amount is necessary to carry out synchronous measurements and its envelopes in domain of crankshaft rotation angle. Very important source of diagnostic information can be shaft acceleration, determined basing on existing system of signals generation. The investigation is to be continued.

Keywords: *natural gas motor compressors, vibration diagnostics*

1. Introduction

In the Polish gas grid, numerous motor compressors type GMVH are used, which play important role sustaining non interrupted gas delivery. In the USA those compressors are in use as well.

Primarily assumed exploitation periods of many motor compressors were significantly extended, what was a source of financial savings. That status had been reached by proper exploitation and good planning and strict realization of overhauling and repair, systematic modernization and failure prevention. For last 20 years, in big gas plants, has been conducted

broad program of automation and installation of control and monitoring systems [1]. Visualization systems encompass slow variable parameters of motor compressors work and their rotational speed, parameters of engines and compressors' systems, parameters of gas pipeline, start, stop and continuous work of motor compressors.

In this year, at next compressor, the company ZAMTECH has installed the engine and compressor cylinders monitoring system, constructed by eng. Łutowicz. Installation of subsequent one is assumed. The concept of constructing of a system dedicated for monitoring and diagnostic of compressors and engines' cylinders work was born in 1998 [2]. Intensive exploitation of a motor compressor, together with extending of inter- repair periods increase a risk of failure, which occurs rare, but cause considerable interruptions of gas flow and high costs of repair.

The company ZAMTECH has taken action of technical condition' evaluation of compressors being in exploitation, and evaluation of relation between intensity of work and technical condition. Beside polish universities, American experts have been invited to cooperation, because of their experience deriving from a population of over 1500 similar compressors. Exploitation of American compressors is conducted basing on technical condition. Identification and verification of exploitation process is conducted on the basis of technical condition of objects. Evaluation and verification of exploitation process is carried out at all its stages, including evaluation of spare parts quality. Once, for example, a difference between weights of the same elements coming from different producers was detected, what could be a reason of enhanced vibration.

One element of the program is investigations of vibrations' utility for diagnosis of compressors technical condition and subsequently, failure prevention. At a present stage, investigation has a preliminary recognition character. Previously, similar attempts were taken during routine measurements of foundation and piping vibrations.

2. Implementation of vibration analysis methods for diagnostics of piston engines

Vibration signals are widely used for diagnostic purposes, in practice, only in relation to rotating machines and their bearings. Basing on systematic measurements of vibration, diagnostic parameters' trends can be built, what enable to forecast technical condition and maintenance planning. The service like above is offered for maritime market by specialized companies.

As far as piston engines are concerned, despite periodical interesting in the problem, significant success has not been noted. From late years 50s up to end of 60s, a lot of investigation in domain of vibration diagnostics of tractor engines and other land vehicles was conducted in Russia, as a result of central management, when was undertaken wrong assumption that diagnostics is to be basic factor of exploitation's effectiveness. Many mobile piston and piston rings clearance diagnostic kits, measuring clearance on the basis of spectral analysis of vibrations acceleration, were elaborated and implemented. Own investigations [2] conducted by the method of multiparameter (3 parameters) experiment for square modelling, shown that the method has low accuracy, and clearance value errors overstep 20%.The reason of that was significant vibration dumping, caused by increasing amount of lubricating oil entering upper parts of a piston because of rings' wear.

The proposal of company Vibrometr, which in years 70s offered the monitoring system of piston rings and injection systems, can be assumed as an outstanding. That system was not broadly implemented because of poor vibration waveform processing available that time – lack of proper technical solutions and poor programming as well, for example, analog displays with long persistence were use for realization of noise reduction by averaging. First successful method of use vibration analysis for diagnostics was elaborated by the team from Naval Academy of Gdynia [3]. Their method has been implemented in embedded on-line diagnostic systems for marine diesel engines, and for periodical preventive diagnostic by mobile diagnostic analyzers. That method has been also broadly used by Naval Academy Team for diagnostic of naval ships main engines. Above mentioned method is assumed as useful for early detection of problems with motor compressor GMVH.

Piston engines are very hard to diagnostic by vibration methods. For example, company Windrock offers the module V-Guard II for vibration monitoring with optional generating of threshold alarms. The company does not inform neither about method of diagnostic or what is concerned. The role of operator in that case is to observe vibration parameters' trends and object recognition during measurements procedure.

3. The test rig and experiment description

For investigation, three different configurations of motor- compressor sets were selected. In Fig. 1. is presented the layout of vibration and crankshaft angular speed fluctuation measurement of motor compressor 12GMVH, which is the biggest object among selected for investigation.

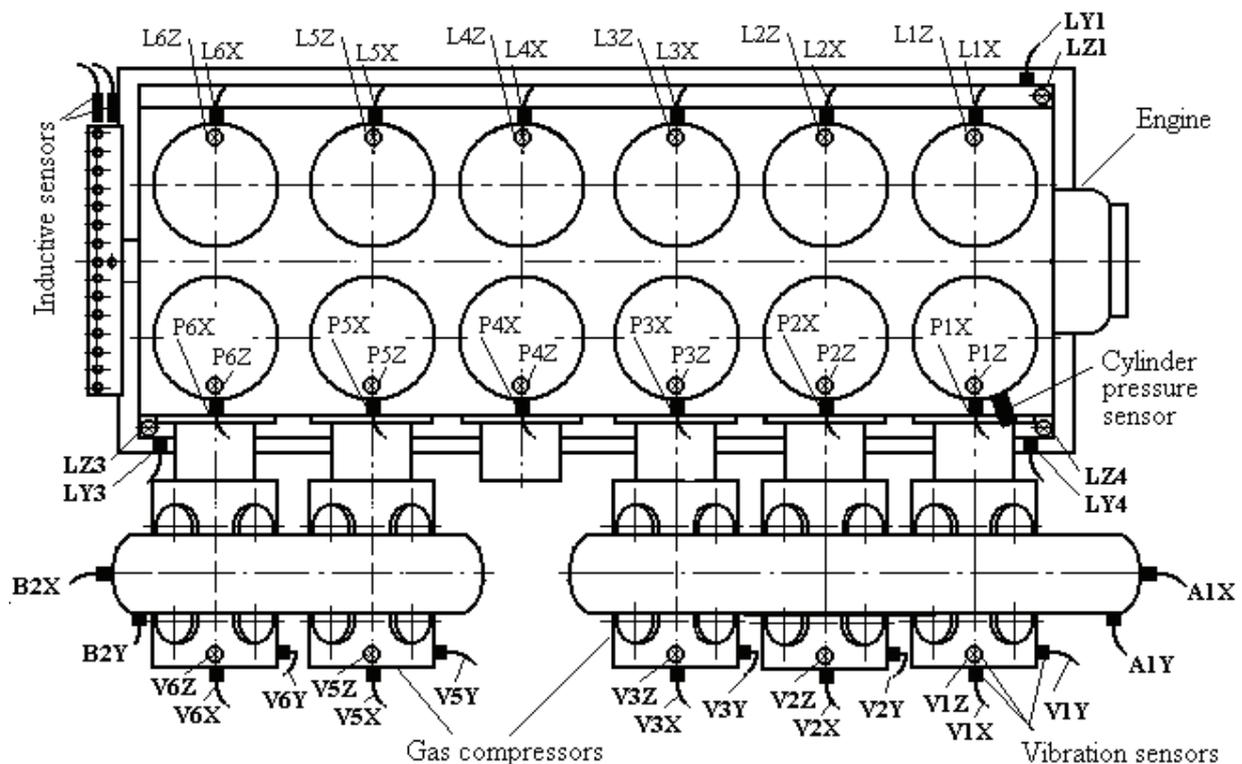


Fig. 1. Dislocation of sensors of vibration, cylinder pressure and angular crankshaft's velocity at the compressor 12GMVH stand

The run of angular velocity was measured by inductive sensors (Fig. 1) and angular acceleration is derivative calculation. Inductive sensor of rotation angle was mounted above of 360 holes drilled at circumference of ignition system wheel. Impulses of angular shafts' position were recorded by existing sensor dedicated for ignition system.

Pressure sensor at indication cock of cylinder P1 was for registration of cylinder pressure chart, together with registration of speed or vibrations.

Simultaneously, two accelerometers with magnetic legs were installed. 3 - dimensional accelerometers were not implemented intentionally because of risk of improper positioning of sensor in uncertain condition.

Vibration acceleration was measured in points as follow:

- engine's foundation legs, points: LZ1, LY1, LZ3, LY3, LZ4, LY4,
- engine cylinders, points: (P1X, P1Z)-(P6X, P6Z),
- compressor cylinders, points: (V1X, V1Y, V1Z)-(V6X, V6Y, V6Z),
- pulsation dumping tanks, points: A1X, A1Y, B2X, B2Y.

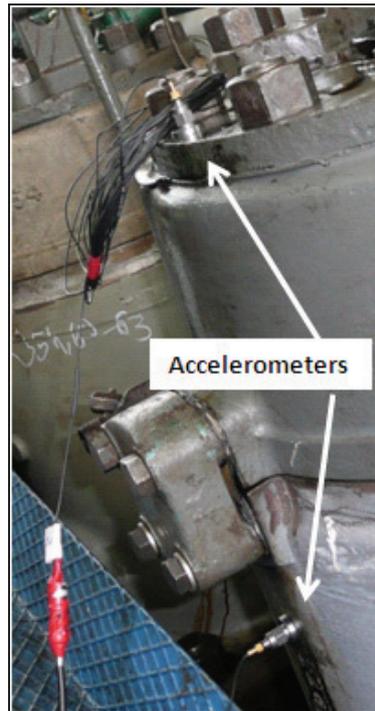


Fig. 2. Acceleration measurement location at 12GMVH motor compressor's cylinders

Measurement, recording and processing of vibration was done using vibration analyzer Pulse 3650 B, with accelerometers type 4514 B produced by Brüel & Kjør, and Matlab software. The character of investigation was rather distinctive. It was the introduction to more advanced research using vibration analysis.

4. Evaluation of diagnostic utility of angular crankshaft acceleration recording

In order to identify the crankshaft angular acceleration, existing installation dedicated for ignition steering was used (Fig. 1). At the flywheel, 360 were drilled, then the inductive sensor was installed above. Additionally, the shaft posses the mark of shafts' position with corresponding inductive sensor. Run of values of 11 revolutions, were registered by both sensor with sampling frequency 65 kHz (Fig. 2). Vibration velocity was calculated basing at period between impulses τ_n .

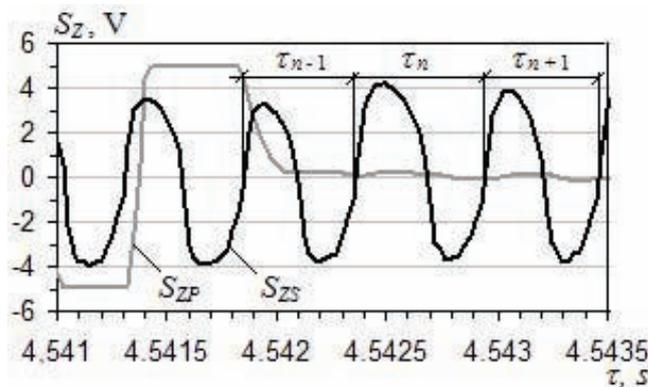


Fig. 3. Fragmentary waveforms of signals registered by inductive sensors

In Fig. 4 are presented superposed 11 runs of angular speed and acceleration of the shaft, in subsequent revolutions, for selected angular zone encompassing gas expansion in the cylinder P1 (Fig. 5).

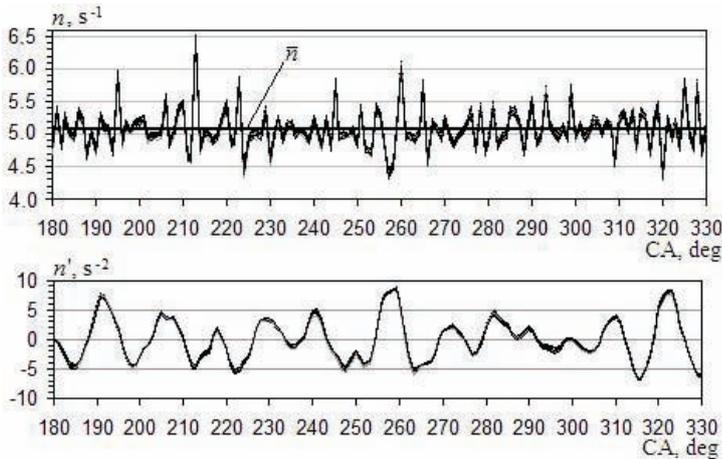


Fig. 4. Instantaneous rotational speed n and accelerations n' for 11 revolutions in expansion chamber, in cylinder P1

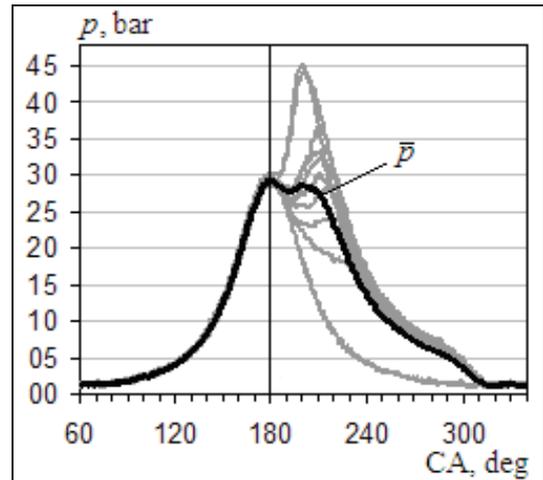


Fig. 5. Pressure run registered for 11 subsequent revolutions, cylinder P1

Determined instantaneous rotational speed values - n , have quite broad spread, achieving up to 30% of mean value (Fig. 4.), but despite of it high coherence of runs can be observed. The reason of that phenomenon is high value of impulse generating errors, due to holes drilling errors and vibrations of inductive sensors. This does not affect significantly determination of angular acceleration because of resetting of sums of deviations within small rotation angle. Determination of acceleration n' of subsequent 11 shaft's revolutions seems to be perfectly overlapped in that scale (Fig. 4), despite of significant dispersion of pressure runs (Fig. 5) – twice misfiring occurred. Nevertheless correlation analysis shows, that in diapason of 230- 240 degrees of crankshaft angle, correlation between acceleration runs and instantaneous cylinder work is close around 1 [3]. It is pointing of possibility of utilisation above mentioned runs values for detection of misfiring and excessive pressure spread. At maritime market, the company LEMAG is offering a system of shafts' angular acceleration and torsion vibrations measurement, based on toothed discs mounted at propulsion shafts. Different utilisation of registered acceleration runs is to be a subject of further investigations.

5. Machine's technical condition evaluation based on effective vibration speed value V_{RMS}

Classic evaluation of considered machine's technical condition by the evaluation of effective vibration speed V_{RMS} can be conducted according to normalisation standards PN-90/N-01358, for the band 10-1000 Hz presented after changing of mounting arrangement; engine is classified to group IV. Above standard can not be applied to cylinders vibration analysis, specifically for horizontal ones. Results of many years of measurement done at those compressors, carried out in several pumping stations, shows that in relation to that machines, criteria of group IV shall be applied, and generally, trends in relation to beginning state must be observed, because, in some points, can exceed the values given in standards, what does not occur in real.

In the case of considered object, V_{RMS} values at engine legs on horizontal direction (L3Y) did not exceed the value of 3.11 mm/s, and on vertical direction (L4Z) 2.82 mm/s. High level of V_{RMS} noted at compressors V5, V6, V1 and at pulsation dumping tank B (Fig. 6). Equal level of V_{RMS} was observed at cylinders of the engine P5, L1 and L5 (Fig. 7).

Not observed before, during investigation of other objects, spectral bands of high value for frequency much lower than revolutionary frequency with the level of 5 Hz (Fig. 8a and 8b). Also displacements above 2 mm, and in one case, even 6 mm were noticed.

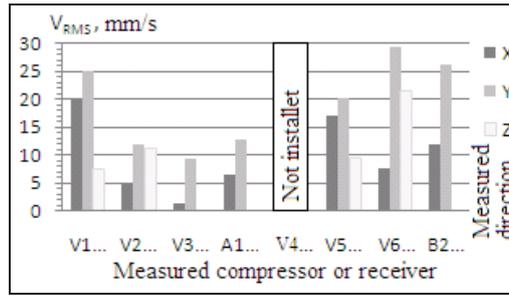


Fig. 6. Values of V_{RMS} registered at compressors and anti-pulsation tanks

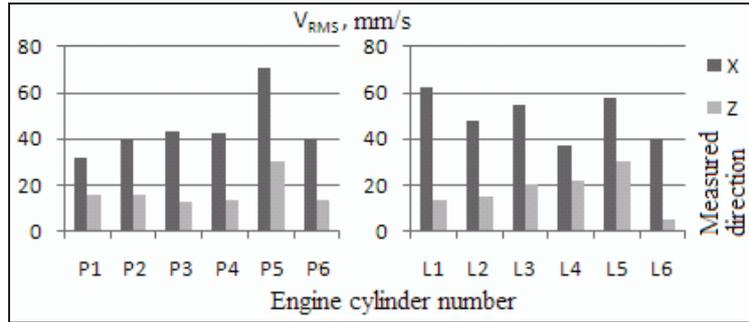


Fig. 7. Values of V_{RMS} measured at engine's cylinders

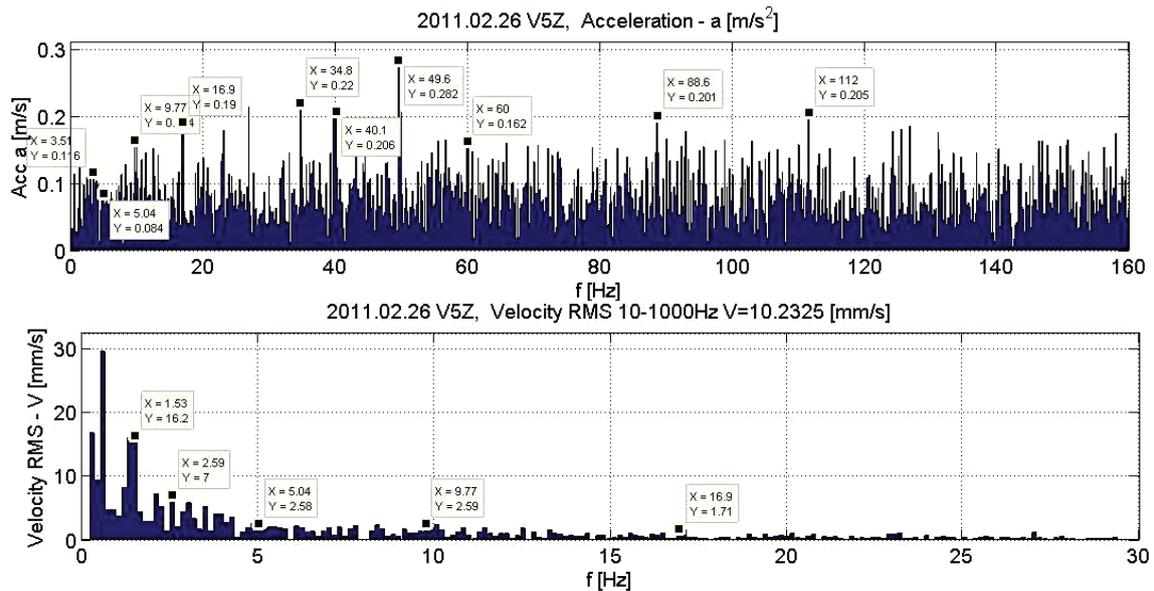


Fig. 8a. Example of acceleration and velocity spectrum measured at compressor V5 in direction Z (vertical) with low frequency, high magnitude bands

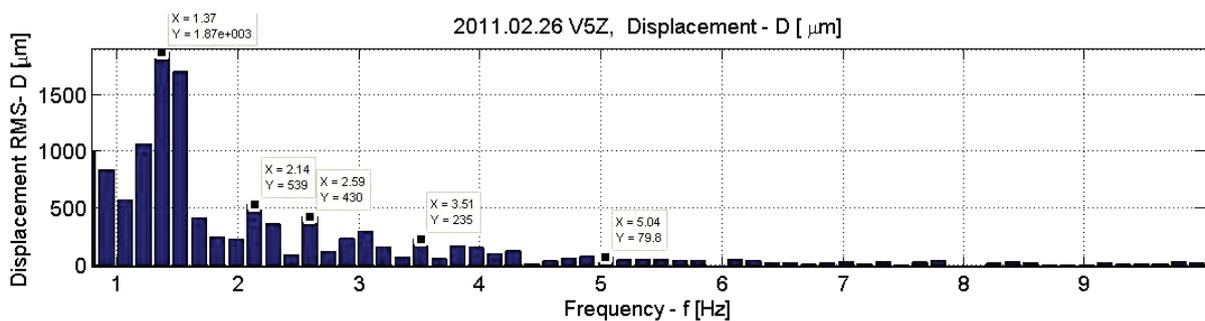


Fig. 8b. Example of displacement spectrum measured at compressor V5 in direction Z (vertical) with low frequency, high magnitude bands

5. Utilization of time run and envelopes of vibration, for diagnostic purposes

Spectral analysis of vibration is an excellent method for objects diagnosis, which are characterized by symptoms having certain frequencies. Multi-cylinders piston machines are objects hard to diagnose by vibration methods. Analyzing of frequency spectra is not enough, what seems to be routine practice. Phase spectrums have to be taken under consideration as well, what provide with full information about signals and noises carried by primary signal.

Primary signal is put under processing (filtration) in order to get rid noises and select proper diagnostic signal. A very often implemented method is synchronous meaning, envelopes and filters. Primary signal, acceleration in our case, is showing generally impulse signals – shocks. There are mostly impulses coming from valves hitting valve seats during closing and opening. In Fig. 9 is shown the sample of leaking valve symptoms of compressor V3. Symptoms in a form of high frequency vibration can be observed.

Possibility of early detecting of valve leaking has been recognized many years ago, but the method did not find an acceptance of exploitation staff. Valve leaking is detected by hand –touch temperature detecting.

In Fig. 9 is shown a sample of acceleration and cylinder pressure envelope, registered at 3 valves of compressor, valve 3 is leaking. Furth more, in Fig. 10 is presented very high level of acceleration envelop for leaking valve, what enable easy identification.

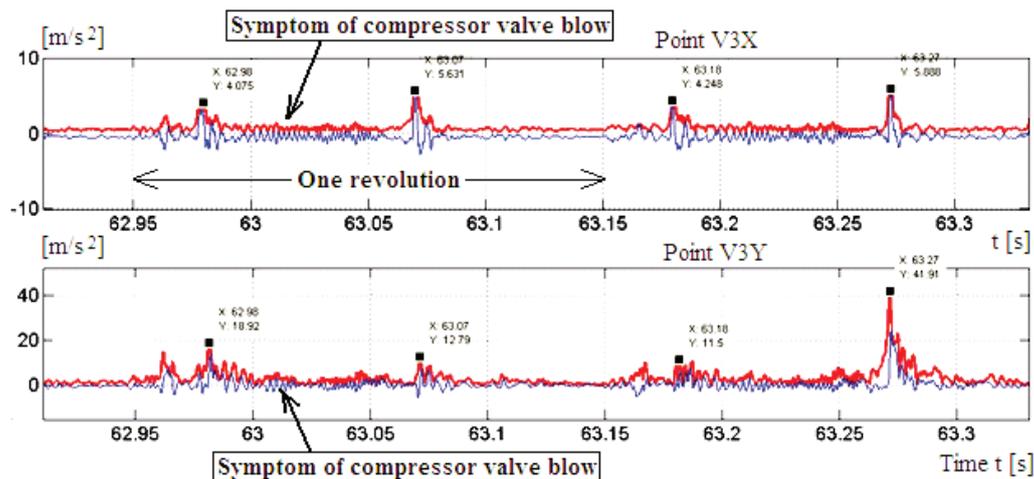


Fig. 9. Acceleration runs and envelops in direction X and Y at compressor V3

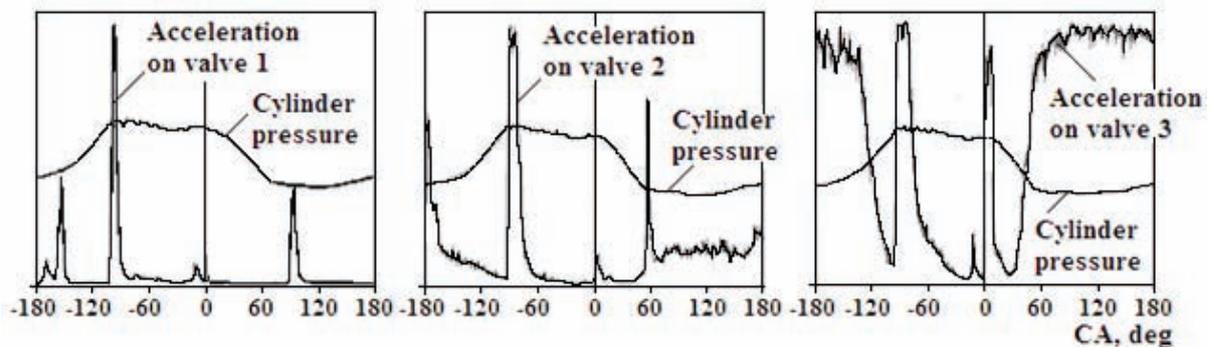


Fig. 10. Envelope of outlet valves, valve 3 is leaking

7. Conclusions

Diagnostic utility of effective values of vibration speed and magnitude spectra of acceleration, speed and displacements are minor for single measurement. Amount of information about an

object can be increased by systematic vibration measurement and trends analyzing.

In order to distinguish diagnostic parameters and obtain more information in relation to investigated piston machines is necessary to implement synchronous measurement of vibrations, noise filtration, time runs' and acceleration, speed and shift of vibrations envelopes analysis

Very important source of diagnostic information can be crankshaft angular acceleration, determined basing on signals generated by ignition system.

References

- [1] *Diagnostic Systems for Reciprocating Engines & Compressors*, www.windrock.com.
- [2] Kłos, M., Łutowicz, M., Polanowski, S., *Multiterminal cylinder pressure monitoring-diagnostic system on natural gas motorcompressors of GMVH type in KRIO Odolanów*, KONES, Vol. 17, No. 2, pp. 195-203, 2010.
- [3] Moskal, S., Polanowski, S., *The conception of monitoring and diagnostic system based on cylinder pressure and vibration for motorcompressors of GMVH type*, Proceedings of 3rd Domestic Science and Technology Conference, Jurata 1998.
- [4] Polanowski, S., *Issledowanije mietodow biezrazbornoj diagnostiki cylindro-porszniowej grupy korabielnogo dwigatiela wnutriennogo sgoranija*, Praca doktorska, Leningrad 1978.
- [5] Polanowski, S., *Analysis of indicators charts in aspect of ship's diesel engine diagnostics*, Research Bulletin of PNA, No. 169A (monograph), Gdynia 2007.
- [6] PREMETS[®] online. LEMAG information No 1 08/12/2004/E, www.lemag.de.
- [7] Witkowski, K., *Using of longitude vibration of cylindrical bush parameters in ship's diesel engine diagnostics*, Diagnostic, Vol. 35, pp. 137-144, 2005.