PREDICTIVE MAINTENANCE
APPLIED TO LASTING EQUIPMENT

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Abstract: This paper highlights the research conducted for proactive maintenance application by analyzing vibration and temperature monitoring during equipment operation, a method that provides a beneficial way clear, comprehensive and thorough to maintain normal operating conditions with low cost of operation and assistance in decision making in maintenance activities. The case study concerns the analysis of vibration and temperature control by monitoring the operation of a screw compressor using information to support maintenance strategies, avoiding outage and reducing unplanned expenses. The paper presents the monitoring method, the devices and related software for a screw compressor of an air conditioning unit. Interpretation of research results, based on a theoretical justification allows continuous assessment of the condition of the equipment and setting intervention thresholds. The conclusions drawn from this paper are generally applicable to assist decision on maintenance activity for similar equipment designed durably.
Keywords: Signal transducers, monitoring software/solutions, decisions, maintenance

1. SCREW COMPRESSORS. INTRODUCTION/HISTORY

These compressors have been made since 1934 by Alf J.R. Lysholn of Ljungstrom-Dampfturbinen Company. At the beginning they were manufactured by the Swedish company named Svenska Rotor Maskiner A.B. They are meant for the achievement of refrigerating powers from 70 kW to 4600 kW. The constructive principle consists of two helical profile rotors, a main rotor (father) and a secondary one (mother): the first one drives the second one, with an intake manifold and a upsetting manifold. Figure 1 shows the schematic diagram of the compressor and the compression process. The secondary rotor can be rotated by a synchronized gear coupling or directly on the main rotor with a thin filter for lubricating oil.

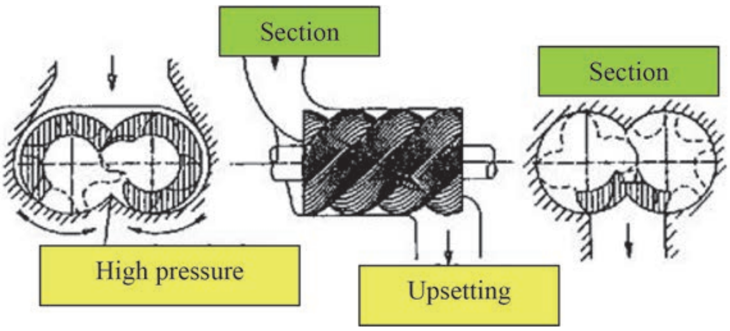


Fig. 1. Schematic diagram of compressor.

Given the major changes occurring recently worldwide and nationwide, the implementation and application of some modern methods of maintenance and repair of the dynamic machines have become an objective necessity.

Taking into account the complexity and value of the screw compressors, we propose the adaptation of the predictive diagnostic solutions necessary any time for the maintenance staff, solutions aiming at the issues of functional, energetic and ecological efficiency. The operating conditions of the machine can be continuously or periodically monitored using specific equipment. In this way, the incipient faults can be detected and fixed within a given time, thus establishing the priorities and avoiding the interruption of operation at inopportune times. Moreover, by means of high performance equipment and specialized technical personnel, one can diagnose the source of the fault occurred, so that the repair consists of the replacement of the faulty component parts only and not all wear parts. This is the solution to make significant savings by reducing the amount of labor and spare parts. In addition, if the repairs can be anticipated, the necessary spare parts will be known in advance, so that the stock will be diminished till liquidation. If the results of a machine monitoring will be stored in a database, as we have proposed, a significant amount of very useful information for a periodic review of the main sources of faults will be accumulated and it will be possible to propose/take measures to avoid their subsequent occurrence.

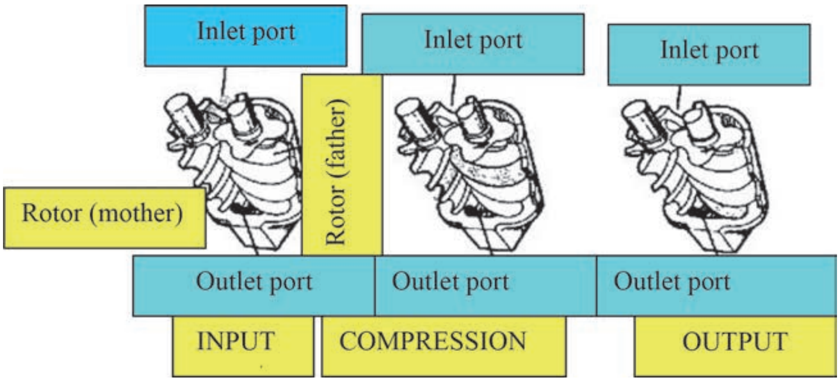
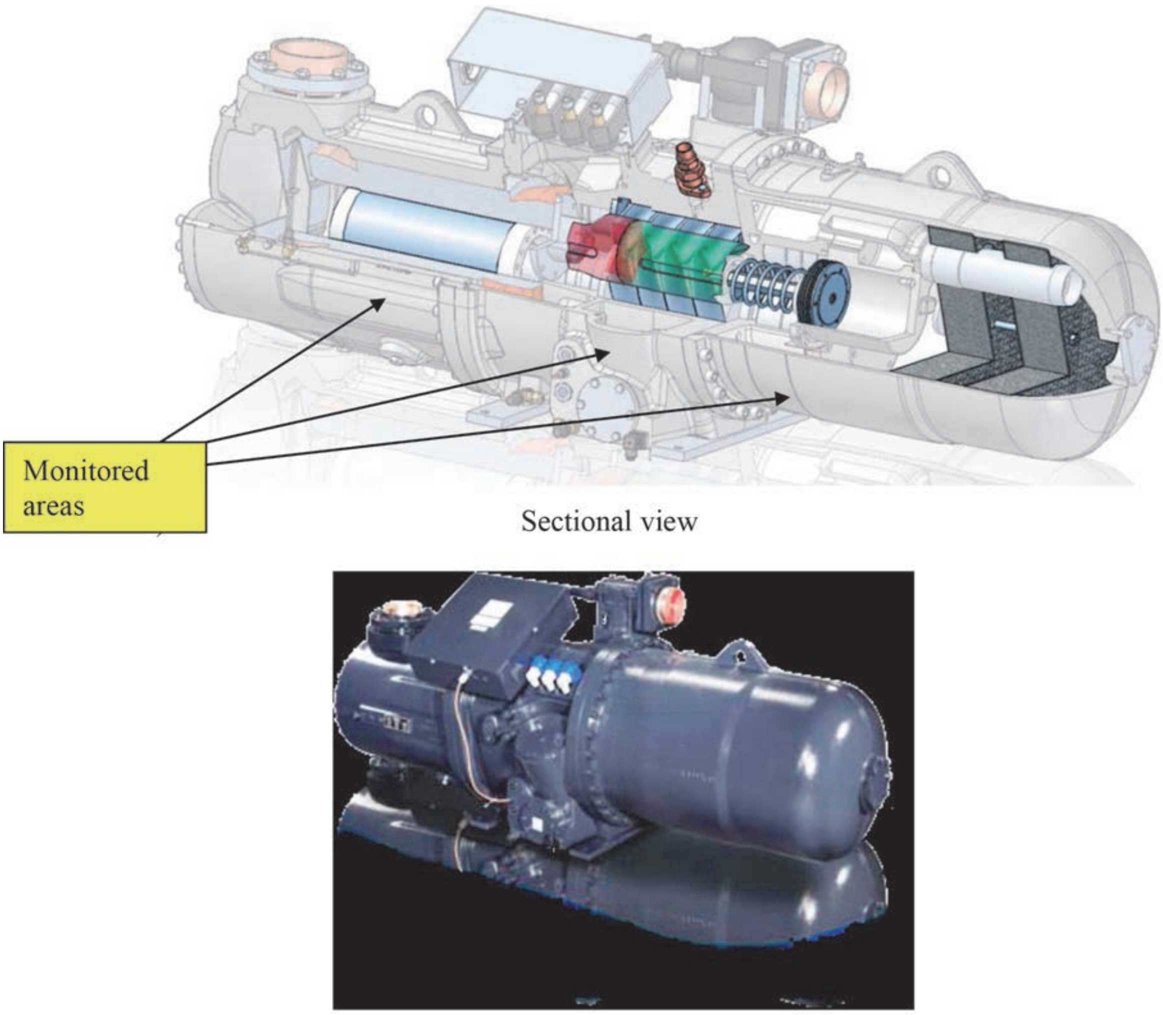


Fig. 2. Process of compression.



b) Overview

Fig. 3. Reciprocating compressor

Such an approach to problems, called **predictive** too, could lead, in the medium and long term, to significant savings for the beneficiary.

The current research is based on vibration analysis that represents an essential aid in the diagnosis of the compressor. In this context we shall analyze the information retrieved from pipes, compressor casing and analysis of casing temperature.

Each part of the compressor has its own vibrations signature. Any change in this signature can be used as an accurate mean of identification of the issues in progress, such as bearings wear, shaft unbalance and degradation of screw compressor tolerance.

This way, the monitoring and diagnostic system will detect not only the possible faults in the initial stage of their development, but will also identify the exact type of failure and its severity. The analysis of vibrations and of the amount of metallic particles from the oil can identify the problems a long time ahead they are seen by maintenance personnel. Companies that conduct research in this field consider that the vibration of a dynamic machine characterizes the best the running condition of a dynamic machine, at the level of the current technique. Vibration is generally due to the dynamic effects of the manufacture tolerances of sub-assemblies, backlashes and direct contact between the moving parts of a machine and also to the unbalanced forces in the parts driven in rotary or alternating movements. Often, low amplitude vibration can excite resonance frequencies of some parts of the machine; these ones are finally amplified up to unacceptable levels. Each component of a machine produces a vibration with one or several specific frequencies. Knowing the spectral components of the global (or compound) vibration, one can determine which of the components of the moving assembly has a problem.

Fig. 4. Assembling zones of vibration sensors.

2. BEARING FAULTS DETECTION

By a continuous monitoring of the screw compressor throughout 80 hours of operation, maintenance specialists have detected a series of failures. It is the case of bearings damage, suction valves damage, pistons damage, etc, as a result of the hydraulic blows occurred because of the control valve oversize. At the same time, compressor overheating entails the reduction of lubricant viscosity and the decrease of its lubricating capacity respectively; thus the *gumming*, carbonization phenomenon of the oil can occur. In this situation, the upsetting valves are merely carbonized.

In practice, the typical method to detect the bearings faults is the broadband analysis of the envelope but if this one is not adapted to the concrete situation, it becomes insufficient to adequately describe the actual situation. The envelope spectrum calculated by the traditional method shows only the harmonics of motor rotational speed, that is why more selective diagnostic techniques should be applied.

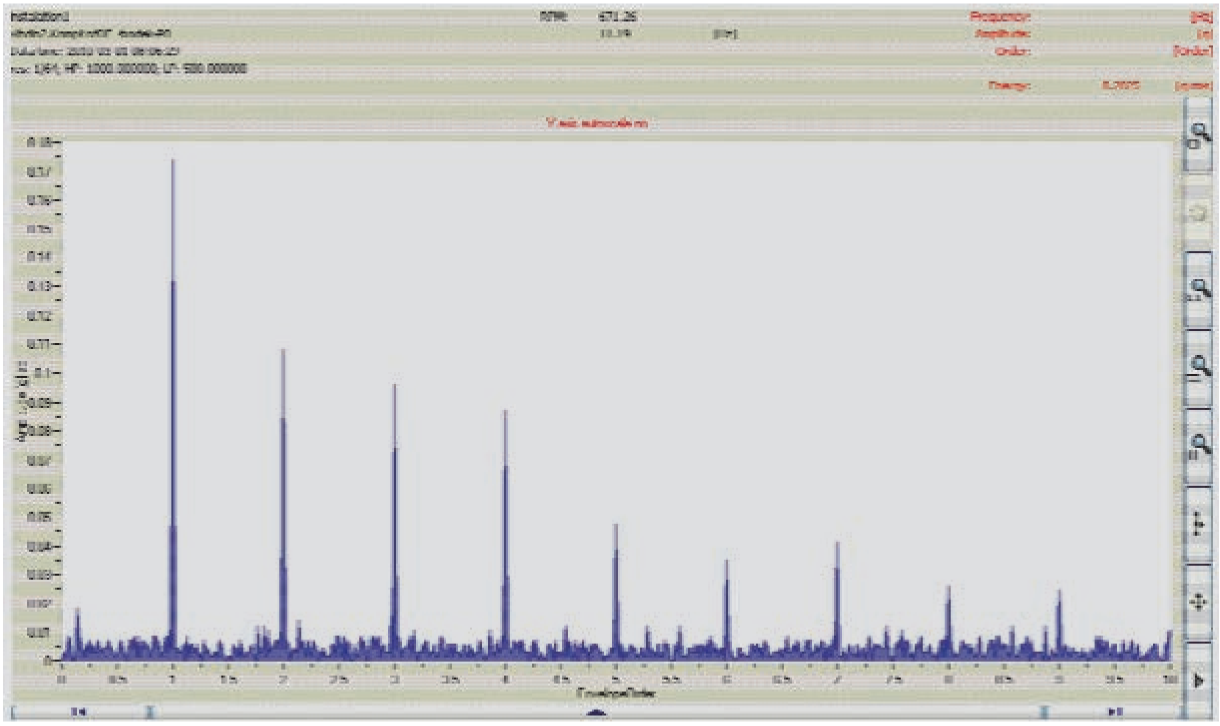


Fig. 5. Classic envelope spectrum

Thus, the first measure consists of the increase of the compressor envelope spectrum resolution up to a convenient level. The envelope spectrum was calculated after the re-sampling of the signal from the 4 sensors, which greatly improved the capture of the spectral lines originating from synchronous sources. Following this decision, the spectrum had sufficient resolution lines to allow the detection of the spectral components coming from the damaged elements of the target-bearing (motor). In figure no. 4 it can be seen the high resolution envelope spectrum. The specialists of maintenance observe in this spectrum the components resulting from the faulty bearing, though the faulty components amplitude is still too low to be easily visible. One can see two peaks characteristic for the bearings inner ring and outer ring, respectively.

The second method applied to determine the bearing faults was the analysis of the narrowband envelope spectrum (NEA), based on Hilbert transform. By means of an appropriate selection of the parameters, the method allows the correct identification of the characteristic components of bearing faulty elements.

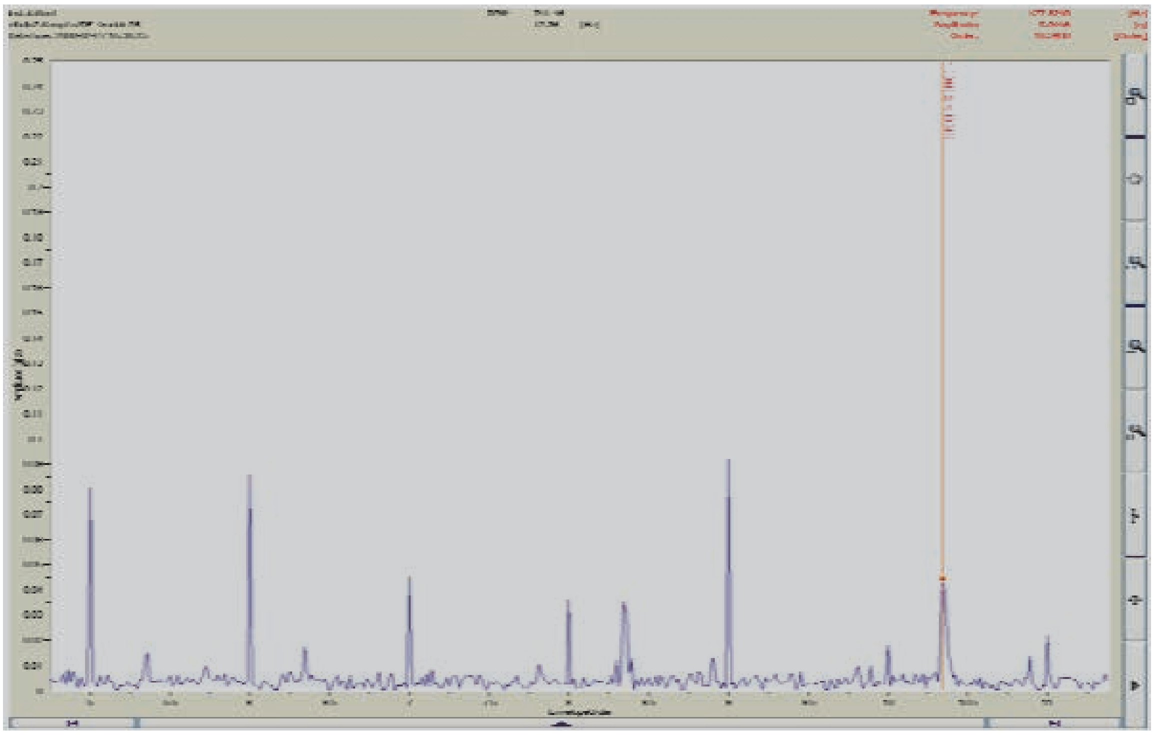


Fig. 6. High resolution envelope spectrum.

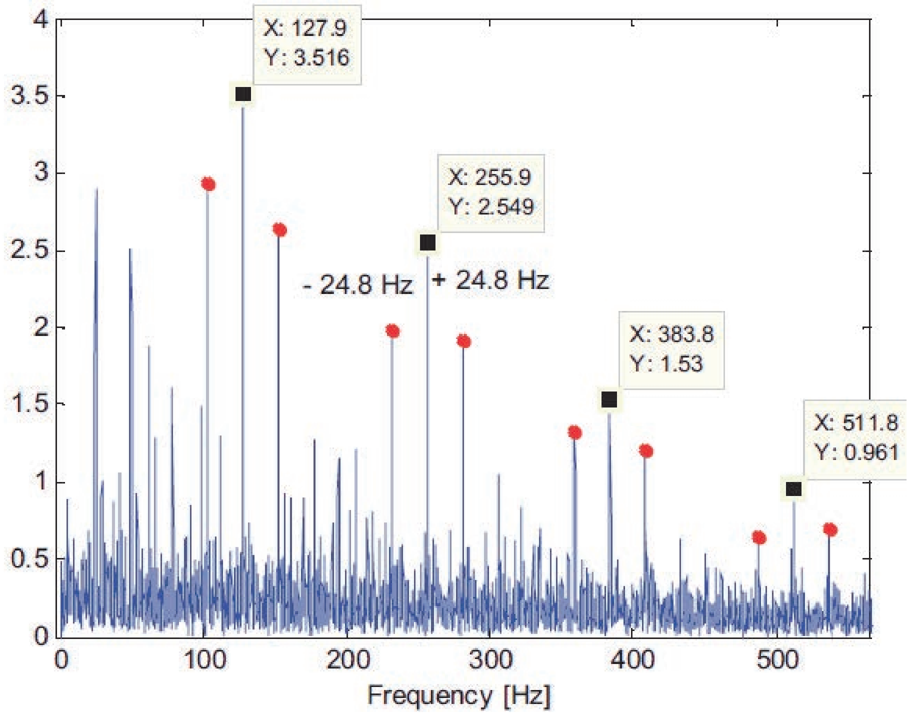
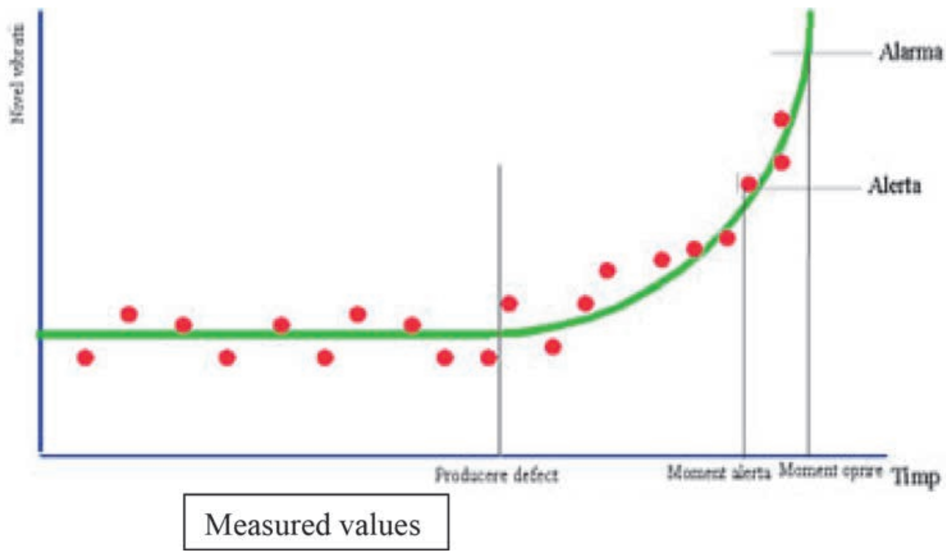
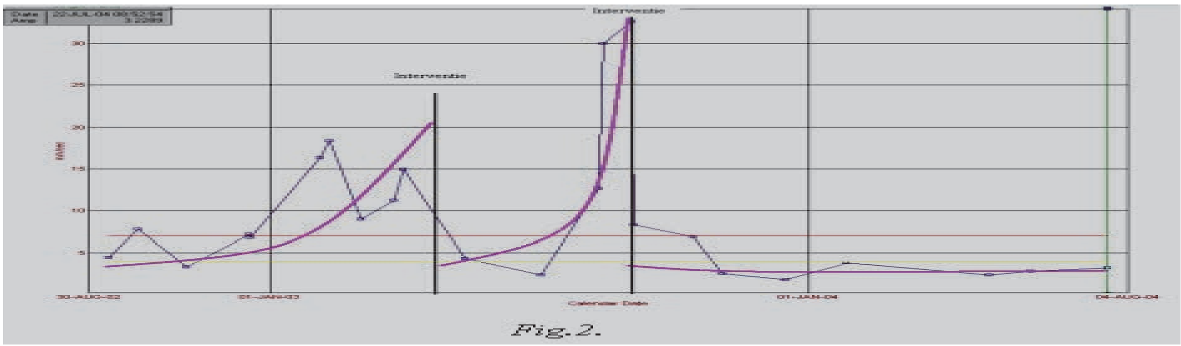


Fig. 7. Narrowband envelope spectrum.

The definition of alert values and alarm limits depends on the particular operating conditions of each and every item and on maintenance specialists' experience too. These values are particularly important in vibro-diagnosis technique because they signal to maintenance specialist that the machine is in an improper operation status and requires interventions to restore it to normal operation. Thus, figure no.1 shows how a fault occurrence is manifested, by the increase of vibration level and the role of alert limits setting so that their signaling is effective. The red dots on the figure represent the measured values of vibration and the green line is just the mean of these values.



a



b

Fig. 8. Values measured:
a) theoretically; b) really.

In practice, the curve aspect is much more sinuous; for example, figure 8 shows the evolution of the average values of acceleration amplitudes of a screw compressor. This diagram highlights the statistical distribution of vibration amplitude values, around some average values, but also their evolution when a fault occurs; in both cases the faults were related to mechanical looseness of the motor bearings.

In this stage, an important element is to define the rate of increase of the average value so that one can determine when the alarm limits are exceeded and which the estimated safe operation time of the machine is. One must determine the rate of growth of vibration average level as the ratio of vibration values difference between two successive measurements and the time interval between these measurements:

$$W = \Delta a / \Delta t \tag{1}$$

where Δa is the difference between the values of the amplitudes, and Δt is the difference of time intervals between the two measurements. The evaluation of the maximum time until exceeding the alarm level is done using the following formula:

$$t = \sqrt{2 \cdot (a_{alarma} - a_{ultim}) \cdot \Delta a / \Delta t} \tag{2}$$

where the alarm is the alert value of the vibration level and the last value of the last amplitude of the measured vibration level.

The formula (2) highlights the importance of the alarm determined level; the estimated period of time for compressor safe operation depends on this value. The current research related to the predictive maintenance within an institution may result in benefits for maintenance management and benefits for service general costs but also for the increase of compressor operation safety.

3. CONCLUSIONS

The proposed research method allows obtaining valuable information leading to the diagnosis of the screw compressor after performing vibration signal analysis, despite the possible external disturbing factors. Therefore, the selection of the most appropriate parameters to be monitored and the improvement of the analysis algorithms are issues on which the specialists of maintenance are currently working.

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MENTENANȚA ANTICIPATIVĂ APLICATĂ ECHIPAMENTELOR DURABILE

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Rezumat: Lucrarea pune în evidenţă cercetările efectuate pentru aplicarea mentenantei proactive prin analiza vibrațiilor și monitorizarea temperaturii în timpul funcționării echipamentelor, metodă ce oferă unui beneficiar calea clară, completă și aprofundată pentru menținerea condițiilor normale de funcționare cu costuri scăzute de exploatare și asistenţa în luarea deciziei în activitatea de mentenanţă. Studiul de caz se referă la analiza vibrațiilor și controlul temperaturii prin monitorizarea funcţionării unui compresor cu șurub, utilizând informaţiile pentru susţinerea strategiilor de mentenanţă, evitarea întreruperii de funcționare și reducerea cheltuielilor neplanificate. Se prezintă metoda de monitorizare, aparatura şi software-ul aferent pentru un compresor cu şurub dintr-o stație de climatizare. Interpretarea rezultatelor cercetării, având la bază o justificare teoretică, permite evaluarea continuă a stării echipamentului și stabilirea pragurilor de interventie. Concluziile care se desprind din această lucrare, sunt general valabile pentru asistarea deciziei în activitatea de mentenanţă la echipamente similare proiectate durabil.