Expert analysis of elements of the diagnostic system for compressor technological equipment

V V Bukhtoyarov¹,², D K Zyryanov¹, N A Bukhtoyarova¹, V S Tynchenko¹,², V V Kukartsev¹,² and K A Bashmur¹

¹Siberian Federal University, 79, Svobodny pr., Krasnoyarsk, 660041, Russian Federation
²Reshetnev Siberian State University of Science and Technology, 31, Krasnoyarsky Rabochy Av., Krasnoyarsk, 660037, Russian Federation

E-mail: vladber@list.ru, vadimond@mail.ru

Abstract. The article discusses the problem of diagnosing technological compressor equipment. The typical causes of defects in screw compressors and the causes of their occurrence are considered. The choice of vibration diagnostics sensors to create a system of complex diagnostics of technological equipment is substantiated. The results of expert evaluation of vibration sensors are presented, which determine the most effective solution for the diagnostic system.

1. Introduction

At the present stage of development of oil and gas production, screw compressors are almost universally used in the preparation and compression of gas. Many processes in the integrated gas preparation, in particular those occurring at the gas condensate separation unit or at the low pressure gas compressor station, are carried out by screw compressors. Since in screw compressors the pumping of the working medium is carried out due to the reciprocal rotation of the screws, this type of equipment is the subject of research by specialists in vibration diagnostics [1-3].

Vibration is a serious problem and can lead not only to a negative impact on production personnel, but also to a decrease in compressor performance, destruction of pipelines and units. Screw compressors are used in various industries for gas compression and pumping, so it is worth considering the main features of diagnostics of defects in them, based on the analysis of working vibrations. In addition to the standard vibration problems inherent in all rotary machines, screw compressors have screw pair defects that determine the difference between the vibration spectra of screw compressors and the spectra of other units.

Vibrations of screw compressors can be caused by the following reasons: poor-quality axial mounting and fixing the position of the screws, an increase in the clearance between the screws, caused, as a rule, by the general wear of the screws or thrust bearings, an increase in the clearance in the plain bearings, in which the rotors rotate and wear of gears connecting screws [4, 5].

Vibrations of the compressor caused by the above problems pose a serious threat to the safety and operational reliability of the compressor, so it is very important to recognize the signs of the appearance of such defects at an early stage of development. In this regard, it seems relevant to select and justify the effective elements of the vibration diagnostic system for such compressors. This is an important stage in the construction of an integrated diagnostic system for compressor technological equipment,
since sensory devices are used to form an information base for further analysis and decision making [6, 7].

2. Description of subject methods
In addition to the usual vibration problems of rotating equipment, there are specific defects in screw compressors due to their design features. The causes of compressor vibration may include [8, 9]:

- Poorly installed and loose base frame.
- Defects in the plain bearings or gearing of the gearbox and the coupling.
- Problems associated with lubrication.
- Defects of rotor blades.
- Malfunctions of the drive motor.
- Rotor imbalance and poor shaft alignment.

Possible specific problems of increasing the vibration level of screw compressors are the following equipment defects [10, 11]:

- Poor-quality axial mounting and fixing the position of the working screws.
- Increase in working clearances between the working screws, which usually occurs due to the general wear of the screws or thrust bearings.
- Increase in the gaps in the radial and thrust bearings, in which the rotors rotate.
- Wear of the gears of the gear pair connecting the working screws.

The above reasons are strongly related to each other, for example, the appearance of an increased clearance in the thrust bearings automatically leads to a change in the clearance between the screws, etc. Tolerances for vibration of equipment and its individual parts are usually established by the manufacturer of this equipment. In the absence of regulatory documents from the manufacturer containing vibration tolerances, the recommended vibration tolerances are used, as presented in GOST ISO standard 10816-1-97 “Vibration. Monitoring the condition of machines according to the results of measurements of vibration on non-rotating parts. Part 1. General requirements”.

However, despite the availability of regulatory and guidance documents, an analysis of studies in this area shows that the control of vibration effects in screw compressors is an urgent technical problem. In accordance with this, the following research objective was set: the creation of an automated system for determining the safe operation of a screw compressor based on an analysis of working vibrations. The implementation of such a system will allow to control and prevent the formation of defects arising from the fault of vibration, even in the early stages of their formation. Generalization of such a system for other elements of technological systems will allow for the implementation of a comprehensive technical solution for the reliability management platform for technological equipment [12, 13].

In terms of diagnosing compressor processing equipment, to achieve this goal, the following steps must be completed.

- Perform an expert evaluation of vibration sensors in order to select the most suitable compressor for installation on a screw type.
- Determine the installation location of the vibration sensors.
- Develop an analyzer program that will allow evaluating the condition of compressor equipment by the totality of vibration indicators collected from all installed sensors.

In the framework of the research presented in this article, the stage of expert evaluation of vibration sensors is described in order to choose the most suitable compressor for installation on a screw type.
2.1. Selection of sensors for expert evaluation
To conduct an expert assessment of vibration sensors and select the most suitable as installed on a screw compressor, it is necessary to determine the range of devices under consideration. According to the results of preliminary analysis and operating experience in research and production facilities, the following vibration sensors are presented as compared ones:

- Vibration transducer VKT-10.
- Digital vibration sensor DVTs-301.
- Vibration sensor Hensford Sensors HS-421.
- Vibration velocity sensor with current output DVST.
- Vibration transducer with HART protocol AV02-0.08.

The following is a brief description of each of the devices considered during the research.

2.2. Vibration transducer VKT-10
The VKT vibration transducer is designed for vibration control of compressors, electric motors, and other dynamic equipment.

Below are the main advantages of the VKT-10 vibration transducer:

- Explosion-proof execution of Exia.
- Low price.
- Intertesting interval 2 years.
- Sealed IP68 housing.
- Arbitrary polarity of connection, MIL-DTL connector.

2.3. Digital vibration sensor DVC-301
Digital vibration sensor DVC-301 is designed to control vibration and can be used in blocking systems of units (pumps, compressors and other technological equipment), in the chemical, petrochemical, food, medical and other industries in normal and explosive operating conditions. The sensor converts vibration parameters (vibration acceleration, vibration velocity, vibration displacement, vibration frequency) along two mutually perpendicular axes into their corresponding digital signals.

The digital signal from the sensor output via the RS-485 serial interface via the MODBUS-RTU protocol can be transmitted via a four-wire communication line to the specialized microcontroller SMK-302-2-4C, SMK-302-2-8C, BUIR-301-16-VTs or to any PC.

The DVTs-301 sensor monitors the vibration parameters along two axes: along the Y axis, which coincides with the axis of the mounting stud, and along the X axis, perpendicular to the Y axis and lying in the plane of the sensor body. Full details of the digital vibration sensor DVC-301 are given in [14].

2.4. Vibration Sensor HS-421
The HS-421 vibration sensors have an analog output of 4..20 mA in proportion to the RMS value of vibration velocity and an additional AC output of vibration acceleration of 100 mV/g. There is experience in the successful use of such sensors to control the vibration of rotating parts of machines in industrial facilities. In general, the HS-421 is characterized as a relatively economical solution with the ability to directly connect to a PLC or any 4..20 mA analog input module.

Below are the main features of the HS-421 vibration sensor:
- 4..20mA output in proportion to the RMS of the vibration velocity.
- Range of operating frequencies from 10 Hz to 1 kHz.
- Degree of protection IP65, IP67 or IP68, work under water, depth up to 100 meters (10 bar).
- Built-in cable or connector (indicated when ordering).
- Operating temperature from -25 to +90 degrees.
2.5. Vibration velocity sensor with current output DVST

Vibration velocity sensors with a current output of the DVST type (hereinafter referred to as the DVST vibration sensors) are designed to control the vibration of various machines and mechanisms with rotating and reciprocating motion. Sensors of vibration velocity with a current output of the DVST type are designed to convert to a direct current of 4-20 mA the mean square values of vibration velocity at controlled points of installations and equipment.

The sensor consists of the following functional devices enclosed in a single housing:

- Piezoelectric or integrated vibration transducer that converts mechanical vibrations (vibration) into electrical ones.
- Matching device that ensures coordination of the output resistance of the vibration transducer and subsequent devices.
- Electronic filter-amplifier that forms a normalized operating frequency band and amplifies a weak signal coming from a vibration transducer.
- Root mean square detector.
- Voltage-current converter, which gives a 4-20 mA current to the communication line, proportional to the mean square value of the vibration velocity at the controlled point.

2.6. Vibration transducer with HART protocol AV02-0.08

Vibration transducer with HART protocol AV02-0.08 is designed for measuring the RMS of vibration velocity in stationary vibrodiagnostic systems with a standard current output (4-20 mA).

Below are the features of this vibration transducer:

- Conversion of a signal proportional to vibration velocity from a piezoelectric element to a standard current signal of 4 ... 20 mA.
- Electrical isolation of the piezoelectric element and built-in amplifier-converter from the housing eliminates the influence on the measurement results of grounding loop currents.
- Robust construction, sealed housing and one-piece armored cable.
- Stability of characteristics and reliability during operation.
- Transmission of a current signal at a distance of up to 1,000 meters.
- Assessment of machine vibration according to GOST ISO 10816-97, GOST ISO 10816-3-2002.
- Digital data transmission via HART protocol.

2.7. Definition of criteria for expert evaluation

Expert evaluation of vibration sensors is outperformed according to six criteria on a 10-point scale. Below are the criteria themselves and a description of the comparative part of each of them. The maximum score according to the criterion “Range of measurement of the vibration parameter” is assigned if the vibration velocity parameter is measured in a range that allows covering all normalized values with a margin, i.e. from 0 to 100 mm/s. With a decrease in the extreme boundary of the range by 10 mm/s 1 point is removed.

The maximum score according to the criterion “Cost of equipment” is assigned if the cost of equipment is in the range from 100 dollars to 150 dollars (excluding installation and maintenance costs). With an increase in value by 15 dollars, 1 point is removed.

The maximum score according to the criterion “Dust and moisture protection category” is assigned due to following rules.

- Vibration sensor has the IP68 category (i.e. it is completely protected from dust and has the ability to work in submerged mode).
- Vibration sensor meets several dust and moisture protection criteria at once, for example IP67/IP68 (up to IP65).
With a decrease in the dust and water tightness category up to IP65, 1 point is removed. If there is a category for dust and water tightness below IP65, the device is assigned 0 points. The maximum score according to the criterion "Operating temperature range" is assigned if the vibration sensor is operable in the range from -55 to +85 °C. By reducing the temperature range by 5 °C, 1 point is removed. The maximum score according to the criterion “Limits of deviation of indicators” is assigned if the error of the sensor does not exceed 5%. With an increase in the sensor error by 1%, 1 point is removed.

According to the criterion “Availability of a digital transmission protocol”, the maximum score is assigned if the vibration sensor has the ability to transmit digital data using various protocols (HART, MODBUS-RTU, etc.). In their absence, the sensor is assigned 0 points.

3. Experimental study

The expert group consists of 3 people, each of which evaluates all the vibration sensors presented for comparison according to each of the criteria. The expert group includes specialists from enterprises of the state oil company that carry out activities related to the operation of screw compressor equipment. The results of expert evaluation are summarized in the Table 1.

| Criterion                                | Weight | VKT-10 | DVC-301 | HS-421 | DVST-3-2-P | AV02-0.08 |
|------------------------------------------|--------|--------|---------|--------|------------|-----------|
| Range of measurement of the vibration parameter | 0.19   | 3      | 10      | 10     | 5          | 10        |
| Cost of equipment                        | 0.17   | 10     | 10      | 2      | 10         | 10        |
| Dust and moisture protection category     | 0.18   | 10     | 0       | 9      | 9          | 5         |
| Operating temperature range              | 0.15   | 9      | 6       | 5      | 6          | 7         |
| Limits of deviation of indicators        | 0.15   | 10     | 5       | 10     | 10         | 10        |
| Availability of a digital transmission protocol | 0.16   | 0      | 10      | 10     | 10         | 10        |
| Sum                                      | 0.19   | 3      | 10      | 10     | 5          | 10        |

In order to identify the most effective sensor in the opinion of the expert group, it is required to multiply the weight of each of the criteria by the ratings made by experts. After that, the summation of the obtained products for each of the sensors is performed. The calculation results are presented in the Table 2.

| Criterion                                | Weight | VKT-10 | DVC-301 | HS-421 | DVST-3-2-P | AV02-0.08 |
|------------------------------------------|--------|--------|---------|--------|------------|-----------|
| Range of measurement of the vibration parameter | 0.19   | 0.57   | 1.9     | 1.9    | 0.95       | 1.9       |
| Cost of equipment                        | 0.17   | 1.7    | 1.7     | 0.34   | 1.7        | 1.7       |
| Dust and moisture protection category     | 0.18   | 1.8    | 0       | 1.62   | 1.62       | 0.9       |
According to the results of the expert analysis, it was found that the most effective of the presented vibration sensors is a vibration speed transducer with the HART protocol AV02-0.08.

4. Conclusion
The article discusses the features of vibration diagnostics of screw compressors, as well as expert assessment is carried out in order to determine the most suitable vibration sensors. Vibrodiagnostics of compressor equipment with the help of vibration analyzers cannot be automated, since it requires the presence of specially trained personnel and the performance of certain actions in the area of operation of the compressor unit. Therefore, it is required to use vibration sensors that can automatically transmit readable readings to the compressor control panel.

According to the results of the expert evaluation, the most suitable vibration sensor for installing it on the RCU VMY536M screw compressor is a vibration speed converter with the HART protocol AV02-0.08.

Acknowledgments
The reported study was partially funded Scholarship of the President of the Russian Federation for young scientists and graduate students SP.869.2019.5.

References
[1] Tsypkin M 2017 Induction motor condition monitoring: Vibration analysis technique—diagnosis of electromagnetic anomalies 2017 IEEE AUTOTESTCON 1-7.
[2] Hübel D and Zitek P 2017 Screw compressor analysis from a vibration point-of-view AIP Conference Proceedings 1889(1) 020011
[3] Robichaud J M and Eng P 2009 Reference standards for vibration monitoring and analysis (Bretech Engineering Ltd)
[4] Tomaszewski J and Rysinski J 2015 Diagnostics of gears and compressors by means of advanced automated system Acta Mechanica et Automatica 9(1) 19-22
[5] Smith D R 2011 Pulsation, vibration, and noise issues with wet and dry screw compressors Proceedings of the 40th Turbomachinery Symposium 57-63
[6] Bukhtoyarov V V, Tynchenko V S and Petrovsky E A 2019 Multi-Stage Intelligent System for Diagnostics of Pumping Equipment for Oil and Gas Industries IOP Conference Series: Earth and Environmental Science 272(3) 032030
[7] Bukhtoyarov V V, Tynchenko V S, Petrovsky E A, Tynchenko V V and Zhukov V G 2018 Improvement of the methodology for determining reliability indicators of oil and gas equipment International Review on Modelling and Simulations 11(1) 37-50
[8] Fujiwara A, Matsuo K and Yamashita H 2011 Vibration analysis of oil-injected twin-screw compressors using simple simulated waveforms Proceedings of the Institution of Mechanical Engineers, Part E: Journal of Process Mechanical Engineering 225(2) 105-16
[9] Zargar O A 2014 Hydraulic Unbalance in Oil Injected Twin Rotary Screw Compressor Vibration Analysis (A Case History Related to Iran Oil Industries) World Academy of Science, Engineering and Technology, International Journal of Mechanical, Aerospace, Industrial, Mechatronic and Manufacturing Engineering 7(11) 2371-7
[10] Wennemar J 2009 Dry Screw Compressor Performance And Application Range. *In Proceedings of the 38th turbomachinery symposium* 116-24

[11] Willie J and Sachs R 2017 Structural and torsional vibration and noise analysis of a dry screw compressor *Proceedings of the Institution of Mechanical Engineers, Part E: Journal of Process Mechanical Engineering* **23**(1) 4-13

[12] Petrovskii E A, Bukhtoyarov V V and Starostina E O 2017 Risk Assessment for the Elements of Production Equipment *Chemical and Petroleum Engineering* **52**(9-10) 642-6

[13] Tynchenko V S, Bukhtoyarov V V, Tynchenko V V, Kukartsev V V and Shepeta N A 2019 Identification and evaluation of reliability factors of main oil pumps *IOP Conference Series: Materials Science and Engineering* **560**(1) 012126