Development of a condition monitoring system for compressor equipment with neural network data analysis

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Abstract. Currently, one of the most widely used and effective types of technological equipment is screw compressor equipment. Along with the fact, that such equipment has a number of advantages that determine its high efficiency, it is characterized by increased wear of important structural elements. This can lead to reduced compressor efficiencies and malfunctions that can result in emergencies. In this regard, the paper presents the results of developing a scheme for continuous monitoring of the technical condition of screw compressor units. Variants of installing vibration sensors that provide data collection of vibration diagnostics are determined. In order to automate the analysis of the collected data, it is proposed to use the method of data mining based on neural networks to recognize the technical condition. The results of testing the neural network data method of a real compressor unit are presented.

1. Introduction

At the present stage of development of oil and gas production, the preparation and compression of gas is not possible without the use of screw compressors. 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 this type of compressor equipment. Among screw compressors, one of the most widely used types in the oil and gas industry is Aerzen VMY compressors. Aerzen VMY are oil-injected screw compressors with an integrated capacity controller that have been developed for suction flow rates from 500 m\(^3\)/h to 8900 m\(^3\)/h and for overpressure - a single-stage compressor has a compression pressure of up to 20 bar.

The VMY series are screw compressors designed to meet the requirements of a wide range of applications for the process gas industry. Initially, it was assumed that these compressors will be used in closed refrigeration cycle systems (ammonia, refrigerants, helium). Nowadays, such compressors are used to compress natural gas, inert gases, ammonia, helium, hydrocarbon, hydrogen chloride, carbon dioxide, mixed and process gases. This type of compressor enables adaptation to a specific operating mode by means of an integrated automated stepless adjustment of capacity [1-3]. The compressor is cooled by oil injection, which allows the compressor to cope with fluctuations in flow, temperature and pressure. However, in screw compressors, there are defects in the screw pair, which can cause an increase in the level of vibration:
• Poor-quality axial mounting and fixing the position of the screws;
• Increase in the clearance between the screws, caused, as a rule, by the general wear of the screws or thrust bearings;
• Increase in the clearance in the plain bearings, in which the rotors rotate;
• Wear of gears connecting screws.

Compressor vibrations 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 such defects in the early stages of their formation [4, 5]. For this purpose, the problem of designing a system of continuous vibration monitoring of the technical condition for the compressor unit is developed and presented in next sections. Taking into account the developed scheme, the neural network data mining approach of vibration monitoring was tested.

2. Screw compressors
The purpose of screw compressors Aerzener VMY.36 is to provide volume-controlled flow with oil injection and compression of process gases and refrigerant gases [6]. No condensation or contamination should be present in these gases. The working chambers of screw compressors are enclosed in the housing one, two or more screws that are engaged. That is, screw compressors can be: single-screw, twin-screw, etc. When the screws move, working volumes of space are formed, limited directly by the screws and the walls of the housing.

Compared to other types of compressor equipment, a screw compressor has several advantages:

• High efficiency compared to other types of compressors (up to 95% compared to piston compressors, the efficiency of which reaches 60%).
• Small contact surfaces reduce friction in the screw block. A lower coefficient of friction, as well as the absence of the need to convert the rotational motion of the engine into reciprocating motion of the pistons, significantly increase the efficiency of the compressor.
• Screw block provides a smooth decrease in the rotation speed, as a result of which the amount of compressed air produced is reduced without the appearance of pressure surges in the system, which are typical for piston installations in the event of a slowdown of the piston. In addition to increasing the efficiency of pneumatic equipment, this effect allows to reduce the volume of the receiver.
• Relatively low working noise.

However, screw compressors also have a number of disadvantages:

• High cost of the main element of the compressor is a screw block. When it fails, there is usually no possibility of prompt repair right at the factory.
• Engineering complexity of mechanisms.
• Screw block is subject to increased wear if the compressor is used in a working space with high dust content.

Given the identified drawbacks of screw-type compressors, the urgent question is to increase their operational reliability through the use of highly efficient methods for determining the technical condition [7-8]. Since the conditions for using compressors can vary significantly depending on operating conditions, it is necessary to use methods for recognizing the technical condition and take into account their results when planning and conducting preventive measures, as well as during operation. Accordingly, it is necessary to develop and implement a scheme for continuous monitoring and recognition of the technical condition of a screw compressor of the selected type. The most suitable
option is to build such a system based on vibration diagnostic methods, as the most informative and developed for this type of equipment [9]. In this regard, the task of selecting and placing vibration sensors for the vibration monitoring system of screw-type compressors is further considered. This will allow continuous monitoring of vibrations, in contrast to periodic monitoring provided by discrete procedures for measuring vibration parameters.

It is important to select and study a method for processing continuous vibration monitoring data concerning the need to implement a continuous monitoring system. In this case, it is necessary to minimize human labor costs, and, consequently, to create a system that automatically determines the current value and predicts the technical state of the type of technological equipment under consideration. To solve such a problem during the study, the method of artificial neural networks was chosen as one of the most effective methods for solving the problem of recognition, classification and prediction [10-12]. This is confirmed by a significant number of successful approbations of the neural network method for solving such problems [13-15]. The following provides a brief description of the artificial neural network method, the selected scheme for its use for vibration monitoring of the technical condition of compressor technological equipment. The results of testing on the data of vibration monitoring obtained on real technological installations for the separation of gas condensate and propane refrigeration unit are presented.

3. Selection of sensors and determining of their installation locations

At the preliminary stage, as a result of expert evaluation, the most suitable sensor for the type of compressor considered was a speed transducer with the HART protocol AV02-0.08. It is this type of sensor that needs to be installed on a VMY536M screw compressor. 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). The following 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.
- Digital data transmission via HART protocol.

3.1. Determining the installation location

The next step is to determine the places for installing sensors and their number. In usual way specially trained people using vibration analyzers take data from certain points on compressor units. For the most part, measurements are carried out without disassembling the compressor and engine at points close to the following installation details:

- M1 - motor bearing from the side opposite to the drive;
- M2 - motor bearing on the drive side;
- C1 - bearing assembly of the compressor unit on the drive side;
- C2 - bearing assembly of the compressor unit from the side opposite to the drive;
- C3, C4 - subsequent bearing units.

Measurement of vibration indicators (often vibration speeds) are carried out in several directions:
- H - the horizontal direction of measurements;
- V - the vertical direction of measurements;
- A - axial direction of measurements.

Based on the foregoing, we can conclude that the most important diagnostic parameter for screw compressor units, and in general for compressor equipment, is the vibration level at the bearing supports. The above points for measuring vibration of screw compressor equipment are presented in figure 1.

Accordingly, the selected sensors must be installed so that they read the readings of the changing vibration velocity precisely at the points used in vibration diagnostics using a vibration analyzer. The technical documentation for compressors of the VMY .36 series stipulates the availability of places for installing vibration sensors at key points of the equipment, for example, bearing assemblies. Based on this, it was decided that to create a system for the automated determination of safe operation modes of an RCU VMY 536M screw compressor based on an analysis of working vibrations, it is necessary to establish about six vibration speed converters with the HART protocol AV02-0.08.

3.2. Artificial neural networks approach for predicting the state of a screw compressor

After the vibration sensor is selected, their number and installation location are determined, it is necessary to solve the problem of predicting the state of the screw compressor by the vibration characteristics taken according to the selected scheme. As one of the options for implementing this task, it is proposed to use prediction using a neural network.

Neural networks are self-learning systems that mimic the activity of the human brain. Let us consider in more detail the structure of artificial neural networks and their application in specific tasks. Despite the wide variety of options for neural networks, they all have common features. Neural networks, like the human brain, consist of a large number of elements of the same type - neurons that mimic brain neurons that are interconnected. Artificial neural networks are one of the most effective methods for searching patterns, forecasting, and qualitative analysis [13-16]. The multilayer perceptron neural network considered in this paper consists of several layers of neurons, each neuron of the current layer being connected to each neuron of the next layer [17].
With the help of a neural network, it is planned to implement an analyzer program, which, in addition to determining the vibration velocity indices on each of the sensors separately, makes it possible to evaluate the state of the compressor installation from the totality of all measurement points.

A neural network will allow to analyze the data received from the sensors and determine the health factor of the compressor equipment. We consider the technical condition (health) factor to be a number from 0 to 1, where a value close to zero or equal to it means the equipment is inoperative, and a value close to 1 means partial or full operability. For analysis within the framework of this work, we set the boundary for the health factor of 0.6.

When analyzing vibrational characteristics at enterprises, the boundary of the condition factor is selected by each operating organization independently. It should be noted that if the condition factor is reduced to a boundary or close to it, urgent measures must be taken to eliminate the problems caused by vibration exposure, up to stopping the compressor, unscheduled maintenance, repair, or, in extreme cases, withdrawal from operation.

4. Experimental study
To predict the state of a screw compressor, a certain array of vibrational characteristics, read by sensors, is required. To do this, we will use a sample of data received from the supervisor. The provided selection consists of 1000 elements. A neural network was created and configured using the STATISTICA program. The existing data array consists of 23 different indicators (horizontally), in which the indicator under number 23 is the condition (health) factor.

All data in this column were obtained experimentally. Some results obtained for several neural networks are shown in table 1.

| Neural Network          | Training Data Error, % | Test Data Error, % |
|-------------------------|------------------------|--------------------|
| Multilayer Perceptron 22-6-1 | 3.3                    | 5.4                |
| Multilayer Perceptron 22-15-1 | 2.7                    | 5.3                |
| Multilayer Perceptron 22-8-1 | 2.4                    | 5.1                |
| Multilayer Perceptron 22-17-1 | 2.7                    | 4.6                |
| Multilayer Perceptron 22-7-1 | 3.6                    | 5.1                |

The results obtained demonstrate the success of testing the neural network approach to solve the problem of vibration data analysis. The accuracy of the resulting neural network models with a multilayer perceptron architecture is characterized by a small value of the standard error of 3% on the training data and 5-6% on the test data. Such values obtained on the data of actually operated compressors allow us to state the possibility of using the considered approach and vibration diagnostics scheme as one of the basic for creating systems for ensuring the operational reliability of this type of technological equipment.

A neural network as an analyser of data coming from vibration sensors, when used in production, will work as follows. Neural network analyser is to obtain values from each sensor separately and determine whether one of the vibration indicators is admitted or other indications. The neural network application will also analyse the general condition of the screw compressor based on the receipt of information from all sensors simultaneously.

Upon reaching the limit value of the condition (health) factor, which acts as the main indicator of the performance of a screw compressor based on the analysis of working vibrations, the neural network will signal the occurrence of defects. So, personnel of the will be able to eliminate them in time, without causing serious damage to the installation, personnel or process.
5. Conclusion
The urgent problem of constructing systems for continuous monitoring of the state of technological equipment on the example of widely used screw compressor units is studied in the paper. The scheme of such a system for monitoring the technical condition is determined, including the choice of the installation scheme of vibration sensors and the method of analysis of data received from them. It is proposed to use vibration transducers with the HART protocol AV02-0.08 for measuring indicators on a compressor unit, and an artificial neural network as a method of analytical data processing. It is assumed that, as part of an automated monitoring procedure, a neural network model will allow for the processing of readings of installed sensors, both individually and in combination.

Usage of neural network will allow to receive timely signals about the occurrence of certain defects of a screw compressor and eliminate them, avoiding damage to the compressor installation, disruption of the process and ensuring the safety of the personnel themselves. This will make it possible to prevent the company from incurring economic losses in the event of a sudden breakdown or accident.

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