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Improving the reliability of the compressor unit using the wavelet transform method.

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Abstract. Centrifugal compressors are an integral part of modern production in such industries as gas transmission, oil refining, metallurgical, machine-building, mining, as well as in electric and heat power engineering. Interruptions in the operation or failure of the compressor lead to decrease in profit or large material loss. Conditions should be created for the safe (stable) operation of the centrifugal compressor. Surge is global (complete) loss of stability, an unacceptable phenomenon for a centrifugal compressor. Compressor surge protection must function during operation. The algorithms used to protect the centrifugal compressor against surge have some drawbacks, which make it impossible to reliably exclude surge.There are many methods for analyzing rapidly changing processes in the flow part of a centrifugal compressor. The wavelet theory is the most accurate and modern method. The use of the wavelet transform method for signal processing allows us to solve the problems of analyzing non-stationary processes of a centrifugal compressor to expand the acceptable range of work and build reliable operation of the anti-surge diagnostic system. In the future, it is possible to use other basic wavelet functions, for comparison and selection of the most suitable one, for the analysis of unsteady signals in a centrifugal compressor.

Introduction

Further development of the centrifugal compressors[1-12] design is associated with increases in rotor rotational velocities, and as a result of loads on structural elements and plant capacities, while maintaining a sufficient level of operational safety both from the strength of the nodes and the stability of the performance. One of the causes of accidents on the compressor is getting into the surge due to an inoperative surge protection system, or not being able to take into account all the factors affecting the compressor in the surge state. Therefore, for centrifugal compressor units, control and automation systems are needed that allow monitoring the gas state in the flow part in real time, this is only possible with systems based on the analysis of non-stationary processes. It is difficult to take into account the wide range of some networks parameters over time when designing, even using modern

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methods for modeling compressor characteristics, since the compressor, firstly, does not work in one mode, and secondly, there are settings on the compressor characteristics that additionally limit the zone work. In addition to ensuring more stable operation of the compressor unit when using a system based on the criterion method of surge protection, for a certain number of compressor units it becomes possible to significantly increase the average efficiency due to the reduction of the operating time at energy-disadvantageous modes.

The objectives of this work:

1. Development of principles and the selection of informative conditions for building a robust (fast, high-quality and reliable) and affordable (acceptable) algorithm for protecting a centrifugal compressor.

Methods

There are two main ways to protect the compressor unit from surge: parametric and characteristic (criteria).

A parametric method of protection is applied in almost all compressor installations, but has significant limitations that must be taken into account, they relate to the quality of the inlet chamber, measuring instruments, network characteristics and actuating controls. The basis of this method is the experimental characteristic of the compressor obtained at the stand, in which the surge margin is shifted by the setpoint 5..10 %, characterizing the total error of the surge protection system. With this approach, it is necessary to ensure flow measurement with sufficient accuracy and stability, which is not always carried out and can lead to emergency situations.

A characteristic method of protection is based on the identification of the characteristic features of the working medium flow behavior in the flow part of the turbo compressor before the surge onset. Signals obtained from different elements can serve as signs of a pre-surge state: the diaphragm of the flow meter in the method of Y.Z. Guzelbaeva [13] or a core in the Mackey R.J. method [14]. These methods are quite indirect and allow the compressor to enter the surge.

At the Department of CVRE, many years of research into the pre-surge condition of a centrifugal compressor were conducted. As a result, a wealth of experience has been accumulated on the nature of unsteady processes occurring in the elements of the flow part, on the basis of which an indicative method of protection was formed, which is based on the timely detection of a rotating pre-disruption and disruption, which allows reliable protection of the compressor from getting into the surge.

The main features of constructing a system and analysis methods for a method based on the timely detection of a rotating stall.

In forming the basic principles for constructing an anti-surge protection system based on the detection of a rotating stall, publications [15, 16, 17] about the properties of the process under study were used. As it is known, the phenomenon of a rotating stall is observed on the left branch of the “head-to-flow” compressor characteristics near the surge boundary. The process of rotating stall is characterized by an increase in amplitude (compared with the previous mode) and a change in the frequency of pressure pulsations, as well as the presence of phase shifts between the signals from two sensors located on the same diameter, but spaced in angular coordinate. Rotary stall is a relatively low-frequency process in absolute motion. Stall zones slowly rotate around an axis with frequency not multiple of the rotational velocity.

The main sources of information or signal in the criteria-based method of surge protection are periods of pulsations (pressure, velocity, etc.). When surging, their periods range from hundreds of milliseconds to units of seconds

The condition of a centrifugal compressor and non-stationary pressure pulsations can be judged by the results of measurements from pressure pulsation sensors located on the impeller (RC) or in stationary elements, behind the impeller, and in the diffuser [15, 16].

Studies have shown that with a rotating disruption, pressure pulsations in absolute motion in the flow part of the centrifugal compressor have a pronounced low-frequency periodic (or quasiperiodic) component, and the period of this component in the stator coordinate system is longer than the compressor rotor revolution period [15]. In the pre-disruption region, chaotic quasiperiodic pressure pulsations are observed. Hidden low-frequency periodicity of pressure pulsations is one of the characteristic signs of the centrifugal compressor pre-surge condition. In addition to the regular presence of low-frequency periodicities, it turned out that in the pre-surge state, pressure pulsations are noticeably more intense than when the compressor was in normal condition. Based on this, in this approach, the essence of the characteristic method consists in the timely detection of hidden periodicities of intense pressure pulsations.

There are many methods for analyzing rapidly changing processes in the flow part of a centrifugal compressor. The main criteria for choosing the required method for the analysis of non-stationary processes in centrifugal compressors are: a) the reliability of the method (this means the low probability of errors for making decisions for any state of the signal under study); b) high speed signal processing, which allows real-time processing to be implemented; c) the availability of the software implementation of the project.

The wavelet theory is based on the expansion in coefficients of specially formed non-sinusoidal basic functions [18, 19]. Wavelet analysis is an extension of the classical method of weighted Fourier analysis. The basic function of the weighted Fourier analysis is the sines and cosines (waves) multiplied by a sliding window. They are usually called time-frequency atoms. In the wavelet analysis, the window is initially oscillating and is called the mother wavelet. Instead of decomposing into sines and cosines, this wavelet is arbitrarily shifted and stretched along the time axis. Thus, the generating (mother) wavelet forms other wavelets, which are the basic functions of the wavelet analysis [20]. The choice of the basis function form is determined by the decomposition problems. The calculations used the biorthogonal wavelet ‘‘bior 1.5’’. After the signal is decomposed into approximating and detailing coefficients, a periodogram and a correlation function are calculated for them on the basis, for automatically determining the stall period, in two ways.

Three model stages were used as an object of study, the results obtained are close, the “IM” stage [17] of the natural gas supercharger first stage model was chosen to represent the experiments 395-21-1 Nevsky Zavod software with an open impeller (D_2=363 mm, b_2=25,3 mm, $\beta_{л2}$= 22,5^0, $\beta_{л1}$=26^0, z_2=12,) with cylindrical blades of constant thickness, outlined by circular arcs. Fixed stage elements are formed by a blade diffuser ($z_3 = 18$, $D_3/D_2 = 1{,}163$, $D_4/D_2 = 1{,}5$; $b_3 = b_4$, $\alpha_{л3} = 15^0$, $\alpha_{л4} = 30^0$). The rotary knee of the stage is made smoothly along circular arcs with a slight diffuser. RGA blades have a symmetrical crescent shape and are outlined by arcs of circles. In the work we used the records of non-stationary processes obtained at the stand of the CVRE Department for this level. Stage tested at u_2 =206 and 275 m/sec. The location of the sensors in the flow part and the modes on the stage characteristic is shown in Fig1

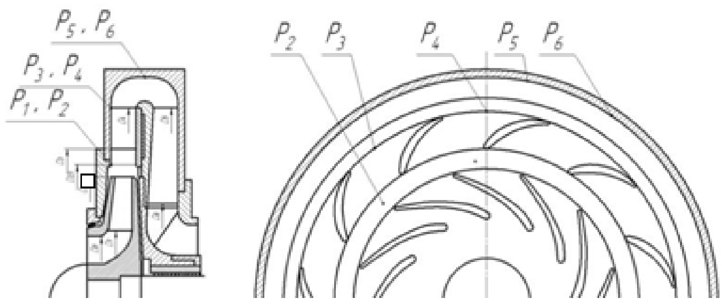

Fig. 1 Arrangement of sensors in the flow part.

According to the results of signal processing, the following results were obtained. In the pre-failure mode F = 0.044 (Fig. 2), the implementations KZ1502-KZ1506 with sampling rate of 18 μs and the results of the wavelet transform in spatial sections are presented. Short-term periodic sections with a characteristic period close to the period of a rotating stall are observed. They are poorly visible on the initial signal, but as a result of the conversion are clearly observed, this makes it possible to more accurately determine the beginning of the onset of pre-failure.

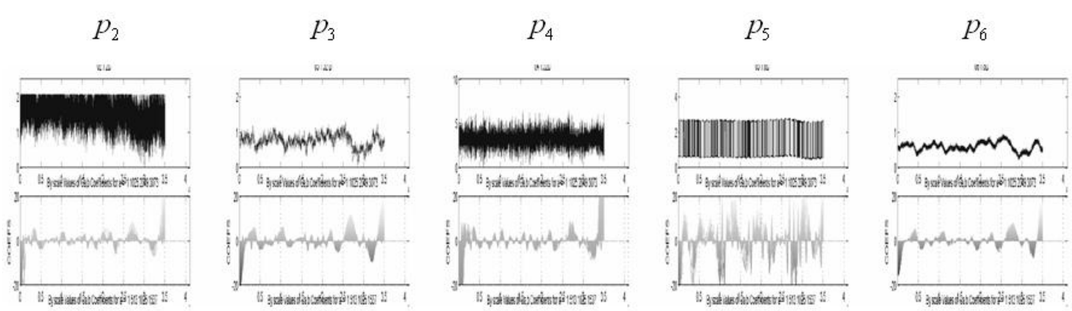

Fig.2 The original signal and the past wavelet transform signal in spatial sections for IV mode.

In V mode of rotating stall (F = 0.035) and VI mode of strongly developed stall (F <0.033), (Fig. 3) and (Fig. 4), records KZ1602-KZ1606 and KZ1702-KZ1706 with sampling of 18 μs are presented, and the results are wavelet transformations in spatial sections. In the pictures obtained by the wavelet transform, a breakdown of the low-period signal is clearly visible even on sensors that have a strong high-frequency interference. In this case, the pressure pulsations have the form of a distinct periodic function; even on the initial signal, a periodic function can be observed.

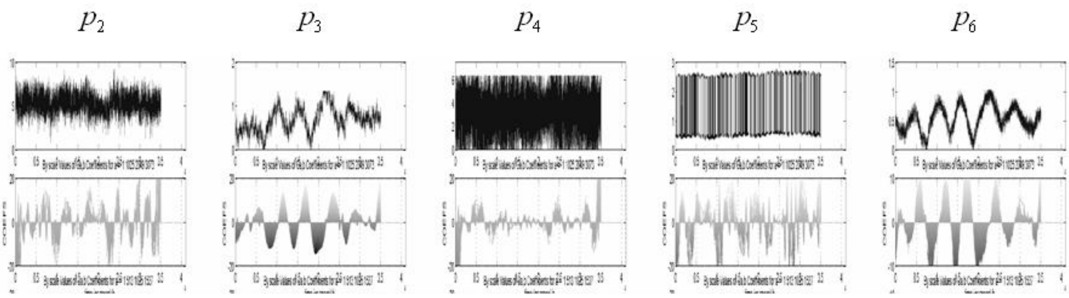

Fig.3 The original signal and the past wavelet transform signal in spatial sections for V mode.

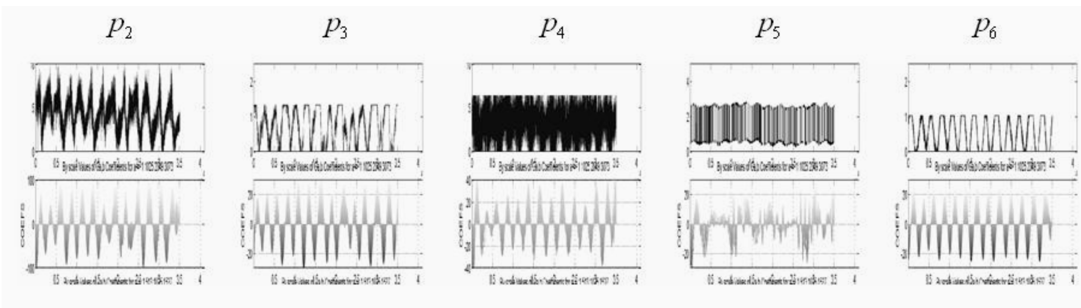

Fig.4 The original signal and the past wavelet transform signal in spatial sections for V mode.

According to the data processing results of nine modes after the wavelet transform, using this technique, it is possible to determine the desired signal period. A positive quality of this method is the high noise immunity. In the regimes from the maximum flow rate to the intermediate flow rate, low-frequency periodic signals did not appear, and there were also no large signal amplitudes, which indicates the correct processing method. The pre-failure mode had a pulsating amplitude periodic signal. In the stall and developed rotating stall modes, a periodic signal was clearly observed in sufficiently long sections for the first, and for the second throughout the observation section.

The use of the wavelet transform method for signal processing allows us to solve the problems of analyzing non-stationary processes of a centrifugal compressor to expand the acceptable range of work and build reliable operation of the anti-surge diagnostic system. In the future, it is possible to use other basic wavelet functions, for comparison and selection of the most suitable one, for the analysis of unsteady signals in a centrifugal compressor.

Conclusions

The use of the wavelet transform method for signal processing allows us to solve the problems of analyzing non-stationary processes of a centrifugal compressor to expand the acceptable range of work and build reliable operation of the anti-surge diagnostic system. In the future, it is possible to use other basic wavelet functions, for comparison and selection of the most suitable one, for the analysis of unsteady signals in a centrifugal compressor.

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