

# Surge protection system development in centrifugal compressor with an indicative method using numerical simulation of unsteady processes and analysis of pressure fluctuation signals

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**Abstract.** Nowadays, anti-surge protection system based on parametric method is widely used. The disadvantage of this anti-surge system is the fact that it is not possible to fully ensure the safe operation of the compressor at low flow conditions, because large measurement error will occur. Other method of anti-surge protection is indicative method. This method is what it is necessary to detect occurrence of rotating stall in time on the score of information criterion. Further the control decision is accepted in connection with the approach to the danger zone of surge. Indicative method is more complicated and requires special signal analysis such as wavelet analysis, correlation analysis. Also in addition to the methods of analysis, important is the length of the sample for processing unsteady pressure fluctuations and the method of its displacement on time. It is now possible to mathematically pre-simulate unsteady processes in the flow part of centrifugal compressor.

## 1 Introduction

The area of operation of centrifugal compressors is strictly limited to the minimum consumption at a fixed rotation frequency, this is due to the presence of surging, which is not permissible in the normal operation of a centrifugal compressor. The condition of the compressor in surging is characterized by a global (total) loss of stability, on the other hand, surging is a self-oscillating process in the "compressor-network" system, Fig. 1. The boundary of the beginning of surging is determined by the shape of the characteristics of the compressor and the network, and, as a rule, is located in the area of costs lower than the boundary of the phenomenon of rotating stall. According to the results of the research, it is revealed that an intense rotating stall is formed in the flow section before surging. At surging, there are powerful fluctuations created in addition to the circumferential unevenness of the aerodynamic quantities and the rotating stall, by the reverse flow of gas through the flow

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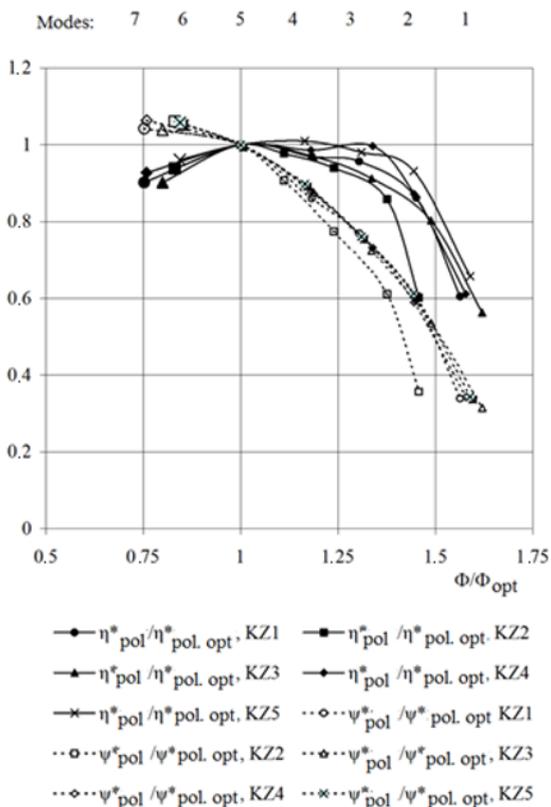
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section, which creates increased loads on the compressor and the installation as a whole [1-5].

### 1.1 Classical system of compressor protection against surging

The basic, now existing, way of protecting centrifugal compressors from surging is the parametric method. But another way is also developing - it is a featuring method [1].

One of the main disadvantages of the parametric method is the possibility of obtaining a large error in the calculation of productivity by the indirect method of determining the gas consumption [2] by the pressure drop in the suction pipe with intense pressure pulsations at close to surging modes of operation of the centrifugal compressor. The anti-surge system, based on this technique, cannot fully ensure the safe operation of the compressor at low consumption rates, since it will have large measurement errors. Another disadvantage of the parametric system - it is a necessity to make a large stock in setting protection from surge due to the error of flow measurement at the time of actuation of an anti-surge valve. When new centrifugal units are put into operation, surge tests are carried out on conditions close to the technical specification, which in the course of operation change and lead to a shift in the surge boundary, most often shifting towards higher costs. To take into account this factor, the setting is increased from 5% to 25%, in some cases the optimal operation modes fall into this zone. A consequence of the large settings before the surge during operation of the centrifugal compressor is a constant work with partially open bypass valve, what is not economical [18].



**Fig. 1.** The characteristic "head-flow" of the KZ stage formed from the impeller of the model stage of the supercharger 395-21-1 and fixed elements of the model stage NC-16 / 76-1.44 stage KZ5 [4]

## 2 Methods

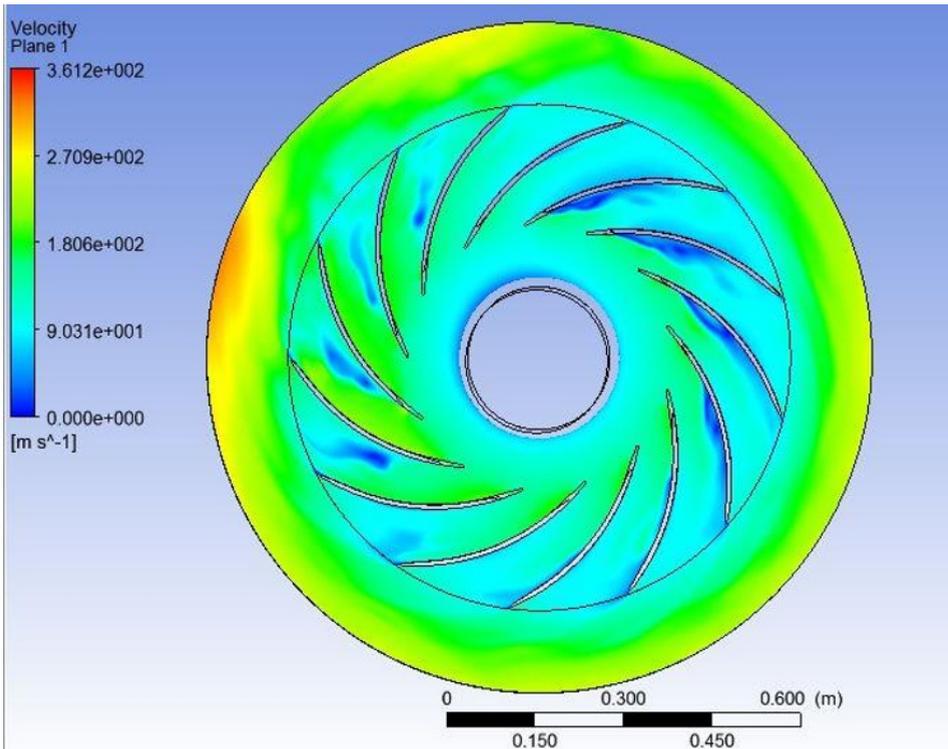
The featuring method of protecting a centrifugal compressor from surge is as follows: based on the information criteria received from pressure sensors placed behind the impeller on the stator of a centrifugal compressor, it requires timely detect the occurrence of rotating stall (or other characteristic phenomena preceding surge) and subsequently decide on approaching the dangerous area of work - surge. The choice of the criterion is carried out with taking into account the characteristic features of the behavior of the gas flow in the flowing part of the turbocharger before the appearance of surging. At present, there are various methods described in the sources [7, 17]. In the present work, the signs and criteria formed on the basis of the many-year research of the research group on the study of non-stationary processes in a centrifugal compressor, headed by Professor and Doctor of Technical Sciences R.A. Izmailov at the department "Compressor, Vacuum and Refrigeration Engineering" SPbPU.

## 3 Results and Discussion

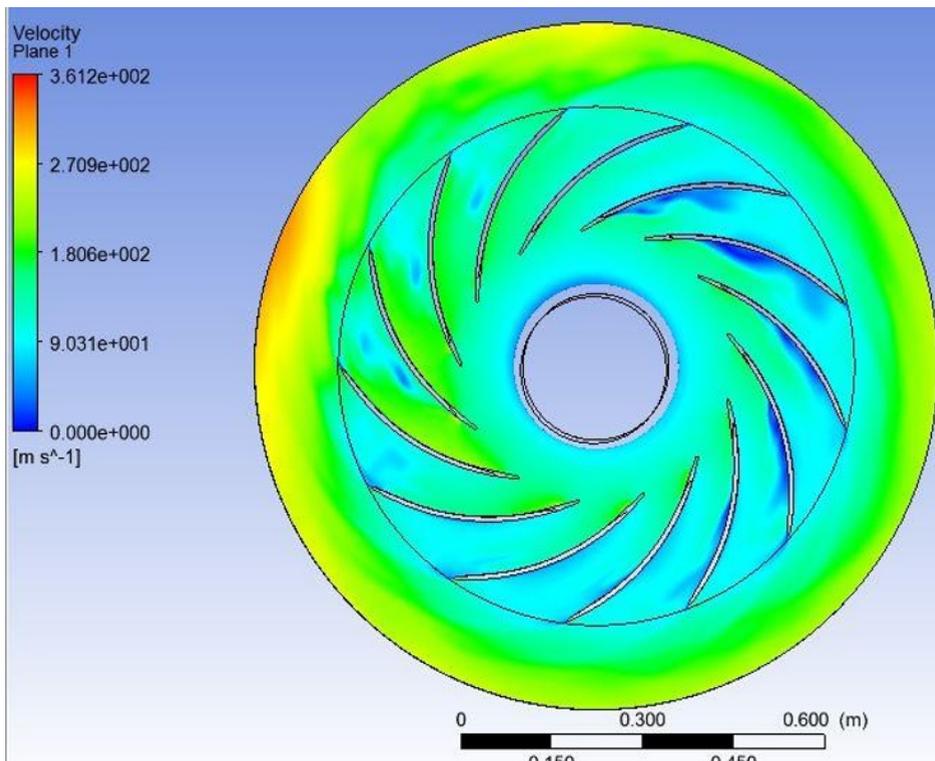
### 3.1 The development of a centrifugal compressor protection system against surging with a featuring method based on numerical simulation

The appearance of available high-power computing facilities (clusters, supercomputers) allows to carry out both complex calculations with simulation of non-stationary currents in the stage of a centrifugal compressor and to simulate the entire compressor's operation process. An important feature of the simulation of non-stationary processes in a centrifugal compressor is the need for calculations in the 360 degree on a circle, since a replacement in a sector leads to a distortion of the results obtained and is not correct from the standpoint of the physics of the nonstationary process. Modeling of non-stationary processes in centrifugal compressor requires 10-20 times more processing power, but also increases the computation time by 15-30 times in comparison with the stationary sector for calculation of the flow section. The initial results of numerical modeling of nonstationary processes in the stages of a centrifugal compressor were obtained at the department of CVRE SPbPU [12]. Later, in [6,9,10,13,19], the simulation of non-stationary processes for a real centrifugal natural gas compressor was carried out according to the characteristics and dimensions of the steps close to the model stage of the department of CVRE.

The preliminary results of calculations in the software complex ANSYS CFX turned out to be the following: a qualitative coincidence of pressure pulsation zones at the exit behind the impeller is observed in the field experiment behind the impeller between the control cross-sections 2 and 3. For the rotational stall mode, the following velocity fields were obtained (Fig. 2, 3): in the flow patterns, the existence of a detachment can be seen in the sector, as well as its displacement in the direction of rotation.



**Fig. 2.** The velocity field at the angle of rotation  $230^\circ$



**Fig. 3.** The velocity field at the rotation angle  $275^\circ$

Proceeding from the obtained results, it can be assumed that the main and one of the most important factors affecting the appearance of non-stationarity in the flowing section of a centrifugal compressor are deviations from axisymmetric in the manufacturing, the quality of manufacturing and assembly of the flow section in a full-scale experiment.

### 3.2 The development of a centrifugal compressor protection system against surging by a featuring method based on the analysis of signals of non-stationary processes and algorithms

At the present time, methods for detecting periodicity, spectral analysis, correlation analysis [14,17], as well as methods for processing the filtering signal and wavelet transform [9,13,12,14,15,18] are checked. As a result of processing the experimental data, the peaks are seen in the patterns of the energy densities of the signal periods.

With the advancement along the tract they become clearer.

The algorithm for the characteristic surge protection system is a set of methods for detecting the periodic component in nonstationary pressure pulsations in order to detect a rotating breakdown in a timely manner and to decide on the inclusion of a surge protection system. One of the algorithms studied, based on signal processing by wavelet transform, consists in the fact that the wavelet transformation of the signal is performed, and after the transformed signal is subjected to two parallel methods for detecting the period of pulsations: spectral analysis and autocorrelation analysis. The obtained periods and their powers are compared, and the amplitude of pulsations proposed by Nguyen Minh Khai [14] performed at the CVRE Department, this is also analyzed, this sequence avoids false alarms of the system.

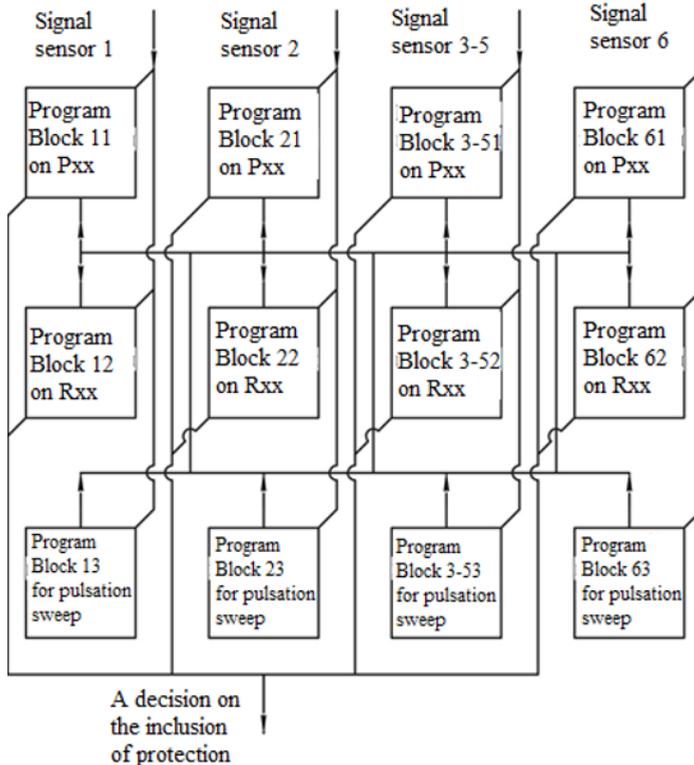


Fig. 4. Scheme of the anti-surge algorithm

To optimize the algorithm (Fig.4) and eliminate the value of excessive overlapping, it should be installed for a particular stage and installation, since a decrease in overlap may lead to an increase in the number of analyzed intervals and, as a consequence, an increase in the overall dimensions of the analysis system and cost.

## 4 Conclusions

Tougher requirements for the energy efficiency of centrifugal natural gas compressors and the purity of the pumped gas force consumers to switch to dynamic-action compressor equipment in areas with lower mass costs and expand their stable operation zone [17]. And the ways of expanding the zone of operation of a centrifugal compressor become actual because of the precise determination of places in the characteristic in which work is not possible. Due to this, there is energy savings at the gas compression [20].

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