The Vibration Monitoring of the Gascompressor Units with Application of Hurst’s Statistics

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Abstract. The gascompressor units work in the unsteady regime which depends on many internal and external factors. For the solution of problems of control, management and forecasting the statistical assessment of a condition of object in real time according to noisy observations of one realization of stochastic process is carried out. The traditional spectral analysis on the basis of Fast Fourier Transformation in this case is inefficient if time scale is much less than duration, which is subject to the analysis. Therefore for monitoring of a condition of the equipment it is offered to use Hurst's statistics by means of which it is possible to investigate quantitatively law of development of a vibration signal and unambiguously to analyze a condition of the gascompressor units. Calculation of economic efficiency from introduction of such technology of monitoring will provide decrease on average by 2.5% of a consumption of gas and specific costs of capital repairs of the gascompressor units at the expense of increase in a total operating time by 20%.

1. Introduction
In monitoring systems and monitoring of a condition of gascompressor units the low-frequency range of a range of fluctuations of its mechanical system is mainly used. This range consists of harmonic and subharmonic oscillations of rotors of turbines of a low and high pressure which are well described by system of the usual differential equations. Application of classical approach for definition of high-frequency components leads to unjustified increase in an order of system, and determination of coefficients of the equations is difficult in view of a large number of the analyzed knots. Important part in the analysis of non-stationary processes in multifrequency signals is existence of a constant control of changes in its amplitude-frequency components. The traditional spectral analysis on the basis of Fast Fourier Transformation (FFT) is inefficient for non-stationary signals with a temporary scale much smaller duration which is subject to the analysis of realization. It is connected with averaging of power of fluctuations in the spectral analysis on all time of supervision of a signal. The most obvious way of application of FFT to the analysis of non-stationary signals will be a splitting realization into separate short sites of identical length with the subsequent application of algorithm of FFT to each of them. However this method has the restriction of accuracy of estimation of frequency of spectral peaks determined by the signal interval size. This feature limits use of BPF in the analysis of the fast-changing stochastic signals to which fluctuations of the processing equipment working in the transitional or qua-
sistationary mode are peculiar. When using autoregression models the accuracy of a frequency scale, close to FFT, can be reached only at a considerable (more than 10000) order of model. It demands considerable computing resources and time in comparison with algorithm of FFT.

Unlike periodic components of a range which are formed at interaction of the structural blocks of gascompressor units among themselves or with a working environment, the frequency of thermoacoustic oscillations can't be described a certain value. For example, for the GT-750-6 unit, with the external combustion chamber, thermoacoustic fluctuations have the limited range of frequencies, and also area of "an attraction of fluctuations", that is the most part of fluctuations has the frequency close to frequency to the maximum amplitudes. These thermodynamic processes proceed in the combustion chamber and define process of functioning of the unit. The received results allowed to confirm existence of such communication, in the range of 2800–5300 Hz. The analysis of the thermoacoustic fluctuations allocated from vibrosignal range of the unit showed that their characteristics along with pressure and temperature of gas mixture, reflect a condition of thermodynamic processes in the engine combustion chamber. This fact was the basis for development of program software for monitoring of gascompressor unit in parameters of thermoacoustic fluctuations.

2. Problem definition

At traditional approach periodic fluctuations are analyzed, and the problem of a filtration consists at the removal of noise from the received signal. At research of thermoacoustic fluctuations the return problem is solved. Namely the useful information about thermoacoustic fluctuations is drawn by removal of periodic components of a signal. At an exception of periodic components of fluctuations there is a loss of some part of information on fluctuations because of zeroing of values of amplitudes of fluctuations. However because periodic fluctuations possess narrow frequency range, their number in a range is limited. And as the power of thermoacoustic fluctuations is distributed in the wide range of frequencies, the small part of power is the share of the deleted spectral harmonicas. Thus, losses of information are small and don't influence results of the further analysis of thermoacoustic fluctuations.

Typical examples of results of work of the offered algorithm are presented in figures 1–4. In figure 1 the site of a range of a vibrosignal of HK-12CT from the periodic component formed by the compelled fluctuations of shovels of the free turbine is represented. On peak of amplitude noticeable change of fluctuations frequency because of change of a rotor frequency of rotation. After processing of a range the same site of a range from a remote periodic component is shown in figure 2. In figure 3 the range site with periodic components against thermoacoustic fluctuations, is given in figure 4 – the same site after processing. The received results clearly demonstrate possibilities of algorithm when determining characteristics in a range the thermoacoustic of fluctuations for the purpose of their further use for monitoring of gascompressor units. For the solution of problems of control, management and forecasting the statistical assessment of a condition of object of management in real time is carried out. The statistical assessment is carried out according to noisy measurements of one realization of casual process. The gascompressor unit often works in the non-stationary mode which can be caused by such factors as change of composition of gas, pressure differences in the main pipeline, change of ambient temperature. Thus there is a loss of efficiency and is reflected in change of a gasdynamic subsystem of gascompressor unit and, as a result, amplitude and frequency characteristics of a signal. Therefore the Hurst's statistics for monitoring of a condition of GPA is offered to use by means of which it is possible to investigate quantitatively regularities of formation of a vibrosignal and unambiguously to judge a condition of gascompressor unit [1, 2].

3. Application of Hurst’s statistics

Now became conventional that many stochastic processes in the nature and equipment possess fractal structure. In the fractal analysis of ranks Hurst exponent is applied to identification of existence and a type of long-term dependence [3]. Processes for which $0.5 < H < 1$ show steady behavior of a trend that is if a row increases (decreases) during the previous period, it will keep this tendency in the future. The probability of such behavior of subjects is higher, than the indicator is closer to unit. Processes for
which $0 < H < 0.5$ is characteristic a sign-variable tendency. For such processes growth during the previous period is replaced by recession during the next period of supervision with probability, that bigger, than closer to zero. At $H = 0.5$ processes in which the trend is absent take place. Than Hurst exponent to 0.5 is closer, a row more noisy and the trend component is less expressed to those. Hurst's method or the analysis is nonparametric [4–6], that is he doesn't contain requirements to the law of distribution of observed casual process. This property of a method should be considered as advantage before the methods of the analysis of casual processes focused on a certain law of distribution.

![Figure 1](image1.png)

**Figure 1.** Initial fragment of a range of vibrofluctuations of the GPA-Z.3 unit.

![Figure 2](image2.png)

**Figure 2.** A fragment of a range of vibrofluctuations of the GPA-Z.6.3 unit after processing.
Calculation of Hurst exponent is made according to the following scheme [6, 7].

1. At first deviations from average value are calculated:

\[ X_{t,N} = \sum_{n=1}^{N} (e_n - M_N), \]

where \( N \) – the period length changing from 2 to length of a temporary row; \( t \) – the variable changing the value from 1 to \( N-1 \); \( M_N \) – average of \( N \) elements; \( e \) – concrete element of a temporary row.

2. On each iteration we receive \( N-1 \) values of \( X_{t,n} \) which we use in the following formula:

\[ R := \text{Max}(X_{t,N}) - \text{Min}(X_{t,N}), \]

where \( R \) – scope of a deviation \( X \).

3. Further we normalize scope division into a standard deviation of \( S \) which is calculated on \( N \) values.

4. We take the logarithm \( R/S \) and \( N \), we build the schedule on the basis of the obtained data.

5. On a function graph of \( \log(R/S) \) from \( \log(N) \) we find an inclination by linear approximation.
The method of statistical modeling by us found tolerance on values of statistics of Hurst. The interval between admissions sets area of operability of gascompressor unit and defines its optimum situation. By results of pilot studies strategy of decision-making in the course of monitoring at change of provision of statistics of Hurst concerning its optimum situation is created (figure 5).

![Figure 5. Monitoring of a condition of gascompressor unit with use of Hurst’s statistics.](image)

4. Summary
The received results allow to organize of conclusion of gascompressor unit in repair only when its state really displays need for carrying out repair. Then becomes possible to pass from service according to regulations to service on a state. Calculation of economic efficiency from introduction of such technology of monitoring will provide decrease on average by 2.5% of a consumption of gas and specific costs of capital repairs of gascompressor unit at the expense of increase in a total operating time by 20%.

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References
[1] Feder Jens 1988 Fractals plenum (Press New York)
[2] Lubkov S V and Novichkov V I 2011 Vibration of cars and mechanisms at operation of the equipment of thermal power plant (Saratov SSTU)
[3] Bendat J S and Piersol A G 2011 Random data: analysis and measurement procedures (New York John Wiley & Sons Inc.)
[4] Combescure D and Lazarus A (2008) Refined finite element modelling for the vibration analysis of large rotating machines: Application to the gas turbine modular helium reactor power conversion unit Journal of Sound and Vibration 318(4-5)1262–1280
[5] Abu-El-Yazied T G, Abu-El-Haggag S Y and Al-Fares F S (2009) Identification of vibrating structures with application to a steel tower World Applied Sciences Journal 6(12) 1673–1674
[6] Zargar O A (2013) Different aspects of gas turbine siemens 162MW-V94.2 vibration analysis Middle-East Journal of Scientific Research 18(4)546–556
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