Application of the rescaled range analysis for vibro-acoustic imbalance control of rotary equipment

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Abstract. The article discusses the possibility of using R/S analysis for vibro-acoustic imbalance control of rotary equipment. An algorithm for R/S analysis is presented. An application package and an information-measuring complex have been developed. Experimental studies on an axial ventilator are conducted. It has been established that in the absence of ventilator imbalance, the vibro-acoustic signal is close to random. With the advent of imbalance, the Hurst exponent changes.

1. Introduction

Reducing the cost of operation, repair and maintenance of technological equipment, are the main and priority tasks of any manufacturing enterprise. In any production, the basis of the technological equipment a large range is the rotor (dynamic) equipment: electric motors, pumps, ventilators, compressors, gearboxes, turbines, etc. These machines are loaded for 365 days a year. In this mode of operation, the equipment often goes beyond the required technical parameters, which requires appropriate attention to increase the operational reliability of the equipment. One of the most common defects in such equipment is the imbalance of the rotor. Imbalance is a vector quantity characterizing the imbalance of rotating parts of machines. Imbalance occurs when the rotation axis does not coincide with the main axis of inertia and leads to a sudden increase in the level of vibration. This vibration can occur both in the transverse and axial directions. [1].

There are a large number of methods for measuring and evaluating vibration, which allow with great certainty to monitor the condition of rotary equipment and determine the presence, type and degree of development of a defect [1,2]. Each method has its advantages and disadvantages and its application in a given situation depends on the type of equipment being diagnosed, on the skills and personal preferences of the specialist conducting the diagnostics, taking into account the specifics of the hardware base.

In recent years, the rescaled range analysis (R/S analysis) is often used to analyze various dynamic systems. The method proposed by the English researcher Harold Hurst [3-8]. In order to identify the possibility of using R/S analysis for vibro-acoustic control of the imbalance of rotor equipment, experimental studies were conducted.

2. Experimental studies
As an object of control, an 8-blade axial ventilator with a rotational speed of 2830 rpm was chosen. The ventilator imbalance was created by alternately fixing to one blade of cargo masses of 0.56, 1.12 and 1.68 grams.

The registration of the vibro-acoustic signals of the ventilator was carried out using an information-measuring complex, the block diagram of which is shown in Fig. 1 [1,2,9]. A program has been developed for analyzing signals using the rescaled range analysis in the LabView programming environment.

The vibration converter AP2038P was fixed on the bearing support of the ventilator shaft, the vibro-acoustic signal was recorded in the axial direction. The ADC sampling rate is adopted at 44.1 kHz. Signals with a length of 20,000 samples were analyzed.

To calculate the Hurst exponent, a dependencies graph \( \log R/S \) from \( \log m \) was plotted and using the least squares method we used the regression equation of the form:

\[
\log R/S = H \cdot \log m + \log c ,
\]

where \( H \) – the Hurst exponent; \( R/S \) – average rescaled range, \( m \) – the length of the periods in which the rescaled range is defined, \( c \) – constant.

The obtained characteristic vibro-acoustic signals and Hurst dependence graphs for them are presented in Figure 2-5. The Hurst exponent was calculated in the interval \( \log m = 3,32 \div 10,5 \). The results of the calculation of the Hurst exponent for vibro-acoustic signals of the ventilator are shown in Fig. 6.

**Figure 1.** Structural diagram of the information-measuring complex: S – vibration acceleration sensor AP2038P, MD – matching device AG01-3; ADC – analog-to-digital converter NI USB-6229, PC – personal computer with installed package of applications.

**Figure 2.** The results of the experiment on the defect-free ventilator: (a) – vibro-acoustic signal; (b) – Hurst dependence graph (black line – regression graph).
Figure 3. The results of the experiment on the ventilator with a cargo of 0.56 grams: (a) – vibro-acoustic signal; (b) – Hurst dependence graph (black line – regression graph).

Figure 4. The results of the experiment on the ventilator with a cargo of 1.12 grams: (a) – vibro-acoustic signal; (b) – Hurst dependence graph (black line – regression graph).

Figure 5. The results of the experiment on the ventilator with a cargo of 1.68 grams: (a) – vibro-acoustic signal; (b) – Hurst dependence graph (black line – regression graph).
Figure 6. The areas highlighted the results of the experiments: 1 – on a working ventilator; 2 – the ventilator with a cargo of 0.56 g; 3 – the ventilator with a cargo of 1.12 g; 4 – the ventilator with a cargo of 1.68 g.

From fig. 6 it is shown that the Hurst exponent allows to reliably determine the presence of imbalance of the ventilator shaft. The vibro-acoustic signal of a defect-free ventilator is close to random, the Hurst exponent for it is located at the level $H=0.5$. With an increase in ventilator imbalance, the Hurst exponent increases, the signal becomes persistent.

The sensitivity of the control with the use of R/S analysis decreases with Hurst exponents close to $H=1$, i.e. when the oscillatory process tends to become deterministic.

3. Conclusion

Experimental studies have confirmed the possibility of using R/S analysis to detect imbalance of the ventilator rotor. Analysis of the Hurst exponent of vibro-acoustic signals can be used in the express control of rotary equipment.

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