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COMBINED VIBRATION AND STRAIN GAUGE ANALYSIS FOR DIAGNOSTICS OF INDUSTRIAL MACHINES

Anvar Valeev

Ufa State Petroleum Technological University, Ufa, Russia, anv-v@yandex.ru

Abstract*: The Paper is devoted to combined vibration and strain gauge analysis for diagnostics of industrial machines. It is suggested to use strain gauge spectrum analysis. For studying it an experimental installation is designed and created. This installation allows getting signal from strain gauge sensors with maximum frequency 12.87 kHz. According to experimental study application of strain gauge spectrum analysis can provide almost the same information as vibration spectrum analysis. Combination of these two spectrums can give more useful information. Particularly it can be used for filtering noise. In the experimental study spectrums were significantly cleared without any instrumental and digital filters, it was done only by analysis of combination of the spectrums. This study can provide more reliable diagnostics of industrial machines.*

Keywords: *Monitoring, industrial machine, strain gauge sensor, vibration, vibration spectrum, strain gauge spectrum*

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1. INTRODUCTION

Currently, a huge amount of industrial equipment and machines is being operated. At the same time, reliability and durability of the machines directly affects economic performance of enterprises and industries. The situation in Russia is more challenging due to a large number of equipment with a long service life. Thus, it becomes relevant to provide reliability of this equipment.

Defects inevitably occur in industrial equipment and may cause failure. For timely detection of equipment defects technical condition is used on the basis of parametric and vibration diagnostics [1]. Vibration diagnostics laboratories mainly use a spectral method for analyzing vibration signals based on Fourier transform. This transformation has certain disadvantages: loss of information about time factor leads to information about dynamics of changes in the spectral composition of the signal, so it does not allow having comprehensive analysis of the vibration signal. In some cases, this makes it impossible to unambiguously identify defects that lead to frequency and amplitude modulation of the vibration signal, such as a violation of the bearing lubrication conditions, bending deformation of the impeller, and there are also difficulties in identifying hidden defects and separating the main malfunctions that have similar diagnostic features. In the conditions of continuous technological process, the failure of the responsible equipment due to the omission of its malfunction can lead to an emergency situation, as well as additional costs during repair, downtime costs, etc. Therefore, in industrial enterprises, timely detection and identification of equipment defects is an important task.

The most widely used vibration control algorithm is based on overall level of the absolute value of root-mean-square value of vibration velocity amplitude. According to it, the root-mean-square value of vibration velocity is compared with the threshold values for different types of machines, depending on their power and technical condition, i.e. they can only be used for the purpose of vibration protection in case of critical defects.

Standard algorithms for assessing technical condition of industrial-type machines based on vibration are based on data from periodic monitoring of the root-mean-square value the vibration velocity in the frequency range from 10 to 1000 HZ and sometimes amplitudes of 2-3 harmonics of rotor speed (rotational frequencies) and comparing them with threshold values. However, this method does not contribute to early and rapid detection of defects and does not take into account changes in the technological modes of operation of the equipment, which lead to an increase in the overall level of vibration, but are interpreted as emergencies [2].

The most advanced method at the moment is the spectral analysis of vibration signal, which loses its effectiveness in conditions of high interference. The analysis of vibration spectrum involves processing a large amount of data, including those that do not carry diagnostic value. Frequencies of various noises, interferences, and resonant phenomena inevitably fall into the spectrum of the vibration signal, and other sources of vibration may contribute to the overall spectrum. Under the influence of noise and other polyharmonic processes, useful signals can easily be lost at those frequencies at which defects most clearly manifest themselves. Therefore, risk of missing a defect is quite high.

Many systems for condition monitoring in real time work on these principles and face problems with filtering and skipping defects due to a large number of different factors that affect the changes in the spectrum. In addition, not all such systems take into account the technical and operational features of a particular type of machine. Ideally, the vibration diagnostic map and the diagnostic algorithm should be compiled individually for a specific series and brand of units, including all practical experience in the field of diagnostics and operation of a particular machine.

From the above, it follows that at the moment there is no method that allows sufficiently reliable identification of defects in industrial equipment. Existing methods use indirect detection of defects based on the experience of operating the equipment. Therefore, they are very poorly served by automation. Current systems for automated monitoring of the condition of industrial equipment mainly determine only the general condition, but not a specific defect.

From the point of view of the industry and trends in the production digitalization, there is also a demand for increasing autonomy of equipment. In this case, there is a need for methods of diagnostics of industrial equipment, which will be implemented in a continuous automated mode, with minimal human participation, with the exception of the possibility of subjective assessment and accidental error. The existing approaches, however, require a high degree of human presence. Although at the moment certain systems of automated monitoring of the state of equipment based on vibration analysis are implemented, they do not provide the degree of versatility, reliability and autonomy that is currently required in the industry.

In addition, we emphasize another request formulated by the current needs of the industry. In the context of the current pace of technology development, new brands and types of equipment appear with increasing speed, respectively, it becomes more and more difficult to develop a long-term experimental empirical base on the operation of equipment and its defects. Thus, it is already necessary to maintain and diagnose the equipment without significant experience. We note that the existing diagnostic methods, such as parametric diagnostics, vibration spectrum analysis, noise spectrum analysis [3], and lubrication analysis [4][5], acoustic emission-based condition monitoring methods [6][7] are based precisely on empirical data – here the experience of diagnosing a single machine cannot be blindly transferred to another. This means that to meet the modern needs of the industry, universal and objective diagnostic methods are required, which are applicable simultaneously for various types of equipment.

So, based on the above, the following challenges and tasks can be concluded:

1. Search for new source information for equipment diagnostics; development of a diagnostic method based on new principles.
2. The task of automating the diagnostic process; conducting it continuously, without human participation, with the maximum degree of objectivity [8].
3. The task of creating such diagnostic methods that will be universal and do not require experimental development and that are applicable simultaneously for different equipment.

In order to solve the mentioned problems, this study proposes to use new approach to obtaining initial information for equipment diagnostics – the use of a strain gauge signal at specified points of the equipment in continuous mode. This approach makes it possible to use new diagnostic methods.

2. CONCEPT OF COMBINED VIBRATION AND STRAIN GAUGE ANALYSIS FOR DIAGNOSTICS OF INDUSTRIAL MACHINES

Concept of combined vibration and strain gauge analysis suggests simultaneous application of these two methods and gives additional synergy. Use of analysis of strain gauge spectrum is rather new way in condition monitoring [9][10]. For this purpose strain gauge sensors are installed under corners of a machine. If a machine is already mounted, then sensors can be glued on machine frame. Strain gauge sensors give information about dynamic forces. As machines are made of steel, then they can be assumed as absolutely rigid, hence all dynamic forces produced by defects influence on the sensors without loss. So, strain gauge spectrum can be clearer than vibrational one.

Synchronous application of vibration and strain gauge spectrums can give additional information due to comparison of them. Generally, they might be almost the same, and due to analysis of mismatch can filter some noise of provide additional possibility for diagnostics and condition monitoring.

3. EXPERIMENTAL EQUIPMENT FOR STUDY OF COMBINED VIBRATION AND STRAIN GAUGE ANALYSIS

For experimental study combined vibration and strain gauge analysis experimental equipment is created. It contains four strain gauge sensors that are installed under an experimental installation that simulates vibration. Amplifiers INA 125 with various amplifying coefficient are used for signal from these sensors. Also a sensor ADXL335 is used (Fig. 1); it measure vibrational acceleration in 3 dimensions. Microcontroller Teensy 3.2 with integrated 12 bit analog-to-digital converter for collecting data (Fig. 2). Data transfers to a computer by USB port and Serial communication protocol.

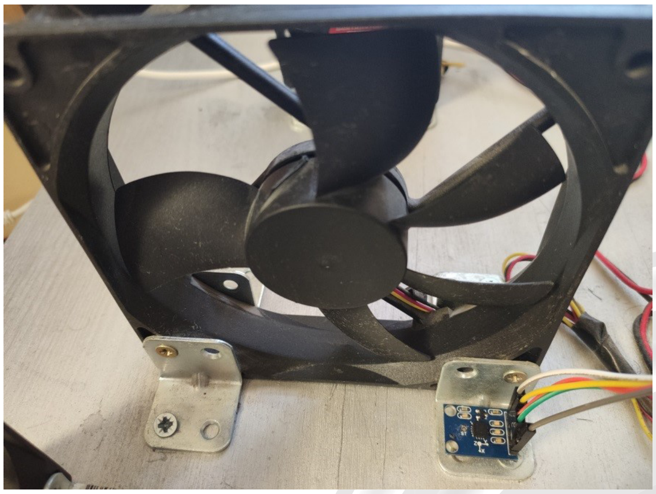

Fig. 1: Source of vibration and installed vibration sensors ADXL335

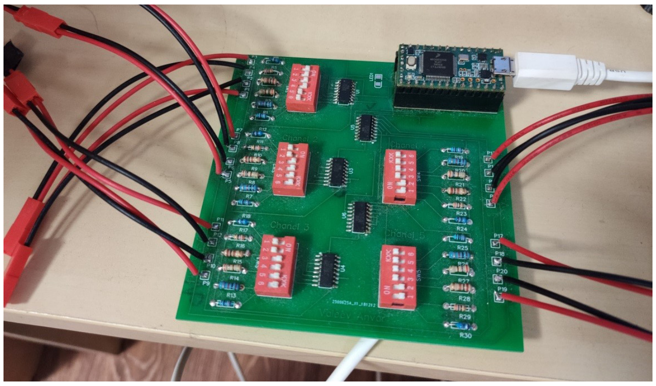

Fig. 2: Experimental equipment for measuring strain gauge and vibration signals

Microcontroller does requests consequentially from 7 channels (4 channels for stain gauge signal and 3 channels for vibrational signal). Minimum delay between requests is 11.1 microseconds. It provides data collection with maximum frequency 12.87 kHz. A computer program for data analysis is made via Python programming language.

The experimental installation has 5 fans with misbalance that creates vibration. Each fan has frequency controlled drive.

4. EXPERIMENTAL STUDY OF COMBINED VIBRATION AND STRAIN GAUGE ANALYSIS

At experimental study 5 fans with misbalance of the experimental installation are turned on in various combinations. Fig. 3 shows typical strain gauge spectrum obtained via experimental equipment.

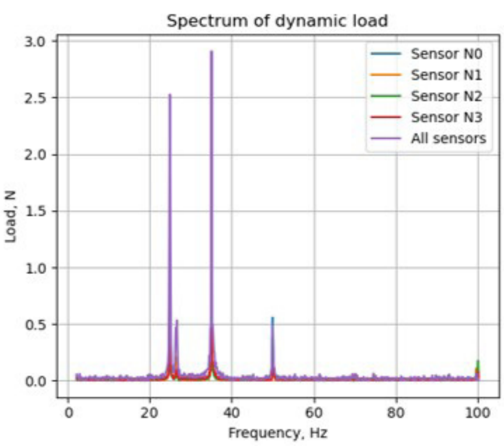

Fig. 3: Strain gauge spectrum with 3 vibration sources

At the same time vibration spectrum is obtained – it is shown in the Fig. 4. Sensors N4, N5 and N6 show vibration level (vibration acceleration) in vertical and two horizontal directions.

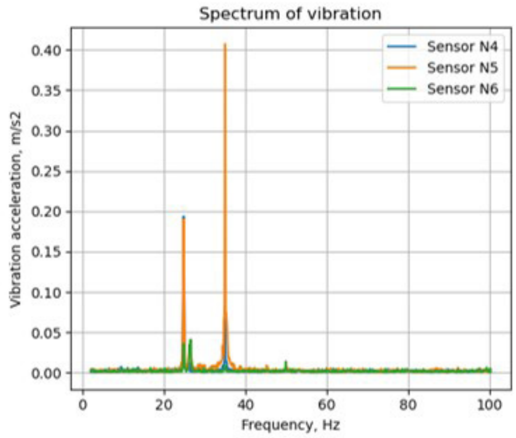

Fig. 4: Spectrum of vibration in 3 dimensions for 3 vibration sources

Note vibration spectrum and strain gauge spectrum generally shows the same: 3 peaks of vibration are clearly seen on the figures. As for strain gauge spectrum a peak for 50 Hz is also seen because the corresponding filter is turned off exactly for this study. The same peak for 50 Hz is also on vibration spectrum but smaller. Also some noise is seen on both spectrums.

So, it should be concluded that strain gauge spectrum can be used instead of vibration spectrum if it is more convenient.

Combination of these two spectrums can give more useful information; particularly it can be used for filtering. As it is seen from the Fig. 3 and Fig. 4 and as it follows from theoretical mechanics, the ratio of dynamic load and vibration acceleration might be near mass of the machines. At can differ from the exact value due to loss and changes in vibration, but let's assess that it might not differ more than twice (note: analysis of this requires further studies, this value is taken as approximate one just for showing features of spectrum combination). But graph describing the ratio of dynamic force to vibration acceleration shows very chaotic figure (Fig. 5).

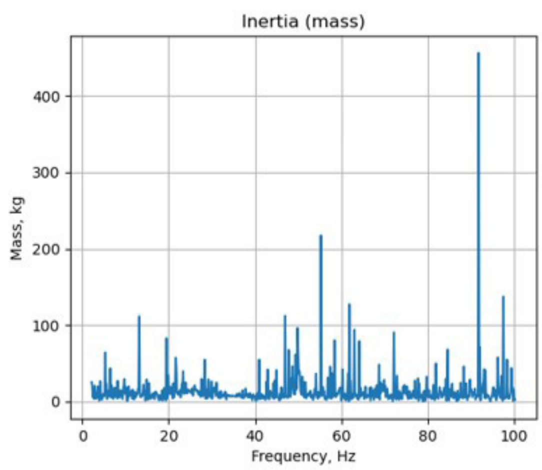

Fig. 5: Ratio of dynamic force to vibration acceleration

Fig. 5 shows that this ratio varies in wide range despite it should be near 6.8 kg (mass of the experimental installation). So, it can be used for filtration. Next consider that any data that differ from 6.8 kg more than twice is noise, hence there is no vibration at corresponding frequency. So, vibration level and dynamic level can be assumed as zero (Fig. 6).

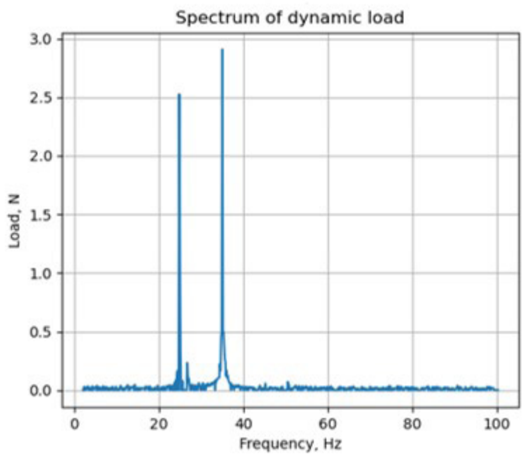

Fig. 6: Strain gauge spectrum (for all sensors) with filtering based on mass assessing

Strain gauge spectrum (for all sensors) with filtering based on mass assessing (Fig. 6) is more clear that original one (Fig. 1) and has less noise. Particularly, 50 Hz noise is filtered. So, three clear peaks are seen on the spectrum, hence spectrum analysis can be provided easier and more reliable.

5. CONCLUSION

Application of strain gauge spectrum analysis can provide almost the same information as vibration spectrum analysis and in some cases can be more convenient and provide more information. Combination of these two spectrums can give more useful information. Particularly it can be used for filtering noise. In the experimental study spectrums were significantly cleared without any instrumental and digital filters, it was done only by analysis of combination of the spectrums.

So, application of strain gauge spectrum analysis and its combination with vibration spectrum analysis are very perspective for industrial machines.

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Anvar Valeev *is Candidate of Engineering Science, Associate Professor of Department 'Oil and Gas Transport and Storage' of Ufa State Petroleum Technological University, leading researcher. Anvar Valeev, a specialist in the field of vibration protection, diagnostics, condition monitoring of industrial equipment, also systems with quasi-zero stiffness, transport and storage of oil and gas. He is the author of over 130 scientific publications and the co-author of textbooks, monograph and patents. Anvar Valeev is supervisor of number of scientific grants. He presented the main results of scientific research at the international conferences in St. Petersburg, Moscow, Samara, Ufa, Shaghai (China), Seoul (South Korea), Athens (Greece), London (United Kingdom), Hiroshima (Japan), Rome (Italy).*