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STATIONARY AUTOMATIC VIBRATION CONTROL AND ANALYSIS SYSTEMS: APPLICATION EXPERIENCE

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In the modern world, there is a growing demand for stationary vibration control and analysis systems. Planetary gearboxes, gear-type stand drives of rolling mills, intermediate roll bearings, electric drive bearings and pump bearings have been equipped with vibration control systems. The objective of this research is to extend the area of use for stationary vibration control and analysis systems in metal industry. This research involves the choice of mechanical vibration quantitative parameters, the definition of concept for vibration analysis results visualization, design and implementation of mimic panels to display vibration analysis results for metal industry units. This research was carried out in the nondestructive inspection laboratory of the Closed Joint-Stock Company "KonsOM SKS" from 2011 to 2016.The research group used methods of data collecting and visualization through server technology and statistical data processing. As results of this research, the increased overhaul equipment lifetime intervals were achieved and science-based schedules for equipment maintenance were formed. Stationary vibration analysis systems have been implemented in shops of a large steel company of the Russian Federation for mechanisms of agglomeration machines, cold and hot rolling mills, bending-stretching machine and floating pump.

Keywords: defect; root mean square; mimic panel; monitoring; stationary vibration control system; vibration analysis; vibration sensor.

Introduction

Vibration of machines, mechanisms, instruments and devices as one of their operating conditions cannot be totally eliminated. To explore causes and indicators of vibration, a research was carried out in both experimental and industrial conditions. Scientific research centers offer methods of analysis, estimation and classification of dynamic impact effects from vibration. One of the wide-spread methods of studying vibration and its effect on the object is studying in real conditions during lifetime of the object. Stationary vibration analysis complexes were created for that purpose. The majority of techniques used there are highly specialized.

Three main stages can be distinguished in the lifecycle of a machine or equipment: design and tests of prototypes; production or repair of serial products, its installation and adjustment at the location of use; condition control during exploitation period between repairs. For many different areas realization of these stages requires vibration analysis. In [1]–[4] vibration study during the design period of machines and tools is considered. Authors of [1] offer spectral method of studying vibration originating in a cutting area at a pull-type broach as a function of cutter edge wear. This method is based on frequency analysis and correlational processing of vibration sensors' signals. In [2], there were specified main directions for research of the cutter, selected a method of nondestructive inspection for efficient estimation of dynamically operating equipment's actual condition. Installation points for vibration sensors were found experimentally on the basis of obtaining the most informative vibroacoustic signal. A direct spectral analysis, which detects periodically repeating vibrations, was selected there as a vibration analysis method. In [3], the objective of vibration velocity reduction for metal-cutting equipment is set. To achieve that objective, calculation automation in a form of a pro-gram and analysis of vibration velocity's dynamics as a function of linear dimensions for the first rolling contact bearing have been done. The authors of [4] presented research results on modeling a grinding machine used in metallurgy, mechanical engineering, shipbuilding, etc. They carried out detailed vibration study during design and creation stages for transport vehicles (aerial, railway and automobile transport) [5]–[9]. In [5], the usage of laser vibrometer for the purpose of a plane engine testing is proposed. In [6],[7] a vibroprotective system for grader cabin suspension is proposed. A structural-effect model of a cardan gear is described in [8]. This model is based on equality between real alternating vibration signal that represents the impact of cardan gear support's energy and fictitious one that is standard deviation. Vibration study of power reactors is also very important. The de-tailed study of in-core instrumentation of the reactors is presented in [10],[11]. Works [12],[13] are examples of vibration analysis' industrial use, they consider mechatronic systems and electric motor post-assembling tests.

In the Russian Federation, the main normative document, which states general principles of measurement and estimation of mechanical vibration is the state standard [14]. This standard uses three main vibration parameters: vibration displacement, vibration velocity and vibration acceleration, also it determines how to establish their threshold values. Fulfillment of the offered principles is a guarantee of satisfactory equipment performance. The standard establishes general terms and conditions and a procedure for determining and assessing the vibration condition of the object. General evaluation criteria are based on vibration displacement, vibration velocity and vibration acceleration measurement. A number of projects based on requirements of this standard are being developed. They include firmware complexes for stationary vibration analysis, which can be built in into production control systems' intellectual support modules for power, extractive and processing industries, mechanical engineering and transport [15].

Main objectives, that can be achieved using vibration measurement and analysis techniques, are: elimination of machine's and equipment's vibration by reducing oscillating forces in the source of that vibration and element's mechanical properties refinement; refinement of the object's vibration resistance to provide reliability of machines and equipment working in conditions of strong vibration excitated both within the studied object itself and applied to it from without; vibration control points preparation that should provide necessary diagnostic information during next lifetime stages of the controlled object.

Stationary vibration control and analysis system developed by "KonsOM SKS" is used to detect equipment's condition deviation from the normal level in real time which makes it possible to prevent deviation of its performance, lifetime reduction or emergency stop caused by defects in various parts of the equipment.

Distinctive features of this system are:

– continuity of the measurements;

– comparison of vibration signals to the reference values;

– formation of warning and emergency signalization.

The objects of the study are the main elements of mechanical and electric equipment.

The subjects of the study are root mean square (RMS) values for vibration velocity calculated at defect frequency for each mechanism.

1. Methods

Since 2012 CJSC "KonsOM SKS" has a nondestructive inspection laboratory and specialists with great experience in the field of vibration control and analysis. Main functions of the stationary vibration control system are:

– **data capture** for signals from vibration sensors and signals from adjacent process control automation systems including rotational speed of controlled mechanism, bearing assembly temperature, oil pressure in lubrication system, etc.;

– on-line **control** of the object vibration parameters, like RMS values of vibration velocity, displacement and acceleration, peak values of these parameters, etc.;

– **structuring** of information and **formation** of a database for object's vibration parameters and studied process' technological parameters;

– warning **signalization** if the object's abnormal vibrational state is registered in accordance with the requirements of the equipment's technical operation rules and state industry standard;

– **visualization** of the vibration parameters and process control automated system's dynamics, trend calculation, graphic representation for actual and archive obtained signal's diagrams;

– data **visualization** on a user computer workstation according to mental perception of the studied object and the process.

Stationary vibration control system consists of: vibration sensors permanently installed on the object; programmable controller; server and user workstations; vibration control and analysis soft-ware. Block diagram for the system components interconnection is shown in Fig. 1.

In stationary vibration analysis system the vibration sensors, matching amplifiers, data processing and storage devices are installed on the studied object on a permanent basis, and data capture is carried out in a continuous mode. User computer workstation for vibration monitoring provides vibrational and technological parameters' visualization on a mimic panel. The workstation is implemented using Flash-technology and "thin client" technology. A "thin client" is a computer or a client program that is purpose-built for remote access to a server. The server does all computations including data processing and file storage on the client's behalf. These technologies do not require the installation of the additional software utilities. All the on-screen forms are Web-pages for standard browser, like Microsoft Internet Explorer.

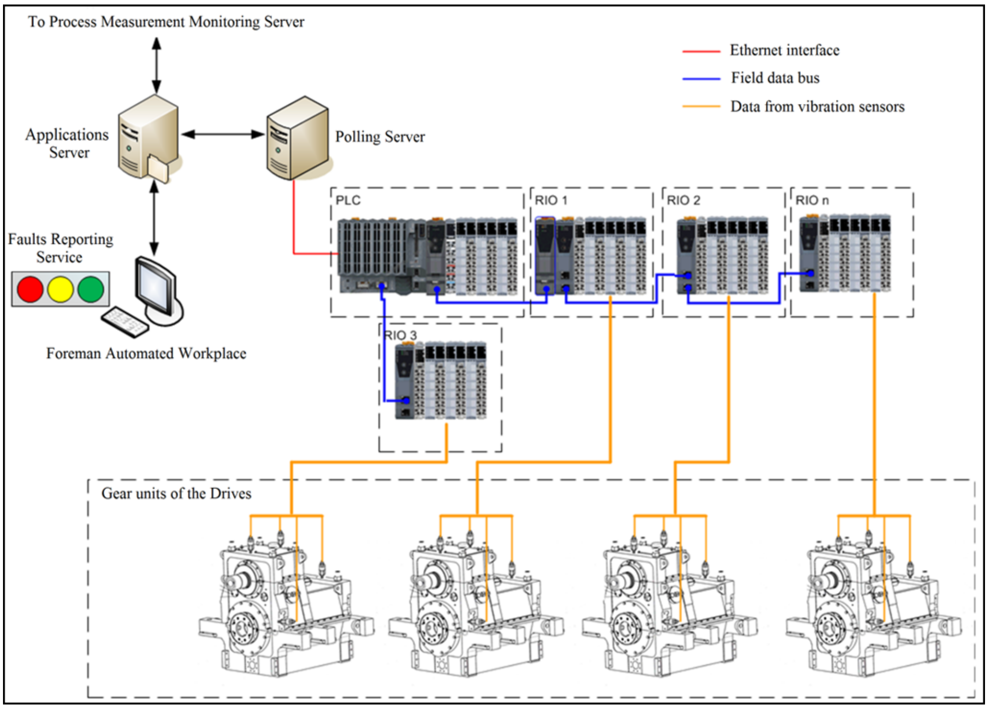

Fig. 1. Block diagram for stationary vibration control and analysis system's component interconnection

Operating procedure for the stationary vibration control system is determined by following technique:

1) continuous **registration** of vibration acceleration signals by sensors installed on non-rotating parts of the controlled object with conversion rate of 100 kHz;

2) **reception** of the signals by electronic diagnostic instrument (controller) and calculation of vibration amplitude for diagnosed objects on the frequencies characteristic to different types of defects;

3) automatic **adjustment** of the defect frequency based on rotational speed of machine drive;

4) **transmission** of information about object's vibration level from electronic diagnostic instruments to the polling server through Ethernet interface using OPC (OLE for Process Control) technology;

5) **processing**, **storage** and **representation** of the data, concerning the vibrational state of con-trolled mechanism on the Web-server in mimic panels.

Information processing including calculation, event formation, data archiving is performed on the polling server by using specialized software complex "Paradigm" developed by "KonsOM SKS".

For quantification of mechanical vibrations, the vibration analysis system uses statistical indicators [14]: peak-to-peak value of vibration displacement H (1), peak value of vibration velocity A (2), mean value of vibration velocity $\overline{v}$ (3), RMS value of vibration velocity σ (4):

$$H = s_{max} - s_{min}, \qquad (1)$$

$$A = v_{max}, \qquad (2)$$

$$\overline{v} = \frac{1}{n}\sum_{i=1}^{n} v_i, \tag{3}$$

$$\sigma = \sqrt{\sum_{i=1}^{n} v_i}, \qquad i = \overline{1,n}, \tag{4}$$

where s is vibration displacement, mm; v is vibration velocity, mm/s; n is the number of studied values [14].

Vibration velocity RMS is one of the most important parameters. It takes into account the development of the studied vibrations in real time and represents the value associated with the signal's energy and destructive ability of vibration. According to normative documents on the assessment of machine vibration measured on its non-rotating parts, the vibration velocity RMS value in the frequency range from 10 to 1000 Hz most accurately reflects risk from mechanical vibrations. Standard [14] is a core document for development of the machine vibration measurement and assessment manuals. The standard contains evaluation criteria for different classes of machines. In most cases metallurgical equipment applies to the second class according to [14]. Requirements of the [14] are the basis of metallurgical equipment vibration analysis.

To visualize the vibration analysis results, there was defined a concept which includes a level color display of the studied signal. In [14] for the second class of the equipment, there were defined threshold levels of vibration, overriding which in a steady-state condition of the operating machine results in getting "Warning" and "Stop is recommended" signals. Graphic representation of equipment condition on a mimic panel uses color-coded indication to represent different parts of the con-trolled machine according to registered vibration level:

1) green color – vibration level (0 ... 1.8 mm/s) is within acceptable limits;

2) yellow color – vibration level (1.8 ... 4.5 mm/s) corresponds to "Warning" mode which warns about vibration level overriding above the permitted limits;

3) red color – vibration level (greater than 4.5 mm/s) corresponds to "Stop is recommended" mode.

The developed vibration control and analysis system is implemented in shops of large metallurgical enterprises in Russian Federation for mechanisms of agglomeration machines, cold and hot rolling mills, bending-stretching machine and a floating pump.

2. The Results

The results of the scientific research made at "KonsOM SKS" laboratory using stationary vibration control and analysis systems were being implemented on industrial enterprises during last five years. The systems that use proposed concept had been integrated in the active process control automation systems. The results of this implementation on metallurgical enterprise equipment are presented in Fig. 2–6.

Fig. 2 shows an active mimic panel of the stationary vibration control system for planetary gear units on an agglomeration machine drive. Vibration sensors are installed to control the input and out-put bearings and all four planet gears. The vibration velocity RMS value according to [14] and that on the defect frequency of the bearing planetary pinions are monitored.

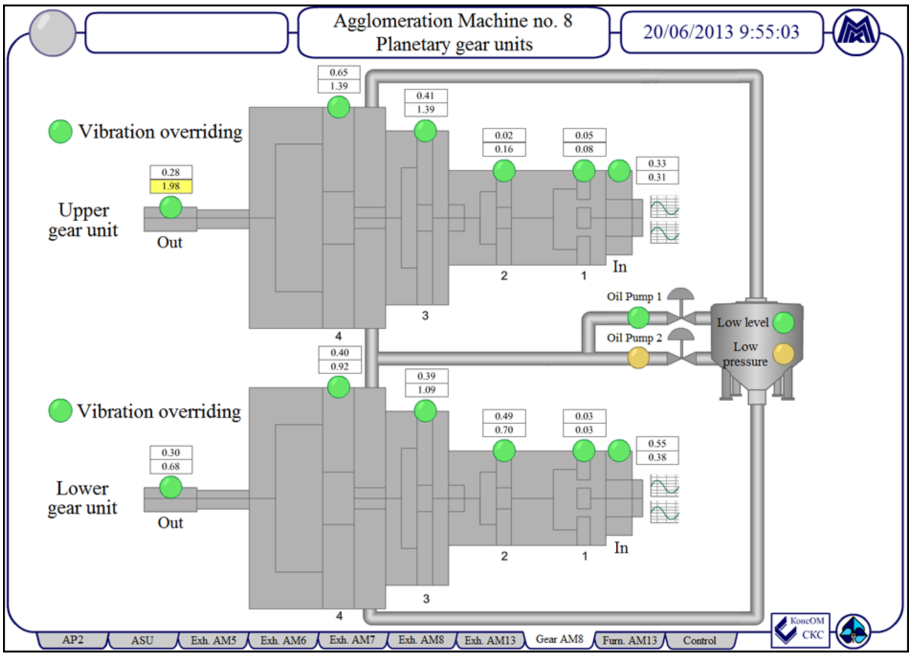

Fig. 2. Mimic panel for vibration control system of the agglomeration machine's planetary gear units

After the planetary gear units' stationary vibration control system had been put into operation, the maintenance personnel could increase time intervals between repairs from six to eight months based on the data that had been collected within those six months.

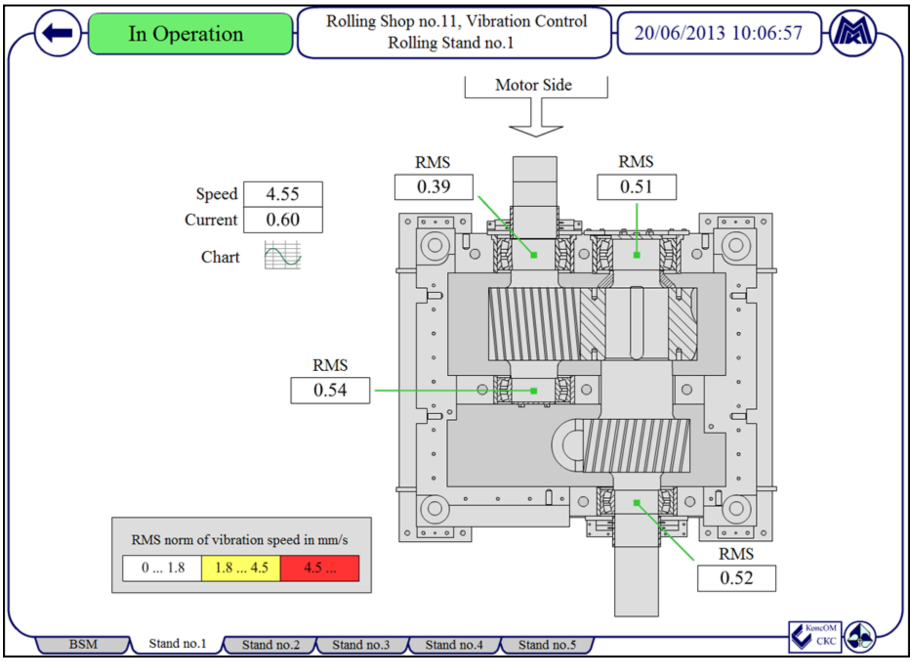

Fig. 3. Mimic panel for vibration control system of the tandem cold rolling mill's gear-type stand

Fig. 3 shows vibration control system's mimic panel for a gear-type stand of a tandem cold rolling mill of a large metallurgical enterprise's plate rolling shop located in the Russian Federation. Twenty vibration sensors are installed at the tandem mill's stands. They monitor vibration level in the bearing assembly, and each gear-type stand has four sensors installed on it. One of the ways to rapidly assess the mechanism's condition is to use vibration velocity RMS values, currents and rotational speed of the drive. In order to identify the relevant series cointegration, the combined charts for those parameters are displayed on one chart, like it is shown in Fig. 4.

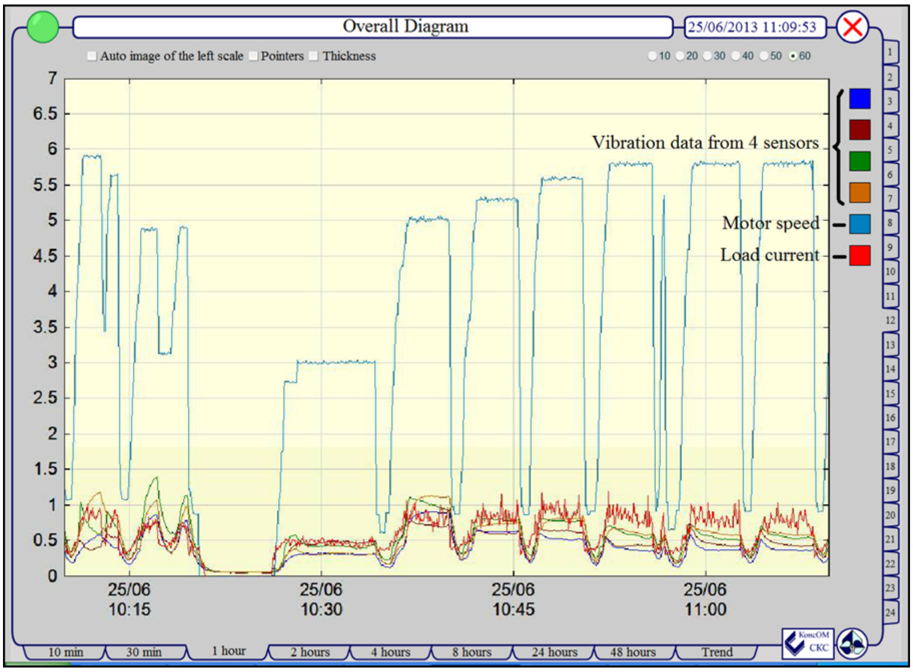

Fig. 4. Dynamic diagrams of the vibration velocity RMS values, motor speed and load current

Fig. 5 shows vibration control system mimic panel for bending-stretching machine drive.

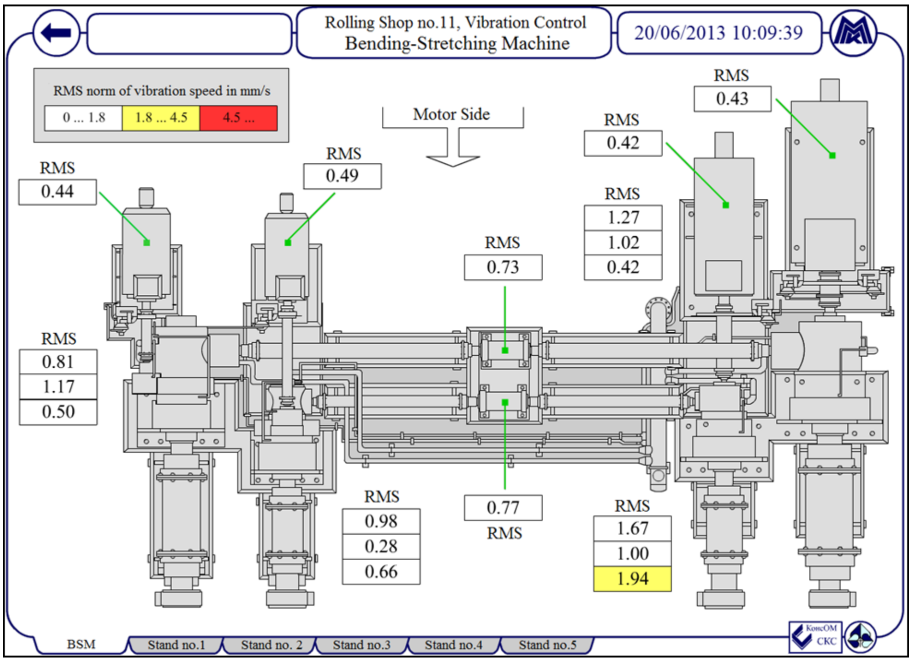

Fig. 5. Vibration control system mimic panel for bending-stretching machine drive

Four vibration sensors are installed on motors, three sensors are located on the matching gear box body for the purpose of condition control of the input and two output rolling contact bearing, and one sensor is placed on the shaft bearing. In that system only RMS values for vibration velocity are registered according to [14].

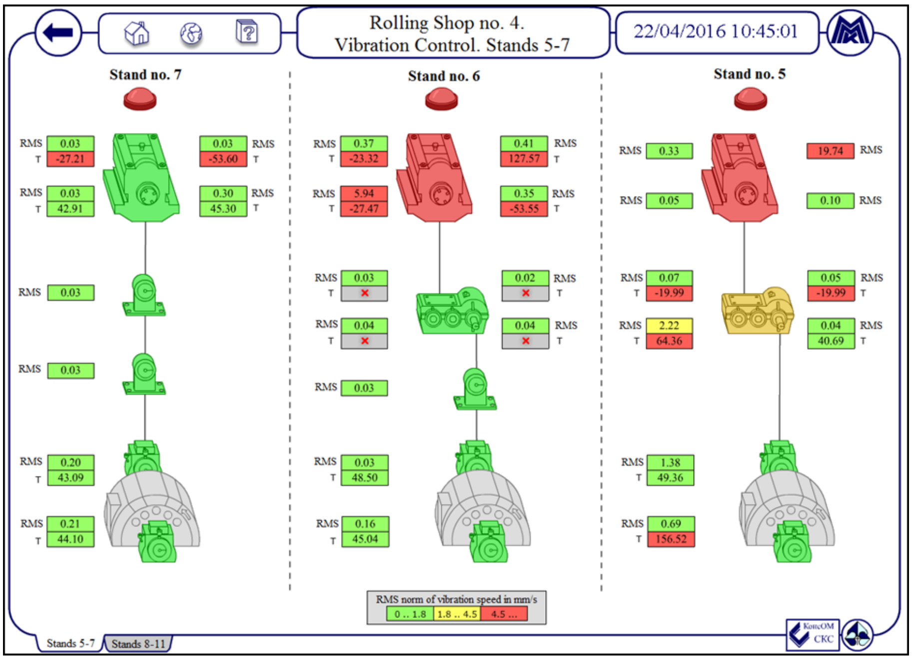

Fig. 6. Mimic panel for vibration control system of a finishing train on the hot rolling mill 2500 (stands 5-7)

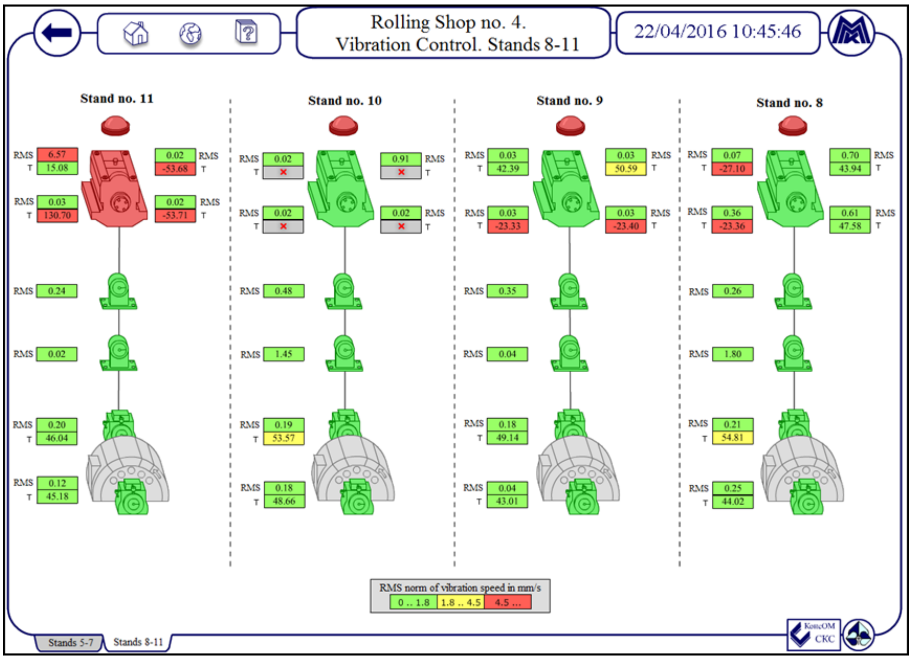

Fig. 7. Mimic panel for vibration control system of a finishing train on the hot rolling mill 2500 (stands 8-11)

Fig. 6 and 7 show vibration control mimic panels for finishing train drives of the hot rolling mill 2500. The vibration sensors are placed on the engine mounting, intermediate shaft support, stand gear boxes and gear-type stands. Also, in order to monitor the condition of the plain bearing, temperature sensors are installed in supports, gear-type stands and engine mountings. This system can simultaneously display vibration parameters, load currents, temperature and drive speed.

Mining production equipment also lends itself well to monitoring and diagnostics by vibration signals. Fig. 8 shows stationary vibration control mimic panel for a floating pump.

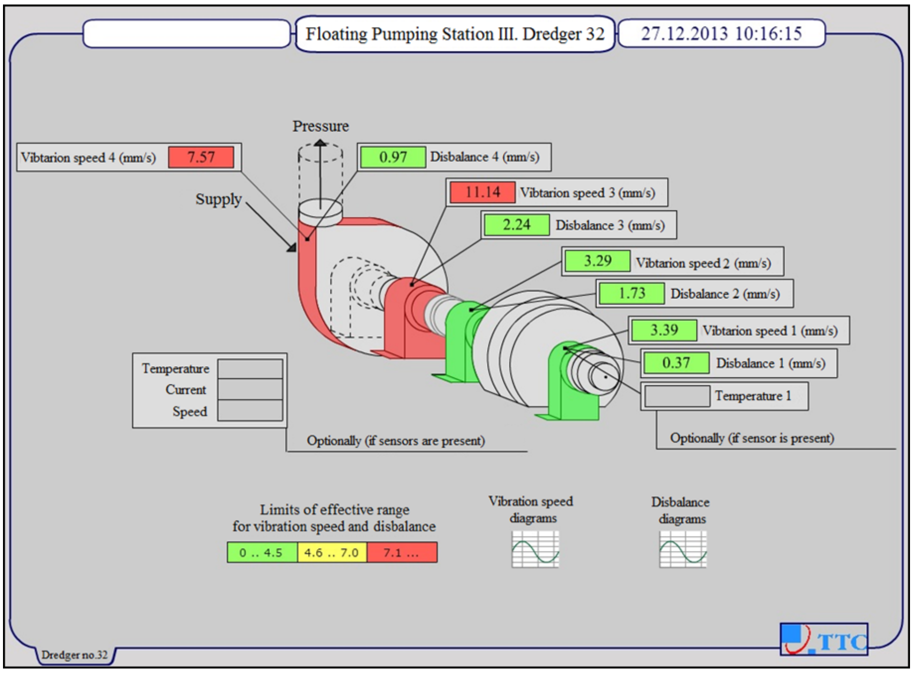

Fig. 8. Vibration control system's mimic panel for a floating pump

The vibration sensors are placed on the engine and mountings of the pump. One sensor is placed on the floating pump's outer casing. Stationary vibration control system registers levels of vibration velocity RMS values according to [15] and those on the frequencies corresponding to unbalance and misalignment defects.

Conclusions

1. Stationary vibration analysis systems and software "Paradigm" created on the basis of general research of objects exposed to vibration allow their implementation in active production with the lowest labor costs possible. Those systems use mimic panels with mental adequacy to the operational processes of real-life assemblies and mechanisms.

2. Improvement of the accuracy of information about mechanism's technical condition requires the use of additional instruments. Accuracy of a shaft location within the plain bearing, called "orbit can be used as such an instrument. To plot the shaft orbit, measurements of the shaft vibrations are made in relation to the stationary part of the bearing in two orthogonally related directions. The orbit change trend shows the degree of bearing backing wear.

3. Currently specialists of "KonsOM SKS" are developing stationary system for measurement and display of the shaft orbit. That system together with absolute

vibration measurement system will make it possible to identify explicitly the bearing assembly condition

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СТАЦИОНАРНЫЙ АВТОМАТИЧЕСКИЙ КОНТРОЛЬ ВИБРАЦИИ И СИСТЕМНОГО АНАЛИЗА: ОПЫТ ПРИМЕНЕНИЯ

Е.Н. Ишметьев, О.С. Логунова, А.Н. Панов, Д.В. Чистяков, Е.Е. Бодров

В современном мире, растет спрос для стационарного контроля вибрации и системного анализа. Планетарные редукторы, шестеренчатый стенд приводов прокатных станов, подшипники промежуточного валка, подшипники электрического привода и подшипники насоса были оснащены системами контроля вибрации. Цель данного исследования заключается в расширении области применения для стационарного контроля вибрации и системного анализа в металлургии. Это исследование предполагает выбор механических колебаний количественных параметров, определение концепции для анализа вибрации, результаты визуализации, проектирования и реализации мнемосхем для отображения результатов анализа вибрации для металлургии единиц. Эти исследования проводились в лаборатории неразрушающего контроля Закрытого акционерного общества "Консом СКС" с 2011 по 2016 годы.Исследовательская группа использовала методы сбора и визуализации на основе технологии сервера и обработки статистических данных. Как результаты этого исследования, длительный межремонтный срок службы оборудования интервалы были достигнуты и научно-обоснованных графиков проведения технического обслуживания оборудования, были сформированы. Стационарные системы вибрационного анализа были реализованы в магазины крупной металлургической компании РФ для механизмов агломерационных машин, холодной и горячей прокатки, изгибно-растяжной машины и плавающих насосов.

Ключевые слова: дефект; средняя квадратическая; мнемосхемы; мониторинга; стационарные системы контроля вибрации; анализ вибраций; датчик вибрации.

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