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VIRTUAL ANALYSIS OF TECHNICAL EQUIPMENT OPERATIONAL STATES VARIABILITY

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Abstract. The efficiency of technological equipment workout is determined by urgency of its maintenance. Perspective method of urgent maintenance is based on control of equipment state variability. To analyse the condition of the equipment in the real-time proposed the virtual control of equipment state variability based on Neyman-Pearson criterion. The results of data processing of oil pump unit showed the ability to detect faults at an early stage of their occurrence.

1 Introduction

Oil pumping stations (OPS) are complex set of oil pumps in main oil pipeline. The necessary condition for operation of trunk pipelines is ensuring efficient and reliable operation of the pump stations. The problem of providing efficient, reliable and safe operation of main oil pipelines becomes quite relevant in connection with the fall in oil prices and the depreciation of the main technological equipment, in particular, the main pump units, as the most energy-intensive OPS equipment.

Conventionally we can group all the faults of the pump unit on three types: fault associated with impaired mounting rigidity of the pump unit and its components; defects of electromagnetic origin; failure of mechanical and hydrodynamic origin.

Continuous operational control of the process equipment operational state is usually carried out with monitoring of a number of indirect parameters that are characterizing technical condition. Usually these parameters are vibration, temperature, pressure at the inlet and outlet. However, in some cases the results of online monitoring analysis do not have the necessary level of completeness and timeliness. Practical experience with the data shows that their validity is often insufficient in cases of operational control.

The main reason is the difficulty of identifying system variability on small sample volumes of controlled signals of hydrodynamic origin. But it is critical to process this data because it contain the information about a false error in deciding to stop the pumping unit. For example, the coincidence of the natural oscillation frequencies of working vanes and pump components with frequencies of oscillations induced by cavitation, especially at low

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feed rates, the appearance of intense oscillations of the blades and the rotor, piping and frame that can be easily removed without stopping the pumping unit, changing its mode of operation.

Therefore, there is a scientific and technical problem of improving the completeness, timeliness and accuracy of maintenance services information support by creation of real-time monitoring the variability parameters.

2 Virtual analysis

The aim of this work is to develop a virtual analyzer (VA) of the operational states' variability of the process equipment based on operational statistical control.

During the operation centrifugal pumps installed in the main oil pipelines, are constantly tense in deformed state. Also the wheel and blades pumps are subjected by combined effect from the transported oil.

Virtual OPS states analyzers can be used to support operator's decision-making as a supplement to the control system that form rapid warning and forecast maintenance requirements in real-time operation of the process. Virtual condition analyzers of technological equipment belong to the display systems class.

Equipment indication systems carry out only the definition of object technical condition without warning instructions for the type of defect. Indication of OPS situation gives to the operator either directly in the graphic control or through a stand-alone interface. Algorithms for subsequent identification of the defect based on the additional information: expertise or regulatory documents. In many cases, performance standards, state and industry standards, examples of which are [1] used as such documents.

OPS scheme typically includes four pump units, one or more may be in operation (Figure 1).

In accordance with recommendations of the regulatory documents that normalize OPS operation, virtual analyzers should display simultaneously at least two trends on any selected measured parameters with the following recommended time intervals (on operator handling time):

- 40 days with 2 hours steps;
- 1 year with 1 day steps;
- 9 years with 7 days steps.

Because all pumps are connected each other and to the collector of receiving and outtake pipes, relations is statistically inhomogeneous perturbations arising from the performance of each pump is transferred to other units and line pipe, making it difficult to identify inconsistencies pump unit from the group pumps still working.

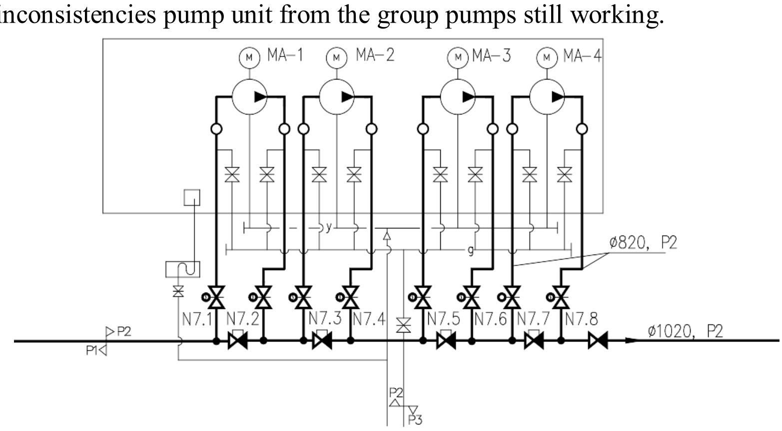

Figure 1. Functional diagram of a pumping station - the main pump unit.

Visual monitoring of operational diagnostic paramaters helds by OPS operator every two hours with control display [2] for the principal and retaining support of pump units. Data is written to the log (statement) of operational diagnostic controls by OPS personnel on duty. Evaluation of the retaining pumps main vibration is carried out on the control and vibration equipment signal. Register magnitude of vibration is made at least once per shift for each monitored point at steady state

The main technical parameters of the main oil pump units are:

P_{in} is an inlet pressure (inlet side) of the pump, MPa;

P_{out} is the discharge pressure (discharge pipe) of the pump, MPa;

T_k is the temperature of the pump housing, ^{o}C;

T_{el} is a motor bearing temperature, ^{o}C;

T_p is a pump bearing temperature, ^{o}C;

V_{el} is a vibration motor (vibration velocity), mm/s.

To process the data of hydrodynamic origin with help of statistical analysis we use the method based on the Neyman-Pearson criterion. According to this criterion we select detection rule that provides the minimum value of the signal crossing the probability of unacceptable change of technological equipment for a given probability of false alarm.

Normative documents established the following classification by value of sudden failure:

1. low risk missing;
2. average risk missing;
3. high risk missing.

Low-risk missing systems must have the value of the risk of sudden failure less than 5%.

Medium-risk missing systems must have the value of the risk of sudden failure in the range 5 – 30%.

High-risk missing systems must have the value of the risk of sudden failure more than 30%.

As shown in [3] special statistical processing of regular measurements in the form of Shewhart cards solves the task of identifying specific (in this case, potentially dangerous) reasons for variations in equipment condition with error probability (the probability of a false rejection) $\alpha = 0.0027 = 0.27\%$. This is far below the standards of low risk passes sudden failure. The statistical algorithms can be supplemented with Shewhart algorithms vibration control equipment, providing additional confidence in the assessment, both at the operational and medium-term horizons of technical tinning and repair planning

Control card for state of the pump unit monitoring is a graph of regular measurement samples of a parameter which characterizes the state of the pumping unit $\boldsymbol{X}$. As $\boldsymbol{X}$ one of the oil pump parameters listed above can be used. Telemetry statistical data collected can be combined in a sample chart on the map *g(X)*.

The sample in this diagram is a sequence of n independent observations $x_1, x_2, ..., x_n$ of X index related to a certain period of time (day, month, year).

Suppose $f(x,\theta)$ describes the distribution of the random observations variable $\boldsymbol{x}$ at a certain value of the distribution functions (average sample medium medium samples, span, etc.). These functions may be integrated into the vector θ .

Using a Shewhart control chart posed and solved the problem of detecting unnatural variability observed parameter, which may be the cause of a change of oil pump operating mode [4, 5].

Especially the process of changing the state of oil pump is a slow change in variability in the form of operational parameters of the trend during the annual period of time and fast as the appearance of a series of unusually grouped outlets controlled parameter on the map in real time characterized by a second period of the survey measurement sensors. We assume that the statistical properties of the time series of measurements, and the reasons for generating changes in vector functions distribution θ remain unchanged or change slowly in the selected intervals. Monitoring of the oil pump status reduced to the control of samples measurements and detection of the controlled parameter changes the observed properties of the vector θ with values from θ_0 to θ_1.

Changing the oil pump operating mode may occur at an unknown time t_0. This event will be called discord operation process. Useful problems solved automated condition monitoring on a system is to detect a disorder in the early stages of its development, operational control of operating parameters and predict operational oil pump state.

Reviewed range of practical problems associated with the operational oil pump states, characterized by a random sequence $\{x_1, x_2, ..., x_n\} = \{x_1^n\}$, which at the time t_0 changing their properties, clearly defined parameters vector θ, $\dim\{\theta\} = r$. Since t_0 the vector θ is set to change point θ_1 $(\theta = \theta_1)$. The moment of disorder t_0 is detected to establish the criteria for evaluating the sequence $\{x_1^n\}$, $N \to \infty$, with the appearance of the next point x_n.

Each time a new sample to test the hypothesis $\theta = \theta_0$, pointing to the absence of the unnatural variability [6].

Because of oil pump hydrodynamic parameters controlling in depending of ambient temperature and oil viscosity their values are changed in considerable limits, the observed parameter is expedient to use the input / output relationship of each pressure pump unit for sampling time averaged. These current values enter the virtual analyzer, which is undergoing continuous analysis of oil pump, which construct control charts for the current mode of his work for a controlled period of time. Data are grouped in the sample and compared with control limits, which are calculated according to the formula (1) [7].

$$UCL, LCL = \overline{\overline{X}} \pm A_2(n) \cdot \overline{R}, \tag{1}$$

where *UCL, LCL* are upper and lower control limits,

$\overline{\overline{X}}$ is an average of medium,

$A_2(n)$ is a coefficient depending on the sample size *n*, equals 0.266 when *n* = 12, because 12 measurements per day,

$\overline{R}$ is an average Range.

For a retrospective analysis of the technological equipment state, the data of one separately working oil pump in period from February to March 2015 is used. The resulting $\overline{X} - R$ chart is shown in Figure 2.

Then from calculations values of current parameters measured in the initial 72 hours after installation or repair of the pump were excluded, as well as measurements of switches of the measuring lines on oil account nodes and start/stop of controlled pump or neighboring oil pump units of OPS.

By introducing these amendments (the data were excluded for 20, 25 February and 5, 14 and 16 of March), the control $\overline{X} - R$ chart of variability of medium and dispersion of sample data for a single oil pump shown in Figure 3.

It was decided to set the upper and lower control limits equal to 3.09σ. This corresponds to the fact that at the exit for the border at least one point of the sample data on the oil pump state probability of an erroneous conclusion about the absence of irregularities in his work does not exceed 0.001.

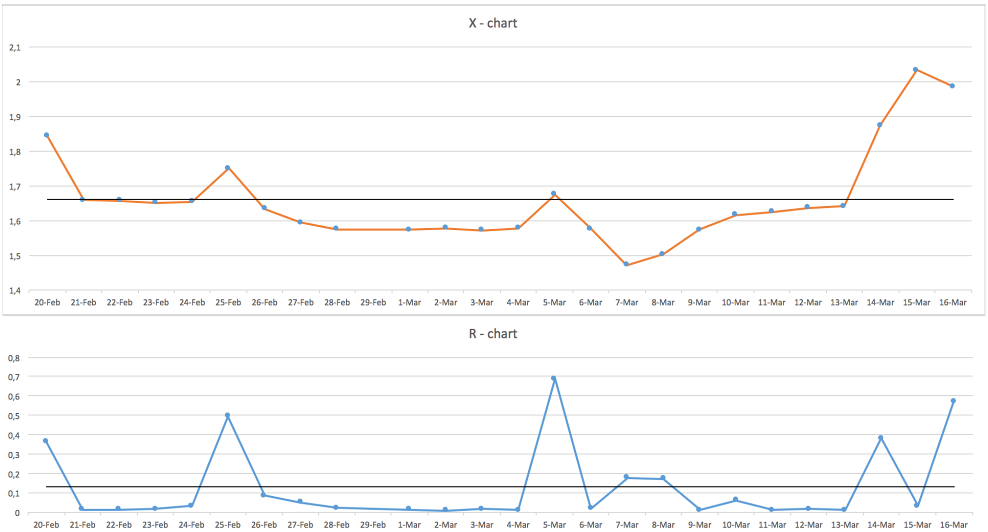

Figure 2. $\overline{X}-R$ Shewhart control chart.

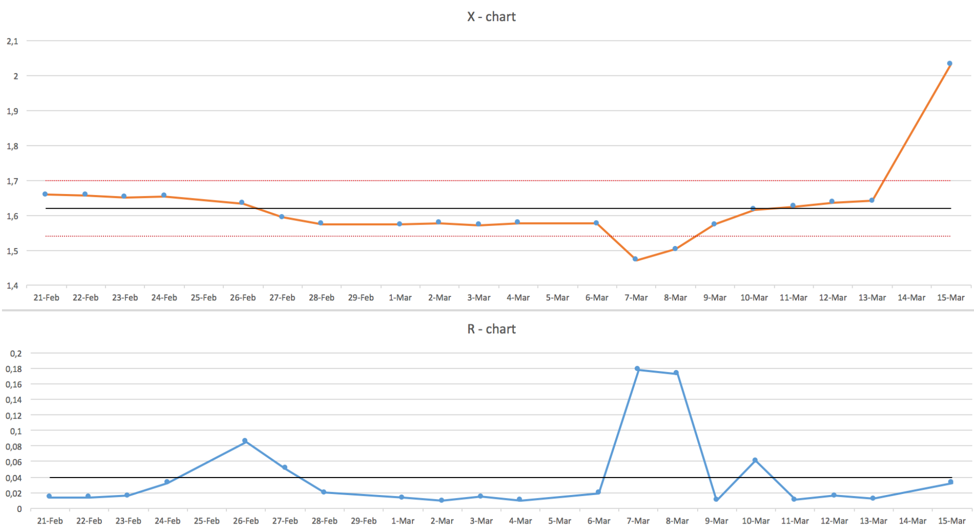

Figure 3. Adjusted $\overline{X}-R$ Shewhart control chart.

Analyzing the arrangement of the control points of the chart in relation to the control limits are consistently on the charts scale and the average values in the samples, we can conclude that on March 6, there were signs of abnormal operation of the pump unit.

It should be noted that the vibration control data in this period has not yet foreshadowed discrepancies in the work. However, March 15 pumping unit has been shut down for repair service.

Thus, using the state on the control chart, we can watch the development of the inconsistencies in the pumps at an early stage, to begin to identify the reasons for using online monitoring tools and start preparing for a stop unit.

3 Conclusion

Checking the virtual analyzer performance was carried out on the data, which were obtained in the actual operating equipment (trunk unit MN7000x210).

It was found that Shewhart chart is quite informative for the assessment of the overall technical condition of OPS pumps.

They allow to identify the early stages of oil pump disruption.

The proposed virtual evaluation of equipment on operational state in online mode allows to identify the controlled samples variability in the quantitative control of the pump unit state.

The proposed method of virtual analysis of the OPS pump state variability allows to realize the maintenance system on equipment actual condition.

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