Diagnostics of the critical axial displacement of the sectional pump shaft in the conditions of kimberlite mines

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Abstract. This work is devoted to the development of a new method for the operational identification of the operation of a sectional pump with a critical axial displacement of the shaft. Its further introduction into production will, with a high degree of probability, increase the operational reliability of sectional pumps.

1. Introduction
An unplanned failure of a sectional pump in an underground mine or coal mine can cause an emergency situation up to the flooding of the extraction of solid minerals operating facility. It is known that one of the main reasons for the premature loss of performance of the sectional pump is the failure of the hydraulic balancing device [1-3]. To identify the limiting technical state of the hydraulic balancing device, due to the displacement of the sectional pump shaft to the critical value, in practice, axial shaft displacement sensors are usually used.

Practice shows that in the drainage systems of underground kimberlite mines in the Russian Federation, the use of axial shift sensors is an effective technical solution only for a while. Frequent failures and a certain complexity of reconfiguring this control and measuring device are the main reasons for the decrease in the accuracy of the results it gives, which ultimately negatively affects the efficiency of operation of sectional pumps [4].

The purpose of this work is to develop a new method for operational identification of the occurrence of critical displacement of the shaft of the sectional pump in real time, since relying on well-known technical solutions is not always a justified solution, as practice shows.

2. Materials and methods
In theory, in addition to measuring the axial displacement of the sectional pump shaft itself during its operation using an axial displacement sensor, the achievement of the shaft of its critical axial displacement, and, accordingly, the limiting technical state of the hydraulic balancing device can be rapidly identified in other ways. At the same time, in reality, the identification of the critical axial displacement of the shaft of a sectional pump using any other method has not yet widely applied at industrial enterprises of the Russian Federation. In our case, this is explained, first of all, by a number of production and economic reasons, mainly due to the specifics of the operation of pumping equipment used in the drainage systems of domestic kimberlite quarries and underground kimberlite mines.
Let us consider all the known diagnostic parameters through which, in theory, it is possible to establish the critical axial displacement of the sectional pump shaft.

2.1. Through the running time of the pump
In theory, the shaft of a disconnected sectional pump should in most cases remain in the position in which it was at the moment of disconnection. However, polls of the working personnel of underground kimberlite mines in the Russian Federation showed that this does not happen - the shaft returns to its original position. In addition, systematic stops and starts of pumping units can lead to premature abrasion of the body and rotor parts of the pump [1]. In connection with the abovementioned, we state that the operational identification of the critical axial displacement of the sectional pump shaft at certain time intervals is impossible.

2.2. Through the temperature of the pump bearing
Practice shows that the impellers of sectional pumps used in drainage systems of underground kimberlite mines in the Russian Federation, in most cases, are not equally worn out (figure 1).

Thus, we come to the conclusion that during the operation of the sectional pump, the arising axial forces are mainly unevenly distributed over the surfaces of the impellers. In theory, this can lead to imbalance of the rings of the rear rolling bearing (to date, all sectional pumps used in domestic underground kimberlite mines are equipped with rolling bearings) of the pump. In this regard it can also lead to additional heating of the bearing due to the intense friction [5].
\[ M = \frac{\mu \cdot P \cdot d}{2} \]  

where \( M \) is the moment of frictional forces in the bearing; \( \mu \) is the coefficient of friction; \( d \) is the inner diameter of the bearing; \( P \) is the resulting load on the bearing, which, in turn, is equal to [5]:

\[ P = \sqrt{P_1^2 + P_2^2} \]

where \( P_1, P_2 \), the radial and axial load on the bearing, respectively.

Based on the abovementioned, it can be stated that, in theory, there are close cause-and-effect relationships between the temperature of the rear bearing and the axial displacement of the shaft of the sectional pump. This hypothesis was tested on 4 sectional pumps used in the main drainage system of the “Udachny” underground kimberlite mine [4]. As the observation period, we used the time period from December 25, 2013 to June 1, 2015 (~ 1.5 years), since during this time period the axial displacement sensors worked properly. As can be seen (figure 2), no close relationship was found between the operating temperature of the rear bearing unit \( t \) of the sectional pump and the axial displacement of the shaft \( X \).

![Figure 2. Dependences \( t = f(X) \) and its approximation by a linear trend: a…e – sectional model pumps JSH 200 № 1…№ 5.](image)

However, in 6 out of 7 cases when the rear bearing assemblies reached a temperature equal to 60 ÷ 63 °C, the studied pumps operated at a critical axial displacement of the shaft. It should be noted that the bearing assemblies of the abovementioned pumps are equipped with a water cooling system, which distinguishes them from other sectional pumps operating in domestic underground kimberlite mines. The results of pilot tests carried out by workers of the underground mechanical energy section at one of the pumps showed that, under the same operating conditions, the operating temperature of bearing
assemblies equipped with a water cooling system is on average 5 ÷ 7 °C lower than the operating temperature of bearing assemblies not equipped with the abovementioned cooling system. At the same time, do not forget that an increase in the temperature of the rear bearing of the sectional pump can be caused not only by axial displacement of the shaft, but also by a number of other production reasons, for example, mine water entering the bearing, contact with which over time can lead to deterioration of the operational properties of the lubricant, and in this regard - to the release of a certain amount of heat. In connection with the abovementioned, we come to the conclusion that, in theory, a noticeable increase in the temperature of the rear bearing can only be an indirect sign that the sectional pump shaft has reached its critical axial displacement.

2.3. Through the water flow in the pump discharge pipe
Polls of workers at “Udachny” and “Mir” underground kimberlite mines indicate that the most appropriate way to rapidly identify the critical axial displacement of the sectional pump shaft is to carefully monitor the change in the water flow in the discharge pipe. Practice shows that in the conditions of underground kimberlite mines, control over the flow of water in the discharge pipe of the sectional pump was carried out using meters only in relation to sectional pumps of the main drainage units. To date, such a method for diagnosing the critical axial displacement of the shaft of the sectional pump has generally ceased to be practiced. Polls of workers at underground kimberlite mines "Udachny" and "Mir" indicate that this is caused, first of all, by the high price of flow - meters and certain errors in their operation on water with a significant content of iron oxides [4]. Thus, it can be seen that at present it is relevant to find an alternative to flow - meters to record changes in the water flow in the discharge pipe. A change in the flow of water in the unloading pipe will necessarily lead to a change in its speed of movement. It is known that the speed of movement of liquid in a pipe has a causal relationship with the vibration state of the latter. Thus, we state that, in theory, it is possible to quickly identify the critical axial displacement of the shaft of the sectional pump due to careful monitoring of the vibration state of its discharge pipe. The disadvantage of this method is possible ambient "noise" during measurements, which are explained by mechanical vibrations of the discharge pipe, transmitted to it from the operating pump. This insignificant drawback is eliminated by additional fixing of the discharge pipe to the pump foundation.

3. Research results and analysis
Mathematical processing of the results of experimental studies on a pumping unit (based on cantilever pump model K8 / 18) indicates that the flow q of water in a pipe simulating a discharge pipe correlates well with the RMS vibration velocity v of this design (figure 3) [4].

![Figure 3. Dependence v = f(q) and its approximation by a linear trend.](image)

Entering into the derived regression equation (see figure 3), the lower threshold (3 m³/h - for pumps with Q = 300 ÷ 400 m³/h and 2 m³/h - for pumps with Q = 150 ÷ 250 m³/h), weighted average value (6 m³/h - for pumps with Q = 300 ÷ 400 m³/h and 4 m³/h - for pumps with Q = 150 ÷ 250 m³/h)
and the upper threshold (9 m³/h - for pumps with Q = 300 ÷ 400 m³/h and 6 m³/h - for pumps with Q = 150 ÷ 250 m³/h) of the value q, it was found that the deviation of the RMS vibration velocity υ from its weighted average value, both downward and downward increases by 16% (for pumps with Q = 150 ÷ 250 m³/h) and by 20% (for pumps with Q = 300 ÷ 400 m³/h) are critical.

The approbation of the method for the operational identification of the critical axial displacement of the sectional pump shaft was carried out on one of the JSH-200 pumps of the main drainage unit of the “Udachny” underground kimberlite mine using the “Becker Mining Systems” automation system operating at the mine.

Pilot tests carried out on the selected sectional pump have confirmed the effectiveness of the method for operational identification of the critical axial displacement of the shaft. It was found that the RMS vibration of the unloading pipe of the sectional pump increases with the operating time of the hydraulic balancing device. During the tests, the hydraulic balancing device was replaced at an operating time of t = 315 h, which was accompanied by an increase in the vibration level of the unloading pipe υ (figure 4), according to studies [4]. At the time of replacement, the hydrofoil was badly worn out, which once again emphasizes the effectiveness of the approved technical solution.

Figure 4. Dependence υ = f(t) and its approximation by a linear trend.

4. Conclusion
Based on the results of the research carried out, the following main conclusions can be drawn:

- The most reasonable solution is to use the change in the vibration state of the discharge pipe due to the change in the water flow in it, as a criterion for the sectional pump shaft to reach its critical axial displacement in the drainage systems of underground kimberlite mines in the Russian Federation;
- Pilot tests carried out indicate the effectiveness of the proposed method for operational identification of the critical axial displacement of the sectional pump shaft through the vibration state of the discharge pipe.

References
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