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Modeling of Wear-Out Failures and Service Life Improvement of Sealing Units

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Abstract

The article is concerned with a new method of setting up and solution of boundary value problems of reliability theory for sealing units on the basis of wear resistance criterion of sealing elements. The research group carried out theoretical study of service life for the standard "roller - shoe" friction couple on the basis of wear resistance of shoes manufactured from different sealing materials. Theoretical results were verified and the most durable sealing materials were introduced into commercial operation.
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Keywords: Sealing unit; Failure pattern; Sealing element; Wear resistance; Durability; Service life.

1. Problem Description

One of the most important issues of metallurgical production is to improve the reliability of hydraulic drives providing precise positioning and high conveying speed of operating elements of various mechanical systems. Positive-displacement hydraulic engines and hydraulic valves are widely used as actuating and control devices [1]. Their technical state determines the service life of hydraulic systems and the level of performance indicators of an industrial enterprise. In its turn, the main cause of hydraulic unit failure is deterioration of sealing elements of movable sealing units [2]. However, the instant of their failure is not very well defined, it is assessed approximately by experience or by the time when leaks of hydraulic fluid appear due to faults in air tightness caused by abrasive wear development. Practical experience shows, that the service life of sealings is very short, it does not exceed 10% of the service life of other friction couples of hydraulic cylinders and hydraulic valves. At the same time the constantly growing requirements to improvement of plant productivity and product quality as well as to reduction of

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maintenance time and emergency downtime make it necessary to significantly improve the service life of hydraulic units as far as wear resistance of their sealing elements is concerned.

That is why there are two important scientific problems to be solved on the stage of a hydraulic system design:

- development of adequate mathematical models of wear-out failures for movable sealing units;
- theoretical design analysis of feasible solutions aimed at improvement of sealing part wear resistance to provide the required level of durability of the designed hydraulic drive taking into account its configuration, application and operating conditions.

2. Development of failure pattern for movable sealing units

Analysis of traditional approaches to modeling of the wearing process of tribocouplings shows that these approaches are based on various classes of empirical and semi-empirical relationships between the wear rate (wear intensity) of triboelements and operating conditions [2-4]. Generalization of classical equations of the phenomenological [5, 6] and the conceptual [7-9] approaches, of the thermodynamic [10-14] and the kinetic [15-17] models as well as relationships developed within the frame of modern combined theories and strategies [18-20] makes it possible to come to the following conclusion.

Practical application of traditional models for estimation of service life of sealing friction assemblies on the design stage requires preliminary model or full-scale tests of engineering samples to obtain some physical quantities comprising the model. Such tests can be both expensive and time-consuming. To reduce the costs and to develop a purely analytical model of sealing element failure, the authors made use of the general methodological approach [21] to forecasting of the technical object reliability, they also used the energy-mechanical concept of stationary tribosystems wear-out [22]. This concept was developed on the basis of simultaneous solution of fundamental equations of the molecular-mechanical [7] and the structure-energy [18] theories of friction.

In this case, the physical and mathematical model of movable sealing unit failures is represented as a one-parameter boundary value problem of reliability theory of the stationary coupling class. However, it is also assumed that the sealing friction couples preserving the tightness of sealing operate most of the time in the steady state mode of fatigue wear under normal operating conditions. Practical experience shows that in this case, wear of the steel coupled element (a piston plunger, a shaft, a slide valve, etc.) can be neglected.

According to the general theory of reliability forecasting [22], the average value of the inside diameter of a seal ring (a set of rings, sleeve gaskets) $\bar{x}_t$ taking into account its contraction during assembling can be taken as the state parameter of the hydraulic unit. In the process of sealing wear with the average rate of $\bar{\dot{y}}$, its diameter increases from its initial value $\bar{x}_t = \bar{x}_0$ to the limiting one $\bar{x}_t = x_{np}$. It can be assumed that the limiting value x_{np} is equal to the minimum design diameter of the coupled element (a piston plunger, a shaft, a slide valve, etc.) to avoid development of looseness and abrasive wear of elements in future operation.

In this case the closed equation system describing physical relationships of the process of wear-out failure formation for sealing friction couples will take the following form:

- equation of movable sealing unit behavior:

$$\bar{x}_t = \bar{x}_0 + \bar{\dot{y}} \cdot t; \tag{1}$$

- equation of transition of a friction couple to the limiting state:

$$\bar{x}_t = \bar{x}_0 + \bar{\dot{y}} \cdot t = x_{np}; \tag{2}$$

- equations for the estimation of the average life of a hydraulic unit and its service life:

$$\bar{t} = \frac{x_{np} - \bar{x}_0}{\bar{\dot{y}}}; \quad \bar{t}_{сл} = (1 + \Pi) \cdot \bar{t}; \tag{3}$$

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