тикальную силу F) и скорость относительного перемещения пятника и подпятника с четырьмя конструктивно-технологическими параметрами. То есть C – это комплексный параметр, позволяющий определять область устойчивой работы адаптивного регулятора шкворневого узла. Иными словами, задаваясь значениями входящих в него переменных и постоянных величин, можно получить матрицу чисел уравнения регулятора в матричной форме, обеспечивающего устойчивое движение объекта управления.

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INTERRELATION BETWEEN EXTERNAL EXPOSURE AND ADAPTIVE SYSTEM OF A PIVOT NODE

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ABSTRACT

In a system of a railcar the node «center plate – center pad» is one of the most responsible in the bogies. One of the promising ways to solve the problem of increasing longevity, reducing a wear rate of thrust and bearing surfaces of a center plate and a center pad is to implement the principles of adaptive control in mechanical systems. Theoretical studies were carried out to find an optimal mode of node's functioning, in which the processes of friction will occur in the lubricating layer that provides a minimum value of a coefficient of friction and wear rate. Their results are presented in this article.

ENGLISH SUMMARY

Background. *Development of projects related to intelligent control systems is among main provisions of the program of implementation of the strategic guidelines of scientific and technical development of JSC «Russian Railways» [2]. These projects include a proposed design of a self-organizing system of a pivot node (Pic. 1).*

Objective. *The objective of the authors is to investigate the principles of adaptive control in relation to a node «center plate-center pad».*

Methods. *The authors use modeling, mathematical methods and analysis.*

Results. *Design feature envisages pits, filled with composition lubricants, on thrust and bearing surfaces of a center plate and a center pad of a bogie [3].*

The principle of functioning is as follows: when a center plate is sliding to a center pad as the wear of a working surface occurs, a lubricant will get into a contact area and will cover the surface of friction and reduce a wear rate [3, 6]. In the course of destruction of a lubricating layer this process will be repeated, providing a constant supply of lubricant at all times during operation.

To optimize functioning of this structure it is necessary to determine the dependence of external influences (load-speed mode) on work of a pivot node with an adaptive system. Load-speed mode is determined by speed V_B of a car and a vertical force F transmitted from a frame on an undercarriage.

In the system «center plate- center pad» these parameters are denoted, respectively, via speed $V_П$ in relation to movement of a center plate and a center pad and contact pressure P distributed over mating surfaces. At the same time, since each of these parameters in the operating conditions and a design of a pivot node has a precipitation-analytical description, its functioning should be considered as a function of random arguments. All within the framework of a chosen approach to solving the problem will correspond to excited motion of an object.

Based on current understanding of characteristics of a kinematic contact of flat surfaces, which include a system «center plate-center pad», an analytical description should take into account first of all the nature of the pressure distribution on mating surfaces, the change in their relative position, which is the result of deformation and wear, but eventually should link these parameters with operational, structural and geometrical parameters of a pivot node.

In [4] it was found out that in case of kinematic contact of flat surfaces during rotation of bogie's wheels distribution of contact pressure, velocities and conditions of wear do not remain constant for all points of conjugate bodies. This situation is further complicated by the presence of systematic distortions arising with reverse motion with small amplitudes. In addition, a considered design presupposes the presence on working surfaces of holes of different diameters, changing the nature of the contact, and it makes a fundamental difference for decision with respect to a model problem [4] for flat solid surfaces.

The author [4] offers a method for solution of these tasks, based on the condition of contact surfaces, which refers to the features of process of conjugation wear, presuming that for any form of the worn surfaces of parts we observe a full contact of conjugate contact zones.

As for a pivot node a contact condition will mean that a sum of wear U_{1-2} of a center plate U_1 and a center pad U_2, measured in the direction of convergence on the axis of a controlled object, is constant:

$$U_1 + U_2 = U_{1-2} \to const. \qquad (1)$$

Thus, for any point of the mating surfaces of a center plate and a center pad if the contact condition is met, equation remains:

$$J_{1-2} = J_1 + J_2, \tag{2}$$

where J_1, J_2 are respectively wear rate of a center plate and a center pad.

If k_1, k_2 characterize material, P_1, P_2 mean contact pressure, V_1, V_2 – speed of a center plate and a center pad, then:

$$J_1 = k_1 \cdot P_1^m \cdot V_1; \tag{3}$$

$$J_2 = k_2 \cdot P_2^m \cdot V_2. \tag{4}$$

For points of a center plate and a center pad with the same coordinates, $P_1 = P_2 = P$, $V_1 = V_2 = V$, and hence:

$$J_1 = k_1 \cdot P^m \cdot V; \tag{5}$$

$$J_2 = k_2 \cdot P^m \cdot V. \tag{6}$$

We substitute (5) and (6) in (2):

$$J_{1-2} = k_1 \cdot P^m \cdot V + k_2 \cdot P^m \cdot V = P^m \cdot V \cdot (k_1 + k_2). \tag{7}$$

A pivot node has an abrasive kind of wear in conjunction with oxidative processes [5], for which there is a linear dependence of the wear rate on the pressure [4, 5], in which the exponent is $m = 1$. In this case, equation (7) takes a simpler form:

$$J_{1-2} = P \cdot V \cdot (k_1 + k_2). \tag{8}$$

We solve (8) in relation to P:

$$P = \frac{J_{1-2}}{V \cdot (k_1 + k_2)}. \tag{9}$$

Each point on a surface of a considered system has its peripheral speed V, which depends on the distance R_i to the center of rotation and frequency n of rotation. If R_i is equal to a current radius ρ, then:

$$V = 2 \cdot \pi \cdot n \cdot \rho. \tag{10}$$

Then

$$P = \frac{J_{1-2}}{2 \cdot \pi \cdot n \cdot \rho \cdot (k_1 + k_2)}. \tag{11}$$

Vertical force F will be related to the pressure P in the system «center plate-center pad», having a contact surface A, by a formula

$$F = \int_A P dA = P \cdot A. \tag{12}$$

According to our invention [3, 6] the contact area A is associated with a total area A_1 and the total area of holes A_2:

$$A = A_1 - A_2; \tag{13}$$

$$A_2 = \psi \cdot A_1; \tag{14}$$

$$A = A_1 - A_1 \cdot \psi = A_1 \cdot (1 - \psi), \tag{15}$$

where ψ – ratio of correlation of areas of chips to a total area of a surface.

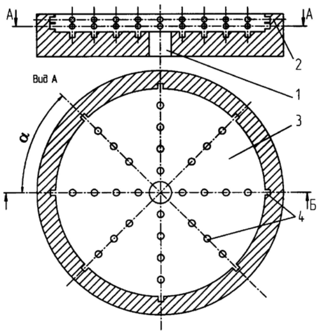
Then:

$$F = P \cdot A_1 \cdot (1 - \psi). \tag{16}$$

The author [4] provides a methodology for calculating the area of contact of flat bodies rotating about a central axis and forming conjugations in hte process of wear, with account of a hyperbolic nature of the diagrams of wear for solid surfaces. In this case it is the surface A_1:

$$A_1 = 2 \cdot \pi \cdot (R - r) \cdot \rho. \tag{17}$$

where R, r are the largest and smallest radii of a contact surface respectively; ρ is a current radius of a surface.



Pic. 1. Center pad: 1 – hole for a center pint; 2 – thrust surface; 3 – bearing surface; 4 – pits.

We compose (16) with account for (17):

$$F = 2 \cdot \pi \cdot (R - r) \cdot (1 - \psi) \cdot \rho \cdot P. \tag{18}$$

Hence:

$$P = \frac{F}{2 \cdot \pi \cdot (R - r) \cdot (1 - \psi) \cdot \rho}. \tag{19}$$

From equation of (11) and (19):

$$P = \frac{J_{1-2}}{2 \cdot \pi \cdot n \cdot \rho \cdot (k_1 + k_2)} = \frac{F}{2 \cdot \pi \cdot (R - r) \cdot (1 - \psi) \cdot \rho}. \tag{20}$$

We define a wear rate:

$$J_{1-2} = \frac{F \cdot n \cdot (k_1 + k_2)}{(R - r) \cdot (1 - \psi)}. \tag{21}$$

If working surfaces of a center plate and a center pad are made of the same or similar materials, it can be assumed that $k_1 = k_2 = 1$, then (21) takes a simpler form:

$$J_{1-2} = \frac{F \cdot n \cdot k}{(R - r) \cdot (1 - \psi)}. \tag{22}$$

In this case, a total conjugation wear for some time t will be:

$$U_{1-2} = J_{1-2} \cdot t = \frac{F \cdot n \cdot k}{(R - r) \cdot (1 - \psi)} \cdot t. \tag{23}$$

However, changing the shape of surfaces which are in frictional contact occurs not only as a result of wear of the materials, but also due to deformation of the surface layers [5]. For most of options the dependency of the contact movement δ on the pressure P on a surface can be described by a power law [4]:

$$\delta = \lambda \cdot P^n, \tag{24}$$

where λ, n are contacts, depending on the geometry of a surface and properties of materials.

Substituting in (24) the pressure (19), we obtain an equation that enables to evaluate a shape of the friction surface after removal of the load at any point:

$$\delta = \lambda \cdot \left[\frac{F}{2 \cdot \pi \cdot (R - r) \cdot (1 - \psi) \cdot \rho} \right]^n. \tag{25}$$

Thus, the diagram of pressure and surface shape when worn will be hyperbolic, this conclusion coincides with the results obtained earlier in [4] for solid surfaces.

Nevertheless, the nature of change will be different. Thus, the hyperbolic form of a diagram P for a worn conjugation means that the surface layers in the area of high values of ρ will be subject to a less deformation, the amount of which will be influenced by a parameter ψ. And the lower is the value of ψ, the less is deformation, and the higher is ψ, the greater is deformation. When selecting values of ψ and ρ, it is possible to obtain a more uniform distribution of pressure and deformations on contact surfaces. That is, it becomes possible to control contact processes. This position is useful to keep *in mind when designing a pivot node with an adaptive controller.*

Now we will consider conditions in relation to the system «center plate-center pad» under a simultaneous action of contact deformation and wear.

Since according to contact condition, worn and deformed mating surface must coincide, then for any point on a friction surface a condition will be satisfied:

$$(\delta_1+\delta_2)+(U_1+U_2)=\Delta=const\,, \qquad (26)$$

where δ_1, δ_2 are deformations of a center plate and of a center pad.

Let λ_1, λ_2 consider peculiarities of the geometry of a contact surface of a center plate and a center pad. If at the same time we take into account that according to this embodiment of a pivot node, these surfaces have the same shape, it can be written that $\lambda_1=\lambda_2=\lambda$, which means:

$$\delta_1=\delta_2=P^n\cdot\lambda_1=P^n\cdot\lambda_2=P^n\cdot\lambda\,. \qquad (27)$$

After this, we express wear of a center plate and a center pad through appropriate rate of wear, taking into account (5) and (6) for time t:

$$U_1=J_1\cdot t=k_1\cdot P^m\cdot V\cdot t\,; \qquad (28)$$

$$U_2=J_2\cdot t=k_2\cdot P^m\cdot V\cdot t\,. \qquad (29)$$

We substitute (27), (28) and (29) in (26):

$$(P^n\cdot\lambda_1+P^n\cdot\lambda_2)+(k_1\cdot P^m\cdot V\cdot t+k_2\cdot P^m\cdot V\cdot t)=0\,. \qquad (30)$$

Under linear laws of deformation and wear of a system «center plate- center pad», $m=n=1$, then the equation (30) acquires a simpler form:

$$(\lambda_1+\lambda_2)\cdot P+(k_1+k_2)\cdot P\cdot V\cdot t=0\,, \qquad (31)$$

and when we add a value of speed (10) respectively:

$$(\lambda_1+\lambda_2)\cdot P+(k_1+k_2)\cdot 2\cdot\pi\cdot n\cdot\rho\cdot P\cdot t=0\,. \qquad (32)$$

In another form:

$$(\lambda_1+\lambda_2)\cdot P+2\cdot\pi\cdot n\cdot t\cdot(k_1+k_2)\cdot(\rho\cdot P)=0\,. \qquad (33)$$

The last multiplier of the second component is available in an extended version:

$$\rho\cdot P=\frac{1}{2}(\rho\cdot P+\rho\cdot P)\,, \qquad (34)$$

Then (33) takes a form:

$$(\lambda_1+\lambda_2)\cdot P+\pi\cdot n\cdot t\cdot(k_1+k_2)\cdot(\rho\cdot P+\rho\cdot P)=0\,. \qquad (35)$$

We differentiate this equation on ρ, taking into account that P is a function of ρ:

$$(\lambda_1+\lambda_2)\frac{dP}{d\rho}+\pi\cdot n\cdot t\cdot(k_1+k_2)\cdot\left(\frac{dP}{d\rho}\cdot\rho+P\right)=0\,. \qquad (36)$$

Considering theoretical studies [4], we transform the equation (36), selecting parameters, which do not depend on ρ and P. To make this, we divide the equation (36) in $\pi\cdot n\cdot t\cdot(k_1+k_2)$:

$$\left(\frac{(\lambda_1+\lambda_2)}{\pi\cdot n\cdot t\cdot(k_1+k_2)}\right)\frac{dP}{d\rho}+\left(\frac{dP}{d\rho}\cdot\rho+P\right)=0\,, \qquad (37)$$

and denoting through B:

$$B=\frac{(\lambda_1+\lambda_2)}{\pi\cdot n\cdot t\cdot(k_1+k_2)}\,, \qquad (38)$$

we get:

$$B\frac{dP}{d\rho}+\left(\frac{dP}{d\rho}\cdot\rho+P\right)=0\,. \qquad (39)$$

We transform

$$B\frac{dP}{d\rho}=-\left(\frac{dP}{d\rho}\cdot\rho+P\right) \qquad (40)$$

and integrate

$$B\cdot P=-P\cdot\rho+C=0\,. \qquad (41)$$

We transform once again –

$$B\cdot P+P\cdot\rho=C, \qquad (42)$$

or

$$P\cdot(B+\rho)=C. \qquad (43)$$

Hence

$$P=\frac{C}{(B+\rho)}\,. \qquad (44)$$

We express the left part through (19):

$$\frac{F}{2\cdot\pi\cdot(R-r)\cdot(1-\phi)\cdot\rho}=\frac{C}{(B+\rho)}\,, \qquad (45)$$

and determine C:

$$C=\frac{F\cdot(B+\rho)}{2\cdot\pi\cdot(R-r)\cdot(1-\phi)\cdot\rho}\,. \qquad (46)$$

Conclusion. *Thus, C acts as a value connecting external impact (vertical force F) and speed in relation to displacement of a center plate and a center pad with four structural and technological parameters. That is, C is a complex parameter, which allows determining the area of stability of an adaptive controller of a pivot node. In other words, by setting the value of its member variables and constants, it is possible to obtain a matrix of numbers of controller equation in a matrix form, providing a stable movement of a control object.*

Keywords: *rail transport, tribology, intelligent control, car, center plate, center pad, kinematic contact, external exposure, wear, adaptive system.*

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