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Method for assessing the current and additional load on the parallel kinematic structure mechanisms electric drive system

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Introduction. The problem of the load on an electric drive system in a parallel kinematic structure is considered. The task of developing a fault-tolerant system that provides performing a given process in case of a failure of one or more drives is described. The work objective is to create a method for estimating the current and additional load on each drive of the mechanism of a parallel kinematic structure. The solution enables to correct the operating mode when performing a given process without compromising serviceable drives.

Materials and Methods. Previously, a diagnostic method was developed. It is based on the calculation and analysis of the coefficients of straight lines that approximate the envelopes of the values of the wavelet transform coefficients of electric motor current signals, taking into account the characteristic scales. This makes it possible to determine the current technical condition of the electric motor and find malfunctions. The logical continuation of this approach is the proposed method for assessing the current and additional load. It provides finding the current load on the drive based on the coefficients of the lines approximating the envelopes of the wavelet coefficients of the current signal. To calculate the additional load, the number and location of faulty drives are taken into account.

Results. For each scale of the wavelet coefficients, the relative coefficients and the current load on each drive are determined. The possibility of redistributing the load to two adjacent jacks was checked; the behavior of the system in this case was investigated. The load moved by the faulty jack is redistributed to two adjacent jacks in equal shares — 14.76 % each. The total load on the drives is 44.28 %, which is safe for the servo. The load on the drive of the fourth jack does not change (29.52 %). The drives have a sufficient safety margin. It is established that all three operating modes are acceptable for the studied servo drive, and they do not cause dynamic overloads and premature failure.

Discussion and Conclusions. The experimental studies on the method of assessing the current and additional load have shown its adequacy and high efficiency. It was found that when the drives were disconnected from one of the racks of the mechanism, the system performed a load redistribution on the drives. Thus, it was possible to avoid their dynamic overloads and premature failure. This means that the solution is able to ensure the reliable functioning of the complex at the time of renovation work.

Keywords: parallel kinematic structure mechanism, drive system, assessment of the current and additional load, wavelet transform, fuzzy logic apparatus.

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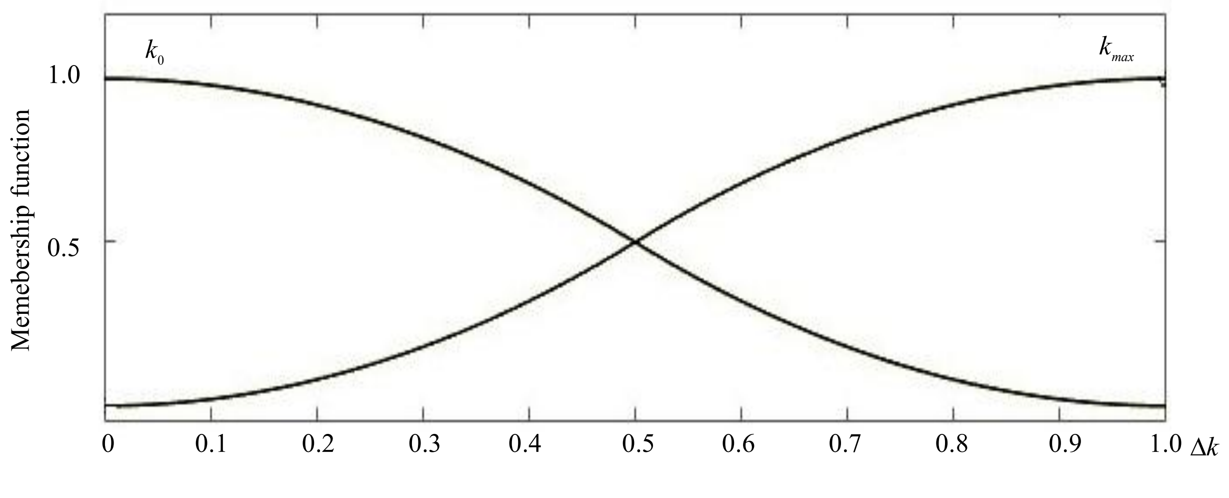
Introduction. During the operation of the mechanisms of the parallel kinematic structure, failures of one or more drives are possible. Among the likely consequences: the tilt of the platform, the curvature or jamming of the rack, unacceptable overloads, premature failure of the mechanism, production stoppage, and significant financial losses. To solve this problem, it is required to create a fault-tolerant system of drives of the parallel kinematic structure mechanisms that makes it possible to adjust the operating mode considering the technical condition. To this end, we need to determine the current load on each serviceable drive, and then, knowing the number and relative location of faulty drives, calculate the additional load on each serviceable drive.

Materials and Methods. Proper operation of drive systems of mechanisms of parallel kinematic structure is ensured through constant monitoring and evaluation of the technical condition of each actuator in real time [1]. For this purpose, a highly effective diagnostic method has been developed based on the analysis of the electric motor current using the wavelet transform [2]. The principle of the method can be described as follows: taking into account the characteristic scales, the values of the wavelet coefficients of the electric motor current are calculated, then the envelope is constructed, and its approximating line is calculated. The analysis of coefficients k and b of the resulting straight line enables to determine the current technical condition of the drive. If for all characteristic scales, $k < 0$, then the drive is serviceable, if $k \geq 0$, it is faulty. Thus, knowing the signs of coefficients k of the approximating lines, it is possible to determine the current state of each drive, calculate the number and location of faulty drives relative to each other [3].

For the subsequent adjustment of the operating mode of the parallel kinematic structure mechanism, it is required to determine the current and additional loads on each drive of the system. The calculation of the current load on the drive is based on the analysis of all the parameters of the approximating line for a known serviceable unloaded electric drive operating in nominal mode. The obtained data are reference coefficients k_0, b_0, to which the current values of parameters k, b are compared. The value of the maximum permissible coefficients $k_{\max,} b_{\max}$ can be calculated from the overload capacity of the electric motor by current K_T [4].

$$\Delta k = \frac{k - k_0}{k_{max} - k_0},\ \Delta b = \frac{b - b_0}{b_{max} - b_0}. \qquad (1)$$

To determine the possibility of increasing the load on the system drives, a model based on a fuzzy logic device has been developed. The inputs of the model are relative coefficients $\Delta k, \Delta b$ (Fig. 1), the output is the corresponding coefficient showing the percentage of load on the engine. If this parameter is zero, the drive operates in the rated mode without load. If it is equal to 100 %, then the engine has a maximum load and it is necessary to change its operating mode.



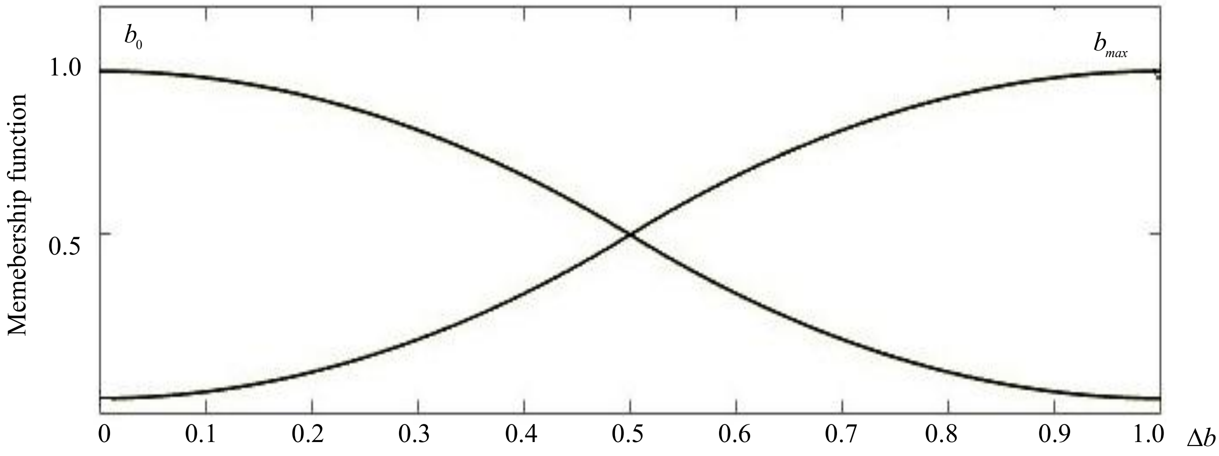


Fig. 1. Input data of the fuzzy model for determining the load on the electric drive

The correlation of the entered sets can be written using the following fuzzy rules:

R_1: *if* k *is* k_0 *and* b *is* b_0, *then* $Load_{ПД}=l_1$;

R_2: *if* k *is* $k_{\max}$ *and* b *is* b_{max}, *then* $Load_{ПД}=l_2$.

The fuzzy inference algorithm *Sugeno* [5–14] is used to determine the value of the output variable.

The proposed model enables to determine the current load on the electric drive as a percentage of the maximum permissible load based on the analysis results of the coefficients of the straight line approximating the envelope of the values of the wavelet coefficients. In case of failure of one or more drives of the system and the permissible current load on the serviceable drives, it is possible to adjust the operating mode and redistribute the released load on the serviceable drives. To do this, we need to develop a model for calculating the additional load.

Let us consider the solution to this problem on the example of a platform with twelve parallel racks, each of which is an electromechanical jack. The uniform lifting of the platform is ensured by the synchronous, uniform movement of all racks at a given speed. To fulfill this condition, when designing mechanisms of a parallel kinematic structure, equal loading of lifting columns is laid. In this case, when the mechanism is operating properly, all the drives should have approximately the same external load

$$Load_{ПД1} \approx Load_{ПД2} \approx .... \approx Load_{ПДn} . \qquad (2)$$

If one of the drives fails, the load moved by it is redistributed to two neighboring drives in approximately equal proportions (Fig. 2).

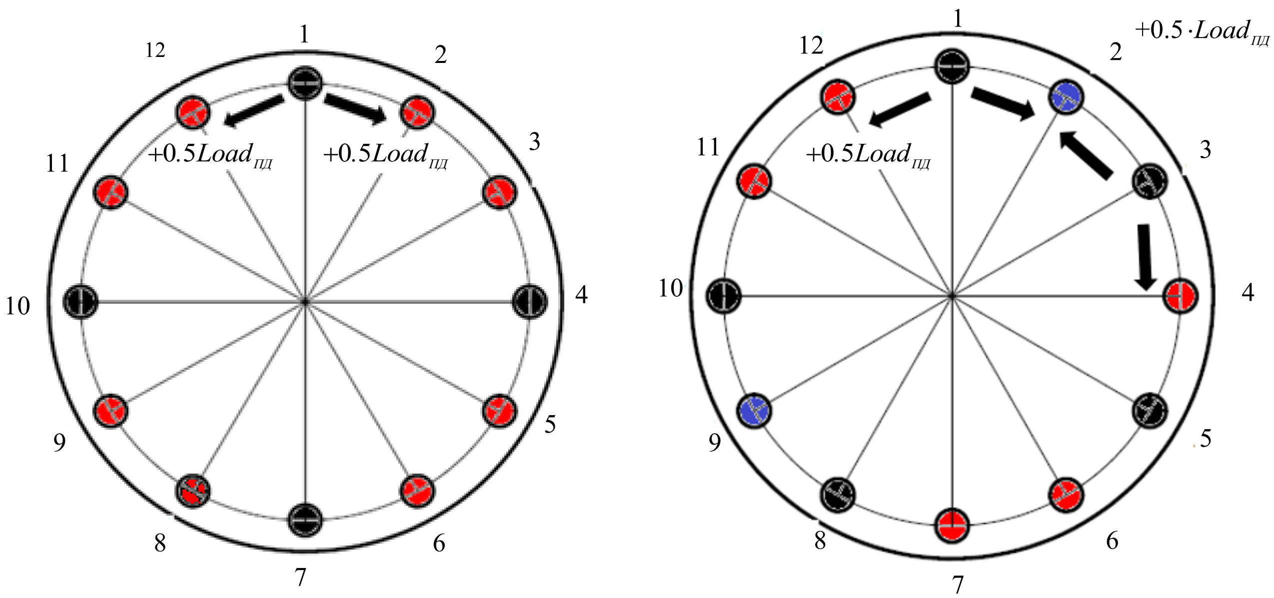


Fig. 2. Relative position of faulty jack drives and possible load correction

In this case, the additional load is calculated from ratio (3) and depends on the load change factor (L_{ch})

$$\Delta Load_{ПДj} = L_{ch} \cdot Load_{ПДi} . \qquad (3)$$

This coefficient depends on the number and relative position of faulty jack drives. Theoretically, the coefficient varies in the range from 0 to *n* in 0.5 increments. The load increase factor is decisive when calculating the additional load on the mechanism drive. For its calculation, a model based on the use of the fuzzy logic apparatus has been developed [7]. The inputs of the model are the technical condition of each drive of the parallel kinematic structure mechanism, the outputs — the load change factor of the drive of each jack. As a result of diagnostics, the current technical condition of the drives is established: “serviceable” or “faulty”. Therefore, for each input of the system in the interval [0 1], *Z*- and *S*-shaped membership functions are set (Fig. 3 a). The serviceable drive will correspond to the input value 1, the faulty one — 0. Growth of the load increase factor greater than 2 causes critical overloads of the jack, so we set five triangular membership functions in the range $L_{ch} \in [0,2]$ in 0.5 increments (Fig. 3 b).

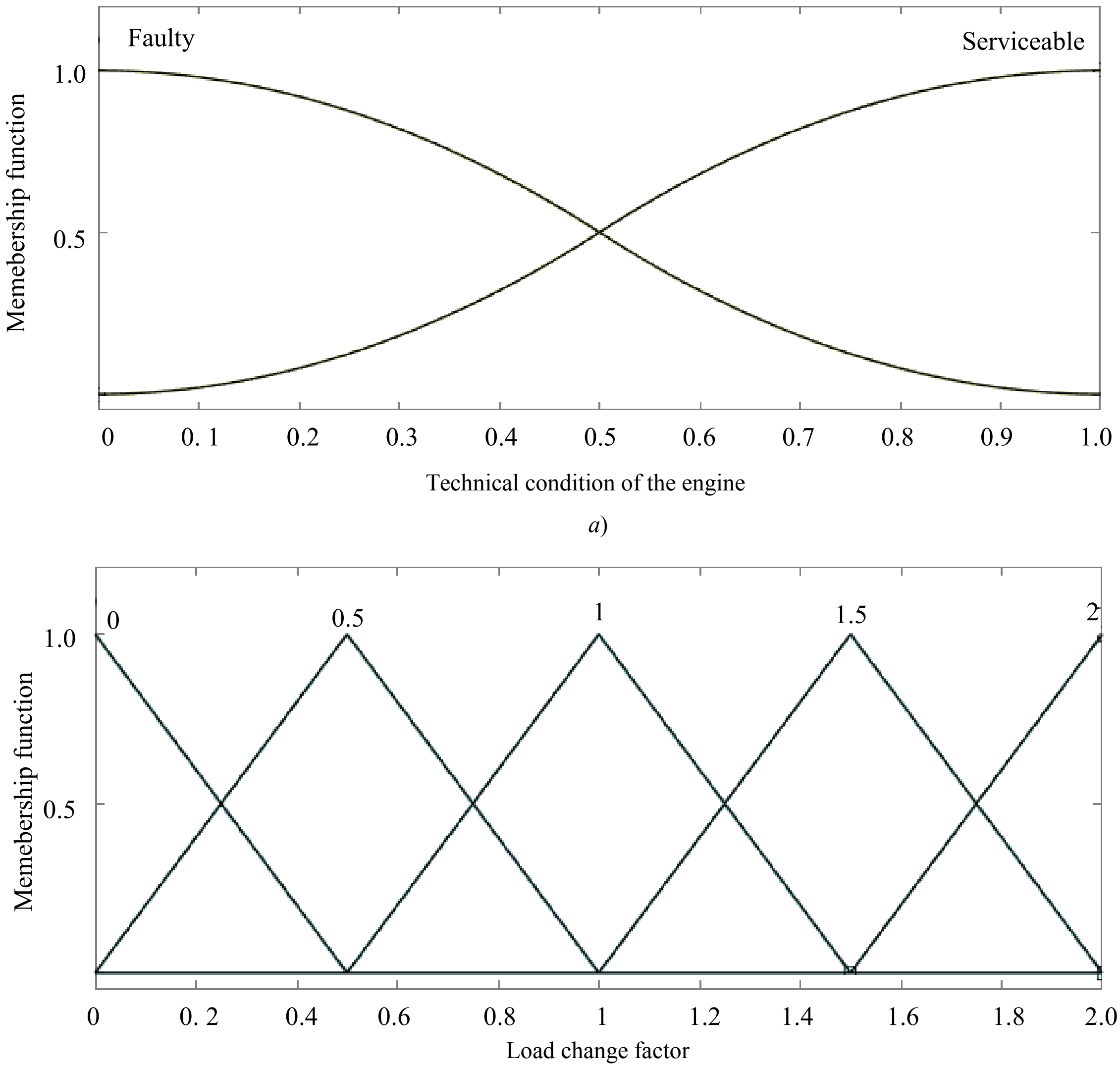


Fig. 3. Membership functions of the fuzzy model for calculating

Mamdani algorithm was used to calculate the load increase factor for the electric drives of the parallel kinematic structure mechanisms [8−10]. The resulting model is based on the analysis of the number and relative position of faulty racks of the parallel kinematic structure mechanism. This data enables to determine the additional load factor for each serviceable drive.

The relationship between the entered sets is recorded in the form of a knowledge base, whose fragment is shown in Table 1.

Table 1

Fuzzy knowledge base of the model for calculating the additional load factor

Jack number								Change factor of the jack load							
1	2	3	4	5	6	…	*n*	1	2	3	4	5	6	…	*n*
1	1	1	1	1	1	…	…	0	0	0	0	0	0	…	…
1	0	1	1	1	1	…	…	0.5	0	0.5	0	0	0	…	…
1	0	0	1	1	1	…	…	1	0	0	1	0	0	…	…
1	0	0	0	1	1	…	…	1.5	0	0	0	1.5	0	…	…
1	0	0	0	0	1	…	…	2	0	0	0	0	2	…	…
1	0	1	0	1	1	…	…	0.5	0	1	0	0.5	0	…	…
….	…..	…	…	…	…	…	…	…	…	…	…	…	…	…	…

Combining the two developed models, we obtain a general model for determining the current and additional loads on the drives of the parallel kinematic structure mechanism (Fig. 4).

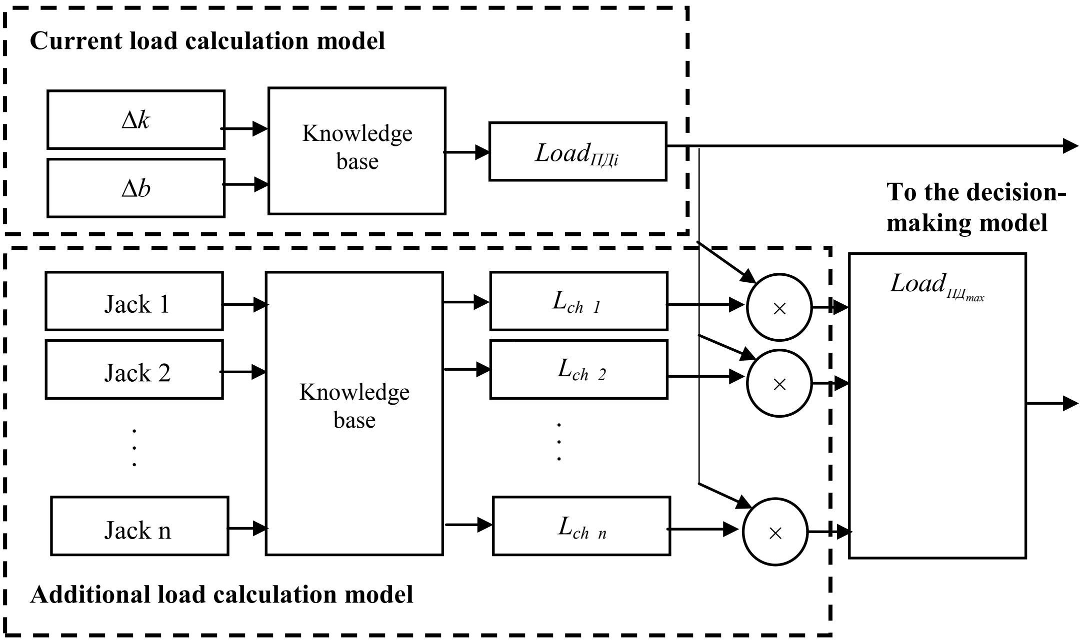


Fig. 4. Structure of the model for calculating current and additional loads on the drives of the parallel kinematic structure mechanism

The given model is based on the number and relative position of serviceable drives of the parallel kinematic structure mechanism. At the same time, taking into account the characteristic scales, the relative coefficients of the lines approximating the envelopes of the values of the wavelet transform coefficients of the electric motor current are analyzed. This data and the fuzzy logic device help to determine the current and additional load to ensure the reliability of electric motors.

Research Results. To check the operability of the proposed method for calculating the current and additional load, a stand was used (Fig. 5). It consisted of four electromechanical lifting jacks with a DC drive KY110AS0415-15B-D2 synchronously moving the load.

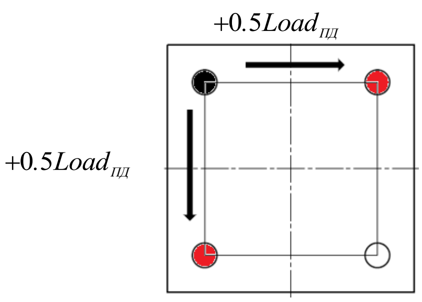


Fig. 5. Location of the faulty jack and a possible option for correcting the operating mode of the parallel kinematic structure mechanism

The current load on the drives is estimated based on the analysis of all parameters of the straight line approximating the envelopes of the wavelet transform coefficients, taking into account the characteristic scales for a known serviceable drive operating in nominal mode. In our case, we are talking about the results of the first measurement of the current signal of the drives when they are installed on electromechanical jacks. The obtained data is used as reference k_0, b_0. The current values of measured parameters *k*, *b* are compared to them.

Relative coefficients $\Delta k, \Delta b$ for each scale of the wavelet coefficients are calculated, and the current load on each drive is determined. The calculations have shown that the average load on all drives is approximately the same — 29.52% of the maximum. The experiment objective is to test the possibility of redistributing the load to two adjacent jacks, and to study the system behavior in this case. The load moved by a faulty jack is redistributed to two adjacent jacks in equal shares — 14.76 % each. Then, the total load on drives 1 and 3 (Fig. 5) is 44.28 %. According to the load diagram, it is safe for the servo. The load on the drive of the fourth jack remains unchanged — 29.52 %. Since coefficient *k* is negative for all drives, and their absolute values are significantly greater than 0, the drives have a sufficient safety margin.

To determine the impact of this load redistribution on the technical condition of the drives, the mechanical and electromechanical characteristics of the servos are analyzed. It is established that all three operating modes are acceptable for the servo drive under consideration. They do not cause dynamic overloads and premature failure. This makes it possible to ensure the reliable functioning of the complex during repair work.

Discussion and Conclusions. A model for estimating the current and additional load on the electric drives of the parallel kinematic structure mechanisms is developed. The data obtained in this way is required for correcting the operating mode of the drive system in the event of a failure of the actuators. To calculate the load, the coefficients of the straight line approximating the envelope of the current wavelet coefficients are used, taking into account the characteristic scales. In addition, the number and mutual position of the faulty jacks relative to each other are taken into account. The experiments validate the adequacy of the methods presented.

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