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ELEVATOR DRUM-PAD BRAKE MECHANISMS: REDUNDANT CONSTRAINTS AND RELIABILITY RISE OPPORTUNITY

Summary. The article deals with mechanical engineering, and transport machines, namely the elevator brake mechanism structure. The article aims to study the number and location of redundant constraints in elevator brake mechanisms and to depict their impact on brake reliability and transportation safety. To study the structure of the mentioned mechanisms, we used classical methods of applied mechanics plus the circuit method of L. Reshetov. The structure of crane disc brakes with short-stroke DC electromagnet and long-stroke AC electromagnet mechanisms was analyzed and redundant constraints were identified. It was shown that the presence of redundant constraints causes friction torque oscillation and lead to load distribution unevenness between brake elements. Based on the provided

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analysis, construction improvement events should be implemented to remove the most dangerous redundant constraints.

Keywords: drum-pad brake, redundant constraint; mechanism, friction torque, reliability, self-alignment

1. INTRODUCTION

The reliability of the braking system has a significant influence on transportation safety, which is vital for automotive vehicles and other transport systems intended for transporting people. The operational safety of an elevator directly depends on reliability of the brake mechanism, especially considering the possibility of gearbox self-braking loss. Disc-pad brakes are widespread in cars and lifting equipment, and in heavy-loading systems, such as elevators, drum-type brakes are also used. This explains the interest in studying ways to increase the reliability of brake systems. In recent years, elevator accidents have often occurred. The main factor of these accidents was the fault of brake mechanisms [1]. The latest research has focused on identifying low-reliability elements in brake systems using goal-oriented methodologies [2], investigation of safety risks [3], brake capacity study [4], and identification of brakes noise and vibration characteristics [5]. Nowadays, drum-pad type brakes are widespread in cranes and elevators. Their characteristic drawback is overheating, which determines a certain amount of modern scientific research in the field of their dynamics [6], parts temperature distribution [7] and friction elements wear features [8]. Based on new studies, new materials [9] and brake mechanisms operation principles [10] are being proposed and researched.

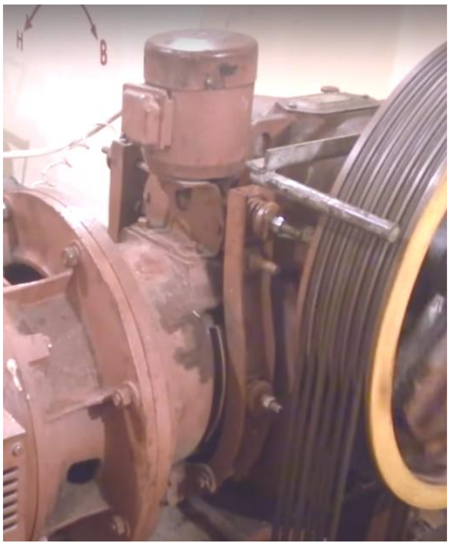
Typically, in drum-pad brakes, to increase safety, each pad can independently press the drum with the levers. This reserve can be leveled by uneven loading of the pads due to driving or brake parts dissymmetry. Therefore, increasing the reliability of brakes by ensuring the possibility of pads self-aligning is a reserve for improving the safety of the operation of elevators and other similar machines. One of the main parts of elevator brakes are lever mechanisms, the accuracy of which determines their operating parameters [11], namely the brake release response time [12].

The presence of redundant constraints in the mechanisms contributes to the increase in the unevenness of the load distribution between the parts [13]. This can lead to the destruction of parts, increased requirements for manufacturing and assembling accuracy [14], and an increase in mechanical losses [15]. There are not many works dedicated to the study of the structure and elimination of redundant constraints in elevator brake mechanisms. For example, the lever mechanisms of crane drum-pad brakes with electrohydraulic and electromagnetic actuators were considered [16], but these elements themselves were not taken into account when compiling the structural diagram of the brake, and the structure of elevator brakes with independent pressing pads remains under-researched today.

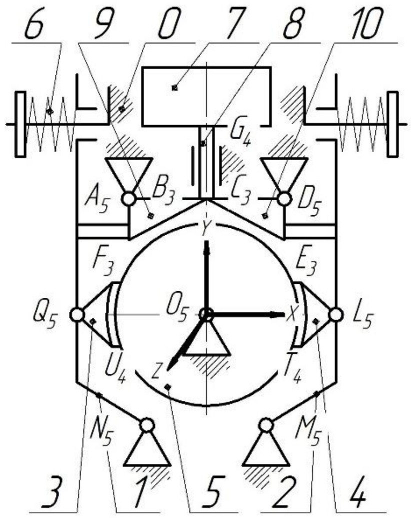
2. METHODOLOGY

Currently, the two most widespread types of drum-pad brakes in elevators are those with a short-stroke DC electromagnet (Fig. 1) and those with long-stroke AC electromagnet (Fig. 2).

The brake mechanism in Fig. 1, b, contains the left 1 and right 2 braking levers, hingedly (with rotary joints M_5 and N_5) connected to the base 0. Pads 3 and 4 are connected with rotary joints Q_5 and L_5 to levers 1 and 2 and have the ability to cover drum 5 with their cylindrical surfaces (T_4, U_4). When the brake pads 3 and 4 are closed against drum 5 pressure is provided by springs 6. Brake opening is provided by a short-stroke DC electromagnet 7, whose rod 8 can interact with rockers 9 and 10 (B_3 and C_3 connections) allowing axial and rotary slide relative to the base 0 (through G_4 joint). Rockers 9 and 10 are connected to the base 0 with A_5 and D_5 rotary joints and are able to interact with braking levers 1 and 2 through connections F_3 and E_3. Drum 5 is fixed relatively to the base 0 with rotary joint O_5.



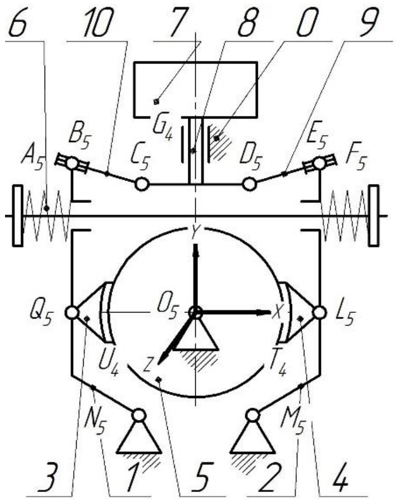
a)



b)

Fig. 1. Elevator brake with short-stroke DC electromagnet:
general view (a) and structural diagram (b)

a)



b)

Fig. 2. Elevator brake with long-stroke AC electromagnet:
general view (a) and structural diagram (b)

The brake mechanism shown in Fig. 2, b, contains the left 1 and right 2 braking levers, which are hingedly (with rotary joints M_5 and N_5) connected to the base 0. Pads 3 and 4 are connected with rotary joints Q_5 and L_5 to levers 1 and 2 and they can cover drum 5 with their cylindrical surfaces (T_4, U_4). When the brake pads 3 and 4 are closed against the drum 5 pressure is provided by springs 6. Brake opening is provided by a long-stroke AC electromagnet 7, whose rod 8 is connected with levers 1 and 2 through beams 9 and 10 using A_5, B_5, C_5, D_5, E_5, F_5 rotary joints. The drum 5 is fixed relative to the base 0 with rotary joint O_5.

Firstly, we consider the structure of the brake mechanism with a short-stroke DC electromagnet (Fig. 2, b). It contains eight movable links (n = 8). The number of 5-class kinematic pairs is P_5 = 7 (A_5, D_5, L_5, M_5, N_5, O_5, Q_5), the number of 4-class kinematic pairs is P_4 = 3 (G_4, T_4, U_4), the number of 3-class kinematic pairs is P_3 = 4 (B_3, C_3, E_3, F_3), number of 2, and 1-class kinematic pairs is $P_2 = P_1 = 0$.

The total number of kinematic pairs is:

$$P = P_5 + P_4 + P_3 + P_2 + P_1 = 7 + 3 + 4 + 0 + 0 = 14 \tag{1}$$

The sum of kinematic pairs' movabilities [17]:

$$f = 1P_5 + 2P_4 + 3P_3 + 4P_2 + 5P_1 = 1\times7 + 2\times3 + 3\times4 + 4\times0 + 5\times0 = 25 \tag{2}$$

The number of independent locked circuits by Gohman formula [18]:

$$k = P - n = 14 - 8 = 6 \tag{3}$$

Independent locked circuits are the following – $N_5Q_5U_4O_5N_5$; $M_5L_5T_4O_5M_5$; $N_5F_3A_5N_5$; $M_5E_3D_5M_5$; $A_5B_3G_4A_5$; $D_5C_3G_4D_5$.

Total mechanism mobility $W = W_b + W_l = 1 + 1 = 2$,
where W_b = 1 – basic mechanism mobility (drum 5 rotation);
W_l = 1 – local links mobility (rod 8 around own axis rotation).

Then the number of redundant constraints in basic variant by Somov and Malyshev formula:

$$\begin{aligned} q_{SM} &= W + 5P_5 + 4P_4 + 3P_3 + 2P_2 + P_1 - 6n = \\ &= 2 + 5\times7 + 4\times3 + 3\times4 + 2\times0 + 0 - 6\times8 = 13. \end{aligned} \tag{4}$$

Redundant constraints number by Ozols formula [19]:

$$q_{OZ} = W + 6k - f = 2 + 6\times6 - 25 = 13. \tag{5}$$

Thereby, the total redundant constraints number in the analyzed mechanism $q = q_{SM} = q_{OZ} = 13$. Using the circuit method [20] confirms the presented calculations (Table 1).

Tab. 1

Circuit method application to basic brake with short-stroke
DC electromagnet mechanism (Fig. 1)

Circuit	Planar movabilities f_p			Non-planar movabilities f_n		
	f_x'	f_y'	f_z''	f_x''	f_y''	f_z'
$N_5Q_5U_4O_5N_5$	Ø ↓ q_1	Ø ▲	QU ↑ W_b	Ø ↓ q_2	Ø ↓ q_3	U
$M_5L_5T_4O_5M_5$	Ø ↓ q_4	Ø ▲	O, TL	Ø ↓ q_5	Ø ↓ q_6	T
$N5F_3A_5N_5$	Ø ↓ q_7	F	N	F	Ø ↓ q_8	F
$M_5E_3D_5M_5$	Ø ↓ q_9	E	M	E	Ø ↓ q_{10}	E
$A_5B_3G_4A_5$	B	G	A	Ø ↓ q_{11}	GB ↑ W_l	B
$D_5C_3G_4D_5$	C	Ø ↓ q_{12}	D	Ø ↓ q_{13}	C	C
$W = 2,\ q = 13$						

The identified redundant constraints prevent the self-installation of brake pads on the surface of the braking drum and can lead to overloading of the mechanism's link (Table 2).

Tab. 2

Redundant constraints presence in the basic brake with short-stroke
DC electromagnet mechanism (Fig. 1) consequences

Redundant constraint	Influence of Redundant constraint presence	Practical way of redundant constraint influence leveling	Leveling absence consequences
1	2	3	4
q_1, q_4	Impossibility of braking pads self-aligning along *X* axis ($f_x' = 0$).	Control and limitation radial and angular misalignment of braking pads and drum along and around *X* and *Y* axes. This leads to an increase in the labor-intensiveness of brake assembling and maintenance. Radial gap in joints *L* and *Q* increases. This leads to delayed brake activation, strokes, and	Braking pads overlay uneven load and wear among themselves. Braking levers and springs experience uneven load.
q_2, q_5	Impossibility of braking pads self-aligning around *X* axis ($f_x'' = 0$).		Braking pads overlay uneven load and wear along their width. Additional loading of braking levers and shafts by bending moment in the *YZ* plane.
q_3			Braking pads overlay uneven load and wear

q_6	Impossibility of braking pads self-aligning around *Y* axis ($f_y'' = 0$).	vibrations during the elevator start process.	along their width. The additional load of braking levers by torque and shafts by bending moment in the *XZ* plane.
q_7	Impossibility of rockers self-aligning along *X* axis ($f_x' = 0$).	Fitting of contact surfaces of kinematic pairs *E* and *F* by scraping. This leads to an increase in the labor-intensiveness of brake assembling and maintenance.	Non-simultaneous withdrawal of braking pads from the drum leads to strokes and vibrations during the elevator start process.
q_9			
q_8	Impossibility of rockers and braking levers self-aligning around *Y* axis ($f_y'' = 0$).		The additional load of braking levers by torque in the *XZ* plane.
q_{10}			
q_{12}	Impossibility of right rocker self-aligning along Y axis ($f_y' = 0$).	Fitting of the contact surface of kinematic pair *C* by scraping. This leads to an increase in the labor-intensiveness of brake assembling and maintenance.	Non-simultaneous withdrawal of braking pads from the drum leads to strokes and vibrations during the elevator start process.
q_{11}	Impossibility of rockers self-aligning around *X* axis ($f_x'' = 0$).	Fitting of contact surfaces of kinematic pair *C* and *B* by scraping. The radial gap in joints *A* and *D* increases. This leads to the increase in the labor-intensiveness of brake assembling and maintenance.	

The most dangerous among the identified redundant constraints belong to power circuits $q_1 \ldots q_6$ which initiate the main disadvantage of the brake mechanism (Fig. 1) – the impossibility of brake pads on drum self-alignment. In addition to those listed in Table 1, this can lead to the creation of braking forces even in an opened brake due to the presence of drum radial beating and/or angular misalignment. Another disadvantage is the creation of a cyclically variable friction moment by the closed brake in the presence of disk radial beating (Fig. 3), which can lead to oscillations (Fig. 4) and a decrease in the fatigue strength of the drive parts.

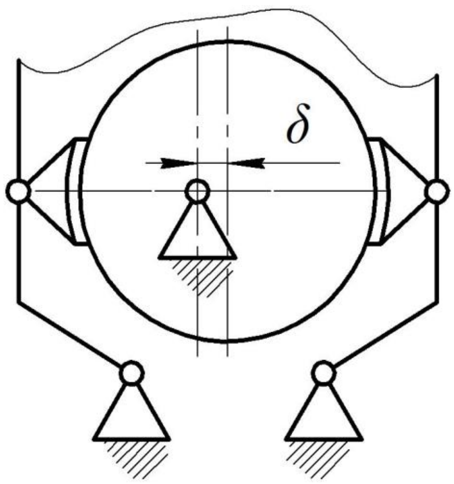


Fig. 3. Braking drum radial beating δ influence

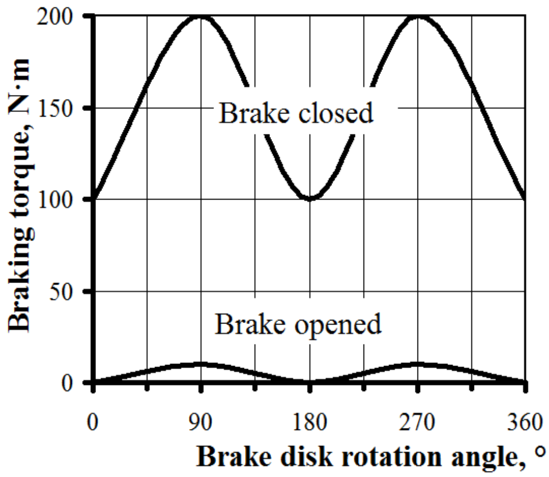


Fig. 4. Approximate influence of the drum beating on the brake friction torque in redundant constraints presence

The mechanism of the brake with a long-stroke AC electromagnet (Fig. 2, b) contains eight movable links (n = 8). The number of 5-class kinematic pairs here is $P_5 = 11$ (A_5, B_5, C_5, D_5, E_5, F_5, L_5, M_5, N_5, O_5, Q_5), number of 4-class kinematic pairs is $P_4 = 3$ (G_4, T_4, U_4), number of 3, 2 and 1-class kinematic pairs is $P_3 = P_2 = P_1 = 0$.

The total number of kinematic pairs is:

$$P = P_5 + P_4 + P_3 + P_2 + P_1 = 11 + 3 + 0 + 0 + 0 = 14 \quad (6)$$

The sum of kinematic pairs' movabilities:

$$f = 1P_5 + 2P_4 + 3P_3 + 4P_2 + 5P_1 = 1\times11 + 2\times3 + 3\times0 + 4\times0 + 5\times0 = 17 \quad (7)$$

Number of independent locked circuits by Gohman formula:

$$k = P - n = 14 - 8 = 6. \quad (8)$$

Independent locked circuits are as follows – $N_5A_5B_5C_5G_4N_5$; $M_5F_5E_5D_5G_4M_5$; $N_5Q_5U_4O_5N_5$; $M_5L_5T_4O_5M_5$; $M_5E_2D_5M_5$; $O_5U_4Q_5A_5B_5C_5G_4O_5$; $O_5T_4L_5F_5E_5D_5G_4O_5$.

Total mechanism mobility $W = W_b + W_l = 1 + 0 = 1$,
where $W_b = 1$ – basic mechanism mobility (drum 5 rotation);
$W_l = 0$ – local links mobilities.

Then the redundant constraints number in the basic variant by Somov and Malyshev formula:

$$\begin{aligned} q_{SM} &= W + 5P_5 + 4P_4 + 3P_3 + 2P_2 + P_1 - 6n = \\ &= 1 + 5\times11 + 4\times3 + 3\times0 + 2\times0 + 0 - 6\times8 = 20. \end{aligned} \quad (9)$$

Redundant constraints number by Ozols formula:

$$q_{OZ} = W + 6k - f = 1 + 6\times6 - 17 = 20. \quad (10)$$

The circuit method confirms the presented calculations (Table 3). The influence of the identified redundant constraints is described in Table 4.

Tab. 3

Circuit method application to basic brake with long-stroke AC electromagnet mechanism (Fig. 2)

Circuit	Planar movabilities f_p			Non-planar movabilities f_n		
	f_x'	f_y'	f_z''	f_x''	f_y''	f_z'
$N_5Q_5U_4O_5N_5$	Ø q_1	Ø q_2	OU W_b	Ø q_3	Ø q_4	U
$M_5L_5T_4O_5M_5$	Ø	Ø q_5	MT	Ø q_6	Ø q_7	T
$N_5A_5B_5C_5G_4N_5$	Ø	G	CN	B	G	Ø q_8
$M_5F_5E_5D_5G_4M_5$	Ø q_9	Ø q_{10}	F	E	Ø q_{11}	Ø q_{12}
$O_5U_4Q_5A_5B_5C_5G_4O_5$	Ø	Ø q_{13}	AQ	Ø q_{14}	Ø q_{15}	Ø q_{16}
$O_5T_4L_5F_5E_5D_5G_4O_5$	Ø	Ø q_{17}	DL	Ø q_{18}	Ø q_{19}	Ø q_{20}
$W=1,\ q=20$						

Tab. 4

Concequences of Redundant constraints in basic brake with long-stroke AC electromagnet mechanism (Fig. 2)

Redundant constraint	Influence of Redundant constraint presence	Practical way of redundant constraint influence leveling	Leveling absence consequences
1	2	3	4
q_1, q_2, q_5	Impossibility of braking pads self-aligning along *X* and *Y* axis ($f_x'=0, f_y'=0$).	Control and limitation of radial and angular misalignment of braking pads and drum along and around *X* and *Y* axes. This leads to an increase in the labor-intensiveness of brake assembling and maintenance. Radial gap in joints *L* and *Q* increases. This leads to delayed brake	Braking pads overlay uneven load and wear among themselves. Braking levers and springs experience uneven load.
q_3, q_6	Impossibility of braking pads self-aligning around *X* axis ($f_x''=0$).		Braking pads overlay uneven load and wear along their width. Additional loading of braking levers and shafts by bending moment in the *YZ* plane.

q_4	Impossibility of braking pads self-aligning around *Y* axis ($f_y'' = 0$).	activation, strokes, and vibrations during the elevator start process.	Braking pads overlay uneven load and wear along their width. The additional load of braking levers by torque and shafts by bending moment in the *XZ* plane.
q_7			
Impossibility of circuits $N_5A_5B_5C_5G_4N_5$; $M_5F_5E_5D_5G_4M_5$; $O_5U_4Q_5A_5B_5C_5G_4O_5$; $O_5T_4L_5F_5E_5D_5G_4O_5$ assembling without tension:			
q_8, q_{12}, q_{16}, q_{20}	- along *Z* axis ($f_z' = 0$)	Radial gap in joints *A*, *B*, *C*, *D*, *E*, *F* increases. This leads to delayed brake activation, strokes, and vibrations during the elevator start process.	Additional loads of braking levers and beams during the brake opening period.
q_{11}, q_{15}, q_{17}, q_{19}	- around *Y* axis ($f_y'' = 0$)		
q_{14}, q_{18}	- around *X* axis ($f_x'' = 0$)		
q_{10}, q_{13}, q_{17}	- along *Y* axis ($f_y' = 0$)		
q_9	- along *X* axis ($f_x' = 0$)		

As can be seen, the most dangerous are also $q_1 \ldots q_7$ redundant constraints which initiate the same effect as in previous construction with a DC electromagnet because they belong to power circuits in both types of brakes. Other constraints belong to control circuits and are not as harmful, especially when using a variable frequency drive.

3. RESULTS AND DISCUSSION

The main way to eliminate the detected redundant constraints without intentionally introducing errors into the design or worsening brake performance is to add mobilities to the mechanism circuits by increasing the classes of kinematic pairs. For both of brake types, it is promising to implement spherical pairs L_3 and Q_3 instead of rotary ones (L_5, Q_5). For brakes with a short-stroke DC electromagnet, it is also useful to modify joints *B*, *C*, *E*, *F* by making their tips spherical and turning these pairs class from 3-rd to 1-st "sphere-plane" pairs (Fig. 5). For brakes with long-stroke AC-electromagnet, spherical joints can be applied in kinematic pairs *A*, *C*, *D*, *F* turning their class from 5th to 3rd (Fig. 6).

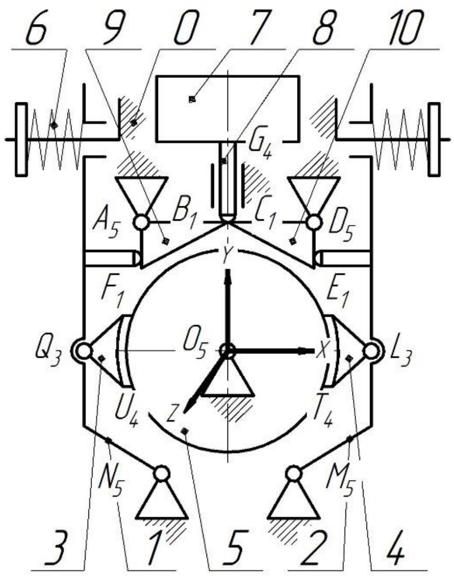


Fig. 5. Modified mechanism for brake with DC short-stroke electromagnet

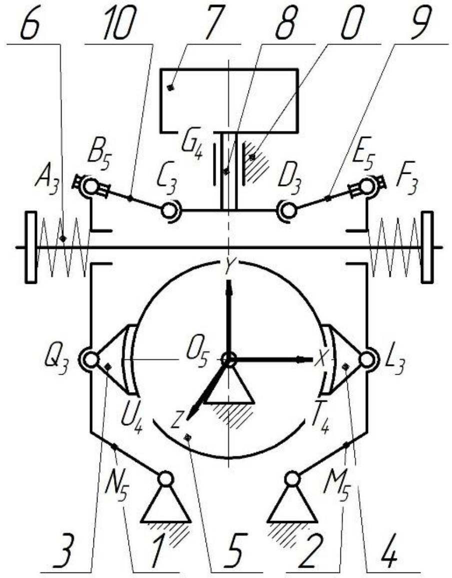


Fig 6. Modified mechanism for brake with AC long-stroke electromagnet

For the modified short-stroke DC-electromagnet brake mechanism (Fig. 5), with an unchanged total number of links, kinematic pairs and circuits, the number of kinematic pairs of the 5-class became $P_5 = 5$ (A_5, D_5, M_5, N_5, O_5), number of 4-class kinematic pairs $P_4 = 3$ (U_4, T_4, G_4), 3-class kinematic pairs is $P_3 = 2$ (L_3, Q_3), 1-class kinematic pairs number is $P_1 = 4$ (B_1, C_1, E_1, F_1), 2-class kinematic pairs number is $P_1 = 0$.

The sum of kinematic pairs' movabilities:

$$f = 1P_5 + 2P_4 + 3P_3 + 4P_2 + 5P_1 = 1\times5 + 2\times3 + 3\times2 + 4\times0 + 5\times4 = 37 \tag{11}$$

Total mechanism mobility $W = W_b + W_l = 1 + 1 = 2$,
where $W_b = 1$ – basic mechanism mobility (disc 7 rotation);
$W_l = 1$ – local links mobility (rod 8 around own axis rotation).

Then, the number of redundant constraints in the basic variant by Somov and Malyshev formula:

$$\begin{aligned} q_{SM} &= W + 5P_5 + 4P_4 + 3P_3 + 2P_2 + P_1 - 6n = \\ &= 2 + 5\times5 + 4\times3 + 3\times2 + 2\times0 + 4 - 6\times8 = 1. \end{aligned} \tag{12}$$

Redundant constraints number by Ozols formula:

$$q_{OZ} = W + 6k - f = 2 + 6\times6 - 37 = 1. \tag{13}$$

The application of the circuit method for the described variant of structural diagram modification is shown in the Table 5, confirming the obtained results.

Tab. 5

Circuit method application to a modified mechanism for brake with DC short-stroke electromagnet (Fig. 5)

Circuit	Planar movabilities f_p			Non-planar movabilities f_n		
	f_x'	f_y'	f_z''	f_x''	f_y''	f_z'
$N_5Q_3U_4O_5N_5$	Ø	Ø	N QU W_b	Q	Q	U
$M_5L_3T_4O_5M_5$	Ø	Ø	MO TL	L	L	T
$N_5F_1A_5N_5$	Ø	F	AF	F	F	F
$M_5E_1D_5M_5$	Ø	E	DE	E	E	E
$A_5B_1G_4A_5$	B	G	B	B	GB W_l	B
$D_5C_1G_4D_5$	C	Ø q_1	C	C	C	C
$W=2,\ q=1$						

For the modified long-stroke AC-electromagnet brake mechanism (Fig. 6), with an unchanged total number of links, kinematic pairs and circuits, the number of kinematic pairs of the 5-class became P_5 = 5 (B_5, E_5, M_5, N_5, O_5), number of 4-class kinematic pairs is P_4 = 3 (U_4, T_4, G_4), 3-class kinematic pairs is P_3 = 6 (A_3, C_3, D_3, F_3, L_3, Q_3), 2-class and 1-class kinematic pairs number $P_2 = P_1 = 0$.

The sum of kinematic pairs' movabilities:

$$f = 1P_5 + 2P_4 + 3P_3 + 4P_2 + 5P_1 = 1\times5 + 2\times3 + 3\times6 + 4\times0 + 5\times0 = 29 \quad (14)$$

Total mechanism mobility $W = W_b + W_l = 1 + 0 = 1$,
where $W_b = 1$ – basic mechanism mobility (disc 7 rotation);
$W_l = 0$ – local links mobilities.

Then, the number of redundant constraints in the basic variant by Somov and Malyshev formula:

$$q_{SM} = W + 5P_5 + 4P_4 + 3P_3 + 2P_2 + P_1 - 6n = \\ = 1 + 5\times5 + 4\times3 + 3\times6 + 2\times0 + 0 - 6\times8 = 8. \quad (15)$$

Redundant constraints number by Ozols formula:

$$q_{OZ} = W + 6k - f = 1 + 6\times6 - 29 = 8. \quad (16)$$

The application of the circuit method, as shown in Table 6, confirms the obtained results.

Tab. 6.

Circuit method application to a modified mechanism for brake with AC long-stroke electromagnet (Fig. 6)

Circuit	Planar movabilities f_p			Non-planar movabilities f_n		
	f_x'	f_y'	f_z''	f_x''	f_y''	f_z'
$N5Q_3U_4O_5N_5$	Ø	Ø	OU QN W_b	Q	Q	U
$M_5L_3T_4O_5M_5$	Ø	Ø	M TL	L	L	T
$N_5A_3B_5C_3G_4N_5$	Ø	G	AB	A	AG	Ø
$M_5F_3E_5D_3G_4M_5$	Ø q_1	Ø	EF	F	F	Ø q_2
$O_5U_4Q_3A_3B_5C_3G_4O_5$	Ø q_3	Ø q_4	C	C	C	Ø q_5
$O_5T_4L_3F_3E_5D_3G_4O_5$	Ø q_6	Ø q_7	D	D	D	Ø q_8
$W = 1,\ q = 8$						

4. CONCLUSIONS

The structure of braking devices mechanisms in transport vehicles and devices significantly affects their reliability and safety of operation. This article proposes measures to improve the structural integrity of elevator brakes, especially those intended for transporting people. The structure of crane disc brakes with short-stroke DC electromagnet and long-stroke AC electromagnet mechanisms is analyzed and redundant constraints are identified. Based on this analysis, construction improvement events are suggested to eliminate the most dangerous redundant constraints.

The performed theoretical studies made it possible to establish the following:

- structural analysis of the basic mechanisms of the elevator drum-pad brakes showed that the mechanism of the brake with short-stroke DC electromagnet contains q = 13 and the mechanism of the brake with long-stroke AC electromagnet contains q = 20 redundant constraints;
- it is shown that the most dangerous, among identified, redundant constraints are in power circuits because they initiate the main disadvantages of brake mechanism – the impossibility of brake pads self-aligning on the drum. This can lead to the creation of braking forces even in an opened brake as a result of the presence of the drum radial beating and/or angular misalignment or the creation of a cyclically variable friction moment by a closed brake, which can lead to oscillations and a decrease in the fatigue strength of the drive parts;

- compensation for the presence of redundant connections is usually performed by increasing the gaps in the kinematic pairs, which leads to delayed brake activation, strokes, and vibrations in the elevator start process;
- possible variants for modifying the structure of the mechanisms for both brake types are proposed, which will reduce the redundant constraints from q = 13 to q = 1 for the short-stroke DC electromagnet brake, and from q = 20 to q = 10 for the long-stroke AC electromagnet brake;
- the developed technical solutions can be implemented in production without significant complications.

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