OPTIMIZATION OF THE MECHANICAL UNITS IN MEDICAL CENTRIFUGE, (CHAIR OF BARANY) WITH VARIABLE MECHANICAL TIME CONSTANT

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Abstract

We researched the influence of the mass, diameter and the structure of the mechanics on the moment of inertia, the mechanical time constant and the coefficient of efficiency for a class of the mechanisms. We offer a specific solutions to optimize the mechanical units and increase the efficiency of the medical centrifuge, intended for astronauts. Studies have been conducted for a wide range of changing mechanical time constant.

Keywords: *mechanism, mechanical units, efficiency, mechanical time constant, medical centrifuge, astronauts, speed, acceleration, optimization, reliability.*

1. INTRODUCTION

The subject of the research in this work are the nodes that make the mechanical-electrical part of the rotating chair for studies of the vestibular system [1], [2]. Typical of it is that you have to provide a trapezoidal speed chart sinusoidal oscillation – pendulous effect and stop impetus.

The chair is designed for responsible research in the selection of pilots and astronauts the electromechanical part (Figure 1) has a changing radius of rotation, which in turn in medical aspect ensures angular accelerations up to 12g. This is are limit in tests for astronauts.

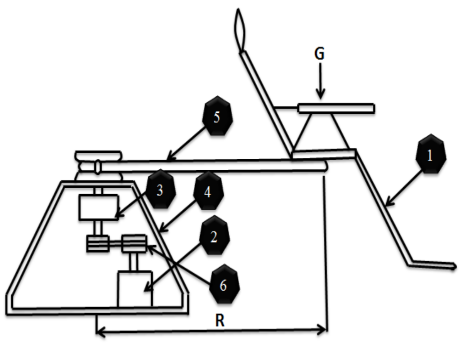

Fig. 1. Electromechanical part of medical centrifuge. Electromechanical part consists of:
1 – chair, 2 – electric motor, 3 – reducer, 4 – housing,
5 – shoulder with changing diameter, 6 - belt drive;

For the sake of high efficiency we offer the following structural changes: elimination of the belt drive and it's replace with perifleks coupler (the coupler is shown in FIG. 2 along with the mechanical properties in Table 1), replacing the coupler with the profiled specifically for the relevant medical centrifuge.

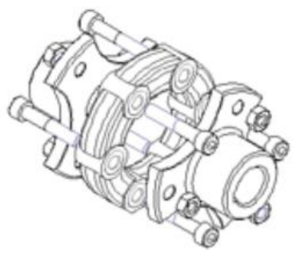

Fig. 2. Perifleks coupler.[3]

Determination of torque $\mathrm{M_H}$

$$\mathrm{M_H} = \frac{P_\mathrm{H}}{\omega_\mathrm{H}} \tag{1}$$

Where:
P_H – is nominal propulsion power.
ω_H – is the nominal rotational speed.

тип-параметър			ДК-60	ДК-80	ДК-100	ДК-150	ДК-200	ДК-250
номинален въртящ момент	Tk n	Nm	10	40	100	400	800	1600
максимален въртящ момент	Tk max	Nm	12	48	120	480	960	1920
максимална честота на въртене	nmax	min-1	3500	3500	3500	3000	3000	3000
диаметри	D	mm	60	80	100	150	200	250
	d1	mm	32	42	47	69	100	150
	dminH8	mm	10	14	19	28	48	55
	dmaxH8	mm	19	24	32	48	65	80
	nxd/R	mm	M6	M6	M8	M12	M16	M20
дължини	l	mm	68	82	122	194	250	325
	b	mm	25	30	50	80	100	130
	e	mm	22	22	24	34	50	65
допустимо несъосие на валовете	Y	mm	2	3	3	4	5	5
макс. относ. завъртане на главините	j	deg	12o	12o	12o	10o	10o	9o
допустимо пресичане на осите	b	deg	2o	2o	2o	2o20'	2o40'	2o40'
допустимо осово изместване	x	mm	2	2	2	3	4	5

parameters selected perifleks coupler for acceleration up to 12 g. Because of these structural changes the kinematic chain acquires the type shown in FIG. 3.

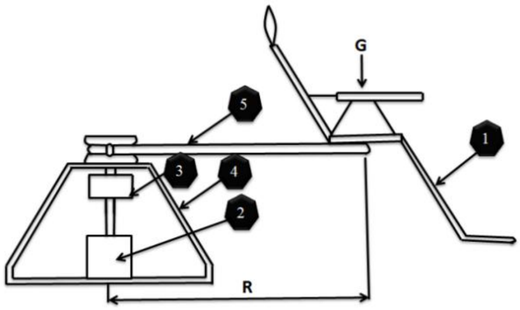

Fig. 3. Electromechanical part with optimized units.

Electromechanical part consists of: 1 - chair; 2 - electric motor; 3 - reducer; 4 - housing; 5 – shoulder with changing diameter;

$$\mathrm{M}_{дв} - \mathrm{M}_{с} = J\frac{d\omega}{dt} \pm \frac{\omega^2}{2}\frac{dJ}{d\alpha} = \mathrm{M}_{дин} \qquad (2)$$

Where:

$\mathrm{M}_{дв}$ – Moment developed by the motor,

$\mathrm{M}_{с}$ – Moment brought to the shaft of the motor,

$\mathrm{M}_{дин}$ – Dynamic moment,

J – Brought inertial moment to the motor shaft,

$\frac{d\omega}{dt}$ – Angular acceleration,

α – Angle of rotation,

$$J = \frac{GD^2}{4g} \qquad (3)$$

Where:

G – Weight,

D – Diameter under which the electromechanical part rotates (D=2R)

Typical of the tests in the electromechanical system is that the parameter G changes from 392 N to 1373 N, and the parameter D - from 0 to 0,6 m, respectively the moment of inertia changes and the mechanical time constant $\mathrm{T_M}$ by orders of the same magnitude. This makes difficult the optimal adjustment of the electric drive in cases where it is constructed by the system with dependent adjustment also makes difficult the design of adaptive control system under these conditions [4].

Mechanical part incorporates all interconnected moving masses: engine, gearbox and the actuating device of the machine are shown on fig. 4. This movement is realized by a motor Д, reducer КРП, perifleks coupler CM1 and rod Б propelling the chair. The working mechanism, on the schematic diagram are armchair with mass m1 and patient with mass m2. Actuating device transfers the cargo m1 + m2, loaded with a mass $m_{гр}$, moving with speed $V_{гр}$, rotating with angular velocity ω and subjected to a force $F_{гр}$.[5]

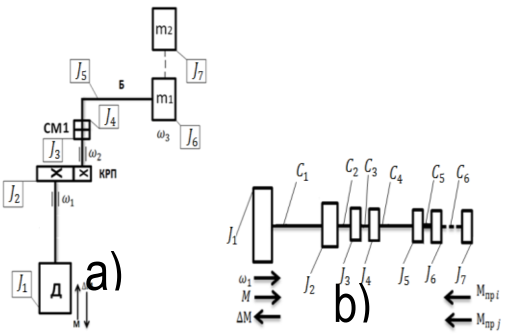

Fig. 4. Schematic diagram of the mechanical part a) and defined kinematic chain b) of medical centrifuge.

On the diagram in Fig. 4 with arrows are shown the applied to the individual mases in the system, adduced moments of the active in the system external forces $M_{пр\,i}$ and $\mathrm{M}_{пр\,j}$. To the rotor of the engine J_1 is applied the electromagnetic moment of the engine M and the moment of the mechanical es ΔM, to properly calculate we assumed to be positive sign the direction of the angular velocityω_1. In simplifying of the scheme it is necessary to calculate all externally applied forces on the masses which are connected by means of solid bodies. The study of the dynamics of the electric drive shows that the direct calculation of mechanical scheme in most cases gives the same output as the detailed calculation of the individual forming mechanism. Therefore we identify the main masses and stiffness and bring it down to a two mass system shown on fig. 5, where the system is broth down to the unit with the lowest stiffness and result inertial momentum.[5]

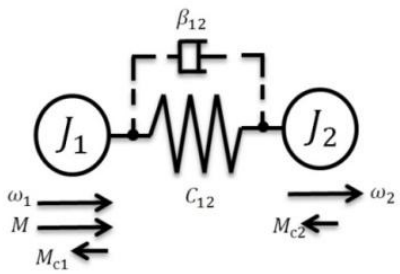

Fig. 5. Summarized two - mass scheme for medical centrifuge

Parameters of two – mass flexible mechanical system (fig. 5), are reduced to the total moment of inertia moments J_1 and J_2, directed to the mechanical connection between them. We accept the moment of elasticity which is brought to the stiffness of a mechanical link J_1 and $J_2 - C_{12}$. The first mass represents the rotor of the engine himself and the mechanical components which have direct contact with him. To this we add the applied electromagnetic moment of the engine *M* and the moment of static load M_{c1}. To the intermediate masses in the mechanism J_2 is applied the resistance moment M_c. [6]

In calculating the above-quoted static moment M_C, when all active forces and momentums in the mechanism are defined. In most cases, losses from friction in the mechanism are unknown and are calculated with the use of the efficiency coefficient of the mechanism.

$$\eta_{\text{мех}} = \eta_1\eta_2\eta_3 \ldots ,[7]$$

Where $\eta_1, \eta_2, \eta_3 -$ are efficiency coefficients of the units in the kinematic chain.

Comparison of mechanisms based on efficiency:

Medical centrifuge before optimization of mechanical units:

$$\eta_{\text{мех}-\text{пр}} = \eta_{\text{CH}}.\eta_{\text{P}}.\eta_{\text{PEM}}.\eta_{\text{ЛАГ}}^5 = 0{,}64 \qquad (4)$$

Where:

$\eta_{\text{CH}} -$ Is efficiency of the coupling.

$\eta_{\text{P}} -$ Is efficiency of the gearbox.

$\eta_{\text{PEM}} -$ Is efficiency of the belt drive.

$\eta_{\text{ЛАГ}}^5 -$ Is efficiency of the bearings.

Medical centrifuge after optimization of mechanical units:

$$\eta_{\text{мех}-\text{сл}} = \eta_{\text{CH1}}.\eta_{\text{P}}.\eta_{\text{ЛАГ}}^3 = 0{,}72 \qquad (5)$$

Where:

$\eta_{\text{CH1}} -$ is efficiency of the perifleks coupler.

$\eta_{\text{P}} -$ is efficiency of the gearbox.

$\eta_{\text{ЛАГ}}^3 -$ is efficiency of the bearings.

If the moment M_{MEX} of the load in the mechanism is positive, the moment of the static load is detriment from the equations. [6],[5]

$$\mathrm{M_C}\omega_1 = \mathrm{M}_{\text{мех}}\omega_{\text{мех}}/\eta_{\text{мех}} + \Delta\mathrm{M}\omega_1 \qquad (6)$$

Therefore

$$\mathrm{M_C} = \mathrm{M}_{\text{мех}}/i_0\eta_{\text{мех}} + \Delta M, \qquad (7)$$

Where $\Delta M -$ is the moment of mechanical losses in the engine.

$i_0 = \frac{\omega_1}{\omega_{\text{MEX}}} = i_1 i_2 i_3 \ldots -$ overall gear ratio from the motor to the actuating device.

The equation of the power capacity can be written in the following way, thanks to the efficiency - in the system.

$$\mathrm{M_C}\omega_1 = M_{\text{мех}}\omega_{\text{мех}}\eta_{\text{мех}} - \Delta\mathrm{M}\omega_1 \qquad (8)$$

In this case:

$$\mathrm{M_C} = (\mathrm{M}_{\text{мех}}/i_0)\eta_{\text{мех}} - \Delta M. \qquad (9)$$

The moment caused by mechanical losses in the engine isn't bigger then 1-5 % of the rated torque of the engine. In this case we assume $\Delta\mathrm{M} \approx 0$, and $\mathrm{M}_{\text{мех}}$ becomes:

$$\mathrm{M_C} = \mathrm{M}_{\text{мех}}/i_0\eta_{\text{мех}}; \qquad (10)$$

For motor rotating in the opposite direction:

$$\mathrm{M_C} = (\mathrm{M}_{\text{мех}}/i_0)\eta_{\text{мех}} \qquad (11)$$

When $\Delta\mathrm{M} = 0$, the equation can be written:

$$M_C\omega_1 = F_{\text{мех}}v_{\text{мех}}/\eta_{\text{мех}} \qquad (12)$$

From where:

$$\mathrm{M_C} = (F_{\text{мех}}/\eta_{\text{мех}})\mathrm{p} \qquad (13)$$

So for motor rotating in the opposite direction:

$$\mathrm{M_C} = F_{\text{мех}}\mathrm{p}\eta_{\text{мех}} \qquad (14)$$

From the kinematic chain in fig. 4 we can write the current example the three most - significant masses are given the rotor, the engine with inertia moment $J_{\text{дв}}$ and load J_c.

$$1/C_{e\text{кв}} = 1/C_1 + 1/C_2 + 1/C_3 + \ldots \text{ (15)[8]}$$

The behavior of the system depends on the variable parameter T_M to get the required quality of the transition process. [1]

The algorithm taking into account the variable mechanical time constant. Is calculated and explained in [1].

Electromechanical time constant is:

$$T_M = \frac{J_{\Sigma.} r_e}{(c\Phi)^2}; = c\Phi = \frac{M_H}{I_H}; \qquad (16)$$

$$J_{\Sigma.} = J_{дв} + J_P + J_{CM1} + \frac{J_C}{\eta_{мех}\, i_p^2}; \qquad (17)$$

$$J_C = \frac{GD^2}{4g}; J_P = 0{,}2J_{дв}; J_{\Sigma.} = 1{,}2J_{дв} + J_{CM1} + \frac{GD^2}{4g\eta_{мех}\, i_p^2}; \qquad G = G_C + G_П; \qquad (18)$$

Where:

$J_{дв}$ – motor inertial moment,

J_{CM1} – inertial moment, perifleks coupler.

J_P – inertial moment of the profiled designed gear,

J_c – inertial moment of the load,

i_p – ratio of the gearbox,

η_{MEX} – efficiency,

From the made calculations it is seen that with the change of the T_M disturbing the optimal setting of the internal and external contour. Fig. 5 and Fig. 6 shows the dependencies between dynamic moment and the parameters G and R.

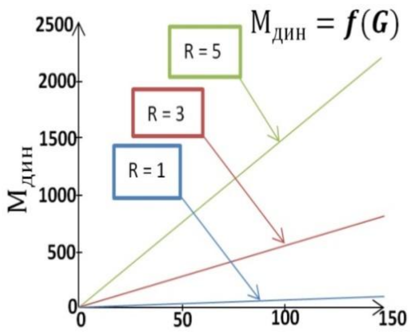

Fig. 5. $M_{дин} = f(G)$, when $\varepsilon = 6$

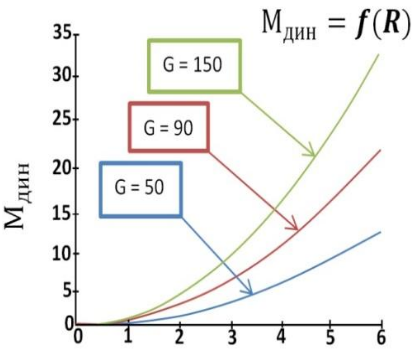

Fig. 6. $M_{дин} = f(R)$, when $\varepsilon = 0{,}6$

The dependence of the dynamic moment and of the two parameters (G and R) is given in Fig. 7.

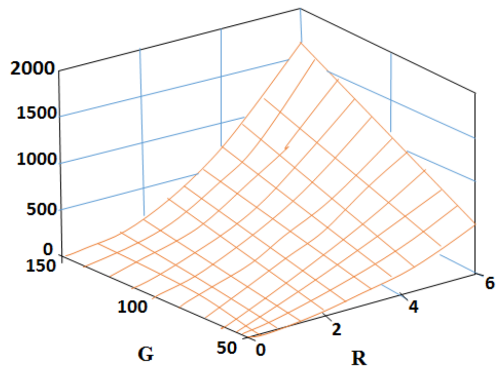

Fig. 7. Dependence of the dynamic moment and of the two parameters (G and R)

2. CONCLUSION

With the applied optimization, the system reliability is increased, noise levels fall due to the applications of perifleks coupler and repair suitability significantly increased due to the lack of belt drive. Because of the absence of belt drive the period for external intervention significantly increases, the system can operate a long time, as independent. From the economical point of view, the price dropped because it is not necessary to purchase a belt drive and repair costs are also drastically reduced. The overall friction in the system is also decreased.

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