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ADAPTIVE DRIVE FOR SPACE ENGINEERING

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Abstract.
Now the brand new self-controlled mechanical systems of motion transfer at absent control have appeared. Self-controlled mechanical systems are created on the basis of a discovery «Effect in mechanics». The essence of discovery consists that the having mobile closed contour has property independently without a control system to adapt for variable external loading. The present paper is devoted the theoretical description of the self-controlled drive and creation of highly effective drives of power units and control systems and stabilization of space vehicles.

Key words: self-controlled system, force adaptation, mechanism with two degree of freedom, closed contour.

1. INTRODUCTION

Drives in space engineering are used for transfer of motion to executive powers, for orientation and motion stabilization.

Now the control systems engineering in the form of optimum circuit designs of drives of executive powers, attitude control systems and stabilization is developed [1]. The general methods of account of drives and control systems by them are developed.

A state-space representation is a mathematical model of a physical system as a set of input, output and state variables related by first-order differential equations. "State space" refers to the space whose axes are the state variables. The state of the system can be represented as a vector within that space.

The state-space method allows abstracting from the number of inputs, outputs and states, these variables are expressed as vectors. Additionally, if the dynamical system is linear, time-invariant, and finite-dimensional, then the differential and algebraic equations may be written in matrix form. The state-space representation (also known as the "time-domain approach") provides a convenient and compact way to model and analyze systems with multiple inputs and outputs.

However now the brand new self-controlled mechanical systems creating new effective possibilities of motion transfer at minimal or completely absent control have appeared.

Self-controlled mechanical systems are created on the basis of a discovery of professor Konstantin S. Ivanov «Effect of force adaptation in mechanics» [2]. The discovery has been reported for the first time in 1985 on 11 World congress under the theory of mechanisms and machines in Milan (Italy). Numerous scientific publications in world press, numerical instances of accounts and the experimental researches executed at world level are confirming the existence of the phenomenon of force adaptation unknown earlier.

The essence of discovery consists that the mechanism with two degree of freedom having mobile closed contour has property independently without a control system to adapt for variable external loading.

The present paper is devoted the theoretical description of the self-controlled drive and creation of highly effective drives of power units and control systems and stabilization of space vehicles.

2. SHORT DESCRIPTION OF EFFECT OF FORCE ADAPTATION IN MECHANICS

The phenomenon of power adaptation can be proved at performance of the power analysis of the kinematic chain with two degree of freedom.

In earlier executed researches [2, 3] it has been proved that the closed contour imposes additional constraint and leads to motion definiteness of the kinematic chain with two degree of freedom at only single input.

If such regularity really takes place, it should be shown as well at execution of the force analysis of a usual mechanism containing a closed contour. The usual mechanism is a mechanism with two input links (Figure 1).

The mechanism contains two entrance links (carriers H_1 and H_2) and the mobile closed contour placed between them containing wheels 1, 2, 3, 6, 5, 4. Wheels 3, 6 and 1, 4 are joined in blocks of wheels 3-6 and 1-4.

The problem of the force analysis of the usual mechanism corresponds to conventional statement.

Statement of problem of the force analysis of the mechanism with two degree of freedom is such: on the given external forces to determine reactions in kinematic pairs and the generalized forces (or moments $M_{H1} = F_{H1} r_{H1}$ and $M_{H2} = F_{H2} r_{H2}$) on two input carriers H_1 and H_2 .

Let's receipt some assumption. We will consider that the active forces do not act on intermediate Assur structural group (a gravities of links and an inertial forces of links are neglected because of them infinitesimality in comparison with forces on input carriers).

The force analysis should be begun from consideration of structural group 1-2-3-6-5-4 in the form of four-bar closed contour with the toothed wheels. The structural group contains the block of solar wheels 1-4, the satellite 2, the block of ring wheels 3-6 and the satellite 5. Such structural group was not considered ever in the force analysis of mechanisms. Because the receipted assumption we will consider that external active forces for considered structural group is the reaction $R_{H1-2} = F_{H1}$, transferred from the carrier H_1 on the satellite 2 in the hinge B , and the reaction $R_{H2-5} = F_{H2}$, transferred from the carrier H_2 on the satellite 5 in a hinge K . Internal unknown forces are reactions in kinematic pairs in points D, C, G, E and also reaction in the motionless hinge A.

The closed contour gives the possibility to make statics conditions.

Let us make statics conditions for contour links 2 and 5

$$R_{12} + R_{32} = F_{H1},$$

$$R_{45} + R_{65} = F_{H2}. \quad (1)$$

It is possible representation of these statics conditions in the form of equal conditions by virtual work principle.

For the satellite 2 we will receive from a moments equations

$$R_{12} = 0.5F_{H1}, \quad (2)$$

$$R_{32} = 0.5F_{H1}. \quad (3)$$

We will multplay equation (2) on V_1 (speed of point D of satellite 2 or peripheral speed of wheel 1). We will multplay equation (3) on V_3 (speed of point C of satellite 2 or peripheral speed of wheel 3). We will receive

$$R_{12}V_1 = 0.5F_{H1}V_1. \quad (4)$$

$$R_{32}V_3 = 0.5F_{H1}V_3. \quad (5)$$

We will add the equals (4) and (5). We will receive

$$R_{12}V_1 + R_{32}V_3 = 0.5F_{H1}(V_1 + V_3). \quad (6)$$

According to the plan of linear speeds of the mechanism (Figure 1) $0.5(V_1 + V_3) = V_{H1}$, where V_{H1} - speed of point B of the satellite 2 or peripheral speed of carrier H_1. Then from the equation (6) we will receive the equation of equilibrium of the satellite 2 by a principle of virtual works with use of powers instead of works

$$R_{12}V_1 + R_{32}V_3 = F_{H1}V_{H1}. \quad (7)$$

In the similar way we will receive an equilibrium condition of the satellite 5

$$R_{45}V_4 + R_{65}V_6 = F_{H2}V_{H2}, \quad (8)$$

where V_4, V_6, V_{H2} - speeds of points E, G, K of the satellite 5 or peripheral speeds of wheels 4, 6 and carrier H_2.

By means of the equations (7), (8) it is possible to receive the equilibrium equation by a principle of virtual works for all mechanism.

Let's add the equations (7) and (8), we will receive

$$R_{12}V_1 + R_{32}V_3 + R_{45}V_4 + R_{65}V_6 = F_{H1}V_{H1} + F_{H2}V_{H2}. \quad (9)$$

It is conveniently in the equation (9) to transform linear parameters of satellites to angular parameters of the central wheels, and also linear parameters of carriers in angular parameters. For this purpose for speeds we will use the substitution under formula $V = \omega r$ with corresponding indexes, and for forces – the substitution of responses on satellites on the responses affixed to the central wheels by principle $R_{12} = -R_{21}$ etc. We will receive

$$-R_{21}\omega_1 r_1 - R_{23}\omega_3 r_3 - R_{54}\omega_4 r_4 - R_{56}\omega_6 r_6 = F_{H1}\omega_{H1}r_{H1} + F_{H2}\omega_{H2}r_{H2}. \qquad (10)$$

Product of force on radius is defining a moment $Rr = M$ with use of corresponding indexes. The equation (10) will become

$$-M_{21}\omega_1 - M_{23}\omega_3 - M_{54}\omega_4 - M_{56}\omega_6 = M_{H1}\omega_{H1} + M_{H2}\omega_{H2}. \qquad (11)$$

The equation (11) contains parameters of all links of the mechanism and represents the equation of equilibrium of all mechanism by a principle of virtual works. We will mark, that such equation can be made only in the presence of a closed contour.

Let's transform the equation (11) taking into account equality of angular velocities of wheels in block of wheels $\omega_4 = \omega_1$, $\omega_6 = \omega_3$

$$-M_{21}\omega_1 - M_{23}\omega_3 - M_{54}\omega_1 - M_{56}\omega_3 = M_{H1}\omega_{H1} + M_{H2}\omega_{H2}. \qquad (12)$$

According to the equation (12) sum of powers of the moments of internal forces on blocks of the central wheels 1-4 and 3-6 is equal to the sum of powers of the moments of external forces on input carriers.

In the left part of the equation (10) the sum of powers (corresponding to the sum of works) of internal forces of a contour takes place. Constraints in contour kinematic pairs are ideal and stationary. Work of external forces cannot pass in work of internal forces. Hence, a work (power) of internal forces on possible displacements is equal to zero

$$-M_{21}\omega_1 - M_{23}\omega_3 - M_{54}\omega_1 - M_{56}\omega_3 = 0. \qquad (13)$$

Or

$$M_{21}\omega_1 + M_{23}\omega_3 + M_{54}\omega_1 + M_{56}\omega_3 = 0. \qquad (14)$$

The right part of the equation (12) represents the sum of powers (corresponding to the sum of works) of external forces of a contour. At execution of a condition (13) we will receive from the equation (12) equilibrium condition for external forces according to a principle of virtual works

$$M_{H1}\omega_{H1} + M_{H2}\omega_{H2} = 0. \qquad (15)$$

The equation (15) analytically represents additional constraint between parameters of the kinematic chain. Hence, the closed contour in the usual kinematic chain with two degree of freedoms and with two input links also superimposes the additional constraint on motion of links.

The condition of interconnection of external parameters (15) predetermines presence of works with opposite signs on external links (carriers H_1 and H_2). The link with presence of negative work cannot be an input link as moment, acting on it, is a moment of resistance.

This main theoretical result leads to an unprecedented conclusion: the kinematic chain with two initial links connected by the closed contour has only one input link. This unprecedented conclusion characterises brand new scientific reality in the mechanics. Undoubtedly, new scientific reality creates brand new mechanical effect.

Brand new mechanical effect characterises occurrence of following brand new properties:

1) Closed contour in the kinematic chain with two degree of freedom imposes additional constraint on motion of links.

2) Kinematic chain with two degree of freedom and only one input link is definable mechanical system (mechanism). This property is determined by presence of additional constraint (15) which is imposed on motion of links in equilibrium condition. We will consider the carrier H_1 as an input link. Then the carrier H_2 will appear the input link. The equation of additional constraint (15) will become

$$M_{H1}\omega_{H1} - M_{H2}\omega_{H2} = 0. \qquad (16)$$

3) Combination of two degree of freedom with additional constraint provides continuous dependence of output angular velocity on loading. This property follows from the formula (16)

$$\omega_{H2} = M_{H1}\omega_{H1} / M_{H2}. \qquad (17)$$

Here M_{H1} - the input driving moment, and M_{H2} - the output moment of resistance (external loading).

The equation (17) expresses the main practical result – effect of force adaptation in mechanics.

The effect of force adaptation has following essence: at the given constant parameters of input power M_{H1}, ω_{H1} and the given output moment of resistance M_{H2} the output angular velocity ω_{H2} is in return proportional dependence on the variable output moment of resistance M_{H2}.

3. ADAPTIVE DRIVE FOR SPACE

The drive for space should have the minimum possible weight and sizes.

The drive weight depends on power of an engine. Power of an engine should match to the maximum loading. Researches of drives of manipulators have shown that the maximum loading is connected with overcoming of the maximum inertial force [2]. For decrease of the moment of resistance overcome by the engine, it is necessary to use the drive with the variable transfer ratio. In the article [2] it was offered to use the adaptive drive of the manipulator with the variable transfer ratio depending on loading. The adaptive gear variator of the drive provides not only smooth regulating of the transfer ratio but also an adaptation to a variable moment of resistance. Thus the gear variator has the elementary design, small sizes and weight. These properties are very important for space devices.

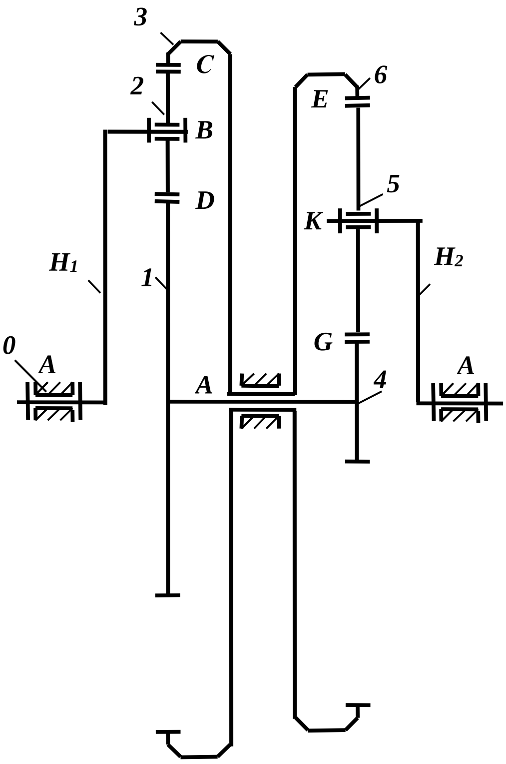

Figure 1. Gear adaptive variator

As it has been proved [2, 3] the closed four-bar contour imposes an additional constraint on motion of the kinematic chain with two degree of freedom, provides definability of motion at presence only one input link and power adaptation to a variable output loading. The developed theoretical regularity [2] allows to execute the power and kinematic analysis of an adaptive variator for the most loaded position of the drive (at the moment of the motion beginning) and to choose the engine.

The adaptive gear variator has a preset value of the maximum transfer ratio $u_{\max}$ ($u_{\max}$ = 5…10) and the maximum output moment of resistance M_{H2} on an output link H_2. It is required to determine the constant parameters of an engine power ω_{H1}, M_{H1} on an input link H_1, power and kinematic parameters of a variator.

Definition of power of an engine:

1) It is defined the minimum output angular speed

$$\omega_{H2} = \omega_{H1}/u_{\max},$$

where ω_{H1} - nominal angular speed of engines of the set type.

2) It is defined the moment of the engine $M_{H1} = M_{H2}/\eta \cdot u_{\max}$,

where - η efficiency of a variator (η =0.9).

3) It is defined power of an engine $N = M_{H1} \cdot \omega_{H1}$.

The required power of the engine in the absence of a variator would appear more than the gained power approximately in $n = \eta$ time.

The kinematic and power the analysis of a gear adaptive variator.

Initial data: constant parameters of power of an engine ω_{H1}, M_{H1} on the input link H_1, the set maximum value of a variable output moment of resistance M_{H2} on a output link $H_2 : \omega_{H1}, M_{H1}, M_{H2}$;

$z_1, z_2, z_3, z_4, z_5, z_6$ - numbers of teeth of wheels; m - the engagement module.

It is required to define the kinematic and power parameters of the mechanism: $\omega_{H2}, \omega_1, \omega_3, M_{12}, M_{32}, M_{45}, M_{65}$.

The solution.

1) Radiuses of toothed wheels $r_i = mz_i / 2, \quad i = 1, 2, 3, 4, 5, 6$.

2) Radiuses of the input and output carriers $r_{H1} = (r_1 + r_3) / 2, r_{H2} = (r_4 + r_6) / 2$.

3) Transfer ratio of wheels 1 and 3 at the motionless carrier H_1: $u_{13}^{(H1)} = -z_3 / z_1$.

4) Transfer ratio of wheels 4 and 6 at the motionless carrier H_2: $u_{46}^{(H2)} = -z_6 / z_4$.

5) Output angular speed $\omega_{H2} = M_{H1}\omega_{H1} / M_{H2}$.

6) Intermediate angular speed of a link 3

$$\omega_3 = \frac{\omega_{H2}(1 - u_{46}^{(H2)}) - \omega_{H1}(1 - u_{13}^{(H1)})}{u_{13}^{(H1)} - u_{46}^{(H2)}}.$$

7) Intermediate angular speed of a link 1

$$\omega_1 = u_{13}^{(H1)}(\omega_3 - \omega_{H1}) + \omega_{H1} .$$

8) Reactive moments on toothed wheels:

$$M_{12} = 0.5M_{H1}r_1 / r_{H1}, M_{32} = 0.5M_{H1}r_3 / r_{H1}, \quad M_{45} = 0.5M_{H2}r_4 / r_{H2},$$

$$M_{65} = 0.5M_{H2}r_6 / r_{H2}.$$

9) Check of reliability of the gained results

$$(M_{21} - M_{54})\omega_1 = (M_{56} - M_{23})\omega_3 .$$

Thus all required parameters are defined.

4. THE MECHANICAL CONTROL SPACE VEHICLE MOTION

Space vehicle motion control is made by means of special engines.

The mechanical control space vehicle motion can be executed by mechanical affecting on the case. Transfer of mechanical force to the case of an operated space vehicle can be executed with the help nonreactive drive. Nonreactive drive contains the nonreactive engine and the connecting gear. Nonreactive engine represents the electric motor with the mobile stator and rotor [6]. The stator and the rotor co-operate among themselves by means of dynamic system with two degree of freedom. Nonreactive engine transfers operating force to the apparatus case through the connecting gear without transfer of reaction of the engine to the apparatus case.

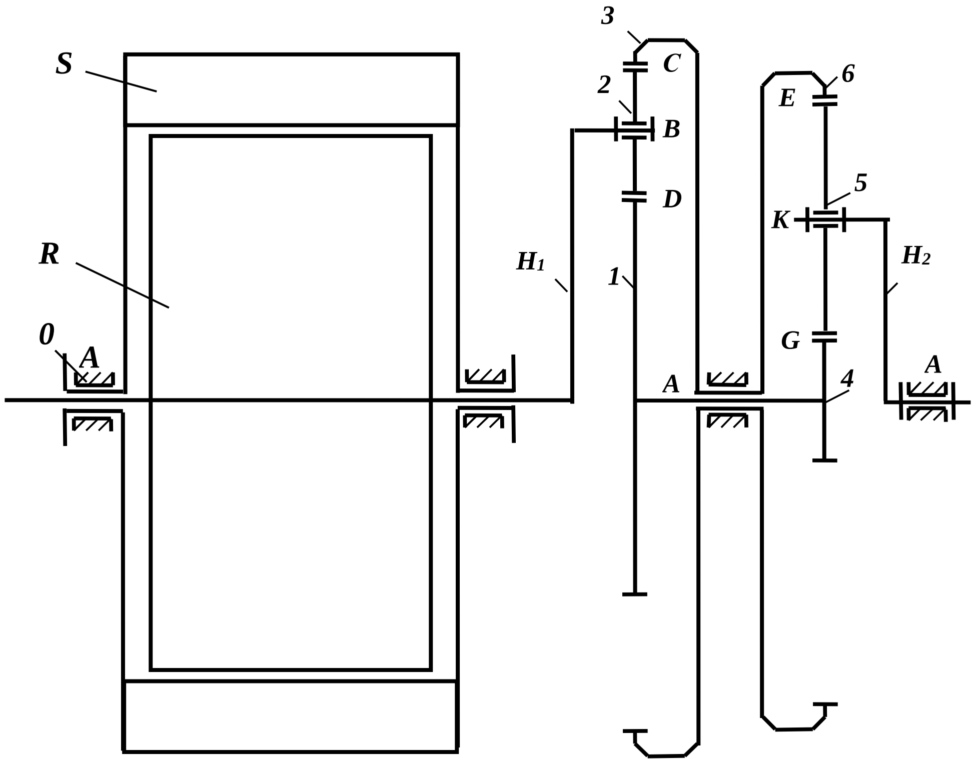

Figure 2. Adaptive nonreactive drive

The adaptive drive containing nonreactive engine and adaptive gear variator can raise considerably the intensity of operating force at rather small sizes and drive weight. Use of the mechanical drive for apparatus motion control especially important for micro satellites with the restricted impellent resource.

The adaptive mechanical operating drive (Figure 2) contains the electric motor containing the mobile stator with a flywheel and a mobile rotor transferring motion on the adaptive gear variator executed under the circuit design of Figure 1.

The adaptive gear variator transfers a torque to the space vehicle case carrying out orbit correction. The nonreactive engine does not transfer reaction to the apparatus case creating only active affecting through a gear variator.

In an operating time the moment of resistance which is overcoming by the output shaft of a variator in the beginning of motion is maximal. This moment matches to the moment of inertial forces of the case. The adaptive variator is adapting for the maximum output moment of resistance and allows to use the input driving moment, which is many times (5... 10) less. This driving moment of a rotor is equal to the driving moment of the stator and is opposite to it in a direction.

The stator with a flywheel possesses the considerable moment of inertia preventing its twirl. Thus, the beginning of transfer of motion on the case occurs at almost motionless stator. It is enough to transfer a power pulse to the apparatus case. After transfer of a direct power pulse it is necessary to stop supply of a power pulse on the case by a run-down of the electric motor and its shut down.

Interacting of an external inertia moment of resistance on the stator and on output shaft of a gear variator is defined by the formula

$$J_F \cdot \varepsilon_S = J_V \cdot \varepsilon_V \ . \quad (18)$$

Where J_F, J_V - a flywheel and apparatus moments of inertia,

ε_S, ε_V - angular accelerations of the flywheel and the apparatus.

Here $\varepsilon_V = \varepsilon_S / u \cdot u_V$.

u - variable transfer ratio of adaptive gear variator,

u_V - transfer ratio from a gear variator to the apparatus.

After substitution of these values in the formula (18) we will gain

$$J_F = J_V / u \cdot u_V \ .$$

That is the flywheel moment of inertia should be much less moment of inertia of a space vehicle.

CONCLUSION

The self-controlled mechanical systems created on the basis of a discovery «Effect of force adaptation in mechanics» allow to create brand new adaptive drives which are capable to adapt for variable external loading. The resulted theoretical description of the self-controlled drive gives the chance of creation of highly effective drives of power units and control and stabilization systems of space vehicles. The main advantages of adaptive electric drives: small sizes, small weight and high power efficiency. Use of nonreactive engines in adaptive drives allows operating in certain limits space vehicle flight, to carry out orientation and stabilization of motion. Adaptive drives are brand new aspect of highly effective space engineering.

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