Theory of a New Drive System for Manipulators

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Abstract: The production operation of the module includes stages: acceleration, breaking and the installed motion. Optimum on power and sizes the drive of the module of the manipulator should overcome the force matching a variable load at different stages of operation at constant power of an engine. For this purpose it is offered to use the adaptive mechanical drive containing the electric motor and an adaptive gear variator with constant engagement of toothed wheels. The adaptive gear variator provides the variable transfer ratio only owing to the mechanical properties lost-free energy on its transformation and without control means.

Keywords: Gearbox, Adaptive Drive, Gear, Variator

I. INTRODUCTION

Accomplishment of a production operation of the module includes acceleration, breaking and installed motion. Acceleration and a breaking are connected with overcoming variable inertia loadings. Loading at the installed motion is less, loadings of transient. The optimum drive of the module of the manipulator should provide transfer of the force matching a variable load on a moving part of the module at different stages of the carried out production operation at constant power of an engine. For this purpose it is necessary to operate the transfer ratio by means of a complex control system. It is offered to use as the optimum drive of the module the adaptive mechanical drive in the form of the electric motor and an adaptive gear[toothed] variator with constant cogging toothed wheels, [1, 2, 3].

The optimum drive of the module of the manipulator should ensure transmission on a mobile link of the module of the effort corresponding variable loading at different stages of executable technological operation at fixed power of the drive. For this purpose it is necessary to operate a transfer ratio by means of a complex control system. It is offered to use as an optimum drive of the module an adaptive mechanical drive in the form of the electric motor and an adaptive gear variator with constant engagement of cogwheels, [1, 2, 3].

The adaptive gear variator ensures a variable transfer ratio only owing to the mechanical properties, without use of any controllers.

II. THE DESCRIPTION OF THE MECHANISM

The mechanism with differential constraint has two degrees of freedom supposed by geometric constraint, and the superimposed differential constraint supposed relative motion of links under act of forces and providing force adaptation to variable external loading. Differential constraint between links can be provided by means of frictional, hydrodynamic or electromagnetic adapting effect. Differential constraint with use of hydrodynamic adapting effect in hydrodynamic transfer of the car has gained a wide dissemination.

The basic difference of differential constraint from geometrical consists in absence of a rigid coupling between links that provides their relative motion and allows gaining the variable transfer ratio. Analytically differential constraint is determined by expression of interconnection of the kinematic and force parameters. Now materials about mechanisms with two degrees of freedom in which adaptation is carried out due to geometrical parameters at absence of an energy loss on creation of adapting effect are published, [1, 2, 3].

The adaptive mechanism with differential constraint contains input structural group with two degrees of freedom and with the superimposed differential constraint and the attached structural groups with zero mobility.

Differential constraint represents the constructive device creating a condition of interconnection of force and kinematic parameters which provide adaptation of the mechanism to a variable load on an output link due to change of its speed of motion.
Force differential constraint between links in the adaptive mechanism should carry out following functions:

1) Perception of a constant of input and variable output loading.

2) Maintenance of relative motion of connected links.

3) Conservation of a regime of the installed motion.

The mechanism with the adapting device (fig. 1) contains input structural group with two degree of freedom and the attached kinematic chain with zero mobility. The input structural group contains a rack 0, an input solar wheel 1 and transfer epicycle wheel 3 attached to a rack. Differential constraint mechanically represents adapting device in the form of, for example, hydrodynamic transfer 4 including pump and turbine wheels, attached to links 1 both 3 and cooperating by means of operating fluid. The attached kinematic chain with zero mobility contains the satellite 2 and the carrier H.

The engine actuates the central solar wheel 1 with a pump wheel, creates a drive moment $M_1$ on an input wheel. The pump wheel 4 creates hydrodynamic moment $M_D$ meeting differential constraint in hydrodynamic transmission, and through a hydraulic fluid actuates a turbine wheel with transmitting epicycle wheel 3. The affixed kinematic chain in the form of a carrier H with the satellite 2 transmits to input structural group (wheels 1, 3) the moments of resistance meeting variable external loading on an output carrier H:

Differential constraint in the mechanism analytically represents a condition of interconnection of force and kinematic parameters of an input solar wheel 1 and transfer epicycle wheels 3 by a principle of possible works.

$$M_1\omega_1 = M_{R1}\omega_1 + M_{R3}\omega_3 + M_D(\omega_1 - \omega_3) \quad (1)$$

Where $M_1$ - the input moment on a wheel 1, $M_{R1}$ - the moment, resistance on a wheel 1,

$M_{R3}$ - The moment, resistance on a wheel 3, $M_D$ - the moment in differential constraint (the hydrodynamic moment), $\omega_1$, $\omega_3$ - angular speeds of wheels 1, 3.

The equation (1) provides an opportunity of definition of intermediate (transfer) angular speed $\omega_3$ by means of which it is possible to determine output angular speed $H\omega$ of the mechanism then

$$\omega_3 = \frac{M_1 - M_{R1} - M_D}{M_{R3} - M_D} \omega_1. \quad (2)$$

III. A GEARBOX WITH DIFFERENTIAL CONSTRAINT

Let's observe an opportunity of creation of the mechanism with the force differential constraint created in the external image by means of the attached kinematic chain, without use of the adapting device. In input structural group of such mechanism the set forth above functions of differential constraint should be provided:

1) Perception of a constant input loading and variable output loading can be provided by connection to an input link of a transfer link with which the attached kinematic chain communicates. Then the input loading will be transferred to a transfer link from an input link and output loading from an attached kinematic chain. Thus on a transfer link of input structural group interacting force and kinematic parameters will occur.

2) Maintenance of relative motion of connected links will be provided, if the attached structural group will transfer to a transfer link of input group with two degrees of freedom the force parameters breaking conditions of static balance of this link. For this purpose the attached structural group should have the matching geometrical parameters influencing on transfer of forces. Then balance of a transfer link can be executed only in view of the kinematic parameters (for example, according to a principle of possible works) which will lead in this case to relative motion.

3) Conservation of a regime of the installed motion of the mechanism is provided with
equality of work (or powers) impellent force and forces of resistance that matches to a principle of possible works.

Thus, differential constraint is imposed on relative motion of the transfer link which is carrying out function of the adapting link.

![Figure 2 - Gear Adaptive Variator](image)

The mechanism with an adapting link and with external differential constraint (fig. 2) contains input structural group with two degrees of freedom in the form of a rack 0, the input carrier \( H_1 \) and the satellite 2 and the attached kinematic chain with zero mobility in the form of blocks of the central toothed wheels 1 - 4, 3 - 6 and the output satellite 5 with the output carrier \( H_2 \).

The arrangement of a transfer link (satellite) on an input link (carrier) in input structural group provides an opportunity of relative motion of links and an opportunity of transfer on the satellite of the kinematic and force parameters of an input and an output. Differential constraint on relative motion of an adapting link of input structural group is imposed by external way - an attached kinematic chain by transfer on the input satellite of the force providing motion of the satellite rather the carrier.

These forces should be not equal on magnitude due to geometry of an attached kinematic chain. As a result of the input satellite it will appear under act of the asymmetrical forces determined by a constant input and variable output loadings. Balance of the satellite at equality of input and output works (powers) can occur only on the move at the account of speeds of points of application of forces. Constraint of acting forces with speeds of their points of the application by a principle of possible works determines the external differential constraint imposed on motion of links of input structural group. Such differential constraint does not contain the parameters connected with power losses on its creation (on creation of hydrodynamic or frictional effect) and does not contain restrictions on a range of change of speeds (peculiar hydrodynamic or a friction coupling). Elimination of necessity to use additional adapting devices in the form of hydrodynamic or a friction coupling provides extreme simplicity of the mechanism as a whole.

Let's observe the basic regularity of interacting of parameters in the mechanism with an adapting link and with the external differential constraint imposed by the attached kinematic chain.

The input carrier \( H_1 \) of the mechanism transfers 2 impellent \( F_2 \) to the input satellite. At presence of two degrees of freedom the impellent \( F_2 \) is determined only by parameters of the engine, bringing carrier, and does not depend on forces of resistance on the satellite. The input satellite has two generalized coordinates in points of cogging of the input satellite with an attached kinematic chain with zero mobility. The output kinematic chain with zero mobility in the form of the output carrier \( H_2 \), the output satellite 5, the block of solar wheels 1 - 4 and the block epicycle wheels 3 - 6 transfers to the input satellite 2 forces of resistance \( R_1 \) - from a wheel 1 and \( R_3 \) - from a wheel 3. Geometrical parameters of an output kinematic chain with zero mobility provide transfer of different forces on magnitude on the input satellite \( R_1 \neq R_3 \) at presence different on magnitude of speed relationships of speeds of wheels in blocks 1 - 4 and 3 - 6. Thus, on the input satellite 2 interacting an independent impellent \( F_2 \) and independent different on magnitude of forces of resistance \( R_1 \neq R_3 \) occurs. Generally \( F_2 \neq R_1 + R_3 \).

Acting forces create a condition of interacting of forces and movings on the input satellite 2 by a principle of possible works

\[
F_2 ds_2 = R_1 ds_1 + R_3 ds_3. \tag{3}
\]

The equation (3) includes the independent set forces \( F_2, R_1, R_3 \) and possible elementary movings of points of application of forces \( ds_1, ds_2, ds_3 \).

\[
ds_1 = h_1 d\varphi, \quad ds_2 = h_2 d\varphi, \quad ds_3 = h_3 d\varphi.
\]

Here \( h_1, h_2, h_3 \) - distances from points of application of forces \( R_1, F_2, R_3 \) up to the instant center of turn \( S \) of the satellite 2, \( d\varphi \) - an elementary angle of turn around of the instant center.
of turn $S$. After substitution of these values in the formula (3) and abbreviation $d\varphi$ we shall gain

$$F_2 h_2 = R_1 h_1 + R_3 h_3.$$  

In input structural group connections between geometrical parameters occur. We shall designate

$$h_2 = H, h_1 = H - r_2, h_3 = H + r_2.$$  

Here $r_2$ - radius of the satellite 2. Then after transformations we shall gain

$$H = \frac{R_1 - R_3}{R_1 + R_3 - F_2} r_2.$$  \hspace{1cm} (4)

The condition (4) represents additional constraint which is induced by acting forces into the mechanism with two degree of freedom. At constant input force $F_2$ output forces $R_1, R_3$ depend on variable external loading that leads to dependence of parameter $H$ on external loading and creates effect of adaptation of this parameter to a variable load. This constraint is the differential constraint providing motion of the input satellite concerning the set independent forces, turn of the input carrier not conterminous with the instant center. The instant center of turn is conditionally motionless, imposes a geometric constraint on motion of the satellite and can be presented by the conditional reaction and look like a statics condition of equality to null of the sum of the independent forces. Point $H$ determines position of the instant center of turn of an input carrier. The instant center of turn is conditionally motionless point, superimposes geometrical link on driving of the satellite and can be presented by the conditional supreme kinematic pair linking the satellite with a rack.

The equation (4) besides in the converted view characterizes the ratio of geometrical parameters of the input satellite $u$ in the mechanism with two degrees of freedom, matching interconnection of three independent set forces

$$u = H = \frac{R_1 - R_3}{R_1 + R_3 - F_2}.$$  

It is necessary to note, that differential constraint ceases to exist, if the output kinematic chain provides equality of reactions $R_1 = R_3$ and $F_2 = R_1 + R_3$. In this case the condition (4) expresses indeterminate form $H = 0$.

The parameter $H$ allows determining the kinematic parameters of a delivering gear of power univocal. At the set input angular speed $\omega_{H1}$ (matching parameters of the engine) linear speed $V_2$ of a point of application of force $F_2$ will matter $V_2 = \omega_{H1} r_{H1}$ ($r_{H1}$ - radius of the carrier $H_1$).

Angular speed of the satellite 2 will matter

$$\omega_2 = \frac{V_2}{H}.$$  

Speeds of points of application of forces $R_1, R_3$ on the satellite will have values:

$$V_1 = \omega_2(H - r_2), V_3 = \omega_2(H + r_2).$$  

Speeds $V_1, V_3$ determine concrete values of two generalized coordinates of a delivering gear of power with two degree of freedom. The output kinematic chain with zero mobility transfers speeds $V_1, V_3$ to the output carrier $H_2$.

Angular speeds of intermediate links 1-4, 3-6 of output kinematic chain are $\omega_1 = V_1 / r_1$, $\omega_3 = V_3 / r_3$. Here $r_1, r_3$ - radiuses of wheels 1, 3. Geometric constraint of a output kinematic chain under condition of $\omega_1 = \omega_4$, $\omega_3 = \omega_6$ looks like

$$\frac{\omega_1 - \omega_{H2}}{\omega_3 - \omega_{H2}} = u_{46}^{(H2)}. \hspace{1cm} (5)$$
Here $\omega_{H^2}$ - an angular velocity of an output spider, 
$\mu_{46}^{(H^2)}$ - a reduction ratio from a sprocket 4 to a sprocket 6 at a motionless carrier $H_2$. The formula (5) allows determining uniquely an output angular velocity $\omega_{H^2}$ of the mechanism at the set output loading which determines parameter $H$. 

According to a principle of possible works for all mechanism

$$M_{H1}\omega_{H1} = M_{H2}\omega_{H2}. \quad (6)$$

At constant parameters of an aerial input (the input moment and input angular speed) $M_{H1} = const$, $\omega_{H1} = const$

$$\omega_{H2} = \frac{M_{H1}\omega_{H1}}{M_{H2}}. \quad (7)$$

The formula (7) determines effect of force adaptation: at constant parameters of input power the output angular speed is in inverse relationship from an output moment of resistance $M_{H^2}$.

IV. CONCLUSION

Thus, the adaptive gear variator in the drive of the module of the manipulator provides overcoming a variable load at constant power of an engine. The drive of the module with an adaptive variator will be optimum on cabarets and power.

V. REFERENCES


