Calculation of parameters for a resilient element of a flat-belt Continuously Variable Transmission

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Abstract. A design approach of mechanical systems with adaptation property to actual parameters is developed. In particular, a design of a flat-belt Continuously Variable Transmission (CVT) with a variable transfer function depending on the level of a transformed power flow is proposed. This is achieved by means of a control chain, built in directly in auto CVT’s pulley. It is shown that if the control chain is built in both CVT’s pulleys, then in a broad range of external loading change, the chain can be executed on the basis of resilient elements with a linear characteristic. It is shown that if the control chain is built in both CVT’s pulleys, then in a broad range of external loading change, the chain can be executed on the basis of resilient elements with a linear characteristic.

1. Introduction

General problems of dynamics calculation in mechanical drives and, CVTs, in particular, are described in detail in fundamental literature [1-6].

Application of mechanical transmissions in machine drives based on CVT designs with a purpose implementation of a progressive method providing transmissions with adaptation property [1] to variable conditions of external loading on a design stage, gives original, easy implementable technical solutions for drives with new properties.

There are technical solutions of CVT drive designs which kinematic link sizes change depending on the level of transformed power flow, providing a stationary, perfect power performance of engine. As a rule, such systems use an additional power source; electrical, hydraulic devices are a part of controls, which significantly complicate the design of drives. The problem can easy be solved technically by using only those structural elements which functioning is based on laws of mechanics. A resilient element of the control chain built in the structure plays a special role. The resilient element deformation defines the controlled motion leading to auto-change of a transfer function of the drive depending on the level of external loading.

2. Problem statement

There are many variants of specifications to design a mechanical transmission, but we shall focus on a calculation of parameters for a resilient element of a flat-belt automatic CVT with automatic change of kinematic sizes in main links depending on the level of transferred power flow. The example is an auto-CVT according to designs [7, 8]. As a mathematical simulation showed, such design can provide stationary functioning of the engine under variable external loading conditions.

3. Theory
The text of your paper should be formatted as follows: An automatic change of a transfer function in CVT velocity is achieved by means of the control chain built in a structure of auto-CVT’s driven pulley. The control chain provides an additional motion of links to the main motion. A schematic diagram of the proposed pulley option is given in fig. 1 [7].

The transfer function of velocity $T_{r\omega}$ will be defined as $T_{r\omega} = \frac{\omega_1}{\omega_2}$ where $\omega_1$ is a value of input motion velocity of a driving link, and $\omega_2$ is the velocity of output link. Thus the relation of velocities in a first approximation is determined by the relation of kinematic radiuses in driven and driving links

$T_{r\omega} = \frac{\omega_1}{\omega_2} = \frac{R_2}{R_1}$.

Figure 1. A variable geometry hyperboloid pulley: 1 – a dead sheave – a driven shaft of a belt transmission; 2 – spherically arranged bearing elements; 3 – a tension spring; 4 – a two-degree-of-freedom dead sheave; 5 – a sliding support of two-degree-of-freedom dead sheave; 6 – a support assembly of a driven transmission shaft; 7 – loading; S1 – a pulling transmission side; S2 – a return side.

Flanges 1 and 4 in a start position are located in a minimum distance from each other, and one-sheet hyperboloid of revolution formed by bearing rectilinear rods 2 has a minimum size of diameter in a throat area.

When a loading of driven shaft 6 increases, the flange 4 turns and displaces relative to the driven shaft 6, stretching the spring 3, thereby the diameter size of hyperboloid in the throat area becomes bigger that leads to the automatic increase in auto-CVT gear ratio and, potentially ensures a single-mode permanent engine functioning in variable external loading conditions. Under extreme maximum calculated loading a kinematic surface of a pulley degenerates in a circular cylinder with a diameter, equal to the diameter of placement of bearing rods 2 on flanges 1 and 4.

The evolution of hyperboloid pulley is possible because of the two-degree-of-freedom support 5 in the dead sheave 4. The dead sheave affected by a variable value of power flow determined by the difference of tension in driving and driven sides (S1-S2), can make additional angular and axial motions leading to a spatial change in orientation of bearing elements 2 representing a structure of rectilinear generators of a hyperboloid kinematic surface as a warped surface. Herewith, the ends of elements 2 are arranged movably on dead sheaves on spherical bearing sliding surfaces.

The evolution of hyperboloid driven link, results in the change of radius in its throat area from the initial minimum value $r=r_0$ to the finite maximum $r=R$ corresponding to the location radius of bearing elements on dead sheaves 1 and 4.
Direct and reverse evolution of the hyperboloid is provided in case of power equilibrium interaction of the transferred variable power flow with the resilient element 3 built in the structure.

The resilient element characteristic determines the functioning mode of auto-CVT therefore the stiffness selection of the spring included in a control chain is in general an important stage of auto-CVT design.

Let a kinematic size of a pulley be a variable size of a throat area in a hyperboloid of revolution.

We give a calculation algorithm of some force relations of a pulley with variable geometry [9,10]:

1. Let us calculate the initial and finite value of axial force \( P_{ax} \) dependent on the variable moment of resistance forces \( M_c \), initial and finite radius of throat area of the hyperboloid and angle \( \beta \):

\[
P_{ax}^{init} = \frac{M_c^{init}}{r_0 \cdot tg \beta_0}
\]

or

\[
P_{ax}^{fin} = \frac{M_c^{fin}}{R \cdot tg \beta_{fin}}
\]

where \( \beta \) is an angle of crossing of bearing rods with the hyperboloid axis.

2. Let us define a constant value of stiffness in a linear resilient element \( k = \frac{\Delta P_{ax}}{\Delta z_{max}} \),

where \( \Delta P_{ax} = \Delta P_{ax}^{fin} - \Delta P_{ax}^{init} \) is a change of axial force in a resilient element for initial and finite value of the moment; \( \Delta z_{max} \) is an axial deformation of the hyperboloid.

3. Let us determine the required stiffness of resilient element by a given rule of changing in a gear ratio dependant on a variable external loading in a certain range.

The diagram of value changing of the required stiffness in the resilient element depending on a variable external loading is presented in figure 2:

![Figure 2](image)

**Figure 2.** Changing of stiffness in a resilient element depending on the variable external loading \( M_c \) under a variable location radius of bearing elements.

4. Results and discussion

Calculations showed that:

1. The required gear ratio autocontrol of auto-CVT in a certain range of external loading change \( M_c = (2...6) \) can be provided with a resilient element with a steady stiffness value that is shown in figure 2. Nonlinearity of stiffness value can be technically compensated with a spring without interturn gaps (technologically «pre-stressed» before).

2. In the evolution of hyperboloid from the initial position, an axial shift of two-degree-of-freedom flange is considerable at the beginning, and if the angle \( \beta \) reduces this shift is decelerated. The axial
force $P_{ax}$ taken by the resilient element increases in the process of evolution that results in the overestimated stiffness value of the resilient element. In the process of hyperboloid evolution we should potentially assume that the stiffness $k$ of the resilient element should be a variable one, and in the course of hyperboloid evolution, the stiffness is to increase, thus it is technically implementable. To reduce the influence of a non-linear section of axial deformation, the general deformation of a pulley should be restricted to prevent small values of the angle $\beta$.

3. When the external loading increases, a kinematic radius of a driven link grows too, i.e. when the kinematic radius increases by the same times, and ideally, peripheral and axial forces remain invariable, the only factor changing the axial force will be the variable angle $\beta$. For adequate changing of auto-CVT transfer function there is a prospective technical solution including two pulleys with variable geometry.

4. If a left part of the pulley is fixed in the axial direction, then the throat area will displace to the right by $\frac{\Delta z}{2}$ in each step, which can be compensated by using of auto-CVT of driving and driven pulleys with variable geometry.

5. Results and discussion
Thus, auto-CVT of the proposed design comprising a variable geometry pulley and a built-in resilient element can provide stationary engine functioning in a certain range of change in external power loading.

Note, however, that in general, the change of auto-CVT transfer function occurs with a certain deviation from the rules of external loading. The auto-CVT with two pulleys of variable geometry will have a great potential in this regard.

In this case, the velocity transfer function, by a linear law of external loading change, will alter, as it is shown in figure 3, i.e. almost linearly.

![Figure 3](image_url)

Figure 3. A gear ratio change depending on a variable external loading with a simultaneous operation of two pulleys with variable geometry.

Thereby the simultaneous operation of two pulleys with variable geometry can provide an adequate gear ratio change depending on the variable external loading in a broad range of its change that will ensure the stationary functioning of the engine under variable external loading conditions.

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