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(REVIEW ARTICLE)

Friction Variator with increase of capacity and minimum slippage during steering

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Abstract

The paper presents the results of the research of an innovative scheme of a friction Variator with a large load capacity and minimized sliding in the process of adjusting the transmission ratio.

This is achieved by making the friction surfaces at the contact point have close modulus and different curvatures, i.e. one to be convex and the other concave, while they must be contours of centroid pairs. In this way the unwanted slippage is minimized when controlling the Variator.

Based on the differential geometry, the equations of the conjugated contours were obtained in the analytical form of which the friction rotary surfaces were constructed.

The range of change in the transmission ratio of the proposed, significantly exceeds three (D>3) - the most common in engineering practice.

Keywords: Transmission ratio; Variator; Centroid pairs; Steering

1. Introduction

The devices implementing a step-less change in the transmission ratio (input – output) work on a variety of principles. Some are mechanical [1], [2], [4], others electrical, electro-mechanical [5], hydraulic, magnetic, or electro-magnetic [13]. Those of them that transmit the movement on a purely mechanical principle are called Variators.

They in turn are divided into frictional and non-frictional. Frictional can contain relative rigid links as well as flexible ones.

Non frictional Variators are found in engineering practice as impulse [4], [6] and those with continuous motion transmission [2], [7], [8].

Long term operation of machines and transport vehicles has proven the effectiveness of friction Variators. This due to: the wide range of changing transmission ratio, smooth transference of movement, high reliability, simplified construction and productively technology for their implementation.

For transport vehicles, the Variator provides optimal movement dynamics with minimal energy consumption [10], [12] and for stationary machines and equipment, favorable transient modes of operation.

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Along with their advantages, they also have the following disadvantage: relatively low load-carrying capacity, due to the fact that the movement is transmitted through frictional forces. This drowback has been removed to some extent with toroidal Variators [14], [15].

Another serious drawback is the presence in most friction Variators of a relative sliding of the point of contact between the friction surfaces during adjustment, which is partially solved in devices with intermediate spheres [3].

The aim of the present development is the synthesis of a friction Variator with large load-carrying capacity and with minimized sliding in the adjustment process.

Highlights

- Variable device with large load capacity
- Minimizing the slippage in the process of adjusting the transmission ratio
- Good range of change the ratio moor then three (D>3)

2. Theoretical considerations

Fig.1 shows the schematic scheme (geometric structure) of the device with variable transmission ratio, where 1 denotes the input link, 2 – the intermediate and 3 output link.

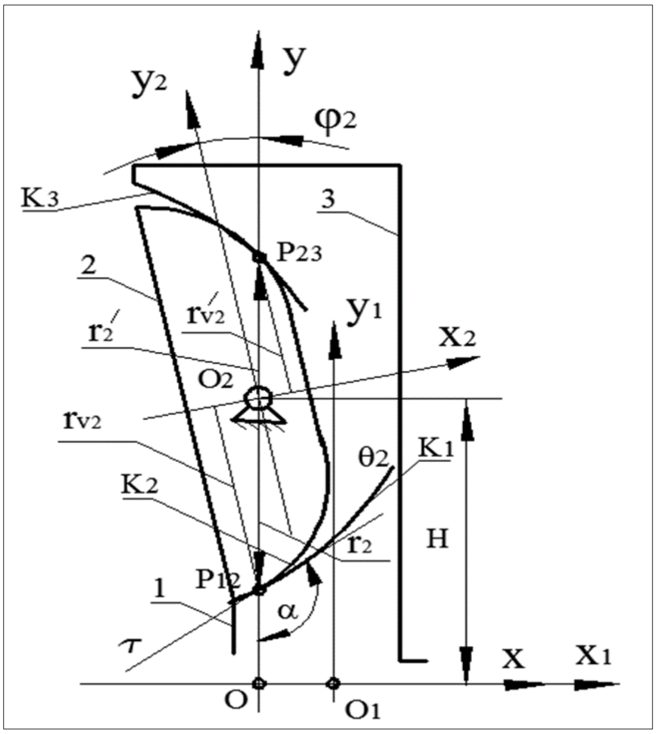

Figure 1 Geometric structure of the variable device

The following two tasks are set for solution:

Forming the friction surfaces K_1, K_2 and K_3 should be such planar curves so that of the points of contact they have curves close in modulus and different in sign, i.e. one to be convex and the other to be concave with curvatures close in value. Doing this will reduce the contact stresses and hence significantly increase the load carrying capacity of friction pairs.

Forming friction surfaces (units) to be contours of centroid pairs, there be minimizing unwanted sliding in the process of adjusting the ratio of angular velocities. This means that the rollover of 1 vs. 2, respectively 2 vs. 3 will be realized.

2.1. Notation and basic dependencies

The following notations have been introduced:

K_1, K_2 and K_3 are the forming planar contours of the friction surfaces, which are obtained from their rotation around X_2 axis, respectively $X \equiv X_1$

- O, X, Y - inertial (stationary) coordinate system, relative to which units 1 and 3 perform translation.
- O_2, X_2, Y_2- coordinate system connected with unit 2
- P_{12}, P_{23} - momentum pools of centroid pairs K_1 - K2, K_2 – K_3
- r2 and r2'-radius vectors of P_{12} and P_{23} in coordinate system O_2, X_2, Y_2
- H – distance between O_2 and axis X
- τ - the tangent of K_1 and K_2 in contact point
- φ_2 - the angle of rotation of the inter-medial unit 2.
- D-practical range of variation of the transmission ratio.

The movement of units 1, 2 and 3 from Fig.1 is a pure rotation around the axis X of 1 and 3 and of 2 – about X_2. The step less change of the transmission ratio is realized by rotation of the unit 2 around O2, whereby the units 1 and 3 are translated during adjustment, it is necessary that the forming curves K_1, K_2 and K_3 are mutually conjugated centroid pairs, i.e. K_1 – K_2, respectively K_2 – K_3.

If k_1 and k_2 denote the curvatures at the points of contact between the contours K_1 and K_2 and ρ_1 and ρ_2 are their respective instantaneous radiuses of curvature, then the condition for curvatures close in modulus and opposite in sign is represented by

$$\frac{k_1}{k_2} = \Delta;\ \Delta \to -1;\ -1 < \Delta < 0;\ \rho_1 > \rho_2;$$
$$k_1 = \frac{1}{\rho_1};\ k_2 = \frac{1}{\rho_2}. \quad \text{.................(1)}$$

$$k_1 = \frac{d^2 y_1 / dx_1^2}{\left[1 + \left(dy_1/dx_1\right)^2\right]^{\frac{3}{2}}} \quad \text{.................(2)}$$

The contour K_2 is preferable set with the polar equation $r_2 = r_2\left(\varphi_2\right)$ in coordinate system O_2, X_2, Y_2 where φ_2 is the angle of rotation of unit 2.

$$k_2 = \frac{r_2^2 + 2\left(dr_2/d\varphi_2\right) - r_2\left(dr_2/d\varphi_2\right)}{\left[r_2^2 + \left(dr_2/d\varphi_2\right)^2\right]^{\frac{3}{2}}}. \quad \text{..........(3)}$$

After substituting (3) in the first equation of (1) we arrive at

$$\frac{\left(d^2 y_1/dx_1^2\right)\left[r_2^2 + \left(dr_2/d\varphi_2\right)^2\right]^{\frac{3}{2}}}{\left[1 + \left(dy_1/dx_1\right)^2\right]^{\frac{3}{2}}\left[r_2^2 + 2\left(dr_2/d\varphi_2\right)^2 - r_2\left(d^2 r_2/d\varphi_2^2\right)\right]} = \Delta \quad \text{, ...(4)}$$

which represents a differential equation containing two unknown functions $y_1 = y_1\left(x_1\right)$ and $r_2 = r_2\left(\varphi_2\right)$.

The relation between them is determined by the conjugacy condition expressed by

$$x_1 = \int r_2(\varphi_2)\,d\varphi_2 \text{ ....(5)}$$

and

$$y_1 = H - r_2(\varphi_2) \text{ ....(6)}$$

Considering (5) and (6) for the derivatives involved in (4), it can be written

$$\frac{dy_1}{dx_1} = \frac{dy_1/d\varphi_2}{dx_1/d\varphi_2} = -\frac{dr_2/d\varphi_2}{r_2} \text{ ....(7)}$$

and

$$\frac{d^2y_1}{dx_1^2} = \frac{d^2y_1/d\varphi_2^2}{\left(dx_1/d\varphi_2\right)^2} = -\frac{d^2r_2/d\varphi_2^2}{r_2^2} \text{ ....(8)}$$

After replacing them in (4), the differential equation acquires the form

$$-\frac{\left(\dfrac{d^2r_2/d\varphi_2^2}{r_2^2}\right)\left[r_2^2 + \left(dr_2/d\varphi_2\right)^2\right]^{\frac{3}{2}}}{\left[1+\left(\dfrac{dr_2/d\varphi_2}{r_2}\right)^2\right]^{\frac{3}{2}}\left[r_2^2 + 2\left(dr_2/d\varphi_2\right)^2 - r_2\left(d^2r_2/d\varphi_2^2\right)\right]} = \Delta \text{ ....(9)}$$

Its solution is the function

$$r_2(\theta_2) = e^{C_2}\cos^{\frac{\Delta-1}{\Delta+1}}\left[\frac{\sqrt{(\Delta+1)}}{\Delta-1}\left(C_1+\varphi_2\right)\right], \text{......... (10)}$$

Which is the equation of the forming contour K_2 . It can be uniquely defined after calculating the integration constants C_1 and C_2, depending on the initial conditions - Fig.2:

$$r_2(0) = R_2, \text{............. (11)}$$

And

$$tg\alpha(0) = \frac{r_2(0)}{dr_2/d\varphi_{2(0)}} = \frac{R_2}{dr_2/d\varphi_{2(0)}} = k \text{ .... (12)}$$

After determining them and subsequent replacement in (10) for the function $r_2 = r_2(\varphi_2)$ Is obtained

$$r_2(\varphi_2) = \frac{R_2}{\cos^{\frac{\Delta-1}{\Delta+1}} f}\cos^{\frac{\Delta-1}{\Delta+1}}\left(f + \frac{\sqrt{\Delta+1}}{\Delta-1}\varphi_2\right), \text{ .... (13)}$$

where

$$f = \operatorname{arct} g\left(-k\sqrt{\Delta+1}\right). \text{ .... (14)}$$

At specific values of the geometric parameters: H = 0, 07 [m], R = 0, 04[m], k= -1[-] and Δ = - 0,85 [-] ,the forming contour (outline) K_2 of Fig.1 - (13) in coordinate system O_2 ,X_2 , Y_2 is depicted as a function of rotation angle φ_2 (-π/9≤ φ_2 ≤ π/2), in Fig. 3 with red line.

To facilitate the following calculations, the complicate function (13) is approximated with high precision with the polynomial -

$$r_2(\varphi_2) = 16,667 - 3,729(\pi/2-\varphi_2) - 1,141(\pi/2-\varphi_2)^2 - -5,235(\pi/2-\varphi_2)^3, \quad \text{........(15)}$$

Depicted with blue color of the same figure.

2.2. Centroid pairs K1, K 2 and K3

The forming contours of the friction surfaces K_1 and K_3 in coordinate O_1, X_1 , Y_1, respectively O_3 ,X_3 ,Y_3, which are elements of the conjugated centroid pairs K_1 – K_2 and K_2 - K_3 after replacement of the polynomial (15) are determined by dependencies

$$K_1 \therefore \left| \begin{array}{l} x_1 = \int_0^{\varphi_2} r_2(\varphi_2)\,d\varphi_2 \\ y_1 = H - r_2(\varphi_2) \end{array} \right. \quad \text{.............(16)}$$

and

$$K_3 \therefore \left| \begin{array}{l} x_1 = \int_0^{\varphi_2} r_2(\varphi_2)\,d\varphi_2 \\ y_1 = H + r_2(\varphi_2). \end{array} \right. \quad \text{............(17)}$$

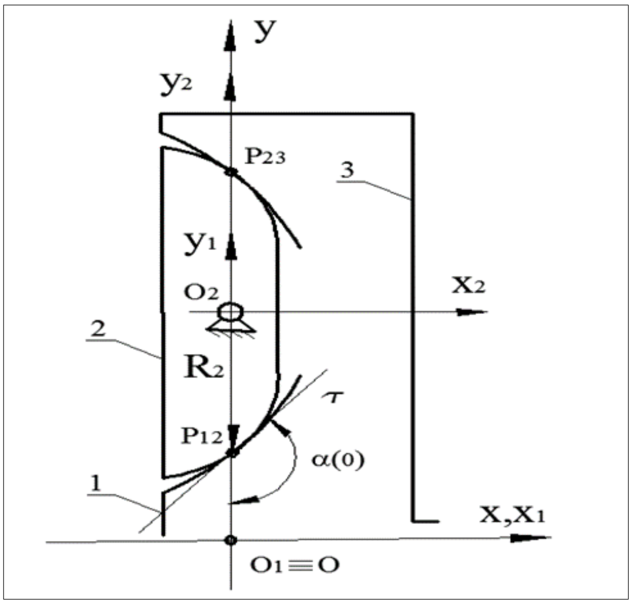

Figure 2 The scheme of the relative moment pols of the velocities

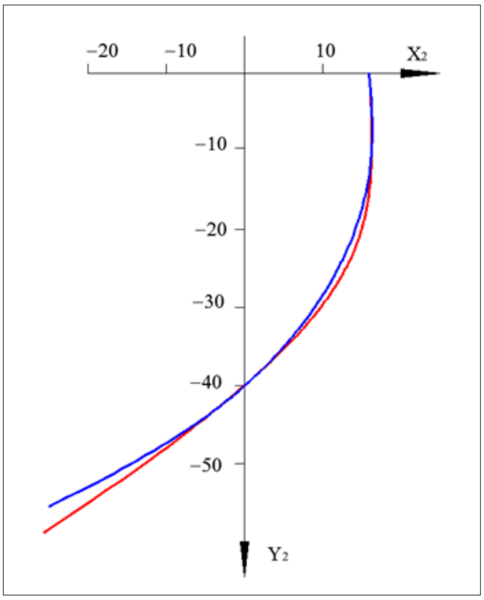

Figure 3 The precision and approximated (in red) contour of K1

2.3. Friction surfaces

The type of the friction surfaces of the variator with increased load capacity and minimized relative sliding in the adjustment process is obtained by rotation of 2π around axis X_2 of the forming contour K_2 (unit 3 – Fig.1); around $X \equiv X_1$ of the forming contours K_1 (unit 1) and K_3 (unit 3).

Fig. 4 , Fig. 5 and Fig.6 are shown in an axonometric view of the mathematical rotary surfaces, which serve as matrices in the automated production in metal of the working friction surfaces of the variator.

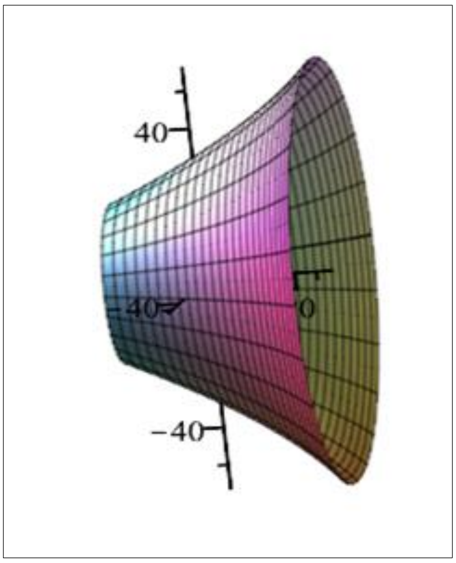

Figure 4 The friction surface of 1 ,obtained thru rotation of K_1 vs $X_1 \equiv X$

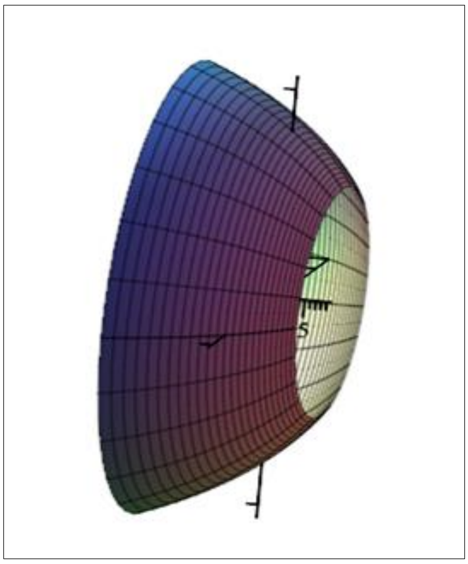

Figure 5 The friction surface 0f 2, obtained thru rotation of K_2 vs X_2

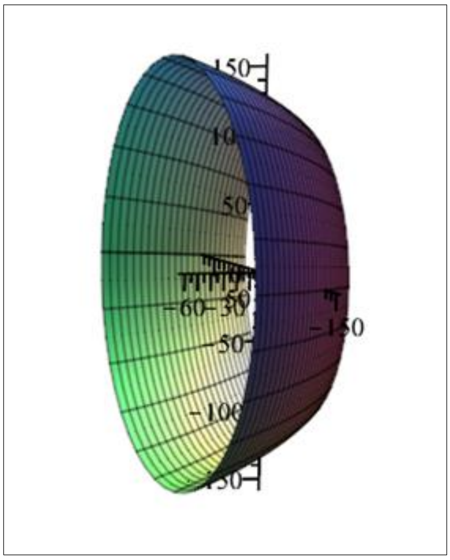

Figure 6 The friction surface of 3, obtained thru rotation of K3 vs X

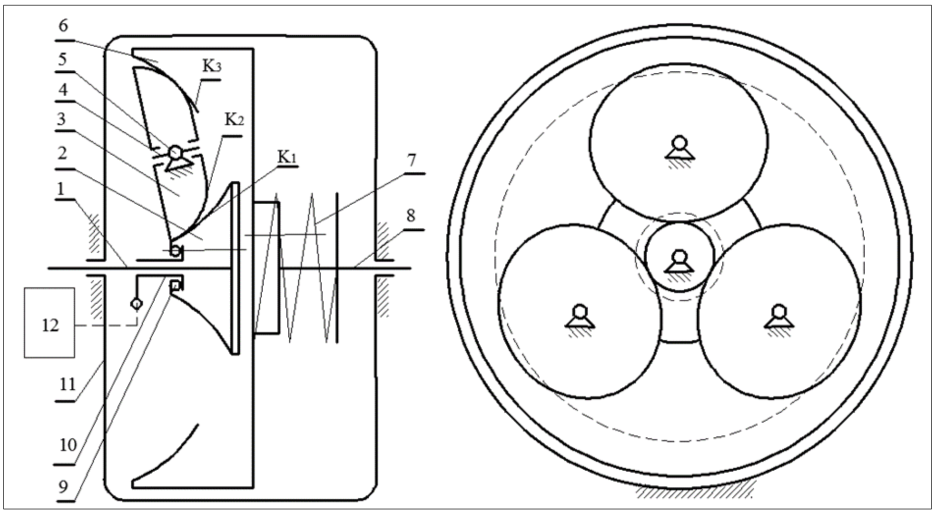

Figure 7 Kinematical scheme in two projection of the variator

2.4. The range of change in the ratio and Kinematical scheme

The change in the transmission ratio is realized by a signal from the control system 12 – Fig. 7, by axial displacement of the units 2 and 10, which are connected to the bearing 9. At the same time, the units 3 and 4 are rotated around the center of 5, and the unit 6 is moves along the axis of 8.

As a result, the radiuses of contact between the friction surfaces change, leading to a change in the ratio of angular velocities.

To further increase the load carrying capacity of the variator, the movement from the input to the output can be realized in multiple streams, in specific case (Fig. 7) – there are three streams.

The change in gear ratio - Fig. 1 can be represented by

$$i_V = \frac{r_{V2}}{H - r_2} \cdot \frac{H + r_2'}{r_{V2}'} . \quad \text{............(18)}$$

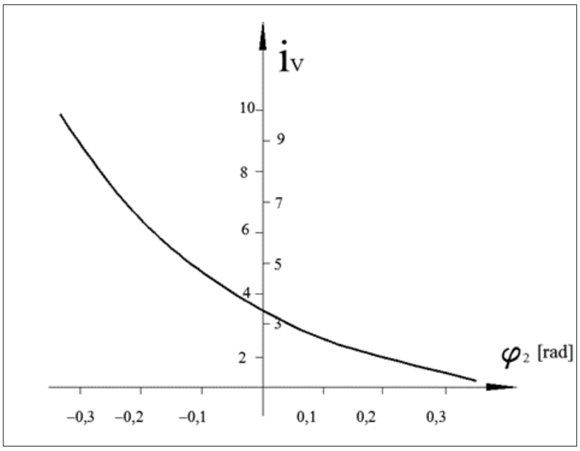

Figure 8 The transmission ratio i_V , as a function of the angle φ_2

It can be seen from the figure that the range of variation of the angular velocities D > 3, required for technical design is achieved with a relative small change in the rotation angle $(-\frac{\pi}{9} \le \varphi_2 \le \frac{\pi}{9})$.

3. Conclusion

The innovative kinematic scheme of the friction variator with increased load capacity and minimized sliding between the friction surfaces in the adjustment process is characterized by:

- The range of adjustment of the angular speed ratio is greater than three (D>3)
- The geometric structure has a convex and concave forming contour of work spaces.
- Relatively simple to make mechanical system.

This is the main advantages of the studied mechanical system compared to existing ones with a variable gear ratio - input/output.

Compliance with ethical standards

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Disclosure of conflict of interest

No conflict of interest.

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