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Design and virtual reality simulation of frontal - sinusoidal ball transmission

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1. Introduction. Design of frontal-sinusoidal ball transmission

The component parts of a frontal-sinusoidal transmission (Fig. 1) are: the driving element which is profiled on its frontal side a closed sinusoidal channel with Z_1 periods; the fixed element *2* which is also profiled on the frontal side a sinusoidal channel with Z_2 periods; the follower (driver element) *3* which is provided with radial channels [1- 4].

Between the two disks profiled through the channels of disk *3* as the linking elements the balls *4* are interposed.

The role of balls *4* can be taken by conical rollers of the sinusoidal channels which have the corresponding section for their profiles.

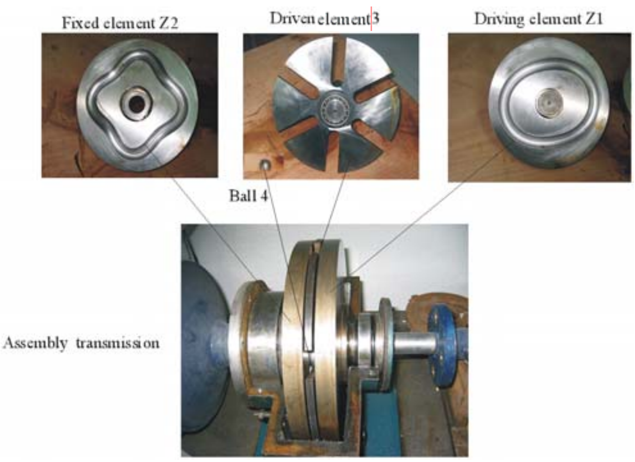

Fig. 1 The main component parts of a frontal-sinusoidal transmission

When assembling a third of the diameter of ball gets in the channel on disk *1*, a third gets in the channel of disk *2* and the middle part gets in the radial channels of disk *3*.

2. Virtual reality model for frontal - sinusoidal ball transmission

The Virtual Reality Toolbox permits viewing and simulation of the interaction with dynamic system in 3D virtual reality environment. The toolbox links MATLAB and SIMULINK with virtual reality graphics, enabling MATLAB or SIMULINK to control the position, rotation, and dimensions of the 3D images defined in the virtual reality environment. The result is a presentation-quality 3-D animation (Figs. 2 and 3).

Through visualization, the Virtual Reality Toolbox provides insight into the dynamic systems that are modeled in SIMULINK [5].

The main advantages of using a virtual reality model are:

- link signals from SIMULINK to virtual reality worlds to control the properties such as motion of the virtual reality objects,
- inclusion of tools for viewing and building virtual reality worlds,
- provide the client/server architecture to enable collaboration among multiple locations,
- producing video recordings for viewing through AVI and WRL file formats,
- interaction with real-time simulations,
- including MATLAB functions for retrieving and changing virtual world properties,
- connecting to common hardware input devices, including joysticks, Magellan SpaceMouse, and Logitech SpaceBall 5000.

The virtual reality model of the frontal transmission with balls is shown in Figs. 2 and 3.

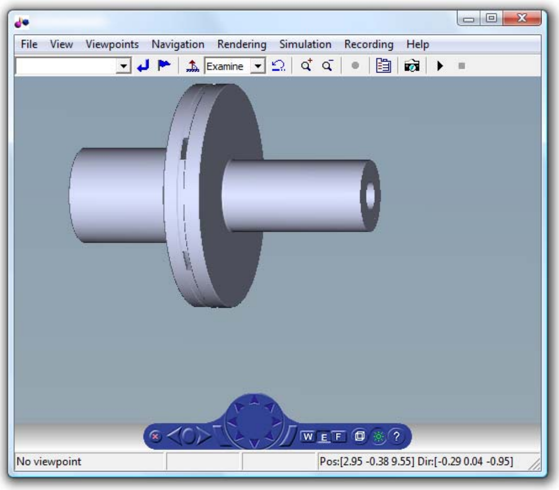

Fig. 2 Virtual Reality model of the frontal transmission with balls

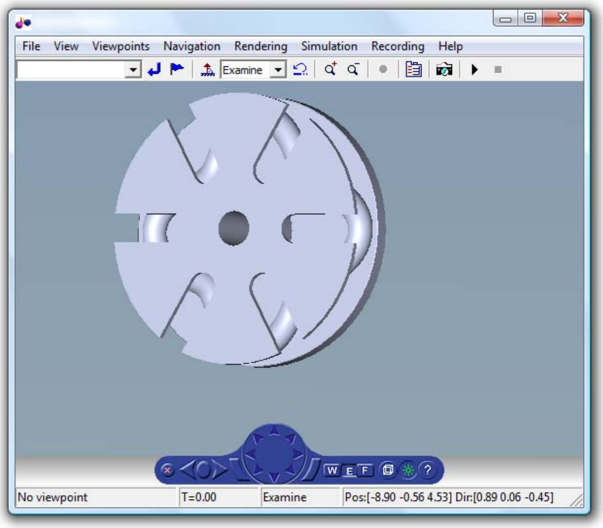

Fig. 3 Virtual Reality model of the frontal transmission with balls, detailed view

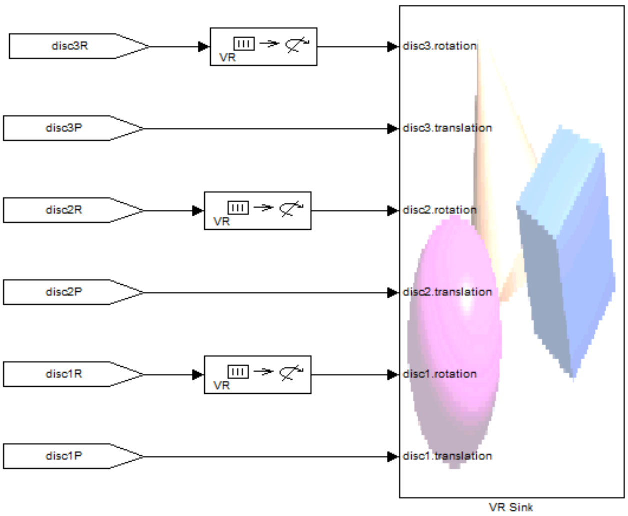

Fig. 4 Virtual Reality toolbox blocks from MATLAB / SIMULINK

The significance of virtual 3D models in physical modeling, control synthesis, performance analysis, dynamic simulation and visualization of real systems is very high. Attention has been paid to the integration of a virtual environment simulator and the process simulation model created in MATLAB/SIMULINK.

The Virtual Reality toolbox from MATLAB/SIMULINK is presented in Fig. 4. The main parameter of dynamic system is Virtual Reality toolbox that is presented in Fig. 5. The Virtual Reality Modeling Language (VRML) and SIMULINK that are toolboxes of MATLAB software were used to show the good graphics and interactive system. With the VRML, output of the system was displayed in terms of three dimensional objects that is equivalent with the actual frontal transmission with balls. Meanwhile, with a SIMULINK model, communication for controlling and manipulating of virtual realism objects is provided to the model and it simulates dynamic systems. The importance of visualized behavior of a frontal transmission with balls is virtual reality environment is one application that allows us not only to study its performance, but also let us to interact in a realistic way with its perception with the real environment.

The Virtual Simulator basically integrates the two important aspects for controlling the frontal transmission; mathematical model of the frontal transmission with balls developed in SIMULINK, the virtual frontal transmission with the balls in its environment created with VRML.

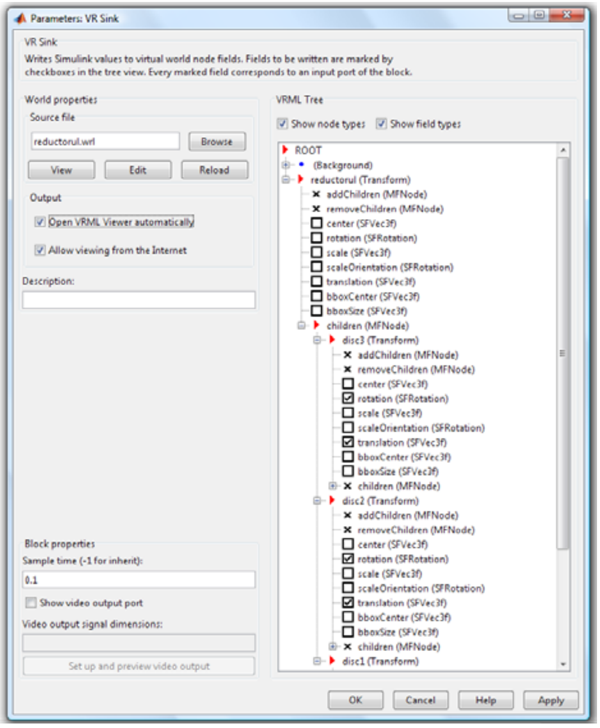

Fig. 5 Main parameters of Virtual Reality toolbox from MATLAB/SIMULINK

This is a first approach of the application of MATLAB's Toolboxes of SIMULINK and VRML. The main objective with this project was to give excellent performance of the virtual frontal transmission with balls based on dynamic, kinematic and geometric model of the real frontal transmission with balls. It is important to notice that applying VRML, it is possible to recreate very realistic frontal transmission with balls and with the joins of the blocks on SIMULINK, it is possible to show real behavior in the real world.

Finally with VRML it is possible to develop a very nice Graphical Used Interface (GUI) and it also has the advantage of be easy to integrate with other programming platforms.

Perhaps the most important advantage with the integration of VRML language and SIMULINK is the easy way to interact on the virtual environment.

3. Transmission ratio determination

It is considered that the medial fiber of the channel Z_1 (Fig. 6) is given by the equation [6]

$$r_1 = r_m + \frac{h}{2} sinZ_1\beta \qquad (1)$$

and the medial fiber of the channel Z_2 is given by the equation

$$r_2 = r_3 = r_m + h/2\, sinZ_2\varphi_3 \qquad (2)$$

where $r_1, r_2 = r_3$ are coordinates which position the points A and C on the curves Z_1 and Z_2; r_m is the medium radius of the channels; h is maximal longitudinal motion of the elements 4; β is the angle between the current radius $r_1 = OA$ and the straight line OO_1^0 (in the initial position); φ_2 is rotation angle of the driving element 2 compared to the reference straight line OC_0; φ_3 is the angle between the current radius $r_1 = OA$ and the reference straight line OC_0 (this one determines also the position of the driven element 3); Z_1, Z_2 are the number of periods of the profiles from the two cylindrical elements 1 and 2.

From the condition

$$r_1 = r_2 \tag{3}$$

$$sinZ_2\varphi_3 - sinZ_1\beta = 0 \tag{4}$$

The angles $\varphi_1, \varphi_2, \beta, \varphi_3$ are considered to be positive if they are measured in the hour sense.

So, between these angles it is true the equation

$$\varphi_3 + \beta = \varphi_1 \tag{5}$$

where φ_1 is the rotation angle of the driving element 1.

With the help of the relation (5) the equation (4) can be written like this [7]

$$sinZ_2\varphi_3 - sinZ_1\left(\varphi_1 - \varphi_3\right) = 0 \tag{6}$$

with the results

$$\varphi_3 = \frac{Z_1}{Z_2 + Z_1}\varphi_1 + \frac{2k\pi}{Z_2 + Z_1} \tag{7}$$

where $k = 0, 1, \ldots, (Z_2 + Z_1 - 1)$, or

$$\varphi_3^{'} = -\frac{Z_1}{Z_2 - Z_1}\phi_1 + \frac{\left(2k^{'} + 1\right)\pi}{Z_2 - Z_1} \tag{8}$$

where $k^{'} = 0, 1, \ldots, (Z_2 - Z_1 - 1)$.

Differentiating Eqs. (7) and (8) with respect to time it is obtained [8]

$$\vec{\omega}_3 = \frac{Z_1}{Z_2 + Z_1}\vec{\omega}_1 \tag{9}$$

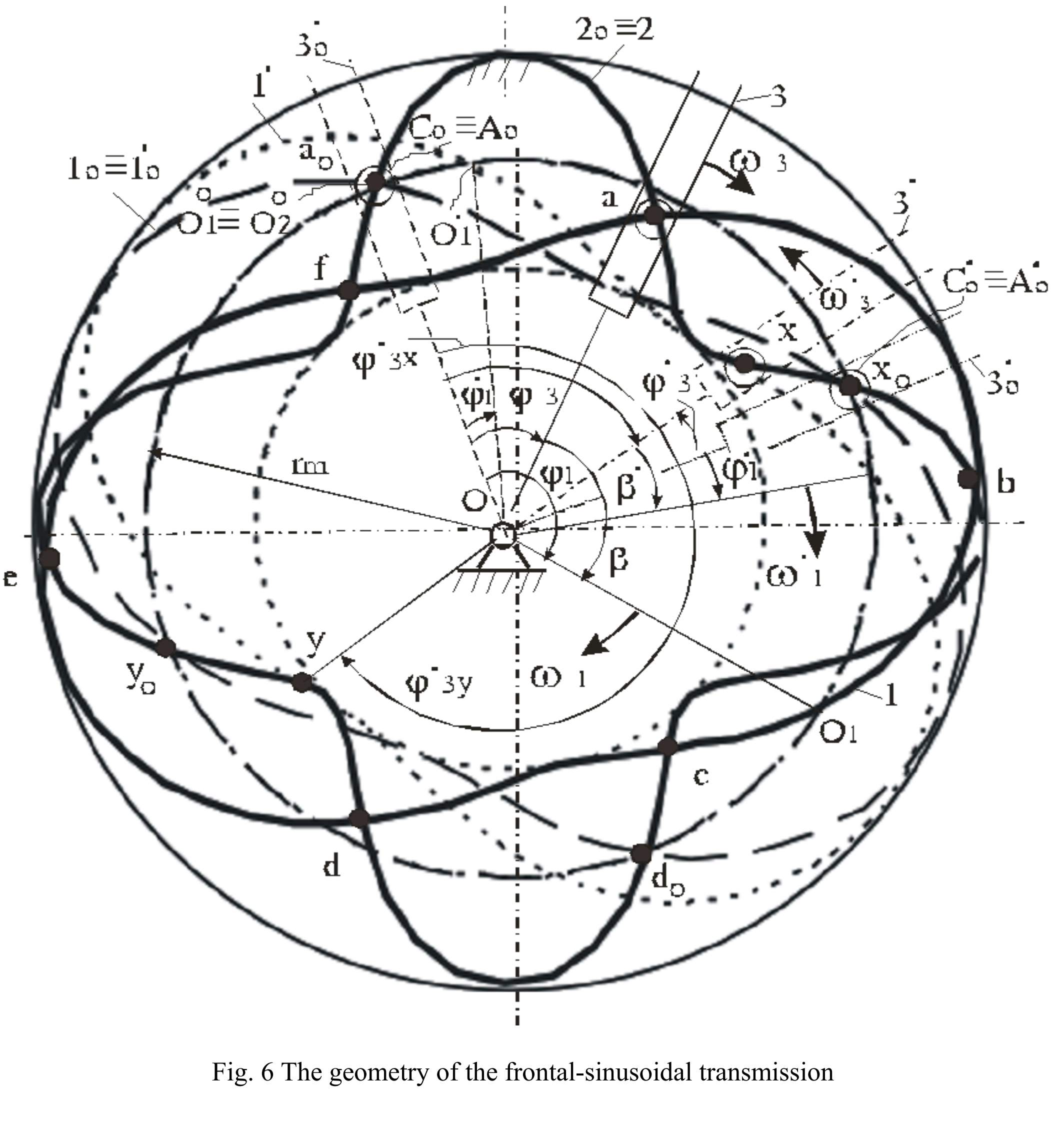

Fig. 6 The geometry of the frontal-sinusoidal transmission

respectively

$$\vec{\omega}_3^{'} = -\frac{Z_1}{Z_2 - Z_1}\vec{\omega}_1 \tag{10}$$

where $\vec{\omega}_1$ is angular velocity of the driving element 1; $\vec{\omega}_3$ is angular velocity of the driven element 3 for the first group of solutions when intermediate elements 4 (the number of balls will be given by the relation $n = Z_3 + Z_1$) are placed in the points *a*, *b*, *c*, *d*, *e* and *f*; $\vec{\omega}_3^{'}$ is the angular speed of the conducted element 3 for the second group of solutions when the intermediary elements 4 (the number of balls will be given by the relation $n^{'} = Z_3 - Z_1$) are placed in the points *x* and *y*.

For this kind of transmission in which the element 2 is fixed there are two elementary transmission ratios

$$i_{13} = \frac{\omega_1}{\omega_3} = \frac{Z_2 + Z_1}{Z_1} \tag{11}$$

respectively

$$i'_{13} = \frac{\omega_1}{\omega_3^{'}} = -\frac{Z_2 - Z_1}{Z_1} \tag{12}$$

In Fig. 2 the three functioning variants of a simple frontal sinusoidal transmission with only one degree of freedom are presented.

With the help of Euler`s relations for determining the relative speed between two bodies of the transmission in Fig. 7 the following vector relations can be written

$$\vec{\omega}_{12} = \vec{\omega}_{13} + \vec{\omega}_{32} \tag{13}$$

$$\vec{\omega}_{32} = \vec{\omega}_{31} + \vec{\omega}_{12} \tag{14}$$

$$\vec{\omega}_{21} = \vec{\omega}_{23} + \vec{\omega}_{31} \tag{15}$$

$$\vec{\omega}_{31} = \vec{\omega}_{32} + \vec{\omega}_{21} \tag{16}$$

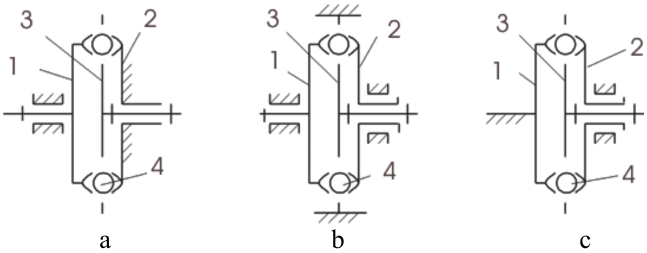

Fig. 7 Functioning variants of a simple frontal-sinusoidal transmission with balls

Next the following notations are being made: $i_{13} = \frac{\vec{\omega}_{12}}{\vec{\omega}_{32}}$ is the transmission ratio between elements 1 and 3 when 2 is fixed; $i_{31} = \frac{\vec{\omega}_{32}}{\vec{\omega}_{12}}$ is the transmission ratio between elements 3 and 1 when 2 is fixed; $i_{21} = \frac{\vec{\omega}_{23}}{\vec{\omega}_{13}}$ is the transmission ratio between elements 2 and 1 when 3 is fixed; $i_{12} = \frac{\vec{\omega}_{13}}{\vec{\omega}_{23}}$ is the transmission ratio between elements 1 and 2 when 3 is fixed; $i_{23} = \frac{\vec{\omega}_{21}}{\vec{\omega}_{31}}$ is the transmission ratio between elements 2 and 3 when 1 is fixed; $i_{32} = \frac{\vec{\omega}_{31}}{\vec{\omega}_{21}}$ is the transmission ratio between elements 3 and 2 when 1 is fixed.

For the second group of cross points of the sinusoids, one can determine the relative speeds and the transmission ratios, in the same way as for the first group so that

$$\vec{\omega}_{12}^{'} = \vec{\omega}_{13}^{'} + \vec{\omega}_{32}^{'} \tag{17}$$

$$\vec{\omega}_{32}^{'} = \vec{\omega}_{31}^{'} + \vec{\omega}_{12}^{'} \tag{18}$$

$$\vec{\omega}_{21}^{'} = \vec{\omega}_{23}^{'} + \vec{\omega}_{31}^{'} \tag{19}$$

$$\vec{\omega}_{31}^{'} = \vec{\omega}_{32}^{'} + \vec{\omega}_{21}^{'} \tag{20}$$

In Table transmission ratios transmission func-

Table

The values of transmission ratios

Transmission ratio	Variation Range of the ratio i			
	$z_1 < z_2$		$z_1 > z_2$	
	Reducer	Multi-plier	Reducer	Multi-plier
$i_{13} = \frac{\vec{\omega}_{12}}{\vec{\omega}_{32}} = \frac{z_1 + z_2}{z_1}$	$(2, \ldots, \infty)$		$(1, \ldots, 2)$	
$i_{31} = \frac{\vec{\omega}_{32}}{\vec{\omega}_{12}} = \frac{z_1}{z_1 + z_2}$		(0, ..., 0.5)		(0.5, ..., 1)
$i^{'}_{13} = \frac{\vec{\omega}_{12}}{\vec{\omega}_{32}} = \frac{z_1 - z_2}{z_1}$	$(0, \ldots, \infty)$			(0, ..., 1.0)
$i^{'}_{31} = \frac{\vec{\omega}_{32}}{\vec{\omega}_{12}} = \frac{z_1}{z_1 - z_2}$	$(0, \ldots, \infty)$		$(1, \ldots, \infty)$	
$i_{32} = \frac{\vec{\omega}_{31}}{\vec{\omega}_{21}} = \frac{z_2}{z_2 + z_1}$		(0.5, ..., 1)		(0, ..., 0.5)
$i_{23} = \frac{\vec{\omega}_{21}}{\vec{\omega}_{31}} = \frac{z_2 + z_1}{z_2}$	(1.0, ..., 2.0)		$(2, \ldots, \infty)$	
$i^{'}_{32} = \frac{\vec{\omega}_{31}}{\vec{\omega}_{21}} = \frac{z_2}{z_2 - z_1}$	$(1, \ldots, \infty)$		$(0, \ldots, \infty)$	
$i^{'}_{23} = \frac{\vec{\omega}_{21}}{\vec{\omega}_{31}} = \frac{z_2 - z_1}{z_2}$		(0, ..., 1.0)	$(0, \ldots, \infty)$	
$i_{12} = \frac{\vec{\omega}_{13}}{\vec{\omega}_{23}} = -\frac{z_2}{z_1}$	$(1, \ldots, \infty)$			(0, ..., 1.0)
$i_{21} = \frac{\vec{\omega}_{23}}{\vec{\omega}_{13}} = -\frac{z_1}{z_2}$		(0, ..., 1.0)	$(1, \ldots, \infty)$	
$i^{'}_{12} = \frac{\vec{\omega}_{13}}{\vec{\omega}_{23}} = -\frac{z_2}{z_1}$	$(1, \ldots, \infty)$			(0, ..., 1.0)
$i^{'}_{21} = \frac{\vec{\omega}_{23}}{\vec{\omega}_{13}} = \frac{z_1}{z_2}$		(0, ..., 1.0)	$(1, \ldots, \infty)$	

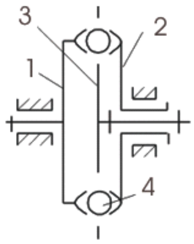

Fig. 8 Diagram of the differential frontal transmission

tions such as a multiplicating transmission, demultiplicatig, changing or not the rotation direction of the output shaft with respect to the input shaft there are presented. All these aspects are presented taking into account the two situations when $Z_1 < Z_2$ and $Z_1 > Z_2$.

In Fig. 8 the differential frontal transmission with balls is presented.

For the differential frontal transmission, in accordance with Fig. 8 the following can be written

$$\vec{\omega}_3 = \frac{Z_1}{Z_2 + Z_1}\vec{\omega}_1 + \frac{Z_2}{Z_2 + Z_1}\vec{\omega}_2 \qquad (21)$$

respectively

$$\vec{\omega}_3^{'} = -\frac{Z_1}{Z_2 - Z_1}\vec{\omega}_1 + \frac{Z_2}{Z_2 - Z_1}\vec{\omega}_2 \qquad (22)$$

where $\vec{\omega}_1$ is angular velocity of the driving element 1, $\vec{\omega}_2$ is angular velocity of the driving element 2, $\vec{\omega}_3$ is angular velocity of the driven element 3 when intermediate elements 4 (the number of balls will be given by the relation $n = Z_3 + Z_1$) are placed in the points of intersection *a, b, c, d, e, f* of sinusoidal channels, $\vec{\omega}_3^{'}$ is angular velocity of the driven element 3 when intermediate elements 4 ($n^{'} = Z_3 - Z_1$) are placed in other points of intersection *x, y* of sinusoidal channels.

4. Conclusions

A new type of mechanical transmission that allows transmission of motion between two coaxial shafts is presented. The frontal-sinusoidal transmission with balls allows motion transmission between two coaxial shafts. Virtual 3D models play important role in layout design of a today factory, physical modeling, control synthesis, performance analysis, dynamic simulation and visualization of real systems.

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GALINĖS - SINUSOIDINĖS PAVAROS SU RUTULIUKAIS PROJEKTAVIMAS IR JOS VIRTUALUS MODELIAVIMAS

R e z i u m ė

Galinė sinusoidinė pavara su rutuliukais – tai naujo tipo mechaninė pavara galinti perduoti judesį tarp dviejų bendrą ašį turinčių velenų.

Straipsnio pirmoje dalyje tyrinėjama galinės sinusoidinės pavaros su rutuliukais geometrija ir kinematika, lemianti pavaros perdavimo santykį. Antroje straipsnio dalyje naudojant MATLAB/SIMULINK sistemas, sukurtas virtualus pavaros modelis ir imituotas jo veikimas. Aprašytas sistemos virtualios aplinkos imitatoriaus veikimas bei jo prijungimo prie kitų (skirtingų MATLAB/SIMULINK) sistemų būdai.

Šios pavaros pranašumas, palyginti su kitomis mechaninėmis pavaromis, yra platesnis perdavimo santykių diapazonas. Tuo atveju, kai visi paprastos galinės sinusoidinės pavaros diskai yra judantys, gaunama viena diferencialinė pavara.

Kitas šios sistemos pranašumas – galimybė sudaryti sudėtingas pavaras jungiant galines sinusoidines pavaras tarpusavyje nuosekliai ir lygiagrečiai.

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DESIGN AND VIRTUAL REALITY SIMULATION OF FRONTAL - SINUSOIDAL BALL TRANSMISSION

S u m m a r y

The frontal - sinusoidal transmission with balls is a new type of mechanical transmission that allows transmission of motion between two coaxial shafts.

In the first part of this paper the study of geometry and kinematics of the elements of frontal - sinusoidal transmissions with balls is presented, determining in the way the transmission ratios. In the second part of the paper

the virtual reality model and simulation made in MATLAB/SIMULINK environment is presented. A virtual environment simulator and the way it can be connected to other simulators (e.g. MATLAB/SIMULINK), is presented.

An advantage of this transmission, as compared to other mechanical transmissions, is given by the possibility to obtain more transmission ratios. In case when all disks of simple frontal-sinusoidal transmission are moving elements one differential transmission is obtained.

Another advantage is given by the possibility of obtaining simply complex transmissions by series and parallel arrangement of frontal transmission units.

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ПРОЕКТИРОВАНИЕ И ВИРТУАЛЬНОЕ МОДЕЛИРОВАНИЕ ЛОБОВОЙ-СИНУСОИДАЛЬНОЙ ПЕРЕДАЧИ С ШАРИКОМ

Р е з ю м е

Лобовая синусоидальная передача с шариками представляет собой новый тип механической передачи, позволяющей передать движение между двумя коаксиальными валами.

В первой части статьи исследуется геометрия и кинематика лобовой синусоидальной передачи, которая обеспечивает определенное передаточное число. Во второй части при помощи систем MATLAB/SIMULINK создана виртуальная модель передачи и имитировано ее действие. Описан принцип работы виртуальной среды имитатора и возможные пути его подключения к другим системам (различным MATLAB/SIMULINK)

Преимуществом этой передачи по сравнению с другими механическими передачами является более широкий диапазон передаточных чисел. В случае, когда все диски лобовой синусоидальной передачи подвижны, имеем дифференциальную передачу. Другое преимущество этой системы – возможность создания комплексных передач, соединяя лобовые синусоидальные передачи между собой последовательно и параллельно.

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