CONCEPT OF NON-FRICTION-BASED CVT

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Abstract: The article presents the results of the considerations on the concept of the continuously variable transmission (CVT) which is not based on the frictional coupling. The authors suggested the theoretical solution to the problem, presenting the basis of the operation of the mechanism which they developed by themselves. It was assumed that thanks to its application the expected result would be obtained, providing high efficiency, the wide range of adjustment and the smoothness of operation. The paper presents the description of the research performed, which comprises the outline of the design and also the simulation tests of the transmission, which led to the verification of the assumed hypothesis. The research results show that the mechanical stepless change of the transmission ratio without using the frictional coupling (unlike in the case of classical CVTs) is possible.
Key words: CVT, modelling, simulation, Scilab, mechatronics.

1. INTRODUCTION

The subject of the research is the innovative method of the stepless transmission ratio adjustment. Classical ways of implementing this process are burdened with imperfections. They are linked to the necessity of applying the frictional coupling [1]. It results in the problems related to the control and the efficiency of the transmission, the wear and tear of its parts and their complicated geometry [1-4]. The suggested solution is a combination of several mechanisms in which rotational motion is converted into linear motion, and forces and torques are transmitted by means of form fitting. Individual components of the transmission under consideration are well recognised and described in the literature in terms of their conventional application. The paper assumes, however, that certain standard mechanical elements may perform different tasks than those performed so far.

Figure 1 presents the outline of the described mechanism. The system under consideration includes a flexible toothed belt transmission. It's both pulleys are passive – they are not directly influenced by the input torque; from one of them the torque is received at the output. The active pulley is a separate component, not contacting directly the belt. The transmission of drive is possible thanks to the ratchets, linear guides and slider-crank mechanisms. The connecting rod (a) is linked to the active pulley (b) on one side, at a point between the rotation centre (O) and the pulley circumference (C). Guiding the point of the connecting rod attachment along the centre-circumference line (O-C) allows the user to influence the length (c) of the crank. It enables the control of the value of the slider (d) linear motion amplitude, causing – with the unvarying deflections period – changes in the linear velocity which is achieved [5]. The other side of the connecting rod moves along the belt (e). The application of the ratchet allows the slider to engage with the belt only at a specific direction of their relative movement and to pull it then [4]. As a result, the form-fitting coupling between these two elements occurs.
The described method of driving the belt produces the fluctuations of the linear velocity due to the slider motion characteristics [5]. The authors assumed that the system encompasses several slider-crank mechanisms with different oscillation phases. At a given time, the belt is actuated by the fastest slider, while the other ones perform idle movements – as a result of the application of ratchets. This enables the reduction of the deviations of the linear forces influencing the belt. The output rotational velocity of the receiving (passive) pulley (f) depends on two factors: the invariable value of its radius and the controllable value of the belt linear velocity.

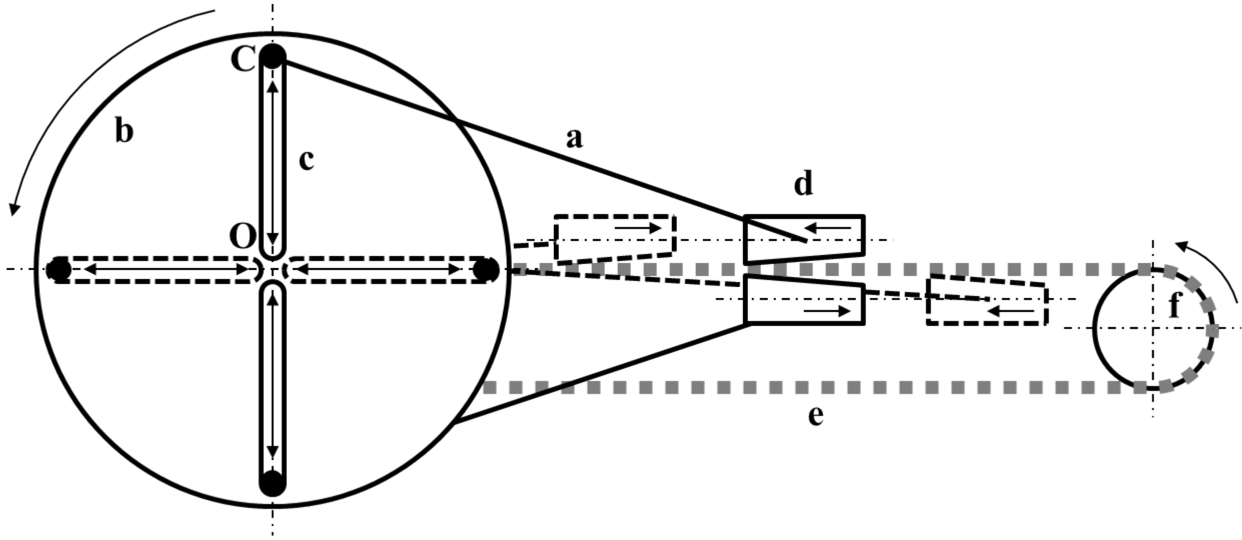


Fig 1. System under consideration

The presented description of the suggested method was created on the basis of the authors' own concept; nonetheless, it has not been supported by exact analysis or scientific experiments so far. The goal of the research is to determine, by means of mathematical models and computer simulations, the kinematic and dynamic relations occurring during the application of the developed mechanism. Such knowledge enables the determination of the features of the system under consideration and its comparison with classic continuously variable transmissions (CVTs). The basic unknown is whether the adopted approach permits the achievement of the expected result while simultaneously eliminating the identified problems. Acquired information can be valuable for designers who create new drive solutions for machines and vehicles. It particularly pertains to the efforts the objective of which is to reduce the mass and the demand for the energy needed for the control. These are crucial and difficult issues nowadays, to which much attention is paid. The research leads to the verification of the assumed hypothesis, which reads as follows: "the suggested method of the frictionless transmission of the drive enables the stepless adjustment of the transmission ratio". The parameters of the movement at the output of the studied transmission should change in a continuous manner, depending on the setpoint.

2. MATERIALS AND METHODS

The research described in the paper is related to the innovative way of the continuous transmission ratio change. The mechanism – the objective of which is to enable the process – is studied. The detected problems and the preliminary ideas of solving them result from the heuristic methods of knowledge acquisition, such as the suggesting method and the morphological analysis. The authors intend to apply these methods in further stages of work, with a view to developing or altering the directions of search and reacting to disparities between the expectations and the results or other complications. The synthesis of knowledge constitutes another important element of the research. With respect to the design and utilisation of the considered device, the authors assumed that the results to which the hypothesis pertains can be achieved by combining the phenomena present in various types of conventional transmissions. New facts in the domain of the CVT are to be discovered as a result of experimenting by using the well-known solutions in an innovative way. Applying the suggested approach and the analysis of such a solution are the objectives of the study.

The phenomenological model of the considered mechanism is the basis for formulating conclusions about the features of the stepless transmission ratio adjustment system. Using the illustrative diagrams and mathematical descriptions, one can examine the accuracy of the assumed concept in terms of the accomplishment of the process in question [5, 6]. Performing appropriate calculations allows determining roughly the parameters of the considered system operation. As a result, it enables the pre-assessment of the features of the developed continuous transmission ratio change method.

In terms of the design of the device, the authors envisage the possibility of adapting existing solutions to new circumstances which result from the adopted concept.

The authors performed the verification of the validity of the adopted concept on the basis of the kinematic and dynamic analysis of the mechanical system under consideration.

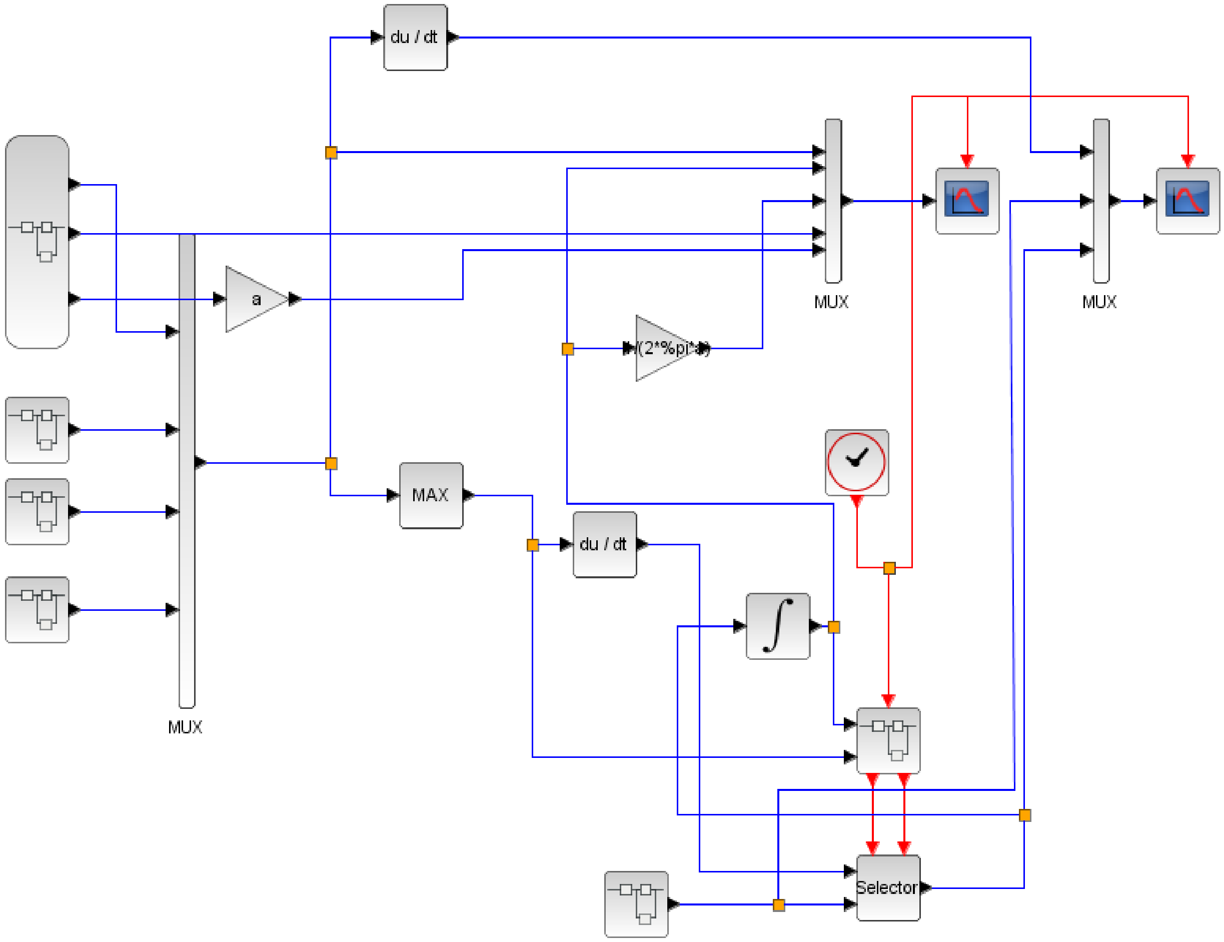


Fig 2. Main calculation diagram in Scilab Xcos application

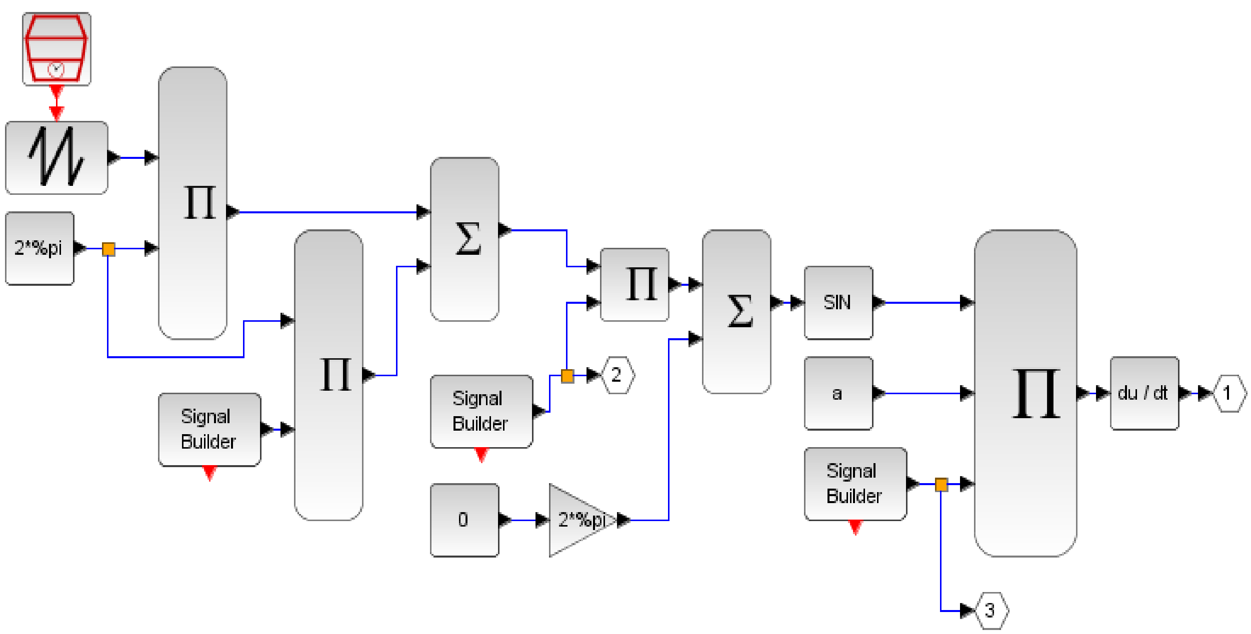


Fig 3. Diagram of subsystem for generating the course of linear velocity of the slider in the Scilab Xcos application

The model of the transmission was created in the Scilab software. The authors used the Xcos tool, which enables defining the relations between individual numerical variables and constants and performing mathematical operations on them through the creation of graphical diagrams. In the environment, numerical methods, such as

Runge-Kutta 4(5) [8] algorithm, are used to calculate the integration result.
Figure 2 presents the main calculation diagram, in which the courses of the output values in the analysed system are generated. It shows recognizable elements representing calculation operations, as well as the blocks of the user-defined subsystems. The most important of the latter are four input generators of sinusoidal waveforms, which are the sources of the instantaneous linear velocity values of the sliders moving along the belt. Additionally, one of them provides information concerning the velocity of the active pulley and the setpoint of the transmission. Its internal structure is presented in the Figure 3. The purpose of other non-standard blocks is to calculate motion resistance (constant value throughout the simulation) and to check whether the condition of the contact between the slider and the belt is fulfilled. The source of the belt acceleration is selected on this basis.

3. RESULTS AND DISCUSSION

During the operation of the drive systems motion resistance occurs. While formulating the model of the operation of the studied transmission, the authors took bearing friction under consideration.

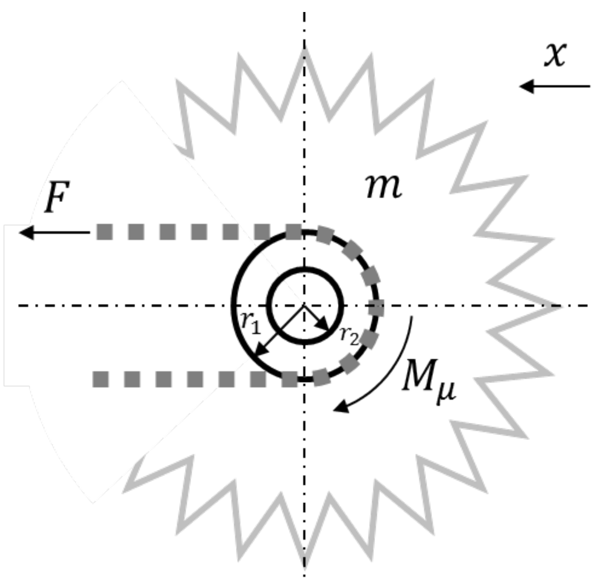


Fig 4. Forces in system under consideration

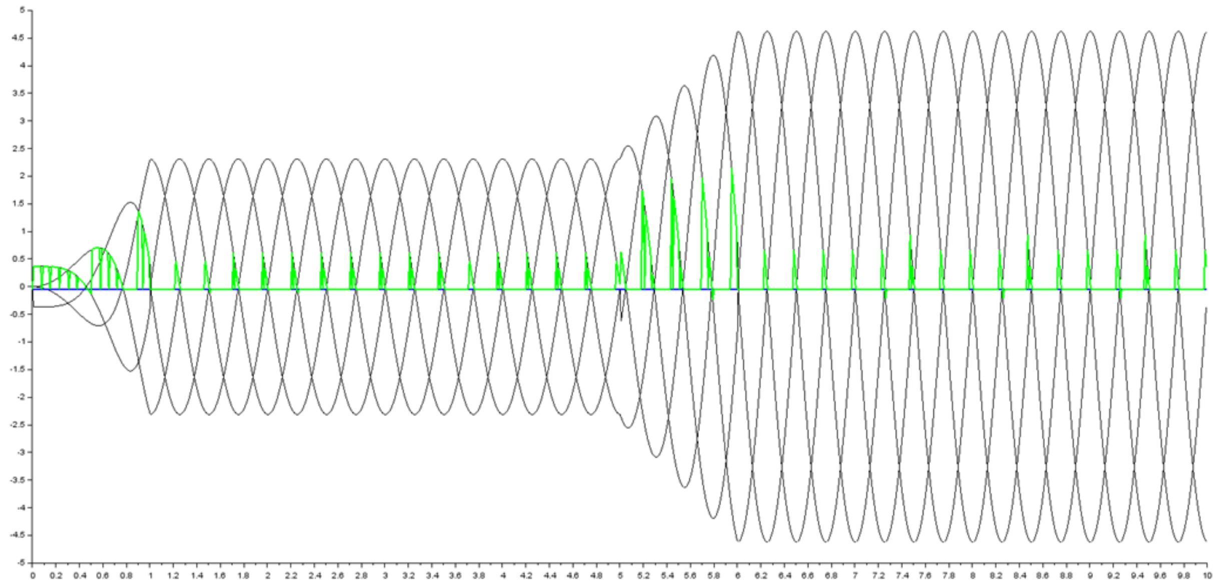
It counteracts the drive force acting on the toothed belt. Figure 4 presents the system of the forces influencing the belt. The dynamic equation of the belt motion is formulated as follows:

$$m_{Bred}\ddot{x}_B = F - \frac{M_\mu}{r_1}, \tag{1}$$

where: m_{Bred} – mass reduced to belt $[\text{kg}]$, $\ddot{x}_B$ – toothed belt acceleration $\left[\frac{\text{m}}{\text{s}^2}\right]$, F – belt-pulling force $[\text{N}]$, $M_\mu = \mu m g r_2$ – bearing friction torque $[\text{Nm}]$, r_1 – passive pulley radius $[\text{m}]$, μ – bearing friction ratio, m – mass sitting on bearings $[\text{kg}]$ g – gravitational acceleration $\left[\frac{\text{m}}{\text{s}^2}\right]$, r_2 – bearing hole radius $[\text{m}]$.
In the analysis of the operation of the transmission the authors assumed that in the drive system the active pulley together with all sliders move in a specific way, regardless of external forces. When the slider engages with the belt, their movement is synchronised, which means that the acceleration of the belt is then equal to the acceleration of the slider $\ddot{x}_S$. It occurs if the instantaneous belt velocity $\dot{x}_B$ is lower than the slider velocity $\dot{x}_S$. During the change of the slider movement phase from the drive one to the return one, its acceleration in relation to the belt decreases. Thanks to the ratchet the belt is no longer pulled$(F=0)$. The belt, together with the whole mass reduced to it, begins to lose velocity due to the motion resistance taken into consideration in the dynamic equation (1). When the belt velocity drops below the slider velocity again, the drive cycle is repeated. The equations (2) determine the belt acceleration values.

$$\begin{cases} \ddot{x}_B = \ddot{x}_S & \text{if} \quad \dot{x}_B < \dot{x}_S \\ \ddot{x}_B = -\dfrac{\mu m g r_2}{r_1 m_{Bred}} & \text{if} \quad \dot{x}_B \geq \dot{x}_S \end{cases} \tag{2}$$

Figure 5 presents the course of the acceleration of components during the simulation of the transmission operation. The active pulley accelerates from 0 to 1 $\frac{\text{rev}}{\text{s}}$ within 1 second, and the setpoint of the transmission ratio (radius of the crank in the slider-crank mechanisms) changes in the middle of the simulation time.

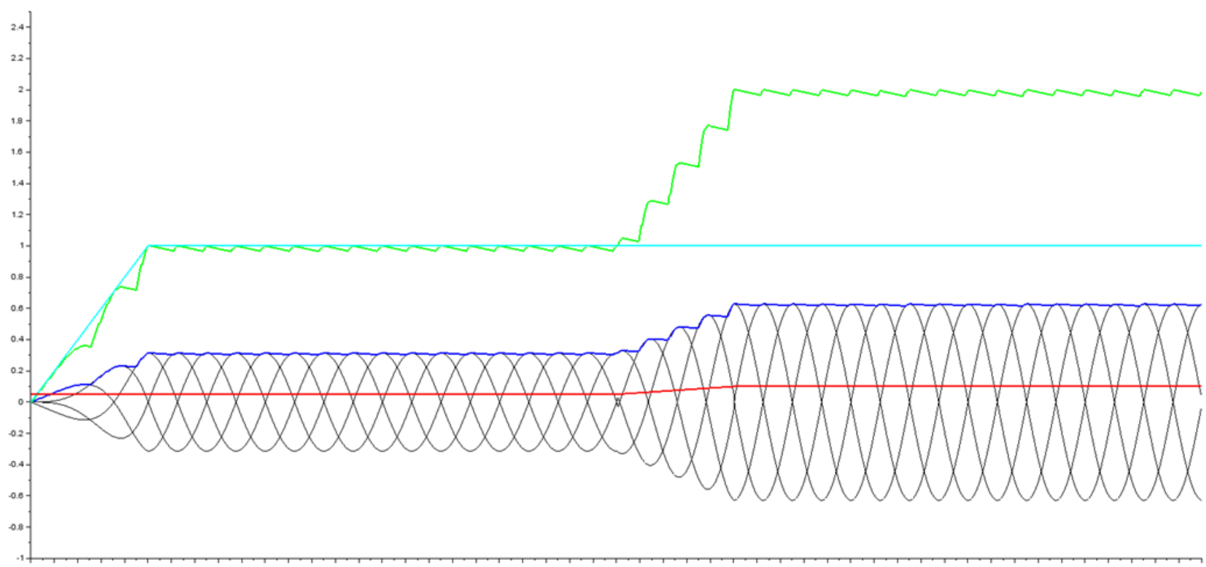


Acceleration of belt $\left[\frac{m}{s^2}\right]$

Acceleration (deceleration) of belt in case of slider-belt separation $\left[\frac{m}{s^2}\right]$

Acceleration of particular sliders $\left[\frac{m}{s^2}\right]$

Fig 5. Acceleration of individual elements in the system under consideration



Rotational velocity of active pulley $\left[\frac{rev}{s}\right]$

Rotational velocity of passive pulley $\left[\frac{rev}{s}\right]$

Linear velocity of belt $\left[\frac{m}{s}\right]$

Linear velocity of particular sliders $\left[\frac{m}{s}\right]$

Setpoint of tranmission ratio

Fig 6. Velocity of individual elements in the system under consideration

One can determine the belt linear velocity by integrating the equations of motion. In the first part of the simulation, the setpoint results in the same radius of both the crank and the receiving pulley (hence the similarity of their rotational velocities). Figure 6 presents the course of the velocity of components during the operation of the device.
The developed device is an innovative combination of several mechanisms and the conducted investigation of the proposed solution gives promising results. The conducted study has led to the discovery of the knowledge being the foundation for creating and analysing innovative drive systems. The authors recognise high potential for the implementation of the investigated CVT in mechatronics. The process of controlling the setpoint (the crank length) could be performed automatically, e.g. by using an actuator in the form of a linear electric drive. Such a device would not require high energy supply, and it would enable the quick and precise reaction to the changing conditions of the drive operation. The mechatronic transmission, based on the concept suggested in the present paper, could be lighter and less energy-consuming as well as more efficient than systems used nowadays.

4. CONCLUSIONS

The authors proved the hypothesis by performing the analysis of the mechanism being authors' own solution. The suggested method of the transmission results in obtaining the output rotational velocity which is close to the expected one. The investigated control system gives the possibility of adjusting the ratio within a specified range. The phenomenological model including the mathematical description of the kinetics of the system under consideration constituted the foundation for the work. On this basis, the authors assessed the potential of the system in providing the stepless adjustment of the transmission ratio. The hypothesis was thus confirmed. Further considerations will be related to the possibilities of applying the developed solution in practice. The current problem is the final design of the mechanism, enabling the physical implementation of the described processes of motion transmission and crank length change.

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