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THE CONCEPT OF A NEW TYPE OF CONTINUOUSLY VARIABLE TRANSMISSION FOR BICYCLE

BY

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Abstract. The paper presents the results of considerations on a new way of stepless change of the ratio in the bicycle. A theoretical solution to the problem has been proposed, presenting the basics of the designed mechanism. It has been assumed that its application will allow to achieve the expected result, ensuring high efficiency, wide range of regulation, as well as the swiftness and smoothness of work. The publication describes the conducted research, including, among others, the development of the structure and the analysis of the transmission mechanism. These activities have led to the verification of the hypothesis. The work has been based on the phenomenological model containing the mathematical description of the kinematics and dynamics of the system under consideration. On this basis, the usefulness of the proposed solution in ensuring the stepless adjustment of the transmission ratio has been assessed.

Keywords: CVT; bicycle; mechatronics; modelling; simulation.

1. Introduction

High popularity of a bicycle as a training or rehabilitation device or as an ecological and healthy mean of transport makes its construction being constantly improved. New solutions are developed to enhance the capabilities of

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the single-track, the comfort of use, to allow monitoring and regulation of the drive and physiological parameters of, respectively, the vehicle and its user. Usually, in professional applications (although it is also more and more often applied to amateur ones) the classic, fully mechanical, bike is replaced by electromechanical devices (Dietrych, 1985; Oleksiuk and Paprocki, 1997). This results in more precision and ease of adjustment of the single-track to riding conditions, cyclist's preferences or to a training programme. The examples of the electromechanical systems include electronically controlled derailleur gears or electric motor pedal assist. Similar solutions have been used to develop ways of automatic control of the cyclist's heart rate by influencing the load during pedalling (Giani *et al*., 2014; Meyera *et al*., 2015). Equipping the bicycle with an additional drive that requires power, and therefore energy storage, can be problematic and costly. It seems to be a better choice to use a mechatronic transmission – a more compact device, the operation of which is much less energy-consuming. In order to achieve the appropriate accuracy and fluency of the control, the stepless change of ratio is necessary. The rolling-friction-based mechanisms used hitherto in cycling are deficient, as in their case the slipping may occur, reducing efficiency and causing rapid wear on abrasive surfaces. Multi-stage transmissions, in which switching between adjacent steps results in a small change of transmission ratio, are sometimes considered as the CVT (Goszczak and Radzymiński, 2018; Grzegożek, 2011; Koziarski, 2001). These often require the use of large, complex systems. Bicycle transmissions are required to be compact and feature low motion resistance, high efficiency, a wide range of accurate and fast adjustment and a low demand for energy needed for the control. The combination of all these features is not present in any of the systems used nowadays. Thus, there exists the need to seek and explore new solutions which would aid in improving the processes of the stepless adjustment of the transmission ratio.

The purpose of the research is to mitigate the lack of knowledge in the field of mechanical engineering, in particular in terms of designing drive systems, through the verification of the assumed hypothesis: “the stepless change of the transmission ratio is possible thanks to the application of mechanical methods with non-friction coupling”. The presented assumption has been made on the basis of the results of the preliminary research, during which the innovative method of the adjustment of the transmission ratio in a continuous manner has been developed. The working concepts of the structure and the operation of the device under consideration have been analysed. The proposed system constitutes an unconventional combination of a few widespread mechanisms, and the deliberations conducted hitherto have yielded promising results. The knowledge that has thus been discovered may constitute the foundation for the new direction of development and implementation activities in the field of the technology.

2. Materials and Methods

The research presented in the article pertains to the method of the continuous change of the transmission ratio, as well as to the mechanism which is to enable it. The identified problems together with their preliminary solutions ensue from the process of devising with the application of heuristic methods, such as the morphological analysis and the suggesting method. The application of these methods is also planned in the further stages of work, in order to develop or alter the directions of search and react to potential discrepancies between the expectations and the results or other entanglements. Another substantial element of the conducted considerations is the synthesis of knowledge. In terms of the design and utilisation of the device under consideration it has been assumed that in order to achieve the results to which the hypotheses pertain it shall be necessary to combine the phenomena existing in various types of conventional transmissions. The application of the suggested approach and the use of the existing solutions in an innovative way as well as the analysis of the results of such activities are intended to result in the discovery of new facts in respect of the stepless adjustment of the transmission ratio.

The analysis of the phenomenological model of the system of the stepless adjustment of the transmission ratio constitutes the foundation for the conclusions concerning the features of the system. The usefulness of the various concepts of the mechanism in the implementation of the phenomenon concerned can be considered on the basis of the overview diagrams and mathematical descriptions. The parameters of the operation of the system in question can be roughly determined by performing appropriate calculations. As a result, it allows to pre-asses the features of the developed method of the continuous change of the transmission ratio.

In the process of analysing the construction form of the device, it is envisaged to verify the possibility of adapting the existing solutions to the new circumstances resulting from the adopted concept. With regard to the cases analysed, it is therefore necessary to identify and investigate the kinematic and dynamic relations that could occur in a given combination.

Reflections on the issue under consideration have led to the development of the outline of the innovative method for the mechanical change of the transmission ratio in a continuous manner. The concept of the construction form of the device which is to allow the implementation of the proposed method has been determined. It is based on the combination of a few widespread solutions, in which some elements work in an unconventional way. The system under consideration includes the transmission with a flexible toothed belt. Its pulleys can be described as passive ones, because none of them is directly influenced by the input torque, but from one of them the output torque is received. The active pulley is a separate component that does not come into direct contact with the belt. Slider-crank mechanisms, ratchets and linear guides enable the transmission of drive. On one side the connecting rod (a) is connected to the active pulley (b) at a point between the centre of rotation (O) and the circumference of the pulley (C). The length of the crank (c) is influenced by guiding the point of attachment of the connecting rod along the centre-circumference line (O-C). It allows to control the value of the amplitude of the linear motion of a slider (d), with the unvarying period of its deflections, causing changes in the achieved linear velocity. The other side of the connecting rod moves along the belt (e). Thanks to the application of the ratchet, the slider can engage the belt and pull it only during the relative movement of these elements with a specific direction. It results in the form-fitting coupling between these two elements.

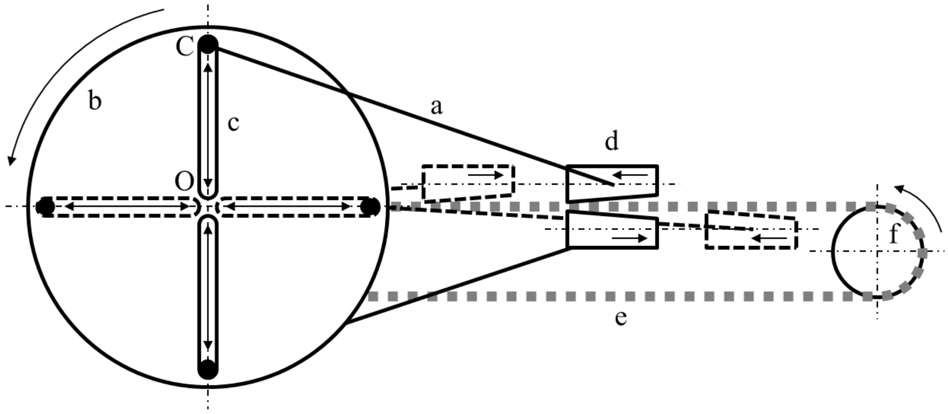

Fig. 1 – Diagram of considered system.

The belt driven this way features the linear velocity fluctuations due to the characteristics of the slider movements. It has been assumed that the system includes numerous slider-crank mechanisms which differ with regard to the oscillation phase. At a given moment, the belt can be pulled by the fastest moving slider, while the others perform idle movements as a result of the work of ratchets. It allows to reduce the deviations of the value of the linear velocity of the elements influencing the belt from the value of the crank amplitude. The rotational velocity of the passive (receiving) pulley (f) depends on the fixed value of its radius and the adjustable value of the linear velocity of the belt.

3. Results

During cycling the motion resistance occurs. The friction in the bearings and the rolling friction of the vehicle wheels have been taken into consideration while modelling the operation of the transmission in question.

These are forces acting against the driving force which acts on the toothed belt. The system of the forces acting on the belt is shown in the Fig. 2.

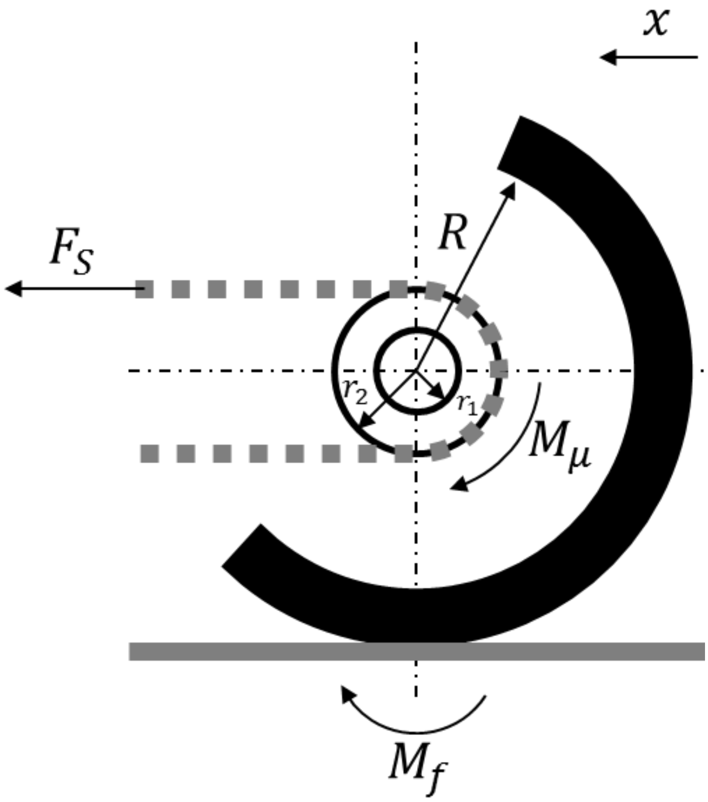

Fig. 2 – Diagram of forces in considered system.

The dynamic equation of the motion of the belt has the following form

$$m\ddot{x}_B = F_S - \frac{M_\mu}{r_1} - \frac{M_f}{R + r_1} = m\ddot{x}_S - \frac{\mu m g r_2}{r_1} - \frac{f m g}{R + r_1}, \tag{1}$$

where: m – mass sitting on bicycle wheels; $\ddot{x}_B$ – toothed belt acceleration; F_S – force of slider acting on belt; M_μ – bearing friction torque; r_1 – crank radius; M_f – rolling friction torque; R – bicycle wheel radius; $\ddot{x}_S$ – slider acceleration; μ – bearing friction ratio; g – gravitational acceleration; r_2 – bearing hole radius; f – rolling friction ratio.

During the analysis of the work of the transmission it has been assumed that the input rotational velocity is constant, which causes a sinusoidal waveform of the value of the linear velocity of the sliders. When the velocity of the belt is lower than the velocity of one of the sliders, there occurs the contact between the two elements. Their motion is synchronised and the belt accelerates in the same way as the slider. The acceleration value is determined by the time derivative of the velocity function – the cosine function. The synchronous movement ends when the acceleration of the slider changes its direction to the opposite one (its braking occurs). Thanks to the ratchet the sliders stops pulling the belt, the velocity of which begins to decrease linearly due to the constant motion resistance. The drive cycle is repeated when the velocity of the belt drops below the velocity of the slider again. The belt acceleration value is determined by the equations:

$$\begin{cases} \ddot{x}_B = \ddot{x}_S \quad \text{if} \quad \ddot{x}_S \geq 0 \wedge \dot{x}_S \geq 0 \\ \ddot{x}_B = -\dfrac{\mu g r_2}{r_1} - \dfrac{fg}{R + r_1} \quad \text{if} \quad \ddot{x}_S < 0 \wedge \dot{x}_S < 0 \end{cases} . \tag{2}$$

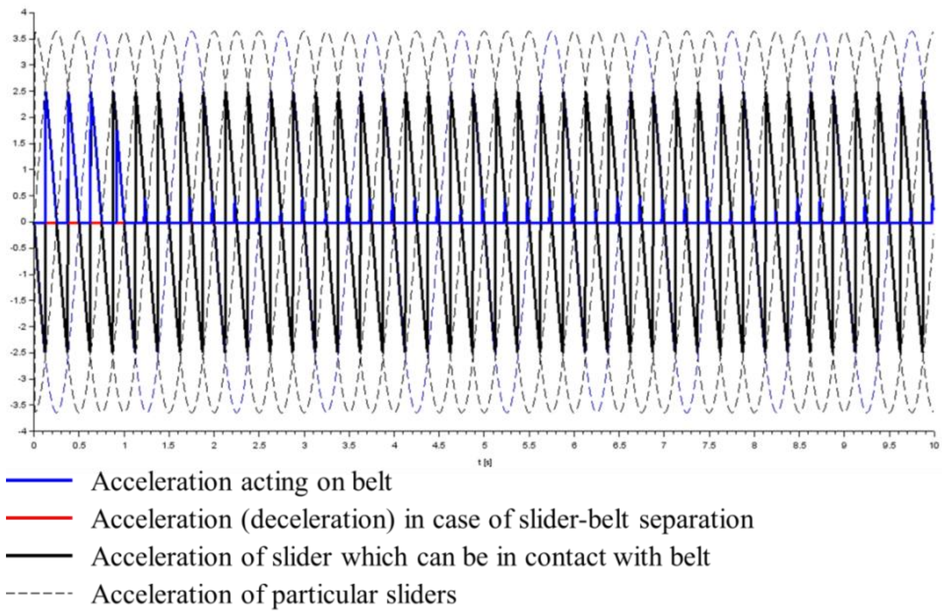

Fig. 3 – Acceleration of elements in considered system.

Fig. 3 presents the course of the values of acceleration of individual elements during the work of the transmission.

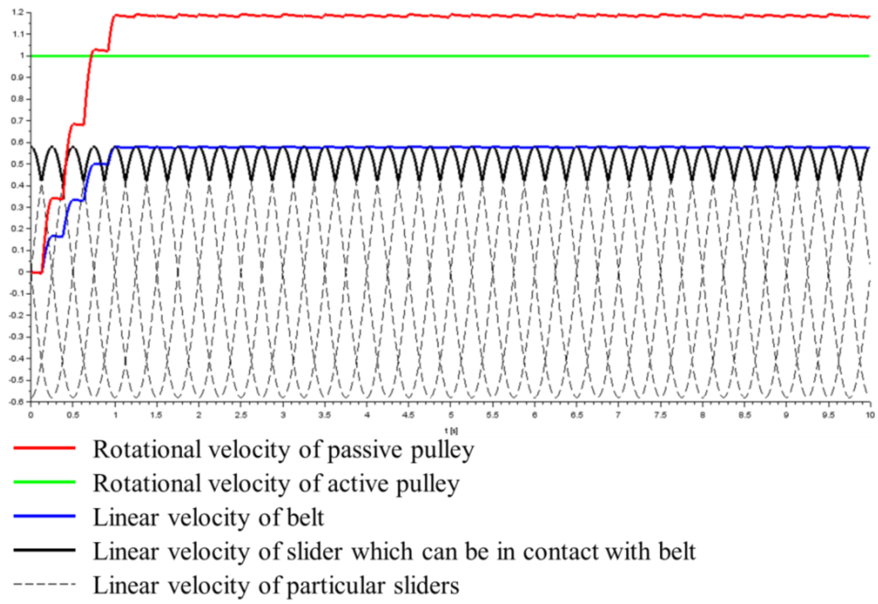

Fig. 4 – Velocity of elements in considered system.

The linear velocity of the belt can be determined by integrating the equations describing its acceleration in specific phases of motion. In the calculations the same value of the radius of the slider-crank mechanism crank (adjustable value) and the radius of the transmission passive pulley (constant value) have been adopted. Fig. 4 shows the course of the values of the velocity of individual elements during the work of the device.

4. Discussion and Conclusions

The results of the research show that there exists a method of the mechanical stepless change of the transmission ratio without the use of frictional coupling – in contrast to classical CVTs. It has been proved on the basis of the analysis of the author's own solution. The proposed method of the transmission ratio control results in obtaining the initial rotational velocity being close to the expected one, with the possibility of its adjustment within a specified range. The hypothesis has thus been confirmed. Further considerations shall pertain to the possibilities of the implementation of the developed solution in the bicycle drive system. The current issue consists in the appropriate design of the whole mechanism, which would allow to implement physically the above-described processes of the transmission of the motion and the change of the crank length.

The measures taken have led to the broadening of the knowledge constituting the foundation for the process of creating and analysing new solutions. It is possible to mitigate the risk of errors and the choice of inappropriate directions for further researches. As a result of the development of cycling, further needs and the problems related to bicycle drive are emerging constantly. Specific functionality is required while limiting size, weight or energy consumption. Particular attention is paid to the energy efficiency and environmental sustainability. The developed method can prove to be very helpful in the pursuit of obtaining the desired features. In the area of the stepless adjustment of the transmission ratio, the results of the considerations are to inspire applied and implementation work. A significant potential for the implementation of the proposed method in mechatronic equipment is recognised.

REFERENCES

Dietrych J., *System i konstrukcja*, Wydaw. Naukowo-Techniczne, Warszawa, 1985.

Giani P., Corno M., Tanelli M., Savaresi S.M., *Cyclist Heart Rate Control via a Continuously Varying Transmission*, IFAC Proceedings Volumes, **47**, *3*, 912-917 (2014).

Goszczak J., Radzymiński B., *Przekładnie o bezstopniowej zmianie przełożenia: CVT*, Autobusy: Technika, Eksploatacja, Systemy Transportowe, R. 19, *6*, 447-451 (2018).

Grzegożek W., *Przekładnie o ciągłej zmianie przełożenia (CVT) w układach napędowych pojazdów*, Wydawnictwo PK, Kraków, 2011.

Koziarski C., *Bezstopniowe przekładnie cierne: ciągła regulacja przełożenia za pomocą tarcia tocznego*, Wydawnictwa Naukowo-Techniczne, Warszawa, 2001.

Meyera D., Zhangb W., Tomizukab M., Sennera V., *Heart Rate Regulation with Different Heart Rate Reference Profiles for Electric Bicycle Riders*, Procedia Manufacturing, **3**, 4213-4220 (2015).

Oleksiuk W., Paprocki K., *Konstrukcja mechanicznych zespołów sprzętu elektronicznego*, Wydawnictwa Komunikacji i Łączności, Warszawa, 1997.

CONCEPTUL UNUI NOU TIP DE TRANSMISIE CU VARIAȚIE CONTINUĂ PENTRU BICICLETE

(Rezumat)

Lucrarea prezintă rezultatele considerațiilor privind o nouă modalitate de schimbare continuă a raportului de transmisie pentru bicicletă. S-a propus o soluție teoretică a problemei, prezentând elementele de bază ale mecanismului proiectat. S-a

presupus că aplicarea sa va permite obținerea rezultatului așteptat, asigurând o eficiență ridicată, o gamă largă de reglementări, precum și rapiditatea și uniformitatea efortului. Publicația descrie cercetările efectuate, incluzând, printre altele, dezvoltarea structurii și analiza mecanismului de transmisie. Aceste activități au dus la verificarea ipotezei. Lucrarea s-a bazat pe modelul fenomenologic care conține descrierea matematică a cinematicii și dinamicii sistemului analizat. Pe această bază, a fost evaluată utilitatea soluției propuse în asigurarea ajustării continue a raportului de transmisie.