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CYCLOIDAL PLANETARY TRANSMISSION

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ЦИКЛОИДАЛЬНАЯ ПЛАНЕТАРНАЯ ТРАНСМИССИЯ

The design and operation principle of the cycloidal planetary transmission (or gearbox) has been presented. The gearbox combines the planetary and parallel mechanisms. The planetary mechanism makes a system of planetary gears and rollers, which determines the proper work of the gearbox. Its fundamental and most important element is the cycloidal planetary gear. The cycloidal tooth profile has been made basing on the equations elaborated by the Fluid Power Research Group at the Mechanical Engineering Faculty of Wroclaw University of Technology. A test stand with the measuring equipment and the results of the research on the gear value have been presented.
Keywords: cycloidal planetary gear (or cycloidal planetary transmission), test stand, gear value

Introduction

Cycloidal planetary gearboxes feature high gear values, small size, compact design at high efficiency and long life performance. The cycloidal gears can be heavily loaded and quickly react to load changes. They are silent, ensure high motion regularity and are made from a smaller number of parts compared to the classic gears featuring the same gear value. Recently, they have been being continuously developed [1, 2].

Design and operation principle

Figure 1 illustrates a cycloidal planetary gearbox designed by the Fluid Power Research Group from Wroclaw. (FPRG Wroclaw).

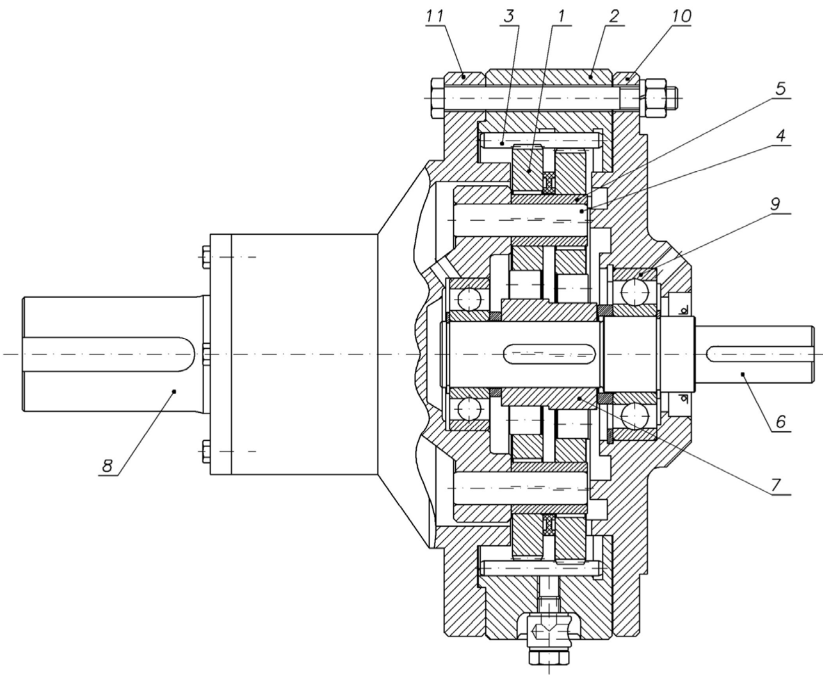

Fig. 1. Cycloidal planetary gear (described in the text)

A feature distinguishing this gearbox from other gearboxes is a pair of cycloidal planetary gears (1). The gears collaborate with rollers (3) located in the central gear (2) which plays a role of the body. The cycloidal planetary gears (1) are located on the drive shaft (6) by means of an eccentric roller bearing (7) and are reciprocally rotated by 180^o angle. A number of curves made according to the cycloidal profile [4, 6, 7], in the cycloidal planetary gears (1) corresponds with the number of teeth z_1. Thanks to the eccentric fixing on the drive shaft (6) of gear (1) during the operation of the gearbox, the gears revolve on the rollers (3). For the passing of the rotational motion from the drive shaft (6) on to the driven shaft (8) pins (4) fixed with sleeves (5) in the holes of both cycloidal planetary gears (1) are used. In order to fully transmit the motion from the driving onto the driven side, the pins (4) are additionally fixed in the holes of the driven shaft disc (8).

Analysis of the cycloidal planetary gearbox's operation principle shows that it is a particular kind of a rolling transmission, all geometrically jointed elements of which roll. The following rolling pairs can be distinguished, namely the cycloidal planetary gears (1) collaborating with the rollers (2) and making a gearing of the cycloidal planetary transmission, sleeves (5) rolling in the hole of the cycloidal planetary gear (1) as well as the rollers of the eccentric rolling bearing (4) are encased in the central hole of the planetary gear (1). Hence, the cycloidal planetary gear is the basic element of all the rolling pairs. An appropriate design of the gear is critical for the proper operation of the cycloidal planetary transmission. In the discussed cycloidal transmission, the cycloidal planetary gears show the epicycloidal teeth profile collaborating with the central wheel's rollers. It is made by the equidistant of the main shortened epicycloid, described by parametric equations (1) developed by the FPRG Wroclaw [4, 8]:

$$x_{eke} = \rho\cdot(z_1+1)\cdot\cos\eta - \lambda\cdot\rho\cdot\cos(z_1+1)\eta + g\cdot\frac{\cos\eta - \lambda\cdot\cos(z_1+1)\eta}{\sqrt{1-2\cdot\lambda\cdot\cos z_1\eta+\lambda^2}}, \tag{1}$$

$$y_{eke} = \rho\cdot(z_1+1)\cdot\sin\eta - \lambda\cdot\rho\cdot\sin(z_1+1)\eta + g\cdot\frac{\sin\eta - \lambda\cdot\sin(z_1+1)\eta}{\sqrt{1-2\cdot\lambda\cdot\cos z_1\eta+\lambda^2}},$$

where:

z_1 – number of teeth in the planetary wheel (gear);
ρ – radius of the wheel (gear) rolling on the base circle[mm];
λ – tooth depth ratio or epicycloid shortening ratio;
g – equidistant shift ratio [mm];
η – epicycloid angle.

Equation (1) defines the cycloidal planetary wheel teeth profile for different values of the toothing parameters, namely for z_1 tooth number, the rolling wheel radius ρ, the epicycloid shortening ratio λ and the equidistant shift ratio g.

Apart from the appropriate tooth profile design, it is critical to provide the proper collaboration of the two gears. Therefore, it is important to check the conditions of the gears collaboration in the system. The following conditions can be determined:

- the condition of generating the curve radius in the cycloidal planetary wheel:

$$\frac{z_1-1}{2\cdot z_1+1} \le \lambda \le 1, \tag{2}$$

- the condition of not undercutting of z_1 teeth in the cycloidal planetary wheel [3]:

$$e \ge g\cdot\frac{z_1+2}{3\sqrt{3}\cdot(z_1+1)}\cdot\sqrt{\frac{z_1+2}{z_1}}\cdot\sqrt{\frac{\lambda^2}{1-\lambda^2}}, \tag{3}$$

where:

e – eccentric on the inlet shaft

- the neighbourhood condition of z_2 rollers of the mating gear [3]:

$$e > g\cdot\frac{\lambda}{z_2\cdot\sin\frac{\pi}{z_2}}, \tag{4}$$

Based on that, the cycloidal planetary gears as well as the entire transmission have been designed for the following data: gear value u=71, output torque M_{wy}=1760 [Nm], the gear's inlet shaft rotational speed n_{we}=1500 [rev/min]. The gearbox has been manufactured in FAMA-Gniew (Poland).

Test stand

Figure 2 illustrates the concept of the test stand for the gearbox.

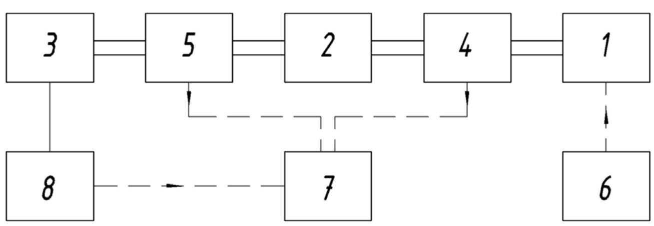

Fig. 2. Test stand diagram [5] (described in the text)

The cycloidal planetary gearbox (2) is driven by an electric motor (1) and loaded by a hydraulic pump (3). Measurement of the mechanical parameters of the transmitted power is performed on the inlet side of the cycloidal planetary gear by means of a low torque transducer (4), whereas on its outlet side, by a high torque transducer (5). The signals from the transducers are passed on to the measuring system (7) and recorded. The electric motor (1) is controlled by the control system (6), and the hydraulic pump (3) is both controlled and supplied by the hydraulic system (8). A design diagram of the test stand made basing on figure 2, has been shown in figure 3.

For the driving of the studied transmission, an electric motor Sg90A-5,5kW-1460 rev/min was used.

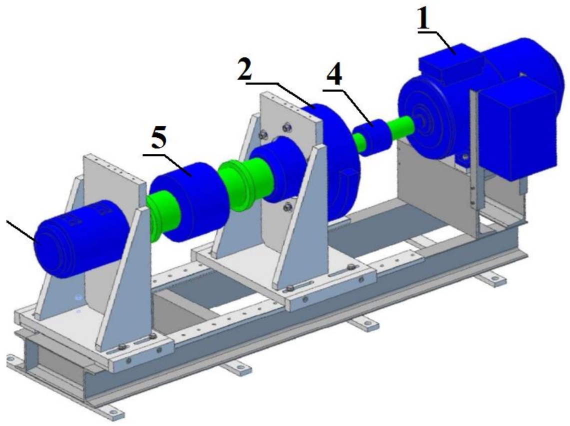

Fig. 3. Design diagram of the test stand [5] (described in the text)

Controlling the rotational speed of the motor's shaft is performed by a Hitachi inverter and is carried out in the range of 0÷1500 [rev/min] at 5 [kW] of the maximum mechanical power. The gearbox was loaded by a low-speed and high torque hydraulic motor HS-1-B made by FAMA-Gniew (Poland). The motor features a geometric working volume of q=1000 [cm^3/rev], and functions as a hydraulic pump. The possibility of controlling the value of the torque on the transmission's shaft is provided by the hydraulic system. Measurement of the mechanical values is performed with the use of a specially designed measuring system, the diagram of which has been presented in figure 4.

The main measuring unit is Spider8-a data recording system (1) which receives signals from the low torque transducers (2) and from the high torque transducers (3) as well as from the hydraulic system (4).

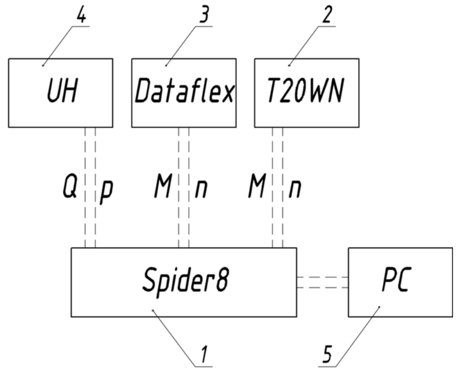

Fig. 4. Diagram of the measuring system [5] (described in the text)

Next, the recorded measurement data is sent to the computer (5), where it is analysed. The measurement of the torque and rotational speed on the inlet shaft of the cycloidal planetary transmission is performed by means of the HBM T20WM torque transducer, whereas on the outlet shaft, by means of the KTR Dataflex 85/2000 torque transducer.

Findings

The gearbox's operation correctness check was conducted at the initial start-up of the transmission. The process was carried out in two stages. At the first stage, the outlet shaft of the transmission remained unloaded. That stage corresponded to the gearbox's operation without the external loading, only at the start-up resistance inside the transmission. At the second stage, the outlet shaft was connected to the loading system. The transmission was subject to loading with the following torque values: M_{wy}=75, 150, 300, 500, 760 [Nm], at the inlet shaft rotational speed n_{we}=500÷1500 [rev/min.]. The initial research showed that the cycloidal planetary transmission worked properly, fluently, and without stoppage. Next, the kinematic transmission ratio of the gear was checked by measuring the values of input speed n_{we} and output speed n_{wy} as well as by defining their ratio. The measurement was conducted at the given values of output torque M_{wy} and inlet shaft speed n_{we}. The measurement results have been presented in figure 5.

It has been observed that the determined gear value at the research is close to the assumed gear value of u=71. The maximum gear value discrepancy is 0.46 [%]. At lower rotational speed of the inlet shaft of the cycloidal planetary transmission, and, consequently, at a lower rotational speed of the outlet shaft, the loading system performance was unstable, which caused several percent discrepancies of the recorded gear value compared to the assumed gear value.

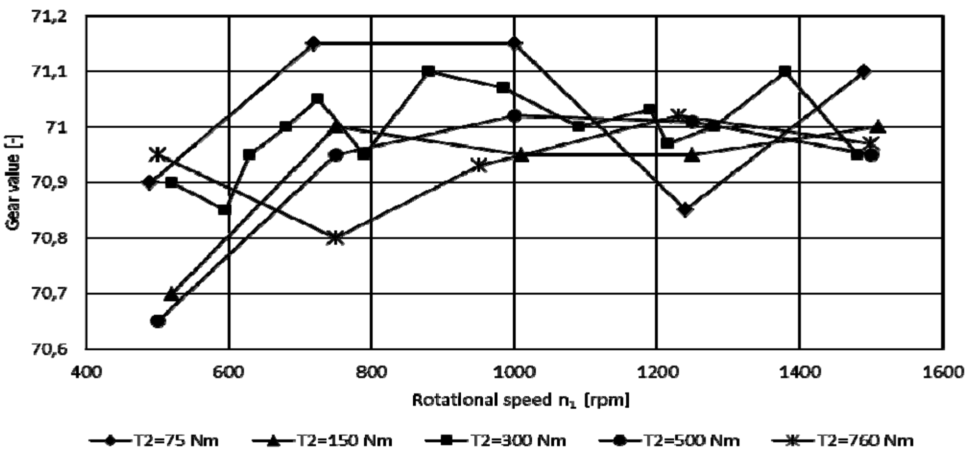

Fig. 5. Gear value measurement results [5]

Conclusion

The advantage of the cycloidal planetary transmissions (figure 1) over the classic transmissions, as well as the inverter or involute planetary gears is also the fact that they are smaller, silent-running, work more smoothly, more efficiently and show high gear value. They can be considerably overloaded and are rather insensitive to frequent motion direction change. Those advantages make them be more and more frequently applied in drive systems. Therefore, the FPRG from Wroclaw designed, built and then tested the cycloidal planetary transmission with the cycloidal gearing made according to equations [4, 5]. The initial research proved the transmission work properly.

Аннотация. *В статье представлена конструкция и принцип действия циклоидальной планетарной передачи (редуктора). Передача сочетает в себе планетарные и параллельные механизмы. Планетарный механизм образует систему планетарных передач и роликов, которые обеспечивают функционирование трансмиссии. Его основным и наиболее важным элементом является циклоидальный планетарный редуктор. Циклоидальный профиль зуба был выполнен соответственно уравнениям, предложенным Fluid Power Research Group факультета машиностроения Вроцлавского технологического университета. Представлен испытательный стенд с измерительным оборудованием и результаты испытаний механизма и определения передаточного отношения.*

Ключевые слова: *циклоидальный планетарный редуктор (циклоидальная планетарная передача), испытательный стенд, передаточное отношение.*

Анотація. *У статті представлена конструкція і принцип дії циклоїдальної планетарної передачі (редуктора). Передача поєднує в собі планетарні і паралельні механізми. Планетарний механізм утворює систему планетарних передач і роликів, які забезпечують функціонування трансмісії. Його основним і найбільш важливим елементом є циклоїдальний планетарний редуктор. Циклоїдальний профіль зуба був виконаний на основі рівнянь, запропонованих Fluid Power Research Group факультету машинобудування Вроцлавського технологічного університету. Представлений випробувальний стенд з вимірювальним обладнанням та результати випробувань механізму і визначення передатного відношення.*

Ключові слова: *циклоїдальний планетарний редуктор (циклоїдальна планетарна передача), випробувальний стенд, передатне відношення.*

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