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ANALYSIS OF GEAR RATIOS OF TWO DIFFERENT TYPES OF CYCLOID DRIVE TRAIN

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Abstract: The cyclo drive train is a special variant of the planetary drive train, where the planets are gears with a cycloid profile, while rollers are placed on the central gears (wheels). An analysis of the gear ratios of two types of cycloid drive train was performed. The first type is a classic cycloid drive train, while the second is a special variant with stepped planets. The cycloid drive with stepped planets can achieve very large gear ratios, while using central gears with a relatively small number of rollers.

Key words: Cycloid drive train, Gear ratio, Stepped planets

1 INTRODUCTION

The cycloid drive trains or drive train with cycloid profile gears can achieve high gear ratio in single stage and have many advantages, as compactness and simplicity of production. They are mainly planetary drive trains, which are used today as speed reducers with classic cycloid gear (figure 1a). Also, it is possible to use the special cycloid stepped gears (figure 1b), which enables a reduction in the volume of the drive train and a smaller number of rollers.

Due to the complicated and costly construction, the use of drive train with cycloid gears was avoided in the past. With the development of the modern CNC machining centers, it is possible to make the production process of these gears cheaper and simpler. Because of very wide area of application, production of cycloid drives has growing character and wide area of application: processing equipment, conveyors, presses, mixers, food industry, robots, automotive plants, spinning

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machines, cranes, etc.

Figure 1. *Classic cycloid gear (a), Stepped cycloid gear (b)*

2 CYCLOID DRIVE TRAIN WITH TWO DEGREES OF FREEDOM (DOF)

In the analysis of a simple cycloid drive, it can be started from an elementary planetary mechanism with internal coupling, replacing, for example, classic involute gears with cycloid gears (figure 2a). Members of the planetary mechanism whose axis coincides with the central axis and receive the external torques are called the basic members [1].

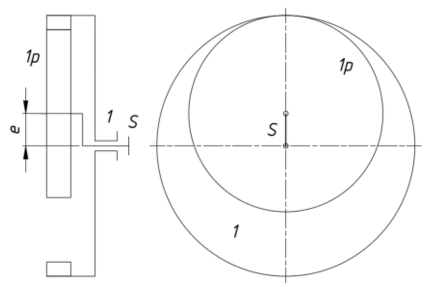

Figure 2. *Transformation of elementary mechanism to simple cycloid drive train*

The members of the elementary mechanism, the central gear (1) and the carrier (S), whose axes of rotation coincide with the base axis, can't be used in this case for the transfer of energy. This can be accomplished by adding another central gear or wheel (2) with the pins placed on the periphery, which meshes with the second cycloid gear (2p) (figure 1.b). The cycloid gears (1p) and (2p) are tightly connected in this case. This gives a simple cycloid drive or three-shaft cycloid drive with two DOF or *three-shaft cycloid drive train*. In literature, such coupled planetary gears (figure 2b) are called *stepped planets* [2, 3].

2.1 Gear ratio of three-shaft cycloid drive train

When denoting the gear ratios, it is necessary to make a difference when denoting the gear ratios of three-shaft cycloid drive with two DOF from two-shaft cycloid drive with one DOF. Therefore, in this study, will be used proposal [4], that the symbol "*i*" means only a constant, design dependent gear ratios (with one DOF).

The orders of two subscripts denote the order of input and output members. For the gear ratios of simple cycloid drive train with two DOF, will be used the symbol "*k*", so that, for example,

$$k_o = k_{12} = \frac{n_1}{n_2} = \frac{1}{k_{21}}, \tag{1}$$

represents the gear ratio between shafts 1 and 2.

It is possible to derive the equations for all gear ratios of simple cycloid drive with stepped gear (Table 1).

Table 1. *Equations of gear ratios of three-shaft cycloid drive train*

Reduced notation	Gear ratio $f(k_o)$
$k_{12} = i_o + (1 - i_o) k_{s2}$	$k_{12} = k_o$
$k_{21} = \frac{1}{i_o} + \left(1 - \frac{1}{i_o}\right) k_{s1}$	$k_{21} = \frac{1}{k_o}$
$k_{1S} = (1 - i_o) + i_o k_{2S}$	$k_{1S} = \frac{1 - i_o}{1 - \frac{i_o}{k_o}}$
$k_{S1} = \frac{1 - i_o k_{21}}{1 - i_o}$	$k_{S1} = \frac{1 - \frac{i_o}{k_o}}{1 - i_o}$
$k_{2S} = \frac{k_{1S} - (1 - i_o)}{i_o}$	$k_{2S} = \frac{1 - i_o}{k_o - i_o}$
$k_{S2} = \frac{k_{12} - i_o}{1 - i_o}$	$k_{S2} = \frac{k_o - i_o}{1 - i_o}$

3 GEAR RATIO OF TWO-SHAFT CYCLOID DRIVE TRAIN

It will be analyzed only drives with the numbers of pins of ring gear by one greater than the numbers of teeth of cycloid planet gear. The gear drives shown in figure 2b have two degrees of freedom (DOF). By blocking one of the basic members, a *two-shaft cycloid drive* is provided, which has only one DOF.

The cycloid drive works as classical gearbox (with a fixed and not rotating shafts) when the eccentric shaft is stopped. This simple working mode can be termed as the basic mode whereby the *basic gear ratio* is realized:

$$i_o = \left(\frac{n_1}{n_2}\right)_{n_S = 0}, \tag{2}$$

where is: n_1- speed of ring gear shaft *1*,
n_2- speed of ring gear shaft *2*,
n_S- speed of eccentric shaft *S*.

The complex general state of motion of a simple cycloid drive can be explained as the superposition of two partial motions. The first partial motion is the rotation of central ring rear (turning and meshing with planets), relative to the carrier. The second partial motion is an equal rotation of all shafts of basic members and it is same as rotation of carrier (eccentric shaft S).

If the two partial motions are superimposed, the total speed of each shaft is obtained as the sum of its partial speed and the basic gear ratio become [5]:

$$i_{12} = i_o = \frac{n_1'}{n_2'} = \frac{n_1 - n_S}{n_2 - n_S} \;, \qquad \text{so that}$$

$$n_1 - i_o n_2 + (i_o - 1)n_S = 0 \,. \tag{3}$$

From the equation (3), the shaft speed of a simple cycloid drive is obtained as follows:

$$\begin{aligned} n_1 &= i_o n_2 + (1 - i_o)n_S \,, \\ n_2 &= \frac{n_1 - n_S(1 - i_o)}{i_o} \,, \\ n_S &= \frac{n_1 - i_o n_S}{(1 - i_o)} \,. \end{aligned} \tag{4}$$

If the numbers of rollers of central gear by one greater than the numbers of teeth of cycloid planet gear, then the basic gear ratio of stepped gear cycloid drive is [6]:

$$i_o = i_{11p} i_{2p2} = \frac{n_1}{n_{1p}} \frac{n_{2p}}{n_2} = \frac{n_1}{n_2} = \frac{z_{1p}}{z_1} \frac{z_2}{z_{2p}} = \frac{z_2(z_1 - 1)}{z_1(z_2 - 1)} \,, \tag{5}$$

where is: $n_{1p} = n_{2p}$ – speed of stepped planets,
z_{1p} - the number of teeth on a cycloid gear *1*,
z_{2p} - the number of teeth on a cycloid gear *2*,
z_1 - the number of rollers on a wheel *1*,
z_2 - the number of rollers on a wheel *2*,
i_{11p} - gear ratio between wheel *1* and cycloid gear *1*,
i_{2p2} - gear ratio between cycloid gear *2* and wheel *2*.

Similar to previous, basic gear ratio of classic cycloid drive is:

$$i_o = i_{1p} i_{p2} = \frac{n_1}{n_2} = \frac{z_1 - 1}{z_1} \,, \tag{6}$$

where is: z_1 - the number of rollers on a wheel *1*,
i_{1p} - gear ratio between wheel *1* and cycloid gear,
$i_{p2} = 1$ - gear ratio between cycloid gear and wheel (disc) *2*.

The gear ratios of the tree possible options of two-shaft cycloid drive can be obtained using equations from Table 1, by setting appropriate gear ratio equal to zero if shaft was stopped (Table 2).

Table 2. *Gear ratios of two variants of cycloid drive*

Working mode	Gear ratio of stepped cycloid drive train *f*(z_1, z_2)	Gear ratio of classic cycloid drive train *f*(z_1)
Minimum increase	$i_{12}=\frac{z_2(z_1-1)}{z_1(z_2-1)}$	$i_{12}=\frac{z_1-1}{z_1}$
Minimum reduction	$i_{21}=\frac{z_1(z_2-1)}{z_2(z_1-1)}$	$i_{21}=\frac{z_1}{z_1-1}$
Maximum increase	$i_{1S}=\frac{z_2-z_1}{z_1(z_2-1)}$	$i_{1S}=\frac{1}{z_1}$
Maximum reduction	$i_{S1}=\frac{z_1(z_2-1)}{z_2-z_1}$	$i_{S1}=z_1$
Reversible increase	$i_{2S}=\frac{z_1-z_2}{z_2(z_1-1)}$	$i_{2S}=\frac{1}{1-z_1}$
Reversible reduction	$i_{S2}=\frac{z_2(z_1-1)}{z_1-z_2}$	$i_{S2}=1-z_1$

Cycloid drive train is mainly used as speed reducers. In order to understand the nature of the change in gear ratios, the theoretical models of a classical cycloid drive and cycloid drive with stepped planets will be considered. It is obvious, from table 2, that if the number of rollers $z_1=z_2$, there is a self-locking of the cycloid drive train with stepped planets. The variant with stepped planets is not used in practice for now, so it is very interesting to examine its possibilities.

Figure 3 shows the changing in gear ratios for maximum reduction (i_{S1}) and reversible reduction mode (i_{S2}). Number of rollers of wheel *1* is one less than the number of rollers wheel *2* are changing. This ratio of the number of rollers is mostly used with classic ones, while it can be different on cycloid drive with stepped planets. It is obvious that the classic cycloid drive can achieve a much smaller gear ratio compared to the cycloid drive with stepped planets, with the same number of rollers on wheel *1*. This enables the production of gear drive with smaller dimensions and a large gear ratio.

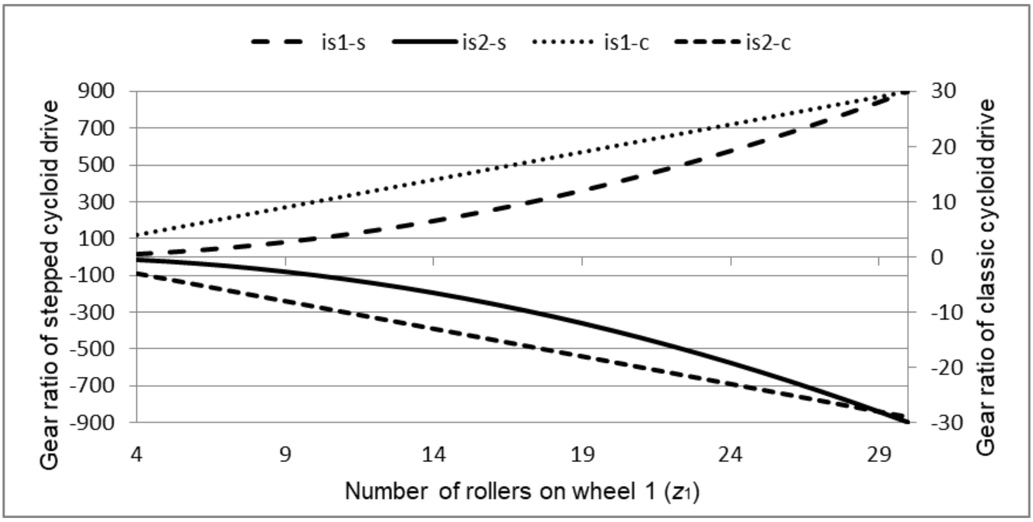

Figure 3. *Gear ratios of reduction working modes*

4 CONCLUSION

The cycloid drive with stepped planets can achieve very large gear ratios, while using ring gears (wheels) with a relatively small number of rollers. This makes it possible to design high gear ratio drive trains with small dimension.

In future research, it is necessary to analyze the efficiency of these drive trains and find the conditions under which self-locking occurs.

LITERATURA

[1] Tanasijević, S., Vulić, A., „Mehanički prenosnici“, Jugoslovensko društvo za tribologiju, Kragujevac,1994.
[2] Looman, J., Zahnradgetriebe: Grundlagen, Konstruktion, Anwendung in Fahrzeugen; Berlin: Springer-Verlag (1996).
[3] Müller, H. W, Die Umlaufgetriebe; Berlin: Spinger-Verlag (2001).
[4] Wolf, A.: Die Umlaufgetriebe und ihre Berechnung; VDI-Z. (91/22); pp. 597–603 (1949).
[5] Willis, R, Principles of Mechanism. London: Parker 1841.
[6] Mačkić, T., Tica, M., Šuba, R.,: Transmission characteristics of simple cycloid drive with stepped planets. IOP Conference Series Materials Science and Engineering 659 (2019) 012071.