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INFLUENCE OF THE PARAMETERS ON THE CONSTRUCTION OF THE POWER BALL PLANETARY TOROIDAL DRIVE

Summary. The article entails the parameters of the stator in a planetary toroidal drive. The depth of groove in the stator changes with the diameter of the stator. The depth of groove is influenced by the parameters of the transmission. It reaches a minimum value at least diameter and this value must also be sufficient.

Keywords. Stator, balls, worm, depth of groove.

WPŁYW WYBRANYCH PARAMETRÓW NA KONSTRUKCJĘ PLANETARNEJ PRZEKŁADNI TOROIDALNEJ Z ELEMENTAMI KULKOWYMI

Streszczenie. Artykuł przestawia zależności występujące w stojanie, analizę proporcji istotnych wymiarów stojana planetarnej przekładni toroidalnej z elementami kulkowymi. Głębokość rowków stojana zmienia się zależnie od średnicy stojana. Na głębokość rowka mają wpływ parametry przełożenia. Wartość minimalną osiąga się przy najmniejszej średnicy, ale również ta wartość musi być wystarczająca.

Słowa kluczowe. Stojan, kulki, ślimak, głębokość rowków.

1. INTRODUCTION

Transmissions are an important part of the mechanical equipment. There are many requirements that these drives must satisfy, such as negligible volition, peaceful operation, small parameters and so forth. With new technologies also come drives, for which elevated standards are required during their production. Planetary toroidal drive is spatial orbital drive. Balls and rollers could be used as rolling elements. The elements of the drive influence the effectiveness of the drive. The drive ratio could be up to *150*. The purpose of the article is to highlight the changes in the depth of the grooves in the stator.

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2. PLANETARY TOROIDAL DRIVE WITH ROLLING OBJECTS – BALLS

Planetary toroidal drive is a coaxial reducer [1]. The drive is composed of these basic parts (Fig. 1): globoidal worm *1*, planets (satellites) in which the balls are placed *2*, calibrated stator *3* and a catch driver of the satellites *4*. The grooves are cut in the globoidal worm; the number of grooves (teeth) is z_1. These grooves represent the teeth in the cogged drives. Inside the stator, the grooves are cut (Fig. 2), the number of grooves (teeth) is z_3. The balls work inside the grooves of the worm and the stator. The planets are anchored inside a catch driver of the planets. The planets are double rotating around their own axis and around the axis of the drive. The input is from the worm and the output is on the catch driver. The teeth (grooves) in the worm and stator can have a congruent or incongruent direction [2], [3]. A change in the direction of the grooves, does not only alter the direction of the entry component's rotation towards the exit component's rotation, but also changes the activity of the drive. The transmission activity is not dependent on the number of rolling figures inside the planet.

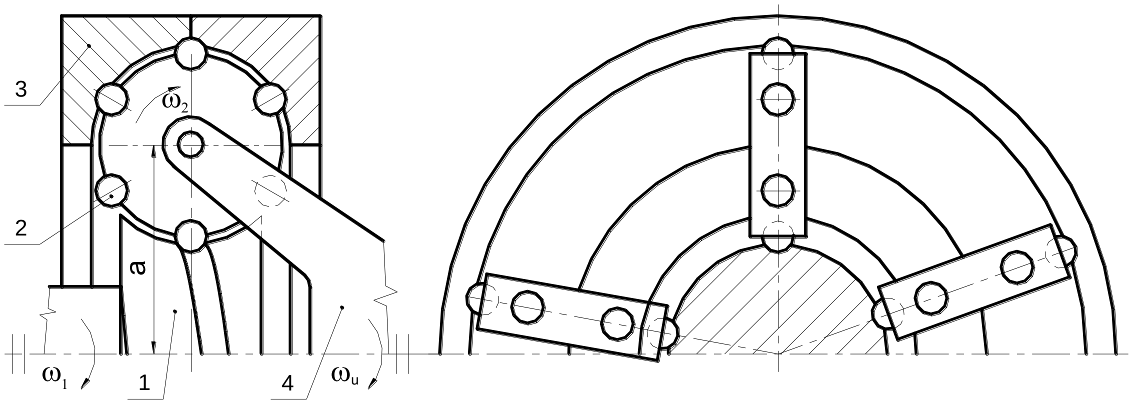

Fig. 1. Planetary toroidal balls drive
Rys. 1. Planetarna przekładania toroidalna z elementami kulkowymi

2.1. GROOVES IN THE STATOR

Grooves in a character of a screw on a toroidal plane are cut into the stator (Fig. 2). The helix angle α_{3i} in the stator's screw is variable. [1], [2].

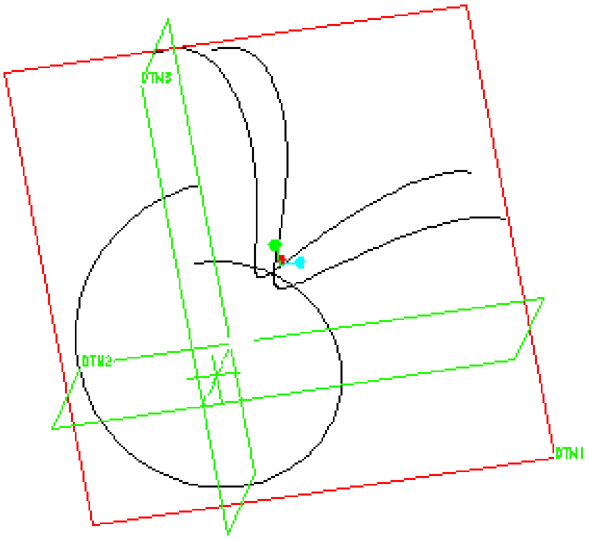

Fig. 2. Grooves of the worm in a globoidal worm and two grooves in the stator
Rys. 2. Rowek śrubowy w ślimaku globoidalnym i dwa rowki w stojanie

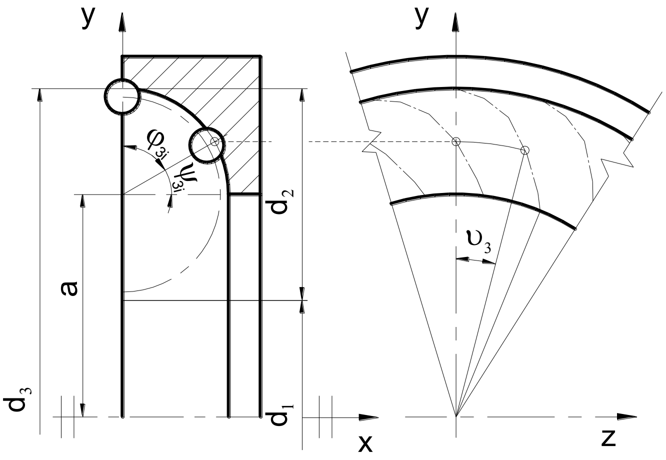

Fig. 3. Part of the stator with grooves – defining the parameters of the drive
Rys. 3. Część stojana z rowkami – określenie parametrów przełożenia

The parameteters of the drive are defined in Fig. 3. The diameter of the worm is d_1, the diameter of the satellite is d_2 and the diameter of the stator is d_3 in the central slit. The diameter of the stator is generally noted with an index *i*. Angle φ_{3i} is steer angle of roller inside the stator [°]. The drive condition is not dependant on the number of roller in the satellite, nor is dependent on the number of satellites.

Gear ratio

$$i = \frac{z_3}{z_1} \pm 1 \tag{1}$$

Where: z_1 – number of teeth (grooves) in the worm
z_3 – number of teeth (grooves) in the stator

Diameter of the stator in a local point

$$d_{3i} = d_1 + d_2 \cdot (1 + \cos\varphi_{3i}) \tag{2}$$

Where: d_1 – diameter of worm in its center [mm]
d_2 – diameter of satellite [mm]
d_{3i} – diameter of stator in its local point [mm]

Tangent of the stator's helix angle α_{3i} changes in response to the stator's diameter

$$tg\alpha_{3i} = \frac{z_3 \cdot d_2}{z_2 \cdot d_{3i}} \tag{3}$$

Where: α_{3i} – helix angle of the stator [°]
z_2 – number of balls in the satellite
z_3 – number of grooves (teeth) in the stator
d_2 – diameter of the satellite [mm]

2.2. DEPTH OF GROOVE IN THE STATOR

Part of the stator together with the grooves for the rollers is in Fig. 4. The grooves are cut without a space. The depth is defined as h_0 at the largest diameter.

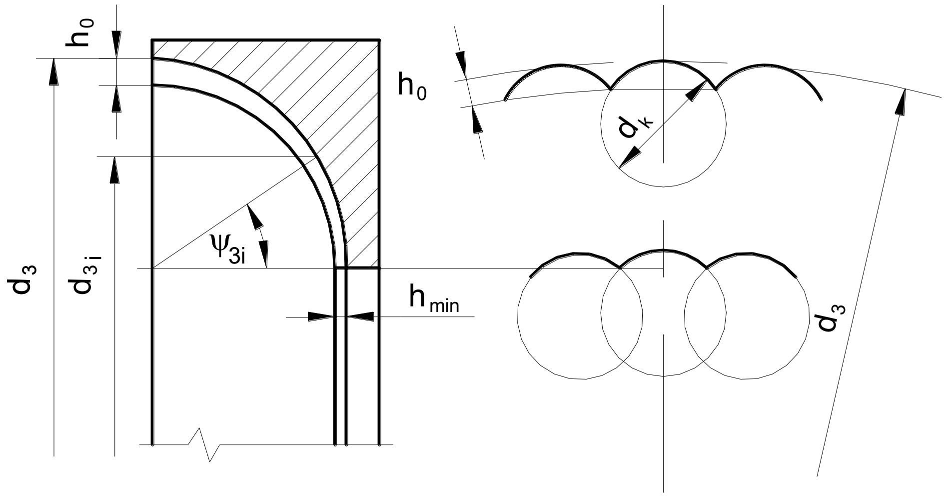

Fig. 4. The depth of the groove in the stator for the grooves without a space
Rys. 4. Głębokość rowków w stojanie dla rowków naciętych bez odstępu

Enlarged ball in the groove of the stator in a head-on plane is drawn in Fig. 5. There, the lenght of the arch AB with a diameter $(d_3\text{-}2h_0)$ is the lenght in the normal plane. It is the chord of the ball where the gear is occuring.

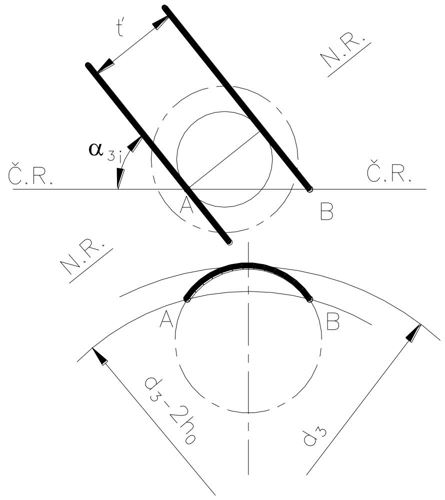

Fig. 5. The ball in groove of a stator in transverse and normal plane
Rys. 5. Kulka w rowku stojana w płaszczyźnie czołowej i normalnej

The length of the arch *AB* (Fig. 4, Fig. 5) in the largest diameter

$$AB = \frac{\pi \cdot (d_3 - 2h_o)}{z_3} \tag{4}$$

Where: AB – length of the arch [mm]

h_0 – depth of the groove in a maximal diameter [mm]

The length of the chord *t′* (Fig. 4, Fig. 5) of a ball while gear is occurring in the groove of the stator

$$t' = 2 \cdot \sqrt{d_k \cdot h_o - h_o^2} \tag{5}$$

Where: t´ – chord [mm]
d_k – diameter of the ball [mm]

The arc *AB* is treated as a straight line after the size of the diameter of the ball d_k is considered

$$\sin\alpha_3 = \frac{t'}{AB} \tag{6}$$

After arch is being substituted for

$$\frac{\pi\cdot\left(d_3-2\cdot h_o\right)}{z_3}=\frac{2\cdot\sqrt{d_k\cdot h_o-h_o^2}}{\sin\alpha_3} \tag{7}$$

When we disregard the value $\left(-\frac{2h_0}{z_3}\right)$ from the left side of the equation, for the largest diameter of the stator applies that (when solving appropriate quadratic function only the smaler element will be considered)

$$h_0=\frac{d_k}{2}-\frac{1}{2}\cdot\sqrt{d_k^2-\left(\frac{\pi\cdot d_3}{z_3}\right)^2\cdot\sin^2\alpha_3} \tag{8}$$

The depth in the local point will be

$$h_{0i}=\frac{d_k}{2}-\frac{1}{2}\cdot\sqrt{d_k^2-\left(\frac{\pi\cdot d_{3i}}{z_3}\right)^2\cdot\sin^2\alpha_{3i}} \tag{9}$$

Individual parametes of the drive such as z_2, z_3, d_1, d_2, d_k can be manipulated in the software that was constructed for the observation of the depth of the grooves. This way, the depth of the grooves can be manifested in relation to the angle φ_{3i}. When the angle φ_{3i} changes, the diameter of the stator changes as well. It can be seen from the description of the relationships (9), that when the diameter of the ball d_k is not changing, only the second part of the equation under the square root is being changed. The minimal depth will be observed at the smallest diameter of the stator.

The change in the depth h_i for following parameters $d_1 = 110$ *mm*, $d_2 = 110$ *mm*, $d_k = 15{,}5$ *mm*, $z_2 = 12$, $z_3 = 72$ can be observed from the Tab.1 and the graph (Fig. 6). From the relationships stated, the depth at the smallest diameter constitutes only about *40%* of the depth at the maximal diameter, which doesn't have to be a sufficient value. Herz's pressures could be the limiting factor. The stator could be designed, so that the angle φ_3 is *70°* at maximum and the angle ψ_i starts at *20°*, in order for the stability of the required depth.

Table 1

The depth of the grooves in the stator for the values $d_3 = 330mm$, $z_2 = 12$ $z_3 = 72$,

ψ_{3i}(°)	d_{3i}(mm)	α_{3i}(°)	h_i(mm)	h(%)
0	220,000	71,5651	1,479	43,01
10	239,101	70,0859	1,749	50,89
20	257,622	68,6775	2,036	59,23
30	275,000	67,3802	2,329	67,74
60	315,263	64,4676	3,108	90,42
90	330,000	63,4350	3,438	100,00

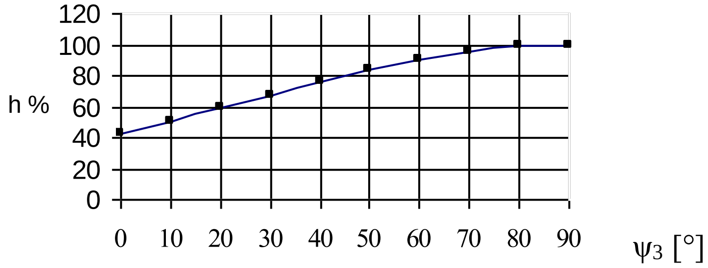

Fig. 6. The depth of the groove in the stator
Rys. 6. Głębokość rowka w stojanie

3. CONCLUSION

Problems arise during designing of new drives. Favorable gear conditions could be achieved by researching different parameters. If there are spaces between individual grooves at the largerst diameter, then the spaces at the smallest diameter would be smaller, but not absent. More favorable gear conditions occur when the number of balls in the satellite is the largest. The depth of the groove in the stator is diminished and its value might not be sufficient at the smallest diameter.

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