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NORMAL FORCES ON A STATOR IN A PLANETARY TOROIDAL ROLLER DRIVE

Summary. This article deals with power activity on a stator in a planetary toroidal drive. The article entails such kinds of parameters which are necessary to influence size and course of normal forces.
Keywords. Force proportions, normal forces, stator, worm, number of rollers in a planets.

SIŁY NORMALNE NA STOJANIE W PLANETARNO-TOROIDALNEJ PRZEKŁADNI WALCOWEJ

Streszczenie. W artykule analizowane są stosunki sił na stojanie w przekładni planetarno-toroidalnej. Zostało w nim omówione, za pomocą jakich parametrów można oddziaływać na wielkość oraz przebieg sił normalnych.
Słowa kluczowe. Stosunki sił, siły normalne, stojan, ślimacznica, liczba walców w satelicie.

1. INTRODUCTION

Various requirements are imposed on the drivers, which can be fulfilled with the usage of unusual or little-known drivers. An achievement of small values of wills, smaller size and lower noise are all part of those requirements. A planetary toroidal drive [2] belongs to the little-known transmissions. The aim of this article is to discus power parameters on a stator in an ideal toroidal transfer and the influence of individual parameters on the size of the normal forces.

2. PLANETARY TOROIDAL DRIVE WITH ROLLING OBJECTS – ROLLERS

Planetary toroidal drive is a coaxial reducer [1]. Roller drive is composed of these basic parts (Fig. 1): globoidal worm *1*, planets (satellites) *4* in which the rollers are placed *2*, calibrated stator *3* and a catch driver of the satellites *5*. A groove is cut in the globoidal worm; the number of grooves (teeth) is z_1. Inside the stator, the grooves are cut (Fig. 2), the number

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of grooves (teeth) is z_3. Rollers with radial axis are placed inside the stator. The rollers are turning around their axis and 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.

In Fig. 1, the planets are placed on the second picture, but their catch driver is not shown for a simplification. While an assemble condition must be fulfilled first, the planets are distributed unevenly. If the number of the planets is n, then the angle among the planets is δ_s and the last angle stays equal to $360° - n.\ \delta_s$.

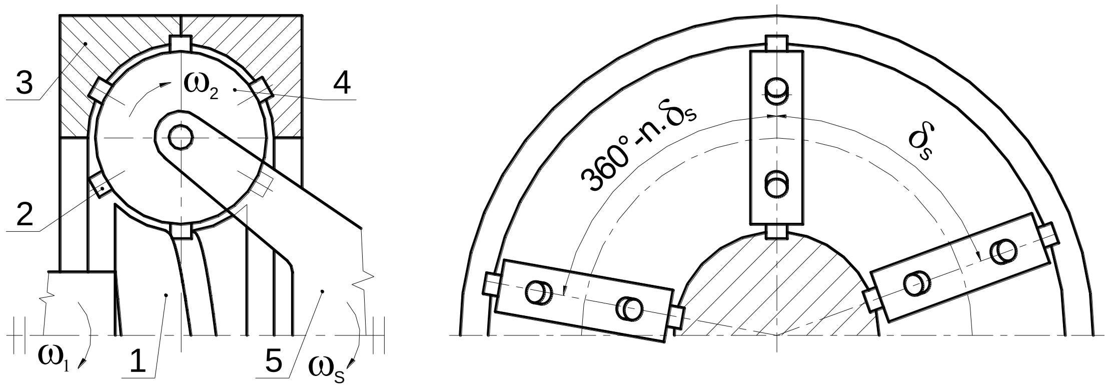


Fig. 1. Planetary toroidal roller drive
Rys. 1. Planetarno-toroidalna przekładnia walcowa

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. An angle φ_{3i} is defined according to a vertical axis, an angle ψ_{3i} accordingly to the horizontal axis [1], [2].

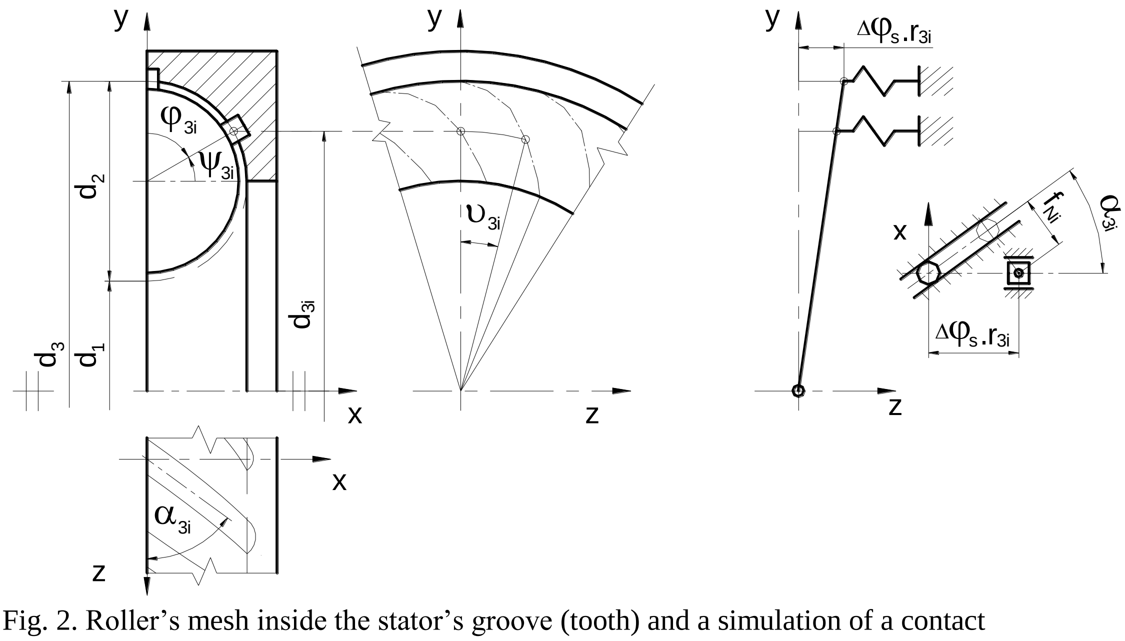


Fig. 2. Roller's mesh inside the stator's groove (tooth) and a simulation of a contact
Rys. 2. Zazębienie walców w rowku stojana oraz symulacja styku

Drive 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

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

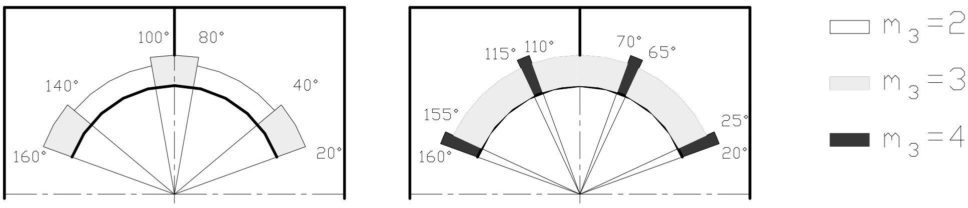
Where: d_1 – diameter of worm in its center [mm]
d_2 – diameter of satellite [mm]
d_{3i} – diameter of stator in its local point [mm]
φ_{3i} – steer angle of roller inside the stator [°]

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 rollers in the satellite
z_3 – number of teeth (grooves) in the stator
d_2 – diameter of the satellite [mm]

In Fig. 3 are alternating points of an intervention, when the number of rolling objects z_2 in one satellite is *6* or *8* and the angle of the stator's half is *70°*. Areas of concurrently intervening objects m_3 in one planet are defined with shadows of grey colour. When $z_2=6$, areas where an intervention of two or three rolling objects are alternating.



$z_2 = 6$ $z_2 = 8$

Fig. 3. Number of concurrently meshing rollers in the stator when a stator's angle ψ_{3i} is from 20° to 160°

Rys. 3. Liczba równocześnie zazębiających się walców w stojanie, jeżeli kąt stojana ψ_{3i} wynosi od 20° do 160°

2.1. Power activity on a stator

Power activities are observed when in ideal transmission (without dropout) with the usage of perfected structural elements. In real concept are forces on rollers influenced with exactness of transfer members, friction, quality of material, and also with the unequal weight induced on individual satellites.

A method of the flexibility theory for statically definite systems can be used to designate normal forces, when following the inscribed assumptions. Simplified model of wheelwork in released drive of the catch driver and a sturdy output on the planets are studied when assigning forces Fig. 2 and Fig. 4 [3], [4]. Springs (Fig. 2) are stimulating a contact between the roller of the planet and the stator's groove, and present firmness *c* conforming the sturdiness of the roller's tenons. When the catch driver is turned in a certain angle $\Delta\varphi_S$, an i- like roller bends in a value f_{N3i} in the groove of the stator. A force, which is then generated, corresponds to the normal force on the roller.

Normal force

$$F_{N3i} = c \cdot f_{N3i} = c \cdot \Delta\varphi_S \cdot r_{3i} \cdot \sin\alpha_{3i} \tag{4}$$

Where: c - stiffness [N/mm],
f_{N3} - perpendicular distance [mm],
r_{3i} - radius of the stator in its local point [mm]

Torque on the stator T_3 designated by a circumferential force

$$T_3 = \sum_{i=1}^{m_3} F_{t3i} \cdot r_{3i} = \sum_{i=1}^{m_3} F_{N3i} \cdot \sin\alpha_{3i} \cdot r_{3i} \tag{5}$$

Where: F_{t3} - Tangential force [N],
F_{N3} - Normal force [N],

Torque on a stator following the entrance moment rotating T_1

$$T_3 = T_1(i-1) = c \cdot \Delta\varphi_S \cdot \sum_{i=1}^{m_3} r_{3i} \cdot \sin^2\alpha_{3i} \tag{6}$$

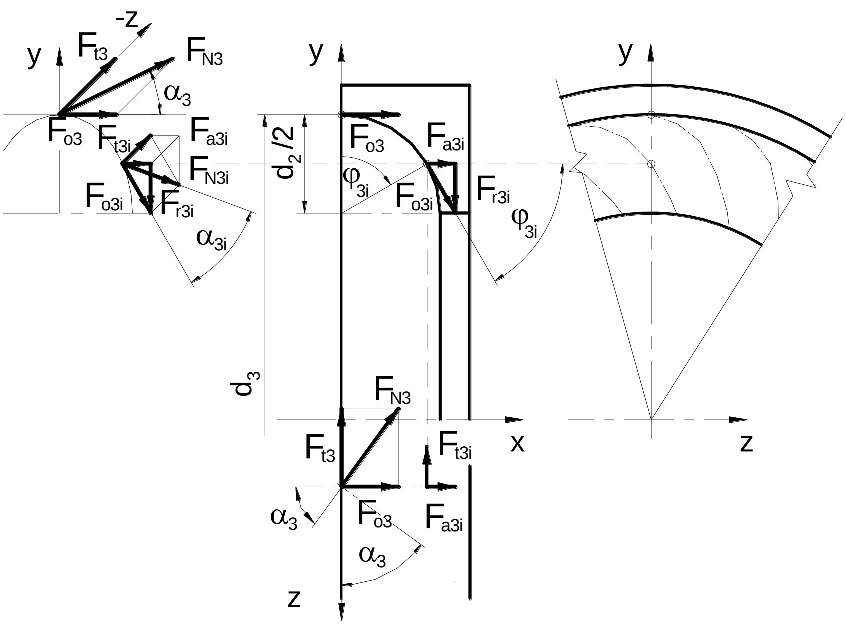


Fig. 4. Force proportions in the middle of the stator and in a local point
Rys. 4. Stosunki sił w środku stojana oraz w określonym punkcie

After expressing the relation $c.\Delta\varphi_S$ from the equation (3) and (7), and simplificating, we obtain a normal force, when using *n* planets

$$F_{N3i} = \frac{T_1 \cdot \cos\alpha_{3i}}{n \cdot r_2 \cdot \sum_{i=1}^{m_3} \cos^2\alpha_{3i}} \tag{7}$$

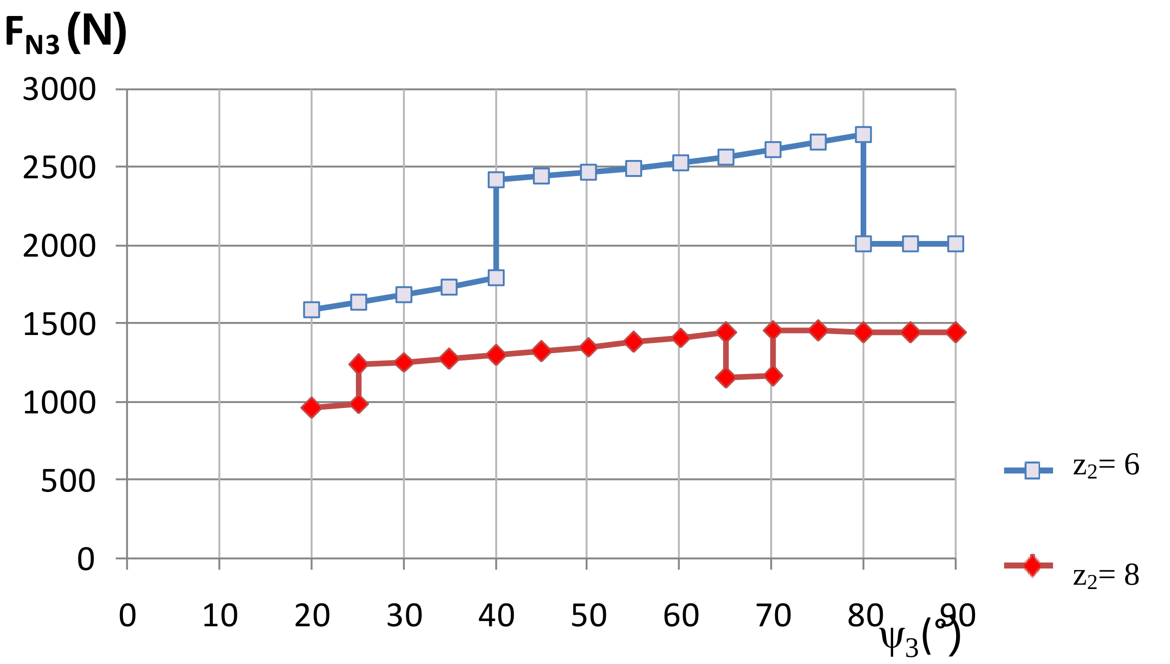
We use relation x_p, which allows the change of diameter of a worm and a planet without any alteration of the outside format. This relation is $x_p = d_2/d_1$. With the change of a parameter, the size of the forces changes as well.

Some of the values for normal forces, with the entrance output 15kW and ω_1=150s^{-1} for two values of the relation x_p, are calculated in a table 1. Normal forces gain lower value, when the satellite has a maximal and the worm a minimal diameter.

Table 1

Normal forces on a stator for the values d_3 = 260mm, z_2 = 6, z_3 = 36, n=6

z_2=6			z_2=8		
ψ_3 [°]	F_{N3}[N] x_p=1,357	F_{N3}[N] x_p=0,8	ψ_3 [°]	F_{N3}[N] x_p=1,357	F_{N3}[N] x_p=0,8
20	1590,75	1657,82	20	957,12	1014,94
	1791,36	1815,46		987,39	1038,36
40	2417,64	2505,45	25	1233,71	1318,04
60	2525,75	2589,91		1444,22	1482,18
	2708,99	2737,76	65	1155,86	1167,66
80				1178,57	1185,18
	2007,23	1983,80	70	1449,88	1486,05
90	2004,22	1980,74	90	1439,78	1477,57



Rys. 5. Przebieg sił normalnych na stojanie dla z_2= 6 oraz z_2= 8 i x_p= 1,357

Fig. 5. Course of the normal forces on a stator for z_2= 6 a z_2= 8 and x_p= 1,357

In Fig. 5, the course of normal forces on stator is displayed. We see, that values of normal forces boldly decrease, when there are 8 rolling objects inside the stator.

3. CONCLUSION

The course of the forces is dependent on the stator's angle, number of rolling objects inside the satellite, and on internal parameters of the transfer. Values of normal forces boldly decrease, when the number of rolling objects inside the planet increases. An increase in the number of objects is limited due to structural aspects.

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