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THE STRUCTURE, EFFICIENCY AND KINETOSTATIC OF A NEW TWO STAGE COAXIAL PLANETARY TRAIN

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Abstract: *Planetary gear systems are widely used in helicopter and aircraft transmissions, automotive automatic gearboxes, many industrial applications and wind power plants as major source of renewable energy. A single stage planetary gear consists of a sun wheel, a ring wheel and the carrier element, which support the planet gears in their rotation around the common symmetry axis of both sun and ring wheels. This arrangement allows a high transmission ratio. In this paper the structure of a new two stage planetary gear with dual path as a speed amplifier is presented. Also the total amplification ratio, the formulas for the global efficiency and the torques on each axis are derived.*

Key words: *Planetary Gear Train, Dual Path Gear Train, Wheel, Global Efficiency, Torque.*

1. INTRODUCTION

Planetary gear systems are widely used in helicopter - aircraft transmissions, automotive automatic gearboxes, many industrial applications and wind power plants as major source of renewable energy. A single stage planetary gear consists of a sun wheel, a ring wheel and the carrier element, which support the planet gears in their rotation around the common symmetry axis of both sun and ring wheels. This arrangement allows a high transmission ratio up to 10 - 12. At coaxial planetary gear trains with dual path the input power is split to its planetary stages, thus leading to a reduced space and weight of the gear assembly, elimination or reduction of centrifugal loads on planet pinion bearings. In addition to this advantage this arrangement allows an increased transmission ratio, which can reach up to 250 -300. On the debit size the efficiency of the split power planetary gear is a special issue as the higher the transmission ratio is the lower the efficiency becomes. Nowadays worldwide wind power is a major source of renewable and environment friendly energy [1], [2]. To gain electricity efficiently in a wind power plant the increase of the speed rate of the fan input shaft is strictly necessary. This is made mainly by placing a high ratio coaxial dual path multi stages planetary gear train amplifier between rotor shaft and generator.

Fundamental works regarding this topic were made by Müller [4] and Terplan [5]. White [2] presents 16 arrangements of dual coaxial planetary stages. This paper deals with the structure, the global efficiency, total gear ratio and occurring forces of a new two stages coaxial planetary gear train from a wind turbine.

2. THE STRUCTURE

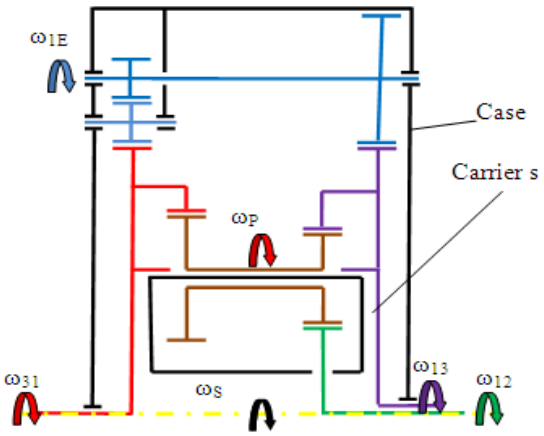

Fig. 1. The kinematic scheme

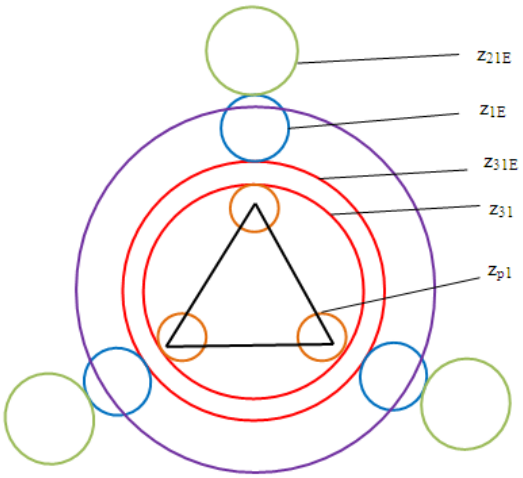

Fig. 2. The front view

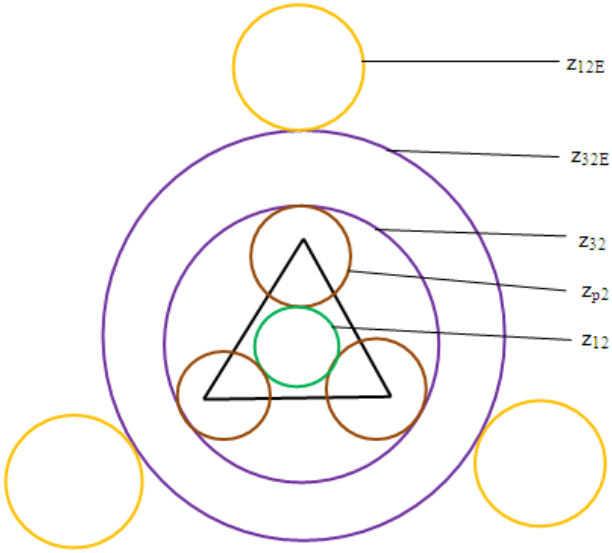

Fig. 3. The back view

In Fig.1 - Fig.3 the kinematic scheme of a new two stage coaxial planetary train are shown. The main stage is a two stage Wolfrom planetary gear whose ring wheel on the second stage is actuated by a fixed gear train z_{31E}, z_{1E}, z_{21E}, z_{12E}, z_{32E}. The main role of the fixed planetary gear is to amplify and invert the rotation of the input shaft.

Notations:

- z_{31E}, z_{1E}, z_{21E}, z_{12E}, z_{32E}, z_{p1}, z_{p2}, z_{12}, z_{32}, z_{31} - the tooth numbers of the gear;
- η_{p301}, η_{p302} - the internal efficiency of the second stage of the Wolfrom gear
- η_{E0} - the internal efficiency of the fixed
- η_T - the total efficiency of the dual path gear

For the fixed gear trai the following equation can be written:

$$\frac{\omega_{32}}{\omega_{31}} = -\frac{z_{31E}}{z_{21E}}\frac{z_{12E}}{z_{32E}} = u_{31} \qquad (1)$$

Where u_{31} is the total transmission ratio of the fixed gear.

3. THE KINEMATICS

According to Willis's theory for each stage of the Wolfrom planetary gear the following relations can be written:

$$\frac{\omega_{31} - \omega_s}{\omega_p - \omega_s} = +\frac{z_{p1}}{z_{31}} = a \qquad (2)$$

$$\frac{\omega_{32} - \omega_s}{\omega_p - \omega_s} = +\frac{z_{p2}}{z_{32}} = b \qquad (3)$$

$$\frac{\omega_{32} - \omega_s}{\omega_{12} - \omega_s} = -\frac{z_{12}}{z_{32}} = c \qquad (4)$$

From Eqn. (2) – Eqn. (4) the following system of linear eqn. can be written:

$$\begin{cases} a\omega_p + (1-a)\omega_s = \omega_{31} \\ b\omega_p + (1-b)\omega_s = u_{31}\omega_{31} \\ c\omega_{12} + (1-c)\omega_s = u_{31}\omega_{31} \end{cases} \qquad (5)$$

By solving eqn. (5) one can obtain the relations of the angular velocity of each part of the entire gear with respect to ω_{31} the angular velocity of the input shaft:

$$\omega_s = A\omega_{31}, \omega_p = B\omega_{31}, \omega_{12} = \omega_{OUT} = u_E\omega_{31},$$
$$A = \frac{\Delta_1}{\Delta}, B = \frac{\Delta_2}{\Delta}, \Delta = a - b, \Delta_1 = 1 - u_{31}a + u_{31}b$$
$$\Delta_2 = u_{31}a - b, u_E = \frac{(1+c)A - u_{31}}{c}; \qquad (6)$$

Assuming that both sages of the Wolfrom planetary gear have the same module and

taking account the geometry of the mechanism, the following relations can be written:

$$\begin{aligned} z_{32} &= z_{12} + 2z_{p2}, \\ z_{32} &= z_{12} + z_{p2} + z_{p1} \end{aligned} \tag{7}$$

4. THE KINETOSTATICS

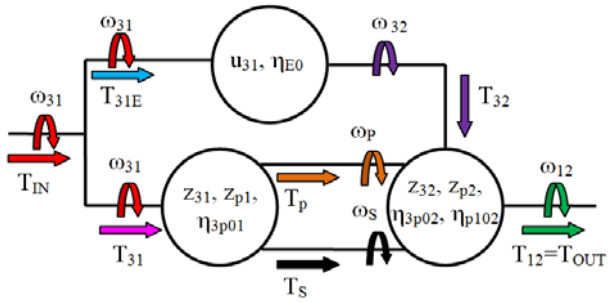

Fig. 4. The black box scheme

In Fig.4 the black box scheme of the dual path gear are shown. This is useful in determining of the torques and the total efficiency of the gear. According to Fig.4 the equation of torque balance at the input shaft have the following form:

$$T_{IN} + T_{31E} + T_{31} = 0 \tag{8}$$

For each planetary sage of the Wolfrom gear the energy balance equations can be written as follows:

$$\begin{aligned} &\eta_{p301}(\omega_{31} - \omega_s)T_{31} + \omega_p T_p = 0, \\ &\eta_{p302}(\omega_{32} - \omega_s)T_{32} + \omega_p T_p = 0, \\ &\eta_{p302}\eta_{p102}(\omega_{32} - \omega_s)T_{32} + (\omega_{12} - \omega_s)T_{OUT} = 0; \end{aligned} \tag{9}$$

The energy balance equation for the fixed gear train have the following form:

$$\eta_{E0} T_{31E} \omega_{31} + T_{32}\omega_{32} = 0 \tag{10}$$

Eqn.(8) – (10) consit a system of 5 linear equations having the following unknowns: T_{31E}, T_{31}, T_p, T_{32}, T_{OUT}. All these unkown will be expressed with respect to the imput torque T_{IN}. According to the notations (2), (3), (4) and (6) the equations (8) – (10) can be rewritten into the following form:

$$T_{IN} + T_{31E} + T_{31} = 0 \tag{11}$$

$$\eta_{p301}(1-A)T_{31} + BT_p = 0 \tag{12}$$

$$\eta_{p302}(u_{31} - A)T_{32} + BT_p = 0 \tag{13}$$

$$\eta_{p302}\eta_{p102}(u_{31} - A)T_{32} + (u_E - A)T_{OUT} = 0 \tag{14}$$

$$\eta_{E0} T_{31E} + T_{32} u_{31} = 0 \tag{15}$$

From Eqn.(11) – (15) yields:

$$T_{31} = -\frac{1}{1 + K_{31E}} T_{IN} \tag{16}$$

$$T_{31E} = -\frac{K_{31E}}{1 + K_{31E}} T_{IN} \tag{17}$$

$$T_p = -\frac{\eta_{p301}(1-A)}{B(1 + K_{31E})} T_{IN} \tag{18}$$

$$T_{32} = -\frac{BK_p}{\eta_{p301}(u_{31} - A)} T_{IN} \tag{19}$$

$$T_{OUT} = -\frac{\eta_{p302}\eta_{p102}(u_{31} - A)K_{32}}{A - u_E} T_{IN} \tag{20}$$

Where:

$$K_{31E} = -\frac{\eta_{p301}\eta_{p102}(1-A)u_{31}}{\eta_{p302}\eta_{E0}(u_{31} - A)} \tag{21}$$

$$K_p = \frac{\eta_{p301}(1-A)}{B(1 + K_{31E})} \tag{22}$$

$$K_{32} = -\frac{BK_p}{\eta_{p301}(u_{31} - A)} \tag{23}$$

$$\eta_T = \frac{\eta_{p302}\eta_{p102}(u_{31} - A)K_{32}}{u_E - A} u_E \tag{24}$$

4. CONCLUSIONS

In this paper the structure of a new two stage planetary gear with dual path as a speed amplifier is presented. Also the total amplification ratio, the formulas for the global efficiency and the torques on each axis are derived. The development of new multi stage planetary gears with higher efficiency is the aim of future works in accordance to the actual global trend of increasing the electricity power generated by wind turbines.

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Structura, randamentul si cinetostatica unei noi transmisii planetare cu doua trepte coaxiale

Rezumat: *Angrenajele planetare sunt utilizate cu precadere în industria constructoare de avioane, autovehicole rutiere, în centralele eoliene etc. În această lucrare se prezintă structura unei noi transmisii planetare cu două trepte coaxiale. Elementul principal al transmisiei este un mecanism planetar de tip Wolfrom cu două trepte. Roata dintată cu dantură interioara de pe treapta a doua este antrenată de la arborele de intrare prin intermediul unui tren de angrenaje fix, care are rolul dea multilica şi inversa mişcarea de rotatie al arborelui de intrare. S-au dedus expresile randamentului total al mecanismului precum şi a momenteleor de torsiune de pe fiecare arbore.*

Cuvinte cheie: *Angrenaje planetare, doua trepte coaxiale, randament global, cuplu*

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