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Geometric-Cinematic Synthesis of Planetary Mechanisms

[1]Nicolae Petrescu and [2]Florian Ion Tiberiu Petrescu

[1]*Bucharest University, Bucharest, (CE), Romania*
[2]*ARoTMM-IFToMM, Bucharest Polytechnic University, Bucharest, (CE), Romania*

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Corresponding Author:
Florian Ion Tiberiu Petrescu
ARoTMM-IFToMM, Bucharest Polytechnic University,
Bucharest, (CE), Romania
Email: scipub02@gmail.com

Abstract: The simple planetary mechanism is geometrically synthesized by determining the four tooth numbers of the component wheels. There are four main conditions that if not obeyed the mechanism will be blocked, will work with interruptions, or will not work at all. (a) The first condition in the geometric-kinematic synthesis of a simple planetary is the uniform loading of satellites (satellite groups) (or the simultaneous engagement condition). (b) The coaxiality condition is the second one to be observed, otherwise, the mechanism is inoperative. (c) The condition for achieving a required input-output transmission ratio is the third major condition, which results from the necessity of conceiving the mechanism according to the required operation. (d) The fourth imposed condition is that of (good) neighboring (of the satellite groups), which is necessary for the larger satellites belonging to two groups of neighboring satellites not to be touched, which is why it is necessary to introduce the additional condition, neighborhood.

Keywords: Automatic Gearboxes, Dynamic Synthesis, Simple Planetary Mechanism, Synthesis of a Planetary Mechanism

Introduction

Today the planetary mechanisms have spread to the machine building industry, especially in robotics, mechatronics, automation, aerospace, automobiles, etc. becoming more and more important so that a good design of them is more than necessary, otherwise there is a danger that they do not work properly, operate with interruptions, shocks, noise and vibration, beatings, blocking, or even break.

Manual gearboxes are increasingly being replaced by automatic or variable transmissions that make a better transition from one gear to another or even a permanent adaptation of the transmission to the demands of the road, so that fuel consumption can drop even by half, the noxes are also significantly reduced, so the noise and vibrations during the operation will be almost eliminated, drivers having the tendency to purchase such cars, which will make their life more enjoyable when they will be driving. In all these situations mechanisms are used which have one or more planetary mechanisms in their composition.

Automatic gearbox and transmission mode transmission mode in an automatic gearbox with planetary gears. The automatic gearbox (s) under study is 4HP20 from the ZF (Fig. 1).

The 4HP20 automatic gearbox has 4 transmission ratios (gears) and a maximum torque of 330 Nm. It consists of 2 simple planetary mechanisms, a blocking hydro transformer (clutch), two clutches, three multidrive brakes and an electrohydraulic control module.

Fig. 1: The automatic gearbox 4HP20 from the ZF

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The 4HP20 is older generation but the same gearing principle applies to 8-speed or 9-speed automatic gearboxes. This box was used on a wide range of cars: Mercedes Benz, Renault, Peugeot, Fiat, Lancia, etc.

Currently, manufacturers such as Renault or PSA (Peugeot-Citroen) are selling cars that use derivative gears on this market in Turkey, Russia, Mexico, China, etc. The Dacia Duster with an automatic gearbox, marketed on the Russian market, has a gearbox similar to 4HP20 (see its components in the Fig. 2).

1. Radiator (cools the transmission oil)
2. Multidisc clutch
3. Multidisc brake
4. Reducer (final gear)
5. Differential
6. Hydrotransformer (torque converter)
7. Multifunctional contact
8. Ventilation valve
9. Lectrohydraulic control unit housing
10. Joja transmission oil

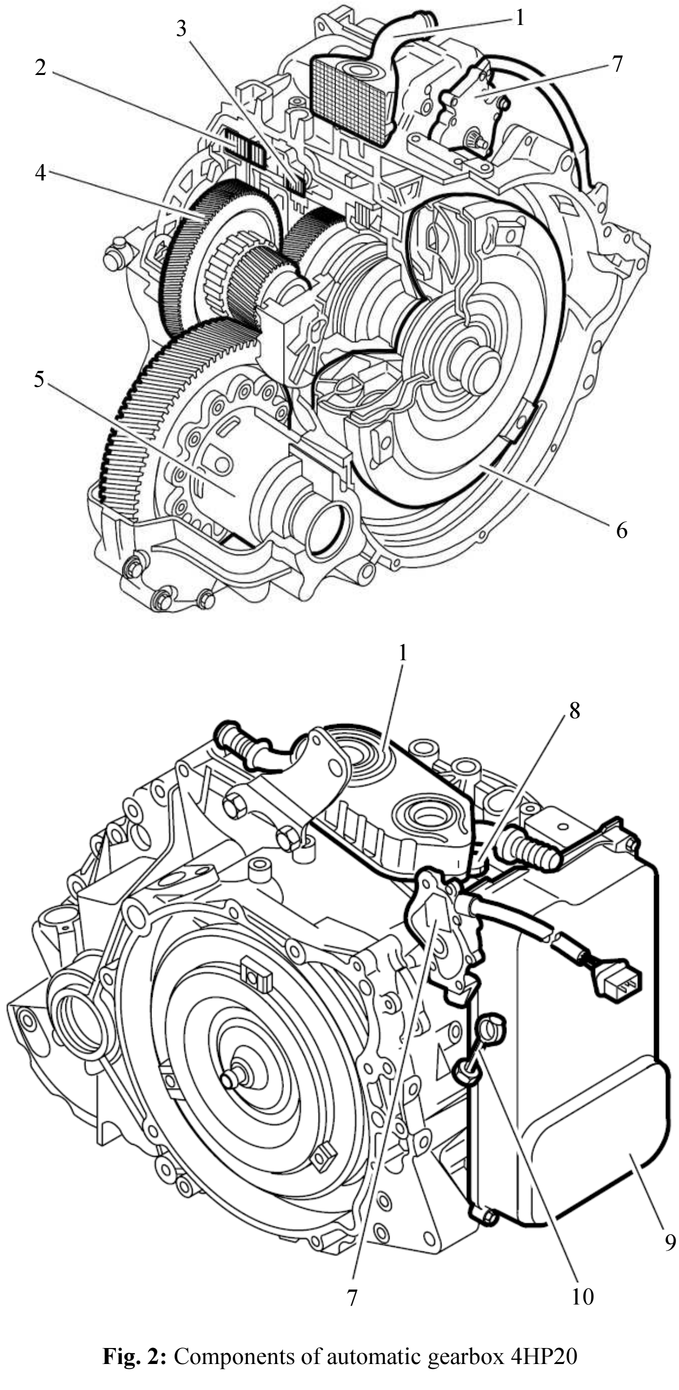

Fig. 2: Components of automatic gearbox 4HP20

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The hydraulic transformer (torque converter) is equipped with a clutch controlled by an electric control valve. Typically, in gears 2, 3 and 4, depending on the operating mode, the transmission computer controls the blocking of the hydrostatic to eliminate hydraulic losses.

The hydraulic circuit is also equipped with a cooling radiator. Because of the fact that it passes through the clutch discs and brakes, the oil can be heated very heavily, reaching temperatures above 100°C. Under these circumstances, the transmission computer controls an electric valve that opens the cooling circuit and allows the oil to pass through the radiator (see the Automatic transmission 4HP20 - cross section in the Fig. 3).

In the Fig. 3 one can see all the components from the cross section of the automatic transmission:

1. Clutch clutch hydrotransformer (torque converter)
2. Turbine
3. Pump
4. Input shaft
5. Free wheel
6. Stator
7. Oil pump
8. Toothed gear drive fixed gear
9. Output shaft speed sensor
10. Simple planetary mechanism 1
11. Simple planetary mechanism 2
12. Input shaft speed sensor
13. Fixed gear reducer intermediate gear
14. Toothed gear reducer
15. Differential crown
16. Crown feed oil clutch

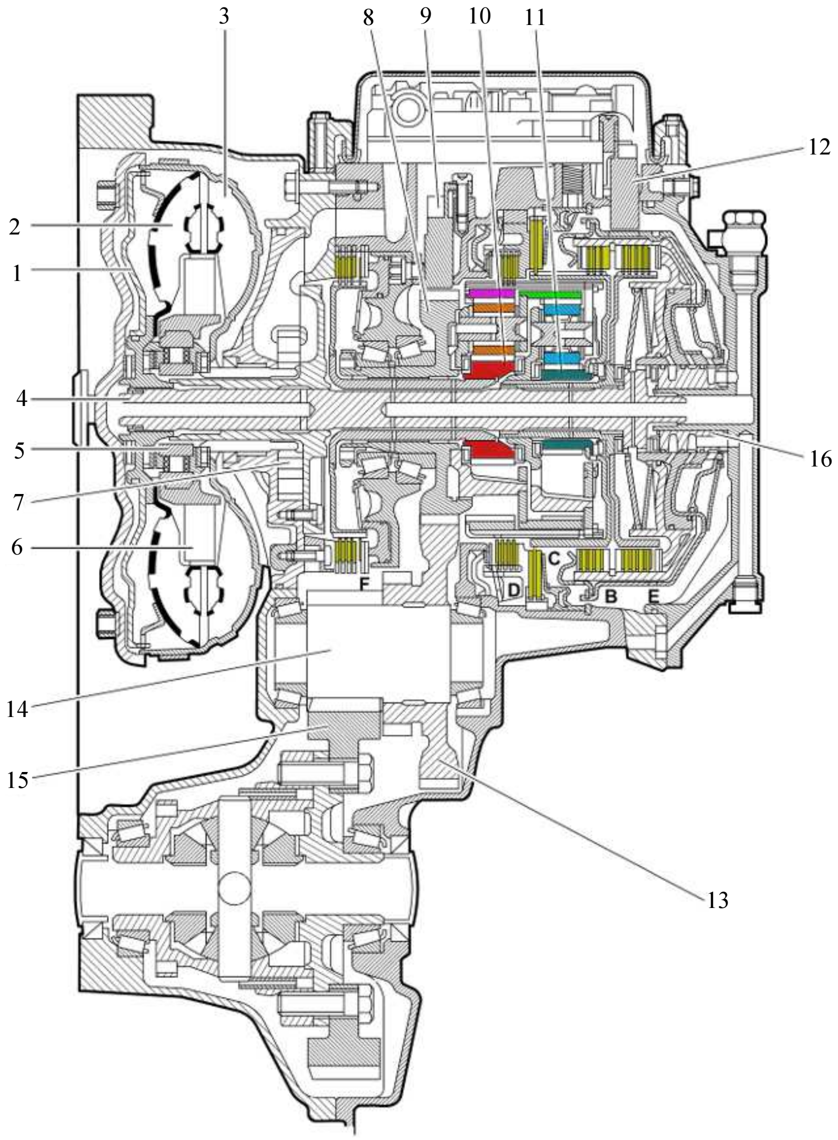

Fig. 3: Automatic transmission 4HP20 - cross section

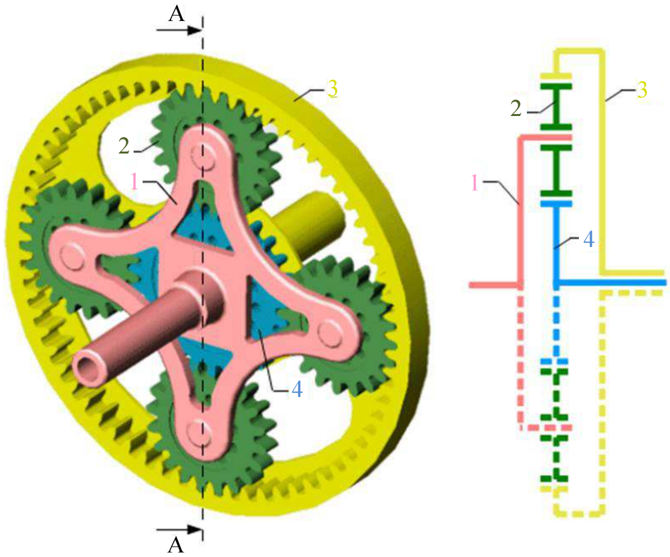

Fig. 4: Planetary mechanisms

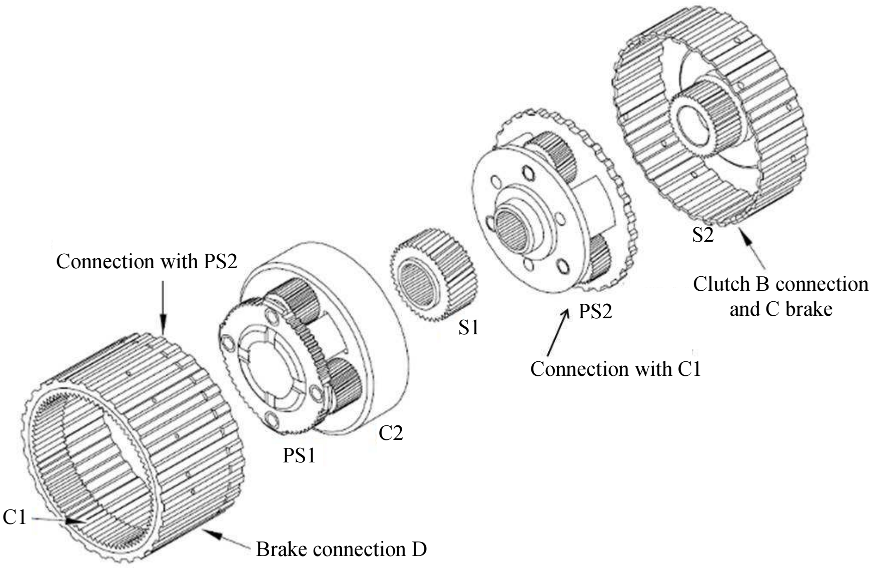

Fig. 5: Combining two simple planetary mechanisms, one can get 4 forward and one reverse track
C1 - planetary gear crown 1
PS1 - planetary harbor plate harbor 1
S1 - solar planetary mechanism 1
C2 - planetary mechanism crown 2
PS2 - planetary gear port 2 satellites
S2 - solar planetary mechanism 2

Planetary mechanisms (Fig. 4) are simple, of the Simpson type. The ratio of each step is formed by planetary mechanisms plus a fixed reducer. To understand how gears are formed, we need to detail how a simple planetary mechanism works. A planetary mechanism consists of 4 elements:

1. Solar
2. Satellites
3. Port-satellite platform
4. The crown

The advantage of a simple planetary mechanism, compared to a gear with gears commonly used in manual gearboxes, is that it can provide several transmission ratios. Practically from a simple planetary mechanism, you can get 4 transmission reports and theoretically as many speeds.

A simple planetary mechanism consists of 3 gears: the sun, the satellites and the crown. By blocking an element and using the other two as input and output, several gears can be obtained.

If the crown sun is rigid, using a multidisc clutch, the entire mechanism will rotate unitarily, the transmission ratio, in this case, will be 1,000 (direct socket).

Obviously, not all transmission reports are directly usable. In other words, a single planetary mechanism is not enough to achieve the gear shifting of an automatic transmission. However, by combining two simple planetary mechanisms, you can get 4 forward and one reverse track (Fig. 5).

Frățilă *et al*. (2011; Pelecudi, 1967; Antonescu, 2000; Comănescu *et al*., 2010; Aversa *et al*., 2016a; 2016b; 2016c; 2016d; 2017a; 2017b; 2017c; 2017d; 2017e; Mirsayar *et al*., 2017; Cao *et al*., 2013; Dong *et al*., 2013; De Melo *et al*., 2012; Garcia *et al*., 2007; Garcia-Murillo *et al*., 2013; He *et al*., 2013; Lee, 2013; Lin *et al*., 2013; Liu *et al*., 2013; Padula and Perdereau, 2013; Perumaal and Jawahar, 2013; Petrescu and Petrescu, 1995a; 1995b; 1997a; 1997b; 1997c; 2000a; 2000b; 2002a; 2002b; 2003; 2005a; 2005b; 2005c; 2005d; 2005e, 2016a; 2016b; 2016c; 2016d; 2016e; 2013; 2012a; 2012b; 2011; Petrescu *et al*., 2009; 2016a; 2016b; 2016c; 2016d; 2016e; 2017a; 2017b; 2017c; 2017d; 2017e; 2017f; 2017g; 2017h; 2017i; 2017j; 2017k; 2017l; 2017m; 2017n; 2017o; 2017p; 2017q; 2017r; 2017s; 2017t; 2017u; 2017v; 2017w; 2017x; 2017y; 2017z; 2017aa; 2017ab; 2017ac; 2017ad; 2017ae; Petrescu and Calautit, 2016a; 2016b; Reddy *et al*., 2012; Tabaković *et al*., 2013; Tang *et al*., 2013; Tong *et al*., 2013; Wang *et al*., 2013; Wen *et al*., 2012; Antonescu and Petrescu, 1985; 1989; Antonescu *et al*., 1985a; 1985b; 1986; 1987; 1988; 1994; 1997; 2000a; 2000b; 2001; List the first flights, From Wikipedia; Chen and Patton, 1999; Fernandez *et al*., 2005; Fonod *et al*., 2015; Lu *et al*., 2015; 2016; Murray *et al*., 2010; Palumbo *et al*., 2012; Patre and Joshi, 2011; Sevil and Dogan, 2015; Sun and Joshi, 2009; Crickmore, 1997; Donald, 2003; Goodall, 2003; Graham, 2002; Jenkins, 2001; Landis and Dennis, 2005; Clément, Wikipedia; Cayley, Wikipedia; Coandă, Wikipedia; Gunston, 2010; Laming, 2000; Norris, 2010; Goddard, 1916; Kaufman, 1959; Oberth, 1955; Cataldo, 2006; Gruener, 2006; Sherson *et al*., 2006; Williams, 1995; Venkataraman, 1992; Oppenheimer and Volkoff, 1939; Michell, 1784; Droste, 1915; Finkelstein, 1958; Gorder, 2015; Hewish, 1970).

Materials and Methods

The simple planetary mechanism (Fig. 6) is geometrically synthesized by determining the four tooth numbers of the component wheels. Four conditions are required.

(a) The first condition in the geometric-kinematic synthesis of a simple planetary is the uniform loading of satellites (satellite groups) (or the simultaneous engagement condition).

In order for the satellite groups to be uniformly charged (thus resulting in uniform and minimal wear with a quiet, long-running, no noise, vibration, shocks), the simultaneous engagement must take place, the satellites being symmetrically disposed at equal distances. It's obviously the satellite groups; if a single group of satellites was used, the loading would be large and especially uneven, with dynamic operation almost impossible because dynamic balancing could not be achieved. For this reason two, three, four, five, etc., satellite groups are used. A very good balance not only static but also dynamic is achieved, for example, when using at least three satellite groups.

If we calibrate the first group of satellites (vertically - Fig. 6) so that the diameter $a_1a_1^{'}$ is an axis of symmetry, in the satellite group the two axes can no longer be positioned generally after the direction $a_2a_2^{'}$ but will be disengaged rotated at any angle α) occupying the position $aa^{'}$. The disbanded positioning of the satellite 2 with the a_2a segment must still fall into a number of steps: $a_2a = n_1.p_1$; the same phenomenon occurs at wheel 2': $b_2b = n_2.p_2$; but also to the center wheel 1: $a_1c = n_3.p_1$; and the center wheel 3: $b_1d = n_4.p_2$; as the process occurs without slipping, the segment a_2a on the satellite wheel 2 must be equal to the segment a_2c on the center wheel 1. In addition $a_1a_2 = z_1.p_1/k$; the relationship 1 follows:

$$\begin{cases} a_1a_2 = a_1c - a_2c = a_1c - a_2a = n_3 \cdot p_1 - n_1 \cdot p_1 \\ a_1a_2 = \dfrac{z_1 \cdot p_1}{k} \end{cases} \Rightarrow z_1 = k \cdot (n_3 - n_1) \quad (1)$$

The relationship 2 is also determined:

$$\begin{cases} b_1b_2 = b_1d - b_2d = b_1d - b_2b = n_4 \cdot p_2 - n_2 \cdot p_2 \\ b_1b_2 = \dfrac{z_3 \cdot p_2}{k} \end{cases} \Rightarrow z_3 = k \cdot (n_4 - n_2) \quad (2)$$

Four relationships can be written immediately (system 3), from which the four simultaneous engagement conditions can be concluded: z_1, z_3, z_3-z_1, z_1 + z_3, all four must be natural numbers, plus multiples of k:

$$\begin{cases} z_1 = k \cdot (n_3 - n_1) = k \cdot N_1 \\ z_3 = k \cdot (n_4 - n_2) = k \cdot N_2 \\ z_3 - z_1 = k \cdot (n_1 + n_4 - n_2 - n_3) = k \cdot N_3 \\ z_3 + z_1 = k \cdot (n_3 + n_4 - n_1 - n_2) = k \cdot N_4 \end{cases} \quad (3)$$

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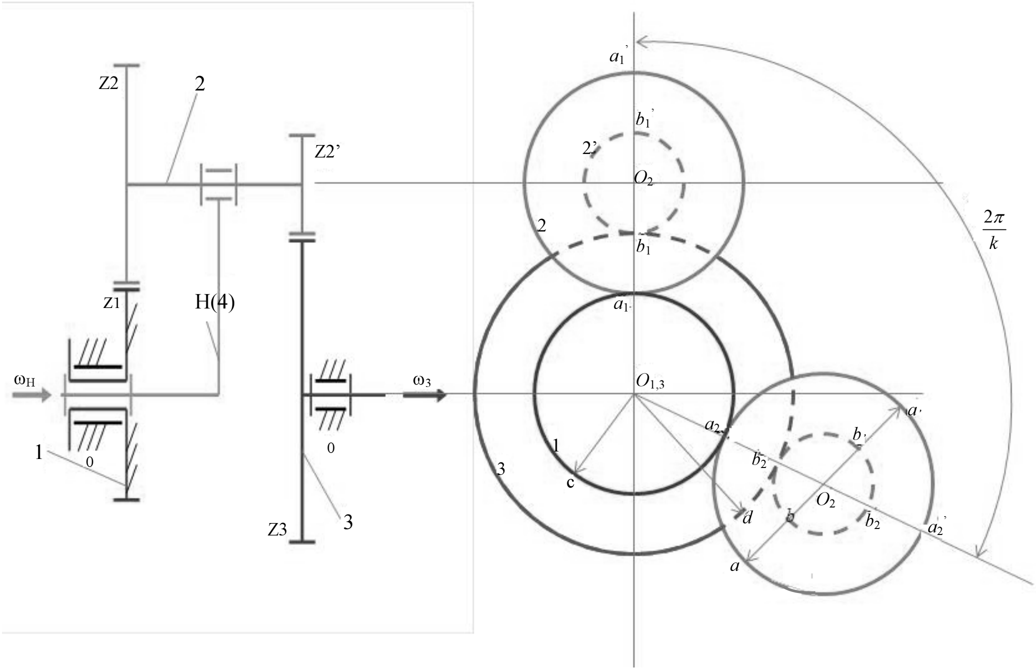

Fig. 6: Geometric and kinematics synthesis of a simple planetary mechanism

b) Coaxial condition

For the axes of all wheels to be coaxial, the condition $O_1O_2 = O_3O_2$ must be met; which can also be written $r_1 + r_2 = r_3 + r_{2'}$; or ½ $(d_1 + d_2 = d_3 + d_{2'})$; or ½ $(m_1z_1 + m_1z_2 = m_2z_3 + m_2z_{2'})$; if we use the same module at both gears $(m_1 = m_2 = m)$ we obtain the particular form of the coaxial condition (4) expressed in two different ways:

$$\begin{cases} z_1 + z_2 = z_3 + z_{2'} \\ z_3 - z_1 = z_2 - z_{2'} \end{cases} \tag{4}$$

(c) The condition for achieving a required input-output transmission, i_{H3}

It is written in the system (5) the relations already known from the planetary cinematics:

$$\begin{cases} i_{H3} = i^1_{H3} = \dfrac{1}{i^1_{3H}} = \dfrac{1}{1-i^H_{31}} = \dfrac{1}{1-\dfrac{1}{i^H_{13}}} = \dfrac{1}{1-\dfrac{1}{\dfrac{z_2}{z_1}.\dfrac{z_3}{z_{2'}}}} = \dfrac{z_2 \cdot z_3}{z_2 \cdot z_3 - z_1 \cdot z_{2'}} \\ \Rightarrow z_1 \cdot z_{2'} = z_2 \cdot z_3 \cdot \left(1-\dfrac{1}{i_{H3}}\right) \Rightarrow z_1 \cdot z_{2'} = z_2 \cdot z_3 \cdot \left(1-i_{3H}\right) \end{cases} \tag{5}$$

(d) The condition of (good) neighborhood (of satellite groups)

For the larger satellites belonging to two groups of neighboring satellites not to be touched, it is necessary to introduce the additional, neighboring condition. In the mechanism used (Fig. 6), the larger satellites are 2 compared to 2', so that the neighborhood condition will be checked only at wheels 2 (Fig. 7).

In Fig. 2, the larger satellites (wheels 2), two neighboring groups were forced close to tangency. More cannot be. The two outer circles of the wheels 2 will come in tangent. The wheels (here and the splitting) of the wheels 2 (exaggerated in the figure, precisely for the understanding of the phenomenon) are tangent to the wheel 1 of the center wheel.

OB distance is the sum of the rays $r_1 + r_2$ (distance between axes).

Angle π/k (half of the angle $2\pi/k$) is known (because k is specified before synthesis).

It can be calculated immediately with sin function trigonometric, length TB:

$TB = BT = (r_1 + r_2)$ .sin $(\pi/k) = m/2.$ $(z_1 + z_2)$ .sin (π/k)

The outer radius of the wheel 2 is written: $r_{a2} = m/2.(z_2 + 2)$.

The neighborhood condition results from the inequality of $BT > r_{a2}$ and is expressed in relations (6):

$$\begin{cases} \dfrac{m}{2} \cdot (z_1 + z_2) \cdot \sin\dfrac{\pi}{k} > \dfrac{m}{2} \cdot (z_2 + 2) \\ (z_1 + z_2) \cdot \sin\dfrac{\pi}{k} > (z_2 + 2) \\ z_1 > \dfrac{z_2 \cdot \left(1 - \sin\dfrac{\pi}{k}\right) + 2}{\sin\dfrac{\pi}{k}} \end{cases} \tag{6}$$

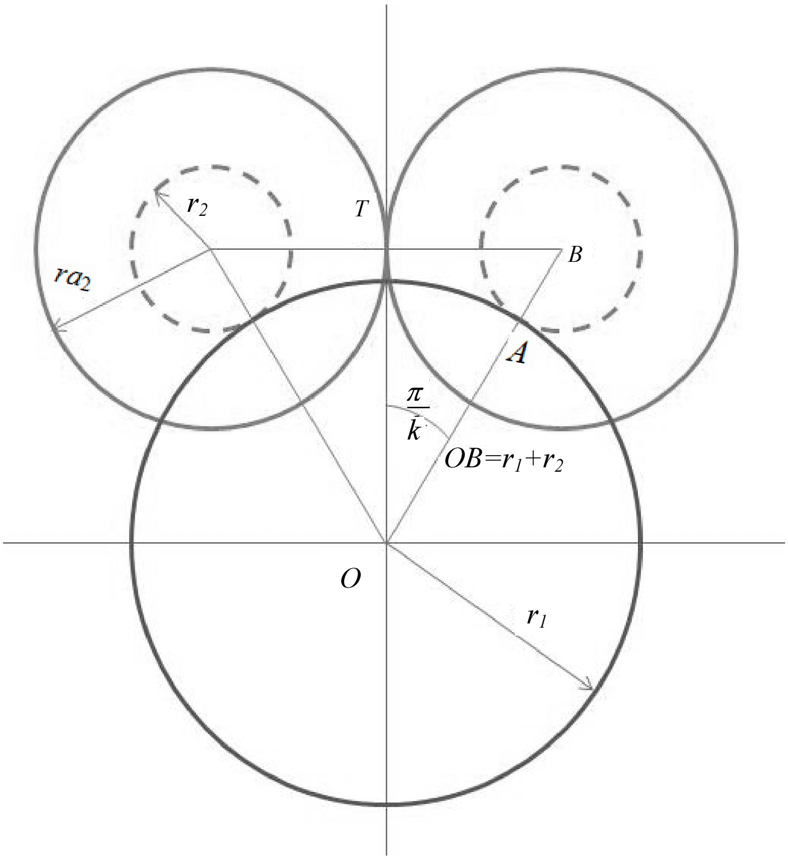

Fig. 7: Neighborhood condition of a simple planetary mechanism

Results and Discussion

The computational relations compiled for all four conditions are recapitulated in the system (7):

$$\begin{cases} z_3 - z_1 = z_2 - z_{2'} \\ z_1 \cdot z_{2'} = (1 - i_{3H}) \cdot z_2 \cdot z_3 \Rightarrow z_1 \cdot z_{2'} = C \cdot z_2 \cdot z_3; C = 1 - i_{3H} \\ \hline z_1 = k \cdot N_1; z_3 = k \cdot N_2; z_3 - z_1 = k \cdot N_3; z_3 + z_1 = k \cdot N_4 \\ \hline z_1 > \dfrac{z_2 \cdot \left(1 - \sin\dfrac{\pi}{k}\right) + 2}{\sin\dfrac{\pi}{k}} \end{cases} \tag{7}$$

Way of working:

- Write the Initial Calculation Relationships (8):

$$\begin{cases} z_2 = z_1 \cdot \dfrac{z_3 - z_1}{z_1 - C \cdot z_3} \\ z_{2'} = C \cdot z_3 \cdot \dfrac{z_3 - z_1}{z_1 - C \cdot z_3} \end{cases} \tag{8}$$

- We give: k and i_{H3}. Calculate immediately: i_{3H} and C
- z_1 and z_3 are chosen so that both are greater than or equal to $z_{\min}$ to automatically observe the avoidance condition ($z_{\min} = 18$), but also the four simultaneous engagement conditions
- Calculate with (8) z_2 and $z_{2'}$. If both are exactly integer numbers, check the neighborhood condition and if that's OK, stop the process

If z_2 and/or $z_{2'}$ are not exactly integer numbers, then they are rounded to the nearest natural value, using the relation (9) to obtain $z_2^*, z_{2'}^*$, with which the required transmission ratio i_{H3}^* is recalculated.

$$i_{H3}^* = \frac{z_2^* \cdot z_3}{z_2^* \cdot z_3 - z_1 \cdot z_{2'}^*} \tag{9}$$

If i_{H3}^* it does not exceed i_{H3} plus or minus about six or seven percent then the calculations are OK and the synthesis ends; Otherwise, the whole process is resumed at the end with another pair of teeth z_1, z_3.

The data gathered at the output will be:

$$i_{H3}^{*}, z_1, z_3, z_2^{*}, z_{2'}^{*}$$

Conclusion

The simple planetary mechanism is geometrically synthesized by determining the four tooth numbers of the component wheels.

There are four main conditions that if not obeyed the mechanism will be blocked, will work with interruptions, or will not work at all:

a) The first condition in the geometric-kinematic synthesis of a simple planetary is the uniform loading of satellites (satellite groups) (or the simultaneous engagement condition)
b) The coaxiality condition is the second one to be observed, otherwise, the mechanism is inoperative
c) The condition for achieving a required input-output transmission ratio is the third major condition, which results from the necessity of conceiving the mechanism according to the required operation
d) The fourth imposed condition is that of (good) neighboring (of the satellite groups), which is necessary for the larger satellites belonging to two groups of neighboring satellites not to be touched, which is why it is necessary to introduce the additional condition, neighborhood

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Author's Contributions

All the authors contributed equally to prepare, develop and carry out this manuscript.

Ethics

This article is original and contains unpublished material. Authors declare that are not ethical issues and no conflict of interest that may arise after the publication of this manuscript.

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