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Contributions to the Structural Analysis of the Double Gear Harmonic Transmission

In this paper, we present the construction and functioning of a new constructive variant of harmonic drive called double gear harmonic transmission (DGHT). In the second part of the paper, we present the desmodromy analysis of the DGHT considering the planar approach of the respective mechanism. At establishing the mobility, class and order of the DGHT we have used the procedure of instantaneous–isokinetic transformation wich followed the identifica-tion of the kinematic groups of the mechanism and the replacement of the higher kinematic pairs by links and by lower kinematic pairs.

Keywords: *double gear harmonic transmission, structural analysis, link, kinematic pair.*

1. Introduction

In the last 5 decades, researchers have paid more attention to engaging mechanical transmissions due to multiple advantages that this type of drive attempting to improve them as much as possible, but with insufficient success. The main trend during the present development and modernization stage of technical industry is the automation of manufacturing processes and their integration within systems controlled and co-ordinated by computers.

In this respect it becomes necessary to improve and create new mechanical transmissions able to perform precise motions and to transmit big loads. This new category includes also the gear harmonic transmission, mainly used in the design and manufacture of drives for industrial robots.

The gear harmonic transmission is essentially different from the classic mechanical transmissions as it transmits and transforms kinematic and dynamic parameters of the rotation motion through elastic deformation propagated according to a harmonic law of one of its elements called flexible toothed wheel.

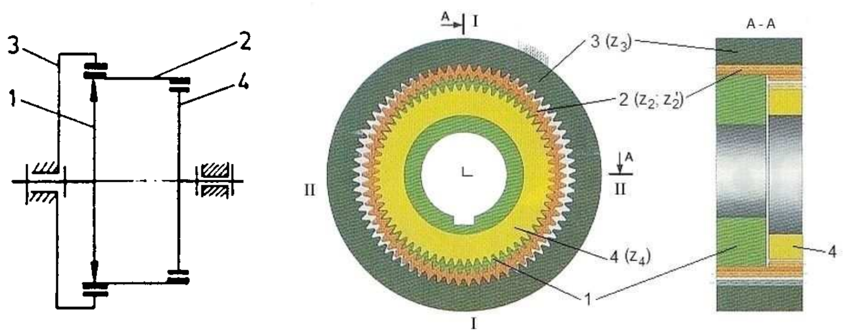
Grace to constructive and functional diversifications of gear harmonic transmissions one has created a new variant of the double gear harmonic transmission.

This transmission exhibits a series of advantages such as: great precision of positioning and repeatability, great transmission ratio (i = 40…150), reduced dead course, extremely small loose motions, small weight and size, small inertia moments, coaxial and modular construction, offering them an increasingly wider range of applicability in the actuator mechanism of industrial robots, machine-tools field, military machines, space systems, servomechanisms etc [1, 4, 5, 6, 7, 8, 9].

2. Construction and functioning of a DGHT

Figure 1-a presents the structural scheme of a DGHT with short flexible wheel under the form of a circular tube with thin wall, open at both ends and having at each end a toothed crown (exterior z_2 and interior z'_2).

A DGHT is made of: a waves generator (1) as input link, a short flexible toothed wheel (2) with the respective exterior and interior toothed crowns, the fixed rigid gear (3) and the mobile rigid gear (4) as output link.



a. b.

Figure 1. The structural scheme of DGHT.

It is based on the same working principle as the simple harmonic transmission, but one must correlate the number of teeth of toothed wheels from the mounting condition:

$$z_3 = z_2 + 2\,;\; z_2^{/} = z_4 + 2 \tag{1}$$

The waves generator being in sliding contact along the entire periphery of the flexible wheel, it deforms this toothed wheel so that it will have four equidistant driving zones: two with the fixed rigid gear having interior teeth and two with the mobile rigid gear having exterior teeth.

Between the two pairs of opposed driving zones (I-I and II-II respectively) there is a 90° angle (Figure 1-b). As these zones are at a 90° angle from each other the transmission of loads is done through bending and torsion stresses. At the beginning of operation one finds in contact on the opposed vertical positions (I-I) the exterior teeth (z_2) of the flexible wheel with the interior teeth (z_3) of the fixed rigid gear, and in the position disposed at 90° angle to the vertical axis (II-II) one can find in contact the interior teeth (z'_2) of the flexible wheel with the exterior teeth (z_4) of the output rigid gear.

The transmission ratio a DGHT is determined with Willis's relation, [2, 3]:

$$i_{14}^{(3)} = \frac{\omega_1}{\omega_4} = \frac{i_{34}^{(1)}}{i_{34}^{(1)} - 1} = \frac{z_2 \cdot z_4}{z_2 \cdot z_4 - z'_2 \cdot z_3} \tag{2}$$

where: ω_1 - the angular velocity of the waves generator;

ω_4 - the angular velocity of the output rigid gear;

z - number of teeth of the transmission gears.

3. The structural analysis of the DGHT

In order to achieve the structural analysis of the DGHT it is necessary to draw their simplified representation by means of structural schemes which should indicate the number of links, their linking way through kinematic pairs, the number and the class of the kinematic pairs. Due to the fact that all these DGHT elements are moving in parallel plans, a planar approach of the mechanism can be admitted a first stage of structural analysis

Taking into account that the plane imposes three joints (constraints) it results that in the structural scheme of DGHT there will be only 4th and 5th class kinematic pairs. In Figure 2-a we have presented the structural scheme of a DGHT which contains 8 elements inter-connected by 6 kinematic pairs of 5th class (A, B, F, I, J and L) and 8 kinematic pairs of 4th class (C, D, E, G, H, K, M and N).

The accurate establishment of the mobility of a DGHT supposes the determination of the number of a independent kinematic chains and of the transmission degree of mobility. According to [2] the number of independent kinematic chains of a transmission is determined with the relation:

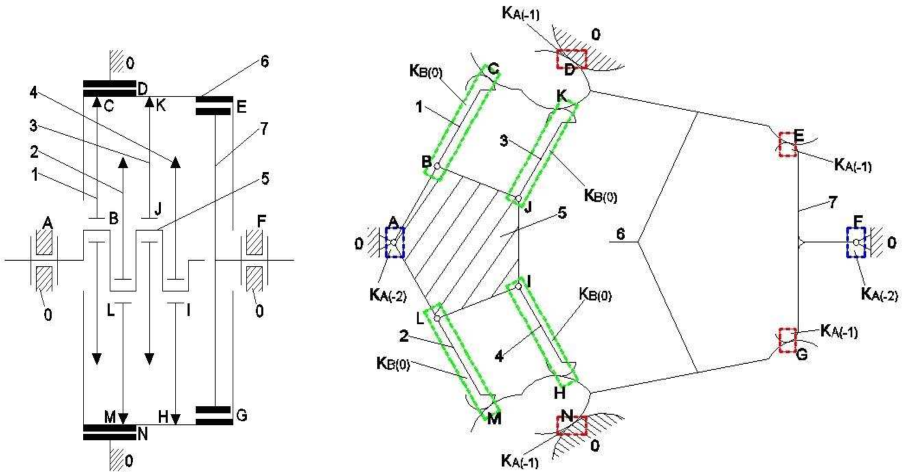
$$N = \sum_{i=1}^{5} c_i - n + 1 = 6 + 8 - 8 + 1 = 7 \tag{3}$$

where: N – number of independent kinematic chains;

c_i – number of the kinematic pairs of class i;

n – the total number of elements;

i – the class of kinematic pair.



a. b.

Figure 2. The planar model of DGHT.

The degree of mobility is determined with the relation P.L.Chebyshev [2]:

$$M = 3(n-1) - c_4 - 2 \cdot c_5 = 3(8-1) - 8 - 2 \cdot 6 = 1 \tag{4}$$

The planar mechanism in Figure 2-b the link (5) is driving and the link (7) is driven and both of them are connected to the ground by the means of a connection $K_{A(-2)}$ (rotation kinematic pairs). As the number of links and kinematic pairs which connect link (5) to link (7) is relatively high, we choose as intermediate driven link (6) connected to the ground by the connections $K_{A(-1)}$. The connection of the intermediate driven link (6) with the driving link (5) is achieved by means of 4 connections $K_{B(0)}$ and with the driven one by means of two connections $K_{A(-1)}$.

The verification of the accuracy of the connections' identification operation is achieved by summing up the number of the freedom degrees of the driving links, of the driven ones and of the connections, this sum must be equal with the number of the degrees of mobility of the mechanisms (5), as follows:

$$\begin{aligned} &n = 3; \sum L_k = 2 \cdot (-2) + 4 \cdot (-1) = -8 \\ &M = 3 \cdot n + \sum L_k = 3 \cdot 3 - 8 = 1 \end{aligned} \tag{5}$$

To find the class and the order of the mechanism we need to identify the kinematic groups of this one, replacing the upper kinematic pairs by the procedure of instantaneous – isokinetic transformation.

Thus, we obtain the equivalent substitute mechanism whose structural scheme is presented in Figure 3 which contains 16 links and 22 rotation kinematic pairs and the number of independent kinematic chains and the degree of freedom remains the same:

$$N = 22 - 16 + 1 = 7; \;\; M = 3 \cdot 15 - 2 \cdot 22 = 1 \tag{6}$$

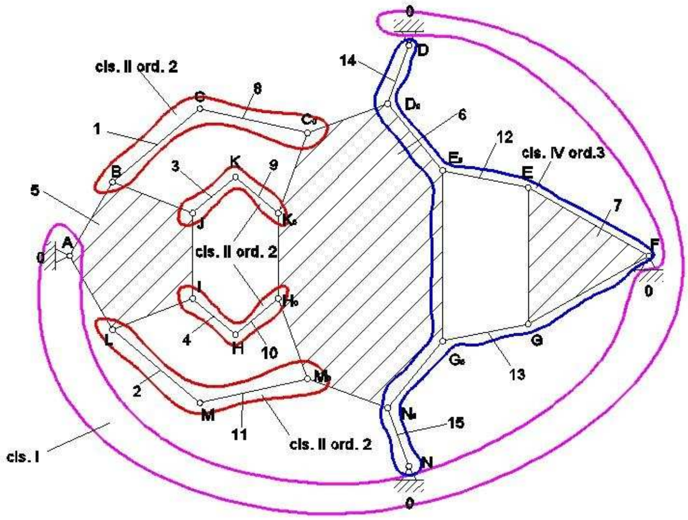


Figure 3. The equivalent substitute planar mechanism of DGHT.

The links (0) and (5) and the kinematic pair A are part of the kinematic group of 1st class and the links (1-8); (2-11); (3-9) and (4-10) together with the corresponding kinematic pairs: B, C, C_o; L, M, M_o; J, K, K_o şi I, H, H_o, are part of the kinematic group of 2nd class, the order 2. The links 7, 12, 13, 6, 14 and 15 together with the kinematic pairs F, E, G, E_o, D_o, N_o, D and N is a kinematic group of 4th class, the order 3.

The class and the order of the DGHT is given by the class and the order of the highest-complexity kinematic group contained, so the mechanism considered is of 4th class, the order being 3.

4. Conclusion

In the paper, we present a structural analysis method of a double gear harmonic transmission. This method is based on the procedure of the instantaneous – isokinetic transformation, resulting in an equivalent substitute planar mechanism. We remark that the kinematic group with the highest complexity in the structure of the DGHT mechanism is of 4th class and the order of this group is 3.

Considering the choice of an optimal variant of double gear harmonic transmission it is necessary to determine the number of mobility degree and to verify the desmodromy condition.

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