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SIMULATION AND UTILIZATION RATIO OF PLANETARY TRANSMITTERS

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S u m m a r y
Planetary transmitters take a very significant place among the gear transmissions which are used in many branches of industry. With regard to the growing requirements concerning the economical consumption of energy, the utilization ratio represents a very significant qualitative and quantitative performance of gears. This paper gives the utilization ratio analyze of planetary transmitters, starting from kinematics of contacted gears and gear profiles, including sliding and rolling losses resulting from the formation of EHD lubrication, with the numerical results of the instantaneous efficiency of a gear pair with internal gearing. Working of the planetary transmitters under defined conditions is simulated by CATIA software, which can be presented by movie, but mentioned in this paper by pictures.

Key words*: gears, utilization ratio, planetary transmitter, simulation*

1. INTRODUCTION

Planetary transmitters have a number of advantages as compared to the transmission with fixed shafts. Under similar operating conditions the planetary transmissions serve longer and produce less noise compared to the fixed shaft transmissions. This power transmission unit can handle larger torque loads relative to its compact size than any other gear combination in standard transmission. The design of planetary gear transmitters requires a whole range of geometrical and kinematics conditions in order to perform the mounting and an appropriate meshing of the gears during their work. The gear trains in operation are characterized by losses in the mechanical energy arising as a consequence of friction between the contact surfaces of the meshing teeth and the friction in the bearings. The power losses within the gears are expressed by means of the efficiency. The effect of instantaneous efficiency of an involute gear drive was studied by E.I. Radzimovsky, A. Mirareti, W.E. Broom (1973) [5], N.E. Anderson, S.H. [1], Loewenthal et al. (1986). The problem efficiency of planetary gear train was studied experimentally by R. Kasuba, E.I. Radzimovsky (1973).

2. UTILIZATION RATIO

By kinematics combinations of toothed pairs with the external and internal contacts we can obtain planetary gears. On the basis the models developed for a gear pair with external and internal gearing the utilization ratio of a planetary transmitters can be determinated.

The analysis considers sliding losses, which are the result of friction forces developed as the teeth slide across each other, rolling losses resulting from the formation of an elastohydrodynamic film. Sliding velocity is defined as the difference in the tangential velocities while the rolling or entraining velocity is the sum.

The instantaneous efficiency is very important parameter for analysis of utilisation ratio. The instantaneous efficiency for internal gear at any particular instant, from the relevant T_1 input and T_2 output torque, is determined according to the expression:

$$\eta_i = \frac{T_2}{T_1} \frac{1}{u_{gb}^H} \tag{1}$$

where u is gear ratio of one pair.

Sliding and rolling losses were evaluated by numerically integrating the instantaneous values of these losses across the path of contact. Contact starts at the intersection of the tip diameter of the internal gear with the path of contact at A_2. The path of contact is tangent to the base circles of two gears. Contact ends at the intersection of the tip diameter of the eternal gear with the path of contact at E_2.

The overall efficiency for gearing under consideration may be written:

$$\eta_{gb}^H = \frac{1}{l} \int_{A_2}^{E_2} \eta_i d\xi \tag{2}$$

where l is active contact length.

The instantaneous frictional force due to sliding of two gear teeth against each other is:

$$F_\mu(\xi) = \mu(\xi) \cdot F_n \tag{3}$$

Here is also to take a friction in gear contact in calculation using friction coefficient. The friction coefficient is calculated by the method of Benedict and Kelley for mineral oil:

$$\mu(\xi) = 0{,}0127 \cdot \log \cdot \left(\frac{\frac{29{,}66}{b} \cdot F_n}{\eta \cdot v_{kl} \cdot v_{ko}^2} \right) \tag{4}$$

The instantaneous force due to build up of the EHD film is:

$$F_R = C \cdot h \cdot b \tag{5}$$

The gear contact minimum film thickness is calculated by the method of Dowson and Higginson [3]:

$$h(\xi) = 1{,}6 \cdot \alpha^{0{,}6} \cdot (\eta \cdot v_{ko})^{0{,}7} \cdot E^{0{,}003} \cdot \frac{R^{0{,}43}}{F_n^{0{,}13}} \tag{6}$$

In an iterative procedure for the determination of the instantaneous efficiency of a gear pair for both external and internal gearing. Based upon the models developed, computer programs for instantaneous efficiency determination were devised [6]. The computer numerical results for the determination of the instantaneous efficiency of a gear pair with internal gearing are shown in Fig.1.

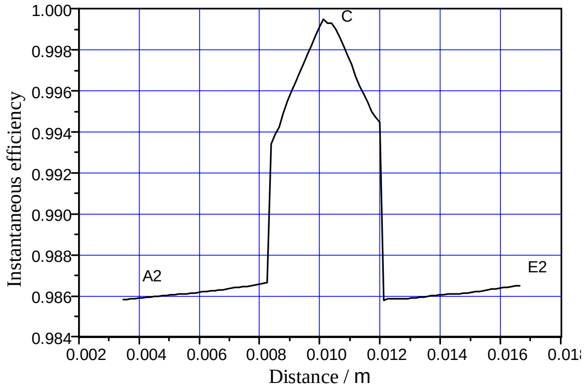

Figure 1. *The instantaneous values of the efficiencies during the contact period*

On the basis the models developed for a gear pair, the utilisation ratio of whole planetary transmitter, as a system of external and internal gearing, may be expressed as:

$$\eta_{aH}^b = \frac{1 - \eta_{ab}^H \cdot u_{ab}^H}{1 - u_{ab}^H} \tag{7}$$

where is:

$$\eta_{ab}^H = \eta_{ag}^H \cdot \eta_{gb}^H \tag{8}$$

3. SIMULATION OF GEARS

The first and basic step for simulation of planetary transmitters work is to make correct external and internal gear profiles and after that gear models.

3.1 Gear profile definition

In an internal (and also external) gear profile analysis there are four different kind of lines in one pitch, which defines complete profile of gear. So there are the involute profile arc, profile foot circle arc, addendum circle arc and trohoide arc as a connection.

In analytic-kinematics way for profile definition it is to define a lot of restrictions and constrains for setting parameter equations each of this profile arcs and angles. For this purpose are defined one fixed coordinate system Cxy located in instantaneous contact point and two relative coordinate systems related to internal (Cx_1y_1) and external (Cx_2y_2) gear profile on Fig.2.

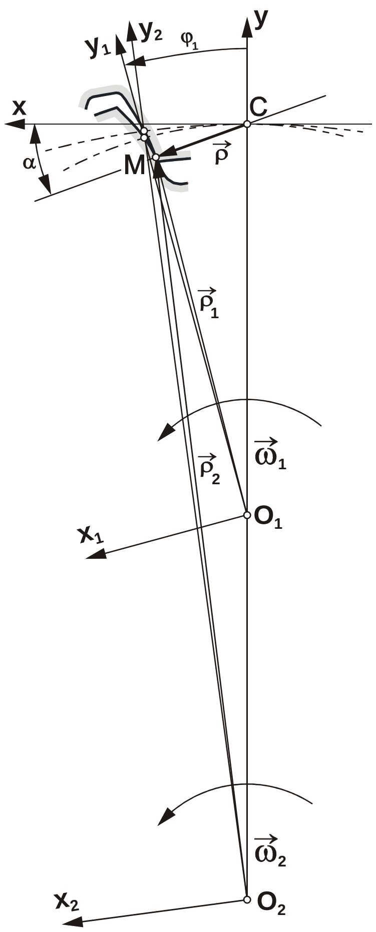

Figure 2. *Gear pair profiles engagement*

After some matrix transformations can be determinated matrix parameter equation for contact line of engaged gear tooth profiles as:

$$\begin{Bmatrix} x \\ y \\ t \end{Bmatrix} = \begin{bmatrix} \cos\varphi_1 & \sin\varphi_1 & 0 \\ -\sin\varphi_1 & \cos\varphi_1 & -r_{w1} \\ 0 & 0 & 1 \end{bmatrix} \begin{Bmatrix} x_1 \\ y_1 \\ 1 \end{Bmatrix} \tag{7}$$

Based on this analytic-kinematics model is developed computer program to define points of gear profiles [7]. This program calculates coordinates of involute gear profile and they could be given in form of table because it is suitable for applying. When we have gear profile coordinates that is simple to import calculated point coordinates into software for graphics presentation of gear engagement into planetary transmitters, as on the Fig. 3.

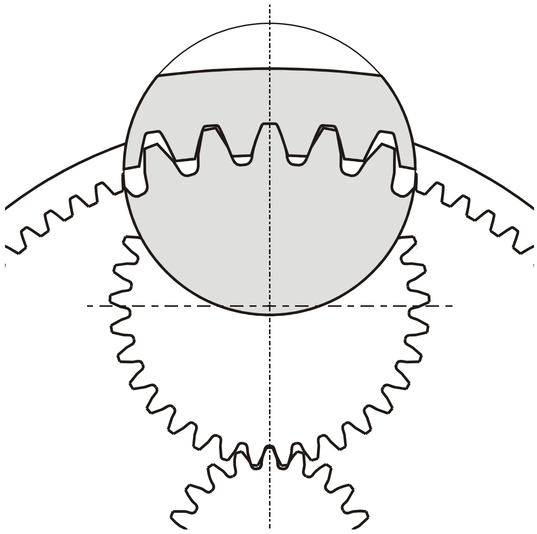

Figure 3. *Gears synthesis in planetary transmitter*

3.2 Gears modeling and simulation

Gears modeling is very useful and important, as to make real gear transmitters simulation, so for lot of other analysis. Many programs are in use today for machine design and modeling of machine elements as are ACAD, Mechanical Desktop, Pro Engineer and last years Solid Works, CATIA etc. But it is to see that modeling of gears (specially internal) with real profiles is not so simple as modeling of all other elements.

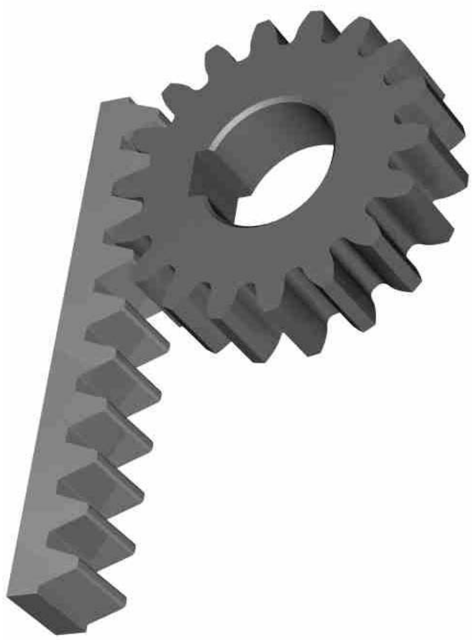

Figure 4. *An example of external flat gear profile engagement model*

First is to make a model of external gear profile engagement, such example is shown on the Fig.3. where is to see a flat gear contact.

After that the internal gear is to modeling, using the fact that cutting tool to make it has a form and profile just like corresponding external gear profile.

So, the Fig. 5 presents whole system of gears in one stage planetary transmitter, which consists from three internal cylindrical gears contacted with one central and also gearing around them.

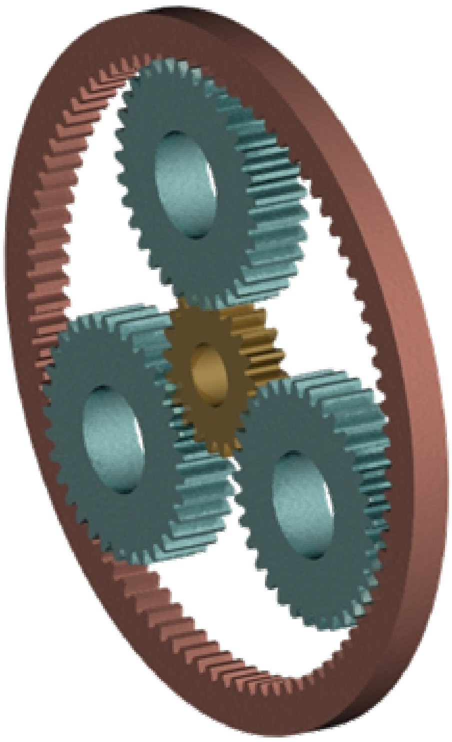

Figure 5. *The model of planetary transmitter section with internal-external gear contacts*

This model of planetary transmitter which is made using software CATIA is necessary for further mechanical analysis, first of structure, but also of heating, temperature etc. Most of that analysis are conducted by finite elements method, but this is not a point of this short paper.

When we are talking about simulation of planetary transmitters, the request is to show kinematics, that means moving of internal and external gears in contact and to explain how works such a system. For this purpose is used specially module of CATIA software where is possible to animate process of contacting and moving whole assembly as a planetary transmitter.

4. CONCLUSIONS

To resume the point of this paper here could be said that whole procedure of simulation for such a system as planetary transmitter is, consists of a few phases and every of them is very specific and important, so we can brief that:

- Involute gear profile definition based on analytic-kinematics way gives proper coordina-tes of points in every gear profile section.
- Internal and external gears models can be used for solving a lot of problems in mechanical engineering of gears, such as contact pressure between corresponding gears and also thermal and other analyses.
- The simulation of kinematics for every assembly design consists from many elements could be made very easy but qualitative. Because of printing form of this paper that multimedia simulation can be shown comple-tely only in presentation.

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