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Improving load capacity parameters of worm gears

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Abstract. Worm gear drives possess several advantages in comparison to other types of transmissions. Some of the most important advantages are: high gear ratio, compact design and vibration damping. Therefore, the author's team focused within the framework of research presented on creating opportunities to improve another very important characteristic feature of worm gears: the load capacity. During the process of investigation, optimization procedures have been created aiming to improve the load capacity parameters of worm gear trains. Different functional parameters and certain geometry parameters have been taken into account such as rotational frequency of the worm shaft, gear ratio, module and geometry dimensions of the worm gear set. The research methodology applied includes several stages. The research results obtained are presented and discussed. Conclusions and recommendations are made.

1 Introduction

Power transmission can be realized by couplings and/or belt, chain, bevel, planetary, spur, helical and worm gear drives. The boundaries of application of mechanical gears as elements of drive systems are determined by the power transmitted, by the rotational frequency of the drive component, by the gear ratio required and by the arrangement of the shafts.

In comparison to mechanical gear sets mentioned, cylindrical involute gear trains and worm gear drives are characterized by the relative good strength parameters and considerable durability.

Besides, worm gear drives are widely used in machine tools, in transport equipment, in vehicles and in precision devices for transmission of motion. Related to other mechanical transmissions, the most important advantage of worm gears is their large gear ratio. It can reach the value of 70 in one stage, which makes possible to obtain a large range of different values for the output shaft's rotational frequency.

The improvement of the methodologies in the area of design theory and investigation of drive systems requires the analysis and application of the scientific achievements of world-renowned scientists and professionals in this field. These requirements impose to define the main challenges in the research area under consideration.

2 Prerequisites for research implementation

The main criterion for worm gear load capacity is the output torque of the worm gear shaft, which is directly connected to the driven machine. Output torque values could be limited certain conditions during transmission operation.

Some significant boundary condition are: pitting, which can appear on the active flanks of the worm gear teeth; wear, which usually on the flanks of the bronze worm gear; heating of transmission and scuffing, which depends on the load and sliding velocity values.

The friction coefficient in the meshing represents a complex characteristic regarding the quality of the worm gear train. Several different approaches and models have been presented in previous research by the authors' team. The German standard DIN 3996: 2012-09 describes a short and clear approach, [1].

On the other hand, the approach described in [2] and [3] presents a more complex and detailed method. Besides, the investigations described in [2] and [3] treat other important problems for worm gear drives. The authors of these publications analyse the temperature and temperature variations in the contact meshing area. They emphasize that these variations could have relative great influence upon the wear of the worm gears.

In other previous publications of the authors' team, the calculations for various parameters of worm gears have been analysed. Some main calculation approaches are standardized in [4-7].

The authors' team and other scientists from the University of Ruse have successfully completed some investigation tasks in the field of energy efficiency of drive systems and transmissions. The results of these studies are presented in detail in the following publications: [8-12].

The literature publications cited summarize the previously performed research studies, which give the reason to formulate the objective of the research presented.

Optimization procedures have to be created aiming to improve the load capacity parameters of worm gear trains. Different functional parameters and certain geometry parameters have to be taken into account.

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Some of these parameters should be: rotational frequency of the worm shaft, gear ratio, module, geometry dimensions of the worm gear set.

3 Research methodology

Especially for this investigation, a new methodology was created including several stages which have different level of importance.

The first stage of the research methodology involves the application of the scientific approach elaborated and described in [13]. It involves calculating the tangential rotational frequency of the worm shaft, the determination of the sliding speed, of the efficiency coefficient and of other important tribology parameters in the meshing of the worm gear set, followed by the generation of database, graphical presentations and analysis of the results obtained.

The second stage of the methodology created includes the calculation of the permissible contact stresses in the worm gear set in accordance with [14]. The calculations have been carried out for different centre distances, different modules, gear ratios and rotational speeds of the worm shaft.

The calculations of the permissible contact stresses are carried out for a worm made of case-hardened steel 16 MnCr5 and a worm gear made of GZ-CuSn12Ni. Besides, the values of the Life factor Z_n and the Contact factor Z_ρ are determined. Their values depend on the center distance, the rotational frequency of the worm gear shaft, the reference diameter and the type of the worm, [1, 14].

Within the framework of the third stage, the necessary parameters are defined, through which it becomes possible to determine the maximum actual contact stresses. And based upon these calculations, the maximum torque output T_2 for each worm gear set is determined.

Within the fourth stage, a summarized database is generated including results obtained for the values of efficiency coefficient in the meshing η_z and maximum output torque T_2 in Nm for different gear ratios, modules, centre distances and rotational frequencies of the worm shaft.

The fifth stage includes graphical presentations and analysis of the results obtained.

4 Results obtained and discussion

Based upon the methodology described, a substantial investigation has been carried out. The object of analysis and discussion of the paper presented will be the results concerning the centre distance a=50 mm.

The calculation results for the efficiency coefficients η_z and maximal output torques T_2 in Nm depending on gear ratios i and modules m (in mm) at centre distance a=50 mm and n_1= 1500 min^{-1} are summarized in Table 1. The calculations are carried out with 9 different values of the gear ratios i and 3 different values of the module m.

Table 1. Results for a=50 mm and n_1= 1500 min^{-1}.

	i	**m**	**η_z**	**T_2**
1	4,83	2,5	0,9314	14,97
2	7,25	2,5	0,9120	24,79
3	9,5	2	0,8994	30,91
4	14,5	2,5	0,8478	58,43
5	19	2	0,8289	72,67
6	29	2,5	0,7445	136,61
7	38	2	0,7161	169,09
8	62	1,25	0,6133	304,03
9	83	1	0,6062	355,66

The presentations of Fig. 1 show the variation of efficiency coefficients and the values of maximal output torque in a graphical way depending on the values of the gear ratio and the module at a centre distance of 50 mm and rotational speed of the worm shaft n_1= to 1500 min^{-1}.

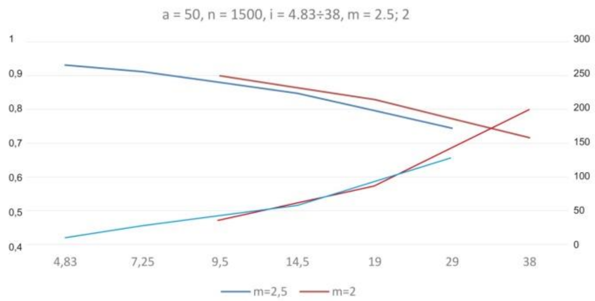

Fig. 1. Variation of the efficiency coefficients and maximal output torques depending on gear ratios and modules at centre distance a=50 mm and n_1= 1500 min^{-1}.

It can be observed that of the area of maximal values of efficiency coefficients and output torques is located in the gear ratio interval between 20 and 29 with modules equal to 2 mm and 2.5 mm.

The calculation results for the efficiency coefficients η_z and maximal output torques T_2 in Nm depending on gear ratios i and modules m (in mm) at centre distance a=50 mm and n_1= 1000 min^{-1} are summarized in Table 2. The calculations are carried out with the same values of the gear ratios and modules.

Table 2. Results for a=50 mm and n_1= 1000 min^{-1}.

	i	m	η_z	T_2
1	4,83	2,5	0,9189	16,51
2	7,25	2,5	0,893	27,31
3	9,5	2	0,884	34,01
4	14,5	2,5	0,8226	64,11
5	19	2	0,8073	79,53
6	29	2,5	0,6943	148,75
7	38	2	0,7103	183,39
8	62	1,25	0,6066	326,76
9	83	1	0,5596	379,81

The contents of Fig. 2 show the variation of efficiency coefficients and the values of maximal output torque in a graphical way depending on the values of the gear ratio and the module at a centre distance of 50 mm and rotational speed of the worm shaft, equal to 1000 min^{-1}.

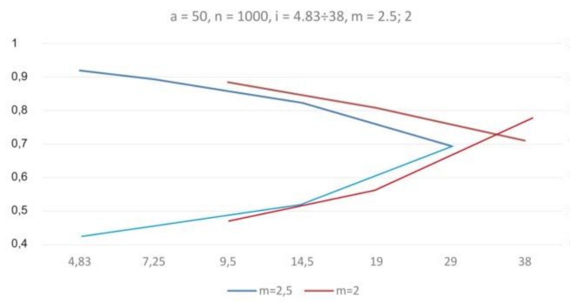

Fig. 2. Variation of the efficiency coefficients and maximal output torques depending on gear ratios and modules at centre distance a = 50 mm and n_1= 1000 min^{-1}.

It becomes clear that of the area of maximal values of efficiency coefficients and output torques is located in the gear ratio interval between 29 and 28 with modules equal to 2 mm and 2.5 mm.

The calculation results for the efficiency coefficients η_z and maximal output torques T_2 in Nm depending on gear ratios i and modules m (in mm) at centre distance a=50 mm and n_1= 750 min^{-1} are summarized in Table 3.

The graphical representations of Fig. 3 show the variation of efficiency coefficients and the values of maximal output torque in a graphical way depending on the values of the gear ratio and the module at a centre distance of 50 mm and rotational speed of the worm shaft, equal to 750 min^{-1}.

Table 3. Results for a=50 mm and n_1= 750 min^{-1}.

	i	m	η_z	T_2
1	4,83	2,5	0,9108	17,69
2	7,25	2,5	0,8844	29,22
3	9,5	2	0,8738	36,34
4	14,5	2,5	0,8188	68,30
5	19	2	0,7814	84,55
6	29	2,5	0,6996	157,43
7	38	2	0,6476	193,41
8	62	1,25	0,5361	342,04
9	83	1	0,5292	395,58

The graphical results on Fig. 3 show that of the area of maximal values of efficiency coefficients and output torques is located in the gear ratio interval between 14.5 and 27 with modules equal to 2 mm and 2.5 mm.

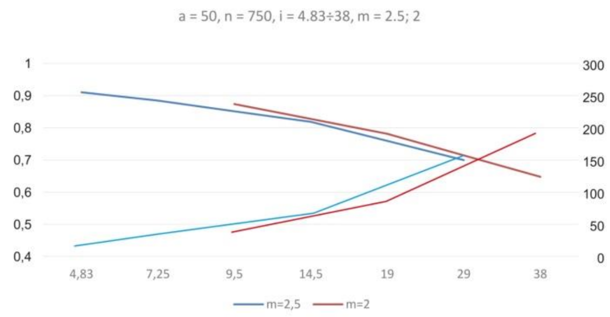

Fig. 3. Variation of the efficiency coefficients and maximal output torques depending on gear ratios and modules at centre distance a = 50 mm and n_1= 750 min^{-1}.

The comparative analysis of the results obtained for 3 different values of the rotational frequency of the worm shaft clarifies that the most favorable range of maximum efficiency in the meshing and maximum output torque is outlined at relatively small values of the gear ratio.

5 Conclusions

The presented research includes significant and clear optimization procedures for determination of tribology and load capacity parameters of worm gear drives, which makes it possible to deduce the following conclusions:

Theoretical prerequisites necessary for conducting the presented research are presented in a summarized form.

They have been described in details in previous publications of the authors' team.

During the process of investigation, optimization procedures have been created aiming to improve the load capacity parameters of worm gear trains. Different functional parameters and certain geometry parameters have been taken into account such as rotational frequency of the worm shaft, gear ratio, module and geometry dimensions of the worm gear set. The research methodology applied includes several stages. Especially for this investigation, a new research methodology was created including several stages.

The presented results have been analysed precisely. The most favourable areas of application of worm gears have been indicated from the point of view of the maximum efficiency coefficients and maximal values of output torques.

The new methodology presented and applied proves that the appropriate selection procedures of geometry and kinematic parameters are especially important for increasing the load capacity of worm gear drives combined with simultaneous increasing of their efficiency.

Therefore, the results obtained are quite significant for engineering practice.

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