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Effect of the Macro-Geometric and Micro-Geometric Modifications on the Static Transmission Error and the Load Sharing Factor of Helical Gears

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ABSTRACT: The aim of this study is to investigate the effects of design parameters and profile modification on static transmission error and load sharing factor of helical gears using an analytical method by Matlab software. In the first step, the main source of the noise in the gear pair, transmission error, is defined. Then, the load sharing factor and static transmission error are calculated using the gear mesh stiffness. In this research, the total stiffness of helical gears and the load sharing factor are determined using an accumulated integral potential energy method. Obtained and available results are compared and are in good agreement. The effect of design parameters such as module, helix angle and so on are studied on average and pick to pick of the helical gears transmission error and the load sharing factor are investigated. These parameters are called macro-geometric parameters of the gear pairs. The results of this study show that the simultaneous modification of macro-geometric modifications and profile modification (micro-geometric parameters) cause to a more uniform load distribution and significantly reduce the transmission error of the helical gear and consequently decrease the noise and vibration of the gearboxes.

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1- Introduction

The gearbox noise is one of the common noise sources in the industry. The gearbox noise came from gear teeth come into and out of contact generally. The transmission error is the main reason for vibration and noise production that transmit to other components of the gearbox, its block and foundation. In these two decay, most of the researchers focused on vibration and noise reduction in gearboxes and transmission error is defined as the main source of vibration and noise [1]. Also, the design parameters optimization and the tooth profile modification are defined as the main solution to reduce transmission error, vibration, and noise [2].

Wan et al. [3] calculated the mesh stiffness of the helical gear pair using the method named accumulated integral potential energy method. They considered the helical tooth such as the series of independent spur teeth with a small width. They validated their results with finite element method.

In this research, the static transmission error and the load sharing factor of the helical gear pair are calculated analytically. For this purpose, the helical gear pair mesh stiffness is calculated initially. Then, the effect of the design parameters such as the helix angle and the tooth profile modifications are illustrated on the static transmission error and the load sharing factor.

2- Initial Definitions

2- 1- Static transmission error (STE)

The STE is defined as the difference between the position that driven gear is there actually and the position that it is expected to be theoretically. On the line of action, this difference is defined as Eq. (1):

$$TE = r_{b_2}\left(\theta_2 - \frac{r_{b_1}}{r_{b_2}}\theta_1\right) = r_{b_2}\theta_2 - r_{b_1}\theta_1 \tag{1}$$

where, $r_{(b1)}$, $r_{(b2)}$, θ_1 and θ_2 are base circle radios and rotation angle of the driver and driven gears respectively.

Also, the STE can be calculated according to the mesh stiffness and the contact force as Eq. (2) [4]:

$$STE = \frac{F}{K} \tag{2}$$

2- 2- Load sharing factor (LSF)

In the meshing of the gear pair, the contact force is shared between the pairs of teeth according to their stiffness. So, the LSF of each pair of teeth is defined as Eq. (3) [5]:

$$LSF = \frac{F_i}{F_{Total}} = \frac{K_i}{K_{Total}} \tag{3}$$

where, subscripts *i* and *Total* refer to a pair of teeth in contact and whole gear pair respectively.

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2- 3- Tooth addendum modification

As shown in Fig. 1, the tooth tip thickness is reduced in this modification. According to Fig. 1 two parameters C_a and L_a are defined as the amount and the length of the profile modification [6].

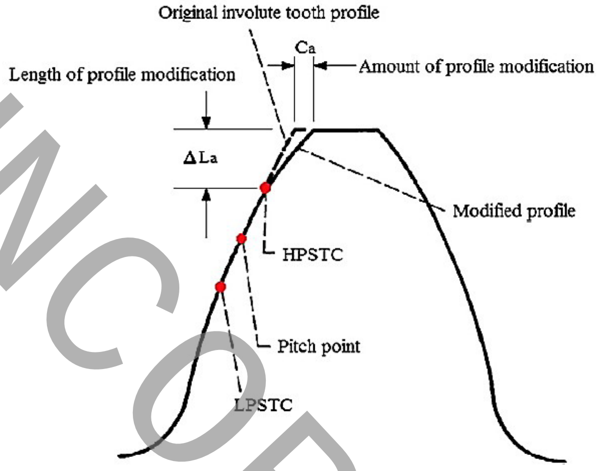

Figure 1. Tooth Addendum Modification [6].

3- Solution Method

The first step to calculate the STE and the LSF is the mesh stiffness calculation. The spur gear mesh stiffness is the basis to calculate the helical gear mesh stiffness.

3- 1- Spur gear pair mesh stiffness

According to the potential energy method, the total potential energy stored in the meshing tooth is expected to contain five components including, Hertzian, bending, shear, axial compressive and fillet-foundation energy, which can be used to compute Hertzian stiffness K_h, bending stiffness K_b, shear stiffness K_s, axial compressive stiffness K_a, and fillet-foundation stiffness K_f, respectively. Then the teeth pair stiffness is divided into the nine parts; axial, bending, shear and fillet-foundation stiffness for each gear tooth and Hertzian stiffness of their contact [3]. The stiffness of two teeth in contact and the mesh stiffness of the gear pair can be calculated by Eqs. (4) and (5):

$$K_i = \frac{1}{\frac{1}{K_{ap}}+\frac{1}{K_{bp}}+\frac{1}{K_{sp}}+\frac{1}{K_{fp}}+\frac{1}{K_h}+\frac{1}{K_{ag}}+\frac{1}{K_{bg}}+\frac{1}{K_{sg}}+\frac{1}{K_{fg}}} \quad (4)$$

$$K_M = \sum_{i=1}^{2} \frac{1}{\frac{1}{K_{ap}^i}+\frac{1}{K_{bp}^i}+\frac{1}{K_{sp}^i}+\frac{1}{K_{fp}^i}+\frac{1}{K_h^i}+\frac{1}{K_{ag}^i}+\frac{1}{K_{bg}^i}+\frac{1}{K_{sg}^i}+\frac{1}{K_{fg}^i}} \quad (5)$$

where, subscripts p and g refer to the pinion and the gear respectively.

3- 2- Helical gear pair mesh stiffness

The tooth surfaces of two meshing helical gears contact are on a straight line inclined to the axes of the gears. The length of the contact zone changes gradually from zero to maximum and then from maximum to zero.

This makes the vibration characteristics of helical gears different from the spur gears.

Therefore, the mesh stiffness of the helical gears cannot be calculated similarly to the spur gears because of the presence of the helix angle. However, if the helical tooth is divided into some independent thin slices whose thickness is dL, the helical gears can be considered as a series of consecutive spur gears with no elastic connection since they are usually insignificant for thin gears with low helix angles [3]. Then the stiffness of the whole tooth can be obtained by integrating along the face width.

4- Results and Discussion

4- 1- Effect of the helix angle on the STE and the LSF

The effect of the helix angle on the STE and the LSF is shown in Fig. 2. According to this figure, the increase in helix angle can reduce and smooth the both STE and LSF. But on the

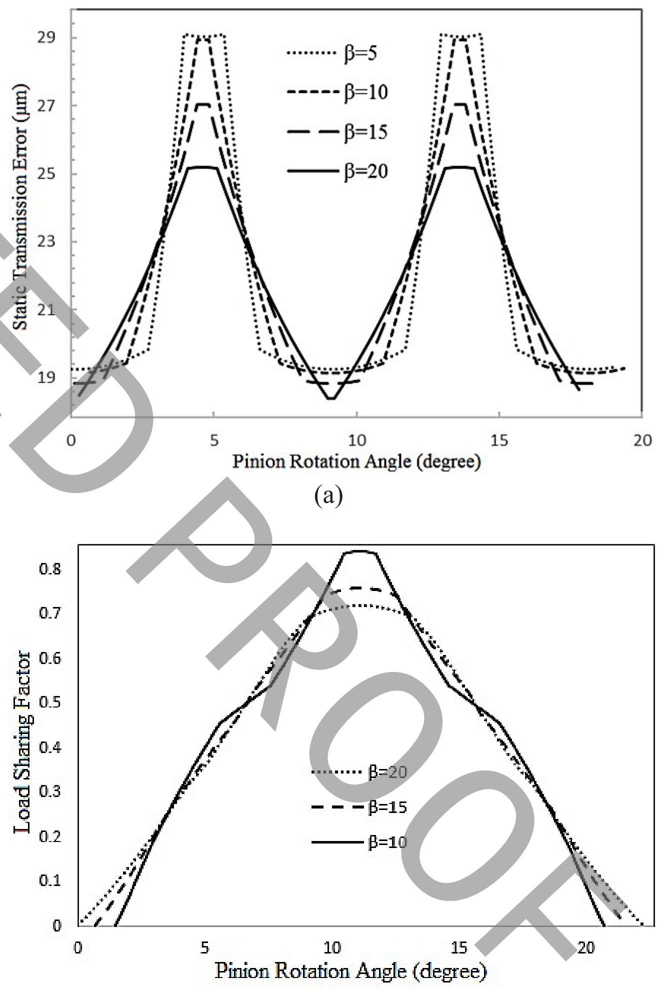

Figure 1. Tooth Addendum Modification [6].

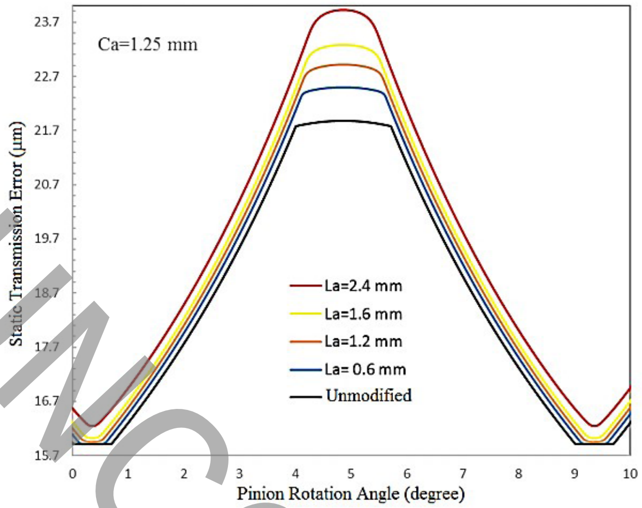

Figure 1. Tooth Addendum Modification [6].

other hand, the increase in the helix angle increases the axial load and makes the bearing operation difficult. So, the helix angle can't increase easily.

4- 2- Effect of addendum modification on the STE

The effect of various addendum modification lengths on the STE is shown in Fig. 3. According to this figure, the increase in addendum modification length increases the STE amplitude but also smooths it.

5- Conclusions

In this research, the static transmission error and the load sharing factor of the helical gear pair calculated analytically and then, the effect of the design parameters such as the helix angle and the addendum modification illustrated on the static transmission error and the load sharing factor. According to the results, the increase in helix angle can reduce and smooth the both STE and LSF. But on the other hand, the increase in the helix angle increases the axial load and makes the bearing operation difficult. So, the helix angle can't increase easily. Also, the increase in addendum modification length increases the STE amplitude but also smooths it.

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