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A method for calculating gear meshing efficiency by measured data from gear test machine

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ABSTRACT

Gear meshing efficiency is an important component of gear transmission efficiency, and the meshing efficiency of gear is directly related to device performance and energy consumption. The gear meshing efficiency can't be obtained directly from the measurement results of gear test machine. It is rarely reported effective method to calculate the gear meshing efficiency with measured data from gear test machine, which limits the verification of theoretical calculation method of gear meshing efficiency. Therefore, a method for calculating gear meshing efficiency by measured data from gear test machine is proposed in the paper. It is suitable for power closed type gear test machine, and suitable for power open one as well. Firstly, according to the type of gear test machine, the corresponding calculation method of gear transmission efficiency is confirmed. Secondly, the gear transmission efficiency under both unloaded and loaded conditions, the total power under loaded conditions and friction-related losses at the bearings are calculated at a given speed, respectively. Finally, substituting the calculation results of friction-related losses at the bearings, total power under loaded conditions and the gear transmission efficiency both unloaded and loaded conditions into the gear meshing efficiency calculation formula, and gear meshing efficiency by measured data from gear test machine is obtained. An example is presented to verify the proposed method.

1. Introduction

It is generally accepted that power losses in a gearbox originate from several sources: gear meshing power loss, windage loss, swinging oil loss and bearing loss. Among them, gear meshing power loss accounts for a large proportion [1]. The research on gear meshing efficiency is of important significance to improve the performance of gear box and save energy.

The determination methods on gear efficiency include theoretical studies and experimental works. Among them, the experiment is an effective means to verify the theory. For the theoretical calculation of gear meshing efficiency, numerous analytical models can be found in the literatures. Kolivand [2] proposed a new spiral bevel and hypoid gear mechanical efficiency model for both face-milling and face-hobbing type cutting methods. Xu [3] proposed a computational model for the prediction of friction-related mechanical efficiency losses of parallel-axis gear pairs. Kahraman [4] introduced a spur gear mechanical efficiency model based on elastohydrodynamic lubrication (EHL). Wang [5] proposed an approach of calculation on sliding friction power losses in involute helical gears with modification. On this basis, Wang [1] proposed a dynamic calculation method of sliding friction losses for a helical gear pair. In the field of experimental research of gear meshing efficiency, very little work has been done. Most of work is centered on gear transmission efficiency test [6,7]. The reasons are as follows: (1) The measurement results from gear test machine cannot directly obtain the gear meshing efficiency, but the transmission efficiency is easier to calculate according to the measured data. (2) The researchers pay more attention to the transmission efficiency, and the meshing efficiency is often neglected. Compared with the transmission efficiency, the meshing efficiency is directly related to the design parameters of the gear. With the further study of the relationship between gear design parameters and meshing efficiency, it is noteworthy that gear meshing efficiency will be paid more and more attention.

Xu [3], Chase [8], Moorhead [9] and Petry [10] only used a torque sensor to measure torque loss at a given speed under both unloaded and loaded conditions, and obtained the experimental calculation of gear meshing efficiency. However, the proposed method has the following problems: (1) The method is only suitable for the calculation of meshing efficiency in power closed type gear test machine and not suitable for that in power open one. (2) The transmission ratio of experimental gear used by them is equal to 1. Therefore, when the gear transmission ratio is not equal to 1, the proposed method cannot be adopted.

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Nomenclature

η	gear transmission efficiency of the test gearbox
T_1	torque measured by the torque sensor 1 (N m) (Figs. 1 and 2)
n_1	revolution measured by the speed sensor 1 (r/min) (Figs. 1 and 2)
T_2	torque measured by the torque sensor 2 (N m) (Figs. 1 and 2)
n_2	revolution measured by the speed sensor 2 (r/min) (Figs. 1 and 2)
P_a	power of gear a (Figs. 2 and 3)
P_b	power of gear b (Figs. 2 and 3)
P_c	power of gear c (Figs. 2 and 3)
P_d	power of gear d (Figs. 2 and 3)
ΔP	supplementary power of the motor (Figs. 2 and 3)
η_T	gear transmission efficiency under loaded conditions
η_S	gear transmission efficiency under unloaded conditions
P_T	total power under loaded conditions
P_S	losses in the form of windage and swinging oil
P_M	losses at the gear mesh
P_B	friction-related losses at the bearings
η_M	gear meshing efficiency
μ_{bi} (i = 1, 2)	coefficient of friction for the bearing
W_{bi} (i = 1, 2)	radial load applied to bearing
d_{borei} (i = 1, 2)	bore diameter of bearing
T	torque applied to a gear
d	diameter of reference circle
F_t	circumferential force
F_r	radial force
F_n	normal force
F_a	axial force
α_n	normal pressure angle
β	helix angle

According to the above introduction, the paper proposes a method for calculating gear meshing efficiency by measured data from gear test machine. It is suitable for power closed type gear test machine, and suitable for power open one as well. Specific objectives of this study are as follows:

(1) The calculation method of gear transmission efficiency is confirmed according to the type of gear test machine. The calculations of gear transmission efficiency at a given speed under both unloaded and loaded conditions are calculated. The total power under loaded conditions is calculated.
(2) The friction-related losses at the bearings are calculated by using the manufacture's specifications and published bearing efficiency models.
(3) Substituting the calculation results of friction-related losses at the bearings, total power under loaded conditions and the gear transmission efficiency both unloaded and loaded conditions into the gear meshing efficiency calculation formula, and gear meshing efficiency by measured data from gear test machine is obtained.

The flowchart for the calculation of gear meshing efficiency is shown in Fig. 1. Based on these work, we will explain in detail how the experimental gear meshing efficiency is calculated.

2. The calculation of gear transmission efficiency

The gear transmission efficiency test machine can be divided into two categories, i.e., the power open type and power closed type [11]. Figs. 2 and 3 are their typical principle diagrams, respectively. Their transmission efficiencies are respectively calculated as follows.

2.1. The calculation of gear transmission efficiency in the power open type gear test machine

In Fig. 2, gear transmission efficiency is calculated as follows.

$$\eta = \frac{T_2 n_2}{T_1 n_1} \tag{1}$$

2.2. The calculation of gear transmission efficiency in the power close type gear test machine

In Fig. 3, the reaction gearbox and the test gearbox are identical. The transmission efficiency of normal-reverse rotation is almost the same.

We assume that the power flow direction is clockwise and the supplementary power of the motor is ΔP. Then:

$$P_a = \Delta P + P_d \tag{2}$$

$$P_b = P_a \eta \tag{3}$$

$$P_d = P_c \eta \tag{4}$$

$$\Delta P = T_1 n_1 * 2\pi/60 \tag{5}$$

$$P_c = P_b = T_2 n_2 * 2\pi/60 \tag{6}$$

According to Eqs. (2)–(6), we obtain:

$$T_2 n_2 \eta^2 + T_1 n_1 \eta - T_2 n_2 = 0 \tag{7}$$

Solving the Eq. (7), we obtain:

$$\eta = \left(\sqrt{\left(\frac{T_1 n_1}{2T_2 n_2}\right)^2 + 1} - \frac{T_1 n_1}{2T_2 n_2}\right) \tag{8}$$

Where, we only give representative calculation methods of efficiency in these two categories of gear test machine. For other gear test machines falling under the two categories, their transmission efficiencies can also be calculated.

3. The calculation of gear meshing efficiency

The power losses under no load conditions represent load independent losses in the form of windage and swinging oil, and load independent bearing losses (Fig. 4). The power losses under loaded conditions represent the power losses under no load conditions, the friction-related losses at the gear mesh and the bearings (Fig. 5).

Therefore, at a given speed, the power losses under loaded conditions can be represented as,

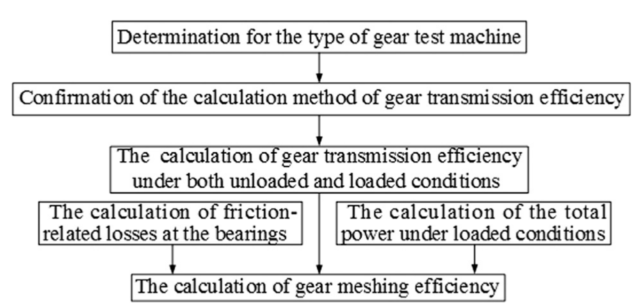

Fig. 1. Flowchart for the calculation of gear meshing efficiency.