Analysis of Profile Modification on Transmission Error of Involute Spur Gear

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Abstract— Transmission error is major factor which is responsible for the noise and vibrations in the gear system. Many authors studied the correlation between Transmission Error (TE) and Tip Relief Profile Modification, since it is a strong tool to modify TE by taking other parameters of the gear fixed. But there is less availability in literature for the work on the correlation between effect of gear parameters, pitch error and tip relief of linear profile modification by the help of interference volume method. In this present work, tip relief of linear profile modification of involute spur gear with consideration of pitch error is done. The modelling, meshing and checking the interference volume of each assembly is done using I-DEAS (Integrated Design Engineering and Analysis Software). The effect of various gear parameters on TE with linear profile modification is analysed.

Key words: TE, Gear, Tip Relief, Profile Modification

I. Introduction

A spur gear drive having quit power transmission demand is used for positive power transmission systems has created a growing demand for a more precise analysis of the characteristics of gear systems. Most of the researchers have clearly established that the transmission error is responsible for the noise of the gearbox. So the estimation of static transmission error is necessary to predict the noise of any gearbox. Transmission error is defined as "the difference between the actual position of the output gear and the position it would occupy if the drive were kinematically perfect" [1]. The basic equation for TE is given as:

$$TE\ (rad) = \theta o - (Zo/Zi)\ \theta i \quad (1)$$

where, θi = Angle of rotation of the input gear,
θo = Angle of rotation of the output gear,
Zi = Number of teeth of the input gear and
Zo = Number of teeth of the output gear.

Many researchers investigated in number of ways to reduce the undesirable transmission error from the spur gear, but tooth profile modification is one of the most effective methods for the minimization of the dynamic vibrations and noise by optimizing the transmission errors. The most popularly applied tooth profile modifications; linear tip relief is adopted here for the work. In this paper pitch error is considered with profile modification on involute spur gear which has a direct effect on the transmission error of the gear drive. It is therefore necessary to analyse the effect of pitch error on the transmission error. Pitch error can be defined as the departure of the actual spacing of the teeth from the ideal one [1].

II. Profile Modification

Profile modification is removing of material up to some extent from the tip of the teeth to reduce the unevenness from static TE. Thus, profile modification is the intentional change of the true involute profile of the gear tooth [2]. Different shapes of tooth profile modification are proposed by various researchers, such as linear, parabolic, circular, straight, quadratic and rotated form profile modifications. Since modifying the root of one member has the same effect as modifying the tip of the mating member, all modifications were assumed to be applied at the tooth tips [4].

The maximum amounts of tip modifications are defined in some existing standards such as British Standard (BS 1970) and ISO (ISO/DIN 1983). In the standards, the suggested maximum magnitude of relief is given out as Ca_max=0.02m and the relief length is ΔLa_max=0.6 m, where m is the module of the gear. The standard tip relief limitations can be chosen as the reference values to calculate the actual profile modification amount where Cn and ΔLn are the normalized relief parameters that clearly show the applied relief (parameters) relative to the limits used in the standards, Ca and ΔLa are actual amount relief and length [4] shown in Fig. 1.1.

$$C_n = \frac{C_a}{C_{a\_max}}$$

$$L_n = \frac{L_a}{L_{a\_max}}$$

Fig. 1.1: Formulas for Actual Length and Amount of Profile Modification [4]

In this paper, the tip relief profile modification is done from the highest point of single tooth contact (HPSTC) to the recess amount of tip end. Another challenge for the profile modification is optimization which produces great effect on the gear performance. There are many factors had taken into account that is low contact ratio, high contact ratio, speed and load before choose an optimum profile modified length and amount by [2].

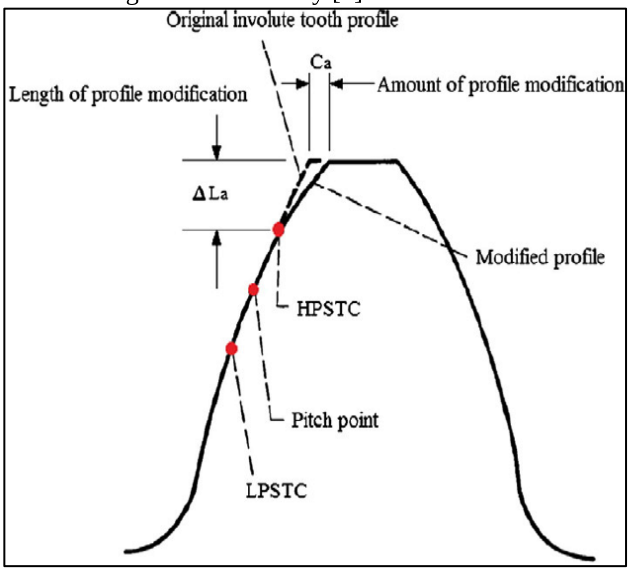

Fig. 1.2: Gear Tooth Profile Modifications [4]

It can be observed that dynamic tooth force can be reduced for Cn = 1 up to certain pinion speed after which the dynamic tooth force is minimum for other modification. Below 1750 rpm and 1750 to 6000 rpm range, normalized length of modification for optimization is found to be 1.0 at most of the speeds, while normalized amount of modification is 1.0.It has been found that the effect of load on profile modification is not significant but geometrical errors have great influence on it, especially on length modification. The optimal modification of profile depends upon speed by [2]. Therefore normalized length of profile modification as 1 and normalized amount of profile modification as 1 because it cover most of the speed range. After that selection of Ln and Cn, calculate the actual length and amount of profile modification by the help of formula given in figure 1.1.

III. Research Objectives

1) To select the optimize parameter for the profile modification of involute spur gear on the basis of previous research papers [2, 5, 6].
2) To generate different theoretical models of the spur gear having different parameters, pitch errors and tip relief profile modification simultaneously,
3) To use interference volume method for determining the static transmission error of ideal involute spur gears in mesh with Erred Gear at each angular rotation of mesh cycle,
4) To predict the effect of tip relief profile modification of pitch error involute spur gear on the transmission error using the interference volume method.
5) To predict the effect of various gear parameter on transmission error using the interference volume method.
6) To compare the available data of Error gear on TE by [1] with the modified Error Gear data on TE so we observe the changes in result and conclusion during this research.

IV. Model Preparation

Model has been prepared in IDEAS software in which different sets of fundamental dimension values module (m)=3,5 and 6, Number of teeth(Z)=18,20,24 and 30, pressure angle (phi)=18,20 and 25) and pitch error of 1% and 2% and optimum Normalized length of profile modification (Ln)=1 and optimum Normalized amount of profile modification(Cn) =1. There are 72 erred gear model which generate in IDEAS software so it is not possible to give figure of each model.

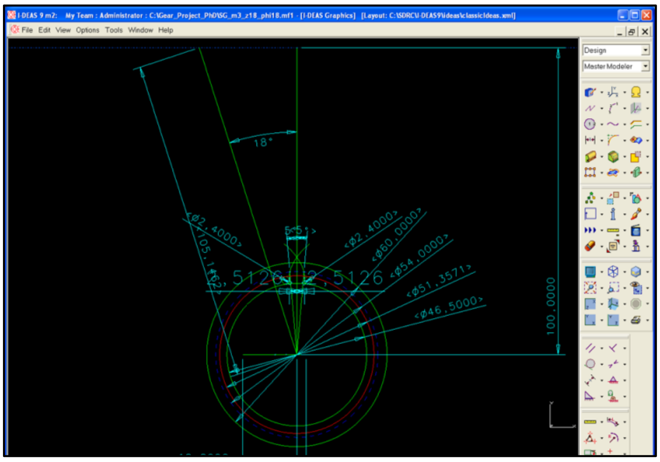

Fig. 1.3: Modeling of Master Gear

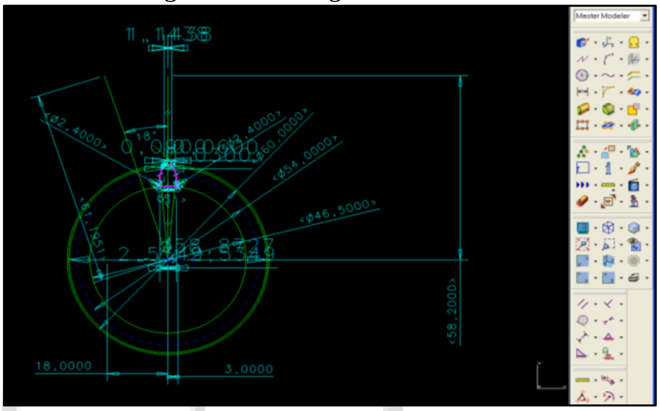

Fig. 1.4: Modeling of Error Gear

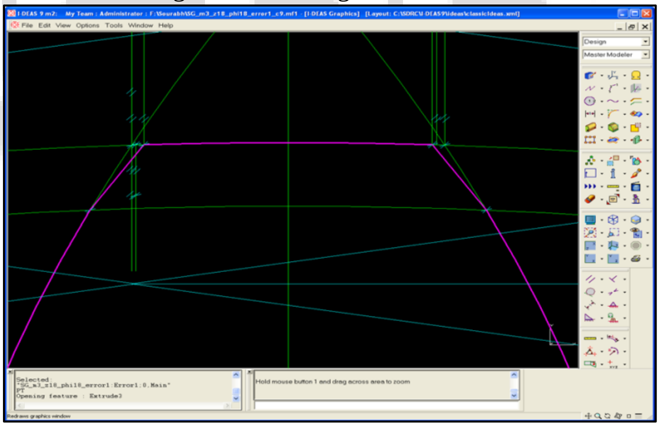

Fig. 1.5: Profile Modification of Involute spur gear

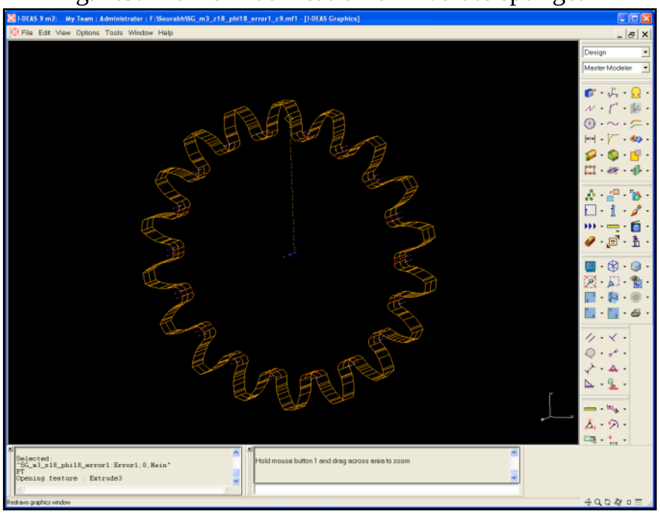

Fig. 1.6: Model of Error Gear

A. Meshing and check interference volume:-

Meshing is done in IDEAS software in which Master Gear is mesh with the modified Erred Gear in these way 72 assemblies was prepared and then checks the volume interference. Checking of interference value by rotating the left *Master Gear* was rotated about z-axis by an angle of 1° in CW direction (amount of angle given was -1°).In the similar way, the right *Master Gear* was given 1° rotation in CCW direction (amount of angle given was 1°).Repeating the same procedure, the interference volume was checked and noted as shown in fig 1.8 and fig 1.9. The rotation required for checking the interference volume were 20° for 18 numbers of teeth, 18° for 20 numbers of teeth, 15° for 24 number of teeth and 12° for 30 numbers of teeth.

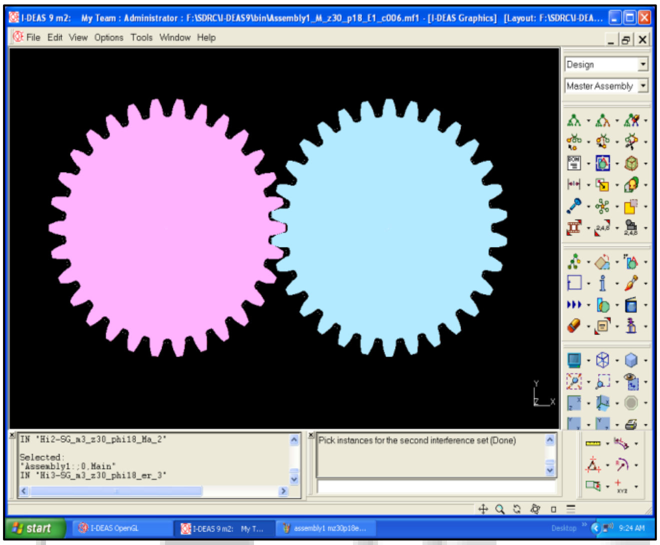

Fig. 1.7: Assembly of Master and Error gear

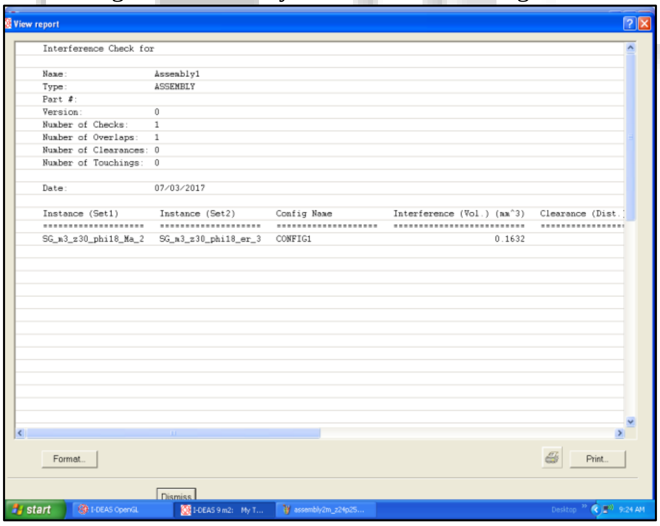

Fig. 1.8: View Report Form

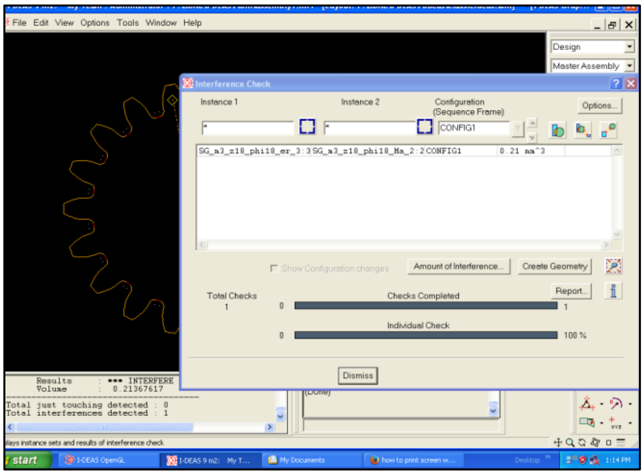

Fig. 1.9: Check Interference volume

B. Effect of module:-

For the present research work, module values of 3, 5 and 6 mm are taken from the preferred series. Here, the most commonly used spur gears are considered. Prediction of effect of module in comparison with the previous data on erred gear by [1] with the modified error gear data. With the help of readings as tabulated, graphs are drawn between interference volume and rotation angle. There are so many graphs which is not possible to represent in these paper but all graphs show same behavior as the graph present in these paper. From the graphs, the general predictions are:

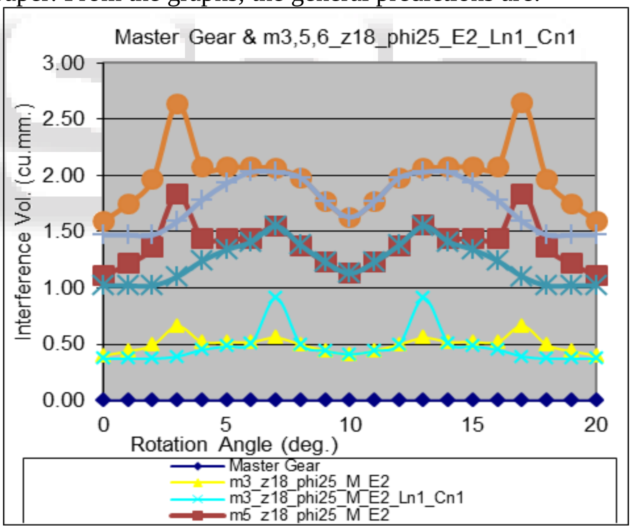

Fig. 1.10: Master Gear & m 3, 5, 6_z18_phi25_E2_Ln 1_Cn1

1) As we increase the module of spur gear the value of interference volume is more in pitch error case as compare to the tip relief profile modification of spur gear with pitch error. These indicate that for higher value of module, the TE is more in previous case as compare to the latest one. For example, graph shown in Figure for 18 numbers of teeth, 18° pressure angle and2% pitch error, the variation of interference volume from 0° to 20° angle of rotation, when curves are traced from module 3 to 6 mm.
2) But some similar character shows in both cases that the value of interference volume fluctuates with change in the value of angle of rotation and there are points with certain peak values. This implies that for continuous rotation of the gear pair, the TE does not remain

constant and indeed fluctuates. There are certain peaks, which are prominent and these are the points of concern for noise generation.

3) The interference volume curve for almost every gear is identical about its midpoint.

For higher number of teeth and higher pressure angle, the curve tends to become flat, interference volume variation becomes less and consequently TE variation is reduced.

d	Master Gear	m3_z18_phi25_M_E2	m3_z18_phi25_M_E2_Ln1_Cn1	m5_z18_phi25_M_E2	m5_z18_phi25_M_E2_Ln1_Cn1	m6_z18_phi25_M_E2	m6_z18_phi25_M_E2_Ln1_Cn1
0	0	0.3990	0.3700	1.1084	1.0200	1.5961	1.4700
1	0	0.4370	0.3700	1.2140	1.0200	1.7481	1.4700
2	0	0.4914	0.3700	1.3650	1.0200	1.9656	1.4700
3	0	0.6599	0.3900	1.8326	1.1000	2.6395	1.5900
4	0	0.5188	0.4500	1.4411	1.2400	2.0751	1.7800
5	0	0.5190	0.4800	1.4416	1.3400	2.0760	1.9300
6	0	0.5186	0.5100	1.4406	1.4100	2.0744	2.0300
7	0	0.5581	0.9100	1.5502	1.5500	2.0595	2.0300
8	0	0.4951	0.5000	1.3752	1.3800	1.9803	1.9800
9	0	0.4422	0.4400	1.2284	1.2300	1.7688	1.7700
10	0	0.4066	0.4100	1.1295	1.1300	1.6265	1.6300
11	0	0.4423	0.4400	1.2287	1.2300	1.7693	1.7700
12	0	0.4953	0.5000	1.3758	1.3800	1.9811	1.9800
13	0	0.5562	0.9100	1.5549	1.5500	2.0605	2.0300
14	0	0.5189	0.5100	1.4414	1.4100	2.0756	2.0300
15	0	0.5193	0.4800	1.4424	1.3400	2.0771	1.9300
16	0	0.5191	0.4500	1.4418	1.2400	2.0762	1.7800
17	0	0.6622	0.3900	1.8392	1.1000	2.6490	1.5900
18	0	0.4916	0.3700	1.3655	1.0200	1.9664	1.4700
19	0	0.4372	0.3700	1.2143	1.0200	1.7486	1.4700
20	0	0.3990	0.3700	1.1084	1.0200	1.5961	1.4700

Fig. 1.11: Table of Interference volume with rotating angle

V. Results and Conclusions

It is predicted from the graphs that the transmission error reduces with reduction in module. This has also been informed by many other researchers who have done the analytical and experimental work related to transmission error. The reason reported being the duration of the critical contact segment is reduced, and hence the TE and consequently the radiated noise are also reduced. In our observations, it is the less amount of interference volume which is responsible for the less transmission error.

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