DETERMINATION OF GEAR TOOTH SURFACE DEVIATIONS IN CASE OF SPIRAL BEVEL GEARS

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Abstract: *Real gear tooth surfaces are measured by co-ordinate measurement systems. Machine setting errors like work piece and tool setting errors issue of spiral bevel gear cutting procedure are detected from the measurement data. As the theoretical gear surface is expressed as a function of machining parameters, an estimated surface is fitted to the real one. The deviations between the design surface and the estimated surface are considered as machine settings errors.*
Keywords: *gear design, spiral bevel gears, tooth surface measurement, CMM.*

1. INTRODUCTION

In order to ensure satisfactory kinematics and dynamic performances and meet more and more stricter NVH (noise, vibration and harshness) requirements, the high performance gear transmissions, as spiral bevel gears, require increasingly fine definition of tooth gear geometry, because spiral bevel gear behaviour is particularly sensitive to the initial geometry of the tooth surfaces. To formalize the theory of geometry definition many authors have attempted [Gosselin 2000, Kawasaki, Zhang] taking into account significant machining parameters and to control tooth surface after machining [Litvin 1996, Márialigeti, Zhang].

In the Klingelnberg Cyclo-Palloid System, a continuous cutting procedure is achieved. Tooth surfaces are basically conjugated [Litvin 1989], both the concave and the convex sides of the tooth surfaces are machined simultaneously. The finishing points of the cutter edge trace the longitudinal shape of the tooth surface (Fig. 1.). The extended epicycloid is obtained by a rolling over motion. Obviously, the shape and the orientation of cutter edges govern the final tooth surfaces. The cutter edge is basically orientated to the instantaneous centre of rotation *I* in mean generating point *P* (Fig. 1.).

According to the recent manufacturing development, spiral bevel gear geometry has become more and more sophisticated. Advance of CNC machines and inspection based on co-ordinate measuring machine give possibilities to identify the cutting errors. Thus the dependence on skilful of workmanship and the trial-and-error method are eliminated. The occurrence of error called error factors [Kawasaki]. After identification of these errors, they will be fed back to the gear cutting process resulting in a more accurate gear.

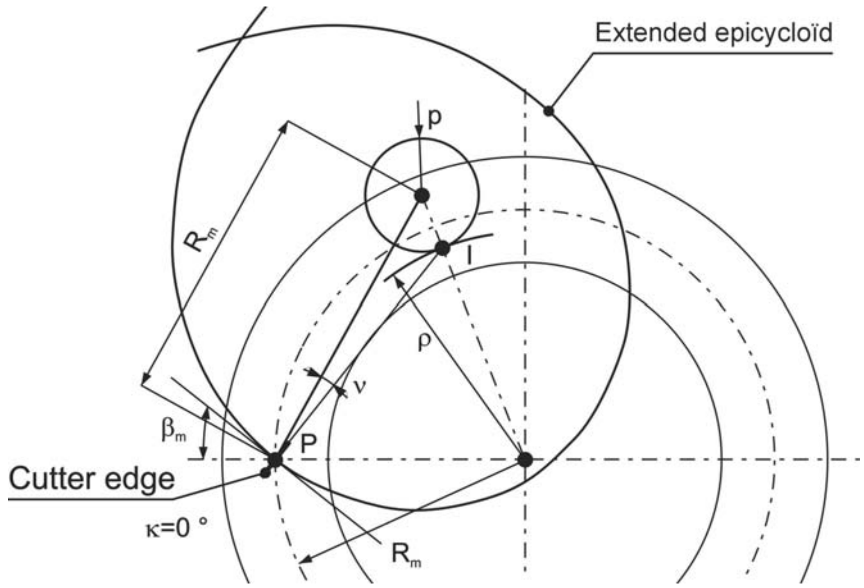

Fig. 1. Tooth surface longitudinal shape in Klingelnberg Cyclo-Palloid System

2. GEAR TOOTH SURFACE INSPECTION

An inspection method was proposed to identify the error factors of gear tooth surface by Kawasaki. Especially this inspection method is applied to Cyclo-Palloïd Klingelnberg gears. Concept of the inspection is based on CMM measurement of tooth surface points. Theoretical tooth surface as function of machining parameters is estimated by the least square method to define how the theoretical surface fit to the measured data. Any deviation is considered as a machine setting error. The feed back of these errors to the cutting procedure can provide more accurate tooth surfaces.

We estimate every Δt of each selected machining parameters separately, considering other's fitness accuracy value equals zero. To select error factors, we consider the most significant, which has the smallest value of fitness accuracy, and an error factor is detected.

Measures are affected on the pinion part of a gear set. Two consecutive convex tooth surfaces were measured (Fig. 2.) in 75 (5x15) points. This large number of points is necessary to have enough large resolution on the tooth surface, furthermore to avoid measurement errors. Each measure was taken in perpendicular direction to the rotational axis of the pinion, and then residual error, deviation between theoretical and the real tooth surfaces, is presented in a symmetrical grid.

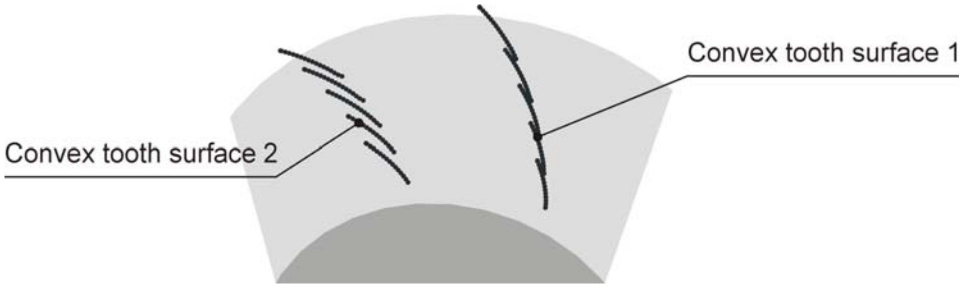

Fig. 2. Measured points on convex tooth surfaces

3. RESULTS

This inspection method for Klingelnberg's Cyclo-Palloïd spiral bevel gears is proposed to establish a manufacturing validation procedure. Gear parameters are presented in previous publications of the authors [Marialigeti, Lelkes]. The following machining parameters are selected as error factors in spiral bevel gear cutting: machine distance M_d, head cutter radius R_h, pressure angle α_n, pitch cone angle δ_m, external cone distance R_e, and offset distance I_x along x_s axis of global co-ordinate system of the machine. Spherical probe radius is r_0=0,99585 mm. Values of deviation, residual errors, are calculated in measurement points. Each value of fitness accuracy Δt and angle of rotation about gear axis Φ (between theoretical and measured values) were calculated.

Results for convex tooth surfaces 1 are shown in table 1. In both two cases, the offset distance I_x has the smallest value, thus this parameter should be considered as the best fitted to the measured data.

Error factor	Error	Φ (°)	Δ*t* (μm)
M_d	-0,218 mm	57,969	18,03
α_n	2,563 °	58,068	44,99
R_h	0,453 mm	57,611	20,36
δ_m	-0,854 °	58,739	31,86
I_x	0,177 mm	57,927	13,73
R_e	-0,256 mm	58,130	40,25

Table 1. Results of the first inspection, convex tooth surface 1

Than, we redo estimation by ΔI_x equals 0,177 mm and 0,156 mm, for tooth surface 1 and 2 respectively, so this error factor should equal zero. In addition, we estimate values of M_d, R_h, α_n, δ_m, and R_e parameters separately to determine values of other error factors. Based on the first estimation, we can observe that only one error stays to be significant. Pressure angle α_n, has the smallest fitness accuracy Δt. Therefore a new estimation is needed to eliminate the effects of setting problem of pressure angle. The other factors of M_d, R_h, δ_m, and R_e of parameters are now very close to the machining parameter values.

After second estimation, the values of error factors are not considerably higher that they were after the first estimation (Tables 2.), each fitness accuracy has almost the same value. To eliminate the errors corrective cutting is necessary increasing in two machining parameters, as offset distance and pressure angle. Deviation values between theoretical and measured tooth surface show (Fig. 3.) that almost identically positioned peaks can be find on both surfaces. These peaks are not changed by estimation, and they can be as results of machining setting error or heat treatment problem. Thus we should suppose that this pinion would not work properly.

Error factor	Error	Φ (°)	Δ*t* (μm)
M_d	0,0003 mm	57,927	13,46
R_h	-0,004 mm	57,931	13,47
δ_m	-0,017 °	57,942	13,44
R_e	0,007 mm	57,925	13,46

Table 2. Results of the inspection after the second estimation, convex tooth surface 1,

ΔI_{x1}=0,177 mm, $\Delta\alpha_{n1}$=2,697 °

Direction of the cutter edge is not considered as error factor estimation for machining parameters. Since this parameter has important effect on contact pattern localisation [Lelkes

2002], the setting of the cutter edge was studied. The angular values of the cutter edge rotation were estimated after estimation of error factors. The angle of rotation κ of the cutter edge equals 0,011 both for tooth surface 1 and 2, thus the cutter edge is well oriented to the instantaneous centre of rotation in the pitch plane in mean generation point *P* (Fig. 1.).

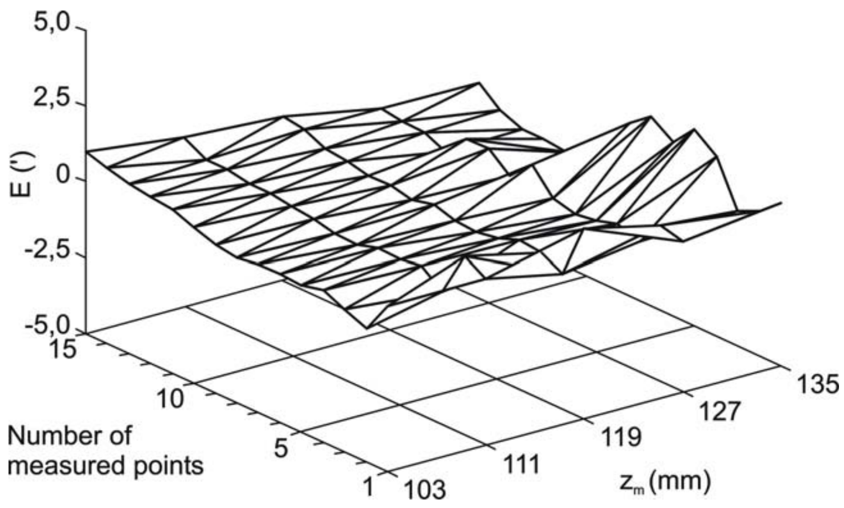

Fig. 3. Deviation values, convex tooth surface 1, ΔI_{x1}=0,177 mm, $\Delta \alpha_{n1}$=2,697 °

4. CONCLUSION

Numerical determination of deviations of real tooth surfaces from the theoretical ones is applied as a first step to validate the manufacturing accuracy.

Two consecutive tooth surfaces were measured by 3D CMM measurement system in many points to detect machining parameters errors. We observe that error factors are repeating. This is based on the quasi-similar value of error factor related to offset distance and pressure angle. The error factor of offset distance is the most significant. In addition, peaks are shown on both surfaces almost in the same area. These errors of the pinion part predict that the gear set will not probably satisfy NVH requirements during working. Therefore a corrective cutting, with the fed back of significant errors, is necessary to have more accurate gear.

To identify the setting of the cutter edge, rotation value is determined. The cutter edge is not rotated from its basic position.

5. ACKNOWLEDGEMENTS

We thank the French Research Ministry and the Hungarian Ministry of Education (grant no.: FKFP 0240/97), also well as the Ganz Dawid Brown Transmission Co., Budapest, for supporting the present collaborative research program. Special thanks are also due to the National Institute of Applied Sciences in Lyon and the Budapest University of Technology and Economics for the collaborative PhD. student facilities.

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