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Evaluating the Influence of the Disc Tool Axis Position Errors on the Machined Helical Gear Surface

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***Abstract* - This work has presented advanced methods for determining disc tool profiles for machining helical gears and how to evaluate gear errors, as well as the influence of tool axis position errors on the machined gear surface by 3D comparing the tool surfaces corresponding to the tool axis positions. Experimental results for ISO standard helical gears confirm that the precision of the disc tool determined by the proposed method is very high (0.01 mm), with a helix angle greater than 20 degrees, undercutting is likely to occur, the influence of the angle between the tool axis and the machined gear axis on the gear surface deviation is on the order of 0.05 mm per 0.5 angular deviations.**

Keywords: Disk tool, helical gear, characteristic curve, undercutting, envelope method.

I. INTRODUCTION

Iso helical gears is often machined by milling and grinding with disc tools. Disc tool profiling is calculated from envelope theory. Livin [1] has studied determining the envelope to a family of surfaces by giving the meshing equations of kinematics pairs. More recently, advanced numerical solutions for the envelope problem have been presented [2-6]. In the other direction, Stoic N. [4] has studied the disc tool setting errors to compensate for the disc tool deformation and wear. Authors in [7-9] presented 3D CAD Boolean operates-based solutions to design disc tools machining helical surfaces. Authors in [10-13] have reported envelope methods based on the CATIA graphical platform for profiling rotation tools.

Traditional analytical methods are fundamental to other methods and give precise solutions. However, they are complex and more difficult. The numerical analytical methods are based on traditional analytical methods, which solve approximately a system of five nonlinear meshing equations, so they have some disadvantages, like traditional analytical methods. The Boolean method is a novel method that simulates the actual envelope process, like the material-cutting process. Still, the method takes a long time to perform and cannot be directly used for reverse engineering because the object is not solid. The solutions using the normal projection command in the CATIA graphical platform are exciting but cannot be performed in some cases.

Based on the state of the previous work mentioned above, this work implements advanced disc tool profiling methods for evaluating the influence of tool axis position errors on the machined helical gear surface by 3D comparing the tool surfaces corresponding to the tool axis positions.

II. METHOD FOR GEAR DISC TOOL PROFILING AND DEVIATION EVALUATION

The meshing condition of a kinematic pair, including pinion and gear pair and gear and cutting tool pair, is derived from the envelope concept to a family of surfaces. Litvin [1] generally denotes surfaces 1 and 2 for a meshing surface pair, including pinion and gear or machined gear surface and its envelope-cutting tool. The coordinate systems S_1 and S_2 are fixed into surfaces 1 and 2. Surfaces 1 is presented by a vector function $r_1(u,\theta)$; $r_2(u, \theta, \tau)$ is the vector function presenting the surfaces family surfaces 1 represented in S_2, where τ is the motion parameter. As a meshing condition, surfaces 1 and 2 are tangent together, which deduces Equation 1 below [1].

$$N.V = 0 \qquad (1)$$

Where $N = (\partial r1/\partial u \times \partial r1/\partial \theta)$ represents a normal vector to surface r_1, and $V = \partial r_1/\partial \tau$ represents a relative velocity vector of the points on the surfaces r_1 with respect to the surfaces r_2.

In the case of the helical surface and its disc tool surface, Equation (1) deduces Equation (2) below.

$$\left(\overrightarrow{Ad}, \overrightarrow{Nv_{\Sigma}}, \overrightarrow{p_1}\right) = 0 \qquad (2)$$

Where $\overrightarrow{Ad}$ presents the disc tool axis; $\overrightarrow{Nv_{\Sigma}}$ presents a normal vector of the machined gear surface at the contact point; $\vec{p}$ presents the position vector of the contact point. In the CATIA platform, such characteristic curves can be created by projecting the disc tool axis normal to the helical gear surface, as shown in Figure. 1.

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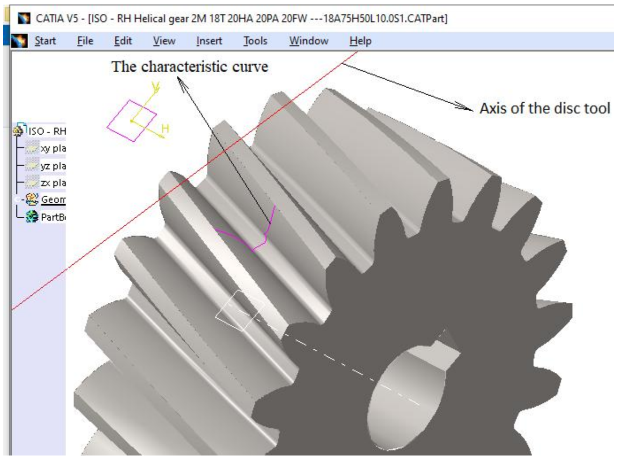

Figure 1: The characteristic curve was created by the CATIA [16]

Import the heliacal gear 3D model with the characteristic curve into the AutoCAD platform and run a subroutine written in Auto lisp following the algorithm shown in Fig. 2 below.

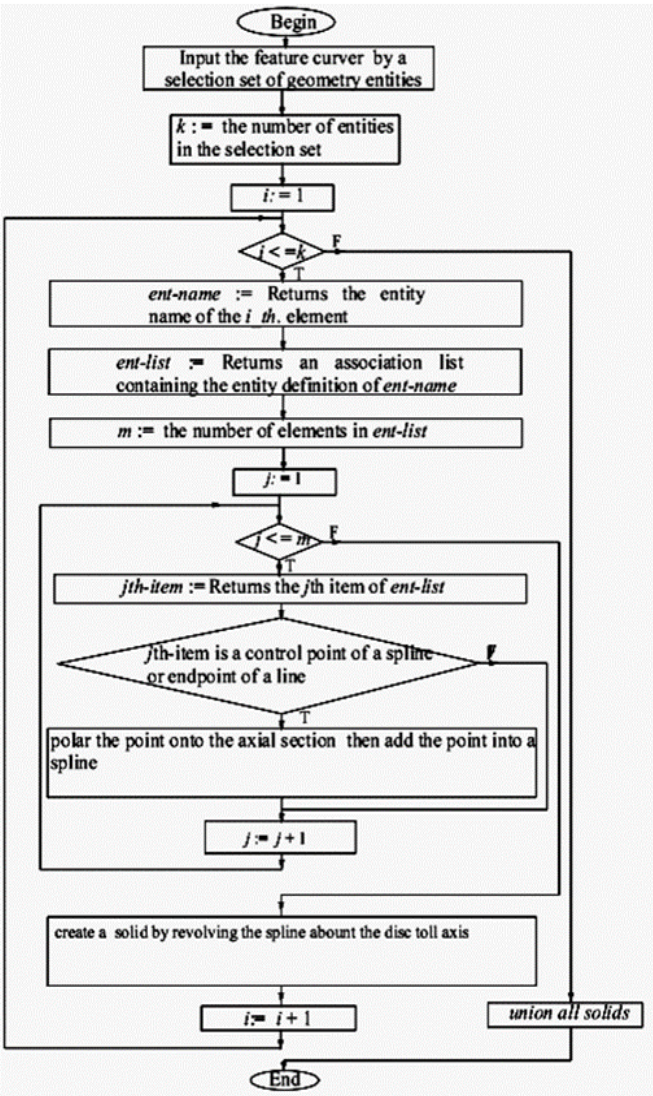

Figure 2: The algorithm block diagram

In the AutoCAD package, the Autolisp subroutine above picks up every point on the characteristic curves to calculate the coordinates of points on the disc tool axial section to create the disc tool 3D model.

III. RESULTS AND DISCUSSIONS

As an experimental sample, an ISO helical gear was created in the Solid Work, as shown in Figure. 3.

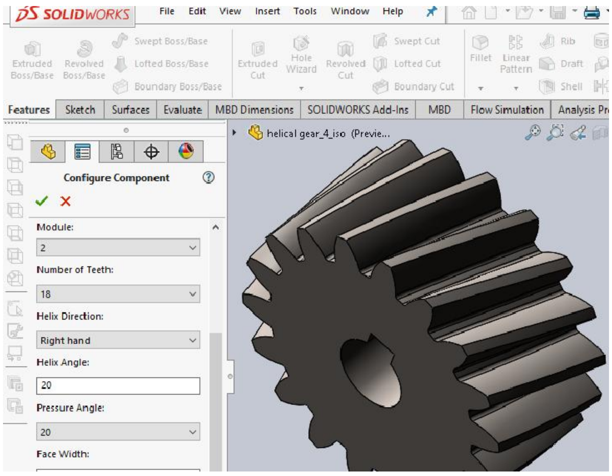

Figure 3: The ISO standard helical gear

Import the helical gear into the CATIA package and create the disc tool axis with position parameters, as shown in Figure 4. Use the project command in the CADTIA package, and the characteristic curve is created. The gear, the characteristic curve, and the disc tool axis were imported into the AutoCAD package, then run the subroutine, which follows the algorithm shown in Figure 2, written in Autolisp (a programming language in AutoCAD) to create the disc tool, as shown in Figure 5.

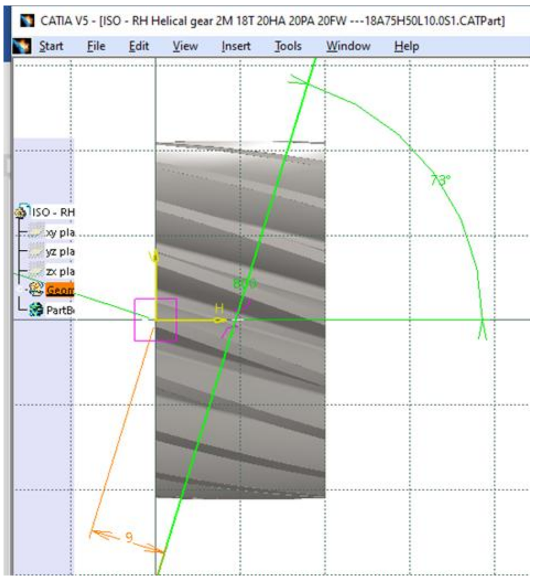

Figure 4: Disc tool position sketching

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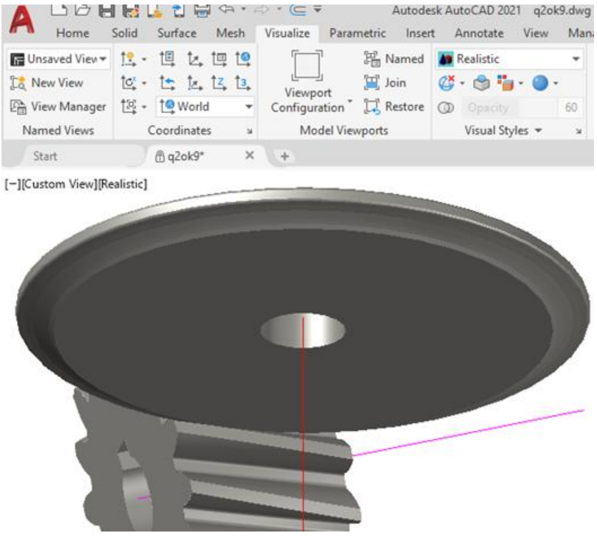

Figure 5: Disc tool 3D model was automatically created in AutoCAD

Repeat the above steps with changes in the position of the tool axis.

In case study 1, the angle between the axis of the tool axis and the machining gear axis is changed to 72.5 degrees, and the 3D model of the tool is compared with the 3D model of the tool in a 73-degree angle position, as shown in Figures 6, 7 and Table 1.

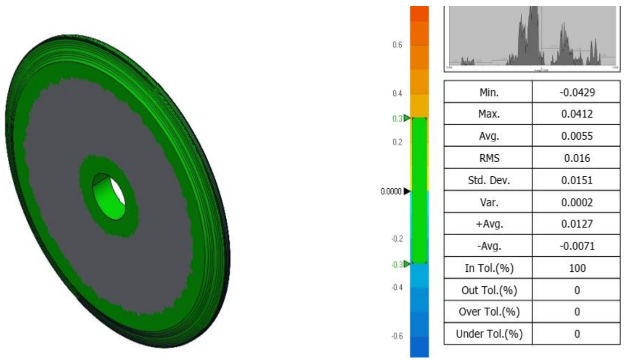

Figure 6: 3D surface comparison in case study 1 by the Geomagic

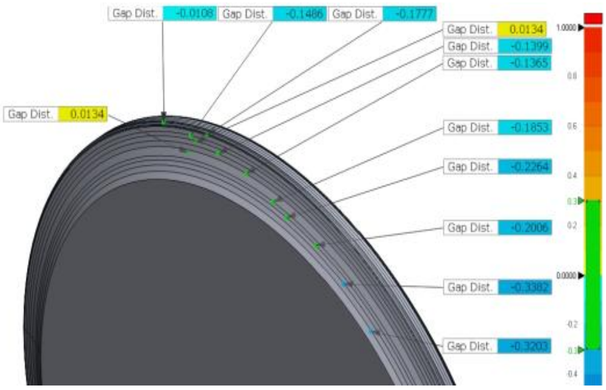

Figure 7: 3Dpoints comparison in case study 1 by the Geomagic

Table 1: 3D points comparison in case study 1by the Geomagic

Name	Reference Pos.			Measured Pos.			Gap Dist.	Tolerance
	X	Y	Z	X	Y	Z		
CMP1: 1	-14	30.1915	16.2598	-13.9962	30.1832	16.2539	-0.0108	±0.3
CMP1: 2	-10	31.0662	16.5468	-9.9896	31.0342	16.4021	-0.1486	±0.3
CMP1: 3	-6	31.3178	16.7545	-5.9921	31.2779	16.6206	-0.1399	±0.3
CMP1: 4	-2	31.3606	16.887	-1.9974	31.3231	16.7558	-0.1365	±0.3
CMP1: 5	2	30.6694	17.193	1.9955	30.5943	17.0237	-0.1853	±0.3
CMP1: 6	4	30.1496	17.3367	3.9877	30.0579	17.1301	-0.2264	±0.3
CMP1: 7	8	29.3428	17.3366	7.9785	29.2638	17.1535	-0.2006	±0.3
CMP1: 8	12	27.5387	17.5242	11.9388	27.4003	17.2217	-0.3382	±0.3
CMP1: 9	15.9999	24.8867	17.7712	15.9174	24.7576	17.4899	-0.3203	±0.3
CMP1: 10	21.9998	19.7825	17.7709	21.8818	19.6761	17.4787	-0.3326	±0.3
CMP1: 11	23.9999	16.3288	18.1711	24.0043	16.3318	18.1786	0.0093	±0.3
CMP1: 12	-10	29.9999	14.3067	-9.9804	29.9416	14.4734	-0.1777	±0.3
CMP1: 13	-12	28	13.8207	-12.0027	28.0063	13.8091	0.0134	±0.3
CMP1: 14	-14	25.4807	12.931	-14.0039	25.4877	12.9203	0.0134	±0.3
Min.	-14.0000	16.3288	12.9310	-14.0039	16.3318	12.9203	-0.3382	
Max.	23.9999	31.3606	18.1711	24.0043	31.3231	18.1786	0.0134	

In case study 2, the minimum distance between the tool axis and the gear shaft is changed to 49.5 mm, and the 3D model of the tool is compared with it in the distance position of 49.5 mm, as shown in Figures 8, 9 and Table 2.

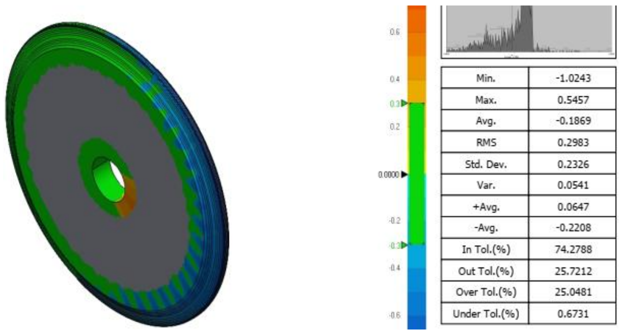

Figure 8: 3D surface comparison in case study 2 by the Geomagic

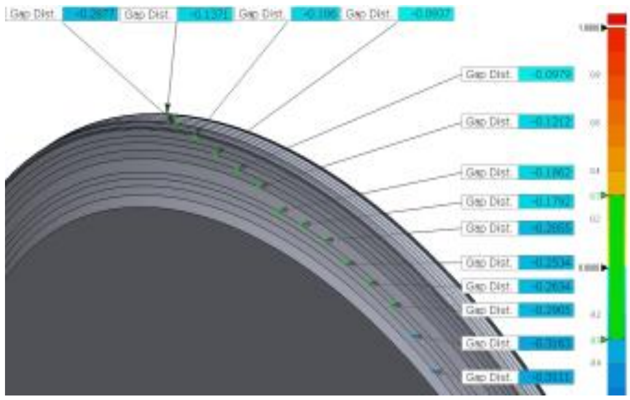

Figure 9: 3D points comparison in case study 1 by the Geomagic

Table 2: 3D points comparison in case study 2by the Geomagic

Name	Reference Pos.			Measured Pos.			Gap Dist.	Tolerance
	X	Y	Z	X	Y	Z		
CMP1: 1	-13.9987	30.1533	14.872	-13.9543	30.0554	14.9567	-0.1371	±0.3
CMP1: 2	-11.9999	31.1125	16.0985	-11.9013	30.851	16.0306	-0.2877	±0.3
CMP1: 3	-10	31.4348	16.465	-9.9931	31.4136	16.3613	-0.106	±0.3
CMP1: 4	-8	31.2769	16.6337	-7.9945	31.2551	16.5427	-0.0937	±0.3
CMP1: 5	-6	31.3178	16.7545	-5.9944	31.2898	16.6608	-0.0979	±0.3
CMP1: 6	-4	31.1686	16.8868	-3.9959	31.1356	16.7703	-0.1212	±0.3
CMP1: 7	-2	30.6694	17.193	-1.9948	30.594	17.0228	-0.1862	±0.3
CMP1: 8	0	30.7345	17.1929	-0.0003	30.6618	17.0292	-0.1792	±0.3
CMP1: 9	2	30.6694	17.193	1.995	30.5861	17.0052	-0.2055	±0.3
CMP1: 10	4	30.1496	17.3367	3.9862	30.047	17.1054	-0.2534	±0.3
CMP1: 11	6	29.8163	17.337	5.9787	29.7107	17.0966	-0.2634	±0.3
CMP1: 12	8	29.3428	17.3366	7.969	29.2284	17.0714	-0.2905	±0.3
CMP1: 13	9.9999	28.3363	17.524	9.9526	28.1928	17.2411	-0.3163	±0.3
CMP1: 14	12	27.0435	17.7712	11.9399	26.9072	17.4981	-0.3111	±0.3
CMP1: 15	16	24.2204	18.1712	15.8441	23.9868	17.7792	-0.4822	±0.3
Min.	-13.9987	24.2204	14.8720	-13.9543	23.9868	14.9567	-0.4822	
Max.	16.0000	31.4348	18.1712	15.8441	31.4136	17.7792	-0.0937	

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Case study 1, Figure 6 shows that the RMS deviation of two disc tool 3D surfaces in the angles 73 and 72.5 degrees is 0.016 mm. Figures 7 and Table 1 show which point the max point deviation is 0.33 mm.

Case study 2, Figure 8 shows that the RMS deviation of two disc tool 3D surfaces in the two axes distance 50 and 49.5 mm is 0.029 mm. Figures 9 and Table 1 show which point the max point deviation is 0.64 mm.

The undercutting appears for the ISO standard helical gear with a helical angle of more than 20 degrees, as shown in Figure 10.

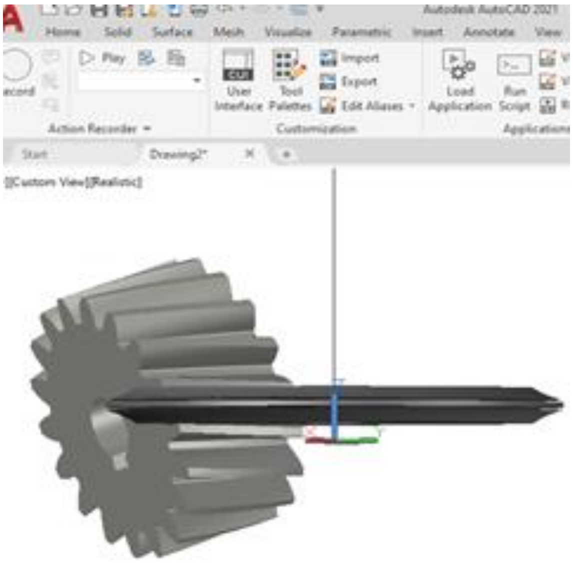

Figure 10: Undercutting lead disc tool error

Evaluating the influence of tool axis position setting errors on the machined gear surface by 3D comparing the corresponding tool surfaces has not been mentioned in previous works [1..16].

IV. CONCLUSION

This work has presented advanced methods for determining disc tool profiles for machining helical gears, how to evaluate machined gear errors, and the influence of tool axis position setting errors on the machined gear surface by 3D comparing the tool surfaces corresponding to the tool axis positions. Experimental results for ISO standard gears lead to the following conclusions.

- With a helix angle greater than 20 degrees, undercutting is likely to occur, so determining the position of the tool axis to avoid this problem is very important.
- The influence of the angle between the tool axis and the machined gear axis on the gear surface RMS deviation is on the order of 0.16 mm per 0.5 angular deviations.
- The influence of tool axis distance on machined gear surface deviation is significant, so the tool setting must be accurate at this distance.

Similar research for other types of gears will be carried out in the future.

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