Research on Precision Forging Tooth Billet of Driven Bevel Gear

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Abstract This paper researched on the driven bevel gear 344. We used the precision forging process instead the traditional tooth processing of rough milling, studied the truck driven bevel gear tooth precision forging process and the precision forging die structure, developed the driven bevel gear tooth electrode shaping and the electrode tooth mold manufacturing methods.

Keywords Driven bevel gear · Tooth billet · Precision forging technical · Tooling

1 Introduction

In recent years, the precision forging technology was more and more widely used in the automotive industry because of its own characteristics. It especially played an important role in lowering production costs and improving product quality. The tooth surface of driven bevel gear for heavy trucks is now commonly produced by rough milling after making ordinary forging blank and then fine milling (or pull teeth),with low productivity and high material consumption. Because of the stress during the machine grinding of teeth-shaped and notching, the deformation during

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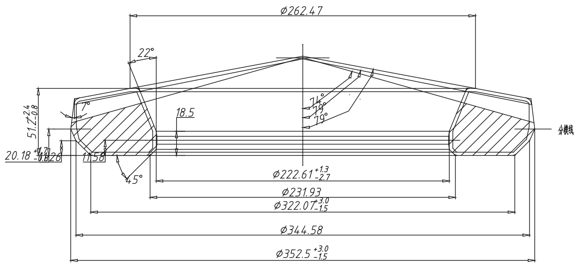

Fig. 1 Figure of the rough of precision forging gear blank

heat treatment is difficult to control, which affects the gear tooth accuracy after the heat treatment. In addition, a large amount of metal flow lines of parts is cut off during the machine cutting tooth. It leads to the lower part strength. Processing methods using precision forging tooth to replace the rough milling alveolar can improve production efficiency and part quality, while also reducing the cost of parts manufacturing.

2 The Design of Process

The project uses a combination technology program of experiment and numerical simulation analysis. Process: Cutting—heating—upsetting—punching—reaming—precision forging on friction press—normalizing—machining—carburizing—machining after heat treatment.

2.1 Design of Forgings Figure

According to GB12361-2003 and GB12362-2003, we determine the parting surface and the machining allowances and tolerances of precision forging rough.

Considering the factors of subsequent fine milling, the uneven shrinkage after forging and normalizing deformation, etc., the tooth side margin was decided for 0.5 mm (unilateral),and the others was 1.5 mm. Forging diagram as shown in Fig. 1.

2.2 Calculation of Open Forging Crack Force

Theoretical formula [1]

$$\mathrm{P} = \alpha\left(2 + 0.1\frac{F\sqrt{F}}{V_{\mathrm{F}}}\right)\sigma_b F = 2907 \text{ ton}$$

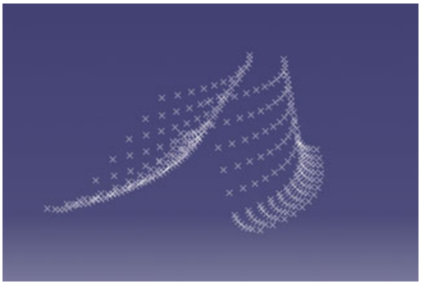

Fig. 2 Tooth surface points cloud data of the driven bevel gear 344

In the formula:

P nominal pressure;

α related to the coefficient and forging, $\alpha = 4$ at open die forging and $\alpha = 5$ at closed die forging;

F the projected area of the forging in the plane;

VF forging volume;

σb tensile strength of the metal at final forging

Approximate formula: [2]

$$\mathrm{P} = (9.5 \sim 10)\ \sigma_b F_{\mathrm{F}} = 2275\ \text{ton}$$

In the formula:

P the pressure of the screw press;

σb tensile strength of the metal at final forging;

FF the projected area on the horizontal die surface of the forging.

Through the above calculation, forging tonnage of 1600 tons friction press (available with borrowed equipment) was insufficient. So we needed to form reaming blank. The under voltage calculation should be fully considered when design forging die cavity.

2.3 Design of Tooth Profile

The tooth surface data "point cloud" generated by Kimos was the basic to form the electrode. The accuracy of the gear tooth shape electrode was ensured when processing it by the machining center. They were shown in Figs. 2, 3 and 4.

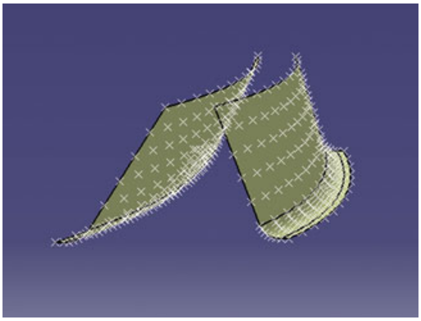

Fig. 3 NURB tooth surfaces of the driven bevel gear 344

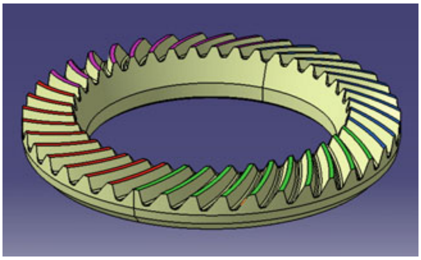

Fig. 4 Gear model of the driven bevel gear 344

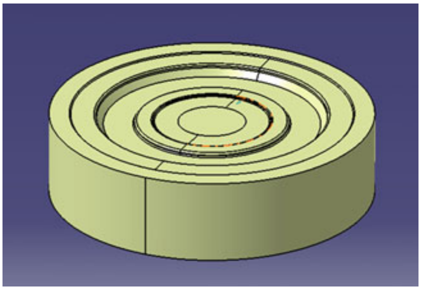

Fig. 5 The upper forming die

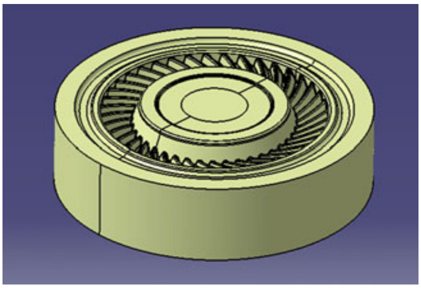

Fig. 6 The lower forming die

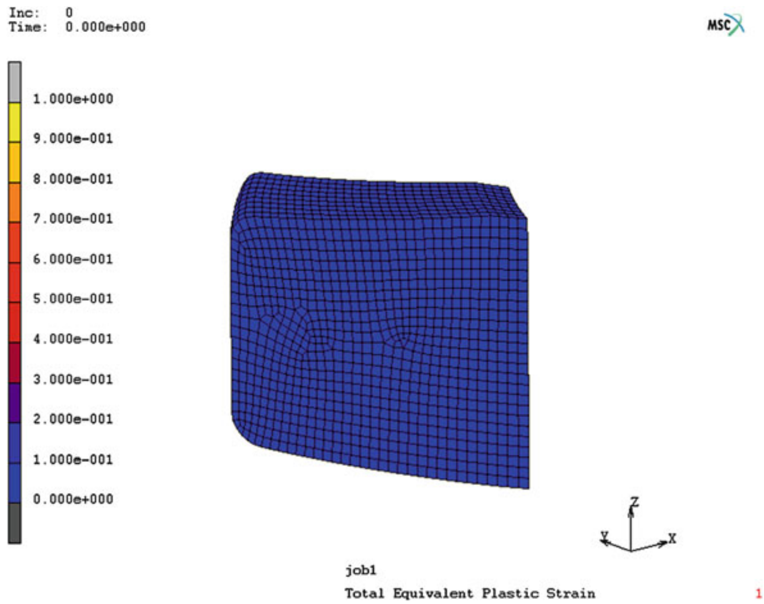

Fig. 7 Total equivalent plastic strain of billet state

3 Finite Element Analysis

3.1 Model of Finite Element Analysis

Figs. 5 and 6

3.2 Quantitative Analysis of the Forming Process

As shown in Figs. 7 and 8, we made quantitative analysis of the forming process of the driven bevel gear 344 with MSC.Marc. We only did process analysis calculation of one tooth because of its rotation cycle structure.

Analysis of simulation results:

Through the forming simulation, we knew that the effect of tooth filling was good. The forming load was about 3048t. The rolling ring billet size and the die structure were optimized according to the simulation.

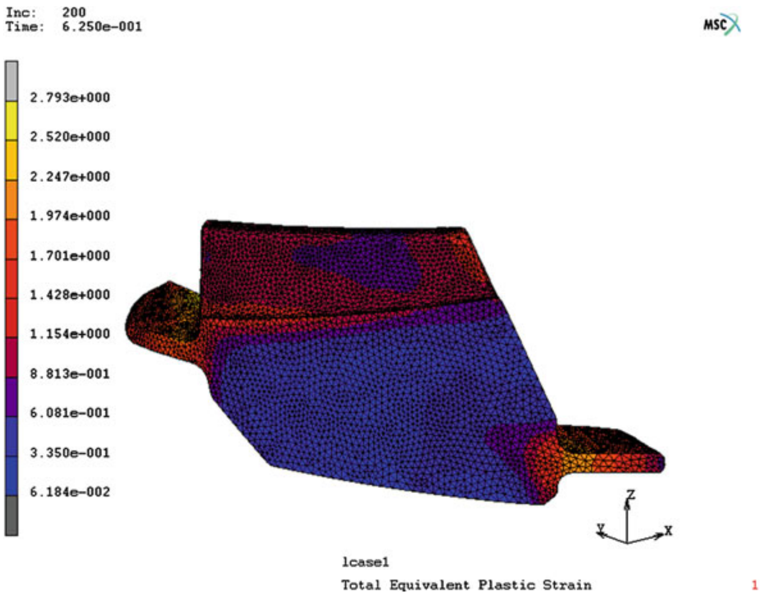

Fig. 8 Total equivalent plastic strain after forming

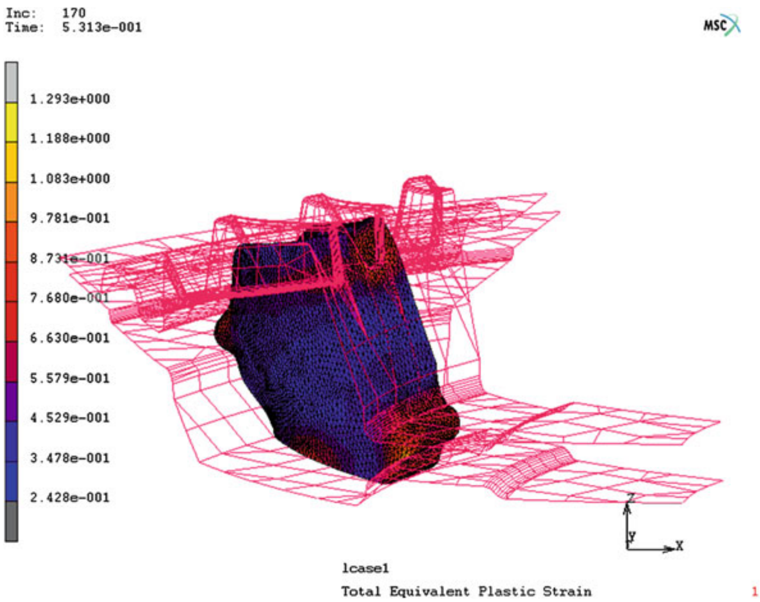

Fig. 9 Total equivalent plastic strain of intermediate state

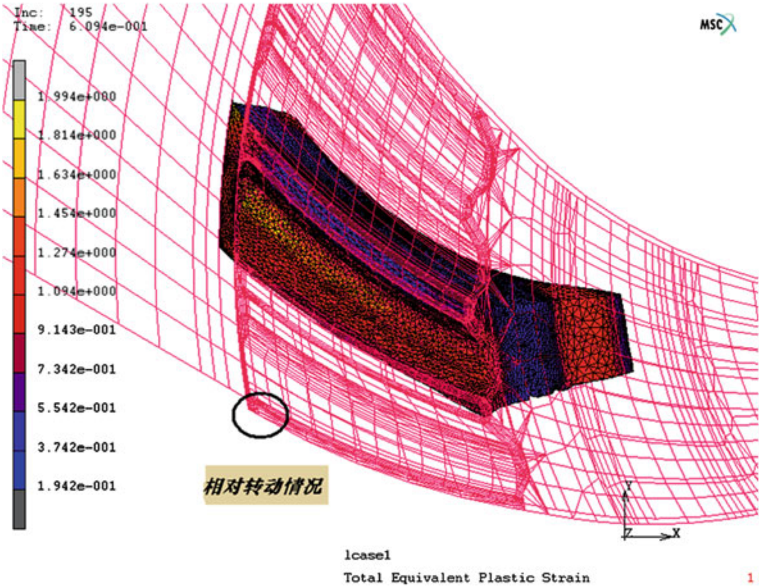

Fig. 10 Rotation of the mold in the molding process

3.3 *Simulation of the Tooth Die with the Circumferential Direction Free*

During the forming process, there was circumferential current trend about the metal because of the presence of the tooth helix angle. There must be circumferential thrust on the tooth mold must be the role of weeks to, which will affect the mold strength, life, and even part accuracy. The simulations were shown in Figs. 9 and 10.

The above analysis showed that using the floating punch could reduce the forming load to a certain extent. It could be seen that we could design a punch with free circumferential spin, which was beneficial for improving the life of the die and reducing the forming force. The technology had been patented.

4 Mold Design and Manufacturing

4.1 *Design of Mold Structure*

Because the tonnage of forming equipment was less than that used in the experiment, we considered a 1 mm undervoltage during the design of the final forging die bore. Due to the presence of the driven bevel gear arc tooth helix angle, there

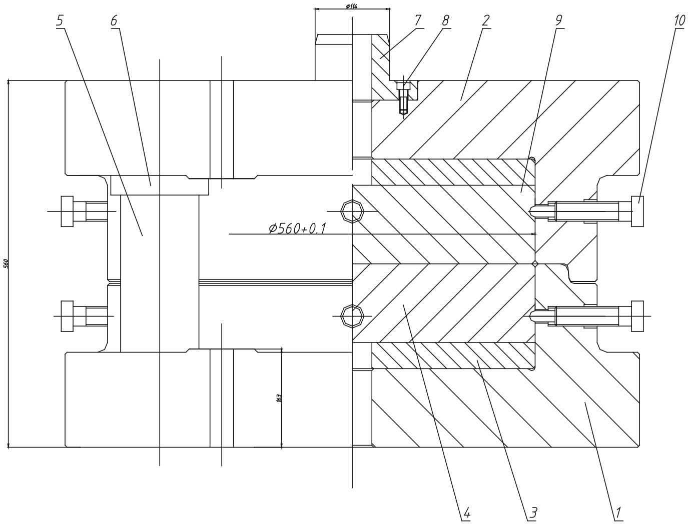

Fig. 11 Mold structure diagram

Fig. 12 Mold electrode processed by the machining center

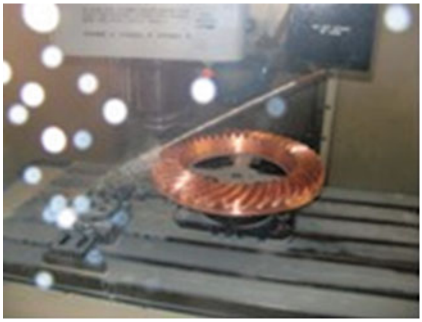

Fig. 13 Tooth cavity processed by EDM

Fig. 14 Precision forging

Fig. 15 Appearance of cold forging

was larger tangential force on the mold tooth site. So we designed the institutions of the tooth mold rotation in order to ensure the strength of the mold tooth parts. The mold was shown in Fig. 11.

4.2 Processing of Tooth Mold

We processed the mold electrode using the machining center. The technical characteristics of it was that we could modified the root of the tooth, which could ensure that the tooth root of the gear blank after the precision forging was no longer processing in the subsequent fine milling process. In addition, the tooth part could be modified according to the need.

First, we processed tooth electrodes using a machining center as shown in Fig. 12. The accuracy of the tooth electrode was grade 7 (DIN3965). Then the tooth cavity was processed by EDM. The tooth mold after processing was shown in Fig. 13.

Table 1 Machining accuracy of face bore (mm)

Gear	1#	2#	3#	4#	5#
Face flatness	0.037	0.032	0.023	0.047	0.042
Internal roundness	0.011	0.008	0.013	0.008	0.01

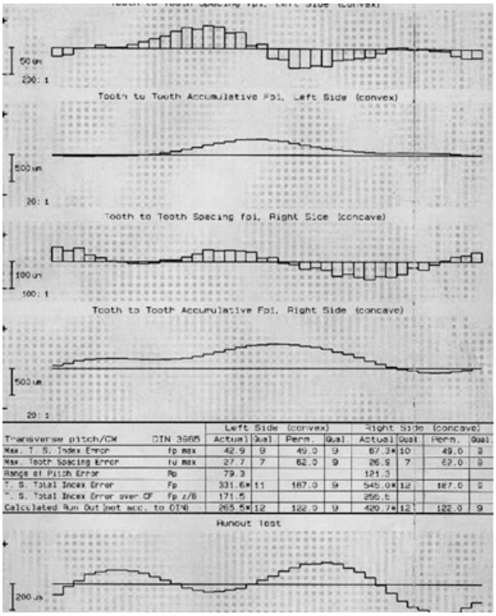

Fig. 16 Precision of forging gear billets (positioning surface after processing)

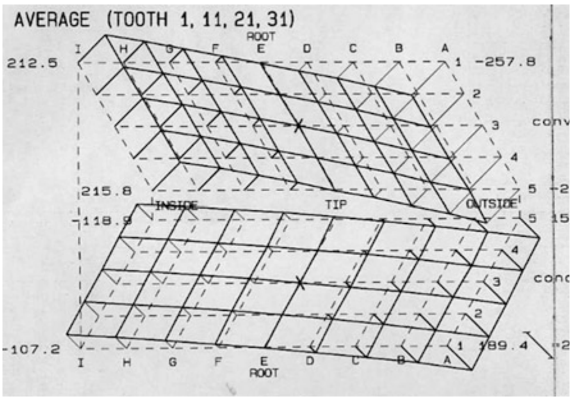

Fig. 17 Tooth appearance of forged gear billet

Table 2 Precision of precision forging gear billets (μm) DIN3965

	Convex			Concave			
Part number	fp	fu	Fp	fp	fu	Fp	Fr
1#	119.6	186.1	381.9	34.1	25.9	200.1	365.8
2#	60.3	63.4	385.8	44.8	30.4	294.4	254.6
3#	93.1	122.3	554.1	69.7	46.8	374.9	224.9
4#	94.1	128.1	616.2	39.8	43.4	262.7	375.9
5#	78.3	55.3	522.3	36.1	37.8	244.1	309.4
Corresponding accuracy of grade 11	126	159	478	126	159	478	240

Table 3 Error of helix angle and pressure angle (deg)

		Pressure angle	Helix angle
1#	Convex	−0.017	0.491
	Concave	0.207	0.34
2#	Convex	0.026	0.500
	Concave	0.195	0.421
3#	Convex	−0.064	0.584
	Concave	0.308	0.37
4#	Convex	−0.086	0.534
	Concave	0.443	0.361
5#	Convex	0.041	0.523
	Concave	0.253	0.315

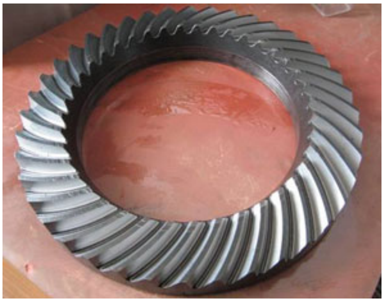

Fig. 18 The driven bevel gear 344 in the fine milling before heat treatment

5 Forging Process

Experimental equipment: Furnaces—750 kg air hammers—400 reaming machine—1600-ton friction press

Experimental material: 20CrMnTiH

Billet Size: Φ130X180: 18.75 kg

Heating temperature: 1200 ± 50 °C

Forming process: heating—upsetting—punching—(heating)—reaming—forging. The test processes were shown in Figs. 14 and 15.

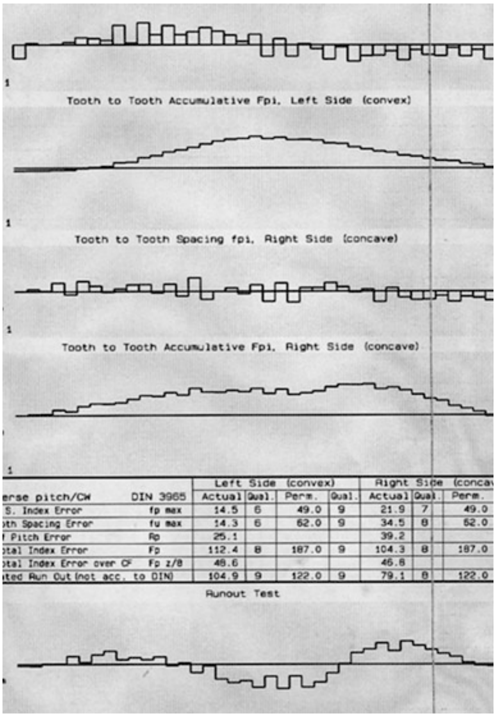

Fig. 19 Precision after the fine grinding of teeth

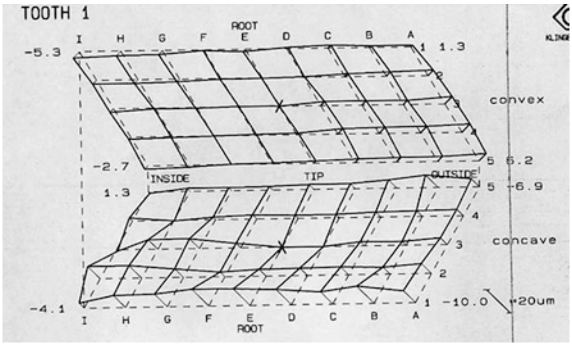

Fig. 20 Tooth appearance after grinding of teeth

Test results and analysis of the forging: As a result of three strikes forged and the mold release and cleaning up the oxide after one hit, the tooth surface of the gear billets and the situation of filled with were good. The forging structural dimensions were satisfactory addition to the thickness, which was ultra-poor about 2.5 mm because the devices forming pressure was insufficient.

Table 4 Accuracy of precision forging gear after finishing before heat treatment (μm) DIN3965

		2#	6#	Corresponding accuracy of grade 7
Maximum error of single pitch (μm)	Convex	16.3	17.1	22
	Concave	33	27.3	
Adjacent pitch error (μm)	Convex	22	29.9	28
	Concave	52.8	38.9	
Accumulated pitch (μm)	Convex	44.9	43.4	83
	Concave	95.4	68	
Ring gear beat (μm)		78.3	78.5	62
Internal roundness		0.01	0.009	
The flatness of the back		0.043	0.041	

Fig. 21 The driven bevel gear 344 after carburizing

6 Subsequent Machining and Detection of Precision

6.1 Processing Reference Plane and the Hole in Tooth Positioning

The testing situation was shown in Table 1.

6.2 Accuracy Assessment of Precision Forging Gear Billets

Upon completion of the positioning face and hole processing, measurement and evaluation data of the forging gear billets were shown in Figs. 16, 17, Tables 2 and 3.

Analysis of test data:

Precision was assessed in accordance with DIN3965. The accuracy of single pitch was grade 7 while the cumulative accuracy was about grade 11 and the diameter jump accuracy of ring gear was grade 12. Margin detection of tooth thickness was in parts of the midpoint of the tooth surface. The test results showed that the control of each gear margin was basically the same, was about 1.1 mm (both sides).

Table 5 Accuracy of precision forging gear after heat treatment (μm)DIN3965

		2#	6#	Corresponding accuracy of grade 8
Maximum error of single pitch (μm)	Convex	19.5	22.8	31
	Concave	37.7	35.5	
Adjacent pitch error (μm)	Convex	22.3	28.9	39
	Concave	43.8	65.3	
Accumulated pitch (μm)	Convex	109.2	103.5	117
	Concave	168.6	131.1	
Ring gear beat (μm)		172.9	112.1	87
Internal roundness		0.039	0.044	
The flatness of the back		0.238	0.081	

6.3 Fine Milling the Tooth

We processed the teeth with the Gleason 600 HC gear cutting machine pole forming method. Hardness after normalizing of the gear billet was 156-176HB.

Gear after fine milling was shown in Figs. 18, 19, 20 and Table 4.

6.4 Change of Gears Precision Before and After the Heat Treatment

Precision: Without preparing the corresponding fixture, there was no pressure quenching during the heat treatment process, which resulted in different degrees of loss of accuracy about roundness of the positioning surface and flatness of the end face. As a result, the tooth pitch cumulative precision and ring gear diameter jump accuracy had decreased, the general precision was about grade 9 after heat treatment, with an average accuracy loss of 2 grade. The single pitch accuracy changed little. We could see them in Fig. 21 and Table 5.

Tooth appearance: Tooth appearance after heat treatment changed little. The helix angle decreased about 0.01°, while the pressure angle had an increase of 0.05°.

7 Conclusion

1. The test proved that the modeling of the hot precision forging driven bevel gear tooth billet was accurate, the mold method is feasible and the margin of tooth side was reasonable. The technology was: efficient with material savings, the metal flow line of the driven gear was reasonable, the heat deformation was small, and the intensity was high. Compared with the ordinary forging process,

precision forging process of the driven bevel gear could save 13 min/piece, and 3.6 kg materials/piece.

2. According to DIN3956, the accuracy of the tooth electrode processed by the machining center was 7 grade. In addition to the ring gear beating was 12 grade, the other accuracies of tooth precision forging billet were all less than 10 grade.
3. The accuracy loss of the tooth precision forging billet after fine milling that was heat treated deformation under the pressure quenching conditions was quite with the full-cut gear under pressure quenching.
4. Through the experiment, we knew that the tooth surface of the precision forging driven bevel gear tooth billet had a hard layer, which influenced the life of the fine milling cutters.

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