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A Study on Fp Z/8 of Anti-Backlash Gear in an Engine

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엔진용 백래쉬 방지 기어의 Fp Z/8에 관한 연구

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ABSTRACT

The high speed of an engine balance box may cause significant additional gear noise. Gear accuracy is the most useful key to reduce gear noise, but the small tooth width and thin-walled anti-backlash gear introduce challenges to the manufacturing process. In order to reduce the gear noise caused by gear pitch error, this paper investigates the correlation between influencing factors and gear pitch error by analyzing the processing technology, tooling fixture, and equipment accuracy. By improving the process and optimizing the gear design, the gear machining accuracy was improved and the processing cost was saved.

Keywords: Antibacklash Gear(백래쉬방지 기어), Grinding Teeth(기어 연마), Gear Noise(기어 소음)

1. Introduction

In the working cycle of an engine, the piston undergoes reciprocating linear movement in the cylinder at high but uneven speeds, thereby generating large inertial forces. The crankshaft balancer can effectively balance first-order vibration, but not second-order vibration[1]. The balance box counteracts second-order vibration by generating a force in the opposite direction to the piston force. Finally, the anti-backlash gear is designed to reduce the additional vibration and noise introduced by the balance box.

Fig. 1 shows a common commercial engine balance box, where the red area is the anti-backlash gear. The balance box consists of a drive gear, anti-backlash teeth, balance shaft, balance block, and shell body composition. The anti-backlash gear is a primary component for the function of the balance box, and consists of a fixed gear, bias gear, spring, circlip, and pin. The width of the bias gear is only 4mm, making its teeth difficult to grind.

Many studies have been conducted on the processing of thin-walled and small-tooth width

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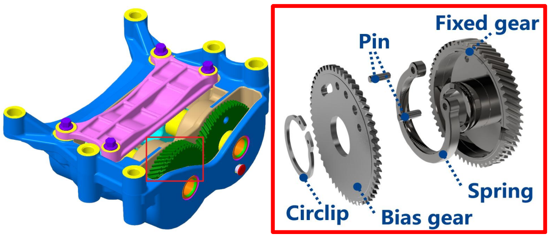

Fig. 1 The anti-backlash gear in engine balance box

gears. Li Min et al. eliminated the reverse rattle of gears between camshaft after implementing anti-backlash gears[2]; Fu Jiangang studied the effect of individual structural parameter changes in the number of teeth, modulus, and tooth width on the warpage deformation value[3]; Xu Xueli et al. obtained high-precision grinding through analysis of the preliminary processing methods, hot sleeve equipment, and tooling fixtures of thin-walled gear assemblies[4]; Lu Shuye analyzed thin-walled gear parts with thinner thickness, higher processing accuracy requirements, and easy deformation during processing[5]. None of the above studies discussed the effect of processing technology on the gear pitch error. Therefore, this paper focuses on the reasons for the excessive pitch and analysis of the machining process and tooling fixtures to determine the correlation.

The surface roughness obtained at various grinding conditions was measured and analyzed, and the quality of the grinding surface was analyzed using three-dimensional measurements.

2. Background

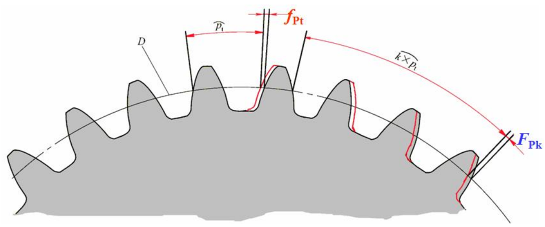

Fig. 2 The schematic of Fp Z/8

Fig. 3 Gleason metrology system for bias gear inspection

Table 1 Bias gear specification

Items	Unit: mm
Number of teeth/Z	51
Normal module/Mn	1.35
Normal pressure angle/an	15
Helix angle/β	25.5
Hand of helix	Left
Base diameter/db	73.127
Measurements over 2 balls	max 80.847
	min 80.785
Measuring ball diameter/Dm	2.5
Profile form deviation/ffa	0.005
Profile angle deviation/fHa	L:-0.012/0, R:-0.005/+0.007
Helix form deviation/ffβ	0.0055
Helix angle deviation/fHβ	L:-0.012/+0.002, R:-0.004/+0.01
Difference between adjacent pitches/fu	0.009
Singer pitch deviation/fp	0.007
Cumulative circular pitch deviation/Fp Z/8	0.016
Total tangential composite deviation/Fi’	0.025
Tooth to tooth tangential com. deviation/fi’	0.011
Radius runout/Fr	0.025

2.1 Introduction of Fp Z/8

As shown in Fig. 2, Fpk is the algebraic difference between the actual and theoretical arc lengths of any k tooth distances, K=2 ~ Z/8 integers. The cumulative deviation of Fp Z/8, which is Z/8 pitch, affects the stationeries of high-speed transmission gears. The gear inspection of Fp Z/8, shown in Fig. 3, is a detection diagram of the bias gear using the Gleason gear metrology system, with the chuck clamping the small boss, the probe aligned with the inner hole, and the end face as the reference[6]. The specification of the bias gear is shown in Table 1.

2.2 Gear Problem & SOP

As shown in Fig. 4, this project was carried out to the SOP (Standard Operating Procedure) stage. In the OTS (Off Tooling Samples) stage, the deviation was not found due to the lack of full inspection of Fp Z/8. In the PPAP (Production Part Approval Process) stage, three out of five products were found to be out of tolerance (the general requirement is 16 μm) during the sampling inspection by the customer, and 300 products were immediately returned to sort again, with a rejection rate of about 8% after sorting.

SOP is forthcoming, but such a large defect rate is severe. First, the company may face customer complaints. Second, the project SOP was delayed, resulting in loss of sales. Third, if the sorting of returned goods in SOP occurs, a special gear detection center would be needed, incurring a large cost as well as a waste of manpower and material resources.

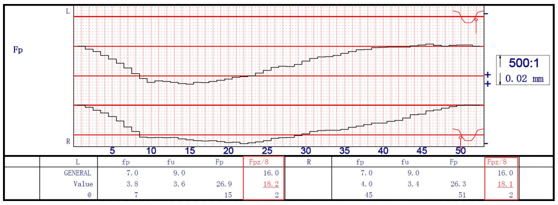

Fig. 4 Fp Z/8 inspection of Bias gear

3. Analysis and Discussion

3.1 Cause Analysis of FP Z/8

In order to solve the Fp Z/8 problem, an internal workshop was organized to analyze the causes with respect to six aspects: human, machine, material, method, loop, and measurement. The reasons for investigating the four aspects are summarized as follows.

3.1.1 Eccentric clamping

1) Installation eccentricity leads to deviation between the actual indexing circle and the theoretical indexing circle, and the positions of points on the indexing circle are changed, resulting in Fp error.
2) Fr is also affected.
3) Installation eccentricity includes machining installation eccentricity and detection installation eccentricity.

This factor will lead to a bad batch. At present, the bad proportion is 8%, so the priority needs to exclude.

3.1.2 Precision of grinding teeth

As shown in Fig. 5, there are several influence factors of grinding precision on Fp:

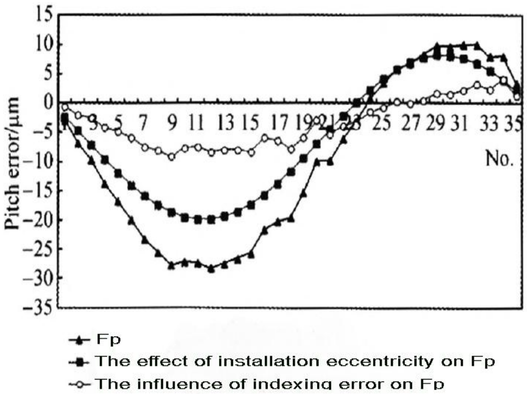

Fig. 5 The influence factors on Fp

1) The number of grinding wheels cannot be divisible by the number of teeth.
2) The indexing mechanism of the gear grinding machine is not accurate enough[7].

3.1.3 Warped positioning plane

The plane shape of the position is shown in Fig. 6, and the locations of the grinding teeth are shown in Fig. 7.

1) The warped workpiece is pressed straight during processing, Fp is stretched, the pressure is released after processing, the workpiece returns to the warping state, and Fp contracts.
2) The problem of fixture positioning the end face or upper gland is that it leads to warping of the workpiece during processing, and Fp is stretched. After processing, the pressure is released, and Fp shrinks.

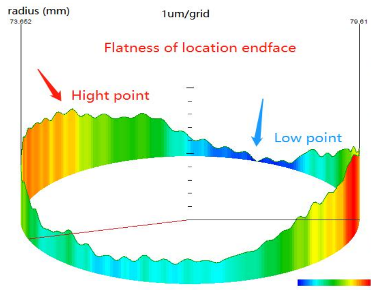

Fig. 6 The plane shape of the positioning

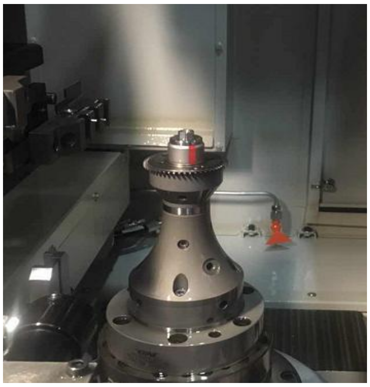

Fig. 7 The location of bias gear grinding

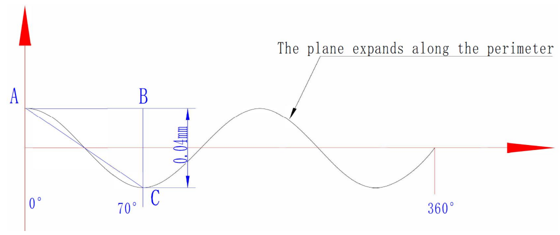

Fig. 8 The schematic of the flatness detection

According to the gear parameters, the diameter of the indexing circle d is 76.28 mm, the flatness detection value is 0.04 mm (as shown in Fig. 8), the flatness wave peak and trough are line segment BC, and the expansion length of the wave peak and trough at the dividing circle is AB=70°Xπ/180°X(0.5X76.28)=46.6 mm. After the plane is flattened, the extension length at the dividing circle is AC-AB = $1.7X10^{-5}$ mm.

It can be seen from the calculation that the planeness has very little influence on Fp. The defect caused by the fixture problem should be batch, unless the upper gland cross float is intermittent failure.

3.1.4 Influence of the inner hole of the workpiece

Due to the problem of roundness, the reference and the tooth are eccentric.

1. A high degree of roundness of the inner hole of the workpiece is shown in Fig. 9.
   After clamping, Fp changes before grinding and shrinks after grinding. The roundness of the inner hole causes the center point to shift during the detection.
2. When the internal expanding fixture is unbuttoned, the opening amplitude of the three petals of the expanding sleeve is inconsistent.
3. It is highly likely that the three flaps of the internal expansion fixture correspond to the four slots of the internal hole, thus affecting the clamping deformation of the workpiece.

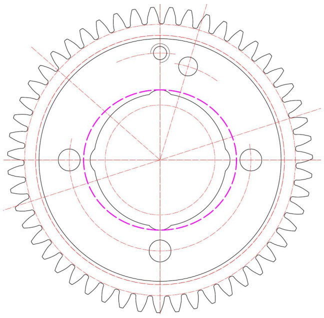

Fig. 9 The schematic for large roundness of the inner hole of the bias gear workpiece

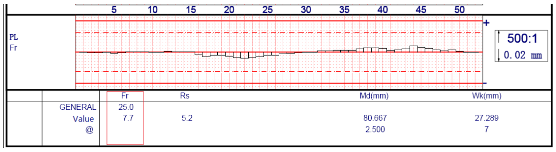

Fig. 10 Fr inspection of Bias gear

3.2 Verification of Analysis

3.2.1 Eccentric clamping

Processing: In this paper, the pitch circle run-out Fr can also be out of tolerance in addition to Fp Z/8, but as shown in Fig. 10, the measured value is less that the general value. Eccentric clamping is therefore excluded as an influencing factor.

Inspection: The measuring head of the gear measuring center is used to align the inner hole center and the end face, and the eccentric clamping of the chuck has no influence.

3.2.2 Accuracy of grinding teeth

The number of grinding wheels is 2 and has no common divisor with the number of teeth (Z=51), and the influence of this factor can affect a whole batch, so this influence factor is also excluded.

3.2.3 Precision of gear parting of grinding

A German KAPP300P gear grinding machine was used. It meets the requirements for manufacturing

Fig. 11 KAPP300P gear grinding machine

accuracy, as shown in Fig. 11, and equipment problems lead to a bad batch, so this factor is excluded[8].

3.2.4 Effect of end-face warping

After carburizing and quenching, the end face has warpage ranging from 0.01 mm to 0.07 mm, and

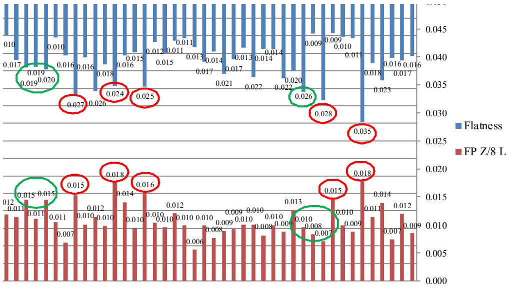

Fig. 12 The correlation analysis between the flatness and Fp Z/8 (Left tooth flank, unit: mm)

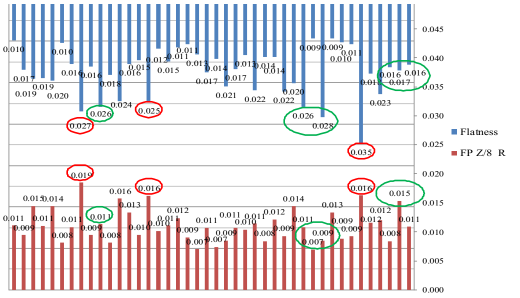

Fig. 13 The correlation analysis between the flatness and Fp Z/8 (Right tooth flank, unit: mm)

after grinding and hard turning, it still has warpage ranging from 0.01 mm to 0.03 mm. This is due to the relative thinness of the workpiece.

For the correlation analysis between end warping and Fp Z/8, there is no direct relationship between the flatness and Fp Z/8 of the left and the right tooth, as shown in Fig. 12 and Fig. 13.

3.2.5 Effect of inner hole roundness

It can be seen from Fig. 14 that the overall roundness of the bias gear grinding hole is good and is not strongly correlated with Fp Z/8, which means that a roundness of 0.0044 mm corresponds to Fp Z/8 of 0.0175 mm, and a roundness of 0.123 mm corresponds to Fp Z/8 of 0.011 mm. This suggests that the roundness of the normal grinding ability has no direct influence on Fp Z/8.

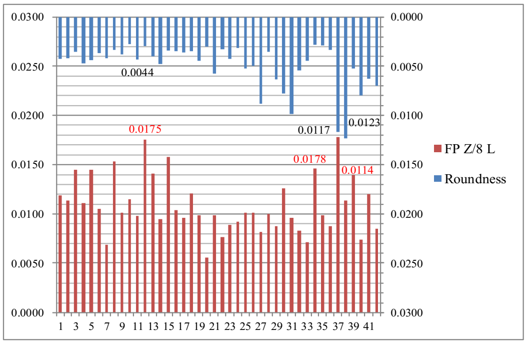

Fig. 14 The correlation analysis between the roundness and Fp Z/8 (unit: mm)

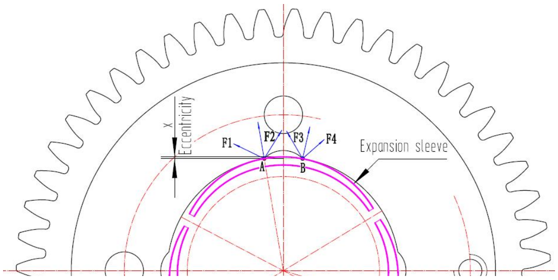

Fig. 15 The schematic of positioning and clamping of gear grinding tools

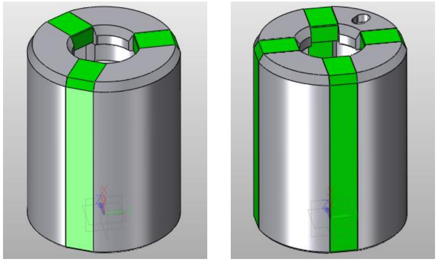

Fig. 16 Two different expansion sleeve structures

3.2.6 Influence of positioning error of discontinuous inner hole and expansion sleeve

As shown in Fig. 15 and Fig. 16, when the 1-lobe of the 3-lobe expansion sleeve is aligned with the four slots of the bias gear, of which the first slot is positive, the clamping force generates the components F1, F2, F3, and F4 at points A and B. At the same time, the eccentricity of the workpiece is caused by the absence of contact at the highest point of one lobe of the expansion sleeve. The eccentricity can be calculated by the width of the groove and the diameter of the inner hole X, 0.16 mm. Because the diameter of the expanding sleeve is smaller than the aperture, the actual eccentricity is larger than the calculated value.

However, since the contact points are A and B, and the component forces are generated at A and B, the eccentricity also generates a transfer, which is not fully reflected in the radial run-out Fr. The decomposition of force and eccentricity can be used to calculate the clamping force and the tensile strength of the workpiece after carburizing and quenching. Points A and B are the positions at the junction of the inner hole and broaching groove after grinding. These two points are involved in positioning and are bound to affect the grinding quality.

Moreover, the expansion sleeve has a 1/3 chance to contact the workpiece groove, and the workpiece

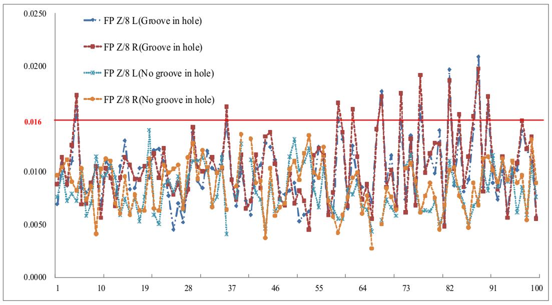

Fig. 17 The test of Fp Z/8 between groove in hole and no groove in hole (unit: mm)

groove has a 1/4 chance to contact the highest point of the expansion sleeve (1/3X1/4=1/12), which means the proportion is 8%. The statistical analysis of the unqualified rate is also 8%, and the side also roughly confirms the assumption.

The test was carried out with the workpiece in the canceled slot, and all of the tested products meet the requirements of the drawing, as shown in Fig. 17. Finally, the replaced four-part expansion sleeve was used to meet the process capacity requirements.

4. Conclusions

Through the analysis of the tooth pitch error of the anti-backlash gear in the balance box and the verification of the processing inspection, the following conclusions were obtained:

1. There is no strong correlation between the roundness of the gear inner hole and the tooth pitch error;
2. The flatness of the gear has little effect on the tooth pitch error;
3. Contact between the grinding tool and the oil groove leads to eccentric clamping, which eventually causes tooth pitch error. The probability of calculating the out-of-tolerance condition is 8%, which is consistent with the actual test result.

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