Stabilization of gear machining accuracy by controlling gear honing machine vibration

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Summary

Ghost noise originating from gear accuracy is one issue concerning automotive transmission quality. In this study, it was determined that abnormal gear honing machine vibration, which can suddenly occur during machining, is transferred to the gear tooth surface and gives rise to ghost noise. Therefore, a method was established for monitoring and detecting abnormal machine vibration so as to prevent the release of defective gears.

1. Introduction

Ghost noise originating from abnormal tooth surface geometry is an issue related to the noise and vibration produced by the transmission. This study focused on the gear honing method that is the cause of such abnormal tooth surface geometry. As a result of investigating the cause, it was found that abnormal tooth surface geometry originates from unusual gear honing machine vibration. Because such vibration can be detected based on the level of its magnitude, stable manufacturing quality has been ensured by monitoring the vibration level for all gears produced on the honing machine. This paper describes the details of the investigation.

2. Ghost noise

2.1 Explanation of ghost noise

Among the types of noise stemming from the transmission, gear noise originates from gear meshing, striking sounds are caused by gear nicks, and rattles are produced by backlash. Gear noise originating from gear meshing includes an order component (referred to here as the first order of gear meshing) matching the number of meshing gear teeth, order components that are integral multiples of the meshing order, and ghost noise having an order component other than the integral multiples. It is necessary to eliminate this ghost noise because it is heard as an annoying abnormal noise in the cabin.

2.2 Example of ghost noise analysis and its cause

Figure 1 presents an analysis of cabin noise data at the time ghost noise was detected for a transmission. The horizontal axis shows the noise orders per axle rotation, the vertical axis is the driving time with acceleration/deceleration events, and the different colors indicate the cabin noise level. The data show that the 0.8th-order component that deviated from the first-order component of gear meshing was higher compared with other order components.

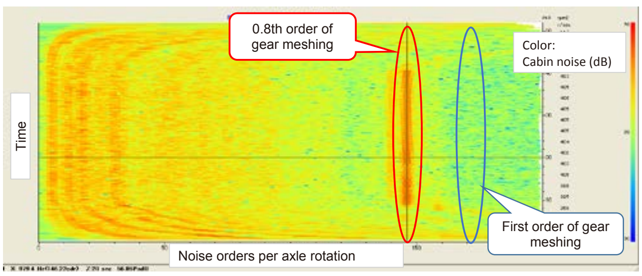

Fig. 1 Cabin noise data at the time of ghost noise detection

Fig. 2 Gear data measured at the time of ghost noise detection: Measurement of tooth trace of all teeth

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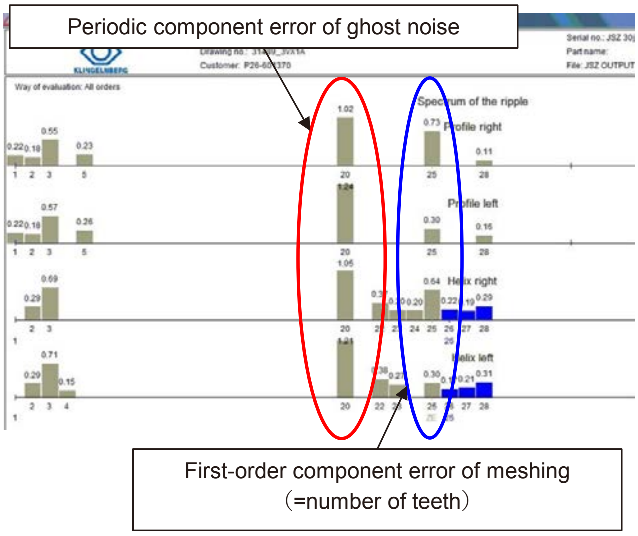

Fig. 3 Gear data measured at the time of ghost noise detection: Measurement of periodic component error

The gear causing this higher order component was then identified by conducting tests in which the parts of the transmission were replaced in turn, and the accuracy of the identified gear was investigated. The measured gear surface data in Fig. 2 show the presence of abnormal undulation geometry. In addition, a spectrum analysis was performed on the measured gear surface data. High values were found for the spectrum corresponding to the 0.8th-order component detected in the cabin noise, and the order coincided with ghost noise. Figure 3 presents the results of a spectrum analysis performed on the measured tooth trace data.

The foregoing results revealed that the true cause of the ghost noise examined in this study was the undulation geometry of the gear tooth surface. This indicated that the cause of ghost noise could be identified by analyzing the tooth surface geometry in detail.

3. Explanation of gear honing

3.1 Gear manufacturing processes

The sequence of processes in gear manufacturing is shown in Fig. 4. Following hobbing and gear shaving, carburizing and quenching are performed. Heat treatment strain occurs during quenching, causing deformation of the tooth profile and tooth trace geometry. Gear honing is then performed to correct that deformation, and the tooth surface geometry is smoothed to suppress the occurrence of gear noise.

3.2 Gear honing process

Gear tooth surfaces are finished to high accuracy in the honing process performed on a gear honing machine. A honing wheel with internal gear geometry is engaged with the workpiece gear to execute tiny cuts and tooth surface smoothing as the rotating wheel is pressed against the workpiece. The configuration of the gear honing machine is shown in Fig. 5.

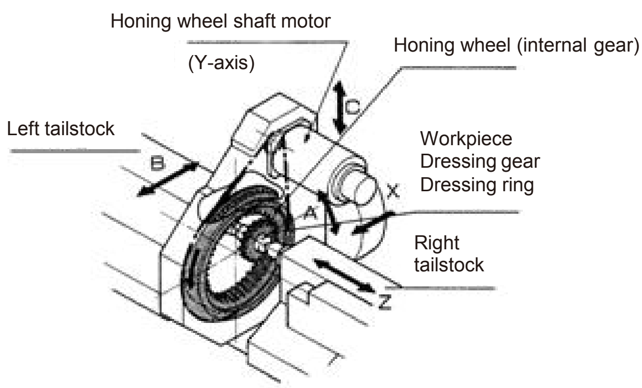

Fig. 5 Configuration of gear honing machine

Tooth surfaces of the internal-gear honing wheel are dressed with an electrodeposited diamond dressing wheel to the accuracy desired of the finished gear. Dressing forms the tooth surfaces of the honing wheel to high accuracy. The honing wheel is then used to finish-machine the gear tooth surfaces. In this process, the accuracy of the honing wheel is transferred to the workpiece to obtain high-accuracy gear tooth surfaces (Fig. 6).

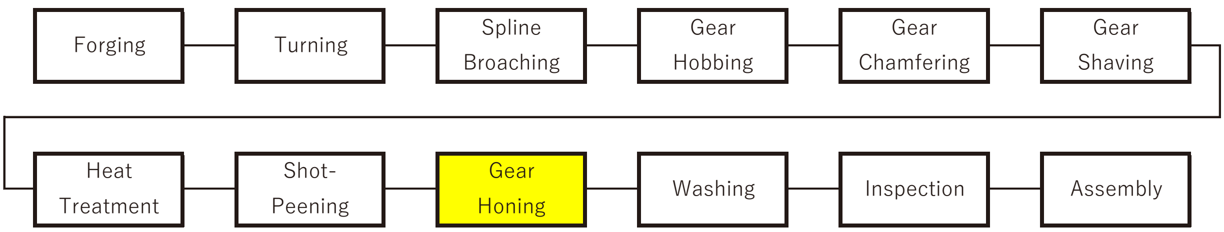

Fig. 4 Outline of gear manufacturing processes

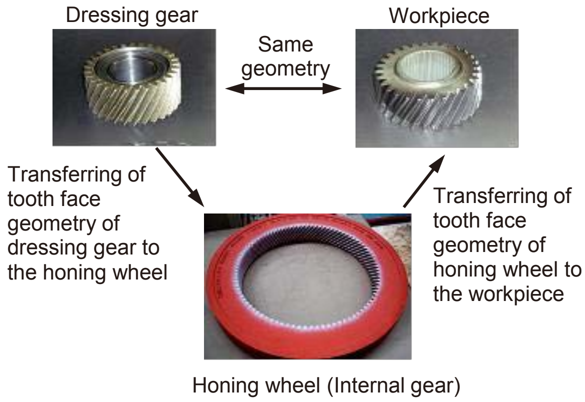

Fig. 6 Honing wheel, dressing gear and workpiece

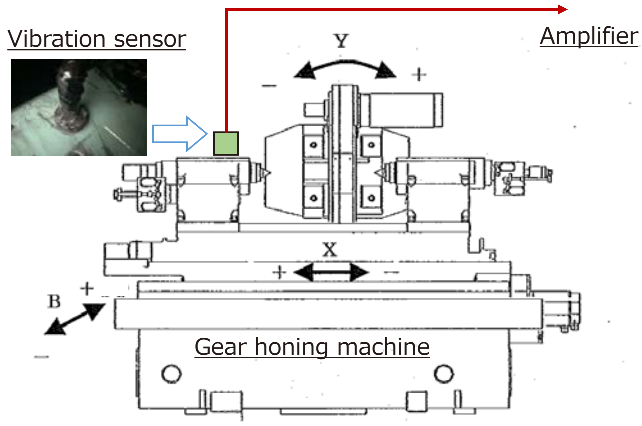

Fig. 7 Vibration measurement on gear honing machine

Because this honing method transfers the honing wheel accuracy to the gear tooth surfaces, the occurrence of rotational speed fluctuation or center distance fluctuation can change the contact condition between the honing wheel and the tooth surfaces, thereby affecting accuracy. Consequently, if vibration that causes center distance fluctuation occurs during machining, undulation geometry is apt to occur on the machined tooth surfaces. Because gear honing is the process that determines the final tooth surface geometry, the tooth trace undulation geometry found on the gears examined in this study was assumed to have occurred in the honing process.

4. Measurement of gear honing machine vibration

4.1 Vibration measurement positions on gear honing machine

A method of monitoring the state of the gear honing machine during the honing operation was examined in order to investigate whether the tooth surface undulation geometry that was the focus of interest in this study actually occurred in the gear honing process. It was decided to measure the vibration of the tailstocks supporting the meshing reaction forces between the honing wheel and the workpiece.

4.2 Method of measuring machine vibration

Measurements were made by attaching an acceleration sensor and an amplifier to the gear honing machine. These devices are generally used to measure machine vibration. The configuration of this vibration measurement system is shown in Fig. 7.

4.3 Explanation of frequency of measured machine vibration

In evaluating the measured data of gear honing machine vibration, an investigation was made of the vibration frequency leading to ghost noise. The spectrum of the gear that produced ghost noise showed a 0.8th-order component (= periodic component error). Assuming that this order component was influenced by vibration that occurred during gear honing, the vibration frequency can be calculated from the workpiece shaft rotational speed. In this study, the workpiece shaft rotational speed was 3,052 rpm and the 0.8th order occurred per workpiece rotation. Accordingly, the vibration frequency can be calculated as follows:

$$\text{vibration frequency (Hz)} = \text{rotational speed (rpm)} \times \text{number of teeth (25 teeth)} \times 0.8/60 \fallingdotseq 1{,}017 \text{ Hz}$$

Therefore, it was assumed that this order component was influenced by vibration of approximately 1 kHz. The workpiece was clamped in the tailstocks by means of a jig. The excitation point response function of the workpiece was measured at the place where impact excitation was applied. It was confirmed that the response function displayed an eigenvalue at the above-mentioned frequency of approximately 1 kHz. The frequency response function data at the excitation point are shown in Fig. 8. Accordingly, it was decided to evaluate the vibration level focusing on vibration in the vicinity of 1 kHz.

4.4 Relationship between spectrum analysis values for tooth surface geometry and gear honing machine vibration values

Figure 9 presents the results of an investigation of the correlation between the vibration acceleration peak value of the gear honing machine near 1 kHz and the spectrum quantity (0.8th-order component) of the tooth surface

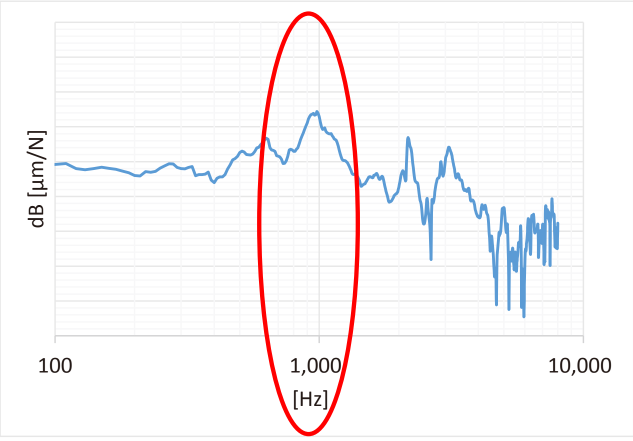

Fig. 8 Frequency response function data

geometry. The figure shows a high correlation between the two values. This means that an evaluation of the vibration level of the gear honing machine can be substituted for a spectrum evaluation of the tooth surface geometry.

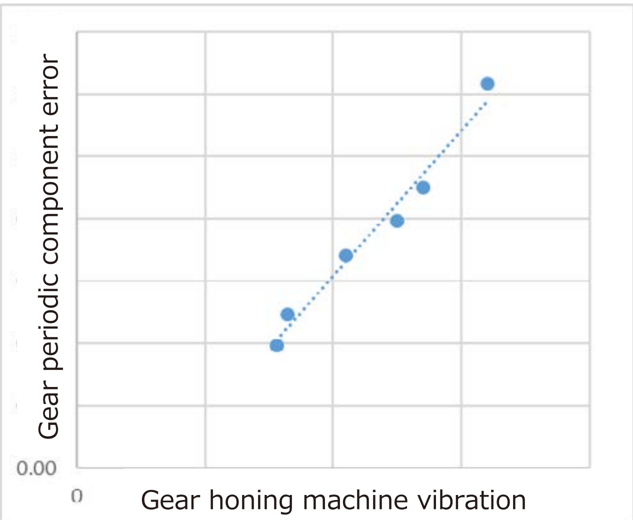

Fig. 9 Graph of gear periodic component error vs. vibration values

5. System for monitoring gear honing machine vibration

As explained here, a high correlation is seen between vibration acceleration at a specified frequency and the spectrum quantity of the tooth surface geometry. This implies that monitoring the vibration level can enable the detection of defective gears. Moreover, if honing machine vibration can be suppressed to a certain specified level, the spectrum quantity of the gear tooth surface geometry can be kept to a low level. Therefore, this can be expected to lead to stabilization of manufacturing quality. Figure 10 shows an example of the vibration monitoring data obtained daily on the mass production line.

As shown in Fig. 10, a judgement criterion (red line) has been defined in relation to the measured vibration data, making it possible to prevent the release of unacceptable products. This has now made it possible to ensure the quality of all manufactured gears.

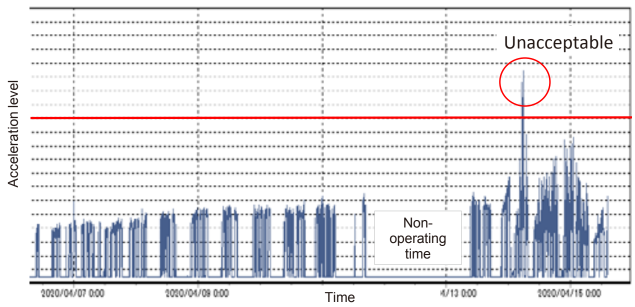

Fig. 10 Vibration monitoring data on gear honing machine

6. Conclusion

This study investigated the cause of ghost noise that originates from abnormal tooth surface geometry and is one issue of the noise and vibration produced by an automotive transmission.

(1) It was found that ghost noise is caused by periodic component error originating from the tooth surface undulation geometry.

(2) It was shown that evaluating the vibration level of the gear honing machine can be substituted for an evaluation of the periodic component error.

Based on these results, the release of defective gears can be prevented by monitoring the vibration level of the gear honing machine.

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