Micro-hole inspection using audible sound

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1. Introduction

Automotive fuel injection plates, gas detection sensors, and high-performance microphones all have micro-hole parts. Because fluid passes through the micro-holes, these components are used for the purpose of controlling a flow rate of the fluid. For guaranteeing their performance, micro-hole shape should be precisely realized for such components. Micro-hole shapes can be inspected using the conventional inspection method such as an optical microscope and a contact 3D scanning. However, these methods cannot guarantee a flow rate of the fluid or are not fast enough for 100%-inspection that is often required in a production line for these components. Therefore, a new inspection method that is simpler and faster is required. For this purpose, a possible solution is a measurement using sound. For example, acoustic impedance measurement utilizing audible range sound is used for volume and surface area measurements of an object in a closed volume. In this study, we propose a high-speed and high-accuracy inspection method using audible sound for micro-holes that are mass-produced by metal stamping, as shown in Fig. 1. This letter introduces details of the proposed method and validates its performance.

2. Methodology

A prototype inspection system consists of an AC voltmeter, a function generator and a cylindrical metal casing with a built-in small loudspeaker (DH-59, Primo Co.) and a microphone (DM-15H-TU, Primo Co.). Figure 2 shows an overview of the inspection system. A micro-hole component is placed on top of the metal casing as demonstrated in Fig. 3. When driving the loudspeaker in the sealed casing with low-frequency sine wave, an excited sound vibrates an air inside the metal casing. The microphone detects the air vibration as a sound pressure. Here, the detected sound pressure varies with a diameter of micro-hole. The holes can be inspected by analyzing the difference between the measured values. This system measures the change in acoustic impedance at the microphone when the sound passes through the holes. It is therefore the same as measuring the flow rate of the fluid passing through the micro-hole.

3. Validation of the prototype inspection system

The prototype inspection system was validated using micro-hole test samples with various micro-hole diameters.

3.1. Test samples

The test samples have a thickness of 0.1 mm and the micro-hole diameter ranged from 50 to 110 μm. Table 1 shows front, back, and average diameters of the test samples. There are two types of hole-machining methods, namely electrical discharge machining (EDM) and metal stamping. The micro-hole diameter was measured with a non-contact type coordinate measuring machine (NH3-SP, Mitaka Kohki Co.). The diameter was measured by approximating the micro-hole shape to a circle by applying least square fitting. The shape of the micro-hole differs depending on the hole-machining method. In the case of EDM, the diameter on a front side is approximately 5-μm larger than that on a backside (Fig. 4). This is because of a stagnant powder around EDM electrode. Yet in metal-stamping method, the diameter of micro-holes on backside is 5-μm larger than that on front side (Fig. 5). Stamped holes have a four-layer structure that includes a shear drop, sheared surface, fractured surface, and burr. The micro-hole diameter on the backside increases due to effects of the burr. The cross-sectional shape is not straight either, so the average of diameters on the front side and backside was chosen as a representative micro-hole diameter of the test samples.

4. Results and discussion

Figure 6 shows a relation between a volume of micro-hole and the measured voltages. The average diameters are also presented along the curve. The results demonstrate that the measured voltage value increases as the micro-hole diameter increases; a 5-μm difference in micro-hole diameter yields a 20-mV difference in voltage in this case, although the changes in voltage become smaller as the micro-hole diameter decreases to below 80 μm. These results indicate that the proposed method is capable of detecting a difference in the micro-hole diameter from the measured voltages. Specifically, for 100-μm diameter micro-holes having a thickness of 100 μm that was tested in this work, the proposed method is able to detect, at least, a 5-μm difference in micro-hole diameter.
Two test samples have the same average diameter of micro-hole (approximately 107 μm). Each was processed by the metal-stamping method and EDM, respectively. These two test samples have different front side and backside diameters, but both do not show a prominent difference in the measured voltage. This implies that the measured voltage is correlated with a volume of micro-hole, not with a diameter or a cross-sectional shape. Since the micro-hole volume is proportional to the flow rate through the holes, the proposed method is suitable for inspection of flow control parts.

An influence of micro-hole diameters that are different on the front side and backside was then examined. The same measurement was performed with the same test samples with upside-down installation. The results show no prominent difference in measured voltage between the original and upside-down installations, thereby also indicating that the proposed method is capable of guaranteeing a flow rate through a micro-hole. However, if a difference in diameters

Table 1  Micro-hole diameters of test samples.

|                  | Front diameter [μm] | Back diameter [μm] | Average diameter [μm] |
|------------------|---------------------|--------------------|-----------------------|
| Metal stamping   |                     |                    |                       |
| 104.5            | 109.8               | 107.1              |
| 116.3            | 110.1               | 113.2              |
| 109.1            | 103.9               | 106.5              |
| 105.1            | 99.4                | 102.3              |
| 101.9            | 95.2                | 98.6               |
| Electric discharge machining |
| 97.8             | 91.9                | 94.9               |
| 82.3             | 77.2                | 79.8               |
| 75.6             | 71.1                | 73.3               |
| 64.3             | 59.9                | 62.1               |
| 51.2             | 48.8                | 50.0               |

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between the front side and backside is larger, its effect on a measured voltage is unknown.

Figure 7 shows a relation between an input voltage to the loudspeaker and the measured voltages. Values of input voltage were 10, 7.5, and 5 V<sub>p-p</sub>. It appears that the measured voltage shifted in proportion to the input voltages. However, a difference in the measured voltage between micro-holes of 95-μm and 113-μm diameter is maximal for 10-V<sub>p-p</sub> input voltage (Table 2). This result reveals that the inspection resolution can be improved by increasing an input voltage to a loudspeaker.

5. Summary

This letter proposed an inspection system for micro-holes using an audible sound. The experimental results indicate that a flow rate through a micro-hole correlates with a voltage measured by a microphone installed in the inspection system, the proposed method would be able to predict a flow rate through micro-hole.

### Table 2  Difference in the measured voltage.

| Input voltage (V<sub>p-p</sub>) | Measured voltage (95 μm) [mV] | Measured voltage (113 μm) [mV] | Difference voltage [mV] |
|--------------------------------|--------------------------------|--------------------------------|------------------------|
| 5 V<sub>p-p</sub>             | 0.168                          | 0.220                          | 0.052                  |
| 7.5 V<sub>p-p</sub>           | 0.240                          | 0.302                          | 0.062                  |
| 10 V<sub>p-p</sub>            | 0.305                          | 0.378                          | 0.073                  |

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