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A Malfunction Pattern Distinction of an Automotive Electric part by Sound and Vibration Frequency Analysis

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소음진동 주파수분석을 이용한 자동차 전동부품의 고장유형 분석

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ABSTRACT

The usage of electric-powered components consisting of several electrical and mechanical parts is continuously increasing in automobiles. Therefore, continuous assessment of the reliability and quality of these electric-powered parts is crucial. In this study, a noise and vibration measurement system for testing and evaluating the different electric-powered parts of automobiles was designed. Further, an FFT analysis was performed on some electric-powered steering assembly test equipment. In the FFT analysis of the noise and vibration signals for each essential fault part, the vibration FFT analysis was significantly compared with the noise analysis. The results showed that the vibration FFT analysis was more effective in determining the reliability and quality of the electric-powered parts.

Keywords: Electric Powered Part(전동부품), Noise and Vibration(소음진동), FFT Analysis(FFT 분석), Malfunction Analysis(고장 분석), Test and Evaluation(시험평가)

1. Introduction

With a continuous increase in the proportion of electric and electronic parts in automobiles, the need for the electrification and quality assurance of automobile parts is growing. Automotive electric parts, including window, brush, chair adjustment, steering wheel angle and length adjustment motors, and electric power steering motors are operated by combining several parts, such as electric motors, gears, and driving parts. Meanwhile, among various test and evaluation methods for the quality control of electric parts comprising several elements to analyze the defects of main components, a method of finding defects in each main component by measuring sound and vibration signals and analyzing the frequency distribution is the most widely used. Among the electric parts, the control

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methods for steering have been studied for the electric power steering system, which has also been applied to autonomous vehicles.[1-4]

In this study, the method of analyzing sound and vibration signals was applied to find defects in each main component of the power steering system comprising an electric power steering wheel and motor-gear-steering shaft among the other electric parts of automobiles.

2. Analysis of Sound and Vibration

2.1 Generation of sound and vibration of electric parts in automobiles

Among the various electric parts of a vehicle, an electric power steering is a device that turns a steering wheel using an electric motor, assisting the force exerted by the driver for operating the steering wheel. In recent years, case studies in which an electric motor directly moves the steering wheel for driving safety support systems, such as a lane keeping support system or in an autonomous vehicle, have been reported. This electric steering system assembly consists of various components, including an electric motor (rotor, brush, commutator, and bearing), reduction gear, and drive shaft, which can be expressed in a simplified form as a vibration system with several excitation sources inside, as shown in Figure 1. The excitation sources have their own natural frequencies, and from these vibration systems, a complex vibration or sound signal is generated by synthesizing various signals. Sound and vibration, such as friction and collision, occur due to

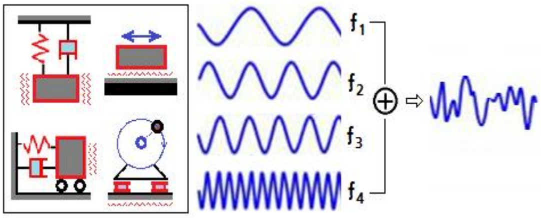


Fig. 1 Sound and vibration from combined parts

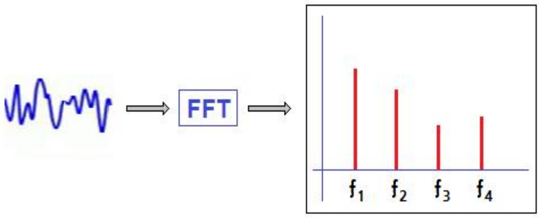


Fig. 2 Signal analysis by using FFTthe combination and mutual interference of the components.[5-7]

2.2. Measurement and analysis of sound and vibration

It is possible to estimate the specific components generating the natural frequencies by analyzing the synthesized signal of sound or vibration produced in a complex vibration system, in which various parts are combined, and understanding the natural frequencies, as depicted in Figure 1. The Fourier transform is used as an analysis method for such a synthesized signal. The Fourier transform determines each frequency distribution and the intensity in the frequency domain from the synthesized signal in the time domain. The arbitrary composite signal generated from a combination part, in which each element part is combined, can be expressed as the sum of periodic functions possessing various frequencies given in Equation (1) by the Fourier transform.

$$F(w) = \frac{1}{\sqrt{2\pi}} \int f(t)\, e^{-iwt} dt \tag{1}$$

A signal measured by a digital measurement system using a sound or vibration sensor is a discrete signal. As the Fourier transform takes too long to analyze an actual analog signal, the fast Fourier transform (FFT) technique is used to facilitate a rapid analysis. Among various methods, the most common FFT analysis algorithm is the Cooley–Tukey algorithm.

$$f_j = \sum_{k=0}^{n-1} x_k \mathrm{Exp}[-\frac{2\pi i}{n} jk] = \sum_{k=0}^{n-1} x_k W^{jk} \tag{2}$$

3. Experimental Apparatus Design

3.1 Experimental apparatus configuration

The sound and vibration measurement system for the electric power steering motor is similar to that of a general digital measurement system. Figure 3 displays the entire measurement system. The experimental apparatus consists of a testbed where the electric power steering motor operates, a measurement system (sound and vibration sensors), data acquisition (DAQ) devices, a PC, and a measurement program. A microphone (PCB 378B02) was used for the sound measurement, and an accelerometer (PCB 352C34) was used as the vibration sensor. NI-9174 and NI-9250 were used as DAQ devices, and LabVIEW was employed for measurement and data analysis. Figure 4 shows the test electric power steering motor and the sound and vibration sensors installed inside the testbed.

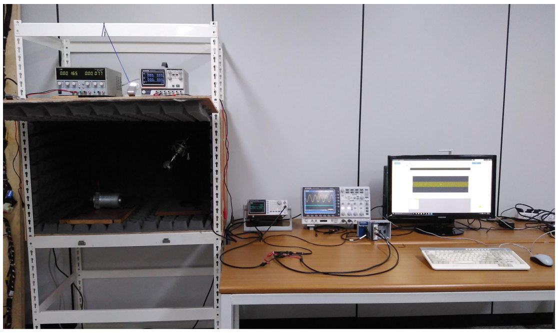


Fig. 3 Sound and vibration measurement system

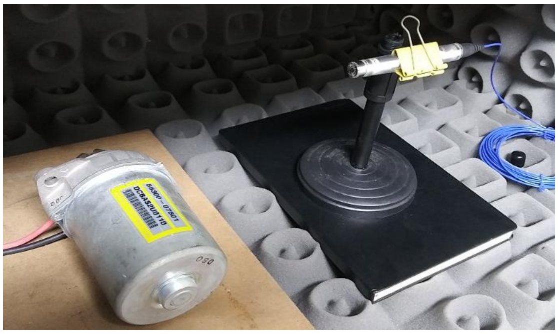


Fig. 4 Sound and vibration sensor

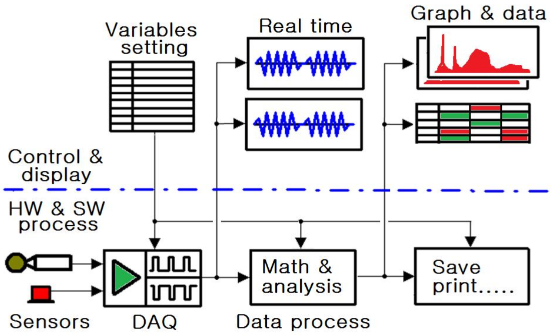


Fig. 5 Layer structure of hardware and software

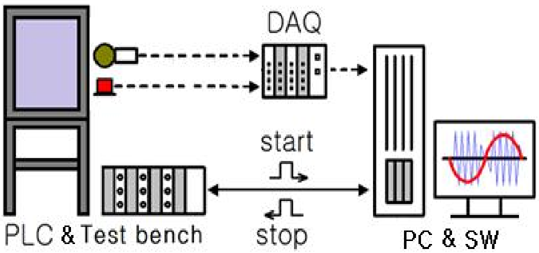


Fig. 6 Communication on the PLC and the PC

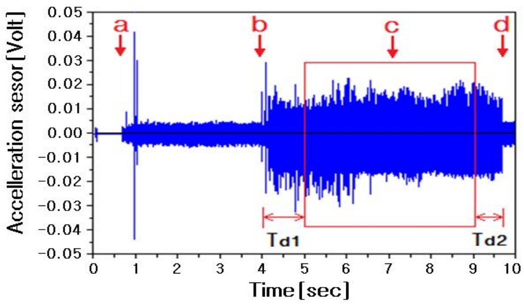


Fig. 7 Vibration signal and signal analysis period

3.2 Measurement process design and experimental method

The sound and vibration measurement system of the electric power steering motor includes signal waveform measurement and real-time display as well as the display and hardware parts of statistically analyzed and processed data. Figure 5 schematically illustrates the configuration of the measurement system for sound and vibration signal analysis, the hierarchical structure of the program, and the processing method. The measurement system can be divided into front control monitor and hardware and software (SW) processes. In the front control monitor, menu selection, variable setting, real-time graph display, mathematical statistical processing, and analysis data are displayed as graphs and data. The statistical analysis data includes RMS, Min/Max, and FFT. In the signal input and data processing parts of the sound and vibration measurement system, the sound and vibration signal inputs from the sound and vibration sensors are converted into digital signals through DAQ and several variables can be preset.

Figure 6 depicts the communication signal of the data inputs start and stop between the sound and vibration measurement system (PC & SW) and the testbed operating the motor. The two devices communicate to send a motor-start signal from the PLC, and the measurement system (PC) receives the signal and starts measuring the sound and vibration of the motor-stop signal. Thereafter, the PLC stops the motor and performs the next operation, such as disconnecting the motor.

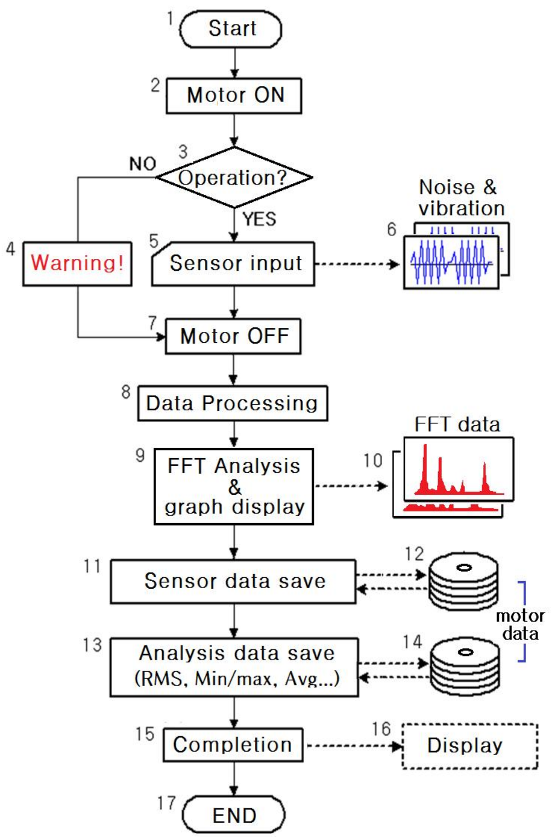
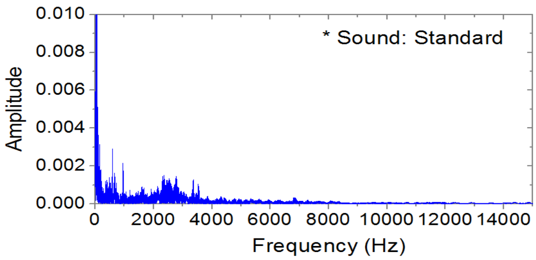


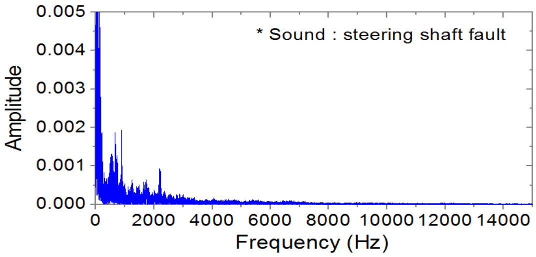
Fig. 8 Flowchart of measurement and analysis

Figure 7 shows the process of input-measurement-analysis of the sound and vibration signals from the entire signal waveform by mutual communication with the measuring system (PC & SW) and PLC installed in the testbed. In Figure 7, ‘a’ indicates the time when the sensor is prepared for measuring sound and vibration after the electric power steering motor is received and fixed in the measurement room. At this time, the sound and vibration signals of the stopped motor are the inputs, which represent noise. ‘b’ is the signal of the vibration (or sound) sensor measured from the time when the electric power steering motor starts operating (ON), which is the signal waveform of the sensor vibration generated by the operation of the motor and input through the sensor. ‘c’ is the signal waveform measured when the sound and vibration signals stabilize after a certain delay time (Td1) has passed from the time when the electric power steering motor starts operating (ON). The measurement period is from the end point of Td1 to the start point of Td2, where Td1 and Td2 can be preset in the program. ‘d’ indicates the time when the electric power steering motor stops operating (OFF). When this happens, the PC analyzes the signal, and the PLC proceeds with the next process to release the motor. The actual sound and vibration signal input and analysis are carried out only in section c.

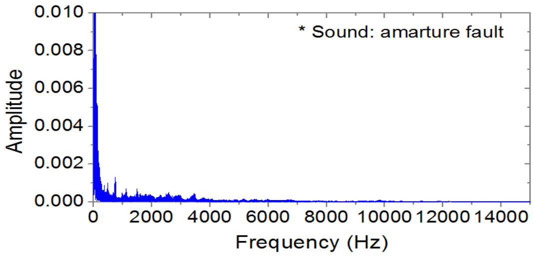
Figure 8 presents a flowchart describing the entire process for measuring the sound and vibration of the electric power steering components. When the motor is turned on in PLC (1), if the motor operates normally



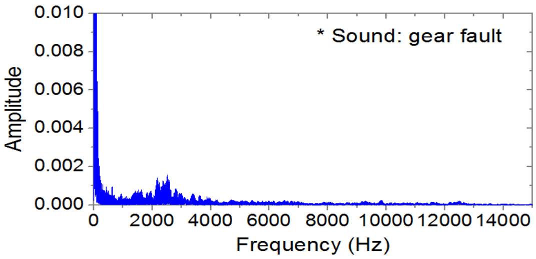
(a) Standard part



(b) Steering shaft fault



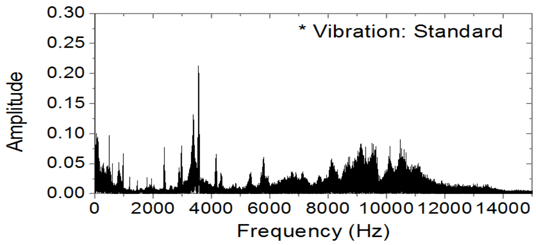
(c) Motor armature fault



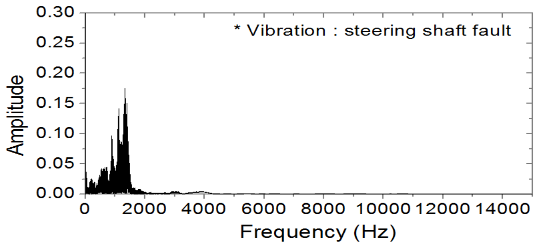
(d) Gear fault

Fig. 9 FFT sound analysis results

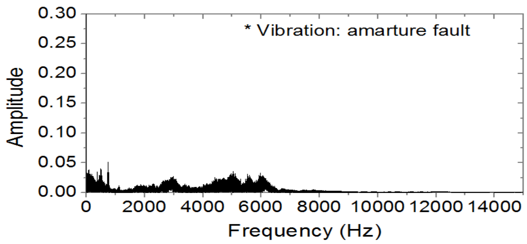
(YES), depending on the operation status of the motor (3), the inspection process is performed. If the motor does not operate (NO), a warning (4) is issued, and the motor is turned off (7). After the sound and vibration signals are input (5), they are displayed on the screen as a real-time graph (6). After performing statistical data processing (8) and FFT analysis (9), the results are displayed on the screen as a graph (10). Subsequently, the sound and vibration input signal data (11) and statistical analysis data (13) are stored in the memory (12, 14). When this process is completed (15), the program is terminated, and the next inspection is performed.



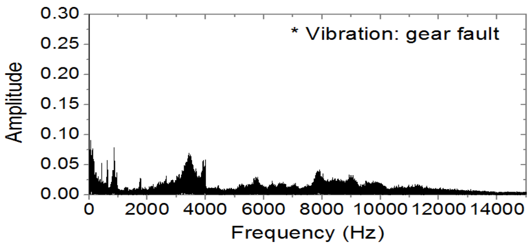
(a) Standard part



(b) Steering shaft fault



(c) Motor armature fault



(d) Gear fault

Fig. 10 FFT vibration analysis results

4. Results and Discussion

4.1 Sound measurement results

Figure 9 shows the results of the FFT analysis of sound signals for normal and defective electric power steering motors. The FFT graphs of several electric power steering motors indicate that the distribution of intensity and frequency differs depending on the type of failure. Overall, there is no significant difference according to the type of failure above approximately 5000 Hz. Therefore, FFT analysis in the range of 0–5000 Hz is effective. In the very low frequency range below 200 Hz, all distributions exhibit high intensities. For the bar fault, eccentricity, gear fault, and misalignment, large values were observed around 2500 Hz, and for a short circuit of lamination, a very weak strength was observed in the entire range except for the low-frequency region. Based on the FFT analysis results of the above sound signal, the fault in the electric power steering motor can be identified, and the fault type can be estimated.

4.2 Vibration measurement results

Figure 10 displays the results of the FFT analysis of vibration signals for normal and defective electric power steering motors. The FFT graphs of several electric power steering motors show that the distributions of intensity and frequency differ depending on the fault type of the electric power steering motor. For the defect of the bar, a large value was apparent in the low-frequency region, with a strong intensity hardly observed above 2000 Hz. Regarding a short circuit of lamination, a slightly higher value was observed near 16,000 Hz. Various frequencies and intensities existed over the entire range for the bar fault, eccentricity, gear fault, and misalignment. Based on the FFT analysis results of the above vibration signal, the fault in the electric power steering motor can be identified, and the fault type can be estimated.

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