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Motor Gear Fault Diagnosis by Current, Noise and Vibration on AC Machine Considering Environment

Sun-Ki Hong, Ki-Seok Kim, Yong-Ho Cho

Abstract**—**Lots of motors have been being used in industry. Therefore many researchers have studied about the failure diagnosis of motors. In this paper, the effect of measuring environment for diagnosis of gear fault connected to a motor shaft is studied. The fault diagnosis is executed through the comparison of normal gear and abnormal gear. The measured FFT data are compared with the normal data and analyzed for q-axis current, noise and vibration. For bad and good environment, the diagnosis results are compared. From these, it is shown that the bad measuring environment may not be able to detect exactly the motor gear fault. Therefore it is emphasized that the measuring environment should be carefully prepared.

Keywords**—**Motor fault, Diagnosis, FFT, Vibration, Noise, q-axis current, measuring environment.

I. Introduction

ROTATING machines are essential devices in the industry in most of case when rotating loads. Once motoring system failure happens, lot of money and effort are required to recover to the normal condition. Therefore many studies have been carried out about the failure diagnosis of motors [1]-[4]. There are lots of reasons for motor failures. For example, bearing, gears, windings and environments of motors. Typical diagnostic method is to measure the noise and vibration of motor system. In addition, the motor q-axis current can be a criterion to detect motor fault. This can reduce the cost and time to diagnose the abnormality of the motor in advance. In addition, the motor can be diagnosed even on operating. However, the measured signals are usually a little bit different at each time and to reduce these kinds of fluctuations, averaging methods [4] are commonly used. In spite of this effort, sometimes those results are not inconsistent.

In this paper, an advanced data acquisition method considering data loss and measurement environment are discussed. The measured data would be not only noise and vibration but also q-axis current. To measure the abnormal motor's signature for gear fault problem, a gear box is connected to an induction motor. In the abnormal gearbox, one or two teeth of the intermediate gear are damaged. A DAQ device is used for the measurements during operation. To detect fault signatures, noise, vibration and q-axis current are measured [5]. A software programmed with LabVIEW is developed to analyze the measured data. The frequency response of the gears is analyzed according to the motor speed [5]. The noise data is changed very fast therefore somewhat special programming technique is considered. From this process, the difference between the normal and abnormal states can be seen by the frequency characteristic analysis for the q-axis current as well as noise and vibration. In this process, the experimental environment like as measuring environment including buffering the measured data and sound isolation system are considered for accurate diagnosis. Though the experiment, well preparation for the measuring environment is critical to get good result as well as the good DAQ devices and software.

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II. Motor Gear Fault

The reasons of motor failure can be caused from bearing, gear, windings of a motor and environments. Bearing failure is caused from the improper installation of shaft or dysfunctional bearing and also happens in the case of electrolytic corrosion and chemical corrosion. Winding failure happens from overload, open phase, layer short and transient overvoltage. Physically, directly touches of the rotor to stator can cause the fault. Environmental causes are damp erosion and chemical material. The causes of the failure of gear are usually from the machining precision, broken gear teeth, gear materials, lubricating performance, mixing with debris, etc. This paper treats a gear failure. In the abnormal gearbox, one or two teeth of the intermediate gear are damaged [5]. By comparing the data of the normal and abnormal gear, the gear failure diagnosis is executed. Fig. 1 shows the damaged gear box (left) and damaged gear teeth (right). If the DAQ device can measure the exact pure vibration and noise except another environmental vibration and noise, it would be enough to compare the measured normal and abnormal fault data. However, the measuring environment can affect seriously to measure the data and has to be considered.

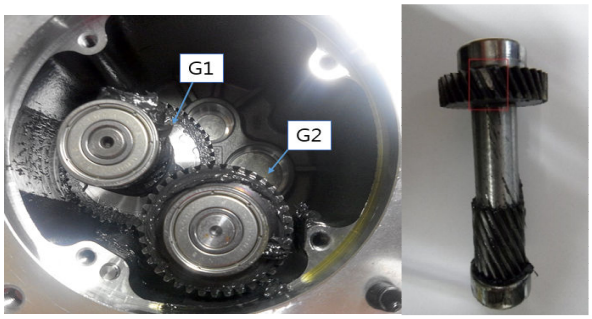


Fig. 1 Damaged gear box and damaged gear teeth

III. Measurement Environment

A. DAQ Equipment

Fig. 2 shows the measuring device and inverter system. The left one is the measurement device for three-phase line-to-line voltage, current, noise and vibration data etc. The right one is the 3-phase inverter to drive the test induction motor. For measuring the line to line voltage, NI-9225 is used, for phase current, NI-4462 is used. For vibration and noise measurement, NI-PXI9234 is used with high precision mic and amplifier. The accelerometers whose sensitivities are 100 mV/G and 10mV/G are used. The measuring software is developed with LabVIEW for data collection [5] and is modified for better performance.

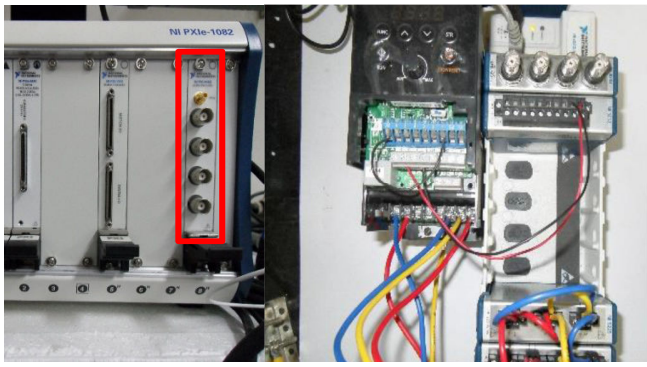


Fig. 2 DAQ and Inverter

B. Gearbox

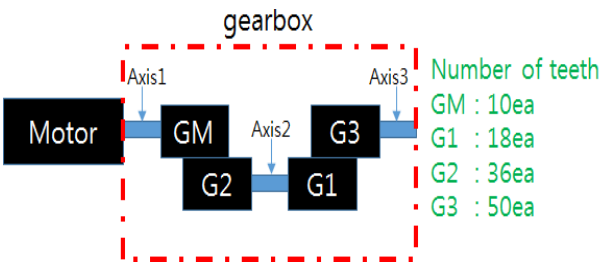


Fig. 3 Gear box structure

Helical gears are used in the test gear box. This gear box is connected with 3-phase induction motor and the gear box shaft is coupled with mechanical load or AC servo motor as a load. There are 4 gears in the box as shown in Fig. 1. Fig. 3 shows the inner structure of the gear box and the gear position. The axis rotating frequency can be found by the number of teeth of each gear. The number of poles for test motor is 4. The frequency of each axis is as follows where frequency f is the applied voltage frequency [5].

$$f_{ax1} \approx \frac{f}{2} \tag{1}$$

$$f_{ax2} = \frac{10}{36} \cdot f_{ax1} \tag{2}$$

$$f_{ax3} = \frac{18}{50} \cdot f_{ax2} \tag{3}$$

The frequency of axis 1 f_{ax1} is approximately half of the applied voltage frequency f because the number of pole of the motor is 4. In this study, gear G2 is damaged as shown in Fig. 1. With these equations, the gear fault can be analyzed by measuring the vibration frequencies [5].

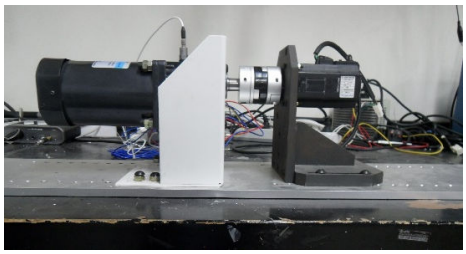
C. Base and Cover for Measurement

In this section, the environment of the measuring system is discussed. The measured data includes noise and vibration as well as q-axis current. Measuring the noise means that the device measures sound. Sound comes from not only motors and gears but also from so many sources like computer fans, voice, winds and etc. If the sound isolation is not enough, the measured data includes many kinds of sounds and some of them are not related with motor and gears. Fig. 4 shows the sound isolation covers. Fig. 4 (a) shows thin cover and Fig. 4 (b) shows doubly isolated cover. The measured data would be different according to the sound isolation covers.

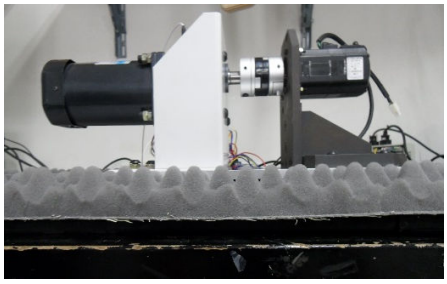
Fig. 5 shows the motor-load set on the table. Fig. 5 (a) shows the motor set is on the wood desk and it cannot isolate the vibration from the table. On the contrary, in Fig. 5 (b), the motor set is on rubber vibration isolator and sound isolator to cut off the outside vibrations.

(a) Thin single isolation cover (b) Thick doubly isolated sound cover

Fig. 4 Sound isolation covers



(a) Motor-load set on wood desk

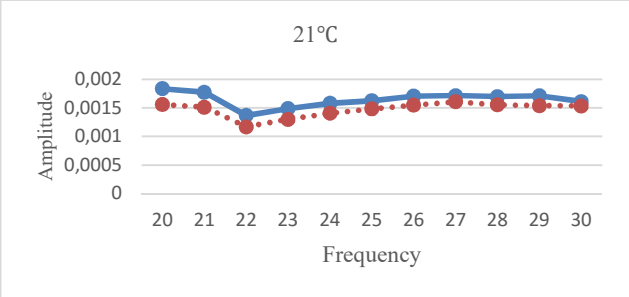


(b) Motor-load set on rubber vibration isolator and sound isolator

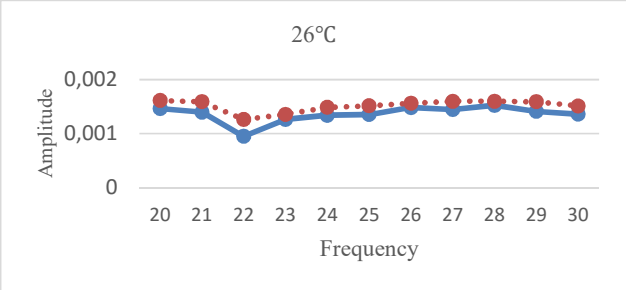
Fig. 5 Motor-load set under bad and good conditions

D.Peripheral Temperature

For the 2 case of ambient temperature of 21℃ to 26°C, the q-axis current measurements are executed. Fig. 6 (a) shows the amplitudes of *q*-axis current for normal and fault gear boxes by adjusting the inverter frequency of 20Hz~30Hz under 21°C. Fig. 6 (b) shows the same case data when the ambient temperature is 26°C. Those data show somewhat different aspect between normal and abnormal gears. When the ambient temperature is low, the amplitudes of the normal data are larger than abnormal data. On the contrary, if the ambient temperature becomes high, abnormal data are larger than normal ones. From this experiment, it is found that the temperature condition cannot be ignored in this kind of measurements. It is found that the ambient temperature may influence the data in the process of collecting data at the experiment.



(a) Currents comparison under 21°C



(b) Currents comparison under 26°C

Fig. 6 Motor currents under 21, 26°C (solid line: normal, dotted line: fault gear)

E. Vibration Measurement According to Axis

The failure part can be found through the vibration data. Vibration measurements are progressed with the accelerometer sensors which are attached on the gear box. The sensitivity of each accelerometer is 100 mV/G and 10mV/G. Only one-axis data for the gear box vibration are commonly used. However according to the condition, the vibrations of x and y axis may be different. In this case, accelerometers are attached to the gearbox on top and side which correspond to x, y axis. The two axes data are obtained by the two accelerometers. With these data, the more accurate vibration amplitude which means vector sum can be calculated with (4):

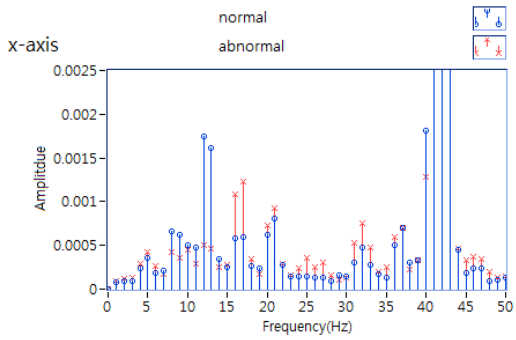
$$A_{vibration} = \sqrt{A_x^2 + A_y^2} \tag{4}$$

The fast Fourier transform (FFT) of vibration data are compared between abnormal and normal gear. With these results, the reason of the motor gear box fault can be detected. That is to say, each shaft has different rotating speed which makes different frequency. From the FFT of the vibration, the fault shaft can be determined with (1)-(3).

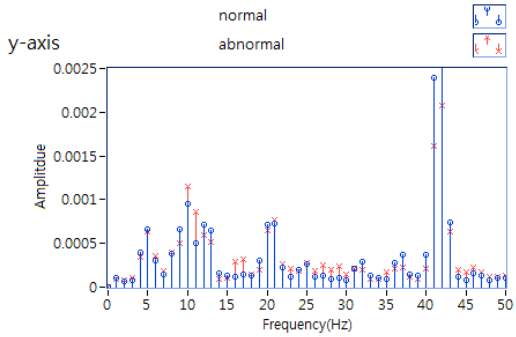
IV. Experiment and Result

A. Vibration Measurement for x and y-Axis

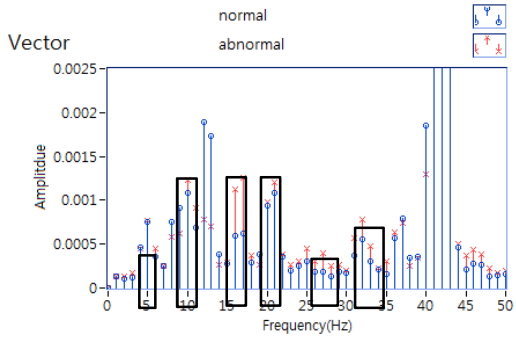
Fig. 7 shows the FFT results of vibrations for x, y axis and vector sum. As shown in Fig. 1, the fault gear is G2 which is associated with the axis 2. From (1)~(3), the frequency of axis 2 is 5.69Hz. As shown in Fig. 7 (c), especially big vibration data are measured at 6Hz, 11Hz, 17Hz, 21Hz and 28Hz. Those frequencies are approximately multiple times of base frequency 5.69Hz.



(a) FFT of x-axis Vibration



(b) FFT of y-axis Vibration



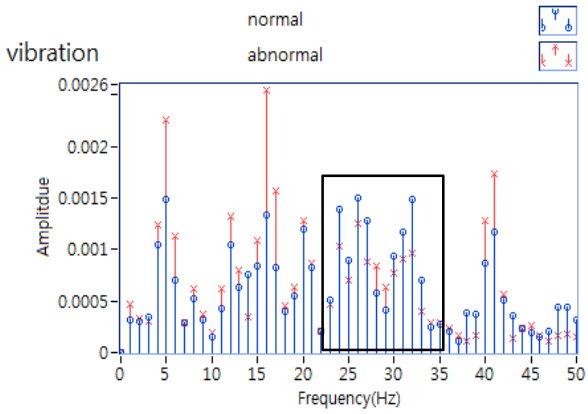
(c) Vector summation of x and y axis vibration

Fig. 7 FFT of vector sum of x and y-axis Vibration

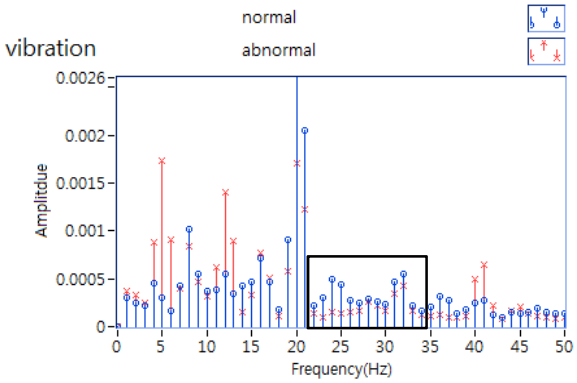
In the figures, the frequencies of FFT results are expressed in integer, and the fault frequencies are not exactly multiple times. However the fault frequency can be easily estimated because the axis frequency is already known from (1)~(3).

B. Vibration Measurement with and without Rubber Isolator

Fig. 8 shows the vibration of the gear box when the motor set is on the desk or on the rubber isolator as mentioned in Fig. 5. At first, the experiments are desired to have same results but the results are very different. That means the fault diagnosis may have wrong results if the measuring condition is not good enough.



(a) Measured vibrations when the set is on wood desk



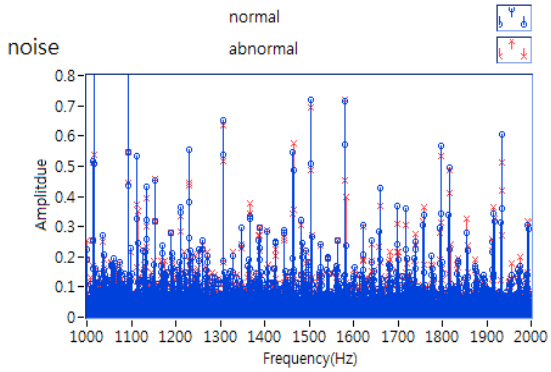
(b) Measured vibrations when the set is on vibration isolator

Fig. 8 Vibration comparisons according to vibration isolator

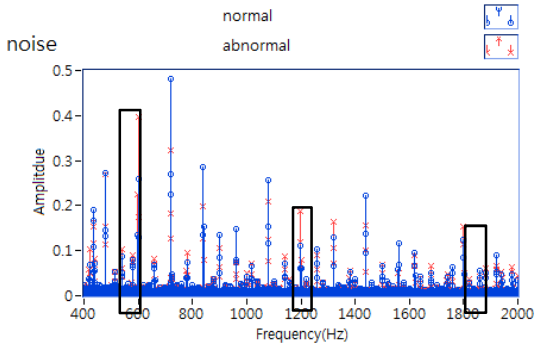
C. Noise Measurement

Fig. 9 shows the FFT of sound noise data when the inverter frequency is 60Hz. Fig. 9 (a) shows the FFT of the sound noise when the sound isolation is not enough as explained in Fig. 4 (a). Fig. 9 (b) is the same case under the good sound isolation condition covered with thick isolator. Those frequencies are approximately multiple times of the operating frequency 60Hz. As can be seen, it is not easy to find the periodicity in Fig. 9 (a) because it includes external noise sounds. Fig. 9 (b) shows much clearness and the periodicity and critical points can be easily found.

V. Conclusions



(a) Noise FFT when the set is in thin isolation cover



(b) Noise FFT when the set is in thick isolation cover

Fig. 9 Noise comparisons according to sound isolator thickness

In this paper, the affections of the measuring environment are mainly discussed. For analysis, a software using graphic language is also developed. It deals with sound and vibration isolation, vibration measuring points and temperature effect. For measuring points, the two-axis vector sum calculation is adopted to enhance reliability. It is found the measured data can be affected by the temperature variation. As a result, motor fault including gear fault diagnosis needs very careful preparation and consistent environment when measuring the fault signals.

Acknowledgment

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