Condition Monitoring

A Novel Electromagnetic Nondestructive Evaluation Method for Rotating Machinery
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ABSTRACT

The paper presents a novel electromagnetic nondestructive evaluation method. In this method, a permanent magnet is utilized to generate a static magnetic field and a pickup coil with several hundred turns is used to detect the eddy current induced inside the rotating machinery. Aluminum flat plate with four EDM cracks is placed in a small-size water pump and detected by this method. Experimental results show that these four cracks can be detected form outside of the pump casing, and the amplitude of the pickup signal is proportion to the depths of the cracks. This electromagnetic nondestructive evaluation method is also applied to the canned pump. By monitoring the movement of the impeller in a canned pump, the rotation speed, the variance of the impeller position as well as the wear of sliding bearing has been evaluated.

Keywords: Electromagnetic Nondestructive Evaluation Method, Rotating Machine, Permanent Magnet, Eddy Current, Finite Element method, Canned Pump

INTRODUCTION

Rotating machines such as rotors, pumps, turbines and fans are among the most commonly utilized industrial components. At this moment the application of vibration analysis to the diagnosis of the integrity of rotating machines is mainly considered. However it is not always possible that vibration can detect any degradation as its signals themselves do not necessarily contain sufficient information about the condition of rotating machines. Some degradation such as tiny cracks appearing at the tip of a rotating impeller, do not influence the mechanical vibration of the machine itself and thus cannot be detected by vibration-based methods until it becomes so large that the integrity of the machine is actually threatened. The wear-out of plain bearings in a canned pump is also difficult to be detected by a conventional vibration sensor because of no additional vibration accrued. However, the wear-out of plain bearings will influence the rotation axis of the impeller and thus can be detected indirectly.

Against the background above, this study proposes a novel electromagnetic nondestructive testing method to detect and evaluate the condition and movement of a rotating impeller. The method utilizes a permanent magnet to generate static magnetic field, which penetrates casing and reaches the target inside. A conductive material moving inside the magnetic field disturbs the magnetic field because of induced eddy currents, and the disturbance is sensed by the induction coil. It should be noted that the magnetic field caused by the sensor is not alternating but static one and measured electromagnetic signals contain variety of frequencies unlike conventional eddy current testing. Consequently one can obtain the information about the characteristics of the conductive material from the measured electromagnetic (EM) signals even though the casing is thicker than a few millimetres.

APPLICATION TO A WATERPUMP

Experimental setup

A commercial water pump [1] is used in the basic experiment. The picture of the pump is shown in Fig. 1(a), and the cross-sectional profile is shown in Fig. 1(b). The case of the pump is made from SUS304 stainless steel which thickness is about 1.5 mm. Instead of a real impeller, an aluminum disk impeller is used measuring 120 mm in diameter and 10 mm in thickness.
The sensor of this electromagnetic evaluation method is shown in Fig. 2(a). The sensor consists of an Nd2Fe14B magnet 30 mm in diameter and a 500 turn pickup coil winding on the magnet. The magnet generates a static magnetic field penetrating the case that induces eddy currents inside the impeller. The coil then detects the magnetic field generated by the disturbance of the eddy currents. Because of the fact that only non-ferromagnetic materials exist, no magnetization is considered. This gives convenient for the numerical simulation.

Some EDM slits are introduced in the disk impeller. The slit test pieces are shown in Fig. 2(b). The EDM slits are penetrated slits which are 0.5mm in width and 3, 5, 10, 20mm in depth separately.

Experimental results

The experimental results from slit test pieces are shown in Fig. 3. Fig. 3(a) is the time sequential voltage signals pickup by coil. When there is no slits exists, the eddy current induced in the aluminum disk impeller will be stable and no voltage signal will be detected by the pickup coil. However, when a slit exists, the eddy current will be disturbed and voltage signals appear. Experimental results show that these four cracks can be detected form outside of the pump casing, and the amplitude of the pickup signal is proportion to the depths of the cracks.

Fig. 3(b) shows the peak to peak voltage ($V_{pp}$) of the measured signals due to the change of slit depth. The relation between the peak to peak voltage and the slit depth is nearly linearity, but saturated when the depth of the slit is too large. This curve can be used as a calibration curve to
estimate the slit depth, which provides a quantitative nondestructive testing method for the cracks in an impeller.

**Numerical simulation results**

Numerical analysis using finite element method is performed and good agreements between numerical and experimental results can be found. Numerical simulation results are compared with experimental ones in Fig. 4.

The credibility of the numerical simulation is proved. This provides us a powerful tool to estimate the EM signals without doing costly experiments and save time as well.

![Figure 3 - Experimental results of EDM slits (depth 3, 5, 10, 20mm)](image)

![Figure 4 - Comparison of experimental and numerical results](image)
APPLICATION TO A CANNED PUMP

Experimental setup

A practice experiment is performed using a canned pump. Experimental setup is shown in Fig. 5. Fig. 5(a) shows the whole canned pump and Fig. 5(b) shows the photograph when a sensor is placing in the axial direction to detect the impeller inside the casing.

![Whole canned pump](image1.jpg) ![Sensor detect from the axial direction](image2.jpg)

Figure 5 - Experimental setup of canned pump (type HN21BJA3C)

Experimental results

Experimental results are shown in Fig. 6. Fig. 6(a) shows the photograph of the impeller, which has 8 fins. There is individual difference between each fin in the shape as well as the electromagnetic property. As a result of it, the measured signals of each fin are also different, as shown in Fig. 6(b). The rotation speed of the pump is about 50Hz, thus the frequency of the fin signal should be about 8 times of rotation speed, 400Hz. The spectrum of the signal is shown in Fig. 6(c). Maximum component in frequency domain is 390Hz. One can deduce that the rotation speed is 48.785Hz with a high precision. This provides a high precision method to monitor the rotation speed of the pump from the outside of the casing.

![Photograph of the impeller](image3.jpg)
Monitoring of the wear-out of the plain bearing

The wear-out of plain bearings in a canned pump is difficult to be detected using a conventional vibration sensor because of no additional vibration accrued. However, the wear-out of plain bearings will influence the rotation axis of the impeller and thus can be detected indirectly by the electromagnetic sensor.

Fig. 7 shows the relation of wear-out condition of the plain bearing and the movement of the impeller. When in normal condition, the impeller rotates steadily and the signals of EM sensor retain a same value. When wear-out occur, the gap between the shaft and the plain bearing will became larger and the position of the impeller will change due to the weight and the centrifugal force. By detecting the position of the impeller, one can estimate the wear-out of the plain bearing to some extent.

In this study, no real wear-out of plain bearing is applied. A displacement of axial or radial direction is used to simulate the wear-out by inserting a plastic film between the shaft and the impeller. The simulation of the displacement of the impeller is shown in Fig. 8. One EM sensor is placed on the outside of the casing of the pump to detect the impeller. For an axial displacement, the distance between the EM sensor and the impeller will change and the EM signals change significantly. On the other hand, a radial displacement will only change the distance slightly only because the slope surface. The EM signal is not so sensitive to the radial displacement comparing with an axial displacement.

The EM signals from the impeller should be processed in order to estimate the displacement. Many signal processing methods are considered and compared in another paper. In this paper, the peak values (refer to Fig.6 (b)) of each acquisition are abstracted. A vector of 8 dimensions is introduced, and average value of normal condition is treated as the origin. The displacement of the impeller can be estimated by the distance from the feature vector and the origin.
(A) Normal condition
(B) Slightly wear-out
(C) Serious wear-out and the impeller hit the casing

Figure 7 - Wear-out condition of the plain bearing and the movement of the impeller

(a) Axial displacement                      (b) Radial displacement

Figure 8 - Simulation of the displacement of the impeller
Experimental results of different displacements are processed and the distance from the origin is compared in Fig. 9. In normal condition without any displacement, the distance varies in a small range which is shown in fig. 9 as $\sigma$. When a plastic film of 0.02mm thickness is inserted between the shaft and the impeller, the distance becomes much larger than $3\sigma$. Distinct difference can be detected and the resolution of axial displacement is less than 0.02mm at least. On the other hand, a radial displacement of 0.1mm is able to be detected according to Fig. 9 (b).

Real wear-out of plain bearing has been considered in the latest study and results will be presented soon.

CONCLUSIONS

This paper proposed a novel electromagnetic nondestructive testing method to detect and evaluate the condition and movement of a rotating impeller.

1) The experimental results of a basic experiment using a small commercial water pump demonstrated that small cracks of the impeller can be detected form outside of the pump casing, and the amplitude of the pickup signal is proportion to the depths of the cracks.

2) Numerical results are compared with experimental ones and good agreements have been found. Numerical simulation can estimate the EM signals quantitatively with high precision.

3) The results of a practice experiment using a canned pump are shown in this paper. The impeller as well as the fin number can be detected form the EM sensor placing on the surface of the casing. It also provides a high precision method to monitor the rotation speed of the pump.

4) The wear-out of plain bearings will influence the rotation axis of the impeller and thus can be detected indirectly by the electromagnetic sensor. Experimental results show that the resolution of axial displacement is 0.02mm, and that of radial displacement is 0.1mm.

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REFERENCES