Infrared Thermographic Inspection of Ball Bearing; Condition Monitoring for Defects under Dynamic Loading Stages

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Abstract
Condition monitoring during dynamic loading conditions of rotational machineries with, the use of contactless, non-destructive infrared thermographic method is proposed. From using a rotating deep-grooved ball bearing, passive thermographic experiment was performed as an alternative technique to proceeding the fault monitoring. Based on the results, the temperature characteristics of the ball bearing under dynamic loading conditions were analyzed thoroughly. As results, it was confirmed that infrared thermography method could be adapted into monitor and diagnose the fault for bearing by evaluating quantitatively and qualitatively the temperature characteristics according to the condition of the ball bearing.

Keywords: thermographic inspection, vibration machinery, ball bearing, dynamic loading, defects evaluation, quantitative imaging

1 Introduction
Through past decades, non-destructive inspection technology has been widely used and its leveraging range is continuously growing trend. Recently, quantitative inspection for machinery equipments and facilities with shock or vibrations with rotating have been required and the application of infrared thermograph technology as a useful measurement tool for its own heat dissipations was useful, in which a non-destructive testing (NDT) as a passive infrared thermography was applied.[1] Since infrared thermographic technology with high performances in sensitivity and resolution could scan a large area at the same time as one of non-destructive tastings, this infrared technology extended its applications including to detect cracks, delamination of defects.

As a methodology of faults monitoring with several advantages such as real-time detection and remote detection, it could be applied into the area of automotive, aerospace industry and nuclear plants. At these days, the applications of infrared applications were quickly expanded to the field of fault detection techniques and its utilizations of condition monitoring for the diagnosis were widely increased [2]. In this study, using the infrared thermography method for the diagnosis of ball during operation, evaluation of fault detection was carried out by experiments.

2. Experimental Configurations

2.1 Thermographic Concepts
Thermographic NDT techniques have been used in a variety of applications, e.g. the inspection of subsurface defects and features, the identification of thermo-physical properties and the detection of coating thickness and hidden structures. In the 1980s, Vavilov and Taylor[2] discussed the principles of thermal NDT, describing its ability to provide quantitative information about hidden defects or features in a material.[3, 4] When the material includes voids or pores in its structure, its thermal conductivity and density decrease, and the thermal diffusivity is altered, so the conduction of heat through the material is affected. Unlike ESPI, thermography measures the surface temperature of an object; the temperature difference between the defect and the sound part indicates the size and location of the defect. In this we have used an IR camera (model Silver 450M by Cedip Corp.).
2.2 Loading conditions of bearing modes
An experiment was performed by using B6204 and B6304 applied as the test piece. B60XX series are the most widely used in the insulation deep groove ball bearing.[5-7] Both Fig’s of 1 and 2 show the thermography system used in this experiment and the schematic diagram for the standard of ball bearing, respectively. From Fig. 2, it indicates the simple device configuration used in this experiment. The bearing B6204 and housing were installed between a power and a measuring bearing in order to simple support.

![Image of experimental apparatus and schematic diagram](image)

Fig. 1 Experimental apparatus for bearing test  
Fig. 2 Schematic of deep groove ball bearing

2.3 Experimental procedures
The bearing B6804 and housing were installed between a power and a measuring bearing for simple support. The simple device configuration and IR camera used in this experiment are shown in Fig. 1~2. And Fig. 3 shows the bearing according to stage of abrasion. The abrasion condition is classified into roughness of 3 sections of 0.5 ~ 0.7, 0.7 ~ 0.9 and 0.9 ~ 1.1 μm in this experiment.

<table>
<thead>
<tr>
<th>Bearing Name</th>
<th>Outer Diameter</th>
<th>Inner Diameter</th>
<th>Ball Diameter</th>
<th>Ball Number</th>
</tr>
</thead>
<tbody>
<tr>
<td>B6204</td>
<td>47</td>
<td>20</td>
<td>7.90</td>
<td>8</td>
</tr>
<tr>
<td>B6304</td>
<td>52</td>
<td>20</td>
<td>9.50</td>
<td>7</td>
</tr>
</tbody>
</table>

Table 1 Specifications and dimensions of ball bearing (unit: mm)

The roughness of normal bearing is smaller than 0.2 μm. In addition, the condition of loading was assumed as circular weights of 1, 3, 5 kg. Fig. 4 shows the circular weights. By using the APM-SC08ADK Servo Motor of 1 HP on 800 W, the experiment was performed in 1000, 2000, 3000 rpm, respectively. The model of the infrared camera used this experiment is the Silver 450 M of Cedip Corp. (France).

![Image of abrasion bearings and circular weights](image)

Fig. 3 The cross section of abrasion bearings(B6204, B6304)  
Fig. 4 Circular weights
3 Experimental Results

3.1 B6204 Spalling testing
The infrared thermographic experiments were performed until the equilibrium temperature after the temperature rose. 50 frames per a second were measured. From the experimental results of Fig. 5, quantitative detection was carried out under the speed of 1,000 rpm, and 3,000 rpm as normal condition, lubricating oil loss condition, and spalling condition of B6204 ball bearings.

![Image of thermographic results](image)

From Fig. 5, each figure shows quantitative assessment of the infrared thermographic diagnosis method research and the result was analyzed thoroughly. However, this problem was solved by applying the infrared thermography technology which has benefits at non-contact and scanning method. As shown in figures of Fig. 6, the images obtained from the results of the experiment with B6204. In the correlation of the color come out in an image, temperature is high as it comes close to the red and low as it comes close to the blue. From these figures, each experimental method was applied to the bearing type of B6204. Also, these results of the other bearing came out with this, similarly.

3.2 Loading testing for bearings
In order to reach 1000, 2000, and 3000 rpm within 3 seconds after starting, the infrared thermography device was set up. The condition of loading was assumed as circular weights of 1, 3, 5 kg mounted to the axis. The change of the temperature characteristic of the bearing was observed on a real time basis. In this experiment, the data was calculated from the connection of intrados and outer-race and the ball of the bearing in which the generation of heat is most serious[4]. When the measured temperature rose for a certain time and the temperature balance was made, the maximum temperature was recorded.

Fig. 6-7 are the graph about results of B6204 and B6304, respectively. The graph shows that the maximum temperature in the roughness conditions of 0.57, 0.88, 1.03 μm was higher than the normal condition in Fig. 6. Also, Fig.7 shows similar pattern also. When the load was applied to the abrasion condition, the generation of heat of the bearing became severe more and the maximum temperature
value was dramatically increased. Therefore, the temperature characteristics according to the abrasion stages of the ball bearing under dynamic loading conditions were analyzed through the infrared thermography method.

4 Conclusions

In this research, the temperature characteristics according to the abrasion stages of the ball bearing under dynamic loading conditions were analyzed through the infrared thermography method. Based on these results, the contactless, non-destructive realtime monitoring and abnormality diagnosis using the infrared thermography method will be applicable and useful for condition monitoring of rotating machine elements in the future.

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References