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Detection of rolling bearing degradation using infrared thermography

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Abstract

Our study deals with the detection and the diagnosis of spalling in rolling bearings. Our idea is to show the correlation which exists between the outside temperature of the bearing cap and the vibratory level generated by increasing appearance of the defect.

We led an experimental study on the test ring which allows the creation in a progressive way, of spalling defect on the external ring of the rolling bearing. On this test rig, we measure simultaneously the mechanical vibration in radial direction (by means of a piezoelectric accelerometer) and the bearing cap external surface temperature (by means of an infrared camera). The results exhibit a significant correlation between both measures.

A detailed of the heat transfer between the rolling elements and the spalling outside border permitted to evaluate the temperature rise due to the heat generated from the defect

1. Introduction

The activity of maintenance of the industrial installations has been used since twenty years and the diagnosis techniques are more and more sophisticated. Several techniques of defect detection are at the disposal of the maintenance engineers today. Among these, we can note the infrared thermography for the detection of defects of electrical or mechanical origin; the analysis of lubricants; the ultrasound detection; the mechanical vibrations.
The last technique uses signal analysis tools which have seen their field of application widening year after year. We can find in [1] the necessary elements to implement the classic signal analysis tools, such as: Fourier Transform, Hilbert transform (for the search for amplitude modulations and\or frequency), as well as the determination of scalar indicators such as: effective value, factor of crest and Kurtosis.

Submitted to radial and / or axial effort which can vary in direction during time, a rolling bearings (figure 1) is submitted to the fatigue due toa variation of load on its rolling elements.
At the end of 19th century, Hertz [2] established the relations which allow to calculate the constraints and the deformations that two surfaces undergo when running without sliding one on the other.

These shear constraints in the rolling elements entail, after certain number of hours of functioning, a loss of metal in surface called spalling. This spalling (figure 2) can

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occur a priori on one of three rolling surfaces (rolling element, track of the outside ring, the track of the internal ring).
This spalling defect is then going to degenerate to provoke the other sources of spalling and entail the progressive destruction of the rolling bearings.

During the passage of the rolling element on the spalling zone, a shock is going to occur. This impact is repeated in a periodic way. The frequency of repetition of the impact depends on the geometry of the rolling bearing and on the speeds of rotation.

The manufacturers of rolling bearing s supply the values of the bearing frequencies. As an example (table 1) we indicate :

Table 1. Frequency of spalling defect

N^{I} rpm	N_e rpm	f_{re} (Hz)	f_{br} (Hz)	f_{er} (Hz)
1490.4	0	76.84	121.88	109.96

N_i: Speed rotation of the internal ring;
N_e: Speed rotation of the outside ring;
f_{be}: Impact frequency if spalling is on the outside ring;
f_{bi}: impact frequency if spalling is on the internal ring;
f_{er}: Impact frequency if spalling is on rolling element,

However measuring the vibration frequencies of the rolling bearing is somewhat cumbersome for maintenance purposes; on the contrary, IR thermography is a fast and non-intrusive method to detect the presence of abnormally warm zones on the surface of the bearing.
We propose here to establish a link between the temperature rise and the rise of the vibratory level of a mechanical component in the course of degradation. Our study particularly concerns the detection of the appearance of a defect of spalling on a rolling bearing [3].

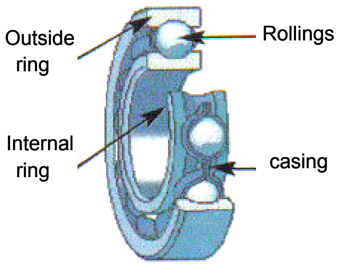

Fig 1. *Rolling bearing*

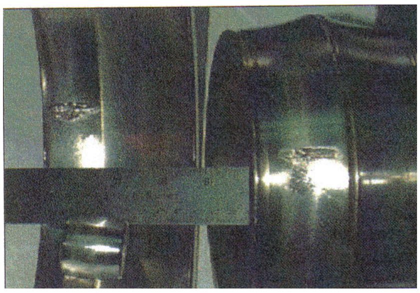

Fig 2. *Spalling defect*

2. The methodology

The methodology is described below (see also figure 3):
Periodic impacts are generated by a spalling zone located between one of both rings of the rolling bearing (an impact in every passage of a rolling on the spalling zone).
These periodic impacts are going to excite the mechanical system structure (movement, connection with the machine frame …).
The whole bearing cap is thus going to vibrate at its echo frequency.

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The damping of the vibration has the effect to transform a part of the damping vibratory energy into heat.
This heat creation induces a rise in the ring temperature, more particularly on its external surface.

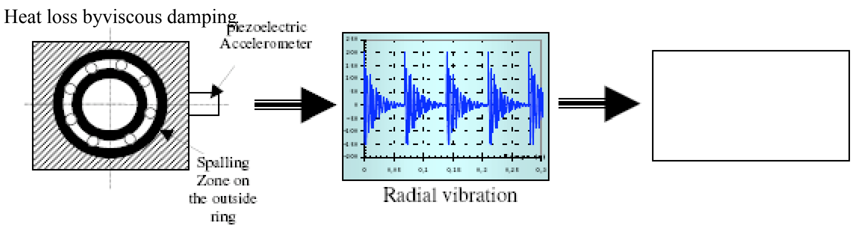

Fig 3. *Rise of temperature of the rolling bearing due to the presence of a spalling zone on the outside ring*

To summarize, we think that the measurement of this temperature rise might allow us to estimate the vibratory energy quantity generated by the periodic impacts, and therefore to estimate the level of the rolling degradation.

3. Description of the test platform

Our laboratory has a test platform (figure 4), which allows us to rotate a rolling bearing with constant movement and adjustable speed of rotation and which main characteristics are:

- AC motor: 1.5 kW, maximum turning speed 1500 rpm.
- Rolling bearing type: angular-contact ball bearing (SKF 7206)

Various defaults can be simulated on this test rig. The default analyzed in this paper concerns a spalling on the inner face of rolling bearing.

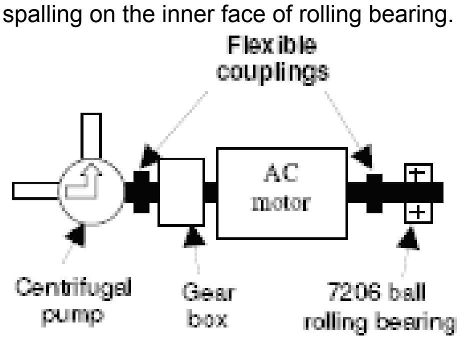

Fig. 4. *Experimental setup*

We can simulate an outside ring defect of the rolling bearing by tightening more or less a tightening screw with radial effort (figure 5).

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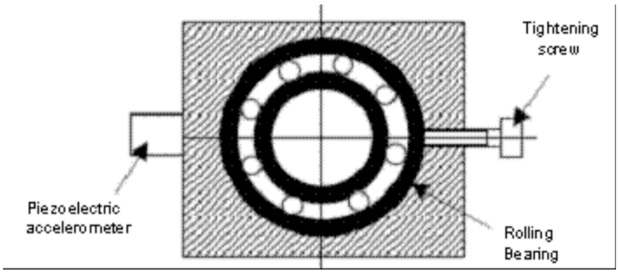

Fig 5. *Experimental setup of defect*

An accelerometer measures the vibration in the radial direction. An infrared thermal camera is used to measure the bearing cap exterior surface temperature (figure 6). (We painted a part of the surface of the bearing cap using a high emissivity paint, Velvet Coating 811-21, to minimise the effect of the reflection and reduce the errors of measure.)

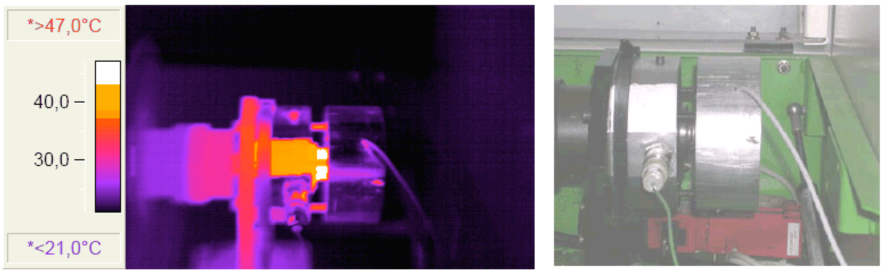

Fig 6: *The bearing cap seen by infrared camera*

The rotation speed of the axis is maintained constant: 1500 rpm
We have measured, for various forces applied by the tightening screw:

- The vibratory level (effective value in mm/s),
- The temperature of the external surface of the bearing cap.

The obtained results are given in figure 7.

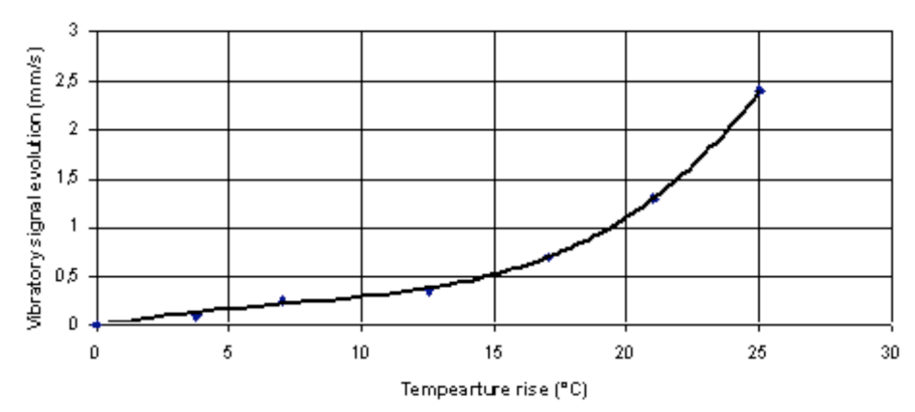

Fig 7. *Evolution of the temperature of the bearing cap according to the vibratory level*

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There is a clear correlation between mechanical and thermal effects.

We have also established a thermic modelling of the bearing cap of the rolling bearing.

4. Numeric model

We are interested in determining the temperature field in the rolling bearing, the bearing cap and the rotation axis. For this purpose, we used a software based on the finite volume method [Fluent].
We remember that the presence of a provoked defect leads to a characteristic vibratory level transformed into abnormal heating of the system, and thus the generation of a heat fluxes adding to the nominal heat production. We wish to verify whether this phenomenon induces a rise of the surface temperature that can be detected by infrared thermography [4]. The modeling part thus consists in changing the fluxes generated and to measure the spatial distribution of the temperature.

The modeling hypotheses are the following:

- We assimilate the rollings to a ring;
- We suppose that the contacts between rings and rollings are perfect;
- The rotation speeds of the internal ring and the rollings are identical.
- Heat production is uniform in the ring

We present in figure 8 the chosen mesh; it is a three-dimensional structured mesh using parallelepiped cells realized under GAMBIT so as to optimize the number of cells with the aim of improving the precision and reducing the computing time, the number of cells is 16079.

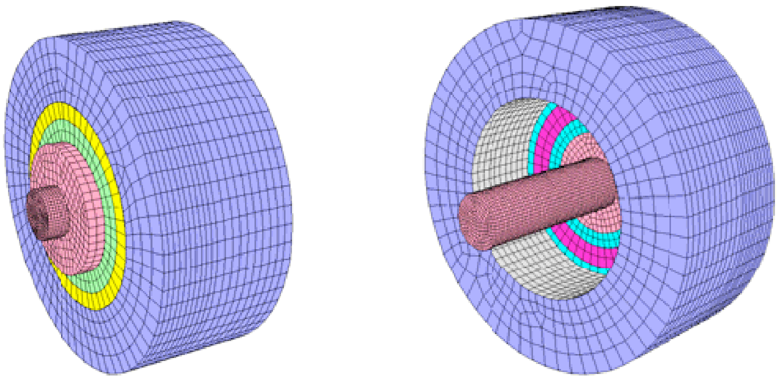

Fig 8. *Meshing of the experimental device*

The computing conditions are as follows:

- Ambient temperature: 20°C
- Internal and external side convection exchange coefficients: 10 W/ m^2/K
- Convection exchange coefficients on the lower and upper faces: 10 W/m^2/ K
- Speed of rotation of the axis: 1500 rpm
- The bearing cap is made of aluminum with thermal conductivity: _ = 202.4 W/m. K

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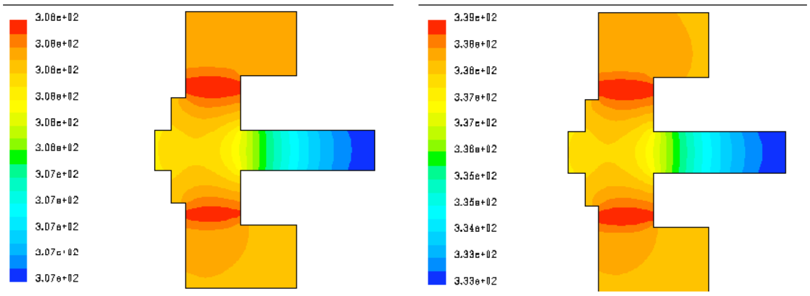
- The rolling bearing and the axis are made of steel with thermal conductivity: _ = 16.27 W/m. K

The figure 9 represents the temperature field on a section of the experimental device for various values of the power generated inside the rolling bearing.



P= 14.8 W P= 44.4 W

Fig 9. *Field of temperatures computed within the bearing cap with movement*

In figure 10, we present the evolution of the difference ΔT between bearing cap and ambient temperatures according to the power generated inside the rolling bearing.

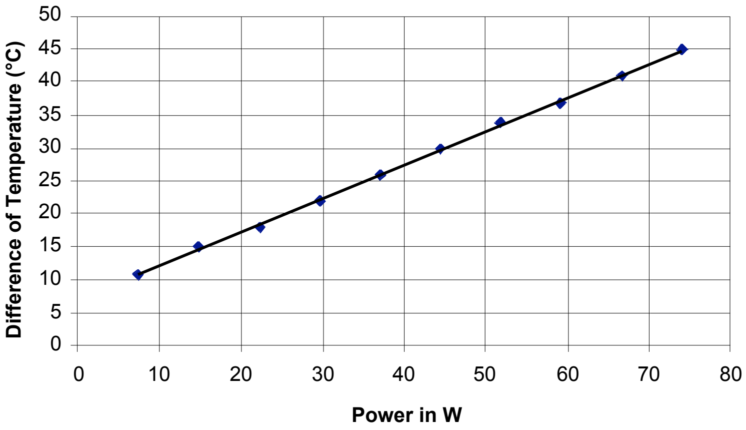


Fig 10. *Calculated evolution of ΔT as a function of the power dissipated by the rolling bearing*

As we could expect, the evolution of ΔT is proportional to the power dissipated by the heat source. The slope coefficient is equal to 0.51 °C/W.

5. Conclusion

The first results obtained are encouraging. Indeed, on the one hand the vibratory defect engendered within the rolling bearing leads to a quantifiable heating of the surface; on the other hand, numeric model highlights a correlation between vibratory defect and heat production but also allows to quantify the involved fluxes.

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This work will have to continue following to two axes. A mechanical model should completed concerning the analysis of the mechanical phenomenon, in order to predict heat generation from the defect characteristics, the approach, purely experimental up to now.
Also, the thermal model must be improved by taking into account other parameters like for instance the contact resistances between different mobile parts of the rolling bearing.

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