Modelling and diagnosis of a crack of a bearing inner ring

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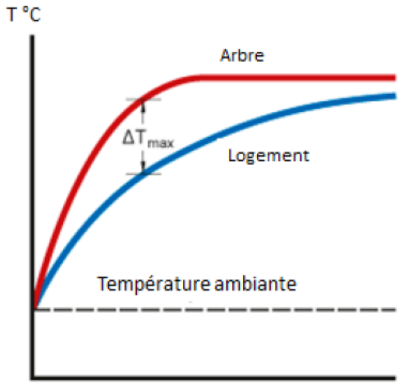
Abstract
Cracking of the inner ring of a bearing can occur for various reasons: poor handling during assembly, thermal stresses during start-up, etc. This results in a loss of tightness between the ring and the shaft with various consequences: fretting corrosion, heating of the inner ring leading to a reduction in the operating clearance and then to the blocking of the bearing, or even the rotation of the shaft in the bearing bore. The collateral damage can therefore be very significant. The difficulty in diagnosing a crack on the inner ring of a bearing is that it will generate a vibratory signature similar to that of other defects located on the inner ring (marking, corrosion, grooves due to the passage of leakage currents, etc.) but with very different consequences. With the experience accumulated at DYNAE in particular on paper machines, some veteran experts are able to identify a cracked ring simply by listening to the measured signal. However, a theoretical formalization of this technique seems desirable in order to achieve a reliable and semi-automated detection. This requires the modelling of the phenomena induced by a cracking and their associated vibratory signature. The method proposed here is based on the concept of Modal Kurtosis, as an improved version of the Spectral Kurtosis allowing to identify the frequency range in which shocks are the most readable, by considering the physical parameters associated with the excitation of the natural modes. The analysis of the envelope signal obtained after filtering is then performed in the spectral and time domains, by estimating the extent of the bearing load zone, the number of shocks per revolution due to rolling elements passing over the crack, and the attenuation factor of the spectral envelope of the modal response. The latter allows to identify another source of shocks, in particular a rotational shock due to a clearance. These processing allow an expert to orientate the diagnosis either towards a ring crack with loss of tightening, or towards other types of defects affecting the inner ring (spalling, grooves). Industrial case studies are presented to illustrate the technique.

1 Introduction

Cracks can occur in bearing rings for a variety of reasons. The most common cause is improper handling when mounting the bearings: hammer blows applied directly to the ring, excessive pressure on a bearing seat or tapered sleeve inducing tensile stresses, or when the bearings are heated and then mounted on shafts which diameters do not comply with the normative tolerances. Cracking, breakage or even bursting of the rings usually occurs soon after commissioning. Another cause of cracking is due to thermal stress during start-up. If the shaft temperature rises too quickly, the inner ring may crack, as it expands more slowly than the shaft due to the temperature of the lubricant. This situation occurs quite frequently in the case of a paper machine drying section during a start-up phase after a technical stop when the temperature and speed rise instructions are not respected. Other causes can be at the origin of bearing ring cracking: axial stresses, flaking, contact rust between outer ring/housing or between inner ring/trunnion, or even micro-seizing due to the sliding of rolling elements.

The consequences of a crack affecting the inner ring of a bearing are immediately reflected in a loss of tightness between the ring and the shaft with various consequences: fretting corrosion leading to matting of the surfaces in contact, heating of the inner ring leading to a reduction in the operating clearance and leading to seizure of the rollers and then blocking of the bearing, or even the possible rotation of the shaft in the bore of the bearing. The collateral damage can therefore be very significant.



2 Development of a diagnostic method for ring cracking

2.1 Context

The method proposed here was developed at the initiative of Christian Pachaud, former technical director of EES-DYNAE. The difficulty in diagnosing a crack in the inner ring of a bearing is that it will generate a vibratory signature similar to that of other defects of similar size located on the inner ring (marking, corrosion, grooves due to the passage of leakage currents, etc.) but with very different consequences, as a simple marking of the inner ring may not evolve over several years. With the experience accumulated in particular on paper machines, some seasoned experts at DYNAE are able to identify a cracked ring by simply listening to the measured signal. However, as this skill tends to be lost, a more theoretical formalization of this technique seems desirable. This requires a better modeling of the phenomena induced by a cracking and their associated vibratory signature in the spectral and temporal domains.

2.2 Methodology

We cannot develop here all the concepts introduced in the proposed method but only give a brief description:

- Introduction of the concept of Useful Spectral Range of the excitation due to the passage of a roller over a crack;
- Calculation of an improved version of the Kurtosis that has been optimized to identify the frequency range in which the shock reading is most readable, considering the physical parameters associated with the eigenmode excitation;
- Calculation of the Spatial Resolution representing the minimal space allowing to separate two successive shocks;
- Modelling of the attenuation factor of the Spectral Envelope of the modal response, which allows the identification of another source of shocks, for example a rotational shock due to a bearing clearance;
- Estimation of the number of sidebands around the inner ring fault frequency, allowing to evaluate the extent of the bearing load zone compared to the theoretical Stribeck distribution;
- Analysis of the high frequency envelope signal in the time domain in order to extract the expected vibratory image during a crack or transverse fracture, i.e. one or more high amplitude shocks in the middle of the load zone during the passage of rolling elements on the crack.

2.3 Case study

This study concerns a felt roll of a paper machine equipped with double-row, split-cage spherical bearings lubricated with pressurized oil. The roller seats are tapered. The vibration signal measured on the driver's side clearly shows a shock (figure 1 left). After application of our method, the spectrum of the amplitude modulation function - the envelope - is calculated (figure 1 right). The number of sideband pairs around the inner ring frequency is estimated to be at least 5, corresponding to a load zone of about 70°, which is relatively low and seems to indicate a large clearance. In addition, there is a significant attenuation of the sidebands with respect to the first harmonics of the rotation frequency, which seems to indicate a second exciting source (shock at rotation frequency).

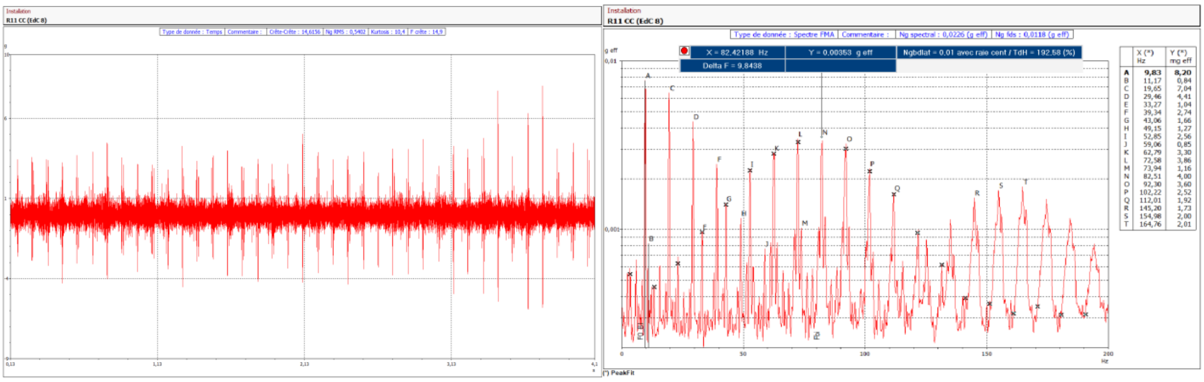


Figure 1: Measured vibration signal and spectrum of the amplitude modulation function in the detected frequency range

The envelope signal is then analyzed in the time domain, and represented in polar form over one shaft turn as well as over 10 turns (figure 2). The first representation shows a clear main peak and two secondary peaks concentrated in a narrow area. The second one superimposes all the shocks taking place on 10 turns, which allows visualizing the loading zone. All these observations allow us to diagnose a ring failure with loss of tightening.

When the bearing was replaced, a transverse break in the inner ring was observed with a crack width of approximately 0.1 mm, a large gap between the ring and the bearing seat, and traces of matting and fretting corrosion affecting the contact surfaces.

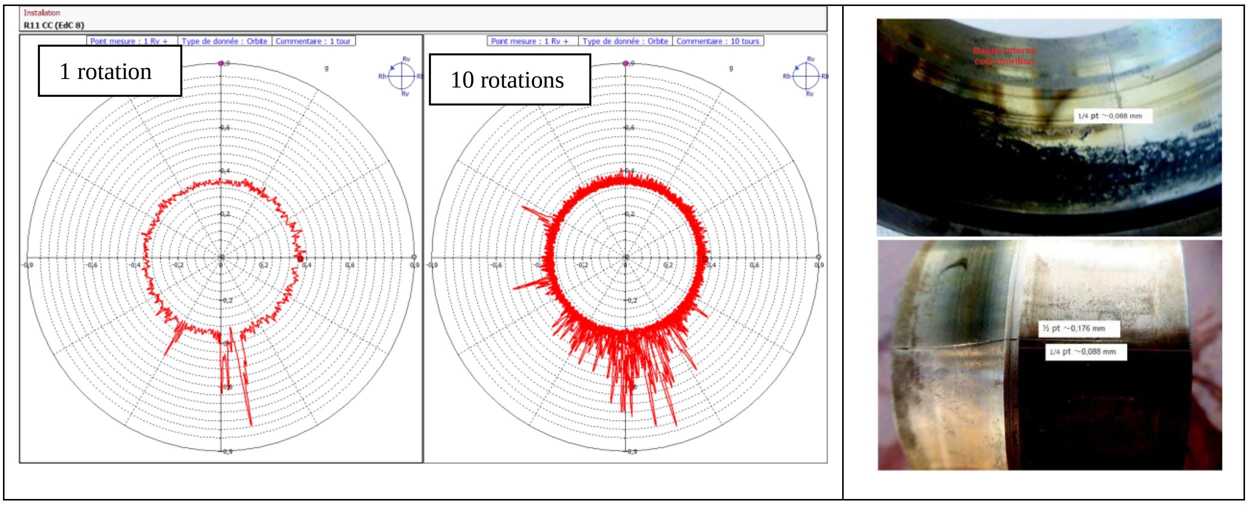


Figure 2: Polar diagram of the time envelope signal over 1 turn and 10 turns - Observation during disassembly

3 Conclusion

The method developed by EES-DYNAE seems promising for the diagnosis of bearing ring cracking. However, it requires advanced processing whose results must be interpreted by an expert. The capitalization of numerous feedbacks could eventually allow automating the procedure.