Rolling Bearing Quality Evaluation based on a Morphological Filter and a Kolmogorov Complexity Measure

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Bearing defective inspection plays a vital role in bearing quality control. Unlike signals in the process of condition monitoring and fault diagnosis, the signal characteristic of defective bearings is much weaker and difficult to be quantified through the acceleration based techniques. In this paper, a novel system is developed to inspect automatically the small defects of roller bearings for on-line quality control. Rather than using acceleration based techniques the system employs a high sensitive eddy current sensor to measure the displacement profiles of the outer race for high signal to noise ratio. Furthermore, a morphological filter is used to enhance the feature signal which is subsequently measured by Kolmogorov complexity measure. Both simulated signals and measured data show that this system is able to diagnose defects including abnormal surface roundness, waviness, misaligned races which are typical quality problems in bearing manufacturing lines.

1. Introduction

Bearings are important components in the industry of machinery. The quality of bearings can directly influence the performance of machines, and may even cause serious disasters. The traditional inspection measures can be classified into two steps to avoid possible defects during manufacturing process: material inspection and assembling inspection. The material inspection is mainly focused on defects on surface roundness, waviness, misaligned races and off-size elements caused by manufacturing error or abrasive wear. The assembling inspection is used to inspect the defects that are caused by assembling process using vibration tests. Currently, the quality evaluation of bearings in manufacture depends on inspectors’ skill. The manual activity of inspection is subjective, which cannot ensure a guarantee of quality. In addition, the traditional time-consuming inspection is quite a human waste. Therefore, a simple automatically inspecting the defects of bearings becomes an important issue, and the method should qualify either the material inspection or the assembling inspection.

Currently, the main bearing defects evaluation methods are using vibration acceleration sensors. The classification standard of bearings is based on the root mean square value (RMS) of vibration signals. NSK (NSK Company Limited in JAPAN) developed a series of NB (NB Company Limited in JAPAN) bearing inspection instruments to evaluate the bearing quality by measuring the peak and RMS value of bearing...
vibration signals in the frequency range from 1 kHz to 15 kHz. The RMS value can describe the average intensity of signals and cannot reflect the details of the bearing defects. In particular, the acceleration method cannot be used to trace to different defective sources such as g defects on surface roundness, waviness, misaligned races and off-size elements caused by manufacturing errors, abrasive wear and other quality related defects.

Unlike signals in the process of condition monitoring and fault diagnosis,\textsuperscript{2-5} the signal characteristics associating with defective bearings are extremely weak. It means that capturing such characteristics requires high performance measurement methods including both effective sensing methods and corresponding signal processing methods. Previously, a series of methods has been developed for extraction of weak signals in acceleration signals, which includes the stochastic resonance, the Morlet wavelet, the cyclic Wiener filter and envelope spectrum.\textsuperscript{6-9} In addition to the low signal to noise ratio (SNR) of the acceleration signals, these methods usually need high computational effort and difficult for online real-time implementation. Therefore, to reduce the high demand for signal processing and achieve more effective monitoring, the authors firstly select more effective sensors for obtaining signals with high signal to noise ratio (SNR) and subsequently develop more accurate analysis methods.

The eddy current displacement sensor is proposed more accurately than the vibration accelerometers, the signal of the eddy current displacement sensor has good signal-to-noise ratio, and the frequency of the signal is the frequency that the roller element passes by one point on the outer ring. T. Yamaguchi used the eddy current displacement sensor to measure the bearing wear directly.\textsuperscript{10} The eddy current displacement sensors can accurately obtain abnormal vibrations caused by tiny defects on rolling bearing components and different signals caused by different defects have different characteristics in surface displacements. As an time domain indicator, which is easy to be obtained, the Kolmogorov complexity measure has been found to be an effective tool for signal analysis and condition assessment in a bearing system.\textsuperscript{11-13} The Kolmogorov can be used to extract characteristics which are then used to evaluate bearing quality and to trace to sources including roundness, roughness, waviness and other indicators of quality defects. Morphology filter is an efficient signal processing tool which is also realized in the time domain.\textsuperscript{14} In this paper, the eddy current displacement sensor is used as the signal source, and the morphological filter and Kolmogorov complexity is used as the indicator for signal characteristics and hence for quality inspection.

The following content of the paper have five more sections. Section 2 proposed the fundamental theory that underlies the morphology filter and the Kolmogorov complexity, and followed by the simulation study in Section 3. the real case study is in Section 4. Conclusions are presented in Section 5.

2. Theoretical Background

2.1 Measuring bearing defects by means of the eddy current displacement sensor

Fig. 1(a) illustrates the working process of the eddy current sensor system which operates based on electromagnetic induction. During the rotation of rolling bearing, a series of small local elastic deformations occurs because of the periodic extrusion between the outer ring and balls on the local area of bearing. Those elastic deformations lead to the displacement changes between the outer ring and the probe of the sensor, and then the deformation can be picked up by the eddy current displacement sensor. Fig. 1(b) shows the signal obtained by the sensor. Clearly, the signal has good signal-to-noise ratio as the distinctive periodicity corresponds to the frequency that the roller element passes by one point on the outer ring. In addition, the peak of the signal represents the distance between the probe and the outer ring, i.e. the deformation of outer ring. Bearings with good quality or defect-free will show a smooth periodic waveform. However, bearings with different defects will exhibit different characteristics, typically with different burrs and impulsive responses added to the periodic fluctuation.

When defects appear on rolling elements and different raceways respectively, the displacement signal will present different waveform characteristics because of the different rotating frequencies of various components of bearing. Meanwhile, different precision problems such as surface roundness, waviness, and misaligned races will cause irregular changes to the waveforms, i.e., the amplitude and smooth degree of the signal will change. The smooth degree can be further evaluated by morphology filter and complexity. Therefore, the quality evaluation and traceability to problems can be made by detecting and identifying characteristics of the displacement signals.

2.2 Measuring bearing defects by means of the morphological filter

As mentioned above, bearings with different quality can be separated by characterizing the periodic impacts and burrs. Thus, a method to eliminate cosine-like trend is needed as shown in Fig. 1(b). Morphological filter is a time-domain nonlinear method, which is based on the match of the structure element and signals. Morphological filter is quite useful for the preprocessing of the signal complexity by eliminating the trend effectively. In this paper, the morphological filter is used to remove deterministic periodic signal corresponding to the elastic deformations in signals while keeping the periodic fluctuations