TELKOMNIKA Indonesian Journal of Electrical Engineering
Vol.12, No.3, March 2014, pp. 1875 ~ 1880
DOI: http://dx.doi.org/10.11591/telkomnika.v12i3.4122

Application of SPM to Detect the Wind Turbine Bearing Fault

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Abstract

With the widespread application of wind turbines, the Maintenance issue gets growing concern. Bearings play a critical role in industrial applications. It is necessary to effectively monitor their health status. The shock pulse method (SPM) can detect the incipient fault of bearings and prevent the fault consequence effectively. However, many researchers used laboratory data to validate the SPM. This paper mainly concentrates on the SPM application on bearing fault detection of wind turbines. Shock pulse signals are derived from the gearbox of industrial wind turbine test rig by SPM instrument. According to frequency spectrum analysis, the bearing fault has been accurately detected and located. The analysis results demonstrate that the SPM technology is potentially effective for detecting the bearing faults of industrial wind turbines.

Keywords: *SPM, bearing fault diagnosis, condition monitoring, spectrum analysis*

1. Introduction

Wind energy has become a new kind of green energy which is widely used. In China, wind energy has become the third largest electricity source until 2012. By now, the installed wind power capacity in China reaches 62.37 GW [1]. However, the current wind generation only represents 5% of the overall electricity market. It is anticipated that the cumulative wind power will grow steadily in the next two decades, and will reach 20-30% market share by 2033. Nevertheless, the high price of wind power will block its development eventually. For wind power, about 20-30% of the costs was spent on operations and maintenance of wind turbine [2]. Traditional maintenance strategies (corrective maintenance and time-based maintenance) are inefficient, wasteful of scarce resources, and very costly. So, innovative maintenance methods are required to control cost. Condition based maintenance (CBM) emerged as a new technology to supplement and enhance the conventional maintenance technique. In CBM, the health of wind turbine can be monitored and predicted based on the degradation information. Generally, early faults detection is critical to CBM implementation. Many researchers had investigated the fault diagnosis method of wind turbine gearbox. Ling et al [3] analyzed the remote fault diagnosis system used for monitoring fault occurrence and diagnosing fault, which is a combination of expert system and artificial neural networks. Feng [4] developed a study on the fault diagnosis method through the combination of decision classification algorithms and expert system. For bearing faults, the energy is often overwhelmed by noise and other structural vibrations (gear vibration). The most popular signal processing method for bearing fault detection is the envelope analysis [5]. Shock Pulse Method (SPM) [6] is a patented technique for using signals from rotating element bearings as the basis for efficient condition monitoring of machines. SPM dianositics reports not noly conditon of rotating bearings but also thickness of lubricating oil, that helps maintenance staff for performing effective preventive maintenance in proper timing [7]. Tandon et al [8] compared the vibration, stator current, acoustic emission and SPM for detecting a outrace defect of induction motor. The results showed that acoustic emission monitoring proved to be the best method and the second is the SPM. Li et al [9] combined the SPM with improved redundant lifting scheme to detect the bearing faults. Butler [10] has reported success of the shock pulse method in the detection of defects in low-speed spherical roller bearings in a paper production line. An on-line bearing condition monitoring

Received August 12, 2013; Revised September 25, 2013; Accepted October 12, 2013

technique based on the SPM has been suggested by Morando [11]. Huang et al [12] proposed neural networks based parameter self-modification strategy using for SPM.

However, many researchers used laboratory data to validate the SPM. For wind turbines, the gearbox structure is more complex than general parallel shaft gearboxes. So, the impulse signals are weak compared to other components. This paper mainly concentrates on the SPM application on bearing fault detection of wind turbines.

2. Wind Turbine Gearbox Experiment

In order to achieve the customer's demand, wind turbine maintenance center need to test the gearbox guaranteeing the gearbox condition indicators to satisfy the standard established by customer. However, technicians do not know the fault location when the condition indicators exceed the predefined threshold. Then, they disassemble the gearbox and inspect every component except the bearings to find the possible fault. They do not check the bearings because all the bearings are replaced by new spare parts. If the bearings are installed inappropriately, this will discount their useful lives and may lead to serious results. The vibration energies produced by bearings are relative small compared to the gears. So, it is very difficult to detect the incipient faults of bearings through the condition indicators provided by customer. In order to solve this problem, additional technology must be used to avoid short bearing life and save operational costs.

SPM can calculate shock value quantitatively. The shock value indicates the bearing condition and is proportional to the damage level. When the shock value exceeds the predefined threshold, the SPM instrument will give an alarm. Then, frequency spectrum analysis can be used to fix the fault location.

There are many condition monitoring tests every month. Except the condition indicators required by customer, SPM instrument was used to monitor the bearings condition. In some tests, bearing fault had been found but the condition indicators were normal. The wind turbine gearbox test rig can be illustrated as Figure 1.

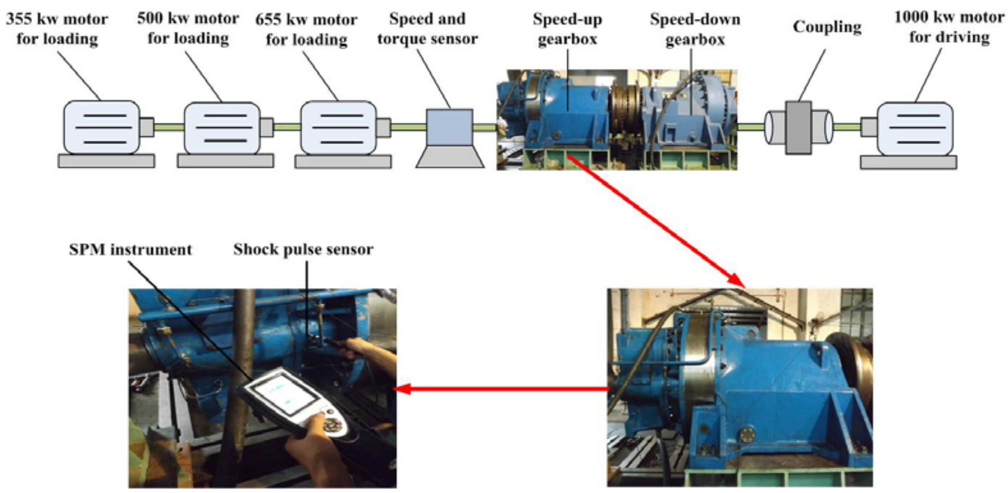

Figure 1. The Diagram of the Gearbox Test Rig of FL600 Wind Turbine

The test rig includes two gearboxes, one is speed-down gearbox, another is speed-up gearbox, a 1000kw motor is used for driving the gearboxes, three motors for loading with power 355kw, 500kw, 655kw respectively, and a speed and torque sensor for measuring the rotating speed and torque. The speed-up gearbox is the test gearbox. In the test gearbox, the ring gear is stationary, a sun gear rotates around a fixed center, and planet gears not only rotate around their own centers but also revolve around the center of the sun gear. The planet gears mesh simultaneously with both the sun gear and the ring gear. Figure 2 presents the structure of speed-up gearbox and measuring points of SPM instrument.

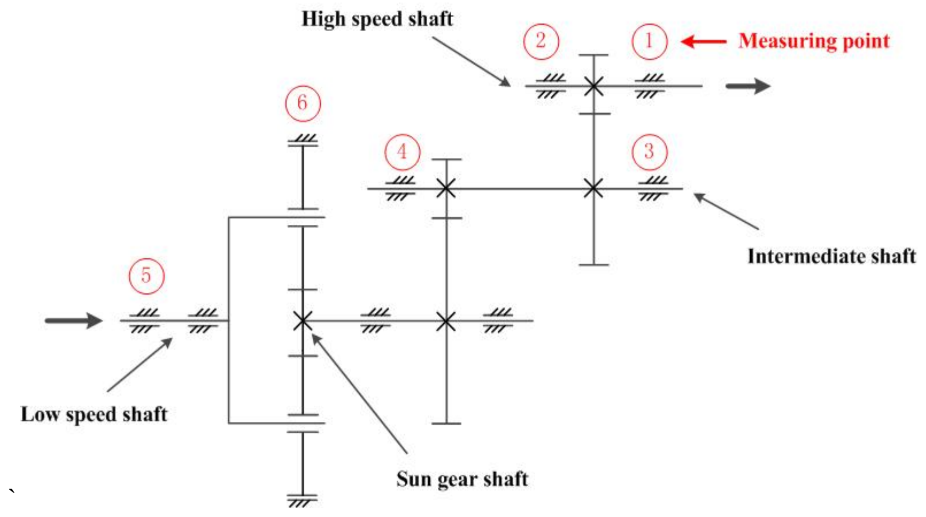

Figure 2. The Diagram of the Speed-up Gearbox and Measuring Points Location

As shown in Figure 2, the speed-up gearbox has four shafts, including low speed shaft and high speed shaft which are viewed as input and output shaft respectively, sun gear shaft and intermediate shaft. Planet gear is driven by low speed shaft, meshing with sun gear. Sun gear meshes with gear of intermediate shaft. Gear of high speed shaft also meshes with gear of intermediate shaft. The rotating speed of output shaft is 1517rpm. Table 1 lists the teeth number of the speed-up gearbox.

Table 1. Gear Parameters of Speed-up Gearbox

Gear	teeth	speed
Planet	48	26.8
Sun	21	176
SG(SG-IS)	67	176
IS(IS-SG)	20	590
IS(IS-HS)	54	590
HS	21	1517
Ring	117	0

SG (SG-IS) denotes the sun gear, meshing with the gear of intermediate shaft. IS (IS-SG) and IS (IS-HS) both indicate the gears of intermediate shaft, but the former is the gear meshing with sun gear and the latter is the one meshing with the gear of high speed shaft.

3. Results and Discussion

In this paper, SPM instrument is employed for monitoring the condition of bearings. Utilizing embedded SPM spectrum module and hand-held shock pulse sensor, data acquisition and processing are implemented. SPM instrument can create real-time frequency spectrum diagrams automatically. Moreover, SPM instrument can connect and communication with the software Condmaster, which can preserve the data and diagrams of frequency spectrum.

In this experiment, four working conditions are arranged according to the different load: 25%, 50%, 75%, and 100%. Six measuring points are chosen and diagrams of frequency spectrum in time variant working conditions are derived. In view of limited space, here we only list the frequency spectrum measured at the high speed shaft, namely measuring point 1 and 2, as depicted in Figure 3 to Figure 6.

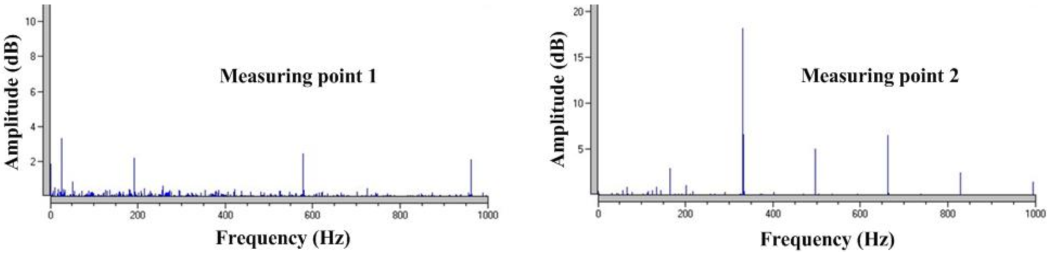

Figure 3. The Diagram of Frequency Spectrum with 25% Load

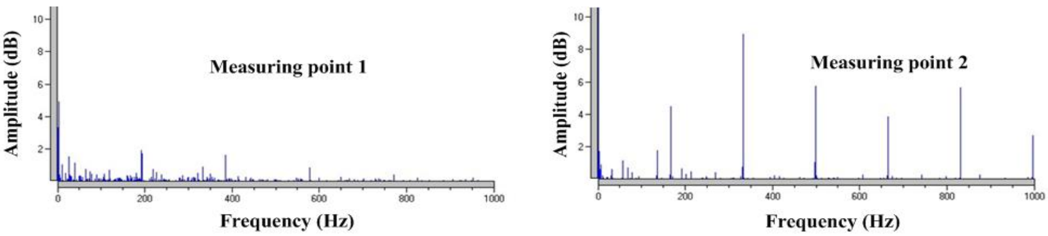

Figure 4. The Diagram of Frequency Spectrum with 50% Load

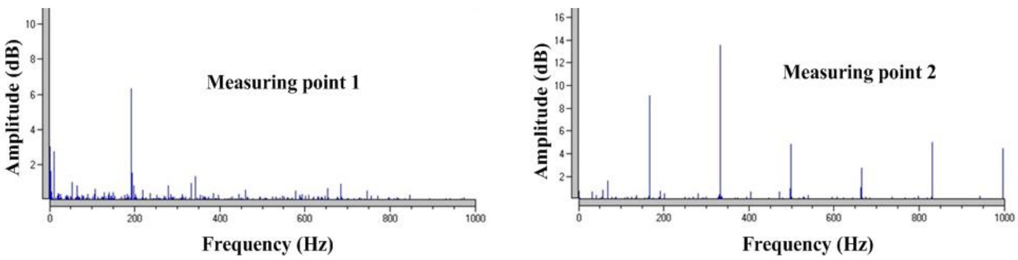

Figure 5. The Diagram of Frequency Spectrum with 75% Load

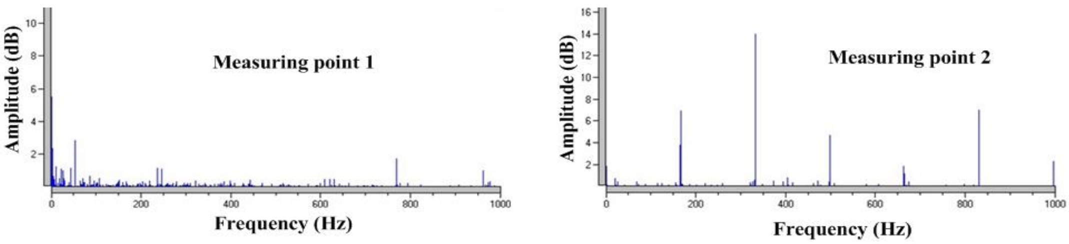

Figure 6. The Diagram of Frequency Spectrum with 100% Load

For the measuring point 1, spectral lines are relatively gentle and do not exist repeated peak value. In other words, there is not obvious fault character. However, fault character can be found at the measuring point 2. The spectral peaks appear five times and the spacing is equal.

As we all known, the purpose of spectrum is to reveal line patterns associated with bearing faults. Characteristic for many fault patterns is the presence of 'multiples' or 'harmonics', which means that the line (or group of lines) is repeated two, three or more times further up in the spectrum. The spacing is 1Z, 2Z, 3Z, ..., nZ, where Z is the frequency of the first line. Based on this theory, we can draw a preliminary conclusion that bearing at measuring point 2 is faulty.

In above theoretical analysis, we diagnose the faulty bearing at a certain extent, but cannot locate explicitly. To address this issue, the characteristic frequency of each element in the faulty bearing will be calculated.

Table 2. Characteristic Frequency of Bearing in High Speed Shaft Input End (HZ)

Position	characteristic frequency
Outer race	6.59
Inner race	9.41
Rolling element	2.68
Cage	0.412

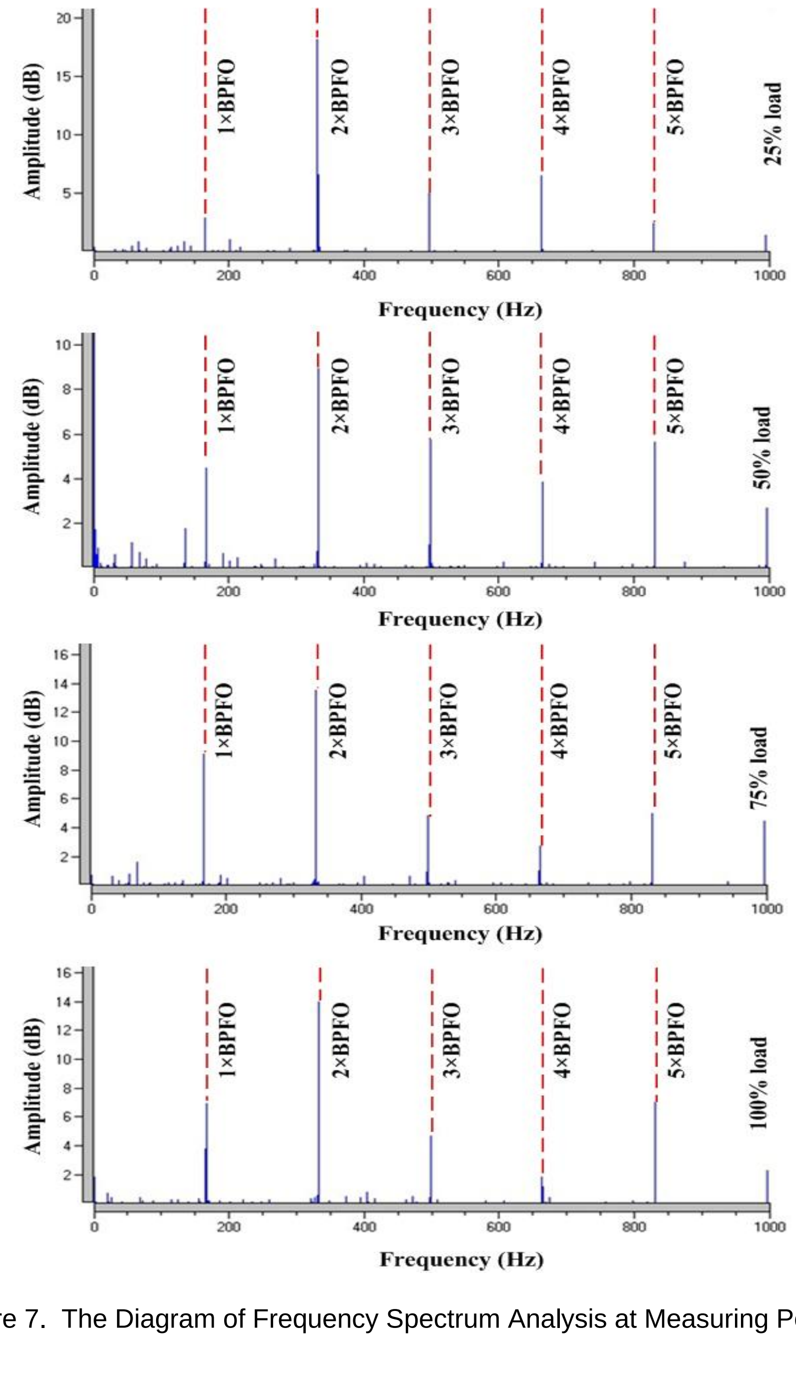

Figure 7. The Diagram of Frequency Spectrum Analysis at Measuring Point 2

According to the recorded speed of output shaft (1517rpm), the speed of faulty bearing is approximate 25.28HZ. In the spectrum diagrams at measuring point 2, spectral peaks appear five times with equal spacing. The frequency of peak value occurring for the first time is 166.25HZ. So we can derive the characteristic frequency of faulty position is 6.58HZ. In contrast with Table 2, the most approximate frequency is 6.59HZ, the characteristic frequency of outer race. Therefore, the diagnosis result is faulty outer race. We label the spectral peaks in terms of the characteristic frequency in the spectrum at measuring point 2. Figure 7 shows the analysis results.

From the maintenance record of industry, we know that bearings in the test gearbox have been replaced with new ones during the overhaul period. However, there still exists faulty outer race in high speed shaft. Since the bearings are used for the first time, the common faults like fatigue, wear, corrosion etc. are not existent, so there is more likely that assembly errors lead to the faulty outer race. When opening the test gearbox, we found assembly errors indeed exist, which is consistent with the analysis result. Accordingly, we suggest reassembling to avoid the further fault.

4. Conclusion

Considering the difficulty in detecting incipient faults of bearings in wind turbine planetary gearboxes, SPM technology has been used to detect and locate the bearing faults. The principle and the effectiveness of SPM have been illustrated by analyzing the frequency spectrum of a planetary gearbox in the wind turbine test rig. According to frequency spectrum analysis, the bearing faults can be accurately detected and located. The analysis results demonstrate that the SPM technology is more effective for detecting the bearing faults.

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