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Research on Operating Condition Effect on the Shock Pulse Method

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Abstract

Rolling bearings are one of the most widely used elements in industrial applications. Shock pulse method (SPM) has proven successfully as a diagnostic tool in determining bearing health. On the basis of illustrating the principle of SPM, this paper mainly concentrates on investigating the effect of different operating conditions on SPM. The shock pulse signals are derived from the wind turbine gearbox test rig by SPM instrument. Through comparing the slope of dB values when the rotating speed or load changes, effect of operating conditions on SPM is analyzed. The analysis results show that SPM is more sensitive to the rotating speed in contrast with the load.

Keywords: *shock pulse method, condition monitoring, bearing fault diagnosis, operating condition*

1. Introduction

Wind energy is the fastest growing renewable form of energy source in the world. However, high maintenance cost of wind turbines seriously hampers its development. As basic components of gearboxes in drive trains, rolling bearings are widely used in wind turbines. In industrial applications, bearings are considered as critical mechanical components and one defect may lead to catastrophic failure of the wind turbines and result in major economic losses.

Condition monitoring is an effective way to detect the defects and prevent the failures of bearings. Many researchers had researched the diagnosis method of bearings [1-4]. A review of vibration and acoustic measurement methods for the detection in rolling bearings is presented for bearings condition monitoring by Tandon and Choudhury [5].

Shock pulse method (SPM) has been widely used as a quantitative method for bearings condition monitoring [6]. SPM is derived from SPM instrument which developed and patented in the early 70's in Sweden [7]. Through years of testing and researching, SPM has been developed and perfected so as to represent the "true" operating condition of the bearing being monitored [8-12].

SPM can provide a direct shock value indicating the bearing condition [13]. By collecting the shock values under different operating conditions, the trend of shock values can be analyzed to predict the operating condition of bearings being tested. In this paper, we mainly investigate the effect of rotating speed and load on the SPM, whichhas not been researched. The shock pulse signals are obtained by SPM instrument from two experiments under different operating conditions.

The structure of this paper is organized as follows. In Section 2, the theories of SPM are illustrated briefly. The assessment parameters of SPM are discussed. In Section 3, the experiments are introduced. In Section 4, the experimental results are analyzed. Section 5 discusses the analysis results and conclusions are given in Section 6.

2. The Thories of SPM

SPM is the monitoring and analyzation of high frequency shock waves generated by a bearing while rotating. When rolling element contacts with a damaged area of raceway in the

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rotating bearing, high frequency shock waves are generated in the interface between the rolling element and the raceway. The shock waves, which present non-continuous pulses, are transferred to the bearing housing through the inner material of bearing. The signals of shock waves are received by the shock pulse sensors which are placed on the bearing housing. The way these signals are separated is really what makes this technology unique. Unlike vibration analysis that monitors a broad vibration band and then tries to isolate unique frequencies, SPM has developed a means to only "look" at the high frequency signals of rotating bearings. The shock pulse sensors are also different from other vibration sensors and operate at their resonance frequency of 32kHz. Accordingly the resulting bearing signals are strongest. The shock pulses will cause the damped oscillation of the sensors at their natural frequency [5]. The amplitude of these signals is proportional to the damage level of the bearings. Then the band-pass filter can filter the mechanical interference near the bearing and only let the high frequency component pass. The resulting high frequency signals pass through the amplifier and then after envelope demodulation [14], the shock values indicating the bearing condition can be derived.

The absolute shock pulse level of a bearing, measured in dB_{sv}, is both a function of rolling speed and of bearing condition. To neutralize the effect of rolling speed on the measured value, SPM then calculate the initial value dB_i, the starting point of the condition scale for a particular bearing. The dB_i value depends on the size of inner race and rotating speed, which is defined as [6]:

$$dB_i = 20(lg\, N + 0.6\, lg\, D - lg\, 2150) \tag{1}$$

Where Ndenotes the rotating speed of the bearing, $D$is the inner diameter.

The condition scale is graded in normalized shock value, dB_n, which is defined as:

$$dBn = 20\, lg \frac{2000SV}{ND^{0.6}} \tag{2}$$

WhereSVdenotes the shock value.

SPM can sample the shock pulse amplitude over a period of time and displays: (1) The maximum value dB_m for the small number of strong shock pulses. (2) The carpet value $dB_c$for the large number of weaker shock pulses.

The maximum value dB_m defines the bearing's position on the condition scale. The difference between dB_m and dB_c is used for analysis of the causes for reduced or bad condition. This method is used for comparative reading on different bearings.

The major benefit of SPM is providing a direct indication of bearing condition on a Green-Yellow-Red scale. Green means a good bearing, Yellow is a bearing with early damage and Red is more severe damage. This is very important when monitoring installed bearings on machines for which there are no trends or comparable readings. These parameters for evaluating the bearing condition can be illustrated as Figure 1.

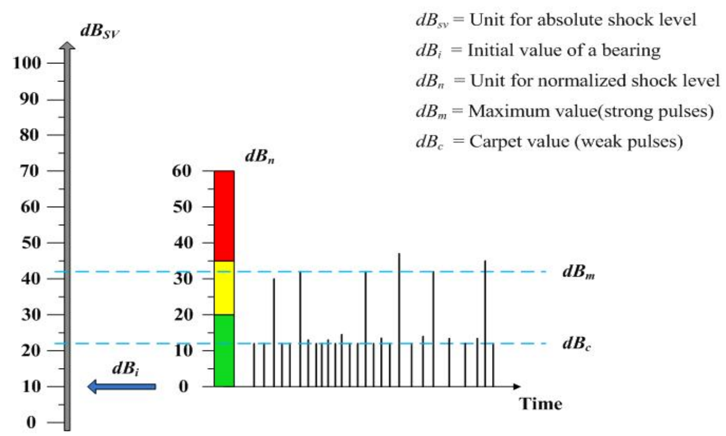

Figure 1. The Diagram of Parameters for Evaluating the Bearing Condition

3. Wind Turbine Gearbox Experiment

Figure 2 shows the wind turbine test rig used for data collection. 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. The inner structure of the test gearbox and measuring points of SPM sensor are depicted as Figure 3.

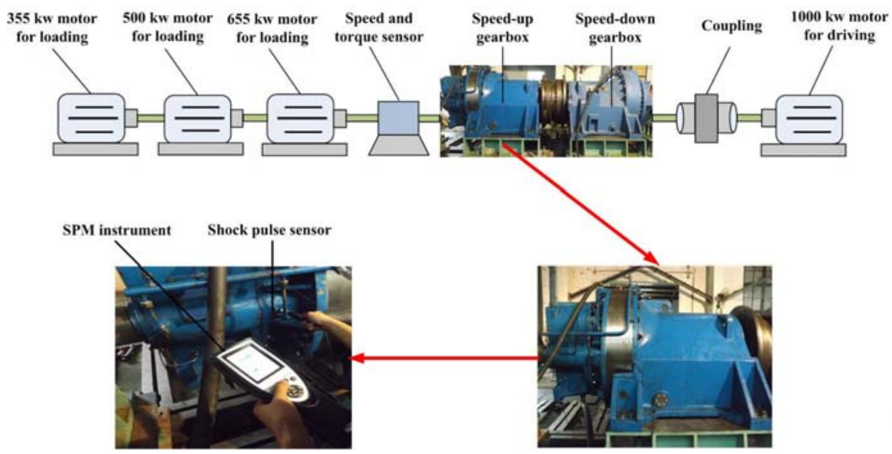

Figure 2. The Diagram of the Gearbox Test Rig of FL600 Wind Turbine

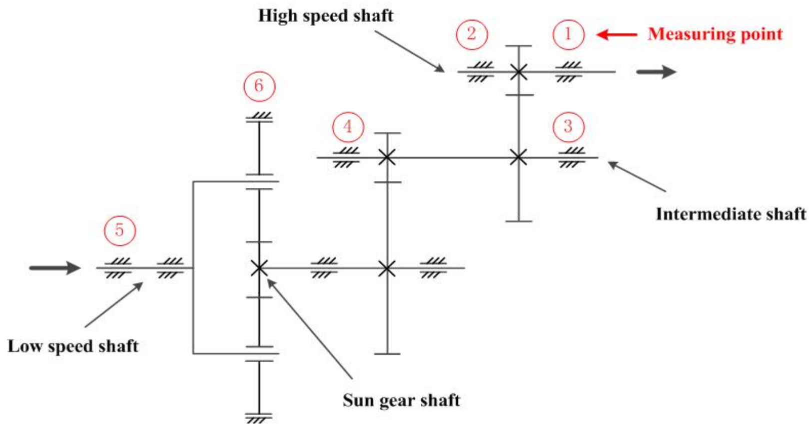

Figure 3. The Diagram of the Test Gearbox and Measuring Points Location

As shown in Figure 3, the test 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.

In this paper, we arranged two experiments. The first is no load experiment but the speed increases from 500 rpm to 1517rpm with an increment of 250 rpm. The second experiment is the constant speed at 1517rpm and five different load levels: 0, 25%, 50%, 75%, and 100%. In each experiment, six measuring points (as shown in Figure 3) are chosen.

4. Experimental Results

The values of *dBm* and *dBc* at each measuring point under different working conditions are derived by SPM instrument. Figure 4-9 show the experimental results at different measuring points.

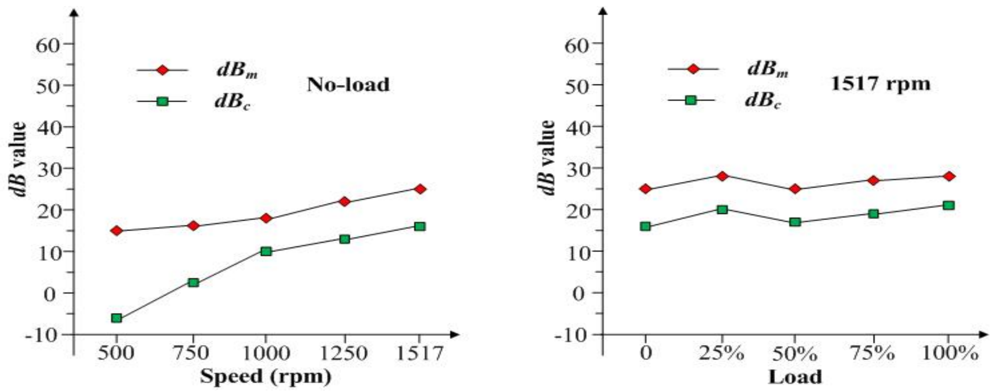

Figure 4. The Diagram of *dB* Values at the Measuring Point 1

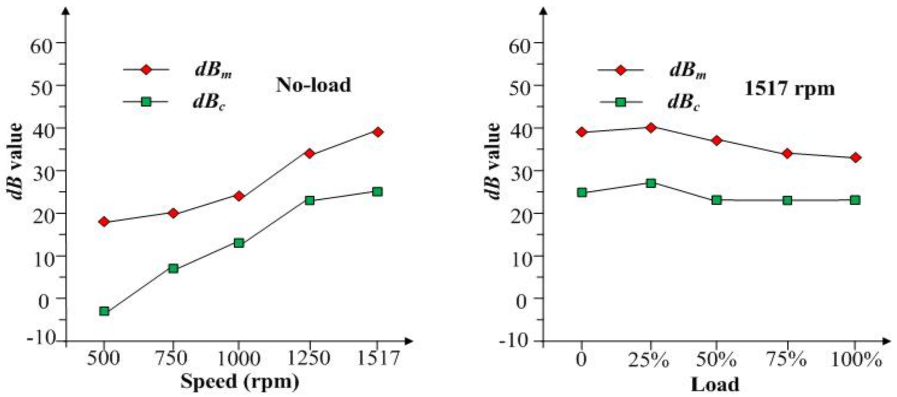

Figure 5. The Diagram of *dB* Values at the Measuring Point 2

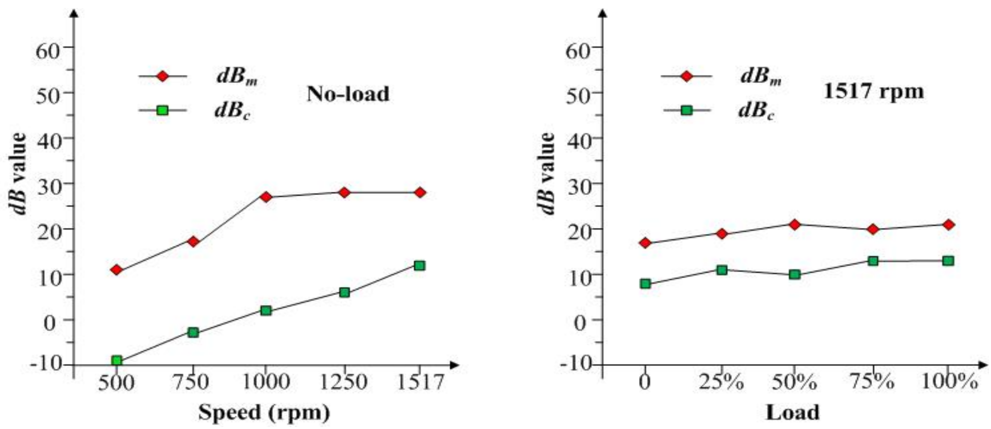

Figure 6. The Diagram of *dB* Values at the Measuring Point 3

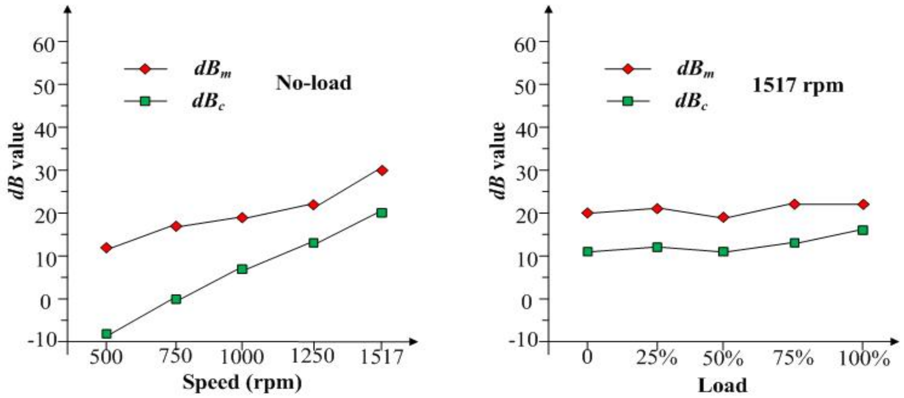

Figure 7. The Diagram of *dB* Values at the Measuring Point 4

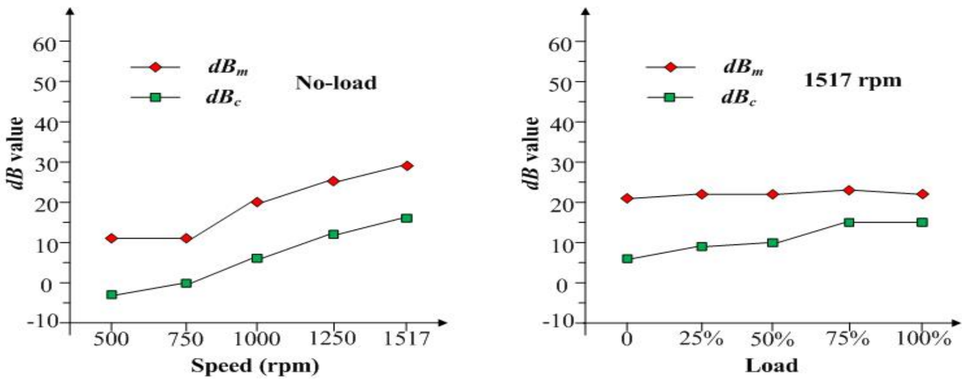

Figure 8. The Diagram of *dB* Values at the Measuring Point 5

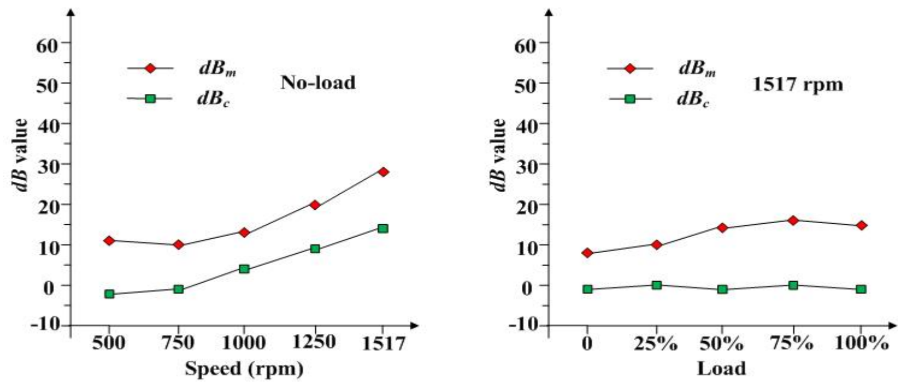

Figure 9. The Diagram of *dB* Values at the Measuring Point 6

According to Figure 4-9, the values of dB_m and dB_c change obviously with the increasing speed. However, when the load is increasing, the change of dB_m and dB_c values is not evident. In order to quantitatively explain this problem, normalization processing of horizontal ordinate is implemented and the slope of the *dB* values at each measuring point under different speed and load is calculated. Table 1 and Table 2 present the results.

Through comparison of the slope, analysis result showsthat the rotating speed has a greater impact on the *dB* values than load. Therefore, SPM is more sensitive to the rotating speed in contrast with load.

Table 1. The Slope of *dB* Values with No-load and Changing Speed

Measuring point	Slope	
	dB_m	dB_c
1	15	33
2	31.5	42
3	25.5	31.5
4	27	42
5	27	28.5
6	25.5	24

Table 2. The Slope of *dB* Values with Constant Speed and Changing Load

Measuring point	Slope	
	dB_m	dB_c
1	3	5
2	-6	-2
3	4	5
4	2	5
5	1	9
6	7	0

5. Discussions

Rotating speed and load are both the basic data of operating conditions in bearings. But according to analysis result, in contrast with the load, SPM are more sensitive to the rotating speed.

As mentioned earlier, SPM needs the rotating speed and inner diameter as input data. Then initial value dB_i, which depends on the speed and inner diameter, can be calculated to obtain the normalized shock value dB_n. The dB_n can indicate the bearing condition and dB_m and dB_c values are derived based on the dB_n. Therefore, the SPM can become a quantitative method for detecting the defects of bearings.

Obviously, the two input data which SPM needs are irrelevant to the load, but are closely related to the rotating speed. Therefore, the analysis result that SPM is more sensitive to rotating speed than load is explainable.

6. Conclusion

The use of shock pulse techniques has proven remarkably successful as a quantitative method for bearing condition monitoring. The principle of shock pulse method and assessment parameters of SPM are illustrated. This paper mainly concentrates on investigating the effect of operating condition on SPM through comparing the dB values when the rotating speed or load changes. The analysis result shows that SPM is more sensitive to the rotating speed in contrast with the load.

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