Evaluation of the Variation Process of Bearing Vibration Based on Non-ordered Gray Relation (Part II: Experiment)

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Abstract. In order to analyze the process of bearing vibration variation, the original vibration data of four kinds of damage diameters are grouped, and the intrinsic data sequence is selected after grouping. Then, the non-ordered gray relation between data sequence of different groups and the intrinsic data sequence is established and the gray confidence level is obtained. The gray confidence level is compared with the set threshold of 90%. Then the variation of the bearing vibration is evaluated. The correctness and feasibility of the proposed method are verified by comparing the assessment with the actual situation.

Introduction

During the service period of bearings, the vibration performance of the bearing decreases gradually with time due to the loss of the constituent element, the movement of the auxiliary sub-gap or the friction, that is, the vibration variation[1]. Rolling bearings as the important implementation of components and wearing parts of a mechanical transmission system, the health condition of its performance is of great significance to maintain the stable operation of the system[2]. For example, the bearing fatigue life, friction torque, vibration and noise and other performances will directly affect operation status of the host[3]. Vibration variation means that the bearing damage occurred and its sustainable development will inevitably lead to functional failure of the host, resulting in huge losses or even disaster. In order to avoid serious disaster, bearing vibration variation evaluation is very important. Therefore, the evaluation of bearing vibration variation process has aroused great concern of scholars at home and abroad.

L.D. Chen proposed creatively the use of atomic absorption spectrometry to determine bearing abnormal sound failure of car engine crankshaft[4]. Based on the derivation of bearing failure model of subway vehicle bogie, J.Q. Liu proposed a intelligent method for fault diagnosis of subway vehicle bogie[5]. EL Morsy used the optimal morlet wavelet filtering and envelope detection to analyze the experimental signals of the inner ring failure of rolling bearing[6]. Uddin S proposed a K-NN classification algorithm which can improve performance in bearing fault diagnosis[7].

The existing method of bearing vibration variation is largely presumed that the probability distribution is known, that is, the data obeys a particular distribution. However, during the service of the bearing, the probability distribution of the vibration sample data is unknown and belongs to the problem of poor information category[8]. Poor information is also called lack of information and the research object presents incomplete feature information, lack of a priori information. Gray system theory, fuzzy set theory, chaos theory and so on can be attributed to the poor information system theory. For example, in the mechanical system assessment, the overall probability distribution is unknown or the probability distribution is complex, and only the small sample data is available for reference, which belongs to the poor information problem[9-10]. In this paper, the non-ordering gray relation in the gray system theory is applied to the evaluation of the vibration variation process of the bearing. The vibration data are grouped and the intrinsic data sequence is selected to calculate the
gray confidence level. By comparing the obtained gray confidence level with the set threshold of 90%, the dynamic evaluation of the bearing vibration variation process is finally realized.

**Experimental Process**

This is a case where the variation of bearing vibration is caused by wear from the surface of the channel. The test data comes from the bearing data center website at the University of Case Western Reserve, which has a dedicated rolling bearing failure simulation test stand. The test bed consists of an electric motor, a torque sensor/ decoder and a power tester. SKF6205 bearings supported the rotation of the motor shaft can be tested. The acceleration of the bearing is measured with an acceleration sensor. Bearing speed is 1797r/min and the sampling frequency is 12kHz. The bearing inner ring channel damage diameter is set respectively to $d_1=0\text{mm}$, $d_2=0.1778\text{mm}$, $d_3=0.5338\text{mm}$ and $d_4=0.7112\text{mm}$. The bearing vibration acceleration signal data sequences obtained by the acceleration sensor are shown in Figures 1 to 4.

The data sequence $X_1$ is divided into four groups of $\omega_1$~$\omega_4$ and each group of has 400 data, that is, $\omega_1=1$~$400$, $\omega_2=401$~$800$, $\omega_3=801$~$1200$, $\omega_4=1201$~$1600$. Then set $\omega_1=1$~$400$ as the intrinsic data sequence, the gray confidence level $P_{12}$, $P_{13}$, $P_{14}$ of the other three groups relative to the intrinsic data sequence can be calculated. Similarly, for the data sequence $X_2$~$X_4$, the gray confidence level $P_{12}$, $P_{13}$, $P_{14}$ relative to the intrinsic data sequence can be obtained as shown in Table 1.

<table>
<thead>
<tr>
<th>Data sequence</th>
<th>The gray confidence level</th>
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<tbody>
<tr>
<td>$X_1$ $(d_1=0.0000\text{mm})$</td>
<td>$P_{12}$: 0.9847, $P_{13}$: 0.9941, $P_{14}$: 0.9681</td>
</tr>
<tr>
<td>$X_2$ $(d_2=0.1778\text{mm})$</td>
<td>$P_{12}$: 0.9823, $P_{13}$: 0.9908, $P_{14}$: 0.9805</td>
</tr>
<tr>
<td>$X_3$ $(d_3=0.5338\text{mm})$</td>
<td>$P_{12}$: 0.9730, $P_{13}$: 0.9830, $P_{14}$: 0.9669</td>
</tr>
<tr>
<td>$X_4$ $(d_4=0.7112\text{mm})$</td>
<td>$P_{12}$: 0.9812, $P_{13}$: 0.9728, $P_{14}$: 0.9743</td>
</tr>
</tbody>
</table>

For the data sequence $X_1$~$X_4$, $\omega_1=1$~$400$ is the intrinsic data sequence. From Table 1, the gray confidence levels of $\omega_2$, $\omega_3$, $\omega_4$ relative to $\omega_1$ are greater than 0.9, that is, bearing vibration variation does not occur, which is consistent with the fact that the bearing vibration under the same damage diameter will not occur. Thus the feasibility of the proposed method is verified.

Through Figure 1 to 4, the larger the damage diameter of the bearing groove surface is, the more intense bearing vibration is and the greater the probability of variation is. In order to simulate the four
damage diameters as the amount of damage produced by the operation of bearing through the four time intervals, the four damage diameter data needs to be grouped and reorganized. Through the operation of four time intervals, bearing vibration variation really happened. In order to simulate the amount of damage produced by the operation of bearing through the four time intervals, the specific approach is as follows. Respectively, taking $\omega_1=1$~$400$ of the data sequence $X_1$~$X_4$, a new data sequence $X_1'$ is formed by connecting them in turn. Similarly, respectively, taking $\omega_2=401$~$800$ of the data sequence $X_1$~$X_4$, $X_2'$ is also formed by connecting them in turn. And so on, $X_3'$ and $X_4'$ is also formed. $X_1'$~$X_4'$ are shown in Figure 5 to 8.

The data sequence $X_1'$ is divided into four groups of $\omega_1$~$\omega_4$ and each group of has 400 data, that is, $\omega_1=1$~$400$, $\omega_2=401$~$800$, $\omega_3=801$~$1200$, $\omega_4=1201$~$1600$. Then set $\omega_1=1$~$400$ as the intrinsic data sequence, the gray confidence level $P_{12}, P_{13}, P_{14}$ of the other three groups relative to the intrinsic data sequence can be calculated. Similarly, for the data sequence $X_1'$~$X_4'$, the gray confidence level $P_{12}, P_{13}, P_{14}$ relative to the intrinsic data sequence can be obtained as shown in Table 2. $X_1'$~$X_4'$ are vibration signal data of the amount of damage produced by the operation of bearing through the four time intervals.

<table>
<thead>
<tr>
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<tbody>
<tr>
<td></td>
<td>$P_{12}$</td>
</tr>
<tr>
<td>$X_1'$</td>
<td>0.7730</td>
</tr>
<tr>
<td>$X_2'$</td>
<td>0.7865</td>
</tr>
<tr>
<td>$X_3'$</td>
<td>0.7385</td>
</tr>
<tr>
<td>$X_4'$</td>
<td>0.7455</td>
</tr>
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</table>

According to Table 2, the change curve of gray confidence level of data sequence $X_1'$~$X_4'$ with the damage diameter increases is shown in Figure 9.
In order to eliminate the influence of random error, $P_{12}$, $P_{13}$, $P_{14}$ corresponding to $X_1 \sim X_4$ are averaged to obtain new gray confidence levels. Then the change curve of new gray confidence level with the damage diameter increases is shown in Figure 10.

![Figure 9. The change curve of gray confidence level of $X_1 \sim X_4$.](image)

From the Figure 10, with the increase of damage diameter, the gray confidence level is getting smaller and less than 0.9, which indicates that the vibration variation of bearing through the four time intervals has already occurred. According to the increasingly small gray confidence level, the malignant factor is increasing and eventually leads to the increasing possibilities of bearing vibration variation. With the increase of damage diameter, gray confidence level curve was like an inverted chair and divided into three stages. When the damage diameter gradually increases from 0, the gray confidence level drops faster, belonging to the first stage. When the damage diameter continues to increase, the gray confidence level decreases slowly, belonging to the second stage. When the amount of damage exceeds a certain value, the gray confidence level began to decline faster, belonging to the third stage. These are consistent with the actual situation. From the bearing service, vibration performance variation occurred continuously and generally experienced three stages, the initial run-in stage, performance degradation stage and performance deterioration stage. In the initial run-in stage, the degree of wear is gradually increased and the variation of vibration performance is significant. The stage of vibration performance degradation experiences a longer time and the vibration performance variation is not significant. In the stage of deterioration of vibration performance, the degree of wear began to increase gradually and the degree of vibration variation began to be significant.

**Summary**

Based on the non-ordered gray relation, the method of evaluating the variation of bearing vibration performance is proposed. The feasibility and correctness of the proposed method are experimentally verified. And the analytical model can analyze the bearing vibration performance variation process without sample probability density function and any prior information, which avoids the huge losses...
or even disaster caused by the bearings failure and provides scientific decision-making. This analysis method is also a useful complement to the existing bearing fault diagnosis theory.

**Acknowledgement**

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**References**


