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The influence of bearing stiffness and gear helix angle on the vibration noise of reducer[1]

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Abstract. With the rapid development of China's current mechanical technology, the traditional reducer has been difficult to adapt to the requirements of the development in the times because its vibration noise was too large. The effect of bearing stiffness and gear helix angle on the vibration and noise of the gear reducer was studied in this paper. The meaning of the vibration and noise of the gear reduce was introduced firstly, and then the application of the bearing stiffness and the diagnosis of the spiral angle of the gear were conducted expedition in this paper. Finally, the research process of bearing stiffness and gear helix angle on the vibration and noise of gear reducer was studied in detail. The experimental results showed that the effect of bearing stiffness and gear helix angle on the vibration and noise of gear reducer had the advantage of reducing noise, which can be used to reduce noise.

Key words. Reducer vibration, bearing stiffness, gear spiral angle, noise reduction.

1. Introduction

With a large number of applications of large scale integrated bearing and gear, the mechanical structure was developing in two directions. Study on the noise reduction of vibration and noise reduction by using modern mechanical technology was one of the key problems that need to be solved in real life [1]. According to statistics, the reliability of the reducer part determined whether the whole hybrid system was reliable in the bearing and gear, so the demand for the reliability of the reducer was more urgent. And the noise was one of the important factors that affected the stability of the reducer, and a series of problems in the vibration noise have been paid more and more attention [2]. The noise caused by the vibration of industrial facilities will not only cause noise pollution in residential areas, but also affected

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the stability of the operating equipment and operator comfort. Therefore, the noise reduction of speed reducer was concerned by people widely. The development of the bearing was introduced firstly, and then the application of the bearing stiffness and the spiral angle diagnosis of the gear was conducted expedition in this paper. Finally, the research process of bearing stiffness and gear helix angle on the vibration and noise of gear reducer was studied in detail [3]. The experimental results showed that the effect of bearing stiffness and gear helix angle on the vibration and noise of gear reducer had the advantage of reducing noise, which can be used to reduce noise.

2. State of the art

Many foreign experts have long been concerned about the bearing stiffness and the spiral angle of the gear on the vibration noise of the gear reducer [4]. Berkowitz proposed the concept of the noise reduction of the bearing reducer firstly in 1962, which opened the prelude of the research on the noise reduction of the simulation speed reducer [5]. Navid demonstrated that the value of the part of the linear reluctance bearing can be solved in 1979, and the simulation of the vibration of the bearing reducer was developed [6]. Researchers have been working to address all component values to determine the speed reducer vibration area and related components since 1980s. The simulation of bearing reducer vibration developed to more direction since then. For large-scale integrated bearings, Salama proposed a network based decomposition of network level reducer vibration noise reduction method in 1984 and the condition was that the network between the associated nodes was controllable and pull all the associated nodes. Because the method was based on the KCL equation, the computation was large and the noise reduction was slow with its limited application. The development of artificial intelligence information processing technology provided a reliable tool to solve the problem of vibration and noise reduction. Gear system had the advantages of high efficiency, compact structure and stable transmission ratio, which was used in various industrial fields widely. The gear box shell can generate vibration and radiated noise in the process of transmission due to the inevitable meshing stiffness and error excitation. Domestic and foreign scholars have conducted a lot of research. Kevin Gerner and others used the method of sound and solid coupling to analyze the sound radiation of the simple gear box structure under the excitation of time varying stiffness. Researches on vibration and noise radiation of gearbox were analyzed by using FEM/BEM method, and they made a comparison with the test results, which demonstrated the effectiveness of the FEM/BEM method. The main excitation components and prediction methods of the vibration noise of the reducer were analyzed by Kevin and Jim, and the vibration and noise reduction method were proposed from the aspects of the geometry of the gear and the stiffness of the gear box. Lin Tengjiao conducted the comprehensive consideration of the internal excitation of the gear system and analyzed the dynamic characteristics of the marine gear box under the rated conditions. Sairui Connor believed on reducer noise radiation was not only affected by the meshing performance of gears, but also had a certain relationship with the inherent characteristics of box, and the experiment analyzed the influence of gear reducer noise radiation. The dynamic response of the gear box was analyzed by Kylie in the method of finite element, and the influence of different bearing connection form and stiffness on the dynamic response was analyzed in the analysis model. The FEM/BEM method was used to calculate the vibration and noise of the gear box and the dynamic characteristics of the dynamic characteristic of the transmission system were considered synthetically. The influence of the bearing support stiffness and the helical angle of the gear on the dynamic excitation and vibration noise of the gear reducer were analyzed. The front end and the top of the bevel gear reducer were weakened obviously, especially at the top of the noise reduction. However, the noise on both sides increased due to the helical gear produced axial excitation.

3. Methodology

3.1. Reducer vibration noise wave changing

The vibration noise of reducer was analyzed, and the result of the decomposition function and the coefficient of the vibration noise of the gear reducer were observed in this paper. We knew that the vibration and noise of the complex periodic reducer can be decomposed into sine function and Fourier series as well as the Fu Liye transform corresponding to the Fu Liye series coefficient. Similarly, noise reducer vibration wave of vibration and noise signal can also be expressed as a set of tree structure. Coefficient of vibration and noise wave transformation of reducer corresponded coefficient of vibration noise of gear reducer. Multi scale decomposition was based on multi-resolution analysis theory and the length of the decomposition coefficient was smaller (by half the ratio) with the larger scale decomposition. We also found that the low frequency coefficient of the vibration noise of the gear reducer was similar to the low frequency coefficients of the original reducer vibration noise wave signal. However, it was noted that the value and length of the low frequency coefficient are not the same as the original reducer's vibration and reconstruction of the reducer vibration noise wave signal. The decomposition process of the vibration and noise of the gear reducer was as follows: Specific process can be designed for high pass filter and low pass filter to obtain high frequency coefficients and low frequency coefficients, and the length of each decomposition of the data halved. Speed reducer vibration and noise wave transform were used to increase the sampling frequency for the inverse of the decomposition process. And zero was inserted in each of the two numbers in order to make a convolution with the conjugate filter, and finally the sum of the convolution results was obtained. We often used the coefficient of each layer to rebuild the gear reducer noise wave signal (noting that although the number of coefficients was smaller than the original gear vibration noise signal, but after the length was same in the reconstruction), and it viewed time of each band domain selectively in the application so as to determine the frequency range of shock component. We regarded it as a reducer vibration noise signal through a series of different types of filters in order to obtain the gear reducer noise wave signals of different frequency range, and the gearbox vibration noise signal was decomposed into wave reducer vibration noise wave decomposition and used coefficients of each layer to the reconstruction of gearbox vibration noise wave signal. The important applications of noise reduction and noise reduction were two important applications in the analysis of vibration and noise. The original reducer vibration noise wave signal can be decomposed into a series of approximate components and detail components by using the analysis of vibration and noise. Reducer vibration noise signal noise concentrated in the reducer vibration noise signal of the details of the signal mainly. Speed reducer vibration noise wave reconstruction can be used to smooth gear vibration noise signal after the use of a specific threshold to deal with the details of the component. The commonly used functions of reducer vibration noise wave can be used to deal with the engineering drawings of bearings. Its process was as follows: The engineering image processing of two-dimensional bearing was consistent with the one dimensional vibration and noise wave signal processing, but some formulas were not the same. The basis function formula was as follows in the engineering image of two dimensional bearing:

$$f[x,y] = \cos\left[\frac{(2x+1)u\pi}{16}\right]\cos\left[\frac{(2y+1)v\pi}{16}\right]. \tag{1}$$

In the formula, x and y refer to the pixel in the spatial domain (corresponding to one dimensional time domain) coordinates, and u and v are the coordinates in the basis function frequency domain. The basis function formula was based on the 8×8 block and value range of x, y, u, v is $\langle 0 - 7\rangle$. The low frequency information was concentrated in the upper left corner of the matrix, and the high frequency information was concentrated on the lower right corner after the vibration of the bearing of the project image was transformed by the reducer. The direct current component was in the [0,0], and the basis function of [0,0] was a cosine function of the 1.5 period in one direction and was a constant in the other direction. The basis function of [1,0] was similar to [0,1], but the direction was rotated by 90 degrees. The used transform basis function is depicted in Fig. 1.

Compression can be achieved by discarding some of the smaller elements of the 64 spectrum (spectrum) after the reducer vibration noise wave transform, which made it possible to achieve compression and that information can be kept as large as possible. The engineering drawing of the upper bearing showed contrast ratio of using different number of frequency domain amplitude (frequency spectrum) from the original bearing engineering image d reconstruction of the bearing engineering image. It can be seen from the bearing of the engineering drawing c that even if the high frequency amplitude (spectrum) of the total 3/4 was discarded, it can be obtained by using the following formula to obtain the spectrum of the original bearing image: the low frequency amplitude (frequency spectrum) result. In addition, the error seemed to be random and can be considered as random noise. Then the appropriate threshold was selected, reconstruction can achieve the purpose of eliminating noise after the reducer vibration noise wave decomposition.

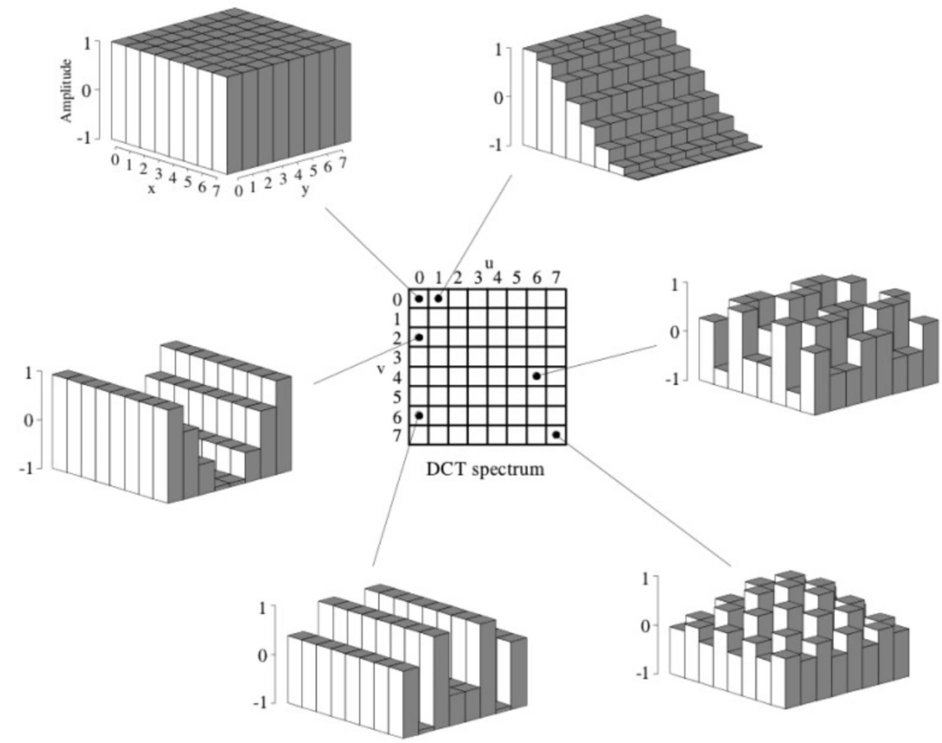

Fig. 1. Transform basis functions used

3.2. Investigation on the application of the bearing stiffness and the diagnosis of the spiral angle of the gear

The relationship between manufacturing industry and its main gear were studied and the data was collected from the angle of bearing and gear in this paper. We used the way of WeChat survey to conduct questionnaire issued to let management who were responsible for the sales of bearings and familiar with the situation in the enterprise investigated fill in the questionnaires. A total of 250 questionnaires were issued with online 100 and 150 copies of the site. 135 valid questionnaires were recovered and the effective questionnaire recovery rate was 54 %. Among them, the field release questionnaires recovered 82, accounting for 59.74 % and online payment of 53 copies of the questionnaire recovered, accounting for 40.26 %. The data were tested by double sample T, and the two had no significant difference ($p > 0.05$), which could be combined together to analyze the data. The specific way was shown in Table 1 and bearing manufacturing in kind was shown in Fig. 2.

We can find other manufacturing companies to provide the same service (reverse score) with A (previously selected by the manufacturing firm), and then find other inspectors instead of A.

Table 1. Business people who fill out their features

Feature		Frequency	Percentage (%)
Industry	Machinery manufacturing	24	17.8
	Electronic Product Manufacturing	25	18.5
	Food processing industry	14	10.4
	Other	72	53.3
Company size	100 or less	25	18.5
	100–499	25	18.5
	499 or more	85	63
Working year	1	4	3
	5 or more	102	75.5

Fig. 2. Bearing manufacturing physical map

Although this will bring loss to our company, but it was difficult to find a distributor that can bring us so low as A company bearing stiffness and gear helix angle rate. At the time of the survey, we asked the manufacturer representative to point out the extent to which they agree or disagree with these statements (1 = disagree; 2 = does not agree; 3 = has no opinion; 4 = agrees; 5 = extremely agrees). The measurement results were analyzed by the factor analysis and then the scores of the two factors were added together

$$\mathrm{InterptPD} = \mathrm{DP_d} + \mathrm{DP_s}\,, \tag{2}$$

$$\mathrm{AsymPD} = \mathrm{DP_d} - \mathrm{DP_s}\,. \tag{3}$$

We can calculate the specific values by these two formulae. These are listed was in Table 2.

Table 2. Multiple hierarchical regression analysis results: the standard line posture

Model	$\mathrm{DP_d}$	DP_s	InterptPD	AsymPD
JPlan	0.165	−0.017	0.024	0.118
JSolve	249	0.057	0.061	306

The above data showed that the stiffness and the spiral angle of the gear had a significant positive impact on the bearing manufacturers to solve the problem. There was a clear negative impact on the speculative behavior of the bearing manufacturers that are perceived by the bearing manufacturers. However, the impact of the joint development plan for the bearing manufacturer and the bearing manufacturer was not obvious. The interdependence between the bearing manufacturer and the bearing demand had no significant impact on the use of relationship governance for bearing manufacturers. But the bearing manufacturer was more dependent on the non-symmetry, which had a significant negative impact. The relationship marketing orientation has no obvious influence on the speculative behavior of the bearing manufacturers' perceptions. There was a positive interaction between the bearing manufacturer and the bearing manufacturer to make plans and to solve the problem. That was to say, bearing manufacturers often make plans with bearing consumers.

3.3. Study on the influence of bearing stiffness and gear helix angle on the vibration and noise of gear reducer

We used the method of extracting the effective points in Fig. 3 when extracting the characteristics of the bearing stiffness and the helix angle of the gear. Altogether 6 characteristic values were extracted from the waveform of the vibration noise of the output response reducer: The frequency response of voltage amplitude corresponding to the frequency of 10 kHz was 1 V. The frequency response of voltage amplitude corresponding to the frequency of 20 kHz was 3 V, and the frequency response of voltage amplitude corresponding to the frequency of 30 kHz was 5 V. The frequency response of voltage amplitude corresponding to the frequency of 40 kHz was 10 V and the frequency response of voltage amplitude corresponding to the frequency of 50 kHz was 20 V. The frequency response of voltage amplitude corresponding to the frequency of 60 kHz was 10 V and the frequency response of voltage amplitude corresponding to the frequency of 70 kHz was 5 V. The frequency response of voltage amplitude corresponding to the frequency of 80 kHz was 3 V and the frequency response of voltage amplitude corresponding to the frequency of 90 kHz was 1 V.

The 9 sampling points can describe the zigzag curve bearing frequency output and can also distinguish between zigzag curve when other components changing. Structure sample set was as follows: As was shown in the figure, the resistance and capacitance of the bearing are measured to be 2 % and 5 % respectively. The output frequency response was normal when changing in this range. The allowable variation tolerance of current was 50 %–70 % and tolerance range of voltage U allowed variation was 40 %–80 %.

According to the above settings, I or U changed in the scope of: small, normal, partial. Symbols L, N, M were used to represent them. Sample data is shown in

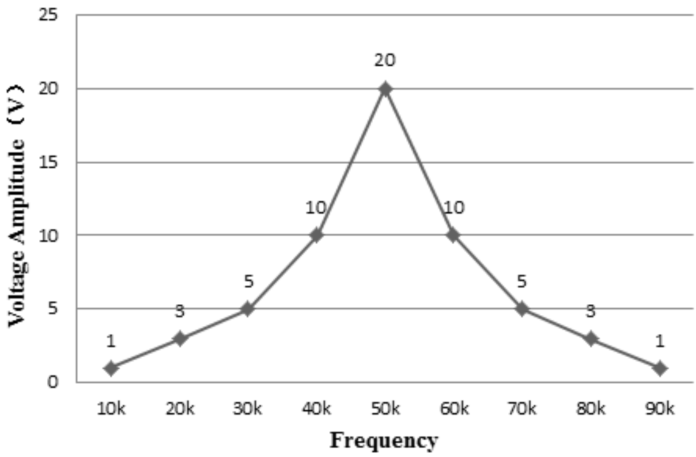

Fig. 3. Output sampling frequency response diagram

Table 3 and Table 4 according to the stiffness of each bearing element and the spiral angle of the gear.

Table 3. The first group pickup

L	N	M
0.02	0.95	0.12
0.03	0.84	0.15
0.04	0.93	0.14

Table 4. The second group pickup

L	N	M
0.08	0.95	0.11
0.05	0.85	0.19
0.06	0.94	0.09

Each of the first or second sets of changes in the component correspond bearing frequency response curve of output sampling time and was considered as the reducer noise input changes. The representation method was used by network output status: 0 (stiffness and gear helix angle) 1 (normal) represented. If both L and M are 1, the bearing component is normal.

The classical two layer perceptron was used to simulate the bearing stiffness and the diagnosis and location of the helical angle of the gear. The formula was as follows:

$$y = g\left(\sum_{i=1}^{n}(K_iF_i - \theta)\right). \tag{4}$$

Among them, K_i is the weight and F_i is the input. Symbol θ represents the limit value and $g(x)$ is the transfer function.

4. Result analysis and discussion

We used the heuristic method to improve the vibration noise of the gear reducer in order to improve the training intensity of the network. That is to say, the method was adding momentum correction. The training sample sequence was input to the gearbox vibration noise network and the mean square error (MSE) was set to 0.011. The double layer perceptron has been spread and the learning speed was 0.5 after several adjustments. Momentum factor 0 network achieved the expected value after 30215 training adjustment. The relationship between the mean square error and the training times of the multi-layer perceptron network was shown in figure. The first 70 local relations between mean square error and training times are shown in Figs. 4 and 5.

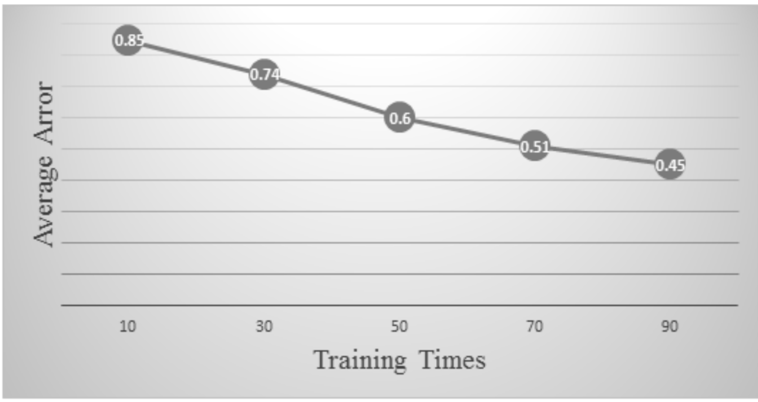

Fig. 4. Average error of the relationship between training times

It can be seen that the average accuracy of partial bearing stiffness and gear helix angle were not stable, but the average accuracy of bearing stiffness and gear spiral angle were stable, which showed that the effect of the stiffness and the helix angle of the gear on the vibration and noise of the gear reducer had the advantage of a certain degree and can be used to reduce the noise of large scale reducer.

5. Conclusion

Bearing and gear, as the representatives of the precision parts, occupied an increasingly important position in modern industrial manufacturing in the modern mechanical manufacturing industry. And the large number of precision parts made it often appear to affect the noise of reducer, so it was necessary to reduce the noise of the reducer by the appropriate method. We used bearing tolerances in order to obtain the bearing on the sample in this paper. Bearing tolerance, as a statistical

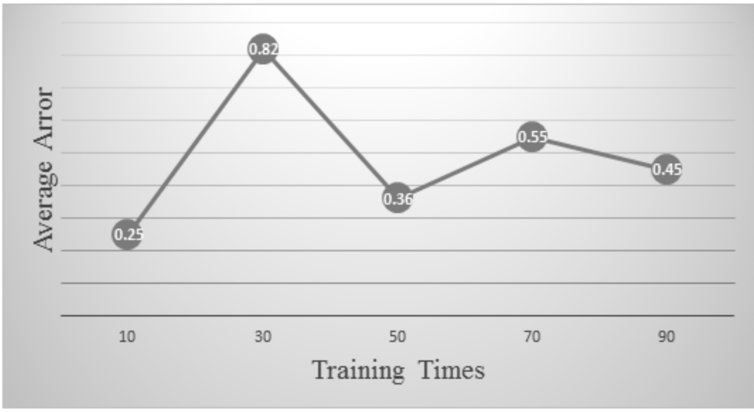

Fig. 5. Average error of the relationship between local training times

analysis of the random response signal and was attached to the nominal bearing, can only be obtained through the simple operation of training and test samples, which can reduce the computational complexity greatly. Firstly, the meaning of the vibration noise of the gear reducer was introduced and then the application of the bearing stiffness and the diagnosis of the helical angle of the gear were investigated in this paper. Finally, the research process of bearing stiffness and gear helix angle on the vibration and noise of gear reducer were studied in detail. The experimental results showed that the effect of bearing stiffness and gear helix angle on the vibration and noise of gear reducer had the advantage of reducing noise, which can be used to reduce noise. And this method was simple and effective and it can solve the problem of high stiffness and high gear helix angle. However, there were still some deficiencies in the research process due to the limitation of my ability and time. For example, the results of this study may not be suitable for other types of bearing stiffness and spiral angle of the gear due to the bearing stiffness and the type of gear helix angle more, which also needed to be explored and studied further.

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