Vibration Characteristics Analysis of Vertical Mill Reducer

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Abstract. The vibration characteristics of gear system have a significant influence on mechanical capacity and durable life of vertical mill reducer. In order to improve the performance of reducer, this paper present the research on inherent characteristic and dynamic response of vertical mill reducer. First of all, the finite element model coupled gear-rotor-bearing-housing of reducer is established including internal dynamic excitation. Then, the natural frequencies and natural modes are worked out by mode analysis, which indicates resonance phenomenon will not occur in reducer system. Finally, the vibration displacement, velocity and acceleration of the reducer are obtained through dynamic response analysis, which illustrates the structure vibration energy mainly concentrates in the engage frequencies and their multiples.

1. Introduction

Vertical mill reducer, a key component of the vertical mill, has been widely used in many fields, such as cement industry, coal industry and chemical industry. As a gear system consists of gear pairs, drive shafts, steady bearings and gearbox body, the vibration would be inevitably produced because of the dynamic excitation that was motivated by tooth mesh during the operation process, which is highly related to the mechanical capacity and durable life of mechanical devices. Therefore, research on dynamic characteristics of the vertical mill reducer has a great engineering value for improving the performance of gear systems.

With the advancing of technology, many scholars have carried out a lot of research work on vibration of gear system, which are mainly focus on establishing [1] and solving [2] of the nonlinear dynamic model, and analyzing the factors that have a big influence on vibration [3]. Among these methods, lumped parameter method [4] is a useful method in terms of studying the complicated and irregular response of gear system. Meanwhile, the Runge-Kutta method [5] and the harmonic balance method [6] are the main solution method for lumped parameter model. However, lumped parameter method can hardly solve the problems of high nonlinear gearbox system because of its excessively simplified model. In this case, the finite element method [7-8] has been widely used in tackling the problems of vibration related to gear system. Additionally, experimental method [9-10] based on vibration detection is also a very important way to study the vibration of gear system, which can provide the support for vibration simulation.

A mountain of work has been done on vibration study of gear system, while the research about vibration characteristics of vertical mill reducer is still little known. Hence, the aim of this paper is to achieve the vibration response of vertical mill reducer by using the Finite Element Method (FEM), which could provide guidance for better design of vertical mill reducer.

2. Simulation of internal dynamic excitation

Vertical mill reducer, as a set of three-level drive mechanism, includes a bevel gear pair, a helical gear pair and a planetary gear pair, which shown in Fig.1. In order to obtain the vibration response of gear system, the internal dynamic excitation of each pair of gear pair should be numerically simulated at first.
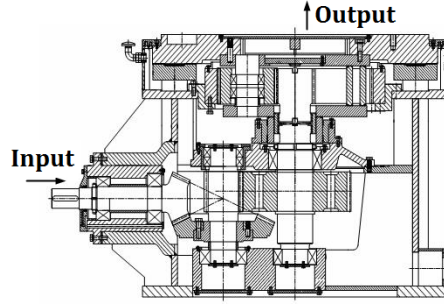
Fig.1: Structural diagram

The internal dynamic excitation can be calculated by the following formula [10]

$$F(t) = \Delta k(t) \cdot e(t) + S(t) \tag{1}$$

Where $F(t)$ is internal dynamic excitation, $\Delta k(t)$ represents variable part of mesh stiffness, $e(t)$ is gear transmission error, $S(t)$ means meshing impact force.
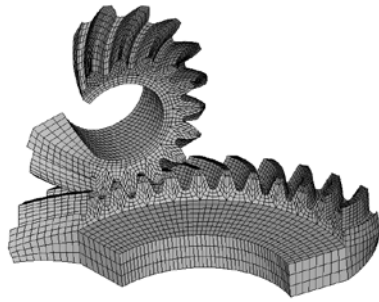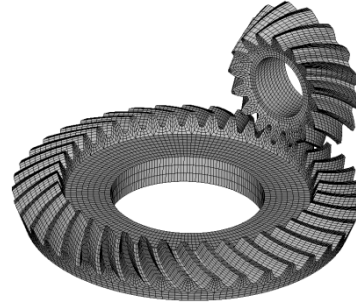

Fig.2: Static contact model

Fig.3: Dynamic contact model

Based on the static contact finite element model of bevel gear pair, as illustrated in Fig.2, the single tooth mesh stiffness is obtained as shown in Fig.4. The impact excitation, as shown in Fig.5, can be calculated through dynamic contact finite element model shown in Fig.3.
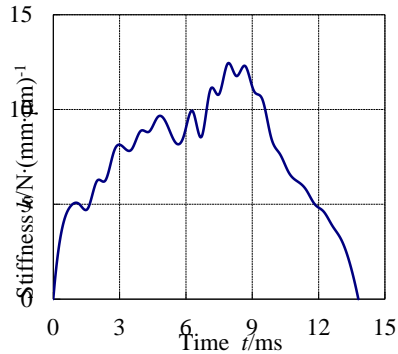

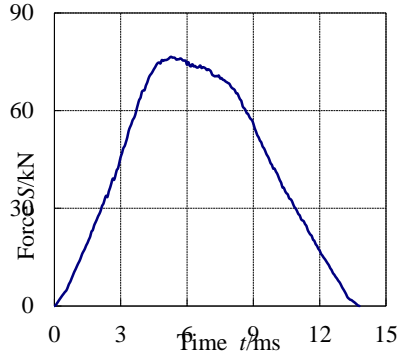Fig.4: Time-varying mesh stiffness

Fig.5: Meshing impact force

Additionally, the gear transmission error can be simulated by sine function illustrated in Fig.6. Finally, the internal dynamic excitation of bevel gear pair, as illustrated in Fig.7, can be simulated through formula (1). According to same method, the internal dynamic excitation of other gear pairs also can be obtained.
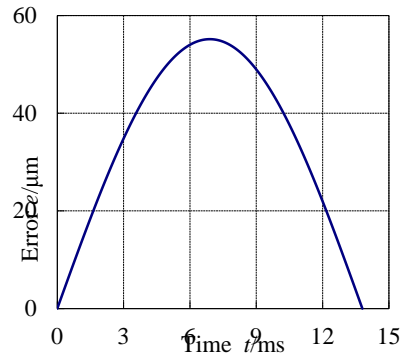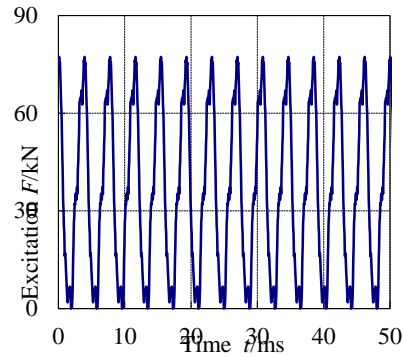
Fig.6: Gear transmission error

Fig.7: Internal dynamic excitation

3. Mode analysis of reducer

Mode analysis is a method based on vibration theory, and the main purpose is to get the inherent characteristics of structural system, such as natural frequencies and natural modes. In this section, the inherent characteristics of vertical mill reducer will be figured out by Block Lanczos method, and the results can be used to investigate whether the resonance phenomenon will occur during this gear system is working.

The solid model of coupling system includes gear-rotor-bearing-housing being established by ANSYS Parametric Design Language (APDL). Then the dynamic finite element model of vertical mill reducer, with a total of 279136 nodes and 1184510 elements, is obtained by using the spring element to stimulate the support between shafts and bearing, and the relationship of gear meshing, as illustrated in Fig.8.
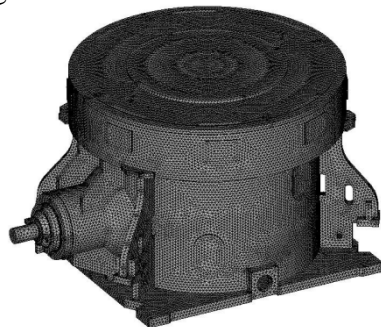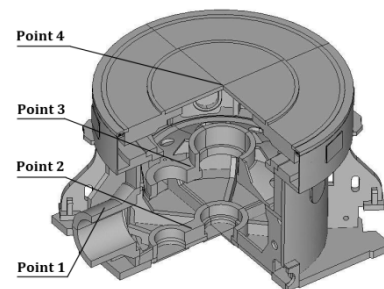

Fig.8: Finite element model

Fig.9: Observation points

The mode analysis of vertical mill reducer is conducted by coding APDL in ANSYS. The first 10 natural frequencies and the first 6 mode shape are shown separately in Table.1 and Fig.10.

Table.1: The first 10 natural frequencies of reducer system

Mode no.	1	2	3	4	5
Frequency/Hz	5.92	10.29	13.29	54.43	69.37
Mode no.	6	7	8	9	10
Frequency/Hz	70.98	76.02	80.91	85.07	90.85

(a) Mode 1   (b) Mode 2

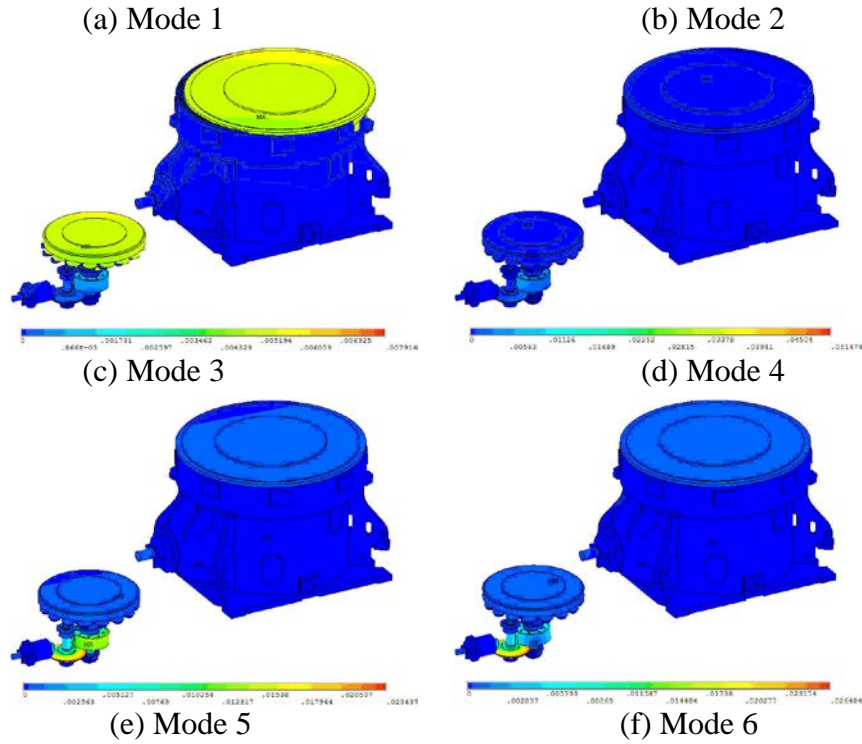(c) Mode 3   (d) Mode 4

(e) Mode 5   (f) Mode 6
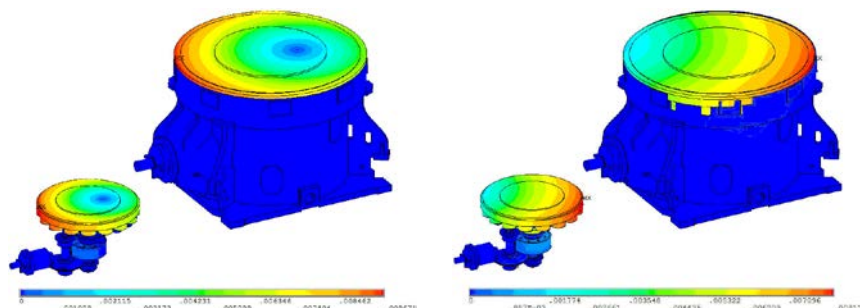
Fig.10: Illustration of the first six mode shapes of the reducer system

The transmission parameters of reducer gear system are as follows: input velocity is 990r/min, the first stage tooth number is $z1/z2=16/40$, second stage tooth number is $z1/z2=19/70$, and the last stage tooth number is 32/48/128. Then the rotational frequency and engage frequency of each stage can be calculated as shown in Table.2. By comparison of the frequencies between Table.1 and Table.2, it is clear that there is no overlap between natural frequencies and rotational frequencies or engage frequencies. Therefore, no resonance phenomenon will occur in reducer system.

Table.2: The rotational frequencies and engage frequencies of gear system

Frequency	Bevel gear pair	Helical gear pair	Planetary gear pair
Rotational	16.5	6.60	1.79
Engage Frequency/Hz	264.00	125.40	45.86

4.   Vibration response analysis of reducer

The vibration response analysis of reducer is based on the finite element model, which is used in mode analysis as well. The internal dynamic excitation is applied on the nodes of contact line, and the dynamic response of vertical mill reducer is worked out by mode superposition method considering the huge model. In order to achieve a steady vibration response, the total calculate time of interest is chosen to be 600 ms with the time step of △t=0.06 ms.

Fig.9 shows the location of observation points. Table.3, Table.4 and Table.5 respectively illustrate the root-mean-square (RMS) value of displacement, velocity and acceleration. The vertical direction (Y) vibration response in both time and frequency domain of point 1 is shown in Fig.11.

Table.3: The RMS values of vibration displacement

Node no.		Point 1	Point 2	Point 3	Point 4
Simulation value /μm	X-direction	3.800	3.941	3.076	14.626
	Y-direction	1.613	15.071	7.090	9.352
	Z-direction	0.810	0.288	1.052	11.530

Table.4: The RMS values of vibration velocity

Node no.		Point 1	Point 2	Point 3	Point 4
Simulation value /mm·s^{-1}	X-direction	3.649	2.358	3.394	0.688
	Y-direction	2.032	10.544	6.477	6.587
	Z-direction	0.689	0.426	1.016	0.590

Table.5: The RMS values of vibration acceleration

Node no.		Point 1	Point 2	Point 3	Point 4
Simulation value /m·s^{-2}	X-direction	5.165	2.754	5.276	0.315
	Y-direction	3.513	13.363	7.743	6.415
	Z-direction	0.789	0.712	1.781	0.337

According to the results of dynamic response analysis, we can conclude the structure vibration energy mainly concentrates in the engage frequencies and their multiples. Additionally, the dynamic response of vertical mill reducer has shown signs of cyclical vibration.
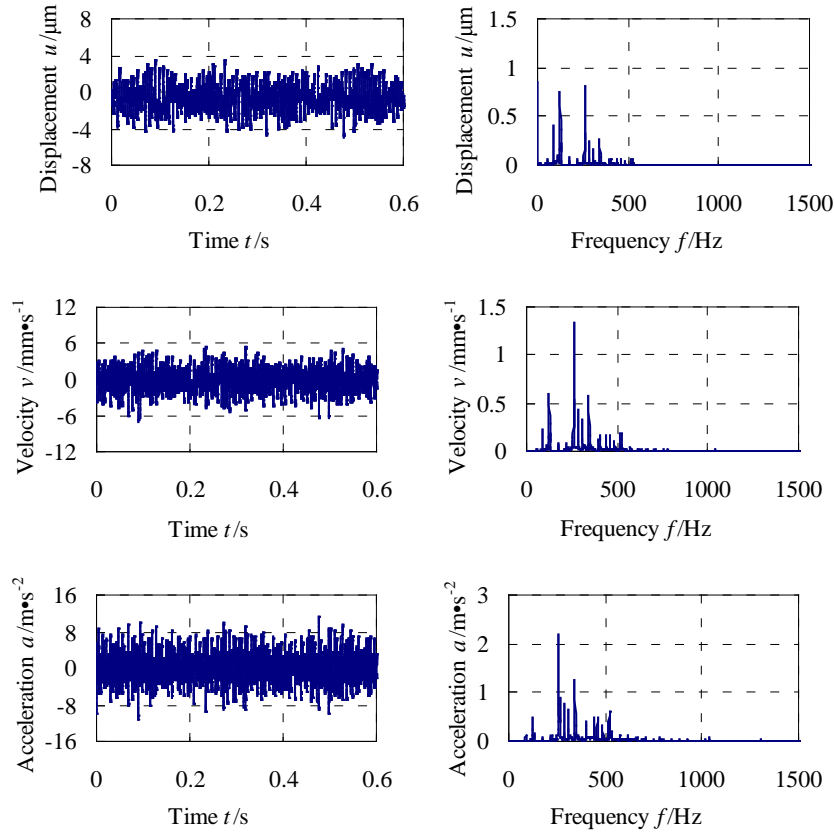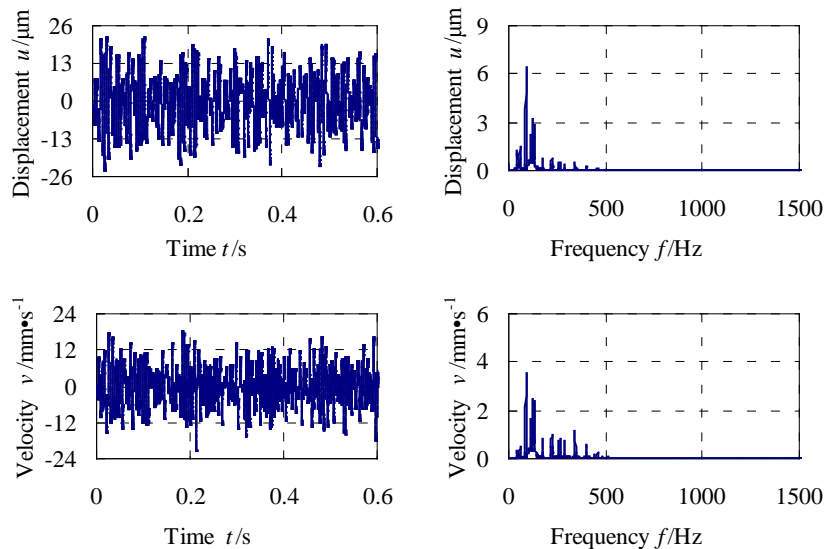

Fig.11: Y direction vibration response in both time and frequency domain of point 1
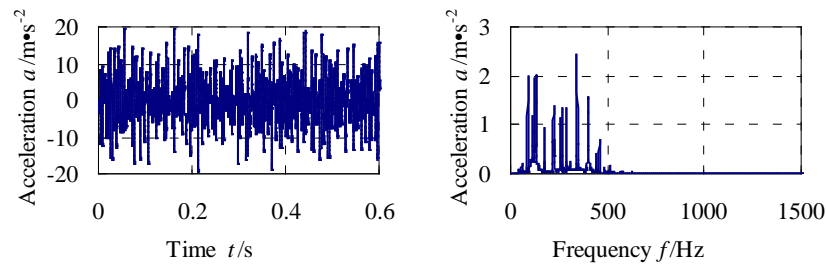
Fig.12: *Y* direction vibration response in both time and frequency domain of point 4

One of the main purposes of vibration response of vertical mill reducer is to study the vibration severity which can reflect the degree of vibration intensity of gear system. It can be expressed as

$$V_{S} = \sqrt{\left(\sum V_{X} / N_{X}\right)^{2} + \left(\sum V_{Y} / N_{Y}\right)^{2} + \left(\sum V_{Z} / N_{Z}\right)^{2}} \qquad (2)$$

Where VS represents vibration severity (unit: mm/s). VX、VY、VZ are root-mean-square (RMS) values of vibration velocity response (unit: mm/s) respectively in X-direction, Y-direction and Z-direction. NX、NY、NZ are the number of points in the three directions respectively.

Vibration severity of vertical mill reducer can be calculated out as 6.922 mm/s finally based on formula (2) and the figures in Table.4.

5. Conclusions

(1) The finite element model coupled gear-rotor-bearing-housing has been established to calculate the inherent characteristics of reducer, and the result indicates that resonance phenomenon will not occur in this reducer system.

(2) Based on the internal dynamic excitation, the dynamic response of reducer has been worked out, and it can be seen that the structure vibration energy mainly concentrates in the engage frequencies and their multiples.

Acknowledgements

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