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Vibration measurement and structural optimization simulation of a boom type tunneller

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Abstract **– In this paper, the method of vibration measurements and structural optimization simulation of AM50 tunneller are presented. The vibrations of the tunneller were measured in real time when it was used for cutting a man-made coal bed as well as cutting a real coal bed. The measured results indicate that in these two kinds of working conditions the vibration characteristics are quite similar, that is, the man-mad coal bed can be used in research on the vibrations of AM50 tunneller instead of the real one. A modal model of the machine was then established, and the intrinsic vibration characteristics of AM50 tunneller were investigated by means of the method of experimental modal analysis. Besides, the vibration response simulation under a set of measured loading spectra and the structural dynamics modification are also carried out with the help of structural analysis software. The results can not only facilitate the structural dynamics modification of AM50 tunneller but also provide the foundation for the optimal design of new types of tunneling machines..**

Keywords - tunneller; vibration measurement ; modal analysis

1. Introduction

The AM50 tunneller is one typical kind of boom tunneller made in China and widely used in Chinese coalmines. However, the tunneller usually vibrates greatly while working, especially while cutting semi-coal bed or other hard coal beds. And the vibrations not only weaken the operational reliability but also hinder the improvement of tunneling efficiency. So, it is quite necessary to conduct systematical research into the vibration characteristics and the dynamic design of tunneling machines. Such research, however, is far from adequate in China. The objective of the research introduced in this paper is to provide an important foundation for the structural dynamics modification and optimal design of the AM50 tunneller and other types of tunneling machines.

2. Vibration measurement of AM50 tunneller

2.1 The condition and method of vibration measurement

Weighing about 25 tons, AM50 tunneller is of low center of gravity and easy to be disassembled. It is mainly composed of cutting head, cutting boom, turning table, horizontal bar, conveyor, tracks, frame, loading apron, electrical controlling box, etc. (see Fig. 1).

According to the structural features of AM50 tunneller, fifteen representative points on its main components were selected as vibration measuring points and the cutting vibration of each point was measured in 2 or 3 directions. Meanwhile, some points on the electrical controlling box are selected to measure the performance of the vibration isolator (see Fig. 1).

The vibration measurements were carried out respectively when the tunneller was cutting man-made coal bed and when cutting the real underground coal bed. The underground measurement is mainly used to verify the reliability of the one on ground. As we know, it is quite difficult to make large-scale measurements under ground, so, we hope to confirm the representativeness and reliability of vibration measurements on ground through small-scale underground measurement.

The man-made coal bed was constructed of cement and stone sand in a certain proportion. The Protodyakonov coefficient of hardness f tested by the authoritative was between 2 and 4 and its material characteristics are quite similar to those of real coal beds. However, since the stone in the man-made bed is of great hardness, the man-made coal bed is more difficult to cut and thus the vibration is much stronger.

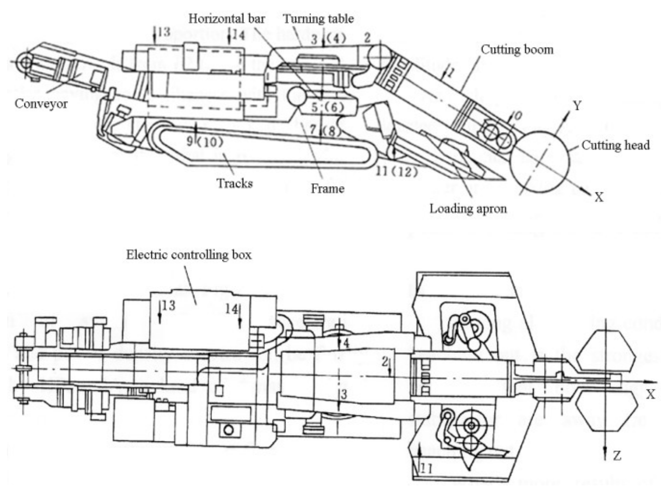

Fig.1 The outline of the tunneller and locations of vibration measuring points

2.2 Vibration measurement when the machine cutting the man-mad coal bed on ground

The experiments on cutting man-made coal bed were carried out on an artificial base which is quite similar to the underground one. In order to simulate as many working conditions as possible, different cutting actions were experimented with different cutting parameters, which include cutting-in, cutting vertically and cutting transversely.

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Through the detailed statistics and analyses of the test data obtained in the above-mentioned conditions, we draw the following conclusions:

(1)The vibration acceleration of cutting boom is the largest, and then followed in turn by that of turning table, horizontal bar, frame, loading apron, electrical controlling box and tracks. The closer the point on cutting boom is to cutting head, the stronger the vibration is; the nearer the point on the body is to the back or bottom, the smaller the vibration.

(2)The vibration acceleration amplitude when the tunneller was cutting in is much larger than those in other cutting modes, which could be explained by that the digging plate and the back stabilizator were both away from the ground in cutting-in. For instance, the vibration acceleration of measuring point 0# on the cutting boom reached 14g when the tunneller was cutting in, while it did not exceed 10g in the other cutting modes.

(3)The vibration acceleration of the electrical controlling box varied little in different directions, which indicated that the vibration of the box was coupled in different directions. However, the maximum vibration acceleration of the box was approximately equal to that of the pedestal, which showed that the vibration isolator did not function very well. The signal analyses in frequency domain showed that it could weaken the vibration amplitude of high frequency but had little effect on those of low frequency (<150Hz) [1].

(4)The energy of vibration signals mainly distributed in two frequency bands under 800Hz, namely, from 50Hz to 100Hz and from 250Hz to 400Hz.

2.3 Vibration measurement when the machine cutting the real coal bed under ground

The experiments of cutting real coal bed under ground were carried out at Pangzhuang Coal Mine, Xuzhou Mining Bureau, China. Six measuring points on the tunneller, point 0,1,3,6,7 and 9, and four points on the electrical controlling box were measured in the experiments. All these measuring points, as shown in Fig.1, were the same as those used in ground experiments. However, since the real coal bed was softer than the man-made one, the vibrations were relatively weaker. According to the amplitude analysis and the spectrum analysis of vibration signals, we draw the conclusions as follows:

(1)The vibration signals picked up under ground had the same characteristics in amplitude distribution as those obtained in ground experiments, although the vibration amplitude was much smaller, the maximum vibration acceleration (at point 0#) being 0.9g.

(2)The vibration signals of each measuring point picked up under ground were similar to those obtained on ground in shapes of frequency spectra.

(3)The vibration characteristics of electrical controlling box under ground were identical to those on ground.

The experimental results proved that, to a certain degree, the man-mad coal bed could be used, instead of the real one, in the research on vibration characteristics of AM50 tunneller, especially on the vibration measurement and the experimental modal analysis of tunneling machines.

3. Experimental modal analysis and structural optimal simulation

To conduct the modal analysis and structural optimal simulation of AM50 tunneller, we established a test system, which is shown in Fig.2. The transfer functions of the machine were obtained by the method of single-point monopulse excitation. Then, by applying an experimental modal analysis based on the measurement of transfer-function, we identified the modal parameters of AM50 tunneller and carried out the structural optimal simulation with the help of professional structural analysis software.

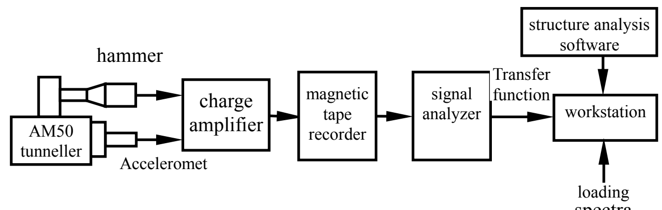

Fig.2 Test system of experimental

3.1 Establishment of the modal parameter model of AM50 tunneller

Basing on the geometrical shape and structural features of AM50 tunneller, we established the modal parameter model of AM50 tunneller in HP332C workstation with the help of SAS3.0, the structural analysis software of American SMS Company (see Fig.3). We have also calculated the modal frequency and damping ratio of each rank mode, which are shown in Table 1.

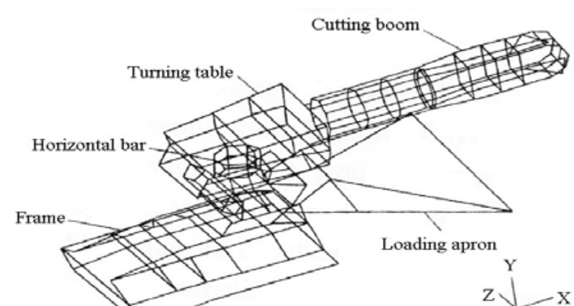

Fig.3 Modal model of AM50 tunneller

3.2 The measurement and analysis of working load spectra

When the AM50 tunneller is cutting in a transverse mode, the working loads are composed of transverse, vertical and axial forces and the torque acting on the cutting head. The coordinate system is located on the cutting boom and moves together with it (see Fig. 4). As such, the three forces and the torque were measured by three sets of strain plates (totally 12 plates), which were arranged on the surface of the cutting boom [2].

Table 1 Modal frequencies and damping ratio

Mode	Frequency(Hz)	Damping ratio (%)
1	62.695	8.173
2	78.978	4.768
3	129.021	9.653
4	188.929	7.201
5	246.813	3.765
6	283.865	2.512
7	304.233	3.645
8	318.981	3.254
9	372.981	4.830

The outcome of power spectrum analysis and autocorrelation analysis showed that the load signals of three component forces were all ergodic stationary random signals. Fig.5 has illustrated a set of three-direction load spectra measured while the tunneller was cutting the man-mad coal bed [3].

The following conclusions were drawn from the analysis of a large number of load spectra of AM50 tunneller.

(1)The power spectra of three forces in different working conditions were quite similar in shape and their frequency components were approximately identical.

(2)As the cutting depth or the cutting width varied, the load spectra saw an obvious change in the line profile around the frequency of 40Hz. The larger the cutting depth or the cutting width was, the higher the convex line profile at 40Hz rose, which indicated that more cutting teeth were working simultaneously.

(3)At high-frequency band, the power spectra of the three forces were similar to those of white noises by and large; at lower band, a dominant frequency of 3.75Hz always existed, which was almost three times the rotation frequency of cutting head f (f =1.23Hz). The fact that the cutting teeth are arranged along three spiral lines (3 start heads) can explain the coincidence.

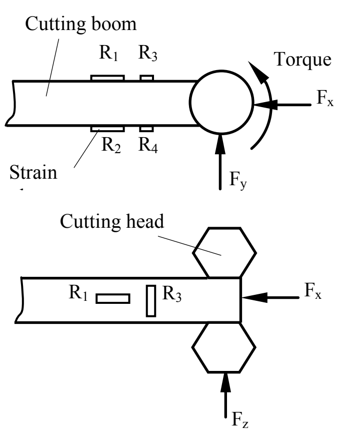

Fig.4 Working load measurements of AM50 Tunneller

3.3 Force response simulation and structural dynamical modification

Based on the modal parameter model and the measured load spectra of AM50 tunneller, the experiments of force response simulation have been carried out successfully with the help of force response simulation software. The modal model was loaded with the same forces and the acceleration responses of 11 representative measuring points were picked up. These typical points include three points on the cutting boom, three on the turning table, one on the horizontal bar, two on the front part of the frame and two the back part of the frame.

The simulation results show that the energy of acceleration spectra of these points is mainly concentrated in two bands, 50~100Hz and 300~400Hz, which is identical to the outcome of practical measurement when AM50 tunneller was cutting the man-made coal bed. The frequency-domain characteristics of vibration responses are determined by both the natural frequency of the machine and the dominant frequency of load spectra; therefore, the two bands mentioned above thus become the key to vibration control. One available measure is increasing the 1st and 2nd rank natural frequencies of the machine properly to keep them away from the dominant frequency of load spectra, which can effectively reduce the lower-frequency vibrations of AM50 tunneller and enhance its working stability. The natural frequencies can be changed by means of structural dynamics modification of the machine, for example, adjusting the structural parameters such as mass, stiffness, damping, etc. With the help of force response simulation software and structural dynamics modification software, we have conducted the structural optimal design and concluded a set of proposals for structural optimization (see table 2). And the simulation results show that, compared with the vibrations of those measuring points on the former tunneller, the vibrations of these points caused by the same working loads decline by 20% on average.

Table2 proposals for structural optimization of AM50 tunneller

No.	Contents of Structural Modification	Proposal
1	Stiffness of bolt fastening in the root of cutting boom	Increasing it by 10MN/m
2	Stiffness of bolt fastening in the front end of cutting boom	Increasing it by 12MN/m
3	Bearing stiffness of the working cylinder in cutting boom	Increasing it by 200MN/m
4	Bearing stiffness of the working cylinder in loading apron	Increasing it by 20MN/m

4. Vibration isolation of the electrical controlling box

4.1 Vibration characteristics of the electrical controlling box

The malfunction of electrical components caused by the vibration of electrical controlling box is one of the main faults of AM50 tunneller. Reducing the vibration of electrical controlling box is quite an effective measure to improve the working reliability of the tunneller.

According to the vibration measurements of electrical controlling box, we drew the following conclusions [1]:

(1)The vibration energy of the pedestal of electrical controlling box is mainly concentrated in the lower band below 100Hz.

(2)The vibration isolator only weakened the high-frequency vibration and had little effect on the lower frequency vibration, which indicated that the stiffness of the rubber isolator used at present was too large, resulting in the vibration isolator being of a higher natural frequency.

(3)The vibration isolator was not installed symmetrically, which could result in the increase of the coupling of vibrations on the body of electrical controlling box, thus leading to the approximately equal accelerations in vertical, transverse and axial directions.

4.2 The optimal design and modification of the vibration isolator

In consideration of the vibration characteristics of electrical controlling box and the characteristics of the vibration isolator, we designed a new kind of steel wire vibration isolator, which is of many advantages:

(1)It can change its shape in any directions to meet the need of absorbing random vibration.

(2)Its non-linear stiffness makes itself adaptable to the working condition of random excitation.

(3)Its ability of absorbing impacts is much greater than that of the rubber absorber.

(4)Its transferring ratio of vibration is quite smaller than that of the rubber absorber, especially in low-frequency domain. The maximum transferring ratio of vibration in the vertical direction is only 20 to 30 percent that of the latter.

With four steel-wire vibration isolators of 300kg/cm stiffness to be used instead of the former rubber isolators, the industrial experiments were carried out on the tunneller in Yaoqiao Colliery, Datun Mining Co. Ltd. The experimental results proved that the vibration of electrical controlling box was reduced obviously and its failure rate declined greatly. When the maximum vibration acceleration of the pedestal was 1.25g, the vibration acceleration of the electrical controlling box was only 0.24g, much smaller than the design target 0.7g [1].

5. Conclusion

The study depicted in this paper is one part of the national main project ‘Study on Vibration Characteristics of a Boom Type tunneller’. It is the first time that a systematical dynamic design research has been completed on such a large complex mining machine as AM50 tunneller, which includes vibration measurement, measurement and identification of load spectra, establishment of theoretical model, dynamic characteristics analysis, structural dynamics modification and optimization, etc. The findings concluded in this paper lay important foundation for further research on the structural optimal design of AM50 tunneller and for the dynamic design of other large complex tunneling machines as well.

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