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Study on fault mechanism of shaft hoist steelwork

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Abstract

Some achievements have been made in detecting the vibration faults in shaft hoist steelwork, but very little information is currently available to help study the faults mechanism. The faults during the run-ups stage are different from the faults during even speed stage. This paper deals with the fault mechanism through establishing the vibration model as the conveyance moves in shaft. By simulation we can see different vibrating instances correspond to different steelwork faults, and then we put forward suitable fault diagnosis methods.

Keywords: shaft steelworks; vibration model; detection method

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1. Introduction

Shaft steelwork is one of the most important components of the infrastructure in an underground mine, as it is used for maintaining the conveyance even running, direction guiding and drop prevention when it transports staff and materials to and from the surface as well as hoists the coal. In a perfectly-aligned shaft steelwork system during hoisting materials, the conveyance will experience very little shock most of the time. However, when the shaft steelwork system has imperfect guide-joints, deflection or guide-plumb, etc., it is possible to lead to non-stationary operation in addition to possible injury or loss of life, even more significant production loss. It has, therefore, become necessary to carefully monitor the condition of the shaft steelwork.

Meanwhile, with the modernization of mechanical equipment, both the hoisting altitude and velocity has increased, which will generate bigger vibration. Some papers introduced many conventional vibration signal processing methods in fault diagnosis (S. Vulli, 2009; Changzheng, 2004; Peter W.Tse, 2004), however, they did not explain the vibrating mechanism of shaft steelwork system and the problem that whether the vibration under run-ups and deceleration is more or less violent than that under even motion; Therefore, the study on the vibrating mechanism of shaft steelwork system and hoist signal characteristics of non-stationary running is still a blank.

This paper is divided into three major sections as follows. Section one opens with the imperfect steelwork patterns and the investigation on fault mechanics of shaft steelwork based on them; section two deals with the

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simulation of the vibration signals in different fault situations through the dynamic model of steelwork faults; the processing results of practical signals are shown in the last section.

2. Fault mechanics of shaft hoist steelwork

2.1. Imperfect shaft hoist steelworks patterns

With the aging of mine, the shaft steelwork will become invalid (Jiang Yao-Dong, 1999; J. S. Redpath, 1977; Wang Peng, 2005). There are many typical shaft steelwork faults, such as loose-joints between rails when there is impact or load deflection during hoisting, rail curving due to the extrusion of peripheral rock and earth, etc. In practice, the generalized imperfect shaft steelwork patterns are shown in Fig. 1 under the assumption that the shaft steelwork is aligned properly on one side and has faults on the other side. In Fig. 1(a), it is a straight guide, but out-of-plumb; In Fig. 1(b), the guide has a certain degree deflection; In Fig. 1(c), one segment of guide has a certain angular displacement; In Fig. 1(d), one segment of guide has a certain displacement in horizontal direction; In Fig. 1(e), there is a pitting fault or protuberant fault on the guide.

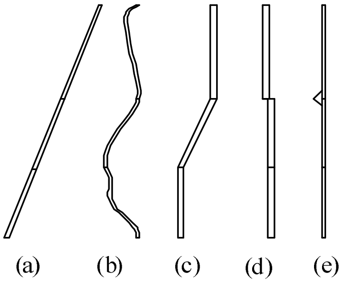

Fig. 1. Imperfect Shaft Steelwork Patterns

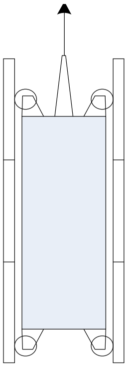

Fig. 2. Hoisting Process

2.2. Dynamic model of shaft steelworks

It is well known that the conveyance in mine is restrained from moving laterally by steelwork that provides the fixed track the conveyance follows as it ascends or descends in shaft. The conveyance is equipped with four sets of rollers, and each set consists of three rollers running on the steelwork, located orthogonally, and supported in a compression spring. The operation procedure of the conveyance is shown in Fig. 2. Over the past several decades (Liu Chun-feng, 2003), the rollers of vertical shaft cage shoe have developed from rigid rollers to rubber roller even to compound-rubber rollers. Since the rollers have stiffness and damp, we can simplify the response model in Fig. 2 between steelwork and conveyance along the trip that the conveyance experiences to a mass-spring system with two degrees of freedom in Fig. 3 (Liao Xiao-bo, 2005; Fu Wu-jun, 2003).

From Fig. 3, we can obtain the lateral vibration differential equation and the lateral turn differential equation of the conveyance as follows:

$$\begin{aligned} & m\ddot{x} + 4c\dot{x} + (2cl_2 - 2cl_1)\dot{\theta} + 4kx + (2kl_2 - 2kl_1)\theta \\ & = (kx_1 + c\dot{x}_1) + (kx_2 + c\dot{x}_2) + (kx_3 + c\dot{x}_3) + (kx_4 + c\dot{x}_4) \end{aligned} \tag{1}$$

$$\begin{aligned} & J\ddot{\theta} + (2cl_2 - 2cl_1)\dot{x} + (2cl_1^2 - 2cl_2^2)\dot{\theta} + (2kl_2 - 2kl_1)x + (2kl_1^2 + 2kl_2^2)\theta \\ & = -(kl_1x_1 + cl_1\dot{x}_1) + (kl_2x_2 + cl_2\dot{x}_2) - (kl_1x_3 + cl_1\dot{x}_3) + (kl_2x_4 + cl_2\dot{x}_4) \end{aligned} \tag{2}$$

where m — the mass of conveyance;
J — the inertia of conveyance moment;
k — the stiffness of conveyance shoe roller;

c — the damp of conveyance shoe roller;
y — the displacement of conveyance shoe roller;
x_1, x_2, x_3, x_4 — the displacements of conveyance shoe rollers, respectively;
θ — the angular displacement of conveyance;
l_1, l_2 — the vertical displacement of four rollers from centroid;
v — the velocity of conveyance run-up.

All of the procedure is manipulated on the assumption that the left steelwork is ideally straight and the right steelwork has fault. So the lateral vibration differential equation between the conveyance and the right steelwork can be simplified as follows:

$$m\ddot{x} + 4c\dot{x} + 4kx = k(x_3 + x_4) + c(\dot{x}_3 + \dot{x}_4) \tag{3}$$

$$J\ddot{\theta} + cl^2\dot{\theta} + kl^2\theta = \frac{kl}{2}(x_4 - x_3) + \frac{kl}{2}(\dot{x}_4 - \dot{x}_3) \tag{4}$$

where $l_1 = l_2 = l/2$. Combining equations (3) and (4), we can obtain the acceleration a of the conveyance bottom:

$$a = \ddot{x} + 0.5l\ddot{\theta} \tag{5}$$

And when the conveyance runs in even speed v, then,

$$x_3 = x_3(vt) \tag{6}$$

$$x_4 = x_4(vt - l) \tag{7}$$

And when the conveyance runs in run-ups stage or deceleration stage, then,

$$x_3 = x_3(v_0 + \frac{1}{2}at^2) \tag{8}$$

$$x_3 = x_3(v_0 + \frac{1}{2}at^2 - l) \tag{9}$$

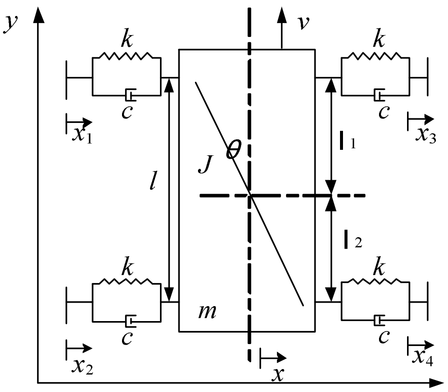

Fig. 3. Dynamic model

3. Model simulations

During operation, the stability of conveyance is subject to the steelwork fault patterns, which can excite the conveyance to vibrate. Here, we can express the steelwork faults by mathematical function. Under the assumption that the steelwork has deflection fault in one steel rail, poor joints and joints with protrusions as illustrated in Fig. 1(b), Fig. 1(d), Fig. 1(e), respectively, we simulated the vibration while conveyance is running over the steelwork fault on the run-ups stage and even speed stage.

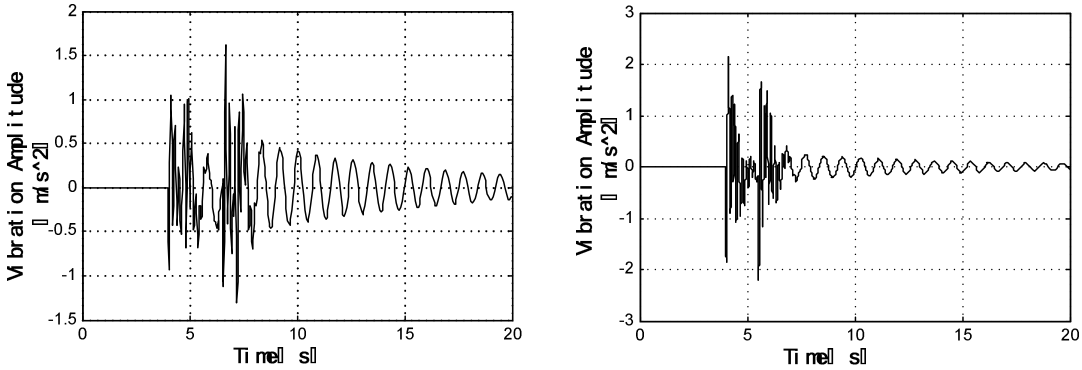

Fig. 4. (a) Curve fault signal response at run-ups stage; (b) curve fault signal response at even speed stage

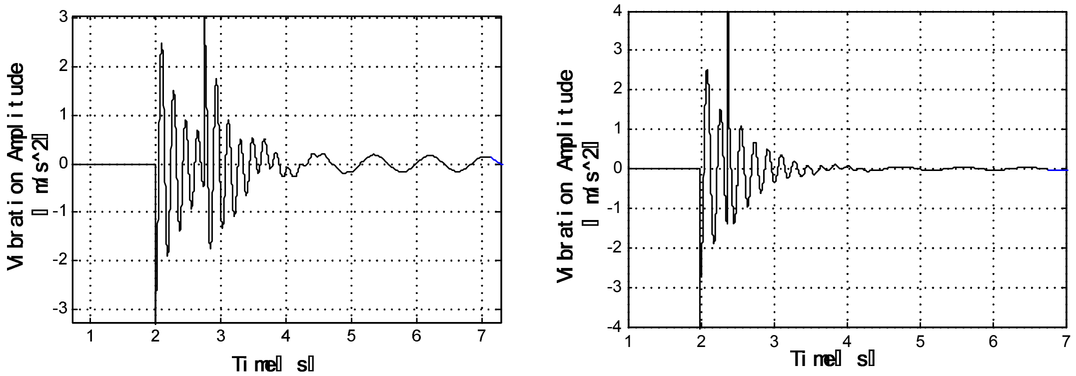

Fig. 4. (c) Displacement fault signal response at run-ups stage; (d) displacement fault signal response at even stage

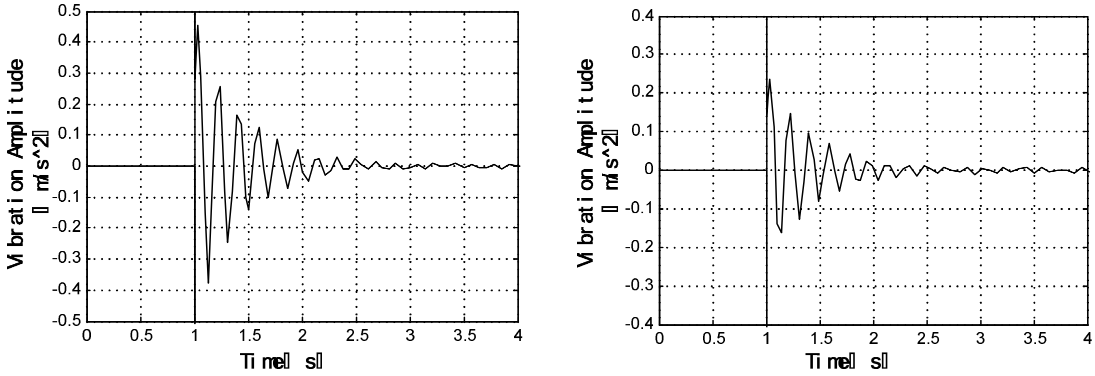

Fig. 4. (e) Protuberant fault signal response at run-ups stage; (f) protuberant fault signal response at even speed stage

A comparison of different faults causing lateral vibration between the run-ups stage and even stage are illustrated in Fig. 4. The simulations indicate:

- In Fig. 4 that there is a impact regardless what kind of fault;
- In Fig. 4 (a) and (b), when there is curve fault on one steel rail during the run-ups stage, the vibration amplitude is lower than that during the even stage; however, the former vibration are running on longer than the latter;
- And when there is displacement at joints in Fig. 4(c) and (d), the signals are the same in shape and amplitude, apart from time interval between the two impacts;
- With protuberant fault in Fig. 4(e) and (f), the signal amplitude at run-ups stage is lager than that at even stage.

4. Practical examples

Let us take a mine as an example. The practical signals in Fig. 5(a) and (b) are measured from the same section of the rails as the velocities of the conveyance going through this section are different. So we can reach the following conclusions: Firstly, as we have seen in the time domain waveform, there are intermittent impacts which indicate that there are faults on the steelworks; Secondly, there are displacement faults between rails judging from the rate of decay of impact signals; Finally, it is concluded that there are different response amplitudes in run-up stage from amplitude in even speed stage.

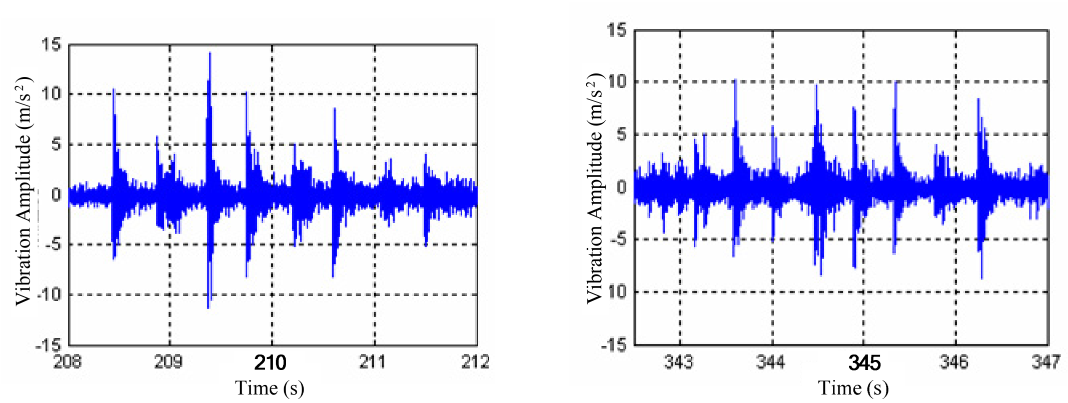

Fig. 5. (a) Curve fault signal responded at run-ups stage; (b) curve fault signal responded at run-downs stage

Therefore, it is deduced that different vibration amplitudes correspond to different velocities on the same fault. In this way, the conclusion of Structural Dynamics Research Corporation (South Africa) is not applicable in this situation any more. It is necessary to discuss the means to sample data and establish guide line to the equipment which has long period of acceleration and deceleration, that is, run-ups and run-downs. Although some scholars (N. Baydar,2000; K.M. Bossley, 1999; K.R. Fyfe, 1997) had studied the sampling method for varying speed machine, the criterion for judging the machine during varying speed at certain location such as the rail fault in shaft have yet not existed.

5. Conclusions

In this paper, we presented a method for description of the motion and established the mathematical model of a conveyance as it moves in a shaft restrained by fixed steelwork. Based on this, the vibration of a conveyance has been simulated on the rail failed. Although our analysis is fairly simple, we believe the mathematical model and simulations give us more inspirations. The most significant conclusions that can be drawn from the figures above are as follows:

- The lateral vibration of a conveyance as it moves in a shaft can be simplified to vibration model of two degree of freedom so as to easily solve the responses to different faults.
- With the simulations of different faults, it is found that the difference of vibration between run-ups stage and even stage tells us that the uniform criterion can not apply to run-ups stage or non-stationary stage.

- Through the analysis above, we should apply different assessment standard to lateral vibration in run-ups stage, and the standard establishment to access the severity of vibration still needs further discussion.
- Also, we have validated that when there are whole deflection faults the mean acceleration become bigger and bigger.

Besides the speed influencing the lateral vibration amplitude of conveyance, the shock magnitude to the conveyance is directly proportional to the weight being hoisted (J.S. Redpath, 1977). So the dynamic mathematic model related to weight need establish and discussion in the future.

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