Dynamics Characteristics of Weight-bearing Beam Coupling System Based on Track Irregularity

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Abstract

Port lifting equipment - field bridges, shore bridge container cranes are important tools for port transportation. With the development of large-scale, lightweight, high-speed and heavy-duty cranes, the dynamic design method based on dynamic load coefficient can no longer meet the design of large-scale port cranes. In this paper, considering the existence of crane track irregularity, the power spectrum of the three major trunk lines of China Railway is used, and the numerical simulation of the crane track irregularity is carried out by the method. After considering the track irregularity, the influence of different speeds and accelerations on the dynamic response of the load-bearing beam under the action of swinging heavy objects.

Keywords

Flexible wire rope, Weights-Bearing Beam coupling systems, Track irregularity.

1. Introduction

Track irregularity is the main source of disturbance for the dynamic function of the wheel-rail system, which will directly affect the quality of the wheel-rail and the safety and stability of the train operation[1]. As a kind of wheel-rail system, the track irregularity of crane load-bearing structure is often neglected due to the small moving speed of short track length. Based on the analysis of dynamic response of heavy-bearing beam, this paper studies the track irregularity of load-bearing structure on bearing beam. The impact of dynamic response.

Firstly, referring to the power spectrum of the three major trunk lines of China Railway[2], the method based on method simulation is used to generate the track irregularity time series. Then, according to the dynamic response of the load-bearing beam of the crane, the influence of the moving mass velocity acceleration on the dynamic response of the crane load-bearing beam is analyzed after considering the track irregularity in the simplified model of the load-bearing structure of the bridge.

2. Organization of the Text

Random track irregularity is the most important excitation source for the dynamic response of the vehicle track. To analyze the dynamic performance of the vehicle track, the track irregularity value must be input in the simulation model. Due to the nonlinearity of the dynamic equations of the vehicle orbit coupling system, most researchers currently use the orbital spectrum to obtain the orbital irregularity amplitude in the time domain in the vehicle orbital affinity dynamics analysis[3]. This method is called numerical simulation of orbital irregularity. .

Commonly used relatively simple methods can achieve time-frequency conversion of track irregularities such as secondary filtering, trigonometric series and white noise filtering. Among them, the secondary filtering method should design a reasonable filter for different orbital power spectrum, which lacks universality; the white noise filtering method treats the random signal as white noise that satisfies certain conditions, and then filters it through the orbital spectrum formula. The simulation results of trigonometric series and white noise method are not high. In this paper, the new method of constructing the equivalent spectral amplitude and random phase for the given power spectral density function is used to simulate the track irregularity [4].

2.1 Conversion of power spectrum function spatial domain to time domain

The analytical formulas of the power spectral density functions given in the paper are all based on the spatial domain. The spatial frequency is independent of the driving speed and is the uneven wavelength. In order to obtain an orbital irregularity time sample that facilitates numerical analysis, the power spectral density function of the spatial domain must first be transformed into the time domain. Assuming that the track irregularity is a stationary stochastic process in which the states are experienced in the spatial domain, the auto correlation function is:

$$R_l\left(l\right)=\lim_{s\to\infty}\frac{1}{s}\int_0^s y\left(x\right)y\left(x+l\right)dx \tag{1}$$

The power spectral density function is:

$$S_1\left(f_1\right)=\int_{-\infty}^{+\infty}R_1\left(l\right)e^{-i\omega_1 l}dl=\lim_{s\to\infty}\frac{1}{s}\int_{-\infty}^{+\infty}\int_0^s y\left(x\right)y\left(x+l\right)e^{-i2\pi f_1 l}dxdl \tag{2}$$

The auto correlation function and power spectral density function of the time domain are:

$$R_2\left(\tau\right)=\lim_{T\to\infty}\frac{1}{T}\int_0^T z\left(t\right)z\left(t+\tau\right)d\tau \tag{3}$$

$$S_2\left(f_2\right)=\int_{-\infty}^{+\infty}R_2\left(\tau\right)e^{-i\omega_2\tau}dl=\lim_{T\to\infty}\frac{1}{T}\int_{-\infty}^{+\infty}\int_0^T z\left(t\right)z\left(t+\tau\right)e^{-i2\pi f_2\tau}dtd\tau \tag{4}$$

The unit of the spatial domain frequency f_1 is $1/m$, $\lambda(m)$ is uneven wavelengths, The frequency of time and frequency is $1/s$ .Assuming that the running speed of the train is $v(m/s)$, the variables in the time domain and the spatial domain have the following transformation relationship:

$$T=s/v\ ,\quad x=vt\ ,\quad z\left(t\right)=y\left(vt\right),\quad l=v\tau \tag{5}$$

$$f_2=v/\lambda=vf_1 \tag{6}$$

From formula (2) and formula (5):

$$S_1\left(f_1\right)=\lim_{T\to\infty}\frac{v}{T}\int_{-\infty}^{+\infty}\int_0^T z\left(t\right)z\left(t+\tau\right)e^{-i2\pi f_1\tau}dtd\tau \tag{7}$$

Bringing equation (3) into (7) gives:

$$S_1\left(\frac{f_2}{v}\right)=vS_2\left(f_2\right) \tag{8}$$

According to the formula (7), the time domain power spectral density function of the track irregularity at different vehicle speeds can be obtained. For the spatial domain expression (5) of China's three major trunk power spectra, the corresponding time domain power spectral density function can be obtained, as shown in equation (9).

$$S_f=\frac{Av\left(f_2^2+Bf_2v+Cv^2\right)}{f_2^4+Df_2^3v+Ef_2^2v^2+Ff_2v^3+Gv^4} \tag{9}$$

2.2 Numerical Simulation of Track Irregularity Based on $IFFT$

For the given power spectral density function of equation (9), a new method of constructing the equivalent spectral amplitude and random phase and then performing *Fourier* inverse transformation is used to simulate the track irregularity. The process is briefly described as follows:

(1) Orbital irregularity The power spectral density is generally a single-sided spectrum, which is first converted into a bilateral spectrum.

(2) Set the number of points N and the sampling time Δ that need to be simulated to generate the uneven sequence column, then the frequency domain sampling interval $\Delta f = 1/(N \bullet \Delta)$. For the convenience of Fourier conversion, generally N is an integer power of 2, and if it is insufficient, it is followed by 0.

(3) Determine the upper and lower limits (f_1, f_2) of the power spectral density function $S(f)$ sampling, then the effective sampling points are $N_e = (f_2 - f_1)/\Delta f$.

(4) If $N_1 = f_1/\Delta f$ is set, the sampling point $0 \sim N_1 - 1$ is outside the effective frequency band and its sampling value $S_i(f) = 0(i = 0 \sim N_i - 1)$. Similarly, the sampled value at the sampling point $N_1 + N_e \sim N/2$ is also zero, ie $S_i(f) = 0(i = N_1 + N_e \sim N/2)$. This gives the $N/2 + 1$ sample points of the power spectral density function $S(f)$. An even symmetric sample sequence $S_i(f)(i = 0 \sim N - 1)$ symmetric to the SSS is then formed.

(5) The amplitude of the Fourier spectrum of the track irregularity sequence is:

$$|F_k(f)| = N\sqrt{S_k(f) \bullet \Delta f} \quad （k = 0 \sim N - 1） \tag{10}$$

(6) Since the uneven sequence $r(x)$ is a random process, its spectral phase must be random. Let ξ_n be a sequence of independent phase factors whose mean values are zero. ξ_n should be complex and its average power $|\xi_n|^2 = 1$. So with $\xi_n = \cos\phi_n + i\sin\phi_n$, the phase ϕ_n is randomly and evenly distributed within the $(0, 2\pi)$. Since the real part of the $F_k(f)$ is symmetric about the $N/2$, the imaginary part is symmetric about the $N/2$, so just find the $F_k(f)$, ($k = 0,1,\cdots N/2$). which is:

$$F_k(f) = |F_k(f)|\xi_n = N\xi_n\sqrt{S_k(f) \bullet \Delta f} \quad （k = 0,1,\cdots N/2） \tag{11}$$

Then use symmetry to get $F_k(f)$, ($k = 0,1\cdots N$).

(7) Performing the Fouier inverse transformation on the sequence $F_k(f)$, the track irregularity sequence $r(x)$ can be obtained.

Take the spatial wavelength as $1 \sim 30m$ (the measurement wavelength range of the track inspection vehicle that obtains the three major trunk orbit spectra) and the running speed $v = 3.6km/h$. Take $N = 2^{20}$, sampling time $\Delta = 0.0001s$, calculate the track irregularity $r(x)$ simulation time series according to the above process, as shown in Figure 1 and compare the power spectral density analysis value and simulation value as shown in Figure 2.

ISSN: 2414-1895 DOI: 10.6919/ICJE.201909_5(10).0036

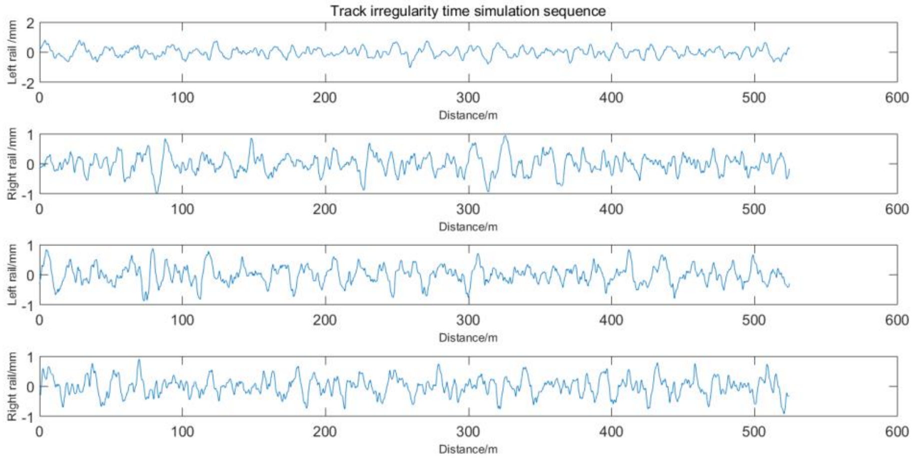

Figure 1. Time series of simulated track irregularities

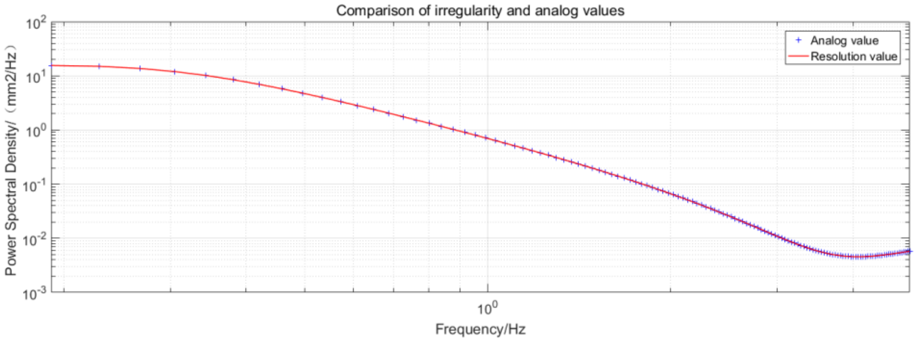

Figure 2. Comparison of the analytical values of the track irregularity power spectrum and the simulated values

As can be seen from Figure 1, between $1\sim14s$, the time series presents a random distribution; the simulated time series amplitude is between $-1\sim1mm$. The comparison between the analytical values and the simulated values in Fig. 2 shows that the two are basically consistent, the simulation accuracy is high, and the results are satisfactory. On the other hand, this also proves the accuracy of the simulation time series, and the resulting time series can be used for dynamic calculations.

3. Orbital geometric irregularity numerical simulation

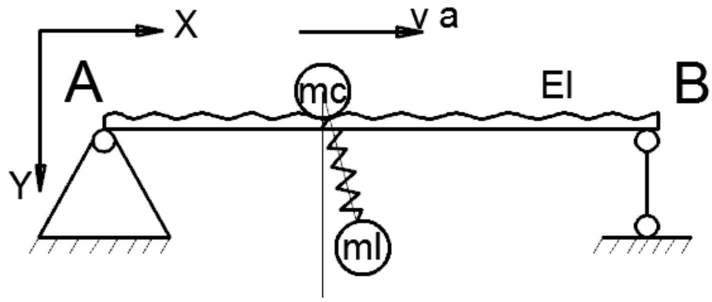

Figure 3. Considering the track irregularity weight-simple beam model

Table 1. Model parameter

$E/(N\bullet m^{-2})$	I/m^4	$mL/(kg\bullet m^{-1})$	m_C/kg	L/m	K/Nm^{-1}
2.15×10^{11}	8×10^{-1}	1.53×10^{4}	6.12×10^{4}	100	6.33×10^{7}

The right rail height and low irregularity obtained at the initial velocity v_0 are used to simulate the track irregularity, and it is brought into the vibration displacement and acceleration response of the simply supported beam. When the same initial velocity v_0 is constant and the acceleration $a_0 = 0,1,2,3m/s^2$ changes, the displacement of the simply supported beam after the track irregularity is considered is shown in Figure 4. The variation of the acceleration of the simply supported beam is shown in Figure 5. In addition, the initial velocity $v_0 = 0m/s$ $v_0 = 10m/s$ is compared with the calculation of the displacement and acceleration of the simply supported beam, which is considered in consideration of the track irregularity and without considering the track irregularity, as shown in Fig. 6 .

It can be seen from Fig. 4 to Fig. 5 that the existence of track irregularity increases the fluctuation of the mid-span displacement of the simply supported beam and the acceleration of the beam span, and the maximum displacement and acceleration of the beam span increases. But without changing the law of change, at the same speed, the mid-span displacement of the simply supported beam increases with the increase of the moving mass acceleration. The mid-span acceleration of the simply supported beam also increases with the increase of the moving mass acceleration.

From Fig. 5 to Fig. 6, it can be seen that the simulation value of the track irregularity is related to the moving mass speed. The higher the speed, the larger the track irregularity, so that the displacement response and acceleration response of the simply supported beam are larger. It can be seen that the influence of track irregularity on the acceleration response of the simply supported beam is greater than the influence on the beam displacement.

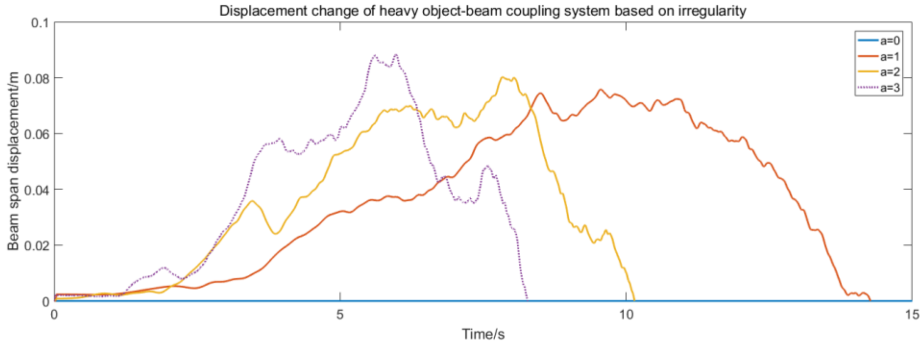

Figure 4. Displacement response of weight-simplified beam system based on irregularity

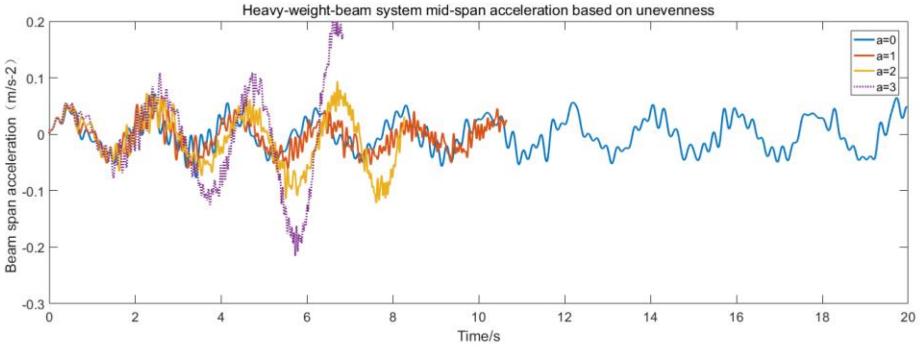

Figure 5. Acceleration response of weight-simple beam system based on irregularity

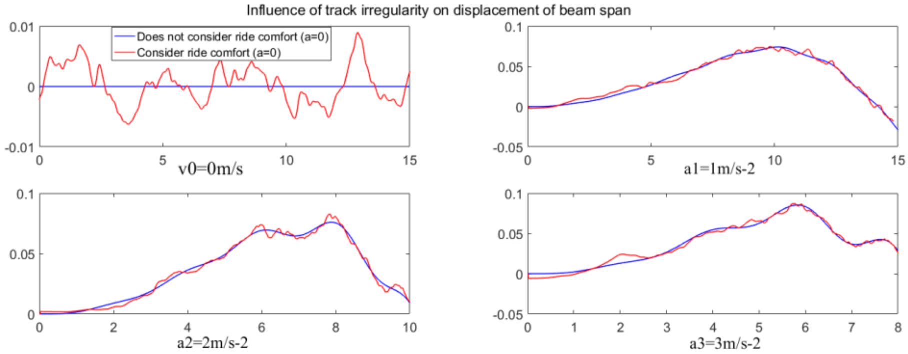

Figure 6. Comparison of the displacement of the simply supported beam

4. Conclusion

This paper discusses the influence of different speeds and accelerations on the vibration displacement and acceleration response of crane load-bearing structures when the weight of the swinging weight with flexible steel wire is moving on the simply supported beam considering the irregularity of the track. The following conclusions are drawn:

(1) Considering the existence of track irregularity, the undulation of the mid-span displacement and the mid-span acceleration of the simply supported beam increases, and the maximum displacement and acceleration of the simply supported beam increase, but the displacement of the simply supported beam is not changed. The law of acceleration increasing with increasing acceleration of the moving mass. It shows that improving the smoothness of the track will reduce the vibration displacement and acceleration response of the beam.

(2) The greater the moving mass velocity, the greater the influence of track irregularity; the influence of track irregularity on the mid-span acceleration of the simply supported beam is greater than the displacement of the beam span, and the greater the moving mass velocity, the more prominent the phenomenon.

(3) Considering the track irregularity, the overall variation of the displacement and acceleration of the front beam is unchanged. The greater the acceleration of the moving mass, the larger the displacement of the front beam and the larger the response of the acceleration; the relative position of the moving mass is relatively larger in the structure of the hinged end and the front tie rod; the relative position is in the front and middle tie rods, ie the two elastic supports During the period, the vibration displacement and acceleration of the front girders are small, and the vibration is relatively stable. When the relative position exceeds the middle tie rod, the trend of displacement and acceleration amplitude is more obvious.

References

[1] K.L Knothe,S.L.Grassie. Modelling of railway track vehicle/track interaction at high frequency[J]. Vehicle System Dynamics,1993(22): 209-26.

[2] K. Hou,J. Kalouse, R. Dong. A dynamic model for an asymmetrical vehicle/track system[J]. journal of Sound and Vibration,2003,267:591-604.

[3] Luis Baeza, Huajin, Ouyang. A railway track dynamics model based on modal substructuring and cyclic boundary condition[J]. Jurnal of Sound and Vibration, 2011,330:75-86.

[4] Ping Lou. A vehicle-track-bridge interaction element considering vehicle' spitching effict[J]. Finite Elements in Analysis and Design, 2005(41):397-427.

[5] X. Lei, N.-A. Noda. Analyses of dynamic response of vehicle and track coupling system with random irregularity of track vertical profile[J]. Journal of Sound and Vibration,20021258(1):147-165.