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Pulse Sequence Frequency Selection Method of High Frequency Shake-out Machine

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Abstract. The pulse sequence frequency is an important control parameter of shake-out machine. Traditionally, the selection is done by trial and error. This method is low in efficiency, wastes energy in repeated impact tests, and the selected pulse frequency reliability is low, so it often fails to get good shake-out effect. Aiming at the shortcomings of the trial and error method, the method of selecting the pulse frequency of air hammer by means of modal analysis and harmonic response analysis of castings is proposed. The value range of frequency is greatly reduced and the optimization efficiency of pulse frequency is improved by means of this method.

Introduction

The shake-out of complex casting has always been a complex and laborious part in the process of casting cleaning. In the process of shake-out, the choice of the shock pulse frequency is traditionally chosen by trial and error. According to the experience, the traditional method shocks the casting by trial and error method, and then cuts the casting to observe the shakeout effect. But this method is low-efficiency, repeated shock tests waste energy and the reliability of the selected pulse frequency is also low. The shakeout effect is not good.

In view of the shortcomings of the above methods, a new method is proposed. The pulse frequency of air hammer is selected by modal analysis and harmonic response analysis. This method improves the efficiency of frequency selection, and the choice of the pulse frequency verified by the practice of the shakeout effect is better. The value range of frequency is greatly reduced and the optimization efficiency of pulse frequency is improved by means of this method.

The Working Principle of Shake-out Machine

The shake-out machine works by using air hammer to repeatedly shock the castings, at the same time, vibrating the casting by vibrating motor to achieve the purpose of shakeout. The air hammer repeatedly shocks the casting, which corresponds to the sequence of pulses acting on the casting[1]. The structure of the shake-out machine is shown in Fig. 1 (1-Lower machine base; 2-Isolator; 3-Upper machine base; 4-Vibrating motor; 5-Air hammer mounting seat; 6-Air hammer; 7-Clamping fixture; 8-Rubber gasket; 9-Casting placing platform; 10-Pneumatic clamping mechanism)[2]. Different castings require different pulse frequency, thus according to tests to select a different pulse frequency.

Spectrum Analysis of Air Hammer Shock Pulse Sequence

The air hammer repeatedly shocks the casting, which corresponds to the sequence of pulses acting on the casting. The periodic rectangular pulse sequence with equal intervals is represented by a rectangular pulse sequence function rec(t,T0,τ,A), as shown in Fig. 2. Based on Fourier transform theory[3,4], the spectrum analysis of pulse sequence of shakeout shock force is carried out. The relationship between the time domain parameters and the frequency domain parameters of the shock pulse sequence is obtained.

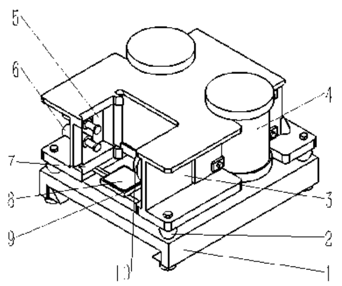

Figure 1. The structure of the shake-out machine

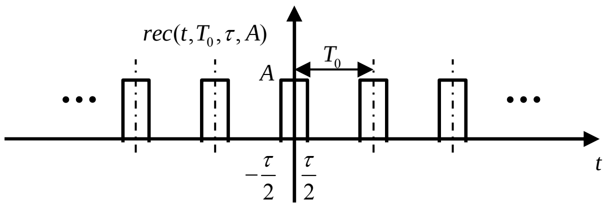

Figure 2. The periodic rectangular pulse sequence

The rectangular pulse sequence can be expressed as:

$$rec(t,T_0,\tau,A) = w(t) * comb(t,T_0)\ . \tag{1}$$

Where: $w(t)$—Rectangular pulse function, as shown in Fig. 3. $comb(t,T_0)$—Comb function, as shown in Fig. 4.

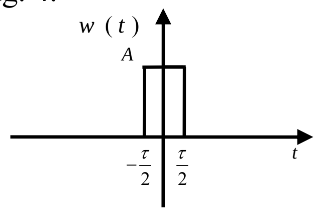

Figure 3. The rectangular pulse function

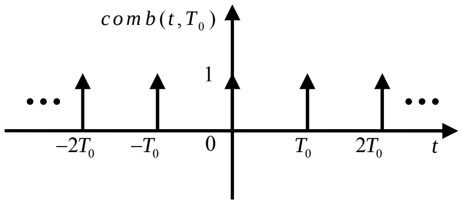

Figure 4. The comb function

$$w(t) = \begin{cases} A & |t < \tau/2| \\ 0 & |t > \tau/2| \end{cases} \tag{2}$$

$$comb(t,T_0) = \sum_{-\infty}^{+\infty} \delta(t - nT_0) \tag{3}$$

According to the convolution theorem, the Fourier transform of the function of the rectangular pulse sequence is:

$$rec(f, f_0, \tau, A) = \frac{A\tau}{T_0} \sin c(\pi f \tau) \sum_{k=-\infty}^{+\infty} \delta\left(f - \frac{k}{T_0} \right). \tag{4}$$

Where: rec(f, f_0, τ, A)—The spectrum of rec(t, T_0, τ, A).

For better study of the relationship between pulse width and spectrum, take the value of amplitude A to be 1, and the value of the period T_0 to be 5s. Changing the pulse width, we can get the spectrum corresponding to the pulse sequence with different pulse width. The relationship between the fundamental frequency amplitude of spectrum and the pulse width is obtained by analysis, as shown in Fig. 5.

Accordingly, for the rectangular pulse sequence force with amplitude A, period T_0 , pulse width τ :

When the pulse width is 1/2 of the period, the fundamental frequency amplitude of the pulse spectrum is the largest. The spectrum is a series of pulse whose amplitude is $A/\pi k \sin(\pi\tau k/T_0)$ and frequency is k/T_0 (k=0,±1, ±2, ±3,...), and the adjacent pulse interval frequency is $1/T_0$. The magnitude of the pulse sequence spectrum is also related to the pulse sequence amplitudes A and harmonic order number k. The larger the pulse amplitude, the greater the corresponding spectrum amplitude. The larger the harmonic order number k , the smaller the amplitude of the spectrum. When the pulse width τ is constant, the larger of the pulse period T_0, the denser the spectrum, and the smaller the amplitude of the spectrum.

Therefore, if the pulse width is equal to or close to 1/2 of the pulse period, and the pulse frequency is close to the natural frequency of the casting, and the frequency spectrum density of the pulse sequence is changed by adjusting the pulse sequence period, more frequency components corresponding to or close to the natural frequency of the casting will be more conducive to the shakeout.

Primary Selection of Frequency of Shock Pulse Sequence of Air Hammer

First of all, using the SolidWorks to build a three-dimensional model of castings. Because the casting structure is complex, the casting is modeled by the block modeling method. After modeling, the local details are processed and some sharp corners are rounded. The overall 3D model and section diagram are shown in Fig. 6.

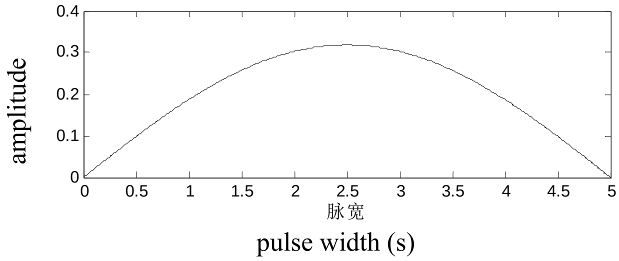

Figure 5. The relationship between the fundamental frequency amplitude of spectrum and the pulse width

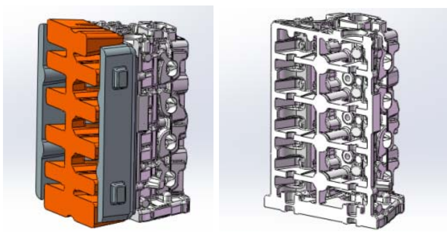

Figure 6. The three-dimensional model of casting

In order to make full use of the resonance effect to obtain a good shakeout effect, the pulse frequency should be chosen to coincide with the natural frequency or near the natural frequency of the casting. Therefore, in order to obtain the approximate optimization range of the pulse frequency, we need to carry out modal analysis of the casting to obtain the natural frequency of each order.

Defining material parameters in workbench[5,6], then according to the actual situation of the project, the casting is elastically restrained[7,8]. The finite element model of castings with 968502 number of elements was obtained by meshing the castings with the type Solid187 elements[9,10], as shown in Fig. 7.

Set the modal extension frequency range[11] to 0-2000Hz. By conducting modal analysis on the casting, the natural frequencies of each order of the casting are obtained as shown in Table 1.

Through the modal analysis of castings, the natural frequencies are obtained, and the approximate frequency range is determined for the selection of pulse frequency.

Combined with the pulse sequence spectrum, the coincidence of the pulse frequency and the natural frequency of the casting will cause the casting resonance. If the fundamental frequency of the pulse spectrum corresponds to the first-order natural frequency of the casting, then the fifth harmonic frequency of the pulse spectrum is close to the seventh-order natural frequency of the casting, the sixth harmonic frequency of the sequence pulse spectrum approaches the tenth order natural frequency of the casting. In this way, more frequencies correspond to the natural frequencies of the casting, so as to better utilize the resonance effect.

Table1. The natural frequencies of castings

Modal order	Natural Frequencies [Hz]	Modal order	Natural Frequencies [Hz]
First	313.71	Sixth	1476.20
Second	362.67	Seventh	1551.20
Third	855.83	Eighth	1679.80
Forth	868.75	Ninth	1694.90
Fifth	1380.3	Tenth	1826.30

Determination of Frequency of Pulse Sequence of Air Hammer

In order to further determine the maximum response value of a certain frequency in the casting, the harmonic response analysis of the casting is necessary, so that the selection range of the pulse frequency can be further reduced. Through the modal analysis of castings, the natural frequencies are obtained, the maximum modal frequency of the casting is 1826.3Hz. In order to obtain the equivalent stress and the deformation of the casting maximum response peak frequency under the action of the pulse force, the harmonic response analysis is carried out.

First entering the ANSYS Workbench[12,13], setting the frequency range and step of the harmonic response analysis. The frequency range is set to 0Hz - 2000Hz, and the step size is set to 50Hz, and Mode Superposition is chosen as the method of solution[14]. In order to compare the response peak at different frequencies, regardless of the magnitude of the stress produced, an arbitrary magnitude of the excitation force is applied to the casting. Therefore, a negative load of 100N along the z-axis is applied on the left end face of the casting to conduct a harmonic response analysis of the casting, as shown in Fig. 8.

By means of harmonic response analysis, the response curves of the equivalent stress and deformation of the bonding interface between the casting and the core sand are obtained, from which the change of the equivalent stress of the bonding interface between the casting and the core sand with the frequency can be obtained, and the maximum response peak frequency of the core sand bonding interface can be obtained. The equivalent stress-frequency response curve in the X direction of the bonding interface between the casting and core sand is shown in Fig. 9.

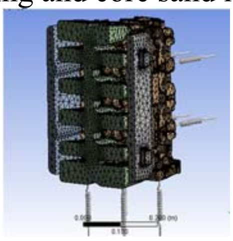

Figure 7. The finite element model of casting

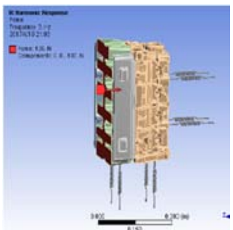

Figure 8. The Harmonic response analysis of casting model

As can be seen from Fig.9, the frequencies of the peak are 313Hz, 880Hz, 1400Hz, 1560Hz, 1680Hz. At the frequency of 313Hz, the response peak of the sand bond interface is the largest, and its equivalent stress is the largest. The peak frequency is mainly near the first, second, seventh and eighth order natural frequencies of the casting. The equivalent stress-frequency response curve in the Y-direction of the interface between the casting and the sand is shown in Fig. 10.

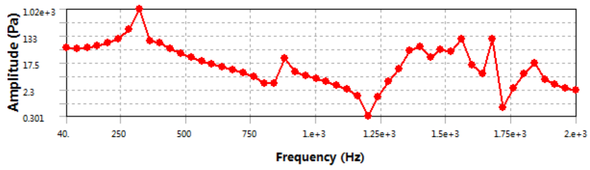

Figure 9. The equivalent stress-frequency response curve in the X direction

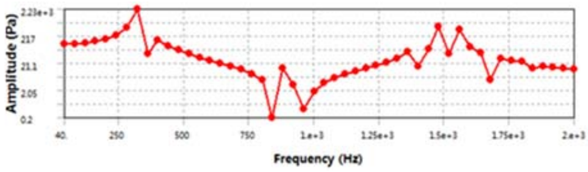

Figure 10. The equivalent stress-frequency response curve in the Y-direction

As can be seen from Fig.10, the frequencies of the peak are 313Hz, 1480Hz, 1560Hz. At the frequency of 313Hz, the equivalent stress of the interface of the sand is the largest. The equivalent stress-frequency response curve in the Z-direction of the interface between the casting and the sand is shown in Fig.11. As can be seen from Fig. 11, the frequencies of the peak are 313Hz, 1480Hz, 1560Hz. At the frequency of 313Hz, the equivalent stress of the interface of the sand is the largest. It can also be seen that the frequency at which the peak occur in the Y and Z directions are the same. Deformation-frequency response of the bonding interface between casting and sand in the X direction is shown in Fig. 12.

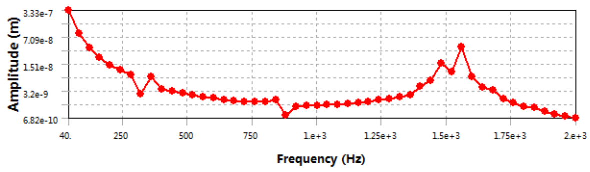

Figure 11. The equivalent stress-frequency response curve in the Z-direction

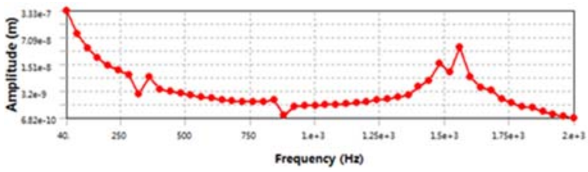

Figure 12. The deformation-frequency response curve in the X–direction

As can be seen from Fig. 12, the frequencies of the peak are 40Hz, 1480Hz, 1560Hz. At the frequency of 40Hz, the shakeout sand bonding interface has the maximum deformation.

Deformation-frequency response of the bonding interface between casting and sand in the Y direction is shown in Fig. 13.

As can be seen from Fig. 13, the frequencies of the peak are 40Hz, 313Hz, 1480Hz, 1680Hz. At the frequency of 40Hz, the shakeout sand bonding interface has the maximum deformation. Deformation-frequency response of the bonding interface between casting and sand in the Z direction is shown in Fig. 14.

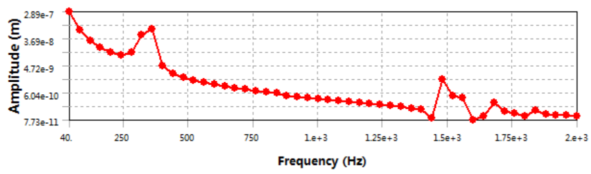

Figure 13. The deformation-frequency response curve in the Y direction

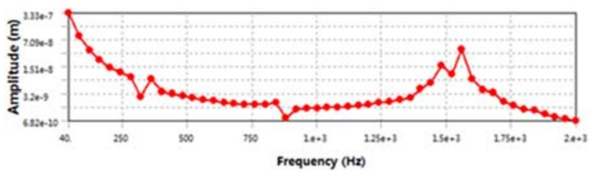

Figure 14. Deformation-frequency response curve in the Z direction

As can be seen from Fig.14, the frequencies of the peak are 40Hz, 313Hz, 1480Hz, 1560Hz. At the frequency of 40Hz, the shakeout sand bonding interface has the maximum deformation. Through the harmonic response analysis, the maximum peak appears near the first frequency of the casting, and at the same time there is a maximum peak at the frequency of 40Hz. Combining the modal analysis, the 40Hz frequency and the first order natural frequency of the casting are determined, which are the frequency of the pulse sequence.

The modal analysis of the castings obtains the natural frequencies of the castings, and the optimal selection range of the pulse frequency is roughly determined, then the harmonic response analysis is carried out. The maximum response peak frequency of the interface between cast and sand was obtained by harmonic response analysis. Combined with the modal analysis of the casting, the frequency of the shock pulse is determined, and the range of the pulse frequency is further reduced.

Conclusion

Spectrum analysis of pulse sequences produced by air hammer shock casting is carried out, the relationship between the time domain parameters and the frequency domain parameters of the pulse sequence and the influence of the parameters on the spectrum of the pulse sequence is obtained.

The frequency spectrum analysis, the modal analysis and the harmonic response analysis are applied to the selection of the pulse frequency, which significantly reduces the range of pulse frequency and improves the efficiency of pulse frequency optimization.

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