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Optimization of Vibration Reduction Performance of Subway Air Compressor

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Abstract

Vibration of air compressor has a great impact on smoothness and comfort of subway. In order to effectively reduce vibration of air compressor, based on finite element model of air compressor and active vibration control theory, vibration reduction optimization design is carried out. By means of finite element simulation and calculation, parameters of damping element, including hanging frequency, stiffness and damping ratio, are optimized by combining sweep-frequency excitation and constant-frequency excitation, and verified by experiments. The results show that the lower hanging frequency of air compressor, the better its vibration isolation efficiency. The higher damping ratio, but the lower vibration isolation efficiency. According to results of sweep-frequency excitation simulation, the optimal hanging frequency of air compressor is 7Hz and damping ratio is 0.06. Results of constant-frequency excitation simulation and experiments indicate that, when the optimal scheme is applied, the vibration isolation efficiency can reach to about 90%, which meets design requirements.

Keywords: subway, air compressor, vibration reduction optimization, vibration test, finite element simulation, vibration isolation efficiency.

1 Introduction

The air compressor of subway is the power device that provides compressed air, whose smooth operation is the prerequisite for normal running of braking device and other pneumatic components, and is related to operation efficiency and braking status of subway [1-2]. Due to high rotational speed of air compressor and the exist of excitation source, vibration and noise will be generated in operation process, which affects passenger comfort. Running state of air compressor has great influence on the comfort index of middle part of subway. Therefore, it is particularly important to optimize the damping mode of air compressor. The purpose of the presented study is to get a better understanding of parameters of damping element of air compressor, including stiffness and damping ratio, and optimization scheme for vibration reduction which is aimed at the index closely related to engineering application. Based on the finite element model of air compressor, including frame, suspension and shock absorber, and active vibration control theory, vibration reduction optimization design of air compressor is carried out, and then is verified by experiments. The influence of different performance parameters of damping elements of air compressor is discussed and studied, which is beneficial for top-down design of air compressor in the process of subway research and development.

2 Methods

Periodic excitation will be generated when air compressor works. Based on this feature, this paper adopts active vibration control theory to conduct vibration reduction optimization, which is defined as dynamic effect of excitation source of isolation equipment on hanging place [3]. According to this theory, usually in practical engineering, frequency ratio of excitation frequency to natural frequency is best between 2.4 and 4.

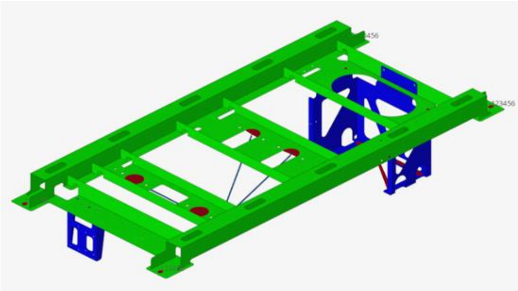


Figure 1: Finite element model of air compressor.

In this paper, a finite element model of air compressor is established as shown in Figure 1, which is used for subsequent simulation calculation and analysis. 1D element is used to simulate spring shock absorber between air compressor and frame, mass point is established at the centroid of air compressor to simulate its mass. The excitation of air compressor is simulated by sweep-frequency excitation and constant-frequency excitation respectively. Sweep-frequency excitation is used to simulate operation of air compressor and the effect of external loads on air compressor. Constant-frequency excitation is used to further check vibration isolation efficiency of damping element when air compressor works normally. Calculation method of vibration isolation efficiency is as follows:

$$Vibration\ isolation\ efficiency = \frac{A-B}{A} \times 100\% \tag{1}$$

Where, A is effective value of vibration acceleration before damping (m/s²), B is effective value of vibration acceleration after damping (m/s²).

In order to verify the vibration reduction optimization obtained by finite element simulation, air compressor is installed on the standard tooling to simulate the loading state. Acceleration sensors are installed before and after damping elements to collect vibration of air compressor under steady pressure, which is shown in Figure 2. Using Equation (1), calculate vibration isolation efficiency to assess whether it meets requirements.

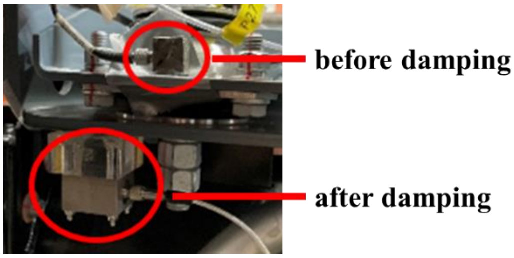


Figure 2: Installation position of acceleration sensor.

3 Results

Figure 3 shows calculation results of vibration isolation efficiency when air compressor adopts different hanging frequencies (5~17Hz), and damping ratio is 0.06. With the increase of hanging frequency, stiffness of damping element increases, but vibration isolation efficiency decreases. When hanging frequency is lower than 9Hz, isolation efficiency is relatively well (above 60%), and the frequency ratio between excitation frequency of air compressor and its natural frequency is above 2.5.

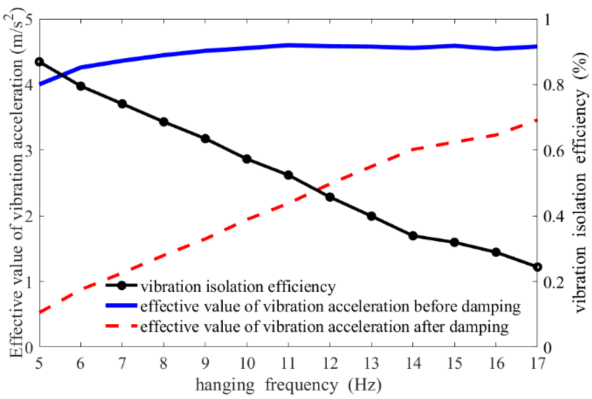


Figure 3: Calculation results with different hanging frequencies.

Table 1 shows the calculation results of vibration isolation efficiency when damping ratio of damping elements is set to 0.10 and 0.20 respectively. Combined with Figure 3, with the increase of damping, vibration isolation efficiency slightly decreases, which is consistent with the trend of vibration transmission characteristic curve of active vibration isolation with single-degree-of-freedom. Considering that stiffness and damping of rubber have certain discreteness, and deflection of air compressor should not be too large, the optimal hanging frequency of air compressor is 7Hz and damping ratio is 0.06.

	damping ratio = 0.10			damping ratio = 0.20		
hanging frequency	A [m/s^2]	B [m/s^2]	vibration isolation efficiency	A [m/s^2]	B [m/s^2]	vibration isolation efficiency
5Hz	3.38	0.494	85.4%	3.705	0.518	86.0%
6Hz	3.437	0.759	77.9%	3.859	0.833	78.4%
7Hz	3.455	0.951	72.5%	3.926	1.065	72.9%
8Hz	3.461	1.146	66.9%	3.974	1.304	67.2%

Table 1: Calculation results with different damping ratio.

Based on the above optimal scheme, unit excitation force of 24.5Hz (main operating frequency) is applied at the centroid of air compressor. Figure 4 shows amplitude-frequency diagram of vibration acceleration before and after damping. The vibration transmission from air compressor to frame can be well suppressed, and vibration isolation efficiency can reach to 90%.

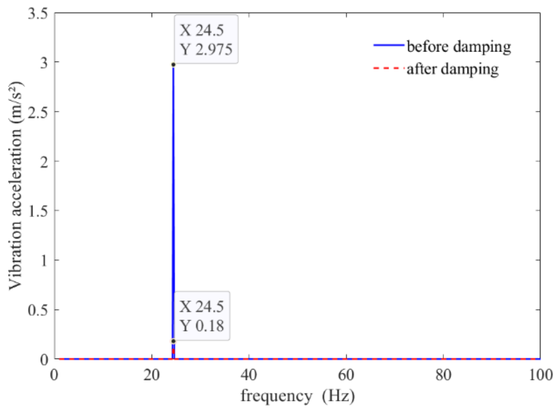
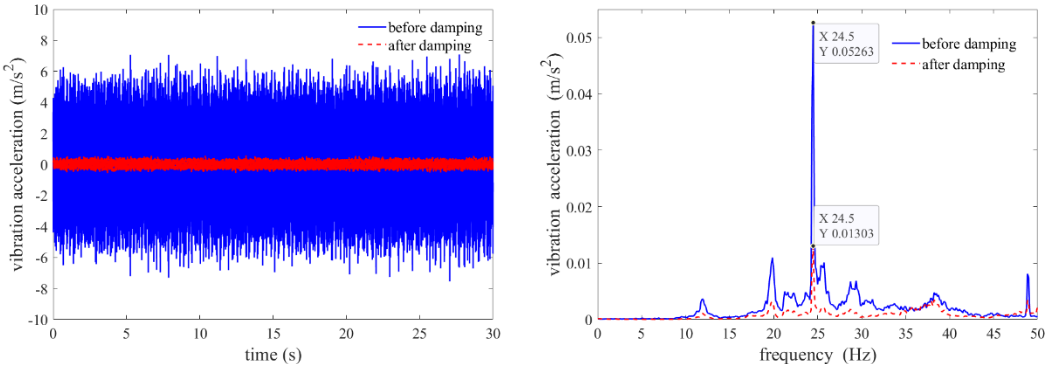


Figure 4: Amplitude-frequency diagram of vibration acceleration before and after damping in 24.5Hz

In order to verify the optimization, vibration reduction test was carried out. As can be seen from Figure 5, vibration transmitted to frame is significantly reduced. Vibration isolation efficiency in 24.5Hz is 75%; effective value of vibration acceleration before damping is 2.64 m/s^2, effective value of vibration acceleration after damping is 0.16 m/s^2, vibration isolation efficiency is 94%, which meet requirements.



a) Time domain b) Frequency domain

Figure 5: Comparison of vibration before and after vibration reduction.

4 Conclusions and Contributions

In this paper, hanging frequency and damping ratio are taken as optimization targets, and vibration isolation efficiency is taken as optimization evaluation results, to achieve the goal of vibration optimization. Based on active vibration control theory, parameters of vibration damping element are optimized through finite element simulation calculation, and rationality of optimization scheme is verified by experiments. The simulation results show that the lower the hanging frequency of air compressor, the lower stiffness of damping elements, and the better vibration isolation efficiency. At the same time, the ratio of working frequency to natural frequency of air compressor should be higher than 2.5 to really reduce vibration. In addition, with the increase of damping ratio of damping elements, the vibration isolation efficiency decreases. Reasonable setting of hanging frequency, stiffness and damping ratio can effectively relieve vibration and avoid excessive deflection of air compressor, which can improve comfort index of subway. Results of constant-frequency excitation simulation and experiments indicate that, when hanging frequency of air compressor is designed as 7Hz and damping ratio is 0.06, the vibration isolation efficiency can reach to about 90%, which meets design requirements. Rich theoretical basis and reliable test data are helpful for further top-down design of air compressor of subway in the process of subway research and development.

Acknowledgements

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