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A MICRO-VIBRATION ACTIVE CONTROL METHOD BASED ON PIEZOELECTRIC CERAMIC ACTUATOR*

Z. Lei, R. Deng†, H. Deng
Shanghai Advanced Research Institute-Chinese Academy of Sciences, Shanghai, China

Abstract

In linear accelerator, ground vibration is transmitted to beam element (quadrupole magnet, etc.) through support, and then reflected to the influence of beam orbit or effective emittance. In order to reduce the influence of ground vibration on beam orbit stability, an active vibration isolation platform can be used. In this paper, an active vibration isolation system is proposed, which realizes the inverse dynamic process based on a nano-positioning platform and combines with a proportional controller to reduce the transmission of ground-based excitation to the beam element. The absolute vibration velocity signal obtained from the sensor is input to the controller as feedforward signal. The controller processes the input signal and then the output signal drives the piezoelectric ceramic actuator to generate displacement, realizing the active vibration control. The test results of the prototype show that the active vibration isolation system can achieve 50 % displacement attenuation, which indicates that the vibration control strategy has certain engineering application value in the construction of large accelerators.

INTRODUCTION

Shanghai High Repetition rate XFEL (X-ray Free Electron Laser) and Extreme light facility (SHINE) currently under construction is one of the most efficient and advanced free electron laser user installations in the world [1, 2]. It consists of a superconducting linac with an energy of 8GeV, three unshaker lines, three optical beam lines, and the first 10 experimental stations. The superconducting linear accelerator is composed of superconducting acceleration modules, each 1.3 GHz module is about 12 meters long, and mainly includes 8 TESLA type 9-cell superconducting cavities [3], couplers, tuners, BPM and superconducting quadrupole iron at one end. In order to achieve the submicron beam stability requirements of the superconducting linac and to suppress the cavity frequency deviation caused by mechanical vibration, the position jitter tolerance is generally not more than 10 % of the beam size [4]. In particular, engineering requires that the amplitude of some quadrupole magnet be less than 0.15 µm (1 Hz-100 Hz) perpendicular to the beam direction. SHINE facility is close to the Shanghai Synchrotron Radiation Facility (SSRF). The German Electron Synchrotron Institute has compared and analyzed the ground vibration of major light sources around the world, and the results show that the ground vibration level of the SSRF campus is significantly higher than that of other light sources [5]. Therefore, it is of practical significance for engineering construction to develop an active vibration isolation platform suitable for large accelerators.

DESIGN OF THE ACTIVE VIBRATION CONTROL STRATEGY

In order to reduce the influence of foundation vibration on quadrupole magnet, an active vibration isolation platform is used to reduce the transfer rate of displacement from foundation to magnet. In this paper, an active vibration isolation system is proposed, which realizes the inverse dynamic process based on a nano-positioning platform and combines with a proportional controller to reduce the transmission of ground-based excitation to the beam elements. The absolute vibration velocity signal obtained from the sensor is input to the controller as a feedforward signal. The controller processes the input signal and then the output signal drives the piezoelectric ceramic actuator to generate displacement to realize active vibration control.

EXPERIMENTAL RESULTS

For the evaluation of the proposed control strategy, the test bench shown in Fig. 1 is used. Ground broadband vibration act as excitation, and four piezoelectric actuator implements the described isolating strategy in the direction of gravity for damping the vibration in the upper mass M (260 kg).

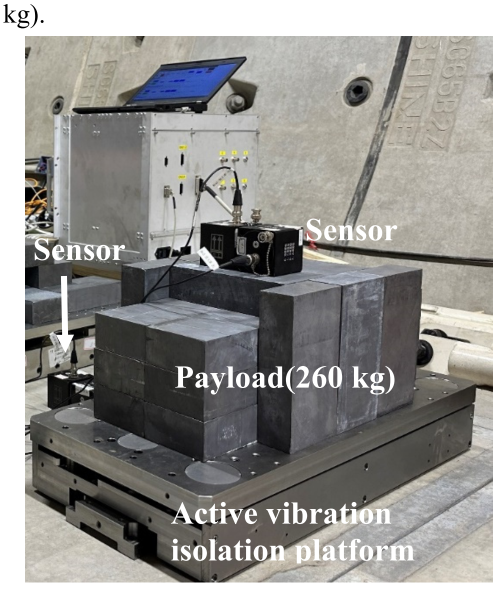

Figure 1: Test bench.

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† dengrb@sari.ac.cn

Figure 2 shows the comparison of the displacement power spectral density obtained from ground and the surface of the payload when the active vibration control is on in a typical condition. The 1 Hz-100 Hz root-mean-square (RMS) value of displacement on the ground is 0.294 µm and on the payload is 0.128 µm, which means a displacement attenuation rate of 56 % is achieved.

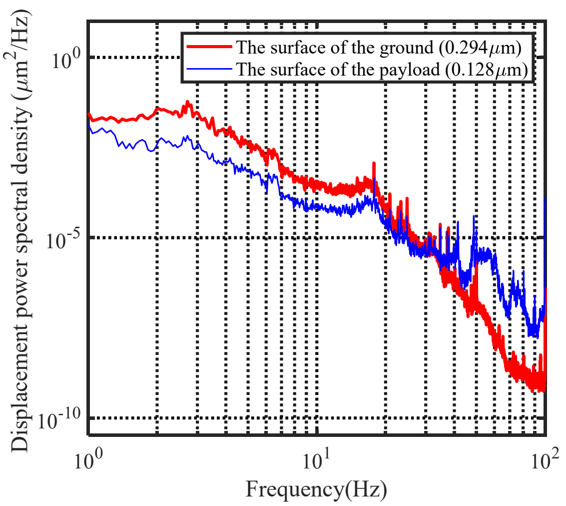

Figure 2: The comparison of the displacement power spectral density in the direction of gravity when the active vibration control is on.

Figure 3 shows the long-term test results of the active vibration isolation platform in the tunnel. As can be seen from the figure, displacement RMS obtained from the payload has a significant raise when the active vibration control turned off.

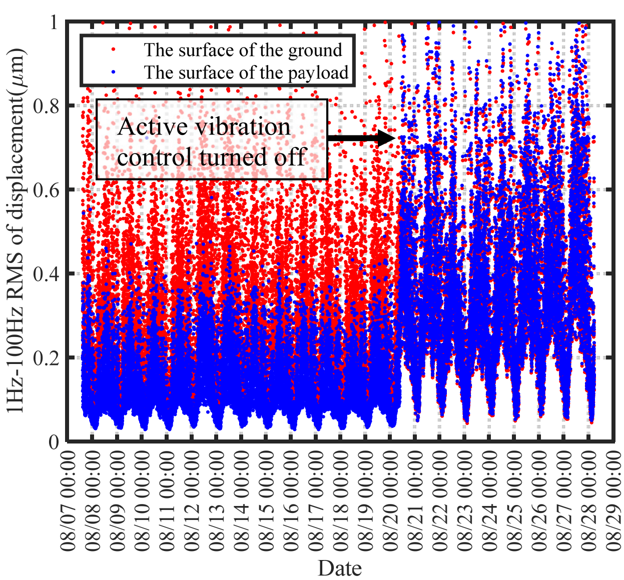

Figure 3: Long-term test results of displacement RMS.

Table 1 summarizes and compares the statistical results of the measured displacement RMS meeting the physical requirement (1 Hz-100 Hz displacement RMS less than 0.15 µm), and the statistical period is 48 consecutive hours from August 8 to August 9, 2023. As can be seen from the table, only 13.71 % of the time of the ground meets the physical requirement, which can be improved to 65.91 % after the active vibration control.

Table 1: Statistical Results of the Displacement RMS

	Less than 0.15µm percentage
Ground	13.71%
Payload	65.91%

CONCLUSION

Vibration control is a challenge for SHINE facility, and the active vibration isolation system proposed in this paper can achieve more than 50 % displacement attenuation in the actual broadband vibration environment, increasing the time to meet the physical requirement of some very demanding quadrupole magnet by 4.8 times.

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