EFFECT OF GROUND VIBRATION ON THE OUT-COUPLED POWER IN A TERAHERTZ FEL OSCILLATOR

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Abstract

To acquire high power out-coupled, we must ensure the co-axis of electron orbit, optical beam and magnetic field. The propagation of ground vibration through the optical platform will lead to misalignment of the optical axis in the FEL optical cavity.Based on measurement results of the ground vibration, simulations of misalignment are studied with GENESIS+OPC. The tolerance of mirror tilt and offset is also discussed.

INTRODUCTION

To maintain high out-coupled power of a resonator free-electron laser, one must guarantee the reflecting mirrors stability and the co-axis of electron trajectory, optical axis and undulator. Misalignment of mirrors resulting from ground vibration may cause a decrease to the output power. In this paper we study the displacement of mirrors resulting from ground vibration, and calculate the effect of mirror offset & tilt on the out-coupled power using GENESIS+OPC[1]. Based on this study, we set tolerances of mirrors offset & tilt and estimate the effect of ground vibration on the stability of a THz FEL oscillator.

VIBRATION MEASUREMENT

The measurement is taken indoor, on the terrazzo floor of our laboratory in Huazhong University of Science and Technology, Wuhan.

The measurement system (CMG series, GURALP) consists of a vibration sensor (T35421), a digitizer (C909), DC power supply and a computer.

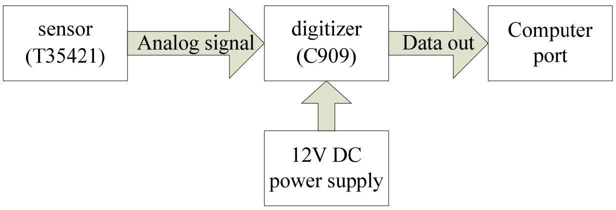

Figure 1: Schematic of measurement system.

Figure 1 shows the linking of hardware in measurement. In the actual measurement, the digitizer and the sensor are set as close as possible to prevent environmental influences on the transmission of analogue signal. After digitizing, the data will be stored and analyzed in PC.

After Fourier transform, the frequency-domain signal of ground vibration velocity $V(f)$ can be converted into the frequency-domain signal of ground vibration displacement by $i\omega D(f)=V(f)$.

The power spectral intensity (PSD) of displacement can be expressed by[2]:

$$S_d(f)=\frac{|D(f)|^2}{\Delta f}. \tag{1}$$

where Δf is the frequency resolution. Thus, the RMS of displacement of ground vibration is obtained by:

$$\sigma=\sqrt{\int_{f_{\min}}^{f_{\max}} S_d df}. \tag{2}$$

In order to reveal the effect of human activities on ground vibration, we pick out two time periods as typical samples: half an hour from 11:00 a.m. representing the time with great amount of human activities, and half an hour from 1:00 a.m. representing the silence time.

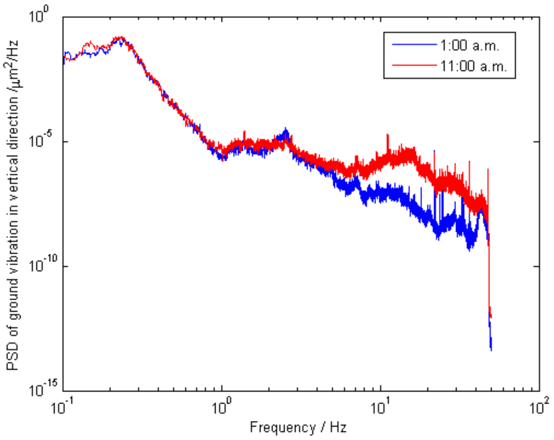

Figure 2: Power spectral density of ground vibration in vertical direction of HUST Terahertz Lab.

Since the sampling rate is 100Hz, here we set the maximum frequency to 50Hz.

These two lines differ little in low frequency, but widely in higher frequency.

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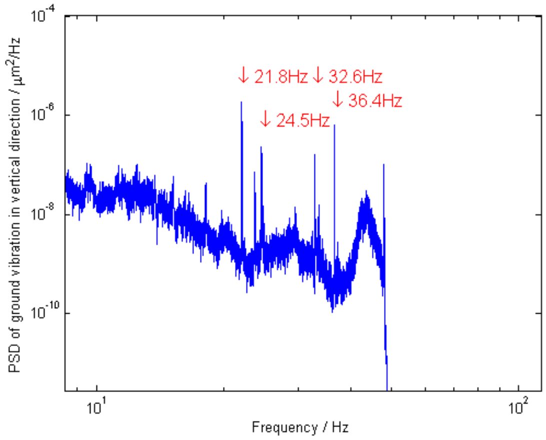

Figure 3: Enlarged image of higher frequency section of ground vibration (1:00 a.m.).

Figure 2 illustrates that the effect of human activities on ground vibration is mainly concentrated on higher frequencies above 10Hz, even late at night, there are still a few peaks in high frequency section. Figure 3 enlarges the section between 10Hz to 50Hz of ground vibration at 1:00 a.m.. Those peaks at 21.8Hz, 24.5Hz, 32.6Hz and 36.4Hz are probably generated by the features of ground and architectural structure.

Assume that the optical table is a simple harmonic oscillator system with eigen-frequency $f_0 = 10Hz$ and damping ratio $\lambda = 1.5$, then this oscillator can be described as below [3]:

$$\ddot{z} + 2\lambda(\dot{z} - \dot{z}_g) + \omega_0^2 (z - z_g) = 0\,. \tag{3}$$

where z is the height of the optical platform, z_g is the height of ground, and ω_0 is the undamped angular frequency of this oscillator.

After Fourier transform, Eq. (3) becomes:

$$-\omega^2 Z + 2i\omega\lambda(Z - Z_g) + \omega_0^2 (Z - Z_g) = 0\,. \tag{4}$$

Therefore, the transfer function can be expressed as

$$H(\omega) = \frac{Z}{Z_g} = \frac{2i\omega\lambda + \omega_0^2}{-\omega^2 + 2i\omega\lambda + \omega_0^2}\,. \tag{5}$$

We can get the effect of ground vibration on the optical platform:

$$\sigma_z^2 = \int \left|H(\omega)\right|^2 \frac{1}{\omega^2} S_v(\omega) d\omega\,. \tag{6}$$

From the spectra of ground vibration velocity and Eq. (6), we obtained the RMS displacement of optical platform in 24h.

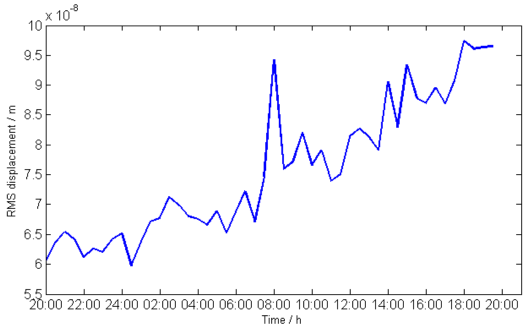

Figure 4: RMS displacement of platform in vertical direction (24h).

Figure 4 shows the RMS displacement of platform vibration in 24h. Around 8:00 a.m., there is a small peak, which is probably caused by the steam of students near the lab. During the whole day, RMS of displacement varies gently in a range from 6×10^{-8}m to 10×10^{-8}m.

Obviously, there is a slightly rising tendency of RMS displacement in 24 hours. Since the terrazzo floor could be uneven, and the measurement sensor is not fixed on the ground, ground vibration may force the sensor to shift toward a certain direction, and results in Figure 4. Though it only causes a small shift in 24 hours, we should consider the accumulation of displacement as a contributing factor to instability in long-term test and operation of FEL.

The vibration in horizontal direction is measured as well. Figure 5 shows RMS displacement of ground vibration in horizontal direction. The very high peak at 3:00 p.m. is caused by human activities in the room. The measurement is taken above the ground and the sensor is very sensitive to the air flow, so here the air disturbance is the main factor of instability in horizontal direction.

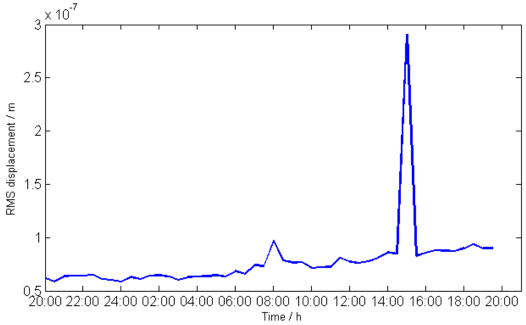

Figure 5: RMS displacement of ground vibration in horizontal direction (24h).

SIMULATION OF MISALIGNMENT

In FEL oscillator, the misalignment of mirror could change the propagation of laser in resonator cavity and lead to modification of optical mode, which would increase the diffraction loss, lower interaction efficiency and result in a reduction of FEL out-coupled power.

Before the building of FEL light source, simulation codes GENESIS/OPC provide a possibility to pre-set the tolerance of alignment.

Table 1: Main Parameters for Simulation of THz FEL

Parameter	**Value**
Beam energy	14MeV
Beam transverse emittance	15mm-mrad
Beam energy spread	0.2%
Bunch charge	200pc
Bunch length	2ps
Micro pulse repetition	2856MHz
Undulator period length	32mm
Undulator periods number	30
Optical cavity length	2.94m
Mirror radius of curvature	1.52m
Mirror radius	30mm
Out-coupling hole radius	1mm

The parameters of electron beam and optical resonator are presented in Table 1. The effects of mirror offset and tilt on out-coupled power are studied with FEL simulation code GENESIS and optical propagation code (OPC). Here we take 10THz as a typical radiation wavelength, set offset or tilt to each mirror in the simulation, and study the tolerance of mirror alignment.

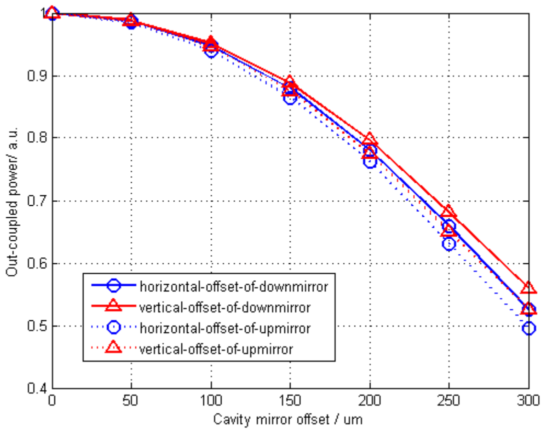

Figure 6: Normalized FEL output power vs. cavity mirror offset.

Figure 6 shows the decrease of saturated output power caused by vertical and horizontal offsets of cavity mirrors. The saturated output power is normalized by the ideal alignment situation. The decline tendencies presented by offset of two mirrors in both directions are nearly the same. When offset increases to 150μm, the remaining output power is less 90%.

Considering of making allowance for design, a requirement of 0.1mm for mirror offset in both directions is reasonable and can be easily laser-calibrated.

Figure 7 shows the dependence of the FEL output power on the cavity mirror angular misalignment. The tilt of mirror in two directions should be controlled in 100μrad or less, which is also can be calibrated by using a He-Ne laser.

Though there is no need to consider rotation of optical platform, the tilt of mirror should still be taken into account. The tilt angle depends on the maximum error of parallelism of rails and ball-screw, which are used in the mechanical structure for cavity mirror adjustment.

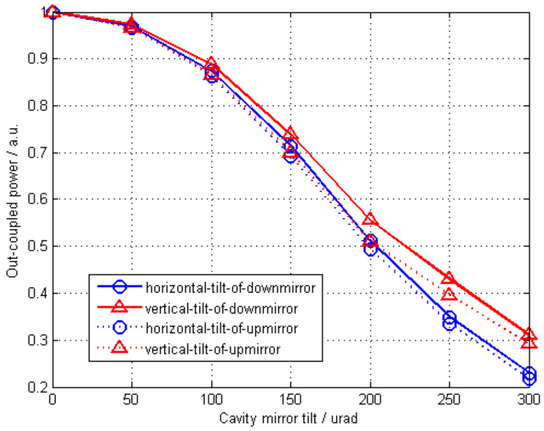

Figure 7: Normalized FEL output power vs. cavity mirror tilt.

CONCLUSION

The effect of ground vibration on the optical platform is restricted in a very small level, which is far more less than the allowance of design requirement. But the cumulative effect of displacement should not be ignored. There will be several air conditioners in the operating room of FEL to control temperature, but air disturbance has a great influence on the vibration in horizontal direction. So we must carefully consider the vibration isolation measurements, piling the platform into ground may help.

The measurement of ground vibration and three dimensional numerical simulation of mirror alignment have been carried out. The result can be taken for reference in cavity alignment and construction of optical platform.

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