On the stabiliy of a vacuum chamber support

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Abstract

For vibration sensitive applications with optical instruments operated under vacuum environment, the mounting of a vacuum chamber above the optical table needs to be carefully designed. Both the large mass of the chamber and the high gravity centre of the chamber, compared with the distance between the narrowest spaced feet, lead to low resonant frequencies with undesired rotational modes. The table tilts from one side to another. The movement varies with different position above the tabletop and will lead to misdiagnosis.

In the laser hutch at PSI SwissFEL 250 MeV, vacuum chambers are elastically supported on a frame and isolated from the optical table with flexible bellows. The vibration measurement is presented to verify the vibration isolation concept of optical table and the uncoupling effect between the chamber and the table.

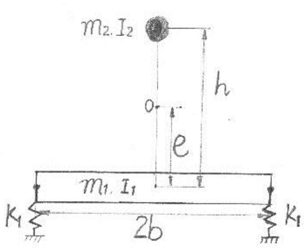
1. Natural frequency of structure with high mass center

Finite element method provides a versatile tool for the investigation of the vibration behaviour. Analytical method, however, is useful at the early design stage as many details are still unknown. The complicated structure is represented and analysed with spring-mass system.

1.1 Rigid body mode of spring-mass system

Optical table, espically those with soft air-spring isolation, exhibits as the first vibration mode a rigid body mode. Considering a spring-mass system shown in Figure 1, a compound has two rigid bodies with mass m_1 and m_2, and moment of inertia I_1 and I_2, respectively. The total mass $m = m_1 + m_2$, and the total stiffness $k = 2k_1$. With $e = m_2\, h/m$, the moment of inertia about the centre of rotation is

$I = I_1 + I_2 + m_1 \times e^2 + m_2 \times (h\text{-}e)^2$. The natural frequency of translational mode f_t and rotational mode f_r can be estimated.



$$f_t = \frac{1}{2\pi}\sqrt{\frac{k}{m}}$$

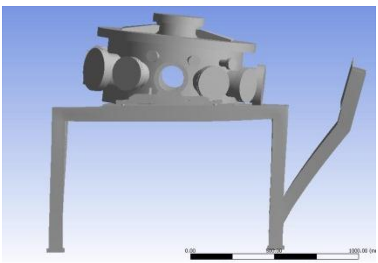
$$f_r = \frac{1}{2\pi}\sqrt{\frac{b^2 k}{I}}$$

Figure 1: Spring-mass system

For structure with high gravity centre the rotational mode could be dominant. Table systems with soft support exhibit rock movement about the roll centre. The motion is stable only if gravity centre is lower than a restricted height [1], [2]. It is therefore advantageous that heavy and high apparatus is supported separately so that the stability of optical table will not be affected.

1.2 Numerical modal analysis of vacuum chamber support

In the PSI SwissFEL 250 MeV laser hutch a vacuum chamber has a weight of 500 kg. The chamber is supported on a welded steel frame, connected with the stiff supported optical table through elastic bellows. Finite element analysis on the chamber support is performed using ANSYS workbench V14.5 with 3D solid elements. The ion pump is represented as a dummy mass at its centre of gravity.



Natural frequency

1. 20 Hz
2. 24 Hz
3. 26 Hz
4. 31 Hz
5. 40 Hz

Figure 2: First eigenmode and natural frequencies

2. Vibration measurement

Vibration measurement has been performed in November 2012 before commissioning.

2.1 Impact testing

Impact testing with modal hammer was performed to verify the uncoupling property of the chamber and table. An impact force was applied on the supporting frame of the chamber, the acceleration response on the table and on the chamber was measured, respectively. The frequency response function (FRF) of the acceleration response to the input force was calculated [Figure 3]. Upon the peak force of 561 N a high vibration of 540 µm/s^2 was measured on the frame. The maximal acceleration on the table during the impact was only 3.1 µm/s^2, at the same level as before and after the impact. From Figure 3 the natural frequencies of the chamber are found at 17 Hz, 21 Hz, 27 Hz, 31 Hz and 41 Hz. The first two natural frequencies from analysis are 3 Hz higher than those from the measurement, while the third to fifth frequency is well comparable. The measurement proves the good damping of the flexible chamber support to the table and ground, and excitations from pumps to chamber can be absorbed. This is beneficial to the well isolated and stable table.

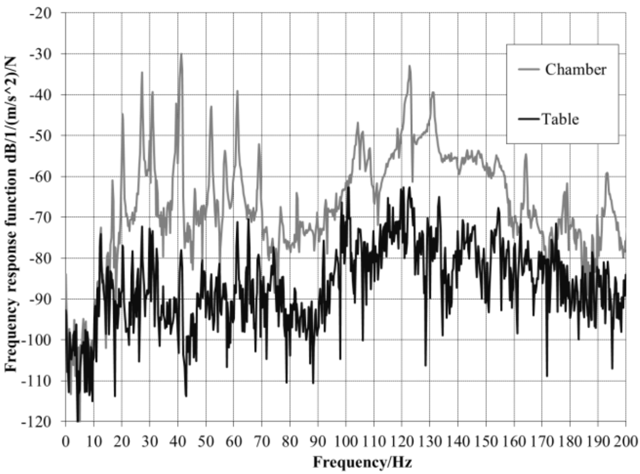


Figure 3: Frequency response function (FRF) of chamber and table

2.2 Random vibration measurement

Ground vibration and vibration on the table and chamber were measured without any excitation. Random vibration in vertical direction was recorded as acceleration time data. From the acceleration time signal the power spectral density (PSD) was calculated. Double integration of the PSD acceleration results in PSD displacement. Table 1 depicts the amplification ration of table to ground was only 1.11, while the ratio of chamber to ground reached 2.38 which is much higher. This measurement evidences again the excellent table stability achieved by the separation of chamber from table.

Table1: Integrated displacement from 5 to 200 Hz and amplification ratio with respect to ground vibration

	Integrated displacement/nm	Amplification ratio
Floor	12.3	-
Table	13.7	1.11
Chamber	29.3	2.38

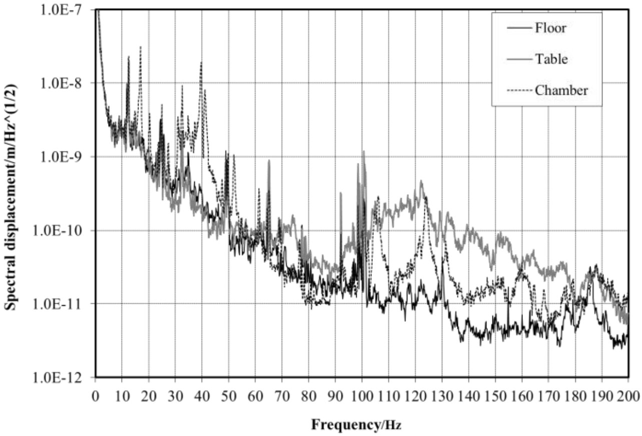


Figure 4: Spectral displacement /$m/\sqrt{Hz}$ on the floor, table and chamber

Acknowledgement:
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References:

[1] CVI Melles Griot Fundamentals of vibration isolation, pp 9.22-9.24
[2] Newport Seminar Notes: Instability & oscillation of high CG table system