VIBRATION CHARACTERISTIC OF A STABLE SUPPORT STAND USING CORDIERITE CERAMIC

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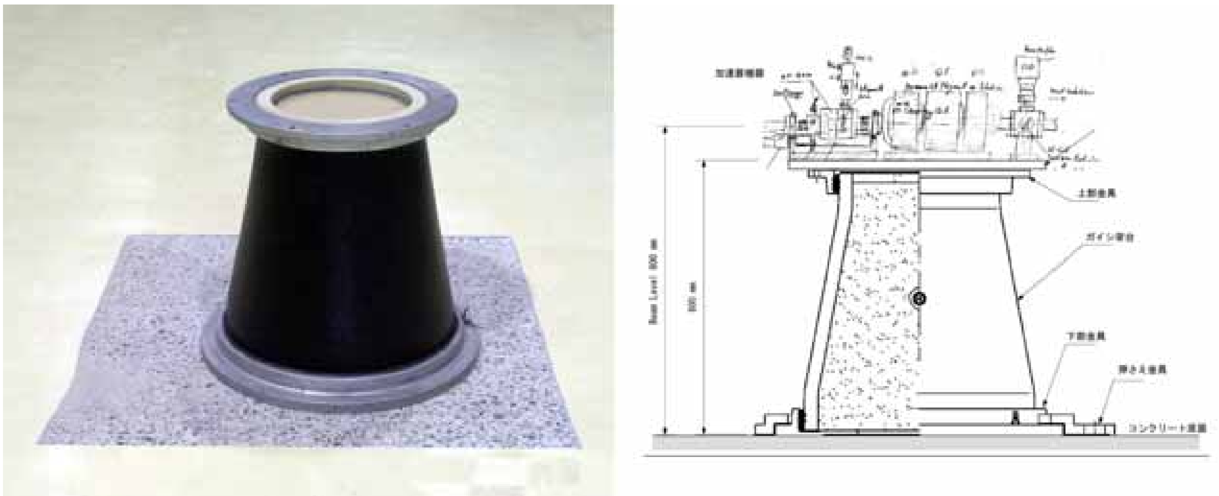
Abstract

We have developed a stable ceramic stand in order to support high-precision BPMs: beam position monitors and focusing elements along the SCSS X-ray FEL accelerator. The support is made of a cordierite material that has a very low thermal-expansion coefficient of ~2 x 10^{-6} /^{0}K. The inside of the stand is filled with sand to increase the inertia by sand weight and to increase its vibration damping by friction among its grains. By employing the above-mentioned devices, the stand provides lower mechanical vibration amplification. In this paper, we describe the stability of the cordierite stand. For example, the vibration amplification was evaluated by a comparison between earth background vibration data measured with seismometers set on the stand and the floor. The low-frequency components below 0.1 Hz of the data include amplification dependent on the thermal expansion of the stand. The effect of vibration damping was compared between the cordierite and a stainless-steel stand. The impulse responses for the comparison between them were measured by vibration generated with a hammer. The damping time of the cordierite stand was about one hundred-times lower than that of the stainless-steel stand. The responses of the stands to strong vibration were also measured by using a shaker having a rotating eccentric mass on the stands. In each case of the above-mentioned measurements, the cordierite stand had smaller vibration amplification and bigger damping than those of the stainless-steel stand.

1. Introduction

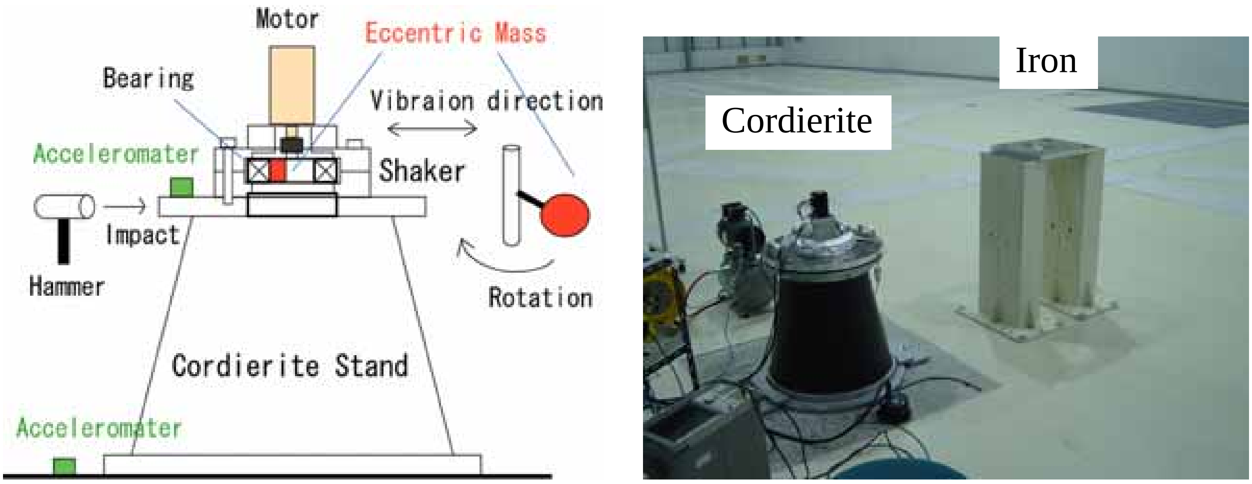
We use a cordierite material to support accelerator components in order to stably generate an X-ray free electron laser,[1] which we are now developing at Spring-8 site. This requires tight alignment. The key issue to successfully obtain an X-ray laser having 1 Å wavelength is that the alignment error of the undulator section should be within 10 μm, because of the error tolerance of the electron beam orbit. Therefore, we must decrease the vibration of the accelerator components caused by such sources as environmental and cooling-water vibration. One of the sources related to unnecessary vibration below 0.1 Hz is mainly the thermal expansion of the support stand for such components as a quadrupole magnet. For example, the thermal expansion of a steel support stand one meter in height is more than 10 μm, for a temperature change of 1 ^{O}K. This value exceeds the alignment error tolerance for the undulator section. An accelerator element having a size of X 0.3 m, Y 1m, Z 0.3 m, which is supported by two steel stands that are one meter tall in the Y direction, tilts by one side of the stands with a thermal expansion of 10 μm, if there is a temperature difference of 1^{0}K between the stands. This tilt causes a 30 μm poison shift of the X and/or Z directions at the top end of the element from a perpendicular line of the ground surface. This position shift is unacceptable, because of the tolerance.

Therefore, we developed a cordierite support stand[2] that has low thermal expansion to reduce this kind of shift and expansion. The support stand (Fig. 1) has casting ion flanges that are cemented to the top and bottom ends of the stand. This fixing technology is used in the case of using a suspension-type insulator that experiences a high voltage for a long time. To suppress unnecessary vibration coming from the environment, and to have massive weight for increasing the moment of inertia, sand is filled inside the stand in order to provide vibration damping by friction among the grains. The outer surface of the stand is coated with black urethane rubber in order to prevent breaking the ceramic. Furthermore, in order to obtain stable coupling between the bottom flange surface of the stand and the ground floor, a concrete floor is grinded as a precision surface plate with a grinding machine for making a flat surface within +/-50 μm/m flatness.[3] By making flat surfaces, we could employ an air-levitation mechanism on the bottom surface of the stand to horizontally align the accelerator element on the stand. The mechanism and the flat floor grinded for adjusting the height provide easy positioning for the vertical and horizontal alignments without any adjustment mechanism, such as a screw. This kind of adjustment mechanism is usually a source of unnecessary mechanical vibration. For checking the vibration characteristics of the stand, as mentioned above, we measured the vibration responses by three methods, such as observation of the earth background vibration noise with a seismometer, the impact response of the stand with a hammer, and the sinusoidal wave response with a rotating eccentric mass shaker. This paper describes what cordierite is as well as the vibration characteristics of the cordierite support stand, and compares the characteristics between the cordierite stand and the stainless-steel stand that is usually used in an accelerator.



(A) (B)

Fig. 1. Photo (A) and schematic drawing (B) of the cordierite support stand for accelerator components, such as a quadrupole magnet and a beam-profile monitor.



(A) Instruments arrangement (B) Photo of the experiments

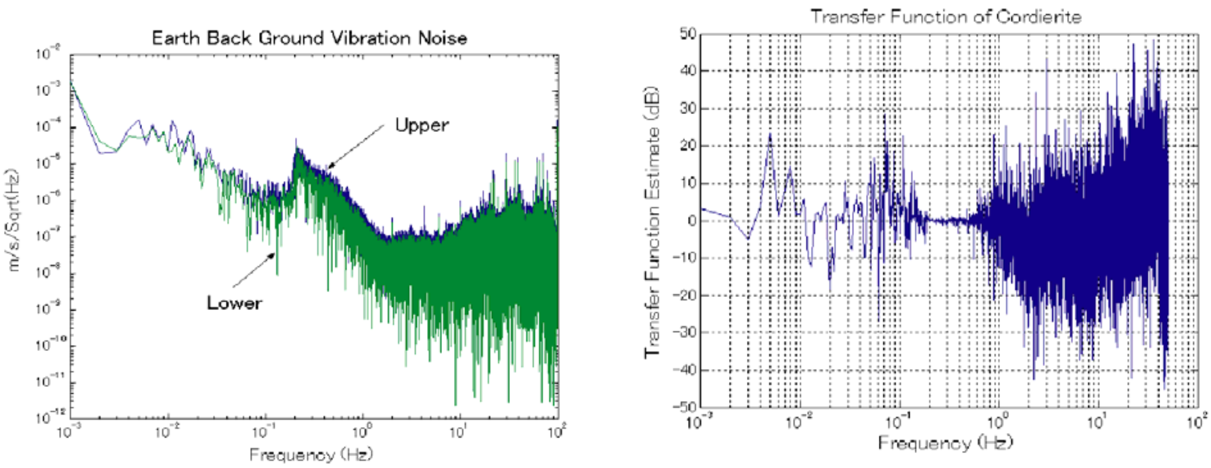
Fig. 2. Experimental set-up used to measure the vibration response of the cordierite and stainless-steel stands. The vibration responses of the stands were measured by three methods, such as observing the earth background vibration noise, the impact response, and the sinusoidal wave response.

2. What cordierite is

Pure cordierite is a natural stone called Iolite. It has a very low thermal-expansion coefficient of 0.15 x 10^{-6} up to 120 ^{o}K. Artificial cordierite ceramic,[4] 2MgO-2Al2O3-5SiO2, is the commercial products for a high-voltage electrical insulator, which is used as a smoke dust chamber in the chimney of a thermal-electrical power plant. The cordierite insulator is usually used under a high-temperature environment, like a chimney. Therefore, the ceramic must have a low thermal expansion. The thermal-expansion coefficient of industrial cordierite ceramic is 2 x 10^{-6}, [5] because of its slightly lower purity. However, this value is ten-times lower than that of iron. The insulator luckily had the shape of a cone trapezoid suitable for a support stand. For this reason, we used it as a stand by attaching flanges on the upper and bottom surfaces, as shown in Fig. 1.

3. Vibration characteristic of the cordierite support stand

So as not to shake the accelerator components by environmental vibration, the cordierite support stand should have the following properties: I, rigidity for reducing any distortion or twist; II, a low thermal-expansion coefficient for decreasing any vibration under 0.1 Hz; and III, a large damping factor in order to quickly reduce any vibration. To evaluate the previously mentioned vibration characteristics of the stand, we conducted experiments, as shown in Fig. 2. The vibration characteristics of the cordierite and stainless-steel (SUS304) stands were also compared. The two stainless-steel stands were connected with a top plate and settled along a straight line so as to place measurement instruments on the plate for experiments. The size of the stainless-steel stand was x, 0.2 m; y, 0.2 m; and z, about 1 m.



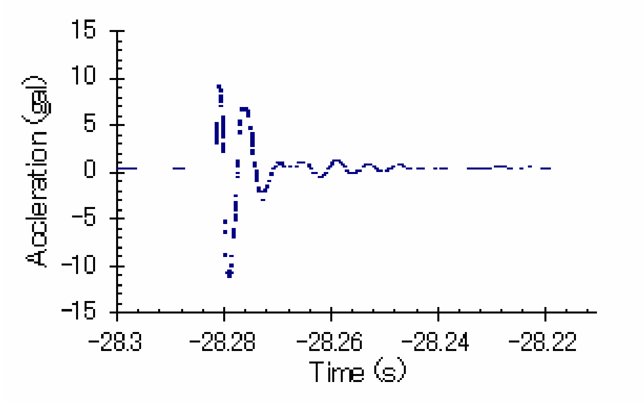
(A) (B)

Fig. 3. Observed frequency spectra (A) of the earth background vibration noise measured on the top plate of the cordierite stand and the ground floor, and the transfer function (B) of the stand, which was calculated from data (A). In the figure (A), the upper part is data measured on the top plate, and the lower part is on the ground.

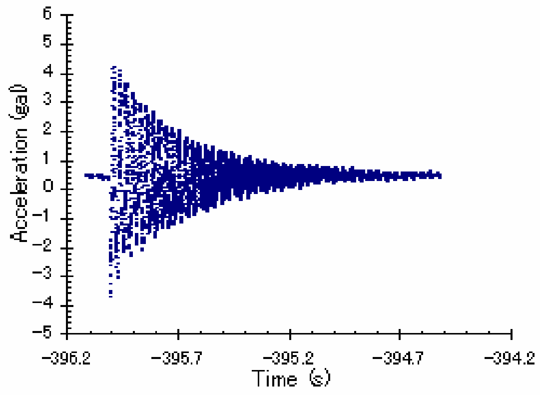
The experimental items for the evaluation were as follows:

A. The earth background vibration noise was measured with highly sensitive/wide band seismometers[6] (made by Gurarup Corp.) set on the top plate and the ground floor in order to check vibration amplification of the cordierite stand. Fig 3 (A) shows the frequency spectra calculated from the measured seismometers data. The transfer function of the stand was also calculated from both data, as shown in Fig. 3 (B). The measurement results show that both spectra have almost the same shape, and the gain of the transfer function is almost unity. We can consider that there was not very big vibration amplification of the stand, from the transfer function data. The shift from unity gain above 10 Hz in the transfer function is mainly dependent on both of the seismometer characteristics. This fact concerning the shift was proved by measurements of the same background vibration with both seismometers placed on the same ground floor.

B. The vibration frequency spectrum below 0.1 Hz includes the thermal expansion of the stand. The transfer function of a frequency region below 0.1 Hz is nearly unity, which shows small vibration amplification with the stand. This small amplification is evidence of a low thermal expansion of the stand. These seismometers have sensitivity for measuring the vibration caused by the thermal expansion, when a temperature change of 0.1 ^{o}K occurs, because its sensitivity is about $1x10^{-10}$ g around the frequency region.

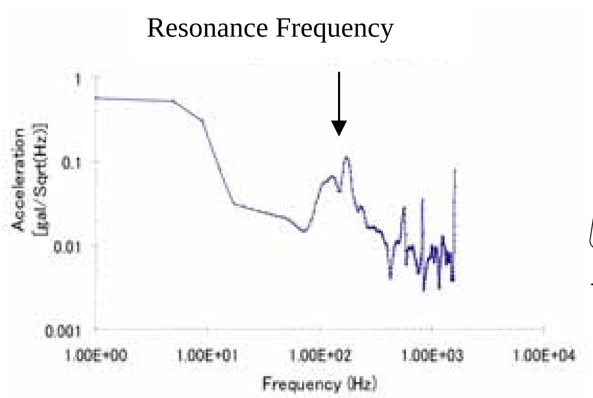


(A)

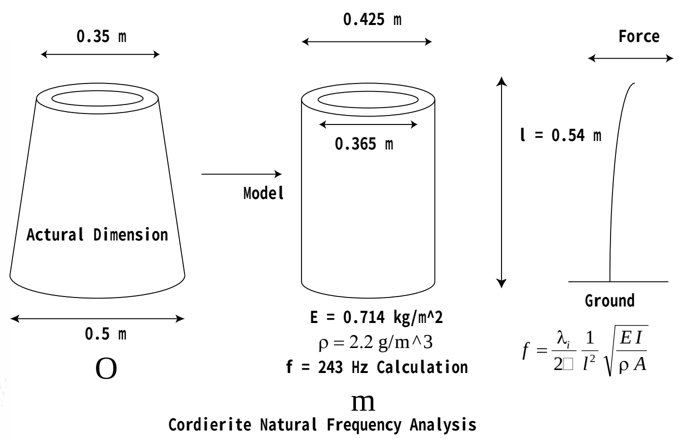


(B)

Fig. 4. Impulse responses of the cordierite stand (A) and the iron stand (B).
The damping factor calculated with the cordierite's data is 0.16. The damping time of the stainless stand is about one hundred-times larger than that of the cordierite stand.



(A)

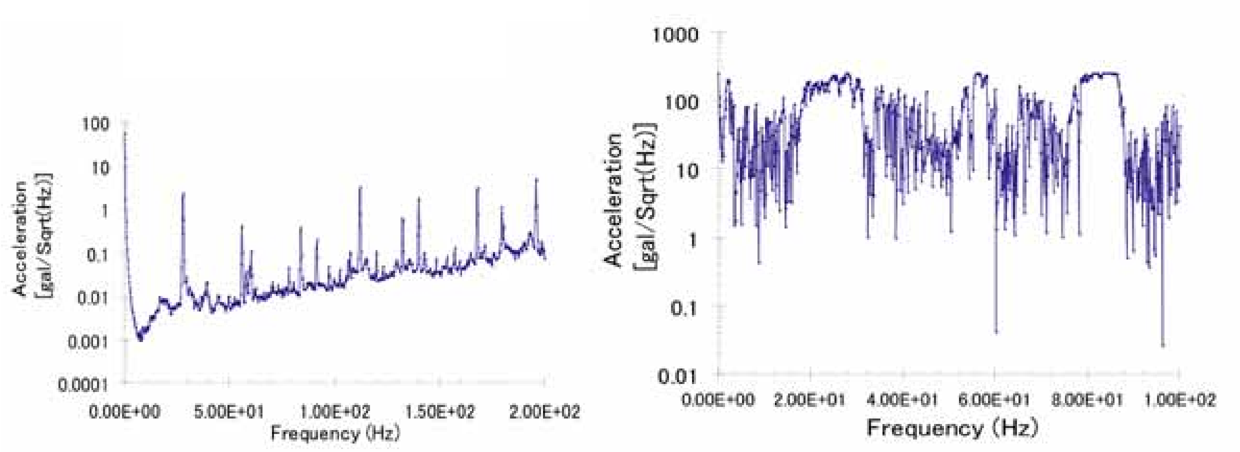


(B)

Fig. 5. (A) Frequency response of the cordierite stand, calculated from the impact response data.
(B) Analytical resonance frequency calculation using a cylindrical model (m) simplified from the actual shape (o) of the cordierite stand.

C. As for issue 3 concerning the vibration damping described above, the cordierite stand is filled with sand to increase the damping factor. In order to observe the vibration damping, impact forces at the top plates of both stands were produced by hitting with a hummer, and measured with a strong motion seismometer (accelerometer) [7] placed on the plates, near to the hitting points. The impact responses of the cordierite and stainless-steel stand are shown in Fig. 4 as measured wave forms. The vibration of the cordierite stand decreases for a short time of about three peaks (Fig. 4 (A)). The damping factor calculated by these data is 0.16, meaning heavy damping. Fig. 4 (B), shows the same impact response in the case of the stainless-steel stand. The damping time of the wave form shown in Fig. 4 (B) is about one hundred-times larger than that of the cordierite stand. Furthermore, the frequency response of the cordierite stand, which was calculated from the impact vibration data by a Fourier analysis, is shown in Fig. 5 (A). The resonant frequency of the cordierite stand is about 200 Hz in the figure. In order to check whether this frequency is the resonance frequency of the cordierite stand or not, an analytical calculation using a cylindrical model (m), Fig. 5 (B), simplified from the actual shape (o) of the cordierite stand, was made. The stand resonance frequency, calculated by using the equation and model shown in the figure, is 243 Hz which is almost consistent with the experiment result.

D. We then measured the sinusoidal vibration responses of both stands. Vibration was generated with a rotating eccentric mass shaker [8] that produced a sinusoidal centrifugal force of 730 N at 28 Hz. The shaker was settled on the top plates of the stands. When the previously mentioned force was applied to the stands, the vibration responses were taken as shown in Figs. 6 (A) and (B). These results show that the response of the cordierite stand is very simple, since it has a clear peak of 28 Hz. Although it also has other higher order resonances, these are simple resonances without any big non-linearity. The higher order resonances come from the cordierite stand shape distorted from a pure cylinder. However, the stainless-steel stand has extreme non-linearity of the vibration response in Fig. 6 (B). We can not clearly recognize a vibration peak at 28 Hz generated by the shaker. The dull peak has a frequency band width of about 10 Hz.



(A) Cordierite stand (B) Stainless-steel stand

Fig. 6. Sinusoidal vibration responses of the cordierite and stainless stands.
The applied sinusoidal centrifugal force to both stand was 730 N at 28 Hz.

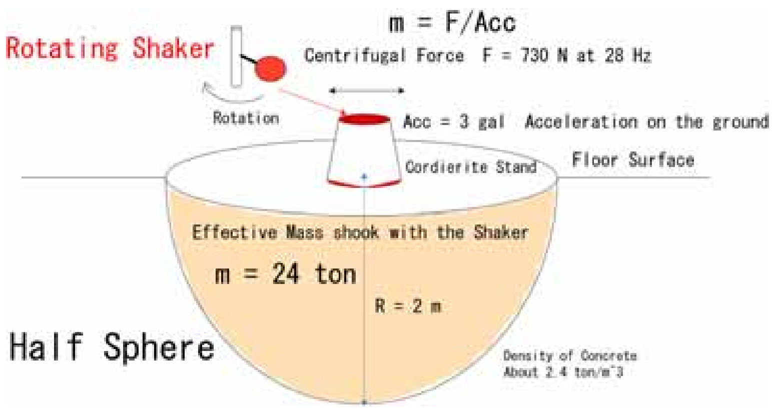


Fig. 7. Effective mass shaken with a rotating eccentric mass shaker at the top end of the cordierite stand.
Acceleration generated with the shaker was measured with the seismometer on the floor.

4. Summary and discussion

All of the experimental results mentioned above show how the cordierite stand is stable. Each experiment proved that the cordierite stand has smaller vibration amplification and lager vibration damping than those of the stainless-steel stand. For example, the frequency spectra of the earth background noise in Fig. 3 (A) have the peaks of marine micro-seism just above 0.1 Hz. The shapes of the peaks measured with the seismometers on the top plate of the cordierite stand and on the ground floor are similar. The transfer function in Fig. 3 (B) is almost unity, which guarantees the small vibration amplification. The impulse response in Fig. 4 (A) shows the nice damping characteristic of the cordierite stand. Figs. 6 (A) and (B) show that the cordierite stand has strong rigidity and small non-linear distortion compared with that of the stainless-steel stand. In order to prove the rigidity of the cordierite stand and the coupling between its bottom flange surface and the grinded concrete floor, we calculated the effective mass shaken with a rotating mass shaker by using an acceleration value measured with the seismometer on the ground floor near by the stand. If the shape of the effective mass has a half sphere, as shown in Fig. 7, the mass is about 24 ton, which was calculated form the measured acceleration of 3 gal and the equation in the figure. This result of the calculation shows nice and stable coupling between the flange surface and the grinded concrete floor.

Based on the above-mentioned results, we proved that the cordierite stand is very rigid and suitable for the X-FEL accelerator, which requires a very stable electron beam orbit.

5. Acknowledgement

We thank the members of the X-FEL development group for their help related to the experiments.

6. Reference

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