

# EXPERIENCES WITH VIBRATION AND DAMPING MATERIAL

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## Abstract

The KEKB accelerator is being upgraded to SuperKEKB, using the same tunnel as KEKB. The upgrade is based on the “Nano-Beam” scheme, wherein the beam size is reduced to 50-60 nanometers in the vertical direction, and 10 microns in the horizontal direction at the interaction point (IP). Vibration in the tunnel, especially at the IP, could be a critical issue that may result in luminosity degradation. Vibration in the SuperKEKB tunnel will be reported along with our test results with the damping material called “M2052” alloy, which is a manganese-based alloy containing copper, nickel and iron.

## INTRODUCTION

SuperKEKB is an electron-positron circular collider with a 3 km circumference that aims to achieve a peak luminosity of  $8 \times 10^{35} \text{ cm}^{-2} \text{ s}^{-1}$  [1], which is 40 times higher than the that achieved by its predecessor accelerator, KEKB. The phase II commissioning of SuperKEKB started in March 2018, and ended in July 2018. The first collision was confirmed on April 25, 2018 by observing the vertical beam-beam deflection, as shown in Fig.1. The beam-beam deflection signal was obtained when the electron beam (HER) was shifted by  $\sim 30 \mu\text{m}$  using a set of dipole corrector magnets in the HER to cause the HER beam to collide with the positron beam (LER) at the IP. This very small offset needed for the first collision is the result of excellent magnet alignment.

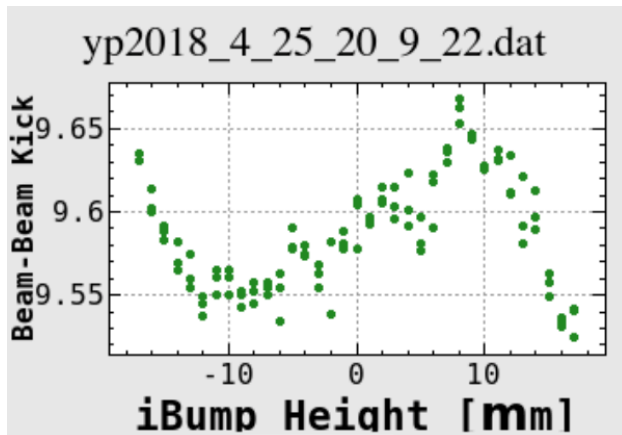


Figure 1: The first beam-beam deflection signal observed at SuperKEKB.

The first collision and the verification of the “Nano-Beam” scheme was established successfully [2,3] with the Phase II optics. The horizontal and vertical beta functions at the IP ( $\beta_x^*$  and  $\beta_y^*$ ), and the horizontal and vertical beam sizes at the IP ( $\sigma_x^*$  and  $\sigma_y^*$ ), will be squeezed down to the

design values in Phase III, which is scheduled to start in March of 2019. Table 1 compares the achieved and the design machine parameters for KEKB and SuperKEKB. The half crossing angle between the HER and LER at the IP, the horizontal and vertical emittances, and the beam current are represented by  $\phi_c$ ,  $\epsilon_x$ ,  $\epsilon_y$  and  $I$ , respectively. The beam size will be reduced to  $\sim 50 \text{ nm}$  in the vertical direction and  $\sim 10 \mu\text{m}$  in the horizontal direction at the IP at SuperKEKB.

Table 1: Machine Parameters.

Parameters	KEKB		SuperKEKB	
	LER	HER	LER	HER
Ring				
$E \text{ (GeV)}$	3.5	8	4	7
$\phi_c \text{ (mrad)}$	11		41.5	
$\epsilon_x \text{ (nm)}$	18	24	3.2	4.6
$\epsilon_y \text{ (pm)}$	150	150	8.64	12.9
Coupling (%)	0.83	0.62	0.27	0.28
$\beta_x^*/\beta_y^* \text{ (mm)}$	1200/5.9	1200/5.9	32/0.27	25/0.30
$\sigma_x^* \text{ (}\mu\text{m)}$	147	170	10.1	10.7
$\sigma_y^* \text{ (nm)}$	940	940	48	62
$I \text{ (A)}$	1.64	1.19	3.60	2.60

## VIBRATION ISSUES AT SUPERKEKB

Vibration at the KEK site and at the various locations in the KEKB tunnel have been measured and presented in the past [4,5]. Figure 2 is a Power Spectral Density (P.S.D.) measurement taken at the SuperKEKB tunnel floor close to the IP [6]. The 3 Hz peak in the vertical direction corresponds to the natural frequency of the soil in the region. The amplitude of this vibration varies over a day and during a week, resulting from human activities such as traffic in the area. It is in the range of several tens of nanometers, which is the same order of magnitude as  $\sigma_y^*$ . A vibration at  $\sim 0.3 \text{ Hz}$  is seen in the horizontal direction, which is caused by winds and ocean waves in the Pacific Ocean. Though the vibration amplitude at  $\sim 0.3 \text{ Hz}$  is larger than that at  $\sim 3 \text{ Hz}$ , it is not a serious problem as collision orbital feedback is expected to compensate for the offset between the HER and LER beams caused by such slow vibration. When investigating the collision, coherency between the HER and LER should also be checked. If they vibrate coherently, some cancellation is expected. If the

HER and LER beams vibrate incoherently, degradation due to the vibration may be enhanced.

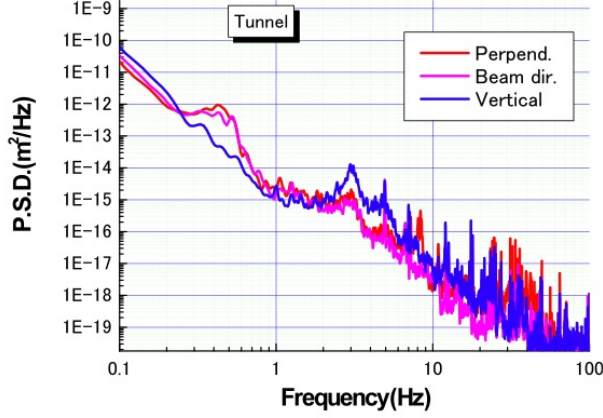


Figure 2: PSD plot of the tunnel floor vibration near the IP.

When the tunnel floor vibrates, magnets that are bolted on the tunnel floor also vibrate at their natural frequencies, which are usually a few tens of hertz. The vibration of the superconducting magnets near the IP will affect the beam orbit and degrade the luminosity more seriously than any other magnets in the tunnel with the SuperKEKB beam optics. Figure 3 shows the SuperKEKB final focus superconducting magnet system (“QCS”), which is located at the IP. There are two cryostats, at left and right sides of the IP. Each cryostat is connected to a movable base made of iron in a cantilever style as is shown in Fig.4. There are 4 quadrupole superconducting magnets, QC1E/P and QC2E/P, in each cryostat.

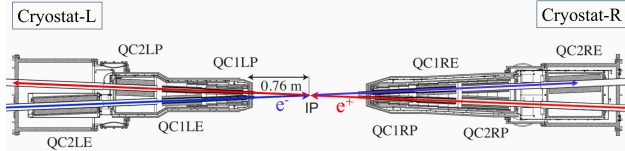


Figure 3: Layout of the QCS magnets and cryostats at the either side of the IP.

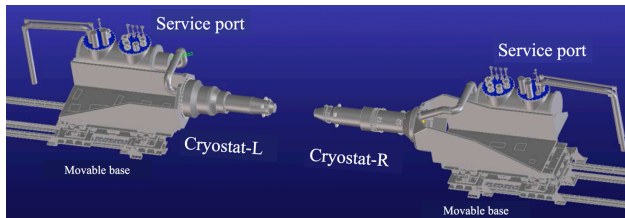


Figure 4: Cryostats are connected to the movable bases in a cantilever style.

The vibration of the QCS magnets was evaluated by a modal analysis using ANSYS. Figure 5 is a P.S.D. of the QC1RE and QC1RP vibration in the vertical direction [7]. There is a good coherency between them up to ~50Hz, though they start vibrating incoherently above ~50Hz, as is shown in Fig. 6. Table 2 summarizes the vibration frequencies, the amplitude and average luminosity loss

simulated for the three main vibration modes. There are two approaches used to cope with this vibration. One approach is to suppress the vibration itself, and the other is to maintain the collision conditions by orbital feedback. We are preparing a fast orbit feedback system for the use in Phase III operation [8].

For suppressing vibration, we have carried out studies using a special alloy called “M2052” in the past. We have not adopted M2052 yet for use with any of the SuperKEKB magnets, though we feel a need to understand the characteristics of this material for potential future use.

A basic comparison between this damping material was made against standard steel using a small dipole corrector magnet to understand the damping effects. The experimental setup and the vibration data are described in the following sections.

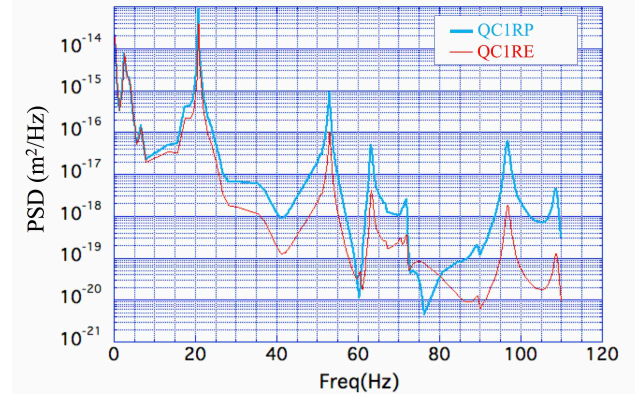


Figure 5: P.S.D. of the vertical vibration of QC1RE and QC1RP magnets obtained from ANSYS.

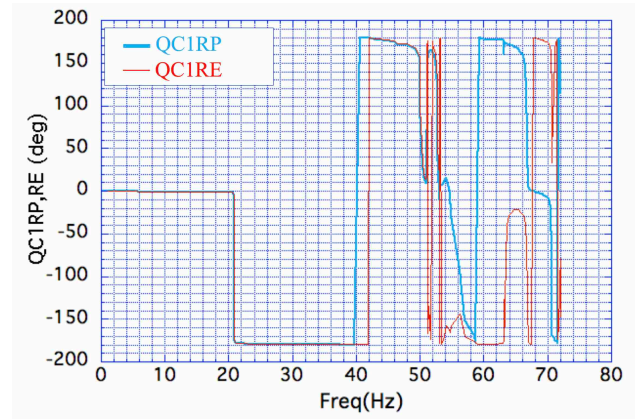


Figure 6: Coherency between QC1RE and QC1RP vibration.

Table 2: Luminosity loss due to vibration.

Freq. (Hz)	Amp. (nm)	Luminosity loss (%)
21	38.9	12.0
53	21.0	5.3
97	6.6	0.9

## EXPERIMENT

A comparison was made using two identical SuperKEKB dipole corrector magnets, which weigh ~150 kg each. A simple magnet support was designed for this test. One support is made of 2052 and the other is made of steel called “SS400.” SS400 is one of the most commonly used general structural steels. They are inexpensive and present superb weldability and machinability. They are often used for accelerator magnet supports.

### M2052

M2052 is manganese-based alloy developed by K. Kawahara at National Institute for Material Science, Japan. It has a nominal composition of 20% copper, 5% Nickel and 2% iron. It has been used mainly in the audio and video field [9]. The physical properties of M2052 are summarized in Table 3[10] and compared with the other materials.

Table 3: M2052 physical properties.

Property	Value	Similar to
Young's modules	30 (GPa)	Al, Ag, Cd
Heat Conductivity	10(W/m·K)	Ti, Sb,Pb, Bi
Specific heat	512.7 (J/kg·K)	Ti,Fe,Cr
Thermal expansion	22.4( $\times 10^{-6}$ /deg)	Al,Ag,Sn,Cu
Density	7.25(g/cm <sup>3</sup> )	Fe,Mn

Figures 7 (a)~(f) explain the damping mechanism of M2052. When an external stress is applied to a rigid body (a), it deforms (b). If more stress is added, twin displacement microstructures develop (c). When the stress is removed, the two microstructures disappear. If more stress is added, the width of the microstructure region becomes larger and/or more microstructures appear (e)(f). This series of appearances and movements of the microstructures changes the vibration energy into thermal energy, resulting in vibration damping. Such structures appear much more easily in M2052 than in other alloys, which makes M2052 more suitable as a damping material than other alloys. M2052 is more costly than the structural steel, partially because the market size of M2052 is much smaller than that of structural steel.

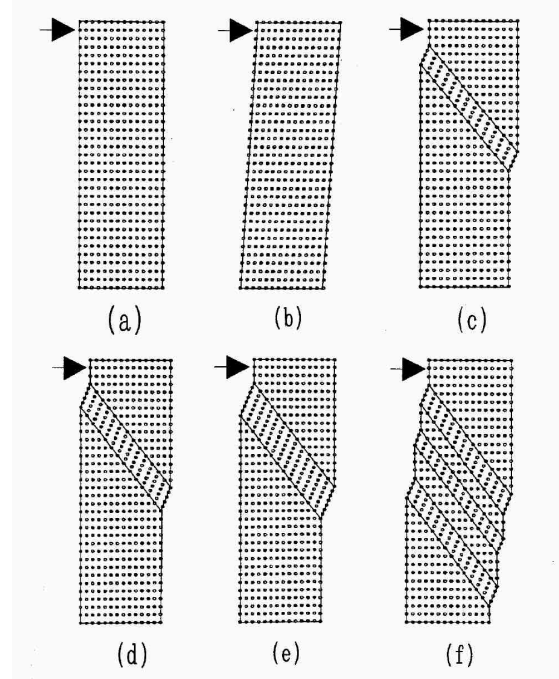


Figure 7: Conceptual diagram of twin microstructure appearances when some external stress is applied.

### Experimental setup

Figure 8 shows the drawing of the support designed and fabricated for the comparison test.

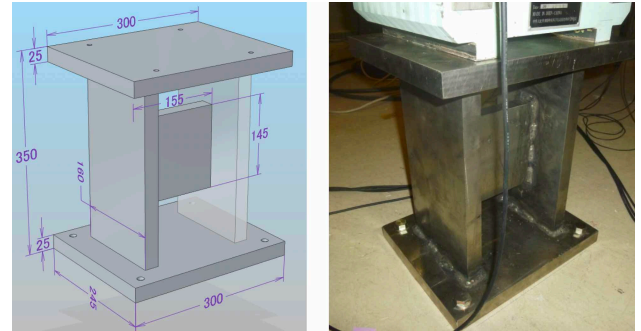


Figure 8: Drawing of the magnet support (left) and the fabricated support made of M2052 (right).

Six one-axis acceleration sensors “MG-102S” from Tokkyokiki Corp. were used for the vibration measurements. The experimental setup is shown in Fig. 8. Two horizontal ( $x$  and  $y$ ) and one vertical ( $z$ ) directions are measured by three sensors. Figure 9 shows the case where floor vibration and the M2052 magnet vibration were measured simultaneously. The three sensor directions  $x$ ,  $y$  and  $z$  are indicated in Fig.9.



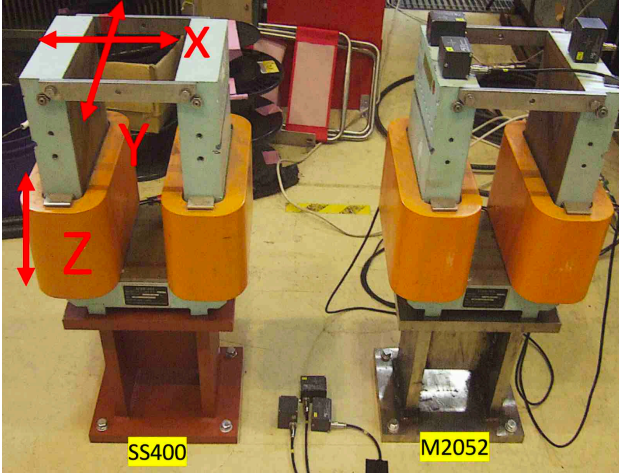


Figure 9: Experimental setup. Two sets of magnets with supports made of different materials are used.

Comparison was made for the following three cases:

- (1) A magnet is mounted on a support made of SS400, where the magnet is connected to the support by bolts made of stainless steel (“SUS304”) and the support connected to the floor by SUS304 bolts.
- (2) A magnet is mounted on a support made of M2052, where the magnet is connected to the support by bolts made of stainless steel (“SUS304”) and the support connected to the floor by SUS304 bolts.
- (3) A magnet is mounted on a support made of M2052, where the magnet is connected to the support by M2052 bolts and the support connected to the floor by M2052 bolts.

### Vibration data

The ratio of magnet vibration ratio to floor vibration (“response function”) was plotted in Figs. 10, 11 and 12. With this configuration of the magnet and the magnet support, the vibration is amplified mainly in the  $x$  and  $y$  directions.

Case (2), where SUS304 bolts were used, presents a more complicated spectrum than Cases (1) and (2). The vibration amplitudes at the natural frequencies did not get smaller.

When we changed the bolts from SUS304 to M2052, damping effects became clearer. M2052 shifts the natural frequencies to the lower values in all three directions and makes the amplitudes smaller than SS400 does.

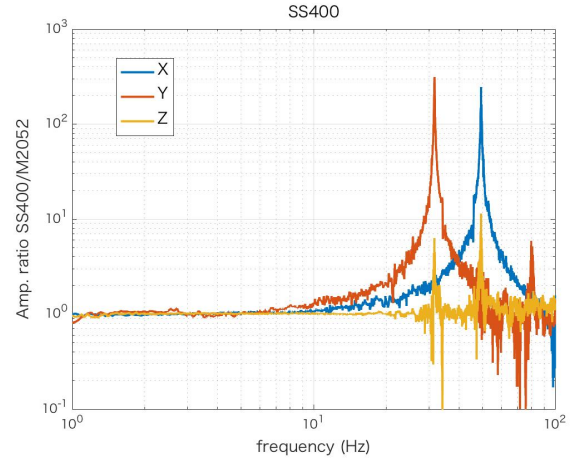


Figure 10: Vibration amplitude ratio for Case (1).

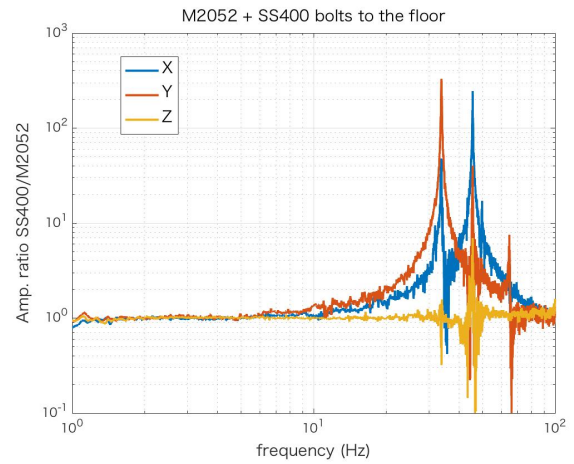


Figure 11: Vibration amplitude ratio for Case (2).

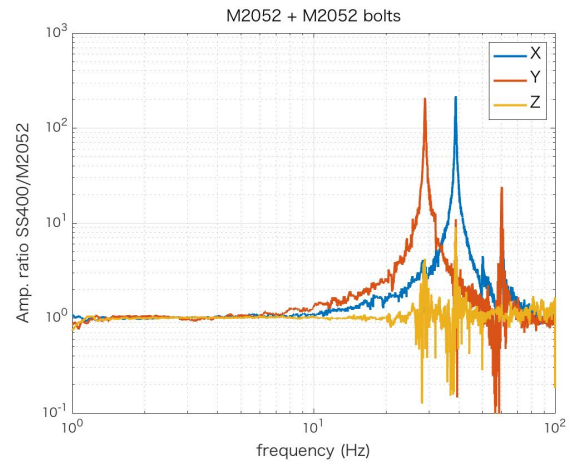


Figure 12: Vibration amplitude ratio for Case (3).

Figures 13, 14 and 15 compare the response functions directly between Case (1) and Case (3) for vibration in the  $x$ ,  $y$  and  $z$  directions, respectively. M2052 shifts the peaks to lower frequencies without making the amplitude larger. This indicates that some of the kinetic energy (vibration energy) was changed into something else by M2052 and according to reference [10], changed into thermal energy.

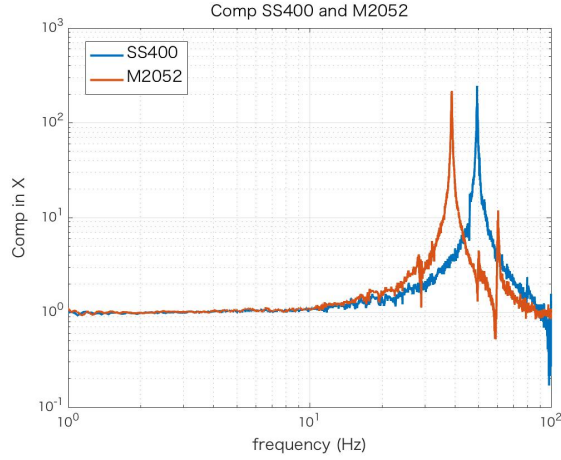


Figure 13: Vibration amplification in the x directions.

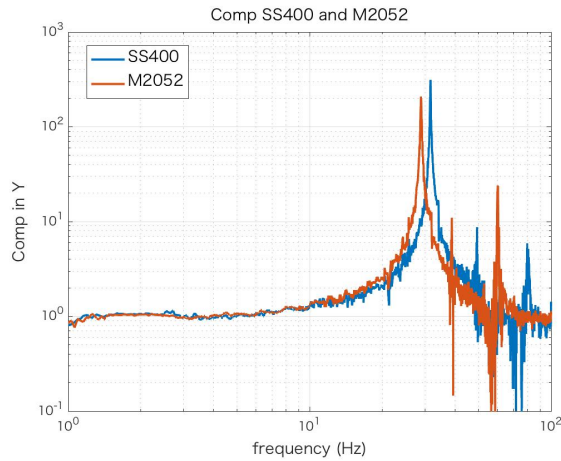


Figure 14: Vibration amplification in the y directions.

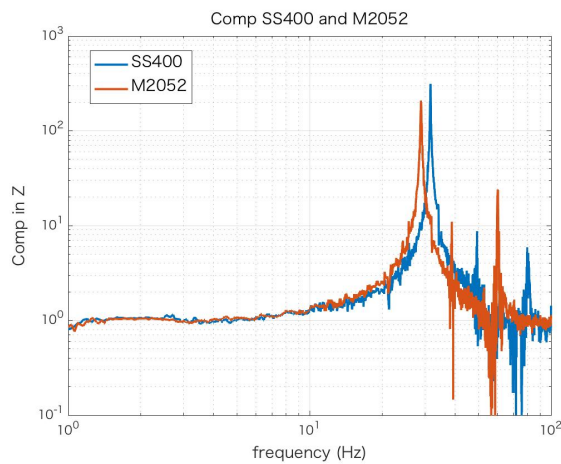


Figure 15: Vibration amplification in the z directions.

We monitored the vibration of the magnets for Case (1) and Case (3) for 24 hours, starting from 9:35 on a weekday. Figures 16 and 17 are the integrated amplitude for frequencies higher than 10Hz and 1Hz, respectively. The dotted and solid lines correspond to Case (1) and Case (3), respectively. It is seen that the vibration becomes larger

during the day time and becomes smaller after midnight for Case (1). These day and night effects are not as clearly seen for Case (3) because the vibrations excited by the day time activities are damped by M2052. The damping effects become less clear if the lower frequency vibration modes are included. M2052 seems to be effective at damping the vibrations at the natural frequencies of the structure.

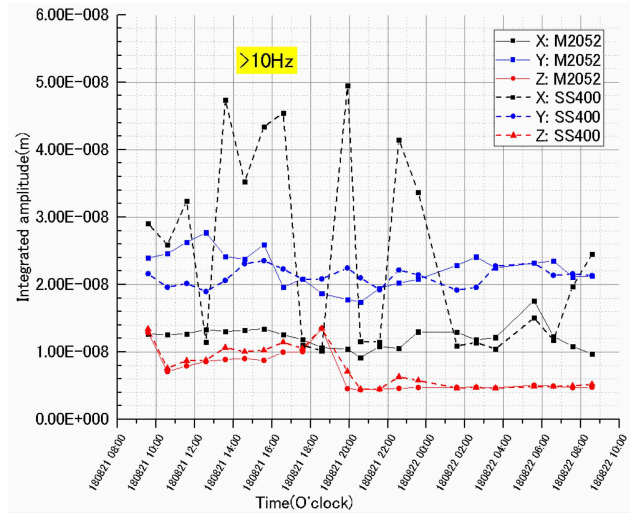


Figure 16: Integrated amplitude for frequencies higher than 10Hz.

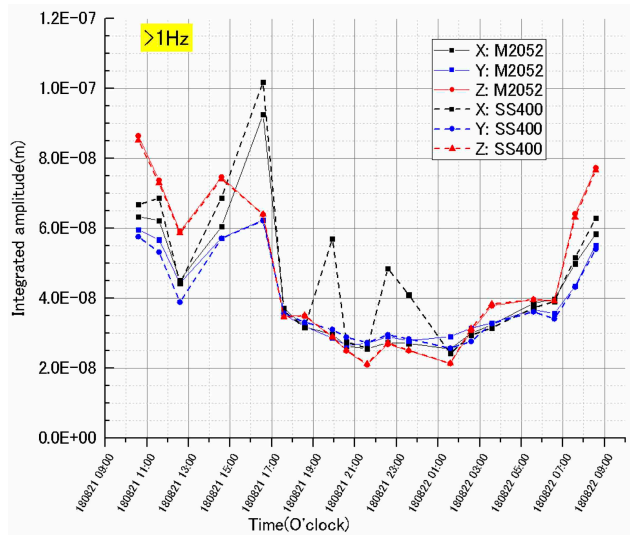


Figure 17: Integrated amplitude for frequencies higher than 1Hz.

## APPLICATION TO SUPERKEKB

A study on applying the damping material to the SuperKEKB QCS or other critical accelerator components is underway.

M2052 was tested with the KEKB cryostat after KEKB operation finished. The test data were compared with a simulation made using ANSYS[11]. When adding the plates made of M2052 to the location (see Fig. 18) that ANSYS suggested as the weak spot, some damping effects

were observed. Adding more plates improved the damping effects as is seen in Fig. 19. Some could argue though that the damping is a result of strengthening the movable base where the cryostat is attached. A comparison should have been made with the plates made of non-damping materials such as SS400 or SUS304. Study of M2052 and other damping materials and methods continues, as vibration issues may become more serious as the beta-functions at the IP become smaller and the size of the colliding beams enter the nano-region in the SuperKEKB Phase III commissioning.

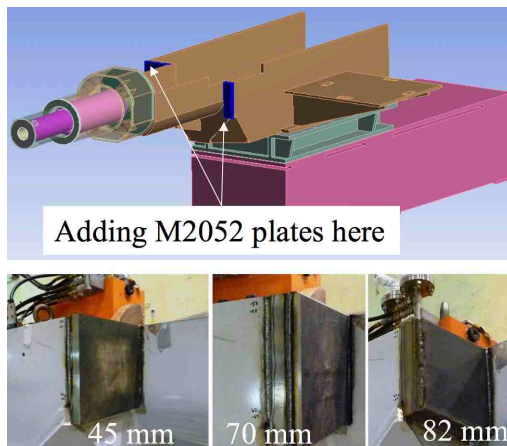


Figure 18: The locations where the plates made of M2052 is indicated for the KEKB cryostat.

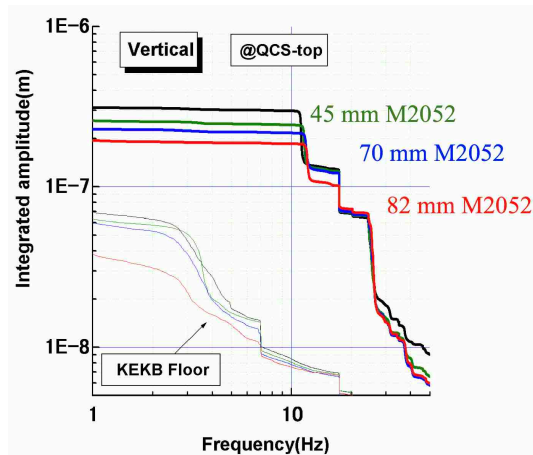


Figure 19: Vibration amplitude for various thickness of the M2052 plates is plotted against frequency.

## SUMMARY

Vibration issues may become more serious at SuperKEKB where the design vertical beam sizes are  $\sim 50$  nm. There are two approaches to cope with the vibration issue, one is to damp the vibration and the other is an orbit feedback at the IP.

Some test data on the damping material M2052 is introduced in this paper. The study was carried out using dipole corrector magnets mounted on a standard supporting table made of SS400, and on a special

supporting table made of M2052. Since the magnets and the design of the support are identical, direct comparisons with SS400 were made. M2052 damps the vibrations at the structure's natural frequencies, which are usually in the range of a few tens of hertz in the magnet system.

A further study needs to be made on where and how to use the material, since the effects get smeared out if the material is not used properly. M2052 may be also useful for not only colliders, but also for light sources.

## REFERENCES

- [1] M. Masuzawa, "Next Generation B-Factories," IPAC'10, Kyoto, May 2010, FRXBMH01, p. 4768 (2010); <http://accelconf.web.cern.ch/AccelConf/IPAC10/papers/frxbmh01.pdf>
- [2] Y. Ohnishi, "Report on SuperKEKB Phase 2 Commissioning," IPAC2018, Vancouver, May 2018, MOXGB1, P. 1 (2018); <http://ipac2018.vrws.de/papers/moxgb1.pdf> doi:10.18429/JACoW-IPAC2018-MOXGB1
- [3] K. Akai, K. Furukawa and H. Koiso, "SuperKEKB collider," arXiv:1809.01958 [physics.acc-ph], Sept., 2018.
- [4] R. Sugahara et al., "Ground Motion at Various Sites in Japan," IWAA'08, Tsukuba, Feb. 2008, MOPCH31,
- [5] H. Yamaoka et al., "The Mechanical and Vibration Studies of the Final Focus Magnet-cryostat for SuperKEKB," IPAC2014, Dresden, June 2014, THPRI005, P. 3770 (2014); <http://accelconf.web.cern.ch/accelconf/IPAC2014/papers/thpri005.pdf> doi:10.18429/JACoW-IPAC2014-THPRI005
- [6] M. Masuzawa et al., "Vibration Issues for SuperKEKB," in Proc. International Workshop for Accelerator Alignment (IWAA) 2010, Hamburg, Sept. 2010.
- [7] [https://kds.kek.jp/indico/event/20554/QCSR-Vibration-Analysis-2016\\_01\\_07.pptx](https://kds.kek.jp/indico/event/20554/QCSR-Vibration-Analysis-2016_01_07.pptx)
- [8] Y. Funakoshi et al., "Interaction Point Orbit Feedback System at SuperKEKB," IPAC2015, Richmond, May 2015, MOPHA054, P. 921 (2015); <http://accelconf.web.cern.ch/AccelConf/IPAC2015/papers/mopha054.pdf> doi:10.18429/JACoW-IPAC2015-MOPHA054
- [9] K. Kawahara, "Application of High-Damping Alloy M2052," Key Engineering Materials VOL319, P217-224. doi:<https://doi.org/10.4028/www.scientific.net/KEM.319.217>
- [10] K. Kawahara and F. Yin, "A New Type of Damping Materials, M2052 Alloys," Journal of Vacuum Society of Japan, Vol42, No 1, P11-17, 1999.
- [11] M. Masuzawa, "Vibration Measurements at KEKB/SuperKEKB, and Experience with Vibration Damping Material," GM2017, Beijing, Dec., 2017. <https://indico.ihep.ac.cn/event/7204/>