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THE MECHANICAL AND VIBRATION STUDIES OF THE FINAL FOCUS MAGNET-CRYOSTAT FOR SUPERKEKB

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Abstract

Construction of the SuperKEKB has been progressed in KEK. The mechanical designs of the cryostats for the superconducting magnets in the interaction region are also being studied. In the cryostat designs, the mechanical strengths of the components were calculated, and the configurations of the cryostats were optimized. Because the vertical beam sizes need to be 50 nano-meter, vibration of the magnets due to the ground motion has been evaluated. We will present the cryostat designs and these vibration studies in this paper.

INTRODUCTION

Construction of the SuperKEKB has been progressed in KEK [1]. The target luminosity of the SuperKEKB is 8×10^{35} cm^{-2}s^{-1}, which is 40 times larger than the KEKB. The vertical beam sizes of electron and positron must be squeezed to the level of 50 nano-meter at the interaction point. The beam final focus system for the SuperKEKB consists of 4-superconducting (SC) quadrupole doublets, 43 SC-correctors, 4 SC-compensation solenoids [2]. Interaction region of the SuperKEKB is shown in Fig. 1. The designs of the cryostats in the left and right side with respect to the beam interaction point are being studied with the progress of the magnet designs. The superconducting magnets are assembled into the two cryostats, QCS-L and QCS-R, and the assembled cryostats are installed inside of the Belle detector.

Table 1: Force Specifications for the Cryostats

	QCS-L	QCS-R
Vacuum Vessel	11kN	31kN
Cold mass	14kN	29kN
EMFa*	40kN	8.5kN
EMFb**	70kN	35kN

*EMFa: Electro-magnetic force at normal operation, the cryostat is extracted from I.P..

**EMFb: EMF at magnet quench. The cryostat is attracted into I.P..

In the design works, the support structure of each cryostat, the mechanical strengths of the cryostat components and the support rods for supporting the cold mass are investigated. As for the vibration issue, the vibration of the superconducting quadrupole magnets due to the ground motion have been studied. Also the vibration characteristics of the concrete bridges where the two cryostats will be placed in the interaction region were calculated and measured.

BOUNDARY CONDITIONS

Load Conditions

The load conditions on the cryostats are the weights of the vacuum vessel and the cold mass, and the magnetic forces in the horizontal direction.

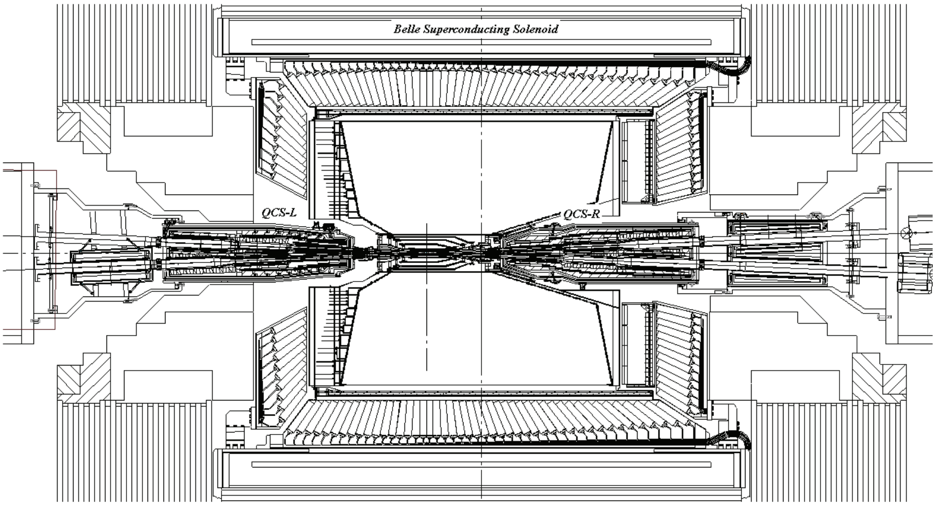

Figure 1: Interaction region of the SuperKEKB. The two cryostats, QCS-L and QCS-R, are assembled inside of the Belle detector.

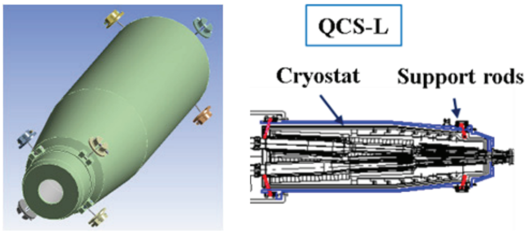

Figure 2: Locations of the support-rods.

The support structure must withstand those forces. The detailed specification of the forces are listed in Table 1.

Support-Rods for Supporting the Cold Mass

The cold mass of 14kN in QCS-L is supported by 8 support-rods as shown in Fig. 2. To carry out FEM analysis, those support-rods were modelled with the spring elements. The spring constant is determined by diameter, length and Young's modulus. The material for the support-rods is titanium alloy (Ti-6Al-4V), its Young's modulus is 106MPa. The location of the support-rods are shown in Fig. 2. The parameters of support-rods are listed in Table 2.

Table 2. Parameters of the Support-Rods

	L		R	
	I.P.-side	Non I.P.-side	I.P.-side	Non.I.P.-side
ϕ(mm)	15	15	11	8
L(mm)	80	132	68	120
k*(kN/mm)	226	141	148	89

*k: Spring constant

CALCULATIONS

Static Analysis

The static analysis of the QCS magnet system in the left side was performed with the condition of the vertical load and horizontal magnetic force. As the result, the maximum vertical deformation is 0.4mm at the top of the cryostat in case of vertical direction as shown in Fig. 3. In case that the magnetic forces of 70kN acts on the cryostat, the cold mass is displaced about 0.7mm in the horizontal direction.

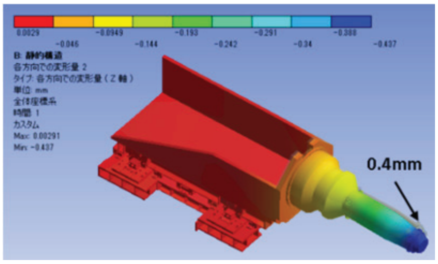

Figure 3: Deformation of QCS magnet in left side.

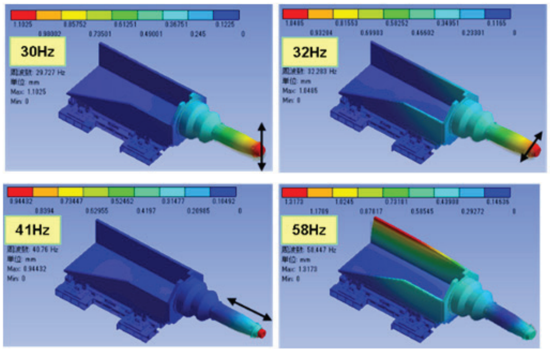

Figure 4: Natural frequencies of QCS magnet in left side.

At the QCS magnet system in right side, the maximum deformation was calculated to be 0.9mm, and the cold mass was moved 0.5mm to the horizontal direction due to the magnetic force.

Support-Rods for Cold Mass

On the design of the support-rods, it should be taken into account two issues. One is the stress in the support-rods, and the other is the buckling distortion. The stress in the support-rods has to be below the allowable stress of the material (Ti-6Al-4V). When the horizontal magnetic force is acting on the support-rods, the force balance of the support system is formed with tension in one side of the vessel and compression in the other side. Therefore, the support-rods have to withstand the buckling force. The buckling stresses of the support-rods were evaluated to be fully below the buckling strength. Also the stresses acting on the support-rods were calculated to be within the allowable stress.

Modal Analysis

Modal analysis in left side was carried out as shown in Fig. 4. All components at the QCS magnet and the moving stage were modelled. The first mode of natural frequency is 30Hz with the modal shape of vertical mode.

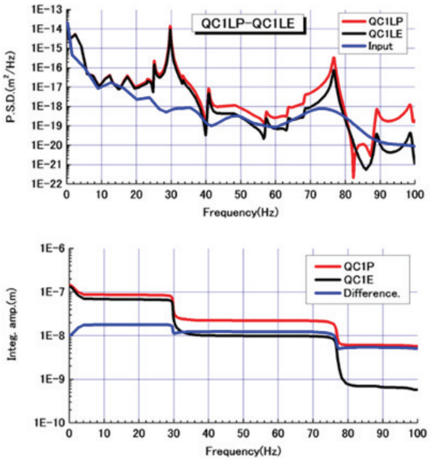

Figure 5: Response of QC1LP and QC1LE due to the ground motion. Upper plots show the power spectrum densities. Lower plots show the integrated amplitudes.

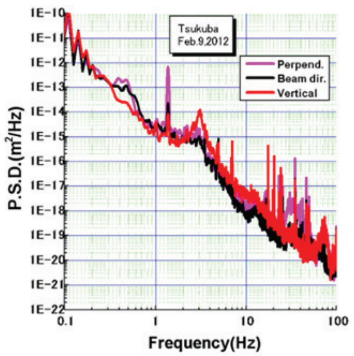

Figure 6: Typical ground motion in IR-region.

The second mode is shown the horizontal mode with natural frequency of 32Hz. The third mode was calculated to be 41Hz. This mode shows the natural frequency of the support-rods. The first mode of the QCS magnets system in right side was calculated to be 21Hz. Because the length of the QCS-R is longer than that of left side, the natural frequency of the first mode became lower.

Vibration Analysis against the Ground Motion

Vibration analysis due to the ground motion was carried out to know the amplitude response at the QCS quadrupole magnets. In this calculation, the real data measured on the floor at the interaction region was used as the input data. And this calculated data was input to the specified positions in the FEM model. And the response amplitudes at the QC1L, QC1R, QC2L and QC2R were calculated. The power spectrum densities and the integrated amplitude at QC1LP and QC1LE are shown in Fig. 5, respectively. The relative integrated amplitude above 30Hz between the QC1LP and the QC1LE was calculated to be 12nm. As the other calculation result, QC1RP and QC1RE are to be 20nm for the frequency higher than 20Hz.

VIBRATION STUDIES IN IR REGION

Typical data taken on the concrete bridge in the IR region is shown in Fig. 6. There are some features in the ground motion. First, there is a resonant peak around 1Hz. Sometimes we observed the 1Hz noise. We haven't understood where this noise comes from. There is a resonant peak at 3Hz, and this is due to the Kanto loam formation geologically. The peak around 30Hz is the resonant frequency of the concrete bridge in the horizontal direction. And the peak around 70Hz is resonant frequency of the bridge in the vertical direction.

The vibration characteristics of the concrete bridge were measured. In this measurement, the resonant frequencies and the mode shapes were measured. Usually, this kind of test is carried out with an impulse hammer and an acceleration sensor. However, those equipment were not used this time because the object was too large. Operational Modal Analysis (OMA) method was applied.

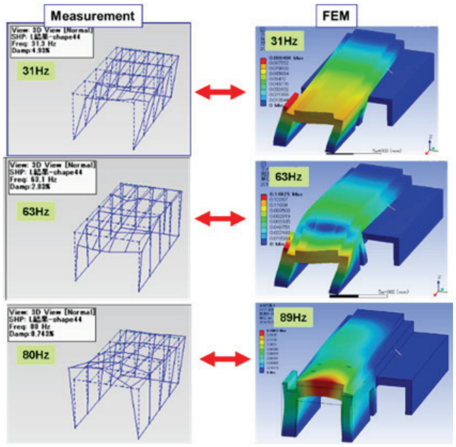

Figure 7: Comparison modal properties between the measurements and the FEM analysis.

In this test, the high sensitivity acceleration sensors, servo-type sensors, were only used. By measuring the relation between the output and input signals, the resonant frequencies and the modal shapes can be made as shown in Fig. 7. And also those measurement values were compared to the results of FEM analysis. As the result, the first mode was 31Hz of horizontal mode. The Second mode was measured to be 63Hz as the bending mode. The third mode was 80Hz in the vertical mode. Therefore, measurement data and FEM analysis showed a good agreement.

CONCLUSION

The mechanical strengths of the cryostats and the components were evaluated. The stresses on the cryostats and support-rods were confirmed below the allowable stresses. Also the buckling strengths of the support-rods were strong enough. Vibration properties of the components in the IR were studied, and the natural frequencies and response against the ground motion were calculated. In the vibration studies of the concrete bridge, it was found that there were some features on the ground motion in IR region. The modal properties of the concrete bridge were measured and compared to the FEM calculations, and they showed a good agreement.

ACKNOWLEDGMENT

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