COMMISSIONING STATUS OF SuperKEKB MAIN RING MAGNET SYSTEM

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Abstract

SuperKEKB is an electron-positron collider that aims for a very high peak luminosity of 8×10^{35} $cm^{-2}s^{-1}$, which is 40 times higher than that of KEKB. The SuperKEKB Main Ring (MR) system is a large system, which consists of more than 1700 water-cooled resistive magnets and about 900 air-cooled correction magnets. More than 400 magnets and power supplies were newly fabricated, tested in installed for SuperKEKB Phase I beam operation. The MR magnet system ran stably without any serious problems, which contributed greatly to the smooth start-up of the MR.

INTRODUCTION

SuperKEKB [1,2] is a next-generation B-factory machine, which was built utilizing the existing KEKB tunnel. The final focus quadrupole magnets (the QCS system [3]) are superconducting, but the rest of the magnets in the Interaction Region (IR), as well as in the entire tunnel, are resistive magnets. The Phase I commissioning was carried out without the QCS system and the detector from Feb. 2016 for 5 months. The IR, which includes the QCS system and BELLE-II detector [4], are currently being constructed for Phase II beam operation. Phase II commissioning of the MR is scheduled to start in February 2018. Commissioning status of the MR magnet system during Phase I operation is reported in the sections below.

POWER SUPPLIES

Most of the MR power supplies (PSs) were reused for SuperKEKB, of which ~620 PSs needed to be overhauled. The types and numbers of the SuperKEKB MR magnet PSs are summarized in Table 1. More than 80% of the PSs are in the range of kilowatts. They drive the corrector magnets and the auxiliary coils, which are used for tuning the beam orbit and correcting beam optics. They are usually operated at very small currents. The total power consumption of the MR magnet system is about 7.5 MW with the Phase I magnet settings. The MR magnets are standardized before starting up the MR, e.g. the magnet currents are slowly increased to the maximum current of each power supply and then decreased to 0 A, with a pause at the top and the bottom. This cycle is repeated several times, and then the current is set at the desired value determined by the machine optics. This standardization process is carried out in three phases, not in synchronization, to avoid large power consumption at the maximum flat top currents.

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The new power supplies for the QCS system [5] are not included in Table 1. All of the recycled power supplies are overhauled, except for the PSs for the corrector magnets.

Table 1: Main Ring Magnet PSs

Output power	# of new PS	# of recycled PS	Type of magnets
0.95MW	2	0	Main dipoles
0.4~1MW	9	0	Wigglers
0.1~0.5MW	0	18	Main quads
2~105kW	92	335	Dipole/Quad/Sx
0.3~2.4kW	138	1681	Correctors
Total	359	2034	

Major Failures in Megawatt Class PSs

Figure 1 shows the monthly frequencies and causes of major failures of the megawatt (MW) class PSs, which took place while the beams were circulating in the MR. These major failures of the MW class PSs resulted in beam aborts. Malfunction, which is considered to be part of the initial failure, disappeared eventually after countermeasures were taken. The failures in February due to the noise in the AC line were caused by the VAR (Volt-Ampere Reactive) system, which compensates the reactive power in the AC power distribution facility. Frequent automated switching of the phase advance capacitors in the VAR system triggered the power supply failure. This problem was dealt with by controlling the phase advance capacitors manually.

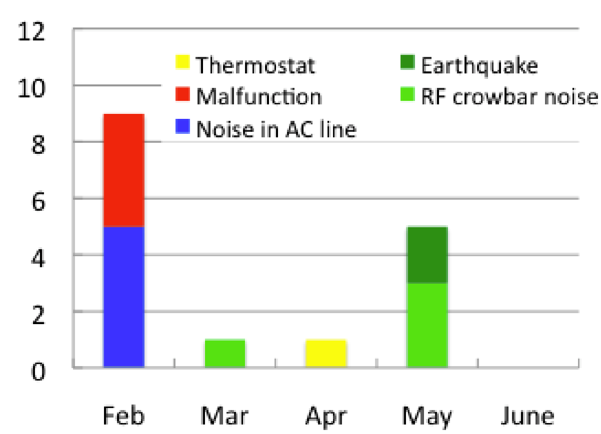

Figure 1: Monthly frequency of major failure occurrence is shown for the MW class power supplies.

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A few failures were caused by noise from the RF system in the same building. Modification was made to the MW class PSs after Phase I operation, and we expect to see fewer or no failures due to the RF system in Phase II.

Major Failures in Other PSs

Figure 2 shows the major failures of the sub-MW class PSs. Some of them are caused by malfunction of the IGBT (Insulated Gate Bipolor Transistor) modules, which are used for certain types of the sub-MW class PSs. There was no trouble until April but the frequency of the malfunction suddenly increased in June. This is probably due to the temperature rise in the power supply buildings. Since there is no AC in the buildings, the air temperature reaches almost 40 degrees centigrade in the summer.

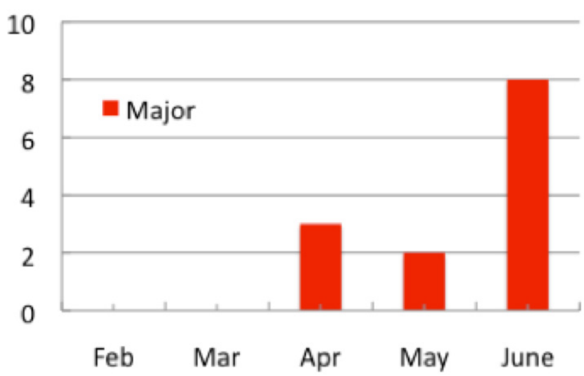

Figure 2: Monthly frequency of major failure occurrence is shown for the sub-MW class power supplies.

A ground fault occurred with one of the sub-MW quadrupole power supplies. A damaged cable was found, and is shown in Fig. 3. Insufficient protection from the sharp edge of the metal pipe in the vertical shaft damaged the cable. This was clearly a human error in the cabling work, which could have been avoided.

Figure 3: Damaged cable at the vertical shaft, which caused the ground fault.

A total of 14 failures occurred among more than 2000 small PSs during beam operation. Those failures rarely accompanied a beam abort. When one happened, we replaced the broken power supply with a spare one. The broken PSs are then sent back to the manufacturer for repair work.

THE MR MAGNET COOLING WATER SYSTEM

Most of the SuperKEB magnets are water-cooled resistive magnets of hollow copper conductor. The number of water-cooled magnets increased from ~1600 in KEKB to ~2000 in SuperKEKB, mainly in the Oho and Nikko sections shown in Fig.4, where newly-fabricated wiggler magnets are installed. The total number of MR resistive magnets, both water-cooled and air-cooled combined, exceeds 2600. The water to the ~1600 magnets was supplied by four pumping systems located near the Tsukuba, Oho, Fuji and Nikko areas for KEKB. Each pumping system is capable of supplying pure water at up to 4000 liters/minute. New utility buildings were built at four new locations in between the existing experimental halls to meet the needs of the increased number of water-cooled magnets for SuperKEKB (Fig.4). Modifications to the water distribution systems, including the addition of pipes from the new utility buildings to the tunnel, were carried out. The water system for the SuperKEKB MR magnets follows that of KEKB. For example, flow rates to the individual magnets are measured using ultrasonic flow meters, and the flow rates are adjusted by closing/opening globe valves if needed. Each magnet is equipped with a flow switch. The proper interlock level was adjusted and tested before Phase I commissioning.

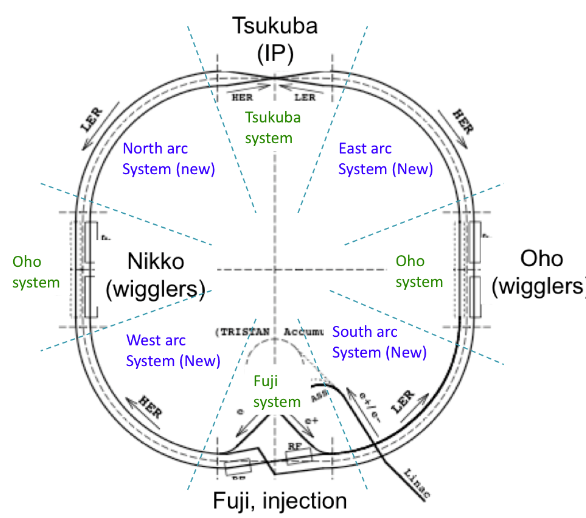

Figure 4: Cooling water distribution diagram for SuperKEKB MR magnets.

There were three interlock incidents triggered by water stops during Phase I. One incident took place during one of the start-ups of the machine after the regular maintenance that takes place every other week. The other two incidents took place while beams were circulating in the MR and they resulted in beam aborts. The first water stop was caused by the wrong setting of the interlock level of

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the flow switch. Actually, a drift in the interlock level is suspected. The second one came from clogging in the strainer mesh of a magnet. Figure 5 compares a new strainer mesh and the clogged mesh. The deposit that caused the clogging was investigated using a scanning electron microscope (SEM). The SEM photos in Fig.6 indicate the presence of copper and oxygen along with silicon and carbon. Copper comes from the hollow conductor and is dissolved in the water as Copper oxide. Iron comes from the strainer mesh itself as it is made of stainless steel. Carbon and silicon contamination were seen in the old KEKB water system back in 2007. Figure 7 shows the infrared absorption spectrum obtained from the deposit sample found then. The spectrum is compared with that of silicon oil and mineral oil, both of which were used in the maintenance work of the pumps. We concluded that the cooling water system for "pure" water has been contaminated with oil used during the maintenance work sometime before 2007 and there is still some oil remaining in the system even today. Once the pure water system is contaminated by oil, it is very difficult to remove it completely from the system, especially when the system is as large as KEKB (SuperKEKB).

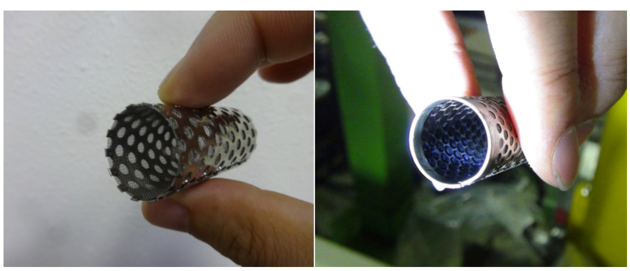

Figure 5: New strainer (left) and clogged strainer (right) are shown.

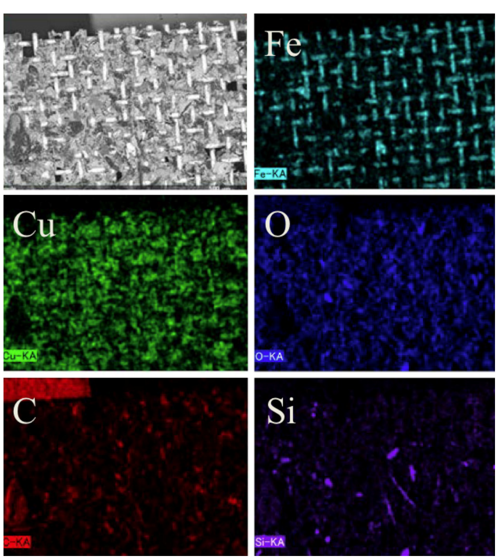

Figure 6: SEM analysis photos show that there are iron, copper, oxygen, carbon and silicon in the deposit. The pattern of the strainer mesh is clearly seen in upper left photo.

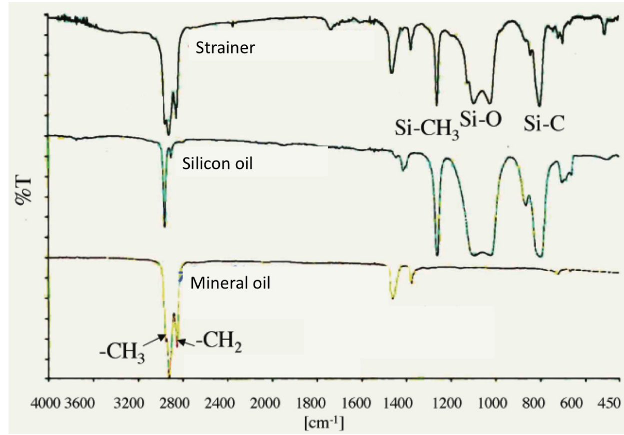

Figure 7: Infrared absorption spectra of the deposit sample of the strainer (top), Silicon oil (middle), and mineral oil (bottom) are shown.

CONCLUSION

The SuperKEKB MR magnet system consists of more than 2600 magnets and more than 2000 PSs. During the Phase I MR commissioning, there were 17 beam aborts caused by PS failure and 2 beam aborts caused by water stops. This low failure rate contributed greatly to the smooth start-up of the machine.

The noise issues with the MW class PSs are expected to improve after countermeasures are taken during the machine shut-down. The contamination in the magnet cooling water system remains as a potential threat. We continue to work to reduce failures and create a more stable system, as a reliable magnet system is indispensable for machine tuning to achieve higher luminosity.

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