FINAL FOCUS SUPERCONDUCTING MAGNET SYSTEM FOR THE INTERACTION REGION OF KEKB

T. Ogitsu, N. Ohuchi, T. Ozaki, R. Sugahara, N. Toge, and K. Tsuchiya
KEK, High Energy Accelerator Research Organization, Oho, Tsukuba, Ibaraki, 305-0801, Japan

Abstract

The superconducting final focus system has been built and installed near the beam collision point of KEKB. It consists of two quadrupole and two field compensation solenoid magnets with a computer-controlled cryogenic system. A system testing and measurements of the magnetic field in combination with the BELLE detector solenoid have been successfully completed.

1 INTRODUCTION

KEKB[1] is an asymmetric-energy, two-ring electron-positron collider at KEK. KEKB circulates electron (8 GeV) and positron (3.5 GeV) beams in opposite directions and collides them at one interaction point (IP). The beam line design requires a pair of compensation solenoids and a pair of final focus quadrupoles near the IP. The decision was made in 1994 to build these magnets using the superconducting technology. Their fabrication was started in 1996 and the installation completed in September of 1997. Initial cool-down testing then revealed that due to a higher-than-expected temperature near the front end of the solenoid coils, their operational current was limited by quenching at about 200 A. However, expeditious remedial measures were taken, and the second cooling-down in January of 1998[2] saw a fully successful commissioning test, which allowed the field measurement of the magnets[3] in combination with the BELLE detector solenoid.

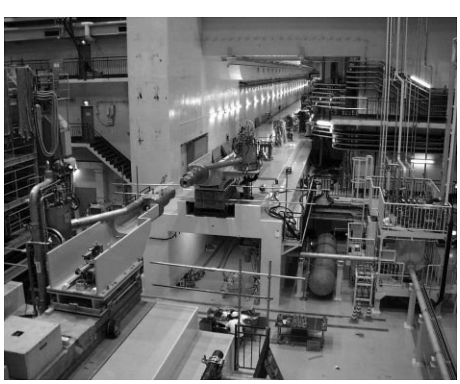

Figure 1: The final focus magnet system. The sub-cooler-cold-box unit is seen on the right side, from which two transferlines are running to the cryostat modules placed on two sides of the IP. The BELLE detector is rolled out towards the left in this photograph.

The basic design and the layout of the system is very similar to the TRISTAN mini-beta insertion quadrupole systems[5]. Two magnet cryostat modules, each containing a solenoid and a final focus quadrupole, were installed on each side of the IP. They are held by cantilever supports made of an open stainless steel tube held via a box structure. The separation between the two cryostats is about 1.3 m. The duct which comes out from the magnet cryostat is connected to a service cryostat, placed side way from the support. From the service cryostat another transfer line runs down and extends horizontally towards the sub-cooler-cold-box unit. The helium compressor, gas tank and their associated hardware are placed at the ground-level together with the magnet power supplies.

Figure 1 shows the picture of cryostats, multi-channel transfer lines, and a sub-cooler-cold-box unit in place.

2 SUPERCONDUCTING MAGNETS

2.1 Compensation solenoid

Two compensation solenoids, S-R and S-L, produce an axial magnetic (B_z) field opposite to the detector solenoid. Table 1 summarizes their parameters. Figure 2 shows the B_z distribution. The coils were made of monolithic NbTi superconducting wire with a cross section of 0.9 mm $\times$ 1.2 mm. After being wound on the helium inner cylinder, the coils were impregnated with Epoxy resin and placed in helium vessels. Before installation into the horizontal cryostat, the coils were tested in a vertical cryostat. There, the S-R magnet required a number of training quenches (40 of these) before reaching the design current. However, it showed no retraining after a thermal cycle. The performance of S-L magnet was excellent. The current reached 600 A, 120 % of the design current, without quenching. The reasons of the different training behaviors between S-R and S-L is not clear. In the system test of 1998, the solenoids were excited with and without detector solenoid field of 1.5 T. Pseudo-quench tests were also performed to see interference effects between the solenoids and the detector solenoid. No quenching occurred for currents up to 110 % of the design values with excellent performance.

2.2 Quadrupole magnet with trim coil

The quadrupoles are iron-free, large bore, and short length superconducting magnets with trim coils. They produce a field gradient of 21.26 T/m. The coil design is based on a set of $cos2\theta$ windings that are clamped by stainless steel collars (316LN). Table 2 shows the main parameters

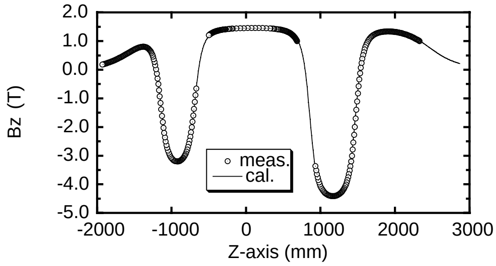

Figure 2: B_z distribution along the beam line when Belle detector solenoid ($B_0 = 1.5$T) and two compensation solenoids are excited. The origin of the z-axis corresponds to the IP.

Table 1: Main parameters of the solenoids.

	S-R	S-L	
Central field	5.80	4.53	T
Current	603	487	A
Max. field on the conductor	5.83	4.59	T
Stored energy	258	121	kJ
Coil			
IR	95	95	mm
OR	116	115	mm
Length	616	461	mm
No. of turns	4981	3749	

of the quadrupoles. The cable is NbTi/Cu Rutherford type cable, consisting of 24 multifilamentary strands of 0.59 mm diameter (Cu/SC ratio 1.8) twisted with a pitch of about 60 mm (filament size 6 μm). It is insulated with two kinds of Upilex tape; 25 μm- and 50 μm-thick tapes.

Inside the coil aperture, three kinds of trim coils (horizontal and vertical steering, and skew quadrupole) are embedded. The field strength of the steering coil is about 0.05 T and the gradient of the skew quadrupole is about 0.4 T/m. They can produce shifting the effective center of quadrupole fields by about 3 mm, and to rotate them by about 12 mrad. The flat coils were made at BNL by the multi-wiring technique, and they were assembled on the helium inner cylinder in the company.

Prior to installation into the horizontal cryostats, the magnets were tested in a vertical cryostat to see the quench behaviors at 4.2 K. Preliminary field measurements were performed with a rotating coil system. The performance of the main coil and trim coils were very good. All coils reached 110 % of their design currents without quenching. The combined excitations of these coils also performed well.

In the system test of January 1998, the magnets were excited up to 110 % of their design currents without quenching, now, under the field of 1.5 T of the detector solenoid. The final field measurement of these magnets were also done with various combinations of coil excitations. Fig-

Table 2: Main parameters of the quadrupole magnets. Numbers within parentheses are measured values.

	QCS-R	QCS-L	
Field gradient	21.26 (21.80)	21.26 (21.68)	T/m
Current	2963	2963	A
Effective length	385 (387.8)	483 (487.6)	mm
Max. field on the conductor	4.3	4.3	T
I_c load line ratio	70	70	%
Main coil			
Inner radius	130	130	mm
Outer radius	144.9	144.9	mm
Overall length	521	617	mm
Collars outer dia.	340	340	mm
Stored energy	69.7	87.5	kJ

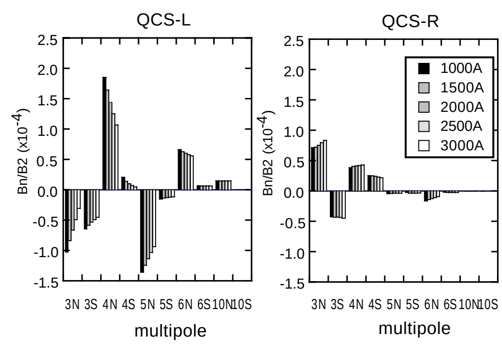

Figure 3: Harmonics of the quadrupoles at 40 mm radius

ure 3 shows the measured integrated harmonics of the quadrupoles at various excitations.

3 CRYOSTAT

Since the cryostats are placed quite close to the detector facility, severe spacial restrictions exist for their design. Thus very compact cryostats had to be built.

A cryostat system consists of three parts: horizontal annular vessel (magnet cryostat) containing the magnets, service cryostat called connection box, and a service duct connecting both cryostats. The helium vessel is made of 316L stainless steel cylinders with different outer diameters for the solenoid and quadrupole coils. In addition, in the case of the left-side cryostat, the quadrupole axis had to be shifted horizontally by 35 mm from the axis of the solenoid. This presented a significant challenge in the assembly of the cryostat.

The helium vessel is surrounded by a thermal radiation shield cooled with liquid nitrogen. The outer shield is a stainless steel shell with a cooling pipe and an inner shield consisting of a 316L stainless steel cylinder with helical grooves for liquid nitrogen. About 30 layers of aluminized Kapton were arranged between the vacuum vessel and the thermal shield. However, since the spacial separation between the helium vessel and the thermal shield is limited

(6 - 7 mm gap), no superinsulation was used. The helium vessel containing the solenoid and the quadrupole was suspended in the vacuum vessel by eight support rods. The rods were designed to withstand large magnetic forces[4]. They were made of titanium alloy, Ti-6Al-4V [ELI], which has a high ultimate tensile strength and a low thermal conductivity. The connection box functions as an interface between the cryostat and the multi-channel transfer line coming from the subcooler box. On the top flange of the service cryostat there are bayonet joints for transfer lines, current leads for solenoid and trim coils, two control valves, and some service ports. The current leads for QCS magnets are on the subcooler box.

During the system test of 1998, the temperature distribution in the cryostats and the strains of the support rods were measured to confirm the performance of the cryostats. The heat load of a pair of cryostats evaluated from the mass flow rate and the temperature increase in the cryostat was about 25 W. A maximum stress of the support rods during cooldown and excitation was less than 330 MPa, corresponding to an allowed stress of Ti-6Al-4V [ELI] at room temperature.

4 ELECTRICAL SYSTEM

A schematic of the electrical circuit for the system is shown in Figure 4. The SCR power supply for QCS magnets is composed of a 3500 A, 15 V main power supply, a 40 A, 15V auxiliary power supply. The main power supply drives two quadrupoles in series, and the auxiliary power supply is used for a fine adjustment of the excitation. The other magnets have their own power supplies. They are switching power supplies. For trim coil power supplies, relay contactors are used to switch the polarity.

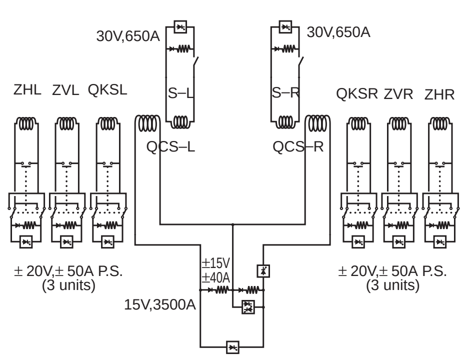

Figure 4: Electric circuit of the magnet system.

The quench protection circuit of QCS is composed of a high speed SCR switch and two energy dump resistors. The values of the resistors for QCS-R and QCS-L are 0.1 Ω and 0.12 Ω, respectively. These were chosen to optimize the time constants of the current decay of QCS-R and QCS-L. For quench protection of other magnets, DC circuit breakers were selected since they did not require rapid decay of the currents in case of quenching. The selected resistors were 0.71 Ω and 2 Ω for the solenoid and the trim coil, respectively. The typical quench threshold is set at 1 V for 10 ms or more.

5 COOLING SYSTEM

The cooling system is very similar to that of the TRISTAN mini-beta insertion quadrupole systems[5]. It has a capacity of 150 W + 30 L/h. The magnets are cooled by single phase LHe of 4.5 K at a flow rate of 20 g/sec during steady state operation.

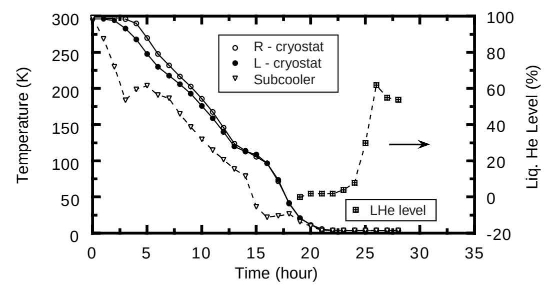

Figure 5: Cooldown curve of the magnet system.

Cooldown was achieved by forced circulation of cold gaseous helium. The temperature of the gas was lowered gradually in order to follow the magnet cooldown. Cooldown took about 27 hours, with a peak temperature difference between magnet and gas of 50 K. Figure 5 shows a typical cooldown curve of the magnet system. The cooling system performed well even during and after a quenching at full current excitations. A typical recovery time after quenching was 4 hours. The heat loads of the system evaluated from the redundant cooling power of the refrigerator was about 75 W + 30 L/h.

6 ACKNOWLEDGMENT

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7 REFERENCES

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