Superconducting Quadrupole Magnet System for TRISTAN Mini-beta Insertions

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Abstract

Superconducting quadrupoles for the mini-beta insertions were installed close to every interaction point and their performances were tested successfully. The system consists of 4 subsystems, which can be operated individually at the local control rooms located near the subsystems and/or at the remote central cryogenic control room.

I. INTRODUCTION

Introducing the strong focusing quadrupole magnet close to the interaction point, the beta-function can be made small. The β_x* and β_y* values are reduced from 1.8 m and 0.1 m to 1.25 m and 0.05 m, respectively. Correspondingly the luminosity increases from 1.6×10^{31} to $\sim3\times10^{31}$ $cm^{-2}sec^{-1}$.

The mini-beta insertions using the superconducting quadrupoles have been introduced at every experimental insertion providing with strong focusing field symmetrically at both sides of a crossing point.

Total system was installed and the performances were tested in 1990 FY. The magnetic performance was checked prior to the installation and the cryogenic performance was examined after installation of all components.

The QCS system is now suffering from beam operation. At present, there is no problem in the routine operation of the QCS system for three months except for the rotational misalignment of the QCS magnets. The magnitudes of the rotational errors were measured by the transverse coupled behavior of the electron beam and re-alignment was undertaken to the order of 0.1 mrad.

II. QCS SYSTEM

The superconducting quadrupole magnet (QCS) system consists of four subsystems. Each subsystem is independent from each other and consists of two quadrupoles, He refrigerator, power supply and local control system. However, all subsystems have been linked to each other through a communication network of an optical fiber and to the central cryogenic control computers.

The QCS magnets have been planned to place as close as possible to the detectors to attain smaller β_y* at the colliding points. The choice was made of the closest end of the magnet inside the cryostat to be as near as 2.5 m from the colliding point. The QCS magnets were positioned in the same configuration to maintain the symmetry around the circumference. Therefore the closest end of the magnet is in the iron pole tip of the detector at two experimental halls (Fuji and Tsukuba). This causes the field enhancement by an order of 10^{-3} and the slight vertical movement which depends on the excitation. The former has been corrected according to the numerical estimation and the latter avoided by fixing mechanically.

The positional error of the QCS magnet is corrected remotely using the adjuster under the magnet. It affords an accurate position control of 1 μm, while the required accuracy is 10 μm or so. It provides with four actions - parallel movements to horizontal and vertical direction, forward tilt and rotation around the vertical axis. This mechanism gives convenience to the precise alignment.

To supply the liquid He to the magnets, the cold box and subcooler are placed near the magnet. The liquid He is pooled in the subcooler and forced into circulation through the He transfer line. These are at 11 m below the ground level where the He compressor is located. The 3500 A dc cable is connected to the current lead which is attached to the superconducting cable running in the transfer tube to the magnets. The cold box has the capacity of 140 W in addition to provide the current leads with the constant liquid He flow of 25 liter/hr to remove the heat from them. The heat load of two QCS cryostats is 20 to 44 W depending on the subsystem. Figure 1 shows a part of the configuration of the system components after the installation. The detector (VENUS) was rolled out for the maintenance and not seen in the photo. There are U-shaped transfer tubes connecting the multiple transfer tube and the cryostat. The cryogenic part of a subsystem is given in Figure 2 which is one of the screen displays. At the ground level the He screw compressor, 20 m^3 He gas tank and 9.8 m^3 liquid N_2 cold evaporator are located (Figure 3).

Figure 1 QCS subsystem in the Fuji experimental hall. Cold box, subcooler, cryostat and transfer tube are shown.

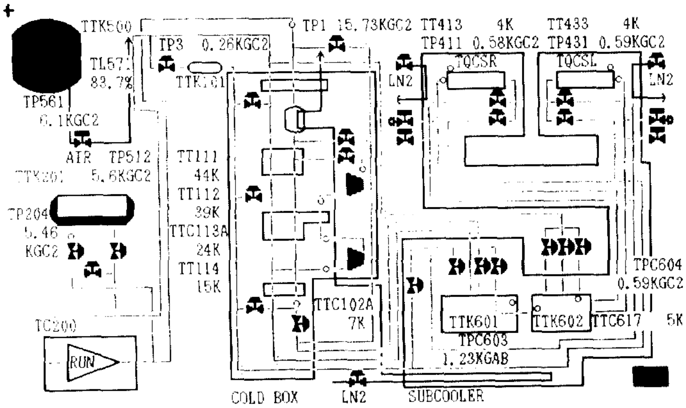

Figure 2 Flow diagram of the cryogenic system. Two QCS magnets are at the right top corner.

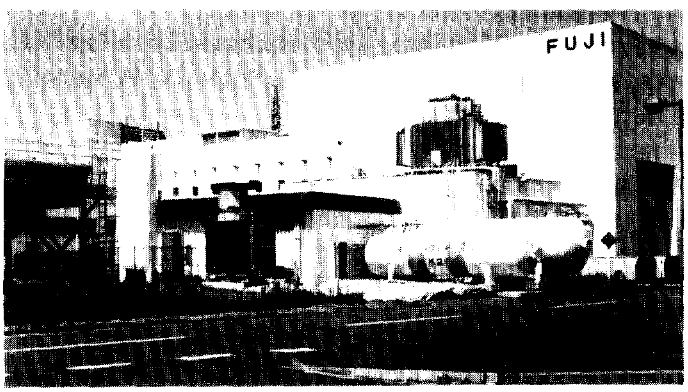

Figure 3 A part of cryogenic system at the ground level. The compressor is in the middle small house.

The power supply consists of the main and auxiliary circuits. The main circuit (3500 A max.) powers both QCS magnets in series, but the auxiliary circuit (40 A max.) is used to power one of the magnets by adding the correction current to the main circuit. The correction current was determined from the field measurements. The main circuit has a thyristor switch to cut out the current in 1 msec the instant that the quench detector senses the voltage unbalance of the magnet or the bus bar in the transfer tube. The power supply has the condenser bank to supply the reverse voltage to the thyristor switch and the stored energy is dumped to the resistor. The dump time constant is 0.48 sec. The QCS magnets are excited according to the reference current pattern which is stored in the memory module in the CAMAC crate and sent to the D-A converter of the power supply [1]. The nominal current at injection (8 GeV) is 700 A and 2480 A at flat top (29 GeV presently). The auxiliary current is also supplied receiving the reference pattern from another memory module.

III. PERFORMANCE

A. He refrigerator

Refrigerators for the QCS subsystems are distributed at the respective experimental halls and equipped with local control systems which serve for the maintenance and for the re-start of the subsystem after restoring from the quench. Each local control system has its own process computer which mainly controls the refrigerator. When the quench detector senses the quench signal, the hard-wired interlock signal is transmitted to both power supply and refrigerator and the process computer receives the signal via power supply to prepare for the emergency. The QCS magnets are protected by the instant cutout of the current and the He gas release from the pressure actuated valve and/or the rupture disc when the inner pressure of the cryostat exceeds the prescribed value. There has been no quench under the normal operation. The flow diagram of the control and interlock signals of a subsystem is shown in Figure 4.

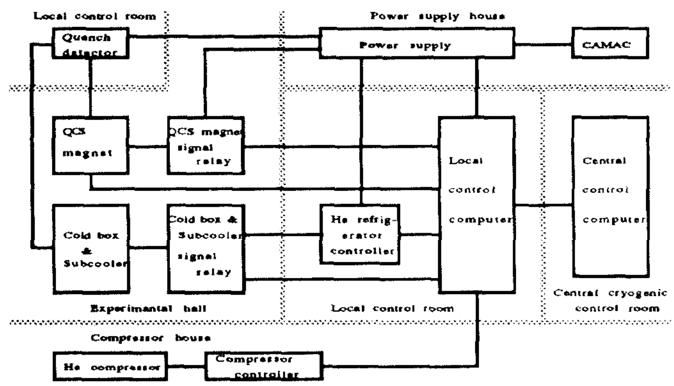

Figure 4 Flow diagram of control and interlock signals of a subsystem.

It takes 3 days to purify the He gas by the purifier with liquid nitrogen trap after filling the He gas tank. The cool down of the QCS magnets are shown in Figure 5 and the required time is about 24 hrs.

B. QCS magnet

The magnetic performances of all QCS magnets were measured in the laboratory (KEK) prior to the installation. At first the bare collared coils were immersed in the liquid He in the vertical cryostat and powered for the training and to measure the coil performance up to 4000 A. Coils passing the examinations were encapsulated in the horizontal cryostats (Figure 6) at the factory and transferred to KEK for the final examinations [2,3]. The field measurements were carried out using the 2 m harmonic probe which was inserted in the warm bore of the cryostat and the result is given in Figure 7.

The magnetic center should be coincide with the beam center accurately and the rotation around the beam axis also be corrected to avoid the transverse coupling. The former was determined from the scattering pattern of the plane-polarized light through the colloidal solution of Fe_3O_4 crystallites in the magnetic field and an accuracy was 10 μm. The latter was estimated from the induced voltage variation of the harmonic probe with an accuracy of 1 mrad.

C. Power supply

Power supply of the QCS magnet is located in the house at the ground level. The cable distance is about 200 m in total for a subsystem. The instant cutout thyristor stack is in the cubicle of the rectifier units of 12 pulses. An acceptance test of the power supplies were carried out on the stability, reproducibility and cutout of the current. The ripple current is 5×10^{-6} at injection and 1×10^{-6} at 3500 A (nominal max. current). The long term stability is less than 2.5×10^{-5} at 3500 A. The cutout forced by the dummy quench signal at 3500 A causes the quench due to the fast variation of current in the superconductor, but there is no sign of quench by the cutout at lower excitation level less than 3000 A. Figure 8 is the block diagram of the power supply.

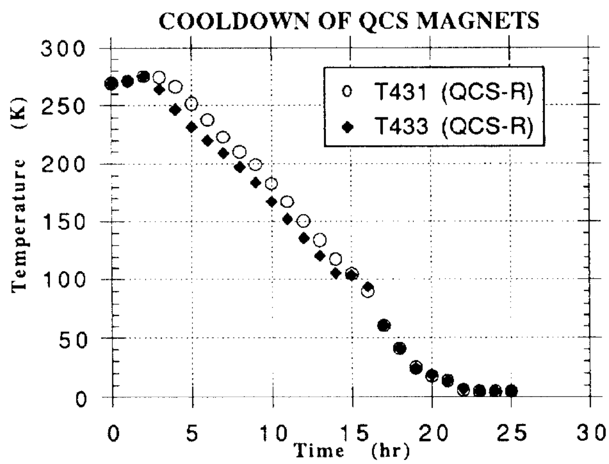

Figure 5 Cool down curves of the QCS magnets.

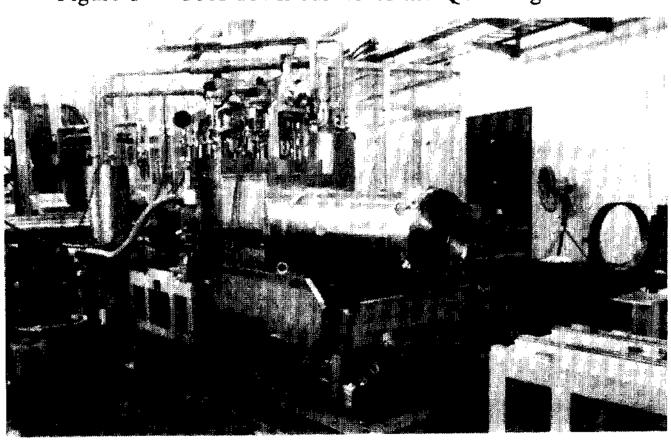

Figure 6 Horizontal cryostat containing the QCS magnet.

D. Control computer

Cryogenic control is made with an aid of the process computers. Each subsystem has one local and one central computer. All computers of 4 subsystems are linked to a common communication network and the control software is so flexible that every computer can handle other subsystem. Daily operation is done at the central cryogenic control room. The cryogenic devices are protected by a hardware protection system which is actuated when the He pressure become out of control. Under the normal condition the operation parameters are optimized by the computer.

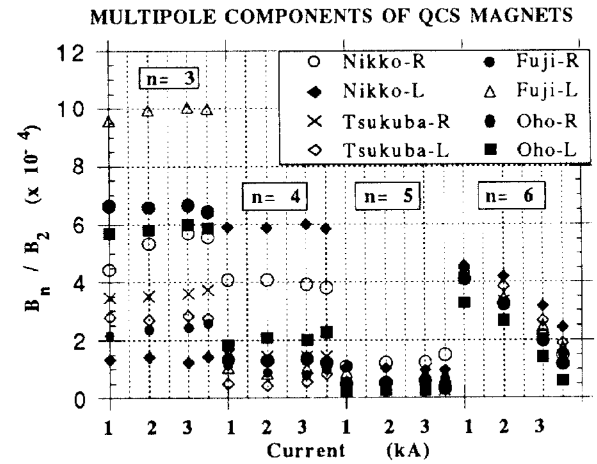

Figure 7 Higher order harmonic contents of all QCS magnets.

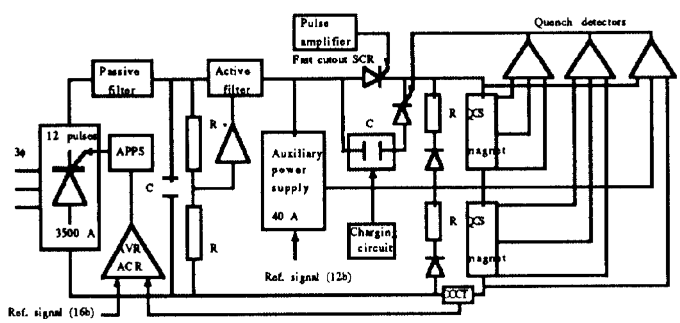

Figure 8 Block diagram of the power supply.

There are several phases in the cryogenic operation - start-up, cool down, stationary state, suspension and emergency. The control computers take care of these phases automatically and/or manually. When an unexpected condition is encountered, a warning message is displayed on the screen. In an emergent state, informations of a subsystem can be shared between computers to watch various parameters such as temperature, pressure, He gas flow rate and so on.

IV. REFERENCES

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