CRYOGENIC SYSTEM FOR TRISTAN SUPERCONDUCTING RF CAVITY

K. Hosoyama, K. Hara, A. Kabe, Yuuji Kojima, T. Ogitsu and Y. Sakamoto
KEK, National Laboratory for High Energy Physics
Tsukuba, Ibaraki, Japan

S. Kawamura
Hitachi Ltd. Kasado Works
Kudamatsu, Yamaguchi,Japan

Y. Ishimaru
Kobe Steel Ltd. Takasago Works
Takasago, Hyogo, Japan

ABSTRACT

A cryogenic system consisting of a helium refrigerator (4 kW at 4.4 K) and a liquid helium distribution transfer system for TRISTAN 508 MHz 32 x 5-cell superconducting RF cavities was designed and constructed. After the performance test of the cryogenic system, 16 x 5-cell superconducting RF cavities in 8 cryostats were installed in underground TRISTAN electron-positron collider and connected to the helium refrigerator on the ground level through the transfer line (total length about 330 m) and cooled by liquid helium pool boiling in parallel. The cryogenic system and its operation experience are described.

INTRODUCTION

Installation of 32 x 5-cell superconducting RF cavities (SCC) in TRISTAN electron-positron collider at KEK was proposed for further upgrading of the beam energy and authorized as a two year project in April 1986. Before starting the construction of the cryogenic system, a model of the cryogenic system with two prototype 5-cell SCC in two cryostats were built in TRISTAN accumulation ring and tested.[1] The design study of a cryogenic system for SCC was started in cooperation with industries in August 1986 and the construction was started end of 1987 and all assembly work was finished by May 1988. The first cool down test of helium refrigerator and transfer line was initiated by the first days of August 1988. The half of SCC, 16 x 5-cell SCC, and liquid nitrogen circulation system for 80 K thermal shield of SCC cryostats and helium transfer line were installed in summer shut down of 1988. The first cool down test of whole cryogenic system was performed on 28 October 1988, commissioning of SCC was started on 11 November 1988 and about three months operation was performed. After the scheduled shutdown the cool down of the system was started on 8 May 1989 and physics run at beam energy 30.7 GeV x 30.7 GeV was performed and this operation continued until end of July 1989. The cryogenic system has a total of about 6,000 hours of operation time from the first cool down test in August 1988 to August 1989. A further installation of 16 x 5-cell SCC to take the TRISTAN beam energy to 32 GeV and upgrading of cooling capacity of helium refrigerator from 4 kW to 6.5 kW without liquid nitrogen by an addition of expansion turbines and compressors were performed in this summer. The operation of 32 x 5-cell SCC will be started in October 1989.

THE CRYOGENIC SYSTEM OVERVIEW

A flow diagram of the cryogenic system is shown in Fig. 1. An isometric showing of cryogenic equipments layout is depicted in Fig. 2. The main parameters of the cryogenic system are listed in Table 1. A helium refrigerator cold box which has cooling capacity of 4 kW by two turbo-expanders T1, T2 with liquid nitrogen precooling

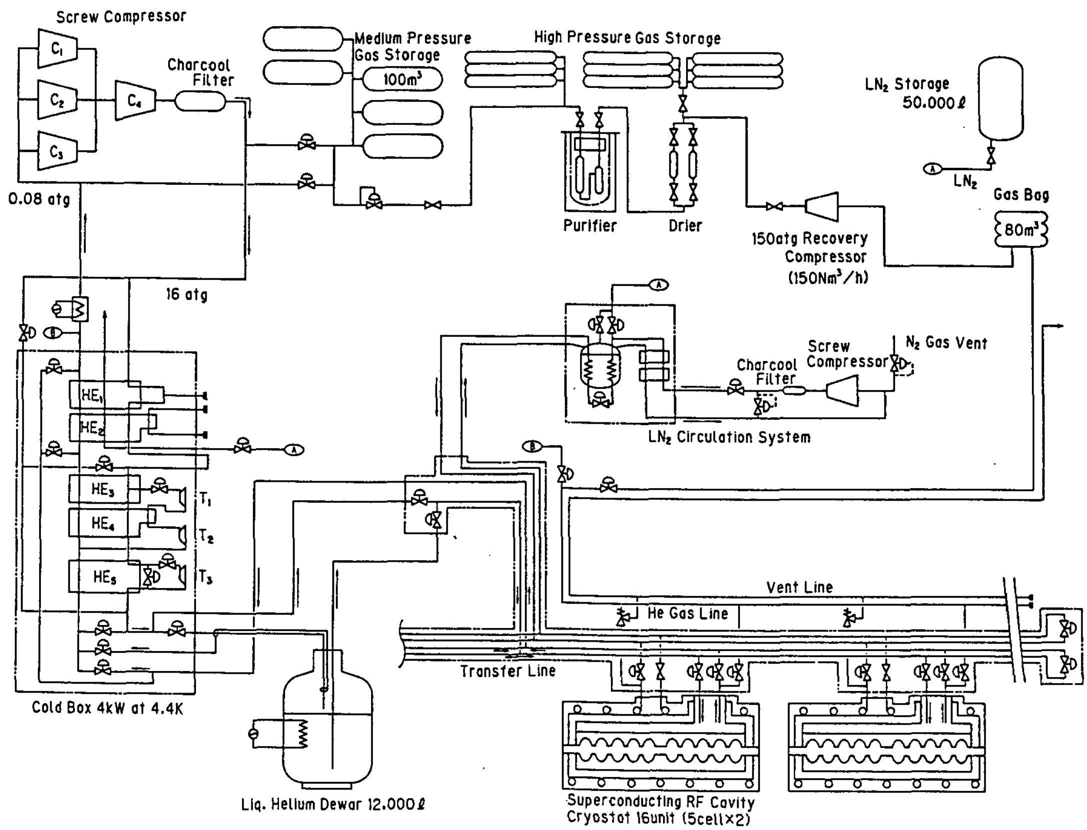
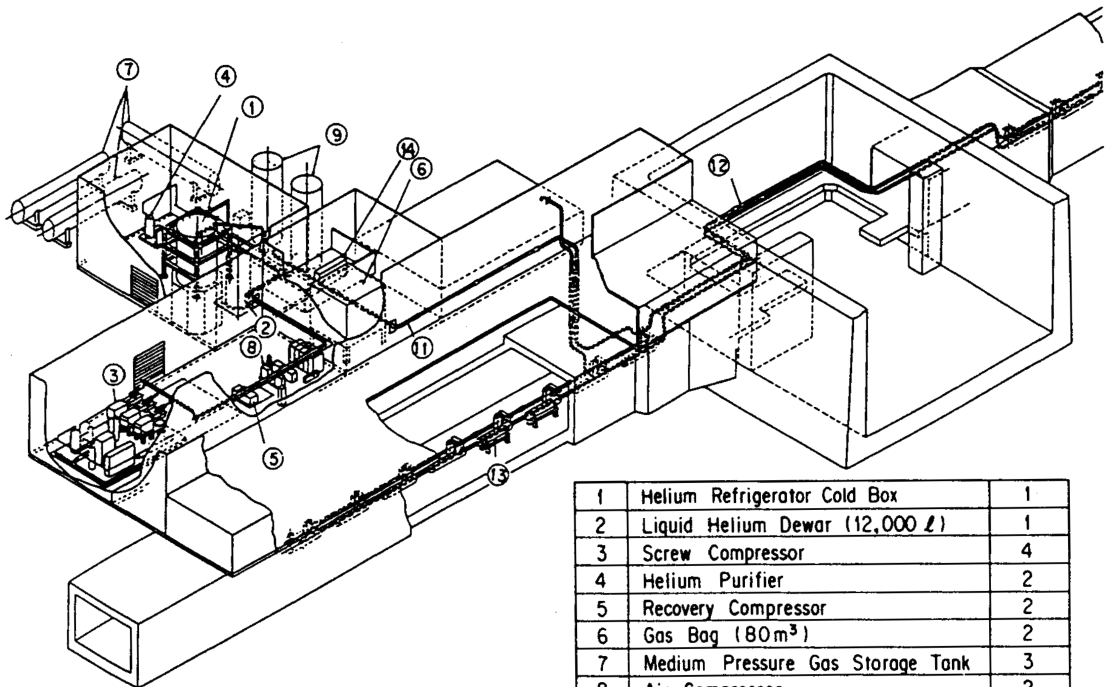


Figure 1 Schematic flow diagram of TRISTAN SCC cryogenic system.

(about 6,000 *l*/day liquid nitrogen consumption), a 12,000 *l* liquid helium storage dewar and a compressor unit were installed in the building on the ground level. The supercritical turbo-expander T3 was installed only for performance test. Sixteen 5-cell SCC in 8 cryostats were installed in the underground (about 11 m depth) tunnel of about 200 m in length TRISTAN RF straight section. Liquid helium produced by the refrigerator was stored in the 12,000 l dewar and then transfer to 8 SCC cryostats in parallel through about 200 m in length multi-channel helium transfer line composed of main and header transfer line. Liquid nitrogen for 80 K thermal shield of the SCC cryostats and helium transfer line was supplied by a liquid nitrogen circulation system. A detailed description of present cryogenic system is given in reference 2 and 3.

Table 1 Main parameters of the cryogenic system for TRISTAN SCC

Cold Box	Hitachi	Compressor	Mayekawa
cooling capacity	4000 W at 4.4 K	number of compressor	(320L x 3 + 320S x 1)
number of turbine	2	design	oil flowded screw
	gas bearing		
LN_2 Circulation System	Kobe Steel	medium pressure tank	100 m³ x 5
cooling capacity	6.5 kW at 80 K	high pressure storage	1350 Nm³ x 3
compressor (75 kW)	6.0 kg/cm²G,	liquid helium dewar	12,000 *l*
	700 Nm³/h	liquid nitrogen tank	50,000 *l*



1	Helium Refrigerator Cold Box	1
2	Liquid Helium Dewar (12,000 ℓ)	1
3	Screw Compressor	4
4	Helium Purifier	2
5	Recovery Compressor	2
6	Gas Bag (80m³)	2
7	Medium Pressure Gas Storage Tank	3
8	Air Compressor	2
9	Liquid Nitrogen Storage Tank	2
10	Cold Evaporator	1
11	Main Transfer Line	1
12	Header Transfer Line	1
13	Superconducting RF Cavity Cryostat	16
14	Control panel	1

Figure 2 An isometric showing of cryogenic equipments layout.

HEAT LOADS

In designing the cryogenic system, we assumed the Q_0-value of cavities to be 1 x 10^9 at the design accelerating field of 5 MV/m. Table 2 shows the estimated heat loads of the cryogenic components. A total heat load of about 4 kW including static heat loss from the transfer lines, cryostats, cold valves and bayonet joints was obtained.

Table 2 Estimated heat loads of the compoents

	4.4 K		80 K	
cryostat	22.8 W/cryostat × 16	364.8 W	48.8 W/cryostat	780.8 W
transfer line (380 m)		412.4 W		5569 W
cold valve & bayonet joint		147 W		294 W
	Total	924.2 W		6643.8 W
RF loss $Q = 1 \times 10^9$ $E_{acc} = 5$ MV/m	90 W/5-cell × 32	2880 W		
	Total	3804.2 W		

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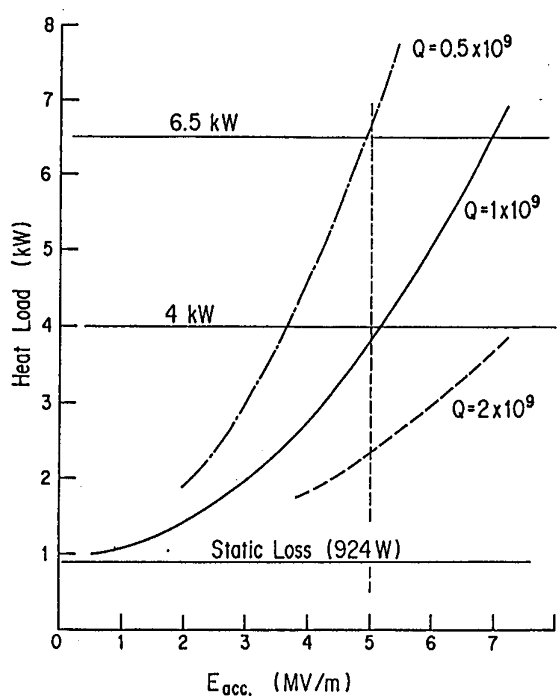

Figure 3 Total heat load of the SCC (32 x 5-cell) cryogenic system as a function of accelerating field Eacc.

The RF loss in the SCC is inversely proportional to the Q_0-value and proportional to square of accelerating field gradient Eacc. The RF loss in the SCC was estimated to be 90 W per 5-cell cavity at the design values of $Q_0 = 1 \times 10^9$ and Eacc = 5 MV/m. Figure 3 shows the total heat load of the cryogenic system, including about 900 W static heat loss, as a function of Eacc at $Q_0 = 0.5 \times 10^9$, 1×10^9, 2×10^9. The measured Q_0-values of the installed 16 SCC were about 2×10^9 and the operation Eacc were about 6 MV/m due to the improvement of cavity fabrication technique.[4] The loss in a 5-cell SCC is reduced from design value of 90 W to 60 W.

SUPERCONDUCTING RF CAVITY AND CRYOSTAT

Figure 4 shows the schematic drawing of SCC and the cryostat. Two 5-cell 508 MHz cavities made of about 2 mm pure niobium sheet were coupled together, enclosed in a liquid helium vessel with an inner diameter of 700 mm. The cold mass was about 1,000 kg and the amount of liquid helium required for the steady state RF operation of SCC was about 830 *l*. The SCC and liquid helium vessel were cooled down mildly by means of convection of cold helium gas in the vessel. An electric heater about 300 W installed at the bottom of the vessel was used to warm up and to compensation the RF heat loss of SCC during the operation. Six platinum-cobalt temperature sensors were installed in the helium vessel to monitor the temperature distribution during the cool down process. The 80 K thermal shield of the cryostat was cooled by liquid nitrogen pipe cooling.

TRANSFER LINE AND DISTRIBUTION SYSTEM

The cryogenic transfer system consisted of two helium lines (supply and return) and two liquid nitrogen lines (supply and return). The main part of the transfer system contained these four lines in a common vacuum pipe. The two helium lines were thermal shielded by a 80 K thin aluminum pipe which was thermally connected to the liquid nitrogen lines. Figure 5 shows the cross section of main transfer line. The main transfer

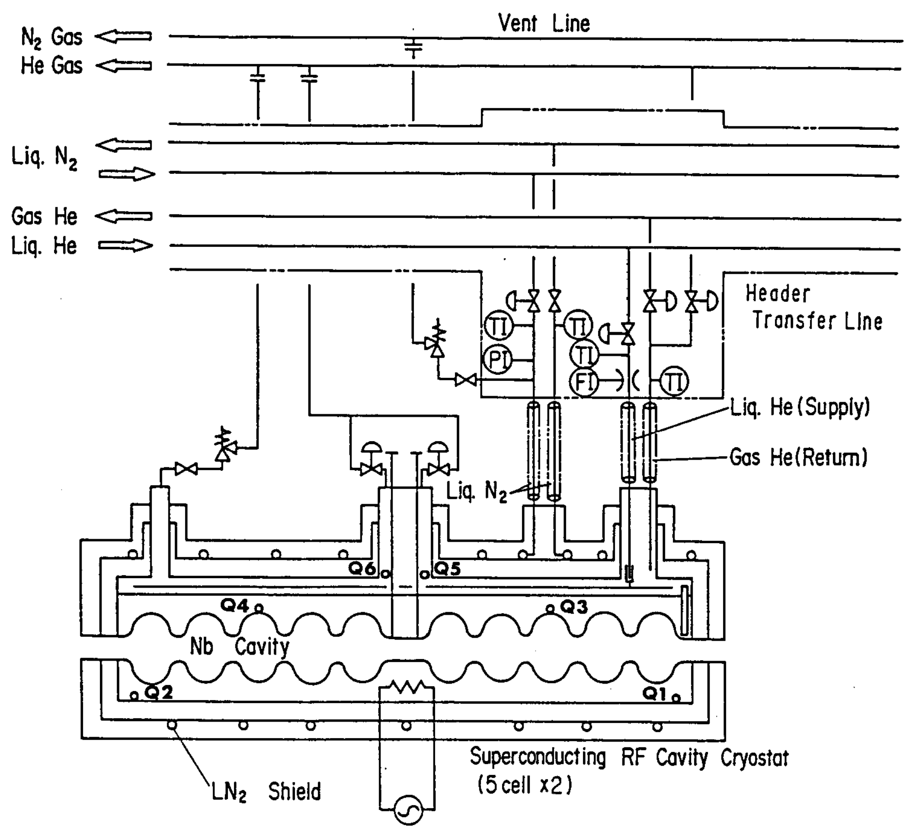

Figure 4 Schematic drawing of SCC. The location of temperature sensors are shown as small circles.

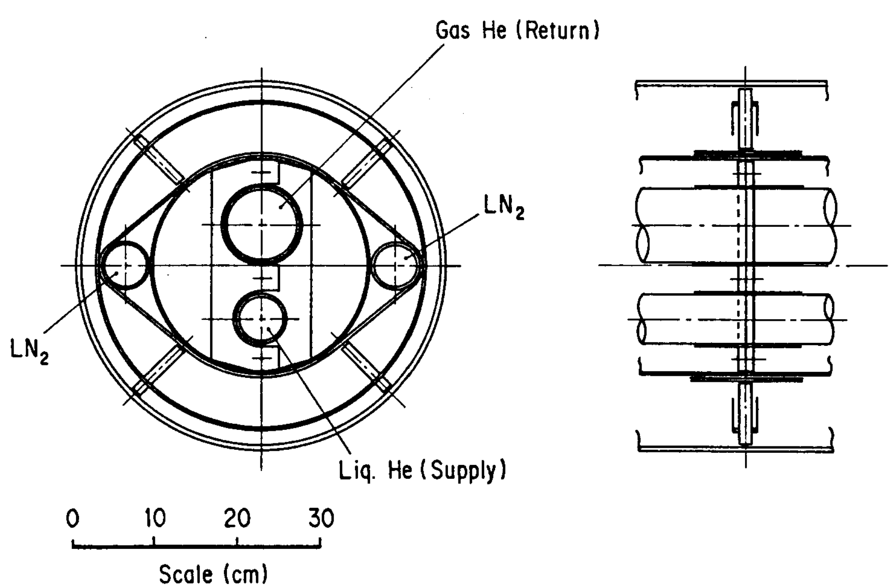

Figure 5 Cryogenic transfer line.

line was connected to header transfer line in the underground TRISTAN tunnel. The header transfer line had 16 connection boxes corresponding to SCC cryostats. Each connection box had 4 bayonet joints ports and 4 control valves. For the connections between the connection boxes and the SCC cryostats, single channel type transfer lines with bayonet joints were used for easy to handle.

LN_2 CIRCULATION SYSTEM

We adopted rather complicated liquid nitrogen circulation system which consisted of wide use commercial available screw type air compressor and aluminum plate fin type heat exchanger, because it is very difficult to attain the economical and stable operation of 16 parallel heat loads by direct supply of liquid nitrogen from the storage tank. The system flow diagram is depicted in Fig. 1 and main parameters are listed in Table 1. The excess liquid nitrogen from the SCC cryostat was used to subcool the flow liquid nitrogen. The enthalpy of vaporized nitrogen gas was recovered at the heat exchanger. The consumption of liquid nitrogen was about 70 *l* per hours for about 4.2 kW (for 8 SCC cryostat case) heat load.

CONTROL SYSTEM

A control system for the cryogenic system is shown in Fig. 6. A distributed process control system composed of commercial available Hitachi EX 1000 was used for control and monitor of the whole cryogenic system. The main feature of this control system was reliability and programing ease. All controls were handled with color

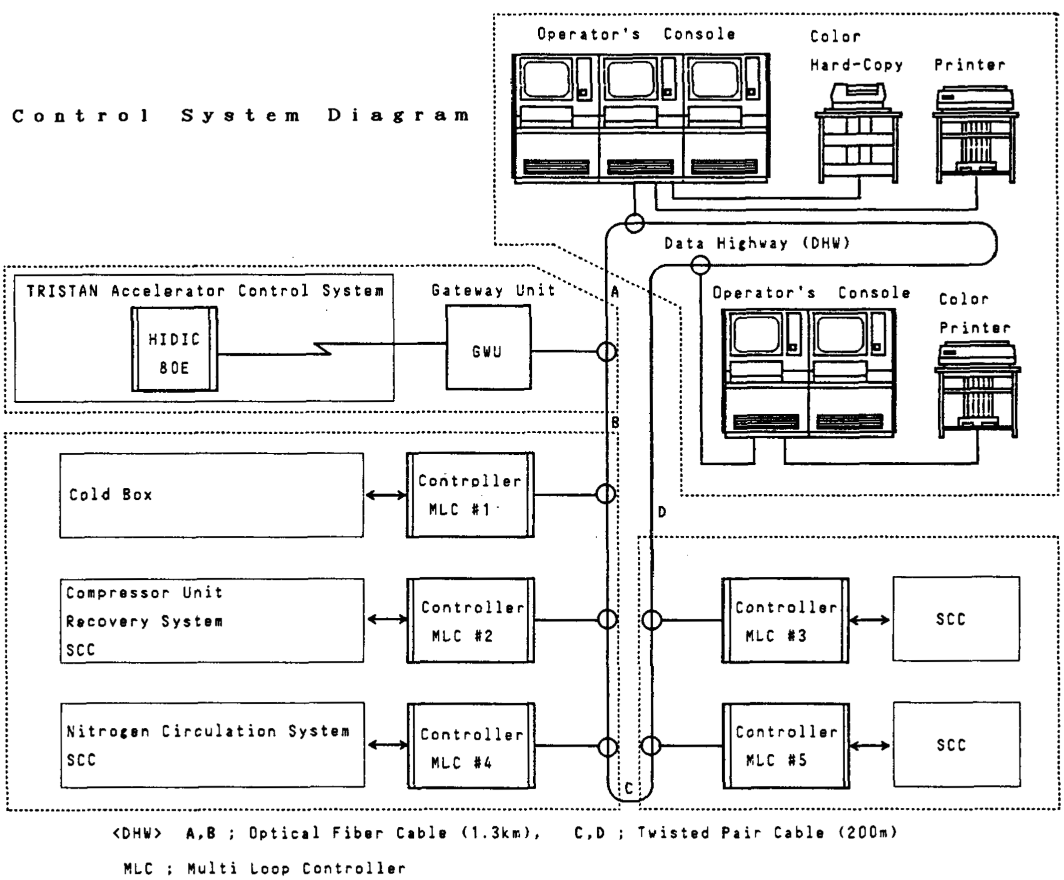

Figure 6 TRISTAN SCC cryogenic control system.

Table 3
Number of input/output data and control loops

analogue	input/output	601/113
digital	input/output	408/240
control loop		114
Total		1,362

Table 4
Specification of trends function

real time trends	10 sec x 2 hours	x 128	points
cyclic trends	1 min. x 2 days	x 128	points
	4 min. x 2 days	x 456	points

graphic operator's consoles. The number of input/output data points and control loops are listed in Table 3. These data were logged on hard disk and the trends could be generated on graphic screen. The specification of trends function is listed in Table 4. These logged data were transferred to two floppy disks and recorded every 2 days. A set of data which were important for the operation of TRISTAN was transferred to HITAC80E computer which was connected to the accelerator control system.

COOL DOWN AND WARM UP

Sixteen SCC in 8 cryostats, the total cold mass about 8,000 kg, were cooled down in parallel by cold helium gas from room temperature. Figure 7 shows a typical cool down curves of one of 8 cryostats. The cold helium gas about 80 K which was precooled by liquid nitrogen at the refrigerator cold box was supplied to 8 cryostats through transfer line. After SCC temperatures reached about 150 K, turbines of refrigerator were started. We stopped the supply of cold helium gas to the SCC cryostats at about 5 K and started the liquefaction in the 12,000 *l* dewar, and then started the liquid helium transfer from the dewar to the cryostats to fill the liquid helium up to 87 % (about 830 *l*/cryostat). The cool down speeds of 8 cryostats could adjust to be equal easily by pre-setting the helium gas flow control valves at connection boxes of header transfer line. It took about 2.5 days to cool down 8 cryostats from room temperature to liquid helium temperature and about 1 day to fill the liquid helium in 8 cryostats.

During operation of the cryogenic system, one or two cryostats were warmed up to room temperature to repair the SCC RF coupler and cooled down while the other cryostats were kept cooling by liquid helium. Figure 8 shows warm up and cool down

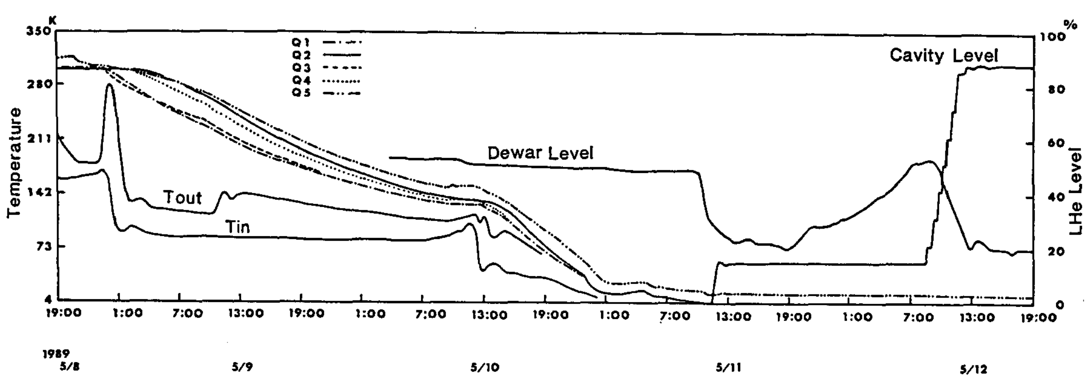

Figure 7 Cool down curves of SCC cryostat.

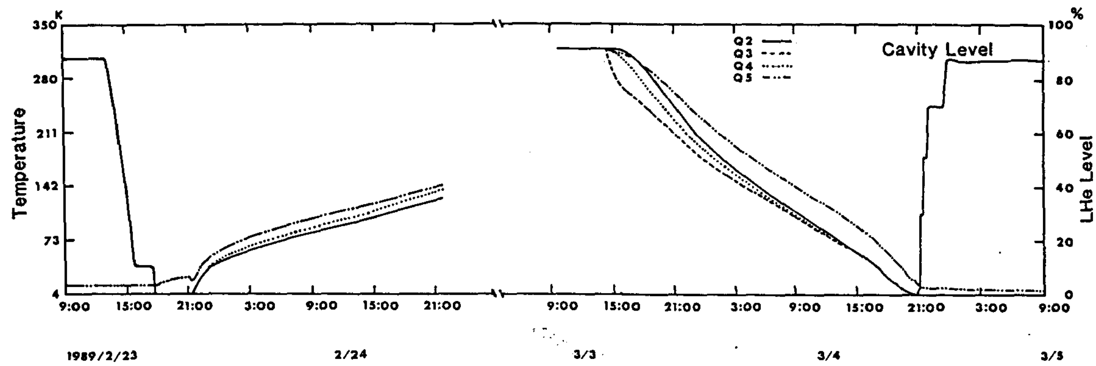

Figure 8 Warm up and cool down curves of one SCC cryostat.

curves of the cryostat. About 830 *l* liquid helium in the cryostat was recovered to 12,000 *l* dewar in about 2.5 hours by means of 200 W electric heater in the cryostat. It took about 4 days to warm up to room temperature by 300 W electric heating in the cryostat. The cooling down of the SCC was performed by liquid helium transfered to the cryostat. The vaporized helium gas from the cryostat was recovered through helium gas line in Fig. 1 to compressor suction. It took about 1.5 days to cool down from room temperature to liquid helium temperature and to fill liquid helium in the cryostat ready for SCC system operation. The cool down speed of SCC was limited by the temperature differences in the cryostat.

OPERATION OF THE CRYOGENIC SYSTEM

Under the steady state operation of SCC, liquid helium in the cryostats must be kept at 830 *l* level. This was performed by controlling the supply valves at connection boxes of header transfer line. The RF loss of SCC in a cryostat increased from about 30 W at beam injection to about 120 W at the top energy in about two minutes. The electric heaters in the cryostats were used to compensate the RF loss and to keep the pressure fluctuation due to the heat load change in the cryostats as small as possible, less than 0.01 kg/cm^2G at operation pressure 0.2 kg/cm^2G. Figure 9 shows typical RF loss, compensation heater and total heat load curves. The RF loss in the SCC was calculated from the monitored acceleration field in the SCC by pick up probe at SCC and measured

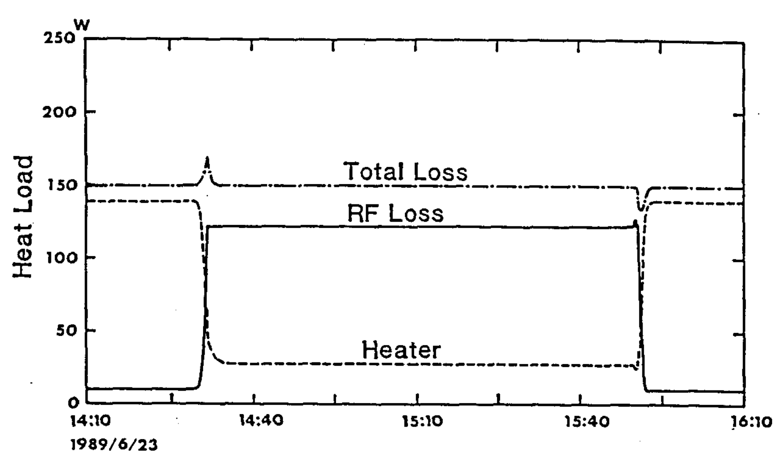

Figure 9 RF loss, compensation heater and total heat load curves.

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Q_0 value of SCC. With this calculated RF loss, the compensation heater was controlled to keep the total heat load stayed at set value, 150 W. The liquid helium level in 12,000 l dewar was controlled by the electric heater in the dewar.

During the first three months operation the helium compressor stopped four times due to a failer of cooling water system, a power failer and two unknown reasons. In these case the refrigerator was restarted and operation of SCC could begin in 8 hours after the compressor stopped.

CONCLUSION

Sixteen 5-cell SCC in 8 cryostats installed in TRISTAN at KEK were cooled successfully by the helium refrigerator. The liquid helium level and the pressure fluctuation in the SCC cryostats were automatically controlled nicely. After the first cool down of whole cryogenic system on 28 October 1988, commissioning of SCC was started on 11 November. The total operation time of the whole cryogenic system is about 6,000 hours. During this period the whole cryogenic system work very stably.

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