COMMISSIONING OF SUPERCONDUCTING RADIOFREQUENCY SEPARATOR CRYOGENIC SYSTEM

A. Ageyev, A. Bakay, E. Kashtanov, S. Kozub, M. Muraviev, A. Orlov, P. Slabodchikov
A. Khartchenko, S. Zintchenko, IHEP, Protvino, Russia

Abstract

The cryogenic and vacuum system is built to cool by superfluid helium at 1.8 K two niobium cavities of the RF superconducting kaon separator being under construction at IHEP. First commissioning runs were carried out. During the last run both cavities were successfully cooled down to the operating temperature and cryostated for several days. System description, test results and planned improvements are presented.

INTRODUCTION

The OKA separated kaon beam facility is under construction at IHEP, Protvino [1]. Two RF superconducting niobium cavities transported from CERN and working at 1.8 K are main parts of the separator [2].

A special cryogenic test facility was built at IHEP to test the cryostats with deflectors [3]. First tests were carried out at 4.2 K. Equipping the test facility with a system of vacuum pumps (pumping group) enabled to make tests at lower temperatures. Thus during two weeks deflectors were tested at 1.8 K and within this period sometimes temperature was as low as 1.6 K.

In parallel with this work the main units of the cryogenic and vacuum plant (CVP) necessary to operate the deflectors on the kaon beam were designed and manufactured at IHEP (liquid helium bath, large vacuum heat exchanger, vacuum header, part of the cryogenic transfer line with distribution box, pumping group).

After the CVP and cryostats with deflectors were installed on the beam, some test runs of the plant were carried out. The results of the last run are presented in this paper.

PLANT DESCRIPTION

Theoretical grounds and principle of operation of the cryogenic and vacuum plant are given in [4]. A simplified flow diagram of the CVP is shown in Fig. 1.

A satellite refrigerator cooling the superconducting cavities consists of the large vacuum heat exchanger HEX, liquid helium bath and of two small heat exchangers located close to the each cryostat with deflector.

Liquid helium plant of the KGU-500 type to feed the satellite refrigerator is commercially produced by GELIYMASH company, Moscow, and it has liquefaction rate of 150 l/hr.

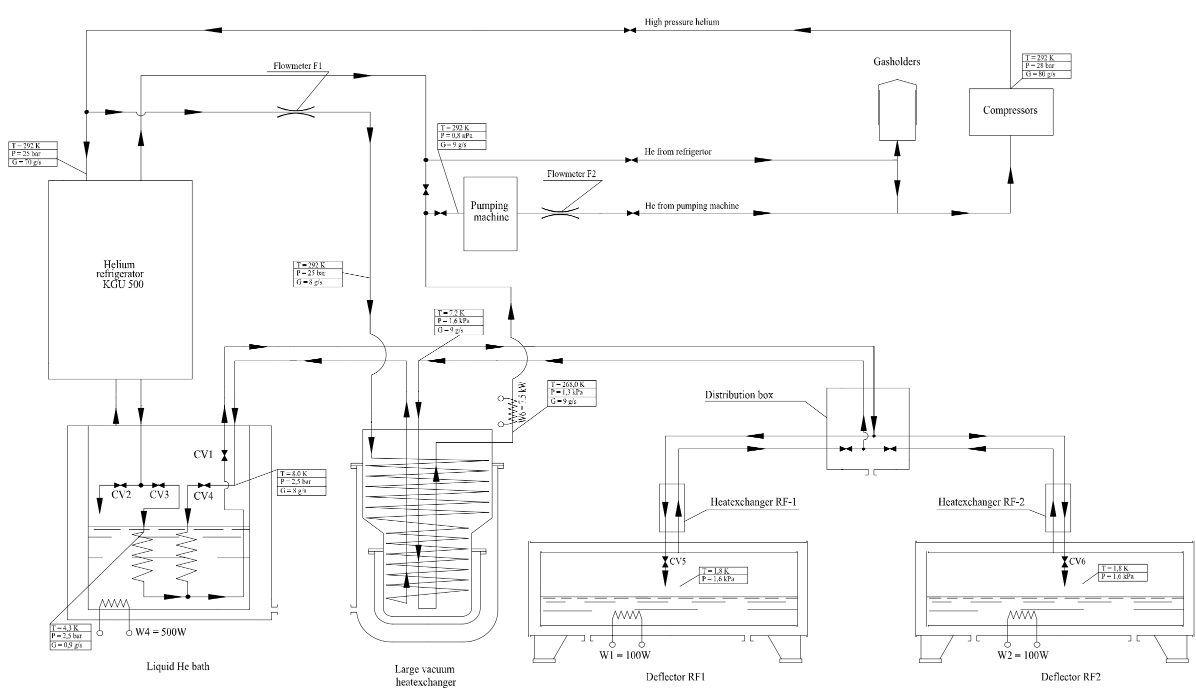

Figure 1: Flow chart of the cryogenic and vacuum plant cooling the superconducting RF deflectors

Some parameters of the cavity and cryostat are given in Table 1.

Table 1: Cryostat and cavity parameters.

Parameter	Value
Cavity length (m)	2.7
Cavity outer diameter (mm)	140
Cavity aperture (mm)	40
Cavity mass (kg)	260
Helium tank diameter (mm)	510
Helium tank length (m)	3.4
Helium tank geometric volume (l)	710
Vacuum vessel diameter (mm)	910
Vacuum vessel length (m)	4.17

The deflectors are arranged on the beam axis at 76 m distance from each other.

Cryogenic transfer line manufactured by CRYOGENMASH company is used to deliver liquid helium and liquid nitrogen from CVP to the cryostats with deflectors and to return helium vapour from the cryostats. Total length of the transfer line is 103 m including 11 m between liquid helium bath and distribution box. Transfer line from the distribution box to the first deflector along the beam (RF1) is 50 m long (branch KK1). Transfer line to the second deflector (RF2) is 42 m long (branch KK2).

Design capacity of the cryogenic system is 250 W at 1.8 K and it should deliver 5 g/s of liquid helium per each deflector. To reach 1.8 K the pumping group is to pump helium tanks down to 1.64 kPa. Pumping group is arranged in 3 stages: 8 Roots blowers of the 2DVN-1500 type of the first stage compress helium from 1.5 kPa to 2.5÷3.0 kPa, 8 Roots blowers of the 2DVN-500 type of the second stage compress helium to 4.0÷5.0 kPa, and the third stage of 8 slide-valve pumps of the AVZ-180 type finally compress helium up to 103 kPa.

Gasholders and compressors located 850 m apart are used in the plant. Low pressure helium returns to the gasholders by the line 150 mm in diameter. Helium pressurized in compressors up to 28 bar comes to the plant by the pipe 80 mm in diameter. Compressors throughput is about 80 g/s.

SYSTEM OPERATION DESCRIPTION

After compressors pressurized helium gas flow is divided in two parts. One part is used in helium refrigerator KGU-500, the other part (main flow cooling the deflectors) goes to the inlet of the heat exchanger HEX. Helium flow at 25 bar and 4.5 K from KGU-500 is fed along a short cryogenic transfer line to the expansion valves in the liquid helium bath. One J-T valve is to keep the level of liquid helium in the bath. The flow through another J-T valve is an additional flow to cool the deflectors. Helium vapor from the liquid helium bath returns to the heat exchangers of the refrigerator, so the plant works in combined mode.

Liquid helium bath contains main and secondary condenser coils. Helium pressure in the bath is 1.3 bar, but in the coils pressure is 2.5 bar to feed deflector cryostats with subcooled helium.

Main helium flow for cooling deflectors is cooled in HEX by recuperation of the cold of helium vapor. After expansion and cooling in the main condenser the main flow is mixed with the secondary one.

Along a cryogenic transfer line this mixed flow comes to the distribution box where it is distributed approximately equal to the low temperature heat exchangers of the cryostats RF1 and RF2. In these heat exchangers helium flow is cooled down to the final temperature and is expanded through the J-T valves into the cryostats RF1 and RF2. Helium vapor, after passing through the low temperature heat exchangers, cryogenic transfer line and large vacuum heat exchanger, has temperature close to the room temperature and it goes to the suction of the pumping group. Helium exhausted by pumping group is mixed with low pressure flow from the refrigerator and goes to the gasholders. Thus the cooling cycle is closed. Main parameters of the plant are given in Table 2.

Table 2: Cryogenic and vacuum plant parameters.

Parameter	Value
Cooling capacity at 1.8 K (W)	250
Power consumption (kW): - compressors and refrigerator - pumping group and auxiliary	500 240 260
LN2 consumption (l/hr): - refrigerator and purification - thermal shields	280 220 60
Cooling water consumption (m^3/hr): - AVZ-180 pumps - 2DVN-1500 pumps - pumping group heat exchangers - other plant equipment	14.4 10.4 2.9 0.6 0.5

PLANT TEST RESULTS

Helium refrigerator and liquid helium bath were cooled down for 24 hours. Then during two days the cryostats with deflectors were cooled by helium flow from the refrigerator at a prescribed rate of 6 K/hr. Warm helium from the cryostats was returned to the gasholders. As a result both RF1 and RF2 were cooled down to 40 K. Further cooling down of the cryostats and filling them with liquid was done one by one with HEX in operation. Initially RF1 within 1 day was cooled down to 4.2 K and filled with liquid helium to 70% (about 500 l). The same procedure for RF2 took 2 days as part of liquid flow was used to keep the level in RF1.

Graphs of the separate and simultaneous filling of the cryostats are shown in Fig.2. Cooling down and filling of RF1 took less time than that of RF2 despite of the transfer line branch KK1 is longer than KK2. Apparently it could be explained by somewhat lower heat leaks due to better vacuum in KK1 than in KK2 (Table 3). Maximum filling rate for both cryostats simultaneously was lower as in this case liquid helium absorbs the heat leak in both branches of the transfer line.

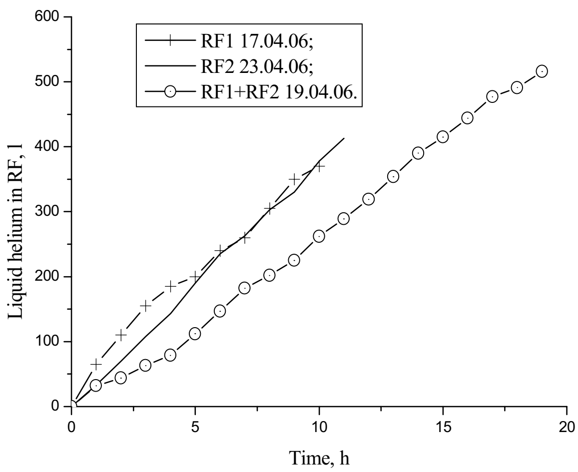

Figure 2: Graphs of the filling of the cryostats helium tanks with liquid helium.

Values of pressure in the insulation vacuum volumes of the plant at different helium temperatures are shown in Table 3. These values were measured while the volumes (except distribution box) were continuously pumped by vacuum stations.

Heat leak to the liquid helium bath was evaluated as 15 W by measuring the evaporation rate. Similar measurements for deflector cryostats RF1 and RF2 resulted in about 17 W.

Table 3: Insulation vacuum in system units in mm Hg.

System unit	**Helium temperature (K)**		
	300	*4.2*	*1.8*
RF-1	$2\cdot10^{-5}$	$2\cdot10^{-6}$	$1\cdot10^{-5}$
RF-2	$8\cdot10^{-5}$	$2\cdot10^{-6}$	$7\cdot10^{-5}$
KK1	$8\cdot10^{-5}$	$8\cdot10^{-6}$	$2\cdot10^{-6}$
KK2	$2\cdot10^{-4}$	$7\cdot10^{-5}$	$6\cdot10^{-5}$
Distr. box	$2\cdot10^{-6}$	$3\cdot10^{-7}$	$2\cdot10^{-7}$

Further cooling down was arranged in steps two hours long, after each step temperature was 0.5 K lower. The level of liquid in helium tanks was stable (about 80%). At each temperature step the deflectors were RF powered during 5 hours. Finally deflectors were tested 26 hours at 1.9 K and 31 hours at 1.8 K. Superfluid liquid level was maintained close to 80% in both cryostats, the pumping group was compressing 8.5÷9.5 g/s of helium gas.

It was measured that to keep 1.6 kPa in the helium tanks at helium mass flow rate of 9 g/s it is necessary to have 0.8 kPa at the 2DVN-1500 suction. Suction pressures of the 2DVN-500 and of the AVZ-180 are 1.6 kPa and 3.5 kPa in this mode, correspondingly. At the exhaust of AVZ-180 pressure was 101 kPa and it was high enough to return helium to the gasholders.

The slide-valve pumps of the AVZ-180 type used in the third stage of the pumping group are not designed for the continuous work and they worked in off-nominal mode (nominal suction pressure should not exceed 2 kPa at long work). This results in the loss of oil from the pumps. Totally over 80 hours of continuous operation 60 l of 224 l were lost with helium flow and it corresponds 0.3÷0.4 % per hour. It is necessary to solve the problem of the oil losses and oil replenishment in the operating pumps while keeping helium piping sealed.

In addition to the problem of the oil loss during the test run the oscillations of helium pressure in the liquid helium bath were observed, very similar to the thermoacoustic oscillations. These oscillations certainly decreased the useful cooling capacity of the system and should be eliminated. On the base of the test results the ways to increase the efficiency of the cryogenic and vacuum system were developed as well as the means to reduce heat leaks at liquid helium temperature.

Heating the deflectors up to the room temperature took two days. The next run with a particle beam in the deflectors is scheduled on December 2006.

CONCLUSION

The unique cryogenic and vacuum system to cool superconducting devices at 1.8 K by superfluid helium with mass flow rate about 10 g/s is built. For the first time in Russia this system supplied 1000 l of superfluid helium into two cryostats with superconducting deflectors and it allowed RF powering of the particle separator. During the test run different modes of the cryogenic and vacuum system were tested, some problems were revealed and now the ways to solve them are developed.

ACKNOLEDGEMENT

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