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STATUS OF THE TTF CRYOGENIC SYSTEM

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ABSTRACT

As part of the TESLA-Collaboration, components of a 1.8 K cryogenic plant, designed for testing superconducting RF cavities at the DESY laboratory, have been designed and built at the CEN SACLAY, LAL ORSAY, FERMILAB, INFN FRASCATI and DESY. Some additional components are being fabricated at IHEP PROTVINO and industry. The general layout of a 1.8 K Test Facility for the test of superconducting RF cavities has been described earlier¹.

The first stage of the cryogenic facility has been brought into operation. During tests of the prototype cavities, the cryogenic performance of the main components of the cryogenic plant was monitored and is presented. This includes vacuum compressors, vertical and horizontal test dewars, a collection box and a helium heater.

For the second stage, required for the operation of the TTF-500 MeV-linac, the construction of the first module cryostat, the capture cavity cryostat, the 6-fold transfer line and the TTF-feedbox is almost finished. The construction of TTF-module transfer lines, TTF-module end caps and a large low pressure heat exchanger has begun. The design of these components and the present status of the installation at DESY is reported.

INTRODUCTION

The cryogenics of a 1.8 K TESLA Test Facility (TTF) for the test of superconducting RF cavities and the operation of a superconducting 500 MeV test linac has been described recently^{1,2}. After the rebuilding of a 900 W 4.4 K helium plant and the installation of a vacuum compressor system and a helium distribution system, a vertical test dewar³ and a horizontal test dewar (CHECHIA)⁴ were brought into operation.

The vertical dewar is used to test the RF performance of single superconducting RF 9-cell cavities at a temperature of about 1.8 K in a liquid helium bath. In addition High Peak Power (HPP) processing and temperature mapping measurements take place in this dewar². In CHECHIA single cavities are tested again, after they have been equipped with their individual helium tanks, the main RF couplers and the higher order mode (HOM) couplers. After the installation of the main couplers, the RF quality Q_{RF} can only be detected by cryogenic heat loss measurements.

The continuous supply of 1.8 K liquid helium which is precooled by means of a low temperature heat exchanger and expanded via a Joule-Thomson valve into a helium bath at a constant level is common for all test cryostats of the facility as well as for the later TTF-test linac. During the first tests of cavities experience can be gained in the operation of the Helium plant, which is valuable for the later operation of the other components.

The complete TTF-linac will consist of a beam-injector including a superconducting capture cavity (CRYOCAP) and four module cryostats (see fig. 1). The detailed status of CRYOCAP and the module cryostats is reported separately in this conference^{5,6,7}. Each module cryostat includes eight superconducting cavities and one superconducting quadrupole. The first module cryostat^{6,7} is under construction at INFN. The module vacuum vessel, thermal shields, supports, tubing and a 300 mm diameter return tube will be delivered to DESY for final assembly, were also a chain of eight equipped cavities and a quadrupole will be inserted into the vacuum vessel.

The operation of the linac will start in several steps. As a first step the injector and one module cryostat will be operated. With the installation of a 100 m long transferline, a TTF-feedbox and the transferlines to CRYOCAP and the first module the cryogenic supply will be similar to the supply of the test cryostats. For the supply of the complete test linac

Figure 1. Simplified flowscheme of the cryogenic supply of the TESLA Test Facility.

(1) 5 K supply Joule Thomson (JT) valve, (2) 7.5 K supply JT-valve (from large heat exchanger), (3) 4.4 K return JT-valve, (4) cool down bypass valve, (5) 1.8 K return isolation valve, (6) relief valve system, (7) low temperature heat exchanger, (8) 1.8 K supply JT-valves, (9) cool down bypass valve, (10) cool down bypass valve, (11) 1.8 K supply JT-valve, (12) subcooler, (13) module quadrupole, (14) $\varnothing$ 300 mm module return tube, (15) liquid level sensor and heater, (16) 70/80 K thermal shield supply (details not shown), (17) 4.4 K thermal shield.

the liquefaction mode of the plant will be changed into refrigeration mode by means of an additional large heat exchanger . The heat load capacity at 1.8 K will thus be enhanced from about 100 W to 200 W .

VACUUM COMPRESSOR SYSTEM

The vacuum pumping assembly is designed to meet the demands of all phases of the TTF project. For helium mass flows in the range of 0.2 to 10 g/s the pressure can be regulated from 10 mbar to 30 mbar with a relative stability better than 1 %. For mass flows lower than 10 g/s the pressure can be lowered to about 1 mbar.

Although cold compressor systems for this pressure range and mass flows up to 10 g/s are available, warm vacuum compressors were chosen for the TTF due to their flexibility and simplicity of operation. After crossing low temperature heat exchangers and a gas heater in the first stage or a large low pressure heat exchanger in the second stage the helium gas is at a temperature of more than 253 K before entering the vacuum compressors.

As shown in fig. 2 the vacuum compressor system consists of four stages. At the low pressure end the gas is compressed by two roots blowers (LEYBOLD RA 16000) in parallel followed by two stages of single roots blowers (RA 13000/RA9001). All roots blowers are dry pumps, only the bearings are oil lubricated. In the last stage four rotary vane pumps (LEYBOLD SOGEVAC 1200) in parallel feed the gas back to the main gas circuit of the helium refrigerator at a pressure of 1.05 to 1.3 bar, which corresponds to the suction pressure of the screw compressors.

The helium mass flowrate is measured at room temperature by one of two parallel flowmeters at the outlet of the vacuum compressor assembly.

Under full stationary load the maximum electrical power consumption does not exceed 150 kW (with 340 kW power installed).

All pump stages are separated by gas coolers. The rotary vane pumps are cooled in addition by oil/water heat exchangers . The oil contamination of the gas is lower than 60 ppm at the

Figure 2. Vacuum compressor assembly. The vacuum compressor assembly consists of two parallel RA16 000 (1), one RA 13000 (2), one RA 9001 (3) rootsblowers and four parallel SV 1200 rotary vane pumps (4), a set of oil filters (5), warm mass flowmeters in the range 0 - 2 g/s and 2 - 20 g/s (6) and two bypass valves (7). Pressures are indicated for the nominal inlet pressure of 10 mbar and maximal massflow of 10 g/s. (Simplified flow scheme)

outlet of the rotary vane pumps and is further reduced to <1 ppm by additional filter elements to avoid any risk of oil condensation in the cold parts of the refrigerator. Breox B 35 oil is used in all vacuum compressors as well as in the screw compressors of the refrigerator.

The suction pressure of the vacuum compressor assembly is regulated by two bypass valves in parallel to the rotary vane pumps and the roots blowers respectively. The whole system is operated by an internal process control system (SIEMENS SIMATIC S5) which communicates with the process computer of the refrigerator. With the desired suction pressure set, the system reacts to changes of mass flow and pressure by operating the bypass valves and switching pumps on and off.

The vacuum compressors are housed in an extra building attached to the TTF-experimental hall but separated by its own foundation with a distance of about 20 m to the test linac. The beam of the linac will be extremely sensitive to any kind of external vibrations. To avoid vibrations as far as possible, the frame of the vacuum compressors is separated from the floor by special damping elements (BARRYMOUNT SLM) in addition, resulting in more than 90 % damping of the vibrations. (The RMS oscillation velocity of 2 mm/s at the frame is reduced to less than 0.1 mm/s at the floor).

The complete vacuum compressor assembly was designed and constructed by the LEYBOLD AG in Germany and delivered to the TTF-collaboration in time and on schedule.

After the vacuum compressor assembly had passed initial acceptance test on the manufacturer's side and at DESY and an operational test of 1000 hours without severe failures the plant has now reached about 4000 hours of operation.

VERTICAL DEWAR

The vertical test dewar has a depth of 3.8 m and an inner diameter of 0.6 m. During the RF tests of 9-cell cavities the dewar is filled with 620 liters of liquid helium at a temperature of 1.8 K.

The vertical test dewar consists of the dewar itself, the outer vacuum vessel with a thermal shield cooled by liquid nitrogen and the top plates. The supply and return tubes, cryogenic valves and the low temperature heat exchanger are installed outside the helium dewar and inside the outer vacuum vessel, leaving free all space inside the helium dewar for the cavity insert, the RF connections and the vacuum equipment. The transferlines including the vacuum insulated helium pumping tube are welded to the outer top plate of the dewar. A more detailed description of the vertical dewar can be found elsewhere³. The dewar has been designed and built at FERMILAB.

Helium of about 4.4 K and a pressure of 1.2 to 3 bar is supplied by the 900 W plant, precooled by a low temperature heat exchanger to about 2.2 K and expanded via a Joule-Thomson valve into the helium dewar. The operation of the JT Valve is controlled so as to keep the liquid level constant during steady state operation. The vapor pressure of the liquid helium bath is lowered to a pressure of 16 mbar by means of the vacuum compressor system. The helium is pumped through the low temperature heat exchanger, the collecting box and the helium heater.

The helium dewar and the insert are equipped with several temperature sensors, a level sensor and pressure gauges. Additional heat load of up to 100 W can be supplied by an electrical heater in the bath. This heater can be used complementary to the changing RF-Power to obtain constant heat loads and more stable conditions.

For the performance tests different helium massflows were adjusted by the heat load of the electrical heater in the helium bath. The liquid helium level was kept constant at a reading of 95 % of the level sensor (this means that a 9-cell cavity is covered with about 20 cm of liquid at its top end). Each setpoint was maintained for several hours to insure stationary thermal conditions.

In fig. 3 the maximum obtainable extra heat load as well as helium bath vapor pressures are plotted versus the pumped helium massflow at 9.5 mbar and 5 mbar pressure setpoint at the vacuum compressors. For a vapor pressure of 16 mbar (1.8 K) the maximum extra heat load turns out to be about 79 W at a setpoint of 5 mbar at the vacuum compressors (about 40 W at a setpoint of 9.5 mbar).

Heat loads in the vertical dewar as well as in CHECHIA can be obtained from the measured liquid level drop while the supplies are closed, or from the absolute pumped helium massflow measured at constant liquid level of the helium bath. Using the second method, it has to be taken into account that a fraction of the pumped massflow is caused by the quality of the fluid at the JT-expansion. This quality can be calculated from thermodynamic state functions if temperature and pressure of the helium in the supply of the JT-valve is known.

The total heat loss results from the static heat loss of the helium dewar including the cryostat insert (cavity, waveguide, couplers, vacuum tubes, supports and cables), thermal radiation and thermal conduction across the helium vessel and the tubing connected to the vessel, and the extra heat loads due to RF operation of the cavity (or the electrical heater): During continuous wave RF operation of a nine cell cavity in the vertical dewar the Q_{RF} -value was calculated from the corresponding heat loss measurements in the helium bath.

Figure 3. Vertical dewar cryogenic performance. The helium vapor pressures of the vertical dewar and the external heat loads are plotted versus the corresponding helium massflows at two setpoints of pressure at the vacuum compressors. For a given vapor pressure in the dewar the maximum external heat load can be obtained from the diagram. For the design vapor pressure of 16 mbar (1.8 K) 79 W external heat can be applied.

The deviation of the Q_{RF} calculated from electrical measurements to the Q_{RF} calculated from the heat losses is smaller than 10 %. In CHECHIA the Q_{RF} can only be monitored by cryogenic measurements after the main RF coupler has been installed⁴.

From the data in fig. 3 a static heat load of 20 - 25 W results for the vertical dewar with a 9-cell cavity if the liquid helium level is in the range of 95 %. This static heat loss can be lowered to about 10 W if the level is decreased further. With a maximum of about 80 W for continuous RF cavity heat load left at 1.8 K, there is enough cryogenic capacity for all RF measurements, HPP preparation and temperature mapping. In addition, was demonstrated during the first cw-tests of the 9-cell prototype cavities that the regulation system will return to stable operation even if heat loads up to 300 W are transferred into the helium bath for some seconds. With minor changes in the design, a second vertical test dewar is under construction at Fermilab.

The continuous supply of helium into the dewar resulting in a constant helium level during the subatmospheric operation has some important advantages in comparison to the more common method of lowering the level during pumping on a helium bath: the time to test superconducting RF cavities at 1.8 K is not limited by an emptied helium bath and about one meter of cryostat length corresponding to about 200 l of liquid helium could be saved. Detailed results of heat loss measurements of the CHECHIA cryostat are presented in a separate paper at this conference⁴.

MAIN TTF TRANSFERLINE

For the cryogenic supply of the TTF-linac a 6-fold 100 m transferline is required to connect the 900 W refrigerator, the helium heater (stage I) or a heat exchanger (stage II) and a feedbox close to the first TTF module cryostat. This transferline has been designed and is under construction now at the DEMACO company in the Netherlands. Fig. 4 shows a cross section of this transferline. At the 70 K level 2 W/m and on the 4.4 K level 0.2 W/m are specified for the overall heat losses of the transferline.

Figure 4. Cross section of main transferline. (1) Vacuum vessel, (2) 80 K thermal shield, (3) glass fiber reinforced plastic (GFRP) suspension, (4) 80 K return tube, (5) 70 K supply tube, (6) 4.4 K return tube, (7) 5 K supply tube, (8) 3.5 K / 16 mbar return tube, (9) 7.5 K supply tube (from large heat exchanger), (10) moving supports, (11) tube compensators.

TTF FEEDBOX

The feedbox is needed to branch the 70 K, 4.4 K and 1.8 K helium circuits to the first module cryostat and CRYOCAP. The simplified flow scheme of the feedbox is shown in fig. 1. In addition the 4.4 K has to be re-cooled in the feedbox to get stable conditions for both the 4.4 K shield of the modules as well as for the JT-supply of the 1.8 K bath. The return gas from the 4.4 K shield of the modules is expanded via a JT-valve into the liquid bath of the subcooler. After the installation of a large low pressure heat exchanger in the second stage 7.5 K/14 bar helium coming from this heat exchanger will also be pre-cooled to about 5 K and then be expanded into the subcooler bath. The low temperature heat exchanger for the supply of the modules is attached to the feedbox. The feedbox has been designed and is under construction at FERMILAB.

MODULE TRANSFERLINES, FEED & END CAPS

Transferlines from the feedbox to the first module (8 m) and to cryocap (3 m) include JT-valves and bypass valves for cool down and warm up (see fig. 1) . By means of flexible hoses only small transversal forces will act on the suspensions of the module cryostat. A sketch of the feed cap connection to the first module is shown in fig. 5. The flanges of feed and end cap have to support 14 000 kg vacuum force. The end flanges are equipped with feedthroughs for optical alignment and a stretched wire monitor system. The module transferlines and the feedcap are designed and constructed at DESY and the endcap at INFN.

Figure 5. The connection of the module transferline to the first TTF-module (feedcap)

LARGE LOW PRESSURE HEAT EXCHANGER

To increase the cooling capacity from about 100 W to 200 W at 1.8 K for the later supply of the complete test linac, the enthalpy of the low pressure gas has to be transformed to a pressure and temperature level which can be used in the cryoplant by means of a Large Low Pressure Heat Exchanger.

In this heat exchanger incoming warm 14 bar helium gas is cooled to a temperature of less than 7.5 K by the counterflow of low pressure gas which enters the heat exchanger at a temperature of about 3.5 K.

At a maximum mass flow of 10 g/s of the low pressure gas the high pressure mass flow has to be tuned to the performance of the heat exchanger resulting in a mass flow of about 9 g/s. The high pressure gas is expanded via a JT valve into the subcooler of the TTF-feedbox (see fig. 1). The high pressure gas flow rate is controlled by the gas temperature in the supply of this JT valve.

At a low pressure mass flow of 10 g/s a pressure drop of only 3 mbar can be allowed, a large thermal stress due to the high temperature gradient is expected. The performance of the heat exchanger will be seriously affected by internal heat flow along the tubes. A small gas heater of 1.5 kW at the warm outlet of the low pressure flow is added to give more flexibility.

The Large Low Pressure Heat Exchanger is installed into a vacuum isolated box, separated from the 4.4 K Cold-Box and from the feedbox of the test linac. IHEP Protvino is in charge for the design of the heat exchanger which will be built in Russian industry.

CONCLUSION

The cryogenic system for the TESLA Test Facility is well underway. The first vertical dewar and CHECHIA have been successfully operated. A second vertical test dewar, the TTF feedbox, main transferline, module transferlines, feedcap and endcap are to be delivered by the end of 1995. Delivery of the large low pressure heat exchanger is planned for summer 1996. Cryogenic operation of the first part of the TTF Linac (first module and CRYOCAP) is expected in the first quarter of 1996.

REFERENCES

1. Horlitz, G., et al., 'A 1.8 K Test Facility for Superconducting Rf Cavities', Adv. in Cryogenic Engineering, Plenum Press, New York, 1993, Vol. 39, (Proc. of the CEC/ICMC Conference 1993 in Albuquerque, N.M.)
2. Grygiel, G., et al., 'A 1.8 K Test Facility for Superconducting RF Cavities', TESLA-COLLABORATION, TESLA 94-08, April 1994
3. Nicol, T.H., et al., 'TESLA Vertical Test Dewar Cryogenic and Mechanical Design', IEEE Proceedings of the 1993 Particle Accelerator Conference, Vol. 2, pp. 989-991, Piscataway, N.J., 1993
4. Duthil, R., et al., 'Cryogenic and Electrical Test Cryostat for Instrumented Superconductive RF Cavities (CHECHIA)', Adv. in Cryogenic Engineering, this conference
5. Buhler, S., 'Status Report of the TTF Capture Cavity Cryostat', Adv. in Cryogenic Engineering, this conference
6. Nicol, T.H., 'TESLA Test Facility Cryostat Design', Adv. in Cryogenic Engineering, this conference
7. Alessandria, F., et al., 'Design, Manufacture and Test of the TESLA-TTF Cavity Cryostat', Adv. in Cryogenic Engineering, this conference