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CRYOGENIC PERFORMANCE OF THE FIRST VERTICAL DEWAR OF THE TESLA TEST FACILITY

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ABSTRACT

A vertical dewar for the test of 9-cell 1.3 Ghz cavities is the first component of the cryogenics of the Tesla Test Facility which was brought into operation. During the tests of two prototype cavities and temperature mapping experiments with a single cell cavity, the cryogenic performance of this vertical dewar was monitored: with a static heat load of 20 W at 1.8 K bath temperature 79 W external heat load is available for the different RF measurements under stationary conditions. Depending on different external heat loads and corresponding helium massflows the resulting minimal obtainable helium bath vapor pressures were measured. Also the pressure drops across the low temperature heat exchanger, collecting box, helium heater and transferlines were measured for different low pressure helium massflows. A first attempt was made to record the Q_{RF}-value of a 9-cell cavity by cryogenic measurements.

INTRODUCTION

The cryogenics of a 1.8 K test facility for the test of superconducting RF cavities 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 assembly[3] and a helium distribution system including different transferlines, distribution and collection boxes and a helium heater[4], the vertical test dewar[5] is the first cryogenic test component of this facility which was brought into operation.

This dewar is needed 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. Also ‘High Peak Power’ (HPP) processing and temperature mapping measurements take place in this dewar[2].

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 test facility as well as for the later TTF-test linac. During the first tests of prototype cavities some experience could be gained in the operation of the plant which is valuable for the later operation of the other components. In addition, some specific design features like pressure drop calculations could be compared to measurements.

Apparatus

The vertical test dewar has a depth of 3.8 m and a 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. All 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 of the helium dewar for the cavity insert, the RF 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 elsewhere [5].

Figure 1

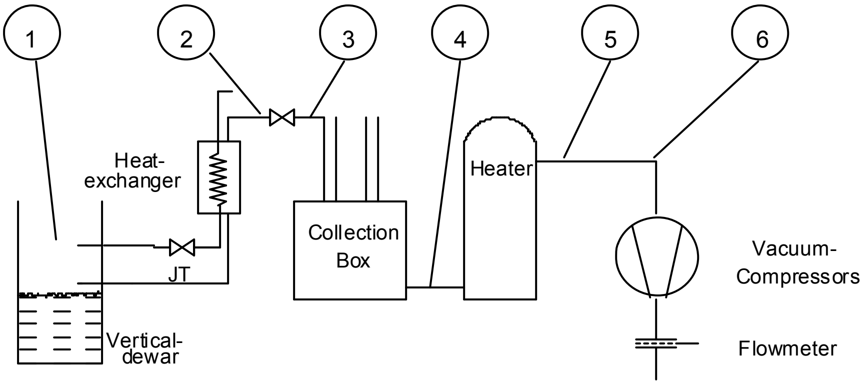

fig. 1
Principle flow scheme of the vertical dewar pumping system

A schematic cooling scheme of the vertical dewar is shown in figure 1. Helium of about 4.5 K and a pressure of 1.2 to 3 bar is supplied by the 900 W plant, precooled by a low temperature heat exchanger and expanded via a Joule-Thomson valve into the helium dewar. The operation of the JT Valve is controlled by the level of the liquid, keeping the level constant during stationary operation. The vapor pressure of the liquid helium bath is lowered to a pressure of 16 mbar by means of the vacuum compressor assembly. The pressure is controlled by a bypass regulation of the vacuum compressors. The helium is pumped through the low temperature heat exchanger, the collecting box and the helium heater. All components including pumping tubes are wrapped with super insulation.

The temperatures around the low temperature heat exchanger are strongly affected by the balance of the supply and return massflows, the absolute values of the massflows and the liquid level in the dewar. To get a liquid fraction of about 90 % the temperature of the helium entering the JT-valve must be lower than 3 K.

During cool down and warm up the low temperature heat exchanger is bypassed and the helium is supplied to the bottom of the dewar and returned directly to the helium distribution system through an extra return valve.

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

The pumped helium massflow is measured at room temperature by two parallel flowmeters at the outlet of the vacuum compressor assembly.

To monitor the pressure drops and temperatures across the complete pumping arrangement pressure gauges and temperature sensors were installed as indicated in fig. 1. The big isolation valve in the return tube of the dewar was replaced by an insert equipped with extra temperature sensors and a pressure gauge. Absolute pressure gauges were used as well as differential pressure gauges. All pressure gauges were recalibrated before the measurements.

The electrical signals from the different sensors were recorded by an integrating data acquisition system ‘COBRA’. The ‘COBRA’ system is running under the UNIX like ‘LINUX’ operating system. Data transfer to the other computers of the TTF laboratory is accomplished by remote procedure call servers and Ethernet. Access to the data is possible via the vacuum control system as well as via the Lab View RF control system.

Results

Absolute pressures for various helium massflows and at several locations in the pumping system are shown in figure 2. The locations are marked by numbers which correspond to fig 1. In fig 2 the pressure at the vacuum compressors was 9.5 mbar and 5 mbar respectively. 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 the 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.

During the first runs non reproducible results for the pressure drops across the low temperature heat exchanger occurred. Mechanical obstructions and effects of liquid in the pumping system could be excluded from the results of the temperature and pressure measurements. It turned out that the heat exchanger could by obstructed by condensing air and humidity entering through several air leaks at feedthroughs in the top plate of the cryostat. When these leaks were fixed, the pressure drops shown in fig 2 were reproducible.

In fig 3 the maximal 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 maximal extra heat load turns out to be about 79 W at a setpoint of 5 mbar at the vacuum compressors (or about 40 W at a setpoint of 9.5 mbar).

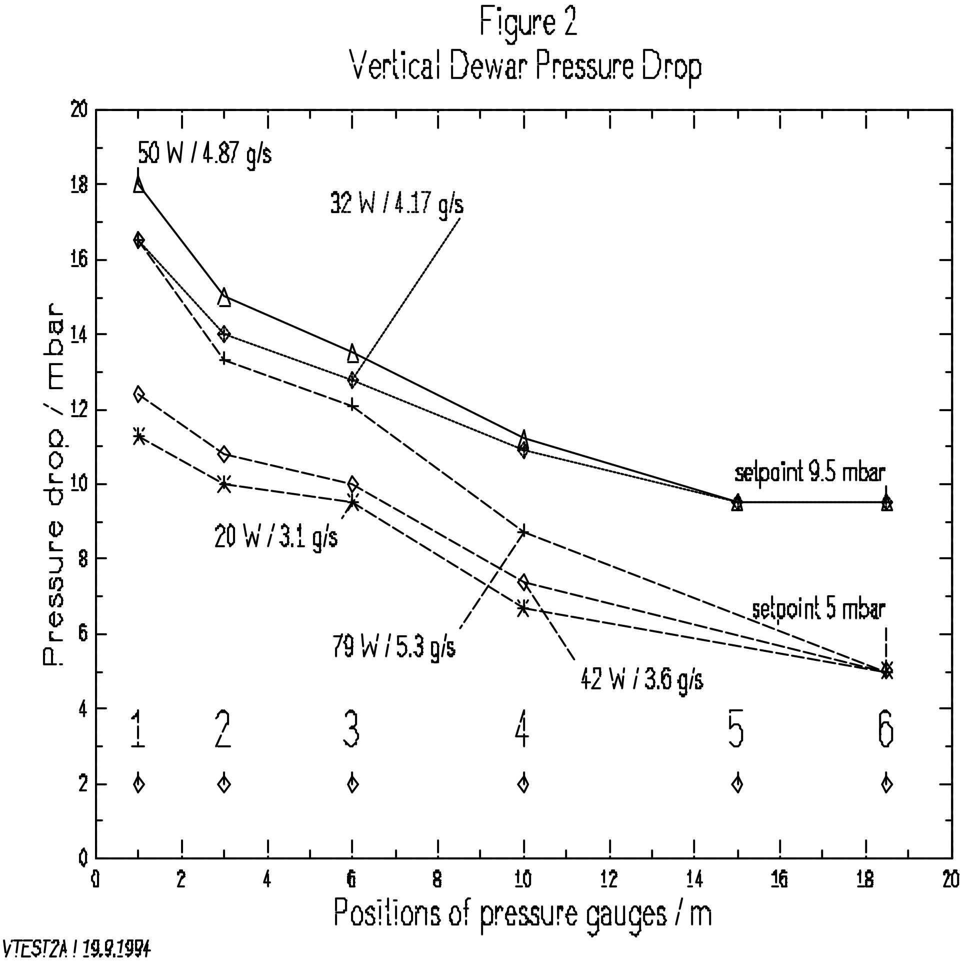

fig.2
Pressures are plotted versus the position of several locations of the pumping equipment of the vertical dewar. Parameters are the pressure setpoint at the vacuum compressors and the external heat loads (the corresponding helium massflows are also indicated). As in fig. 1 the locations are : 1 - helium vapor

pressure in the vertical dewar; 2 - return isolation valve at the dewar; 3 - inlet collection box; 4 - outlet collection box; 5 - outlet gas heater ; 6 - inlet vacuum compressors; the pressure difference 1 - 2 corresponds to the low temperature heat exchanger pressure drop.

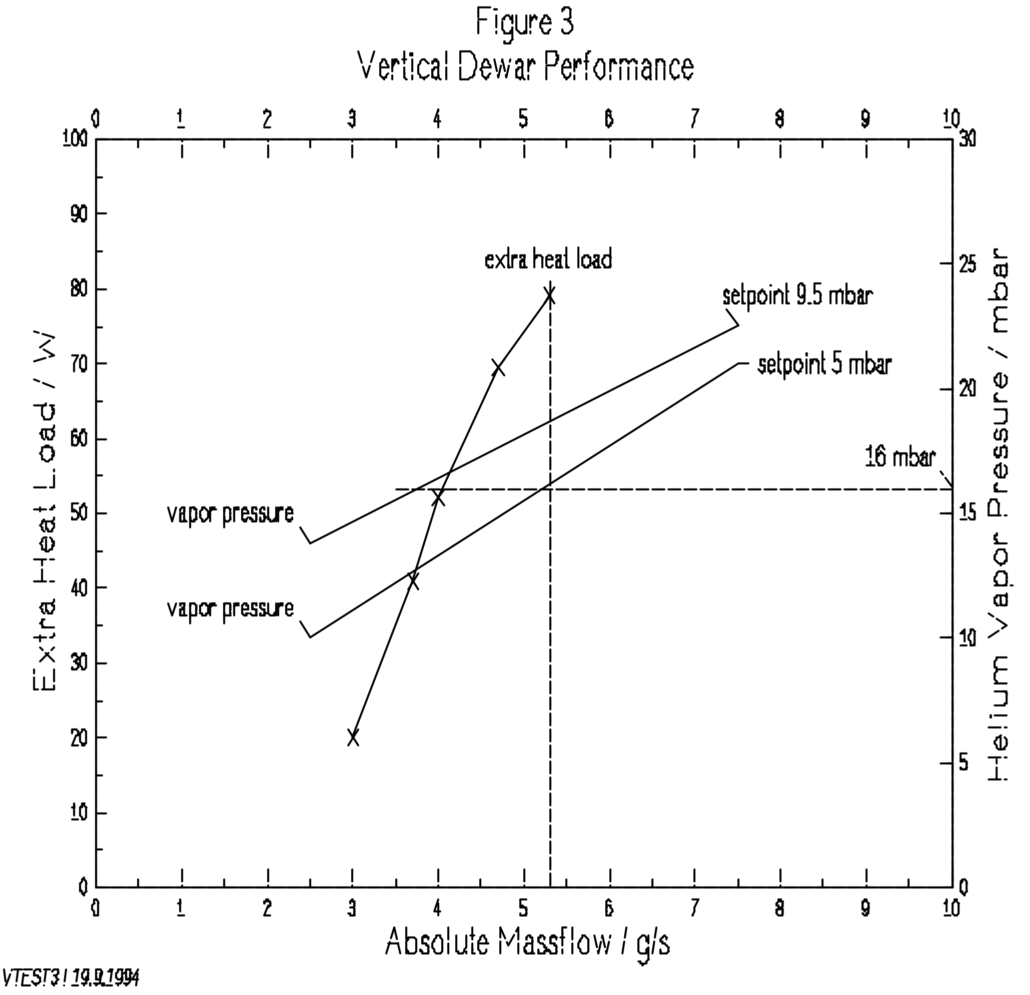

fig. 3

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 maximal external heat load can be obtained from the diagram. For the design vapor pressure of 16 mbar (1.8 K) 79 W external heat load is available in stationary operation as indicated with the dotted line.

During continuous wave RF operation of a nine cell cavity the Q_{RF}-value was calculated from the corresponding heat loss measurements in the helium bath. The change of the absolute heat losses in the helium bath during RF operation compared to the static heat loads is shown in fig 4. The deviation of the Q_{RF} calculated from electrical measurements to the Q_{RF} calculated from the heat losses is smaller than 10 %.

Figure 4

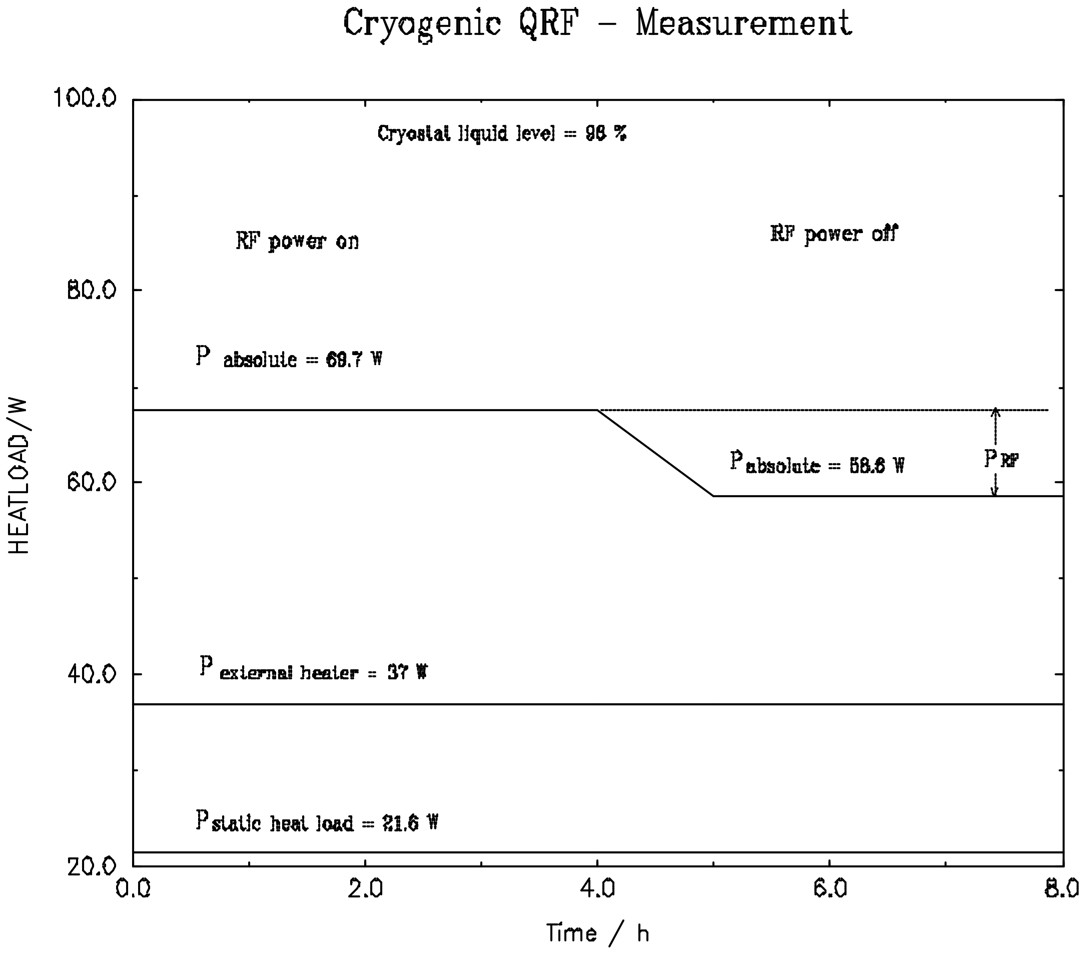

Fig. 4

The absolute heat load P absolute in the vertical dewar is plotted versus time. The change of heat load is caused by switching the RF power of the cavity on and off. To get most stable conditions the electrical heater was also switched on during this measurements.

Discussion and conclusions

Heat loads in the vertical dewar were calculated from the absolute pumped helium massflow measured at constant liquid level of the helium bath:

$$P_{absolute} = \Delta H_{vaporization}\, m_{absolute} (1\text{-Quality})_{JT}$$

$m_{absolute}$ - measured pumped helium massflow
$\Delta H_{vaporization}$ - Enthalpy of vaporization
$(1\text{-Quality})_{JT}$ - liquid mass fraction at the JT-expansion

It was 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 absolute heat loss results from the static heat loss of the helium dewar including the cryostat insert (cavity, waveguide, 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):

$$P_{absolute} = P_{static} + P_{extra}$$

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 % maximal level. This static heat loss can be lowered to about 10 W if the level is decreased further. (It should be mentioned that a thermal shield cooled by liquid nitrogen can be installed under the top plate of the cryostat which will reduce the static heat losses. This shield was originally designed but removed from the cryostat for ease of operation. All measurements shown here were done without this shield). The static heat losses may appear to be quite high, but for stable stationary operation of the dewar a minimal massflow of 2 - 3 g/s in the supply of the JT-valve has to be maintained anyway due to heat losses in the helium distribution system. With a maximum of about 80 W for continuous RF cavity heat load left at 1.8 K, there should be enough cryogenic capacity for all kinds of RF measurements, HPP preparation and temperature mapping. In addition it could be 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.
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.

The measured pressure drops are in line with the calculations as well for the tubing as for the low temperature heat exchanger if some reasonable assumptions are made for the gas temperature of the pumped low pressure helium (table 1). Due to the bad thermal contact of the temperature sensors to the fluid at low pressures, the signal from the thermometers correspond more to the wall temperatures of the tubing than to gas temperature. For the calculations the measured entrance temperatures were applied.
Sometimes it is discussed if a temperature below the λ-temperature can be reached by means of a low temperature heat exchanger of this kind, assuming that a short circuit of the heat transfer will occur as soon as the superfluid transition is passed: we observed temperatures down to 1.8 K at the entrance of the JT-valve at high massflow rates of the pumped gas.

Table 1 : Pressure drop across low temperature heat exchanger

extra heater power (W)	absolute heat load (W)	pumped massflow (g/s)	Δ p measured (mbar)	Δp calculated (mbar)
20	59	3.1	1.4 +/- 0.3	1.7
42	70	3.6	1.7 +/- 0.3	1.8
79	106	5.3	3.2 +/- 0.3	2.5

With the start of the operation of the first vertical dewar valuable information and experience has been gained for the complete 1.8 K cryoplant. The overall performance of the up to now installed equipment is as expected and well sufficient for the different RF-tests of 9-cell cavities - not excluding modifications of the design of future equipment.

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