Laboratory Activities on s.c. Cavities at DESY

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Abstract

Superconducting 500 MHz cavities have been developed at DESY for the purpose of increasing the e^- beam energy of the HERA storage ring. A set of 8 cryostats housing 16 cavities has been built at industry and was assembled at DESY. We report about the first commissioning period of the superconducting cavities in HERA and related developments, too.

Introduction

Sixteen superconducting (s.c.) cavities will be used to increase the HERA e^- energy from 27 (28) GeV to 29 (31.5) GeV at 60 (30) mA beam current. The frequency of 500 MHz is compatible with the high power RF-system of the normal conducting (n.c.) cavities at HERA. Fig. 1 shows the cryostat and two resonators at different stages of production. The design values of the cavities are

$$E_{acc} = 5 \text{ MV/m at } Q_0 = 2 \times 10^9.$$

More detailed design criteria are given in Ref. [1, 2, 3].

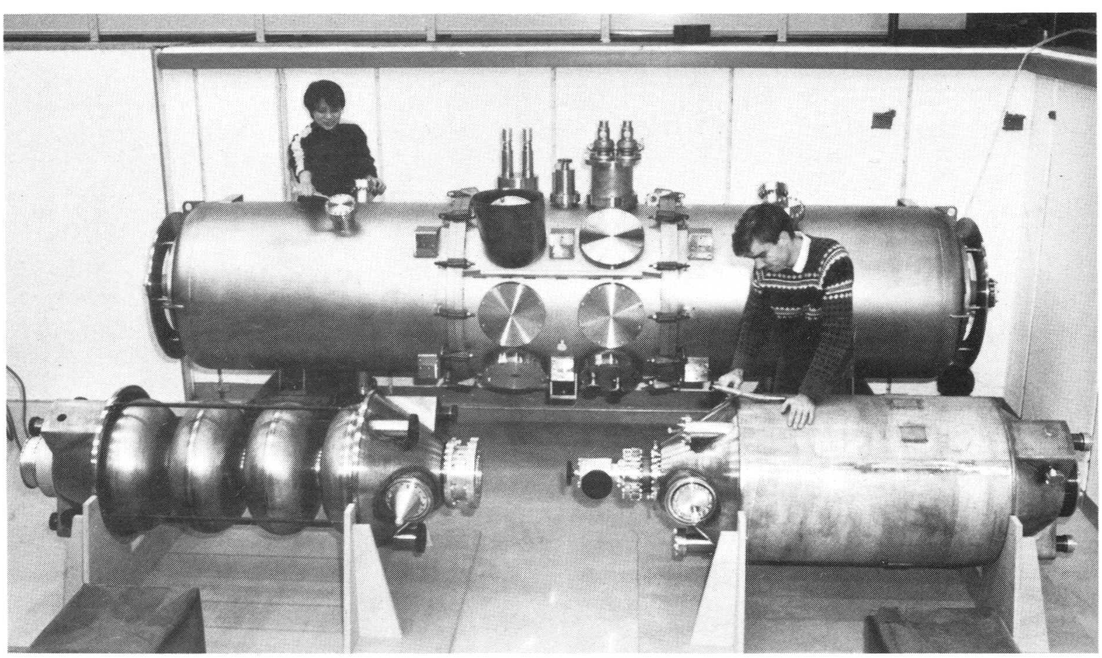

Fig. 1: Superconducting cavity module for HERA during production

1. Fabrication

The sixteen cavities were made from high thermal conductivity Niobium (RRR = 300, delivered by Heraeus). After fabrication each cavity was measured in a horizontal testcryostat (see Fig. 2). Fourteen cavities were limited above 5 MV/m by field emission, two showed a quench at the equator welds at 4.8 and 5.2 MV/m. At this stage a degradation of the Q-value was observed after the second or any further cooldown [4]. Meanwhile this effect has also been observed at other laboratories. It is explained by the precipitation of normal conducting Nb_xH_y during cooldown. For more details see Bonin et al., this workshop. At the final stage of production our cavities cannot be heat treated at 800 ^{0}C in order to degas the Hydrogen. The degree of precipitation depends on the cooldown speed at and below the temperature where the

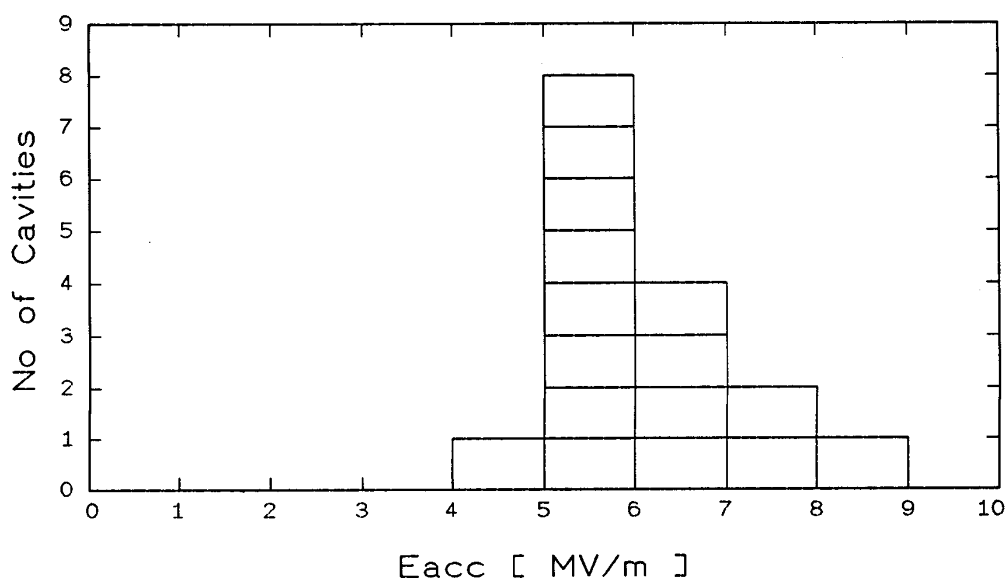

Fig. 2: Measured results of cavity performance

Nb + H system is transformed into the Nb_xH_y-phase (around 100 K). Fig. 3 shows the result after different cooldown conditions. To avoid thermal stress in the cavity system an intermediate temperature was established first (after approx. 24 hours or longer of cooldown). Then the cavity was cooled down to 4.2 K by the refrigerator as fast as possible. Fig. 3 shows that this procedure results in a no longer disastrous degradation of the Q-value.

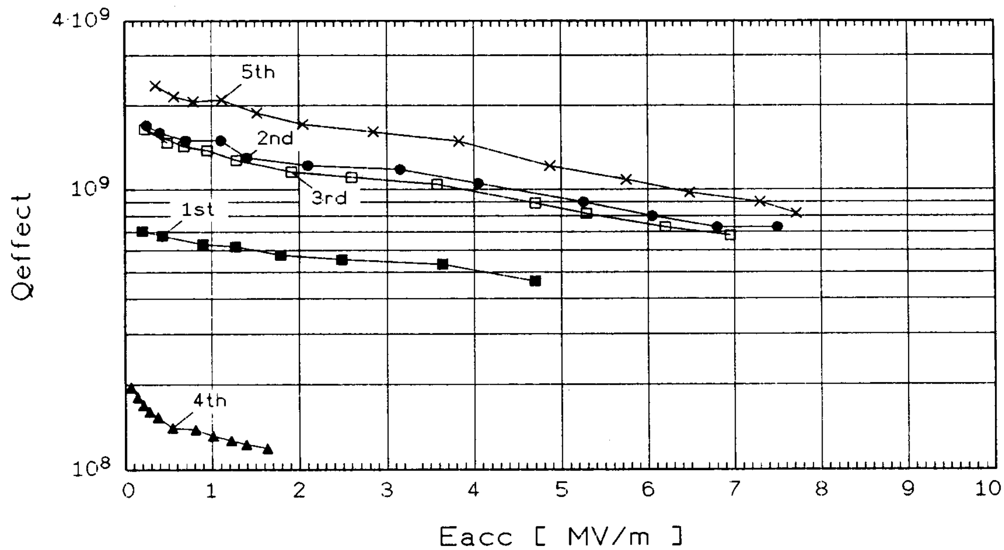

Fig. 3: Measured Q vs E_{acc} curves for different cooldown conditions
1st: continous cooldown from 300 K to 4.2 K in 24 h
2nd (3rd, 4th, 5th): stop during cooldown at 180 K (150 K, 100 K, 150 K) for 20 h; afterwards fast cooldown to 4.2 K in about 1.5 h (1.8 h, 1.5 h, 1.3 h)

During the first acceptance test field emission started as low as 3.5 MV/m. RF-processing and sometimes also He-processing from 20 min to 2 hours were needed to reach the final values of Fig. 2.

After the individual acceptance tests of the cavities the complete cryostats were assembled and measured again before the installation in the HERA tunnel. No degradation of the cavity performance as compared to the acceptance tests have been observed.

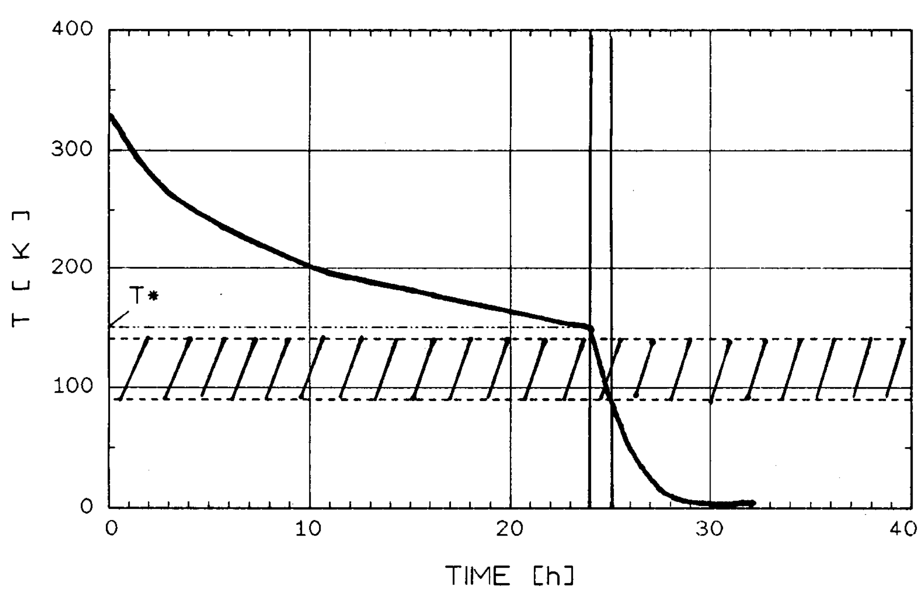

Fig. 4: Cooldown conditions to reduce the effect of the Q desease. For results see also Fig. 3

2. Commissioning of SRF in HERA

2.1 LHe Distribution System

The LHe (4.3 K) and GHe (40 - 80 K) for the cavities are supplied by the large HERA plant. A 165 m long transferline and 8 valve boxes connect the supplybox in Hall West with the 8 cryostats (see Fig. 5). Each cryostat can be cooled down or warmed up seperately by this system. The installation was completed in January, 1991. Cooldown-, warm up procedure and steady state operation are controlled by the same computer system as for the large HERA refrigerator. A detailed description of the complete system is given by W.-D. Möller, this workshop.

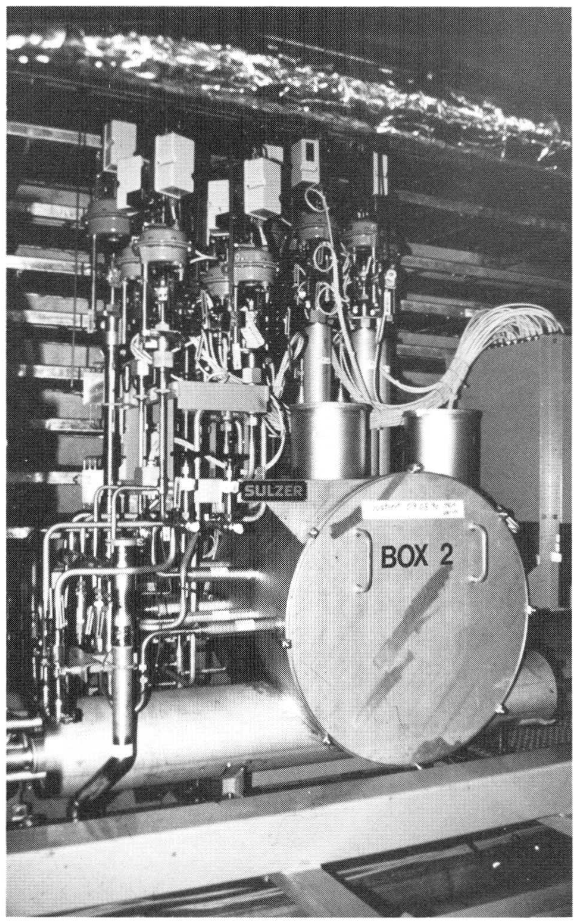

Fig. 5: LHe distribution box in the HERA Tunnel

2.2 High Power Generation and Distribution

The output power of two klystrons (up to 1.6 MW) is added and transfered to the tunnel by a WR 1800 waveguide. In the tunnel 9 directional couplers and 6 magic T dividers split the power to the 16 cavities (up to 100 kW each). The coupling to the cavity can be varied by means of a transformer. It consists of a three plunger unit placed in the waveguide near to the input window. By different settings of the plungers the coupling value can be varied from 0.2 to 5 as compared to no transformer. This is a useful option if the cavities have to be matched for different beam currents. The RF phase can be varied independently in a range of 180 (30) degrees at a transformer ratio of 1 (5, 0.2). An improved version of a remote controlled plunger unit is under construction.

2.3 Cavity Tuning

The frequency of a cavity is tuned by a room-temperature step motor and gear system. One step results in a frequency change of 4 Hz. No fast tuning is foreseen because of the large cavity bandwidth of 2 KHz.
The voltages of each cavity are summed up. This signal is used to control the overall phase and amplitude.

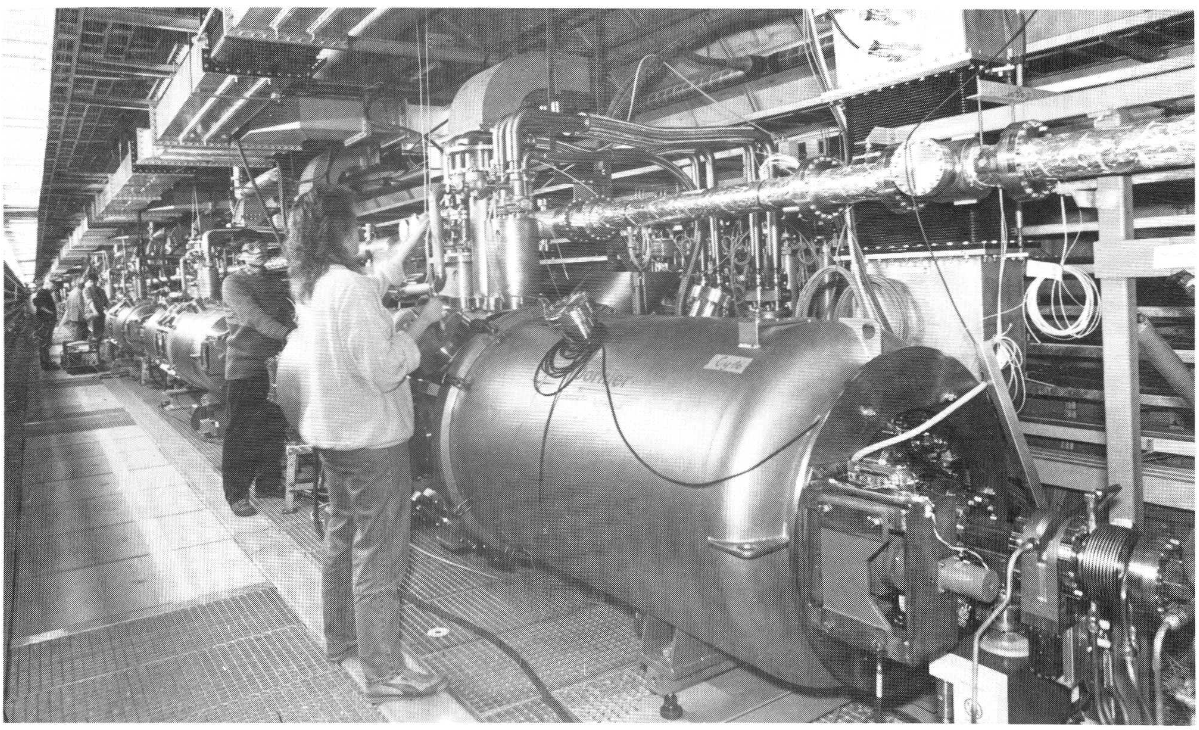

Fig. 6: The superconducting cavities in the HERA tunnel

2.4 Interlock

The klystron or the beam have to be switched off under certain circumstances in order to avoid damage of the cavity. Table 1 lists the data taken and indicates the system's reaction. The RF input window is one of the most critical elements because a broken ceramic will result in a dramatic increase of heat input to the LHe (condensation of air) and in spoiling the clean cavity surface. Therefore several detectors monitor save operation. A quench is detected by an increase of thepressure in the LHe room above a certain threshold level (p ≥ 1.3 bar). The beam is dumped in case of a quench or excessive HOM power production (as indicated by unusual temperature increase of the connectors in the RF cables).

Signals per cavity	klystron off	beam dump
3 HOM coupler, temperature	*	*
input coupler: infrared sensor	*	
input coupler: e^- detector	*	
input coupler: spark detector	*	
input coupler: cooling air	*	
quench detector: pressure in LHe	*	*
vacuum ok	*	
cryogenics ok	*	

Table 1: Interlock data

2.5 Controls and Data Logging

The three main hardware areas are controlled by different specialised computer systems: cryogenics, RF-system and vacuum. The cryogenics (LHe- and GHe-distribution, cryostat) is controled by the same computer as the large HERA plant. 237 analog and 262 digital signals are monitored and 68 control loops are active. Special care has been taken (by hardware and software) to protect the cavities from high pressure ($p \geq 2$ bar) arising from the superconducting magnet circuit

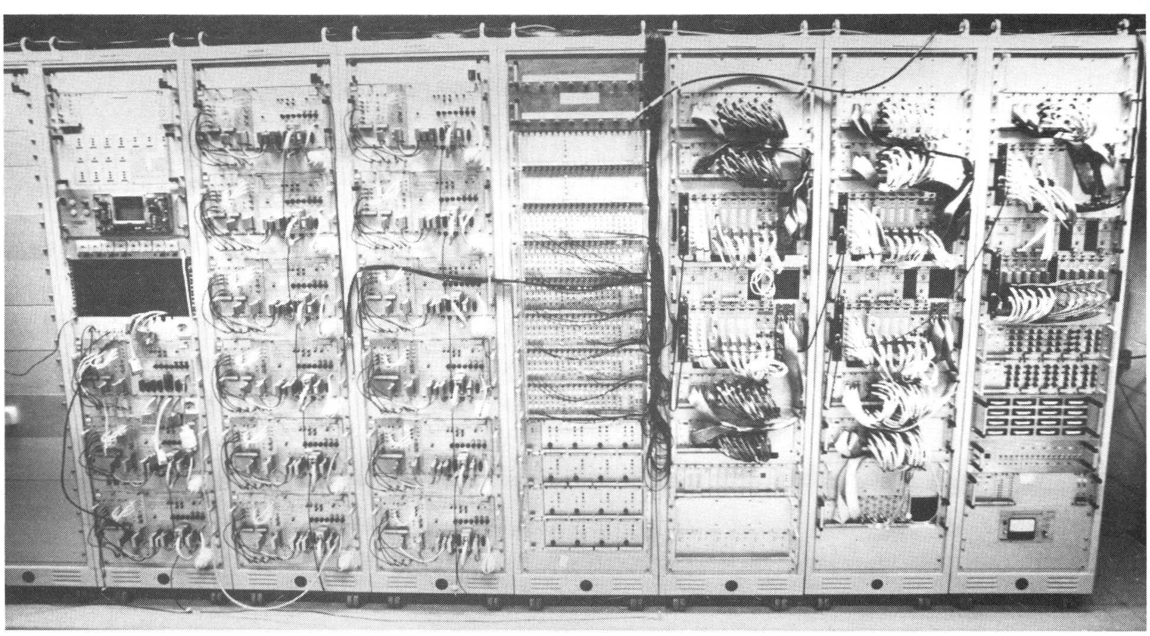

Fig. 7: Some hardware in the local control room. Left: cavity tuning, middle: cavity interlock, right: cryogenic controls.

even under normal operating conditions. 80 channels are active for data logging to enable regular system control as well as trouble shooting.

The operation of the klystron is monitored and controlled by the standard computer system as used for the normalconducting cavities. In addition the cavity interlock (see 2.4) has a hardware link to switch off the klystron fast if needed. The plase and amplitude of the RF power and the frequency of the cavities are controlled by analog circuits. Parameters of the frequency control loop will be set according to the beam current conditions.

The insulating vacuum of the cryostats is pumped by turbomelocular pumps. They are continuously connected even after cooldown. The operation of these pumps, including He leak checking, is done via computer. Routine data logging is also done to monitor for leaks.

A fast data logging is installed in the local control room to analize interlock events especially during the first commissioning periods. 16 channels are recorded (sample rate 10 msec) and data are recorded during 1 min before and after an interlock event. Hereby primary and secondary reactions can be distinguished.

In the final stage the complete control of all subsystems will be managed in the HERA main control room. The experience gained during the commissioning period will result in the final philosophy of simple operation but sufficient data analysis.

2.6 Operating Experience

In 1991 two periods of e^--ring operation were scheduled for June/July and October/November. The results of the second period (after the August workshop) are also included in this report. Table 2 summarizes the major steps of commissioning.

The HERA storage ring was operated most of the time with single bunch current, sometimes with up to ten bunches. The value of the current was below 5 mA, so that the superconducting cavities operated under nearly total reflective conditions (the input couplers are matched to 40 mA beam current). Therefore the power rating of the load at the circulator limited the maximum forward power to 250 kW (550 kW) during the first (second) run. As consequence the maximum gradient in the superconducting cavities was limited to a value below the design number of 5 MV/m. During the second run the 550 kW allowed a gradient of 4 MV/m.

After a short start up period the superconducting cavities were used together with the normalcunducting resonators to increase the circumferential voltage. This was especially beneficial during the measurement runs for e^--beam polarisation. Here the increased synchtroton frequency suppresses depolarising effects.

The design energy of 30 GeV could be reached in the electron ring with the help of the superconducting cavities.

Jan.	acceptance test of LHe distribution system
Feb.	installation of 8 cavities (4 cryostats)
March	first cooldown of 8 cavities
May	installation of 4 more cavities (total 12)
June	first RF operation of SRF in HERA
June/July	first operation with beam:
	- increase HERA e^- from 28 to 30.4 GeV
	- "stabilize" beam for polarisation measurement
	U_{sc}: 20 ... 30 MV; Ib < 4 mA
	P_g 250 kW, limited by load at circulator
Oct.	second operation of 12 cavities with beam:
	- "standard" use of superconducting cavities
	- two dedicated shifts, infect. efficiency
	U_{sc}: 30 ... 50MV, Ib 2 mA
	P_g 550 kW, limited by load at circulator

Table 2: Major steps of commissioning during 1991

During the second run period the superconducting cavities were operated mostly by the shift crew. In the near future "standard operation" will be made easier by improving the computer link from the local to the main control room so that more status information is available.

The superconducting cavities have to be processed after installation or warm up. This is due to multipactor effects in the main coupler. The interlock system at the input coupler detects light (always) or electron current (< 30 μA, only sometimes). The initial processing takes one day for all cavities. We believe that the secondary emission coefficient is increased by desorbed gases which are removed by processing (operation at the multipactor level).

Table 2 summarizes the operating conditions of the superconducting RF system. During 3,000 h the cavities were kept at 4.2 K, during 1,000 h the system was operated with RF and beam.

The interruptions of the LHe supply were caused by irregular operating conditions of the HERA refrigerator. The cavity system must be protected from pressure levels above 2 bar whereas the magnet system withstands pressure up to 20 bar in the LHe supply. The reason is the thin cavity wall construction (5 mm of Niobium sheet material) immersed in a LHe bath. A pressure relief system of several stages protects the cavities very effectively but it needs some time to recover in case of activation. In 11 out of 12 cases the cavities were operational in less than 3 hours after regular supply from the HERA refrigerator started again. In one case 3 (out of 6) rupture discs broke because of excessive pressure increase. Due to a control system error warm Helium gas was blown into the LHe bath and caused the pressure increase.

3. Further Developments

3.1 High Power Input Coupler

The HERA cavities are equipped with a modified version of the CERN coaxial input coupler. Each of the 16 couplers has been trained on a high power test stand before assembly to the cavity. Each coupler transfered 100 kW cw power without problems. Above this level sparking starts at the sharp corner of the welded collar. Furthermore the temperature of the ceramics exceeds values of 80 C.

The gradient of 5 MV/m in the superconducting cavities has to be decreased for beam currents higher than 20 mA. Otherwise the beam power per cavity would exceed the level of 100 kW limited by the power rating of the input coupler.

A prototype of a modified input coupler has been tested up to 300 kW under cw conditions. The thin wall brazed collar of stainless steel is replaced by a thick wall copper ring. Sparking is suppressed and the cooling of the ceramics is improved. The RF power of 300 kW was limited by the absorber in the test apparatus. More experience is needed to manifest a save operating power of 200 kW or more. It is planned to replace the existing couplers in a later stage thus increasing the accelerating gradient of the superconducting cavities at high beam currents.

3.2 Computer Code Transheat

The computer code TRANSHEAT was developed [5] in order to study transient thermal systems like defect induced thermal instabilities (quench). We applied this code to calculate the effect of submillimeter size defects. Also heating during the "high power puls processing" [6] was investigated. For details see X. Cao, this workshop.

References

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4) A. Matheisen et al., Proc. 1991 Part. Acc. Conf., San Francisco, May 1991

5) X. Cao, Proc. 1991 Part. Acc. Conf., San Francisco, May 1991

6) H. Padamsee et al., this workshop