STATUS OF THE SUPERCONDUCTING CAVITY PROGRAM FOR HERA

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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 complete prototype model has been built by industry and was tested successfully under laboratory and storage ring conditions. Meanwhile 16 superconducting 4-cell cavities are under industrial production and will be installed in the HERA tunnel before the end of 1990. We report in detail about RF and cryogenic measurements and discuss recent improvements of individual components.

Introduction

Sixteen superconducting cavities will be used to increase the HERA e- energy from 26 (29.5) GeV to 28.5 (33.6) GeV at 60 (zero) mA beam current. Fig. 1 shows the cryostat and two cavities at different stages of production. The frequency of 500 MHz is compatible with the high power RF-system of the normal conducting cavities at HERA.
The high current of 60 mA implies that the operating gradient will be limited by the power rating of the input window (100 kW in the first stage). The cavities are specified to reach an accelerating gradient of E_{acc} = 5 MV/m at a quality factor of $Q_o = 2*10E9$. More details of the cavity and cryostat design are given in [1], [2].

Cavity

Fabrication

The 16 cavities are fabricated from high quality niobium (RRR = 300, W.C. Heraeus) instead of RRR = 100 material for the three prototype cavities.
The production follows the prototype experience although some changes of spinning and welding parameters were needed for the new material. Details of the production procedure are given in [3]. Fabrication is done completely by industry with the exception of tuning the fundamental mode and the higher order mode coupler filters. Fig. 2 shows a set of cavities after tuning and before the assembly of the quench detector system.
60 carbon resistors are placed on the outside of the niobium cavity and can be monitored during accelerator application.
Due to space requirements the tuning range of the cavity had to be decreased to ± 5 mm which corresponds to a frequency range of ± 435 KHz. This is why the cavity frequency is adjusted after the final chemistry and before welding the LHe vessel (which fixes the absolute length of the cavity). The resonance frequency of the superconducting cavities at nominal length was measured to 499.667 ± 0.1 MHz.

All connections inside the LHe vessel are welded (SS to SS or Nb to Nb) or brazed (Nb to SS) thus avoiding the danger of flange leaks. The final cleaning is done by buffered chemical polishing (BCP) of 40 µm by a mixture of HF: HNO_3: H_3PO_4 (1: 1: 4) with a removal rate of 0.5 µm per 1 min [3]. RF measurements showed that 40 µm BCP was not enough to remove the damaged layer. This result is in contrast to our prototype experience and might be due to changed material parameters of the RRR 300 material. A second BCP procedure was applied to remove another 40 µm surface layer.

At the end of fabrication a high pressure test (cavity "beam vacuum" at 1 bara, LHe vessel at 3.2 bara, "isolation vacuum" at 1 bara) must be made according to the high pressure vessel code. At a measured yield strength of 90 $N/(mm)^2$ for the RRR = 300

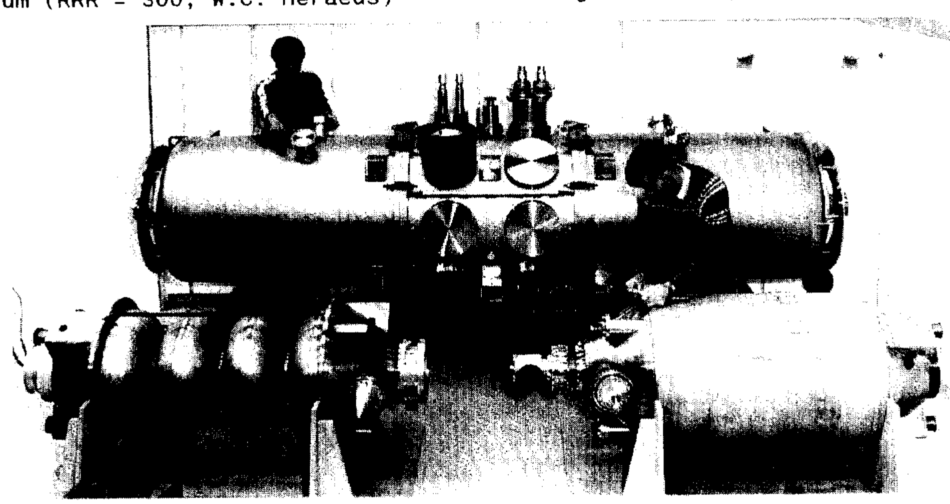

Fig.1: Cryostat and two cavities. The right cavity is completed, the left one lacks quench locator, aluminum fillers and LHe shell.

material this corresponds to a safety factor of 1.5.The yield strength of Nb increases by about a factor of seven at LHe temperature [5] so that a pressure test is more severe at room temperature than at 4.2 K.

HOM couplers

The high current of 60 mA implies very strong damping of the higher order resonances. The three HOM couplers (per cavity) are fabricated from niobium and welded to the cavity. They load the most dangerous resonances to Q values between 500 and 10000 [4]. In addition the dominant modes of the family TM011 are tuned between the HERA spectral lines (10 MHz spacing). The experience with 14 fabricated and measured cavities is that the spread of the TM011 resonances is ± 1 MHz. The resulting HOM power at these resonances induced by 60 mA beam is typically 80 W and in the worst case 120 W. The fundamental mode rejection filter is finally tuned during assembly for the first superconducting test. Q values of 1*10E11 are typical (worst case 2*10E10 resulting in 0.8 W (worst case 4 W) of fundamental mode power at Eacc = 5MV/m.

Fig.2: Cavity prior to installing the quench locator system.

Measurements

After fabrication and final cleaning by BCP the cavities were shipped to DESY. Here the measuring probes and the HOM feedthroughs were assembled in the clean room. At this stage the cavities are completely equipped with the exception of the fundamental high power couplers. The LHe vessel is welded to the cavity (see Fig. 1, right cavity) so that a simple horizontal cryostat can be used for superconducting measurements as an acceptance test. The cavity vacuum is pumped to better than 5*10E-8 mbar before cooldown. As stated earlier the first cavities were cleaned by BCP of only 40 um. They showed Qo values around or slightly below 1*10E9 but all reached fields of 5 MV/m. After a second treatment of BCP (40 um) the Qo values improved to better than 2*10E9 (see Fig. 3). Field emission started at 3.5 MV/m so that RF processing (2 h) was needed to reach the values of Fig. 3.
At the higher accelerating field radiation levels outside the test cryostat were measured to typically 5 rem/h. The maximum accelerating fields were limited by field emission loading. Additional He-processing could even improve the maximum values but has not been tried so far.

During several cooldown cycles of four different cavities we experienced an unexpected and not yet understood phenomenon. A good Qo value after the first cooldown degrades after the second cooldown (as much as factor of 5) but starts to recover after the third cooldown. After ruling out plausible explanations like bad vacuum conditions, insufficient or changing magnetic shielding, frozen magnetic flux due to thermo currents, radiation damage etc. we conclude that the intrinsic properties of the high RRR niobium material might cause this behaviour. More experiments are in process to understand this effect.

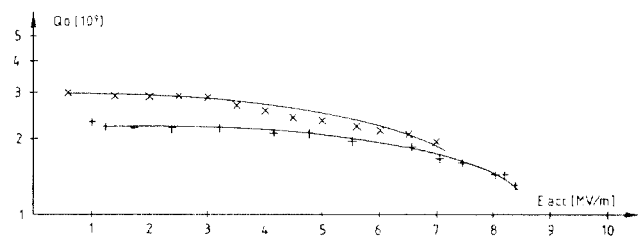

Fig.3: Measured results of the first cavities.

Cryostat

Fabrication

The 8 cryostats are built based on the prototype design [1]. Major features are the fixed point of the two cavities in the middle of cryostat, the tuning devices at both ends of the unit (room temperature), heat exchangers at the beam pipes and the high power input coupler, shield cooling with GHe (40 - 80 K, 15 bar) and a set of flanges in the mid-part for RF and He supply,instrumentation and assembly. The LHe vessel is welded to the cavity and is not part of the cryostat fabrication. A set of 5 nearly completed cryostats can be seen in Fig. 4.

Improvements have been made to reduce the heat load: the fixed point is made of titanium instead of SS, all the heat exchangers are modified and the superinsulation foil at the radiation shield is placed more efficiently. For shielding the cavity against magnetic fields a Mumetal cylinder is placed inside the vacuum shell (at room temperature). We now use radiation resistant ethylene-propylene O-rings instead of expensive metal seals for the vacuum container.

Measurements

After production three cryostats have been measured in respect to static heat load and leakage rate. The static heat loss of the (40 - 80)K shield was determined by measuring the mass flow and the temperature rise of the GHe-flow. The measured value of 60 ± 10 W is satisfactory and compares well with 200 W for the prototype. The 4.2 K losses are determined by the LHe boil off rate. For this measurement the cavities are replaced by a dummy pipe of 3.40 m length and 100 mm diameter. For this

configuration we measured a static loss rate of 2.5 ± 0.5 W.
The total gas leak rate for the shield cooling circuits of three measured cryostats was determined at 80 K and 25 bar to values of < 10E-9, 1.7*10E-7 and 1*10E-6 mbar l/sec. Using a small "holding pump" we could accept even the worst of the three numbers but we prefer to decrease the leak rate to achieve a permanent vacuum system. The high leakage rate turned out to be caused by component failures (bellows).

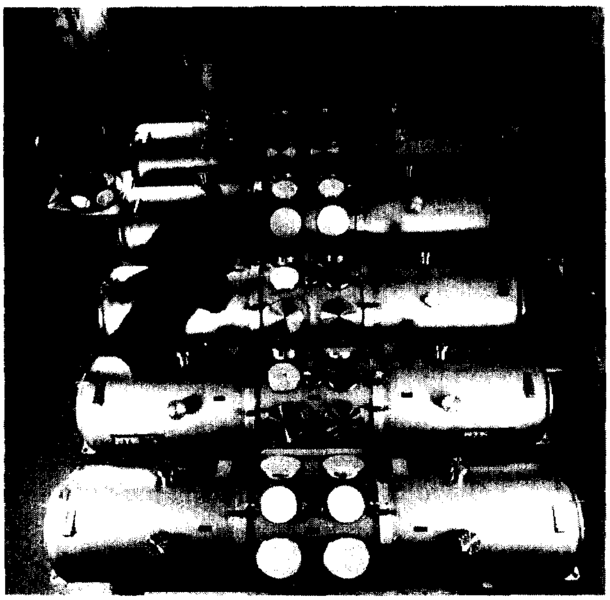

Fig.4: Five cryostats ready for delivery.

LHe Distribution System

A 165 m long transfer line and 8 valve boxes connect the 8 cryostats (16 cavities) to the existing 18 kW HERA refrigerator. A fabrication order was placed with Sulzer in November 1989. The test of individual components (valve boxes, transfer line parts, U-tubes) has started and the installation of the complete LHe distribution system is scheduled to start in the mid July 1990. Fig. 5 shows a valve box during fabrication. Instrumentation includes 87 valves, 99 analog sensors and 270 digital input/output devices. We use the same process control computer EMCON D/3 (TEXAS INSTRUMENTS) [6] as the HERA refrigerator and have developed an appropriate hard- and software package [7].

PETRA Beam Test

In October 1989 another test with superconducting cavities was carried out in PETRA. We used the prototype cryostat and cavities, each demonstrating Eacc = 5 MV/m. At that time the by-pass system in PETRA was newly installed (Hall S) which allows the p-beam to detour the normal conducting cavities of the e-accelerating system. The superconducting cavities were installed in the straight section (Hall NE). Using the by-pass system also for the e- beam we could accept and store the beam without interference by the normal conducting cavities. The aim of the experiment

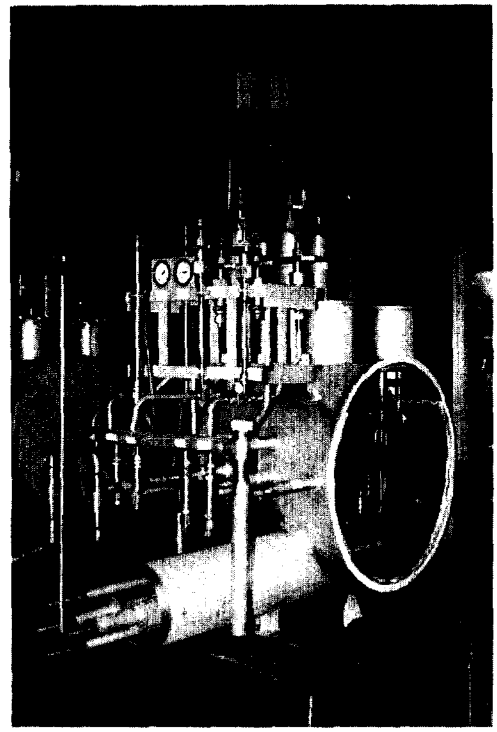

Fig.5: One of eight valve boxes during fabrication.

was to gain operating experience and to determine the instability threshold. Unfortunately the vacuum in the by-pass deteriorated dramatically around 10 mA (multibunch) and the beam lifetime decreased to below one minute so that the stored beam could not be increased. The tight time schedule made it impossible to improve this situation. Up to 10 mA the superconducting cavity system was stable. Because of the general interest of storage ring operation we plan to repeat this test under improved conditions.

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