SUPERCONDUCTING CAVITIES FOR HERA

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Summary

Superconducting 500 MHz cavities are developed to demonstrate the feasibility of upgrading the e⁻beam energy of the HERA storage ring. A prototype module with 2 x 4 cell resonators and appropriate fundamental and higher mode couplers has been designed at DESY and is being built by industrial firms. We report in detail about our design and discuss the results of RF and cryogenic measurements.

Design Consideration

Cavity Parameter

500 MHz was choosen as resonance frequency for the HERA superconducting cavities in spite of successful experiments with 1 GHz resonators at DESY /1/. The three main arguments are the lower transverse impedance (1/10), the decreased cryogenic loses (30 %) and the compatibility with existing high power 500 MHz equipment. For easy exchange with normalconducting structures the free space between quadrupoles was fixed at 5.6 m. This permits the installation of a 2 x 4 cell cavity unit. The cavity geometry follows closely the CERN design /2/ but was slightly modified to reduce the material stress /3/. The high design current of e⁻HERA implies two stringent consequences: first a new higher order mode coupler scheme with sufficient higher order mode damping have been developed; secondly the operating gradient will be limited by the power rating of the input window rather than by cavity properties. A brake of the input window is considered to be the most likely and at the same time also the most dangerous accident because of immediate LHe boiloff. Consequently, we restrict the input power to 100 kW, which limits the gradient to 4 MV/m for a 30 mA beam current (Tab. 1)

frequency	500 MHz
number of cells	4
temperature	4.2 K
Q_0	2×10^9
E_{acc}	4 MV/m
P_{beam}	100 kW
HOM-couplers	3 (two versions)
active length	1.2 m
shape	slightly changed from CERN

Table 1 Superconducting cavity for HERA

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Cryostat

Fig. 1 shows the main layout of the cryostat. The middle part contains all cryogenic-, instrumentation-, nearly all RF-feedthroughs, and also embodies the mechanical fixation point. The radiation shield and all cryogenic transitions are cooled by 40-80 K high pressure He gas. Frequency tuning is accomplished by room temperature step motors and gearings at both ends. The design of the cryostat is based on the concept of closing the beam vacuum as early as possible so that most of the assembly can be done outside of the clean room. All RF windows are at ambient temperature to allow an easy exchange. All seals of the beam vacuum inside the cryostat are looking in the isolation vacuum. There is no seal between beam vacuum and LHe vessel.

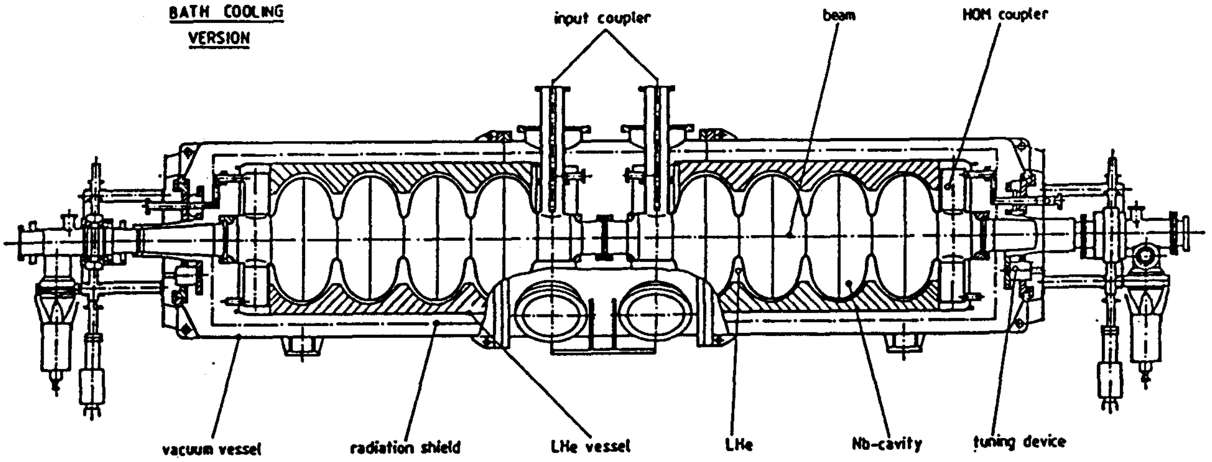

Fig. 1 Main layout of the cryostat. The total length is 5.2 m

Bath Cooling

Fig. 2 sketches the bath cooling version of the superconducting resonator. The LHe container is sealed without any flanges to keep the risk of leaks from LHe to beam - or isolation vacuum small. All parts including input and output couplers are welded by EB (niobium) or WIG (stainless steel). The necessary transition between niobium and stainless steel are HIP diffusion welded parts. A general safety problem for any kind of bath cooling system is the lack of material data for Niobium or Niobium transitions at LHe temperature. Preliminary data of notched bar impact tests /4/ show brittle

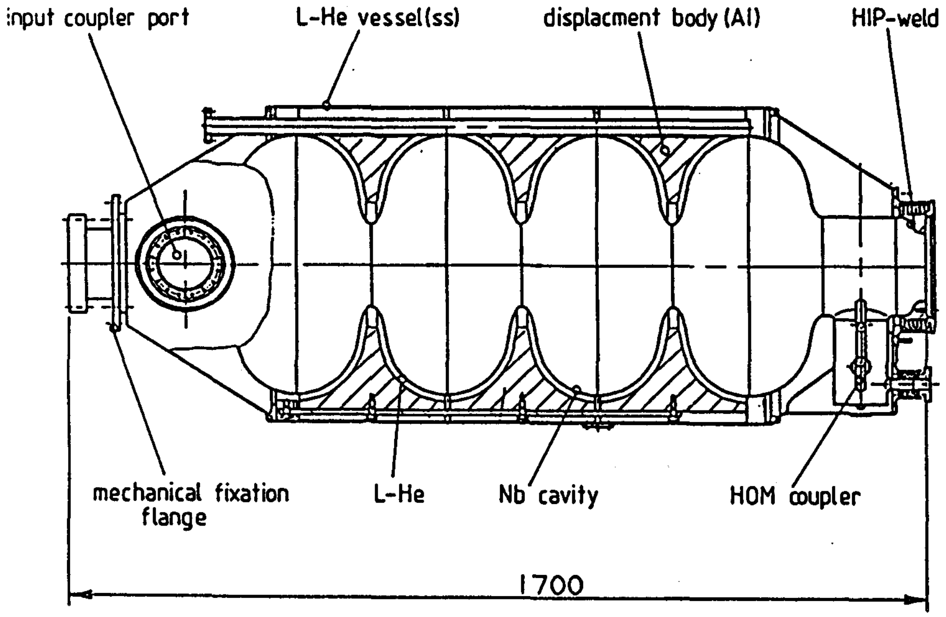

Fig. 2 The bath cooling version of the 500 MHz cavity

behaviour for 50 % of the Niobium specimens. This area needs more investigation if Niobium resonators shall be used on a large scale.For safety arguments the big amount of LHe in the He-vessel is decreased by displacement bodies which are fixed by Nb rods to hold the distance to the cavity constant during cooldown. The volume of one LHe vessel is less than 100 l.

Pipe Cooling

The Niobium cavity can also be cooled by an arrangement of cooling pipes attached on the outer surface /5,6/. To keep the number of pipes small an additional layer of high conductivity metal is needed to produce transverse heat flux. Coatings of electroplated silver and explosive bonded copper are investigated for this purpose. As compared to the bath cooling, this system offers a considerable reduction of safety problems. Furthermore, the cavity is decoupled from pressure varations in the LHe system and the cryogenic system can be simplified. Because of these strong advantages we started a development program for pipe cooling in parallel to the bath cooling production.

Development and Fabrication

Higher Order Mode Couplers

Higher order modes of superconducting cavities have to be damped because of instabilities and power transfer reasons. For a HERA beam current of 30 mA the limit for longitudinal modes is fixed to values of Q around 1000 because of the restrictions of total beam induced power at below 500 watts /7/. The most dangerous transverse modes need to be damped to Q = 10.000 because of beam instability arguments /8/. Following the idea of using loaded coaxial lines with cutoff damping characteristic /9/ we developed a two stub coaxial coupler with an additional fundamental mode filter and capacitive coupled output (see Fig. 3) /7/. The whole unit is EB welded to the cavity, allowing, however, a tuning of the fundamental filter before closing the helium container. The field profile of the higher modes made it necessary to place two different versions of this coupler at the beam pipe of the cavity. One is at the input coupler side, and two are located at the other cavity end. The measured field and shunt impedance values /10/ of the loaded resonator (Cu 1-cell and 4-cell cavity) agree well with the URMEL /11/ calculations. The only exception is the TM012 mode which is highly sensitive to fabrication tolerances but which is sufficiently damped in all cases. The damping values of the most dangerous modes are listed in Tab. 2. Detailed information is given in /7/.

Mode	Frequency	Q
TE_{111}	650 MHz	4000
TM_{110}	716 MHz	6000
TM_{011}	910 MHz	600
TM_{012}	1430 MHz	3000
TM_{010}	fundamental mode	1.0E12

Tab. 2 Quality factors Q of a 4-cell resonator damped by three higher order mode couplers. For comparison, a Cu-resonator without coupler has typical values of Q = 40000.

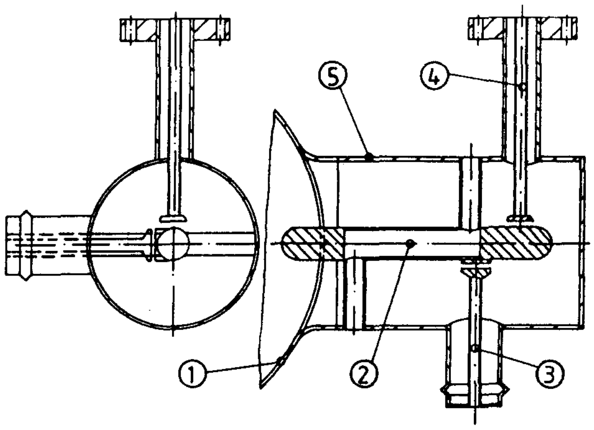

Fig. 2 Cross section of higher order mode coupler, (1: beam pipe next to resonator, 2: two stub coupler element, 3: fundamental mode filter, 4: capacitive coupled output line, 5: outer Nb-wall)

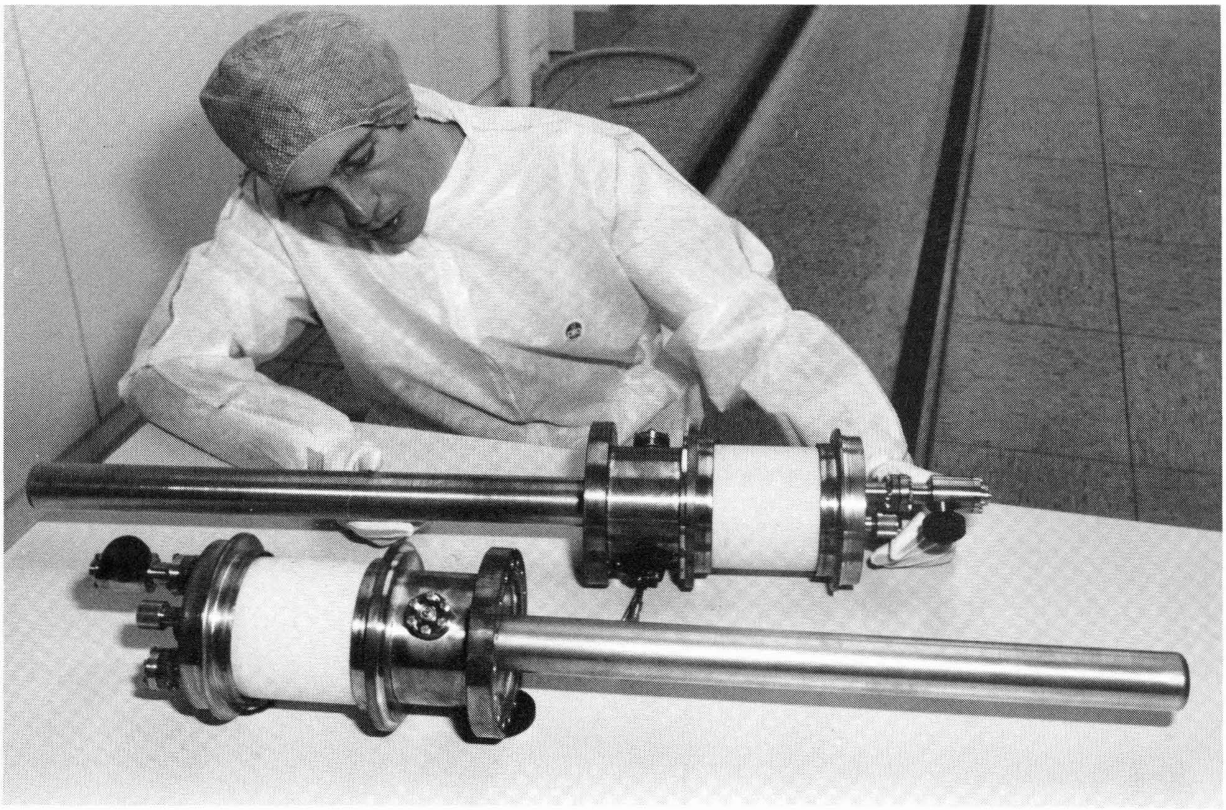

Fig. 4 The high power input coupler

High Power Input Coupler

The input coupler (Fig. 4) consists of a transition between rectangular waveguide and coaxial line, a coaxial cryogenic transition connecting 300 K and 4.2 K level and an electric antenna. The inner coaxial conducter is cooled by He-gas from the outside and has no connection to the LHe area. The cylindric ceramic window is a copy of the LEP design /12/ for the normalconducting cavities. For test purpose this input coupler was mounted on PETRA normalconducting cavity. The power rating was limited to 150 kW by the onset of sparking around the welded collar of the ceramic /13/. For more security of the coupler we have developed a diagnostic system which includes the following devices: two light detectors outside and inside the ceramic to look for sparks, an infrared detector to measure the surface temperature of the ceramic, a mass spectrometer to analyse the residual gas, an UHV feedthrough to monitor charged particles in the coupler and a directional coupler between ceramic and cavity to observe the phase shifting over the ceramic (Fig. 5).

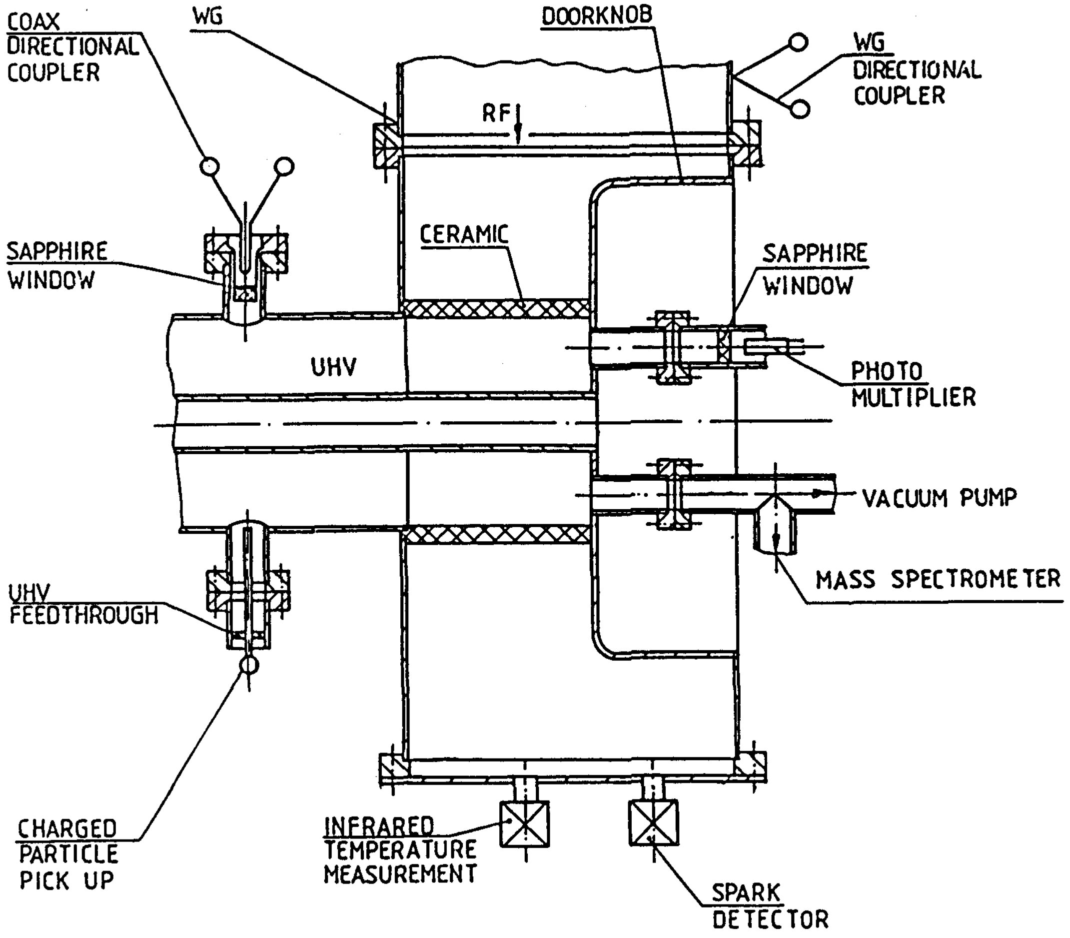

Fig. 5 The diagnostic system of the High power input coupler

Quench Detector

Carbon resistors for thermometry of the outer cavity surface are a useful diagnostic tool. Our system /14/ of 60 fixed resistors around the 4-cell cavity and the couplers is a compromise between mechanical complexity and spatial resolution. Quench experiments with 1 GHz resonators /15/ showed that the klystron power is capable of driving the entire cavity normal conducting within 200 msec. The quench location will be detected with a fast data logging system. A data acquisition system was developed which continuosly monitors all 60 thermometers. The sensitivity is 0.5 mK at 4.2 K. In the event of quench trigger the digital information of the 60 temperatures is simultaneously clocked 256 times into a RAM at any speed up to 0.1 msec. The quench data is downloaded via the IEEE488 bus to a personal computer for display and permanent storage.

Niobium Cavities

Three 4-cell cavities (see Fig. 6) in the bath cooling version have been ordered. They are fabricated with standard spinning and EB welding methods. The resonance frequence, the field profile of the cavity, and the function of the HOM couplers were measured and tuned before closing the LHe-container. The cavity was tumbled to get rid of welding balls and to obtain a smoother surface, cleaned by a buffered chemistry and rinsed with dustfree water as final production steps. After drying and bleeding with N_2-gas the resonator was shipped from the industry to DESY ready for installation.

Fig. 6 4-cell Nb-cavity before closing the LHe container

Niobium-Copper Cavities

For the pipe cooling version, the brazing of cooling pipes to Niobium and electroplating high conductivity silver to the cavities has been tried extensively. At the moment, the silver does not always show sufficient bonding strength to the niobium on the 500 MHz resonators although smaller resonators (1 GHz) showed no problem in this respect. As an alternative explosive bonded Cu to Niobium has been studied recently, and a 1-cell model was built to test mainly the fabricating steps (Fig. 7).

Fig. 3 Pipe cooling version of a 1 cell cavity

Cryostat

Design and fabrication of two cryostats have been ordered at two firms. Besides standard cryogenic problems specific tasks had to be solved:

- The mechanical fixations point in the middle of the cryostat has to withstand a vacuum- and tuning force of 4 tons.
- The maximum axial deviation at the fix point is limited to 0.1 mm during tuning.
- The heat input at the fix point should be kept below 3 watts.
- The sealing technique and radiation shield layout have to meet permanent vacuum requirements.
- All materials have to have a maximum magnetic permeability of 1.01 even after repeated cooldown to avoid trapped magnetic flux in the cavity walls.
- All materials used have to be radiation resistant up to 10E9 rad.

Test area

A new test area has been installed in one of the PETRA experimental halls. This infrastructure consists of a dust free room for handling the cavities, a mounting area for assembly of cryostat and cavities in a vertical position, a test area for cryogenic tests, a 300 W LHe refrigerator and a 100 kW klystron for RF power. Beam tests in PETRA can be easily arranged because the beam line is next to the test area.

Measured Results

Nb-Cavities

A single cell 500 MHz cavity with two higher order mode couplers was fabricated by DORNIER /16/ and measured by DESY. The purpose of this test at 4.2 K was:

- to check fabrication and preparation methods to produce the three 4-cell Nb-cavities for HERA.
- to check the behaviour of higher order mode couplers in superconducting state.

The cavity is epuipped with two higher order mode couplers (TE, TM) according to the 4-cell design. After preparation (tumbling, chemical polishing and rinsing with dust free water) the cavity was shipped to DESY and immediately mounted to the vacuum system. The fundamental mode filters of both HOM-couplers were tuned before cooldown. During the superconducting tests the HOM-couplers showed the expected behaviour. The maximum accelerating field was limited at 8 MV/m by strong field emission loading (10 R/h next to the cryostat). At 5 MV/m a quality factor Q of 2.8 10E9 was measured (Fig. 7).

The first fabricated 4-cell resonator was installed in the horizontal cryostat after fabrication and cleaning by Dornier. A weakly coupled antenna was mounted at the input coupler flange to measure accurately the superconducting losses. During the first run, field emission loading started at 3 MV/m. After several hours of He-processing a maximum field of 6.2 MV/m could be reached, still limited by field emission (10 R/h near the cryostat). The three higher order mode couplers behaved as expected.

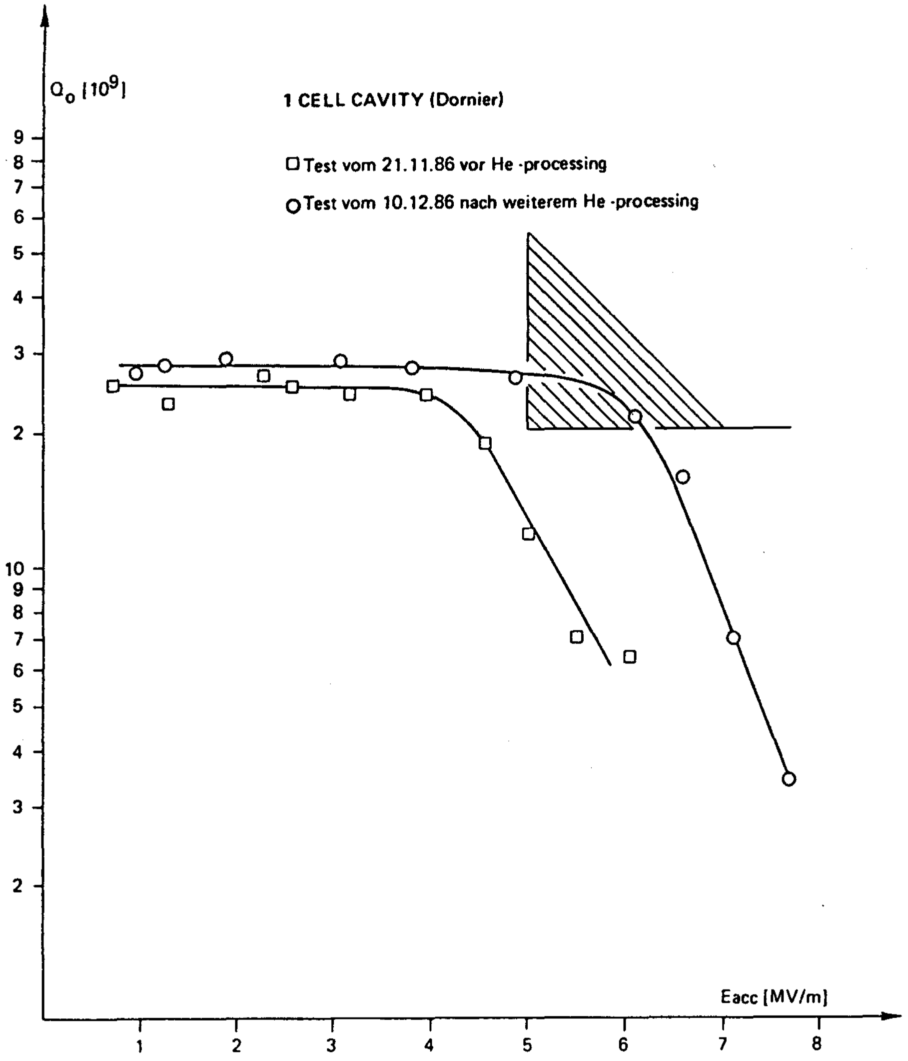

Fig 7 Quality factor vs. accelerating field of the 1 cell 500 MHz cavity with 2 HOM couplers

Single Cell Nb-Cu Cavity

Within the framework of a development contract a 1-cell explosion bonded Nb-Cu cavity without HOM couplers was fabricated at Interatom to gain experience in the fabrication methods. Material characteristics were measured and inspected after each fabrication step. The thermal conductivity of the Niobium deteriorated during brazing the cooling pipes under insufficient vacuum conditions (RRR 112 down to 58). This will be avoided in the future with adequate provisions. Some other fabrication parameters must be optimized based on the experience with this model. The resonator was mounted in the horizontal cryostat at the place of the second 4-cell cavity. It was pipecooled by direct connection to the refrigerator transfer line. 40 carbon resistors were mounted to the cavity surface and the temperatures were read out with our quench location electronics. The maximum field was limited by a thermal quench near the iris region. An ultrasonic test showed that in this region there was no connection between the copper and the niobium.

Cavities	max. E_{acc} MV/m	Q 10^9 at low field	limitation
4-cell, Nb complete	6.2	1.9	quench by field emission
1-cell, Nb complete	8	2.9	field emission
1-cell Nb-Cu pipe cooled	3.3	1.1	quench at iris region

Table 2 Summary of results

Future Developement

Input Coupler

To reach higher power rating we will improve the ceramic-metal transition. In HERA we need for maximum energy at different beam currents a variable match (see Fig. 9, solid line), so we developed a matching transformer in the waveguide with two capacitive plungers which are able to change the coupling by a factor of approx. 10. For safety reasons we tested a kapton back up window in the waveguide up to 200 kW.

Nb-Cu-Cavity

The next 1-cell cavity is being fabricated with optimized bonding parameters by industry.

Pilot Project for HERA

Three of four straight sections in HERA are equipped with 84 normalconducting cavities. This allows a beam energy of 28 GeV (at 30 mA) as shown in Fig. 9 /17/. With additional 8 or 20 cryostats the beam energy increases to 31.5 GeV respectively 35 GeV. In Fig. 10 the correlation between polarisation time and beam energy is plotted. In 1989 we will propose to install 8 cryostats with 16 cavities and the cryogenic system in the HERA straight section west right. This pilot project will enable us to reach a beam energy of 31.5 GeV at 30 mA and a decrease of the polarisation time from T_{pol} = 36 m to 20 min. The measured standby heat loss of the cryostat was 8 watts at 4.2 K with a test pipe installed as a dummy cavity. The aim is to reduce this value further.

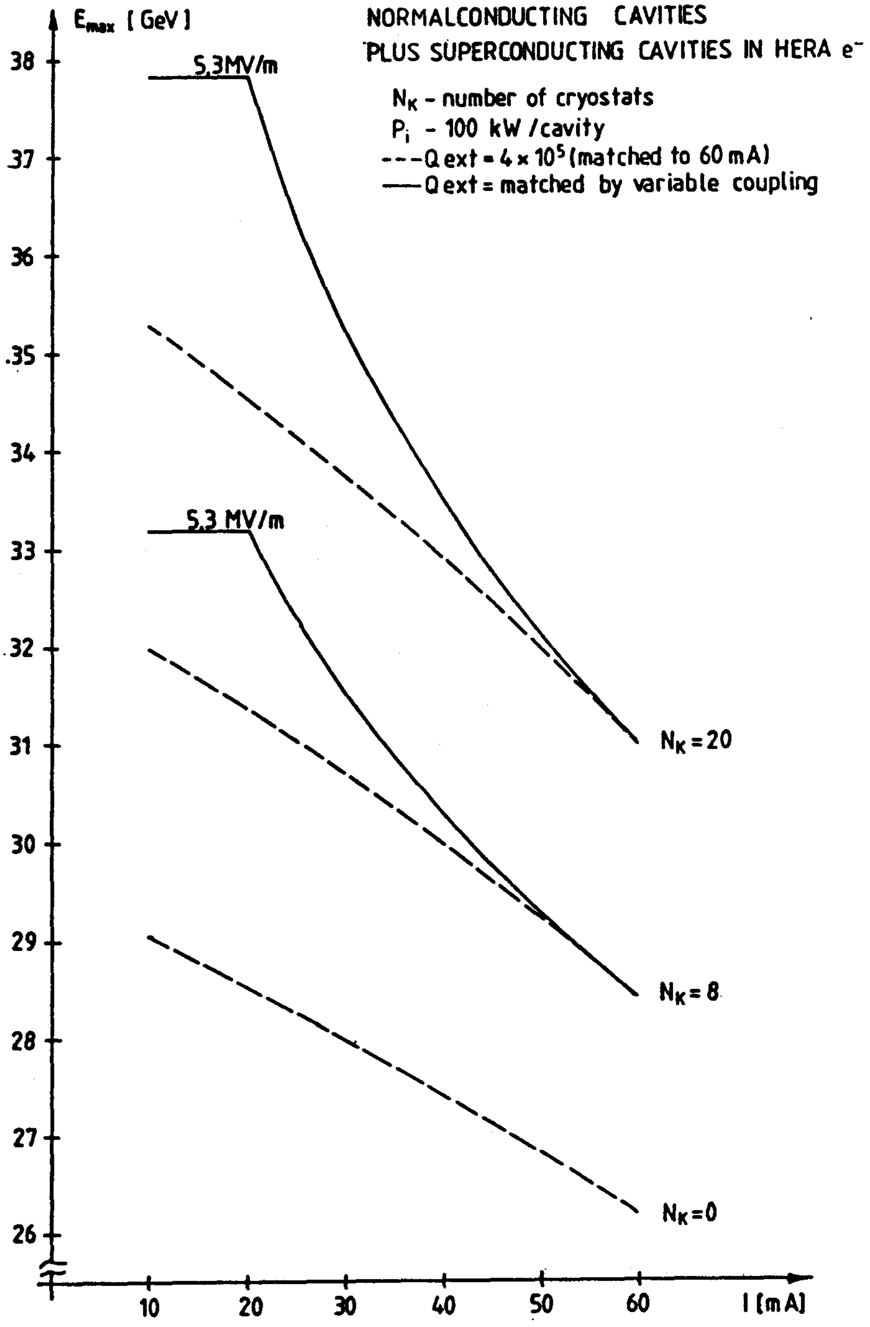

Fig. 9 Normalconducting cavities plus superconducting cavities in HERA e⁻

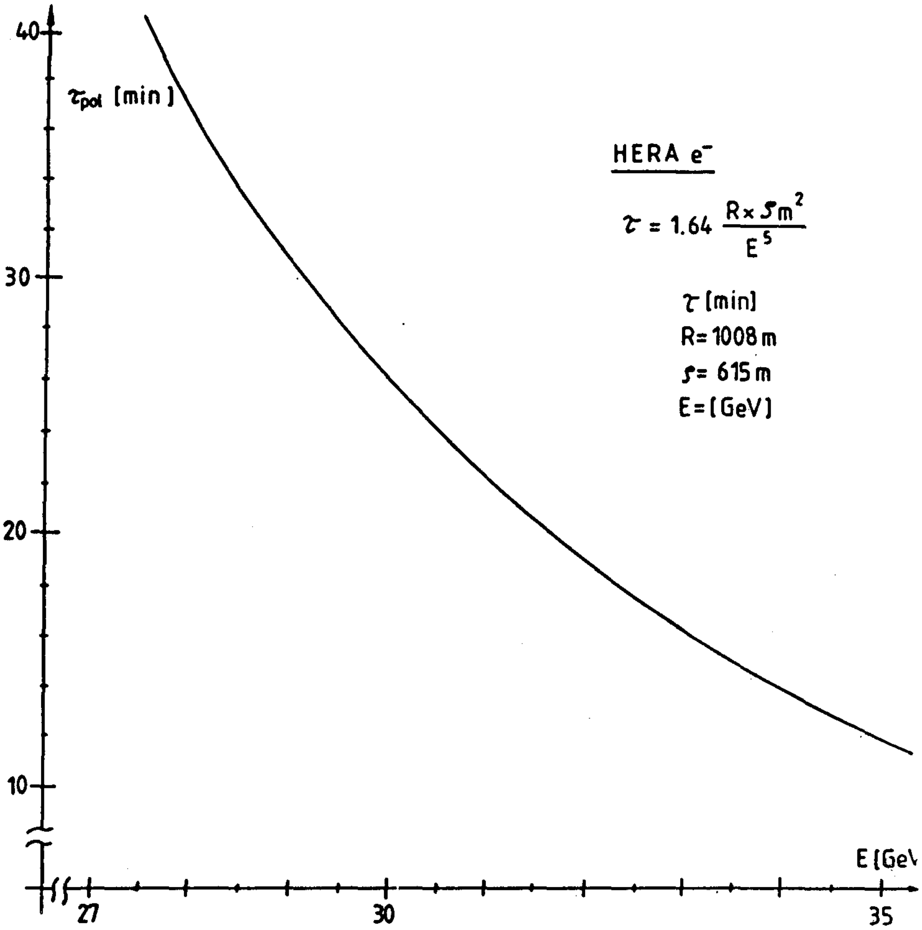

Fig. 10 Polarisation time vs. beam energy

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