SUPERCONDUCTING CAVITIES FOR HERA

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Abstract

Superconducting cavities were developed and built to demonstrate the possibility of upgrading the electron beam energy of HERA. The first prototype module with two 4-cell resonators and appropriate higher order mode and fundamental coupler has been tested in the PETRA storage ring. After this successful beam test 8 modules, containing 16 cavities have been ordered at industrial firms. They will be installed in HERA before the end of 1989. We report about RF and cryogenic test results, our experience with the prototype module and about the cryogenic installation and RF-distribution systems in HERA.

Module Layout

Design Parameter

Tab. 1 gives an overview of some parameters of the module consisting of one cryostat and two 4-cell cavities. The frequence of 500 MHz is compatible with the high power RF-system of the normalconducting cavities at HERA. The distances between quadrupols in HERA cause a module length of 4530 mm. Due to the high design current of electron HERA we developed a new higher order mode coupler concept with sufficient coupling strength. This high current implies that the operating gradient will be limited by the power rating of the input window rather than by cavity properties. To prevent a break of the input window we restrict the input power to 100 kW which limits the gradient to 4 MV/m for a 30 mA beam current. Development work is done to increase the maximum allowable power at the window.

Cavity		
Frequency f	500	MHz
number of cells	4	
working temperature	4.2	K
quality factor Q	2×10^9	
accelerating field E_{acc}	5	MV/m
E_{peak}/E_{acc}	2.2	
H_{peak}/E_{acc}	47	G/(MV/m)
geometry factor	280	
coupling factor	1.63	%
R/Q	462	Ω
power to the beam P(beam)	100	kW
HOM couplers	3 (two versions)	
active length	1.2	m
clean apperture	170	mm
$\Delta f/\Delta l$	87	KHz/mm
$\Delta f/\Delta p$	70	Hz/mbar
Cryostat (with two cavities)		
heat losses in 4.2 K LHe		
stand by loss	10	W
RF losses at 5 MV/m	80	W
heat losses in 40 K He gas	< 100	W
total LHe inventory	190	l
Tuning system		
Δf/step	4.8	Hz
Δf/sec.	2.4	KHz
max Δf	± 870	KHz

Tab. 1 Design parameters

Cryostat

Fig. 1 shows the main layout of the module. The middle part includes the mechanical fixation point of the two cavities. The specified rigidity is ± 0.1 mm at 5 tons RF tuning and vacuum force. All electrical and RF feed-throughs and the LHe and GHe connections are placed in the middle part. The heat shield is cooled by 40 - 80 K high pressure helium gas. Frequency tuning is accomplished by room temperature spindels driven by 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 the clean room. 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.

Cavity

The LHe vessel is sealed to the cavity without any flanges to keep the risk of leeks to the beam- or isolation vacuum small. The transition between stainless steel and niobium is made by HIP diffusion or by brasing techniques [1]. All niobium parts including the higher order mode coupler and the main coupler port are welded by EB to the cavity. Because of safety arguments the amount of LHe in the vessel is reduced to less than 100 l by displacement bodies made from Aluminium.

Higher Order Mode Coupler

Two kinds of two stub coaxial higher order mode

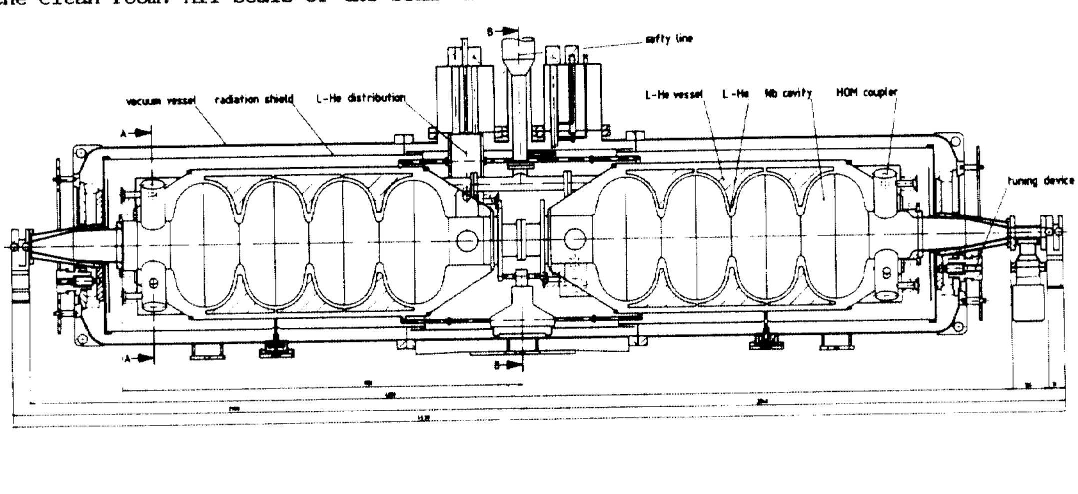

Fig. 1:
Main layout
of the cryostat

couplers with an additional fundamental mode filter are used [3]. They limit the Q values for the longitudinal modes around 1000 and of the transverse modes lower than 10.000. These values are needed to suppress beam instabilities up to the maximum electron current of 60 mA [2]. 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 pipes of the cavity: one on the input coupler side and two on the other end of the cavity. Details of the higher mode spectrum and the damping behaviour are given in [3], [4].

High Power Input Coupler

The input coupler consists of a transition between rectangular waveguide to coaxial line, which finally couples electrically to the cavity. The window is placed in the waveguide and consists of a cylindric ceramic [6]. During a high power test the coupler was limited at 150 kW by the onset of sparking around the welded collar of the cylindric ceramic window [5]. For more security we have developed a diagnostic system which is described in [7].

Quench Detector

Our thermometry system consists of 60 fixed carbon resistors around the 4-cell cavity and the couplers. This is a compromise between mechanical complexity and spatial resolution. The quench location will be detected with a fast data logging system which continously monitors all 60 thermometers with a sensitivity of 0.5 mK at 4.2 K.

Fabrication of the Cavities

Three 4-cell cavities were made by an industrial firm (DORNIER) [1]. The fabrication sequence proposed by DESY was as follows:

industry
- rust test, visual inspection of Nb-plates grinding of bad looking areas
- spinning of cups (messure dimension)
- EB weld of: cells (messure frequency), HOM coupler (leak check), complete Nb resonator (leak check)
- TIG weld SS parts of the LHe container (leak check)
- tumble the whole cavity (2 x 4 days)
- clean cavities by buffered CP

DESY
- tune fundamental frequency
- tune fundamental field profile
- tune HOM couplers

industry
- polish cavity by buffered CP (3 x 30 min)
- rinse with dust free water
- dry with N_2-gas
- close "beam vacuum"
- assemble 60 quench locator resistors
- assemble Al-displacement bodies
- close the LHe container (TIG)
- leak check LHe system
- deliver to DESY for installation into cryostat

Before frequency and field flatness tuning the length of the cavities varied by ± 3 mm, i.e. the frequency ± 150kHz. We tuned the cavities to a field flatness better than 2 %. A force of 2 tons was needed to deforme a cell inelastically. After tuning the length of the cavities varied by ± 2.5 mm. The length of the LHe vessel was adjusted to the individual cavity so that the compensation-bellow is in a neutral position at 4.2 K.

Assembly

In a class 100 clean room the cavities are connected together and all higher order mode and high power coupler antennas are mounted as well. Finally the beam vacuum system is closed by gate valves on both ends of the cryostat. All further assembly (electrical feed-throughs, LHe and He gas connections, closing the cryostat) is done afterwards outside the clean room. For easy assembly the vacuum system is closed with the cryostat in vertical position.

Niobium Copper Cavities

To reduce the safety problems with the LHe and decouple the cavity from the pressure variations in the LHe system the cavity can be cooled by an arrangement of cooling pipes attached on the outer surface. Within the framework of a developement contract two 1-cell explosively bonded Nb-Cu cavities were fabricated at INTERATOM to gain experience in the fabrication methods. Detailed information is given in [8].

Measurements

Tab. 2 shows test results of several cavities under different conditions:

	preparation	Q_0 [x 10^9] (at 4.2 K)	E_{acc} [MV/m]	limitation	comment
4-cell cavities					
I	tumbling BCP	1.9	6.2	field emission	low power input coupler
I	new tuning BCP	1.3	5.1	sparking at high power window	measured before and during beam test in PETRA
II	tumbling BCP	leak tube	at beam flange		
II	end part replaced BCP	1.1	2.5	quench at equator in the repair weld	measured before and during beam test in PETRA
III	BCP		5.0	field emission	low power input coupler
1-cell cavities					
I with two higher order mode couplers	tumbling BCP	2.9	8.0	field emission	check the higher order coupler in in superconducting state
I Nb/Cu	tumbling BCP	1.1	3.3	quench at iris	bad connection between Nb + Cu in the iris region, reduction of RRR to 58 by insufficient vacuum in the furnace
II Nb/Cu	tumbling BCP	1.1	6.9	quench	-

Beam Test

The main purpose of the beam test was to explore the behaviour of the higher order mode couplers. Under single and multibunch conditions with the beams being on and off axis the higher order mode spectrum was carefully measured while the cavity was tuned over its full range. The measured data corresponded to the predicted values. The efficient loading of the superconducting cavity will result in only 100 Watt higher order mode power under HERA conditions. System experience was gained by injection and storage of multibunch (4.4 mA) and single bunch (2.5 mA) currents at 7 GeV with one and both cavity units. The measured synchrotron frequency confirmed the RF calibration at 5.1 MV/m.

Pilot Project for HERA

In HERA there are 4 straight sections. Three of them are equipped with 84 normalconducting cavities. This allows a beam energy of 28 GeV at 30 mA (see Fig. 2). With additional 8 or 20 cryostats in straight section West, each including 2 superconducting cavities, beam energy increases to 31.5 GeV and 35 GeV respectively at 30 mA [11]. After the successful beam test in PETRA the order for 16 superconducting 4-cell cavities and 8 cryostats was placed with industry.

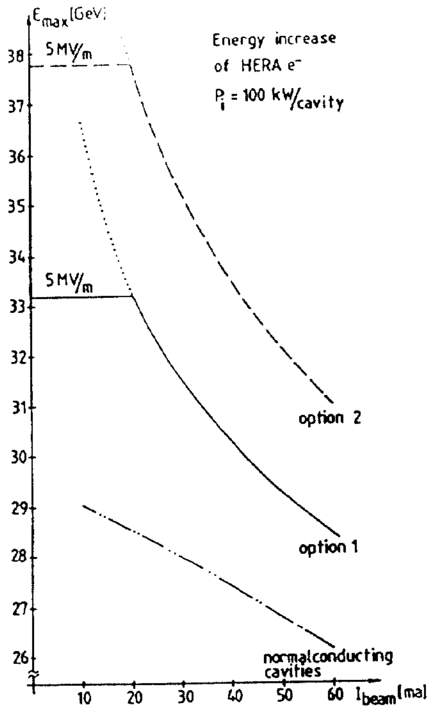

Fig. 2: Energy increase of HERA e⁻-beam

opt. 1: pilot project of 8 cryostats

opt. 2: max. possible installation of 20 cryostats

Cavities

The 16 cavities will be built according to the prototype experience. The quality of the Niobium, however, will be improved from RRR of 100 to RRR of 300. A final treatment of the sheet material ensures that in spite of a high RRR value the material is not too soft (yield strength larger 90 N/mm² [9]). In the prototype the higher order mode coupler stubs and inner coaxial lines are cooled by LHe. In one coupler the orientation of the cooling channel might produce a trapped gas volume inside the tube. To avoid this problem we will now use solid Nb rods with high thermal conductivity. The HIP connection of Nb to stainless steel became leaky in some cases. This is probably due to some uncontrolled parameters during series production. Meanwhile a more reliable brased connection has been developed [1] and will be used for the 16 cavities.

Cryostats

The 8 cryostats also follow closely the design of the prototype. Improvements or changes will be done in following areas:
- modify all heat exchangers at the warm-cold transition to return the load in the 40 - 80 K screening circuit
- modify and enlarge the LHe phase seperator
- retune the radial extension of some flanges to safe space in the tunnel
- place the magnetic shielding at the (40 - 80)K level instead at 4.2 K
- use cables instead of coaxial line by tubes for higher order mode power extraction. This simplification was possible because the strong damping of the higher modes resulted in only 100 W per coupler
- use O-ring seals (radiation resistant up to 10^9 rad [10]) at the outer vacuum vessel instead of expensive metal seals

Some of these changes have already been tested with the modified prototype cryostat.

RF Power Distributing System

One high power klystron station feeds all 16 cavities. Directional couplers and 3dB power splitters (magic-T) are used to feed each cavity from the main line. This mixed arrangement fits into the limited space in the HERA tunnel. Each cavity has a variable transformer near the high power window to match the cavity at varying beam loading conditions. In addition this transformer system allows individual phase adjustment.

He Distribution System

A large He refrigeration system is installed in DESY to supply the superconducting magnets for the HERA-p ring. Some spare refrigeration power will be used to cool the cavities, too. The supply conditions are:
- LHe of 4.3 K and 3.5 bar
- GHe of 40 K and 18 bar supply, 80 K and 17 bar return.

One general problem is the possible high pressure in the magnet supply system. Under special circumstances (quench, cool down, warm up) the working pressure is for above the safe pressure limit of the cavities. So special precautions have to be taken and the connecting lines between cavity and magnet distribution system have to be minimized. It will be the first time to operate 16 superconducting resonators in a storage ring. So a high flexibility of the He distribution system will be helpful to be prepared for unforseen difficulties. Eight valve boxes will serve the eight cryostats so that individual cool down, operation and warm up can be accomplished. After some operation experience a more economic solution with one valve box for several cryostats might be possible.

Acknowledgement

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