IEEE Transactions on Nuclear Science, Vol. NS-30, No. 4, August 1983

SUPERCONDUCTING RF-CAVITIES FOR A 30-GEV PETRA STORAGE RING

W. Ebeling, W. Flauger, W. D. Möller, J. Peters, D. Proch and J. Susta
Deutsches Elektronen-Synchrotron DESY
Notkestrasse 85
D-2000 Hamburg 52, W. Germany

G. Arnolds-Mayer, H. Heinrichs and T. Grundey
University of Wuppertal
Gausstrasse 20
D-5600 Wuppertal 1, W. Germany

Summary

The installation of superconducting rf-cavities offer the possibility to increase the beam energy of the PETRA storage ring to 30 GeV. To investigate the large scale use of superconducting rf technology a prototype cryogenic module compatible with space requirements in the PETRA tunnel is developed. The cryostat has a length of 4.2 m and contains two 9 cell 1 GHz structures of elliptical shape. Rectangular and capacitive loaded circular waveguides are explored for high power input and higher mode output couplers.

Introduction

The advantage of superconducting cavities in e^+-e^--storage rings have been discussed by several authors.[1-4] The basic advantage is the increased accelerating field gradient at reduced rf-power consumption as compared to normal-conducting cavities. The first successful beam test of a 1500 MHz structure in CESR[5] and a 500 MHz single cell cavity in PETRA[6] demonstrated that the storage ring environment does not degrade the superconducting properties of the cavities. A 5 cell 500 MHz superconducting structure has been developed at CERN[7] and will be tested in PETRA this spring. Assuming that we can achieve an accelerating gradient of 3 MV/m, the beam energy of PETRA could be raised to 30 GeV. Parameters of a superconducting PETRA[8] are listed in table 1. As the first step to the realization of this machine, a prototype superconducting module is being built and will be described in this paper.

Table 1 Parameter list of a 30 GeV PETRA with superconducting rf-cavities[8]

Beam energy	E_0 (GeV)	30
Beam current, 4 bunches	I_0 (mA)	4 * 5
Bunch length	σ (mm)	7.3
Active rf-length	L (m)	190
Rf accelerating gradient	E_{acc} (MV/m)	3
Cavity losses at 4.2 K	P_{cav} (kW)	3
Cavity higher order mode power	P_{HOM} (kW)	340
Beam power	P_{beam} (MW)	7.8

Design Criteria

For the superconducting structure, parameters like resonant frequency, cavity shape, number of cells and type of coupler and tuner have to be decided. The resultant mechanical and cryogenic design has to fulfill the space requirements in the PETRA tunnel. Laboratory measurements of superconducting cavities show higher field gradients at higher frequencies.[9] Except for the one-point multipacting limitations[9], this tendency is not understood. Beam aperture limitations restrict the cavity size to equivalent frequencies not higher than 1.5 GHz. For a simple cryogenic system, a working temperature of 4.2 K, the temperature of liquid Helium at atmospheric pressure, is desirable. This restricts the resonant frequency to values not higher than 1 GHz because of the quadratic increase of the superconducting surface resistance with frequency. Following these arguments and considering the fact that rf high power installation at 500 MHz and 1 GHz is available in the PETRA tunnel, the resonant frequency of 1 GHz was choosen. At 1 GHz a single cell has a length of 15 cm. For a free space of 4.2 m between quadrupoles, including the cryogenics a structure of 20 cells is possible. Tuning problems of such a long structure, however, led to the choice of a 2x9 cell unit, leaving the necessary space for decoupling of both units. The relatively large iris diameter of an 1 GHz cavity results in an increased cell to cell coupling and to a considerable amount of higher order mode propagation into the beam tube. Thus it is possible to use input and output couplers at the beam ports of the structure which avoid welds and holes in critical high current regions. Likewise the tuning is not done by moving a piston into the cavity, but by lengthening the whole structure. To suppress multipacting, a spherical[10] or elliptical[11] shape should be used. For easy cleaning a tilted sidewall has to be incorporated in the spherical shape. For reasons of improved mechanical stability the elliptical cavity shape was used.

Description of the Prototype Module

The prototype module is shown in Fig. 1. The total length, including the vacuum valves, is 4.20 m, and the vacuum tank has an outer diameter of 76 cm. For simplicity the input couplers (in the middle of the cryostat) and the output couplers (at the right and left side of the cryostat) are shown in a vertical plane. In reality, however, the axis of the input coupler is horizontal and the output couplers are tilted by 70° with respect to the horizontal plane.
The rf-parameters of the cavities were calculated by SUPERFISH[12] and are listed in table 2.

Table 2 Parameter of the 9 cell cavity

Resonance frequency	f_0 (MHz)	999.33
Cavity diameter	2 R (cm)	27.9
Iris diameter	2 r (cm)	9.0
Length of active structure	L (m)	1.35
Coupling coefficient	k (%)	1.56
Normallized shunt impedance	r/Q (Ω/m)	740
Geometric factor	G (Ω)	259
Peak electric field ratio	E_p/E_{acc}	1.8
Peak magnetic field ratio	B_p/E_{acc} (mT/MV/m)	4.3

For input and HOM-output couplers two types of beam-tube couplers have been investigated:
- rectangular waveguides
- capacitive loaded circular waveguides (see Fig. 2).

For both types of waveguide the HOM output couplers are reduced-size versions of the fundamental input coupler, but show cut-off rejection for the fundamental

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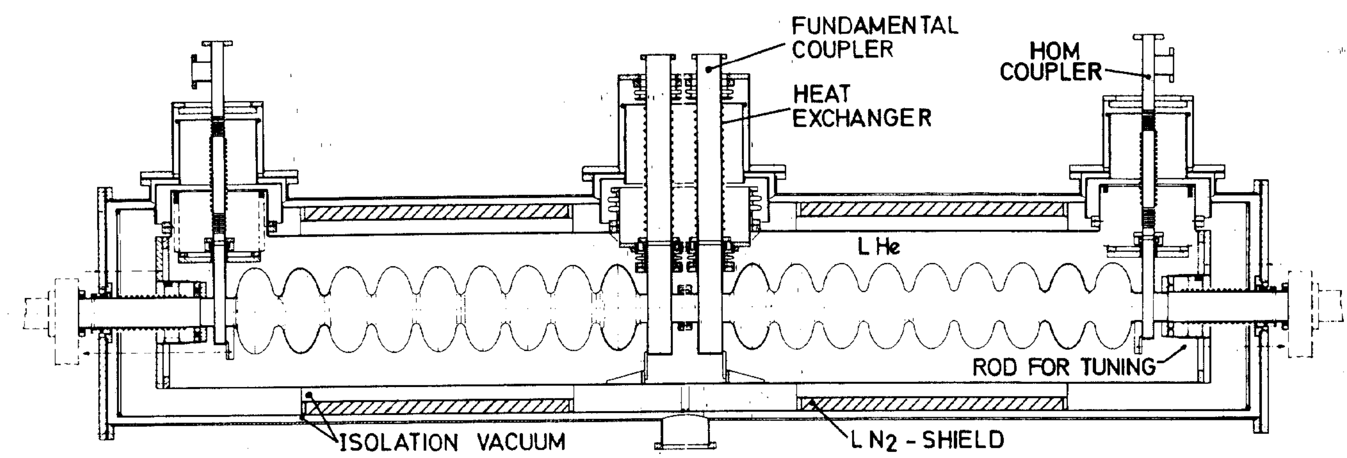

Fig. 1 Longitudinal section of the horizontal cryostat with two 9 cell 1 GHz structures

mode frequency. Extensive investigations have been carried out by varying the size, distance and shorting plane of the couplers. The coupling strength has been determined by measuring the external quality factor Q_{ext} of a single cell Cu-cavity attached to the coupler. In table 3 these values are listed for the three most important cavity resonances. For comparison, the tolerable quality factor Q_{tol} is also listed. The quoted value of Q_{tol} (or even smaller values for improved coupling) should be measured at a single cell to fulfill the calculated coupling of a 9 cell structure. Here the conditions are:

- power match for the fundamental frequency (input coupler)
- beam instability rise time of larger than 2 msec input and output coupler)
- HOM power in the cavity of less than 1 watt (input and output coupler).

Both types of couplers show sufficient coupling strength, but for simpler construction we chose the rectangular type.

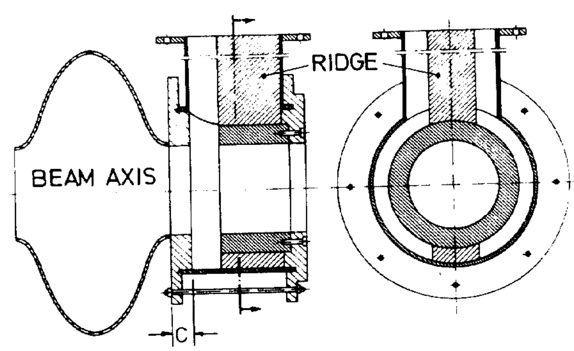

Fig. 2 Longitudinal and cross section of the ridged waveguide coupler model

The frequency of the cavity will be tuned by lengthening the whole structure. For a tuning range of 300 kHz the total length will be increased by 1.8 mm. The accuracy of the step-motor driven hydraulic system is 1 µm equivalent to 160 Hz.

Table 3 Data of input and HOM-output couplers

Mechanical data	input	output	input	output	
a [cm]	18.2	12	9	9	
b [cm]	6.5	3	6.3	5.5	
c [cm]	3.4	1.3	5.5	1.5	
d [cm]	6	1	-	-	
w [cm]	-	-	4.4	4.4	
Electrical data	Q_{ext} $[10^3]$				Q_{tol} $[10^3]$
TM_{010}, 1 GHz	32.1	-	32	-	32.1
TM_{011}, 1.9 "	6.3	0.6	3.4	0.3	7.5
TM_{110}, 1.4 "	18.7/ 14.4	5.5/3.3	2.3	0.2	18.7

c = distance of coupler to cavity
d = distance of waveguide short to beam tube

Cavity Fabrication and Testing

The cavities are fabricated (deepdrawing and electron beam welding by INTERATOM, D-5060 Bergisch-Gladbach, W. Germany) in the following steps:

1. Deepdrawing of cups from 2 mm Nb sheet material (delivered by KBI, Reading, PA. 19603, USA)
2. Inspection of the inner surface and local grinding by abrasive tools at suspicious areas. Cleaning of the cups by chemical polishing (CP: HF, HNO_3, H_3PO_4 in volume ratio 1:1:1).
3. Electron beam welding a cell out of two cups. This equatorial weld is manufactured as an inside weld to gain a smooth inner surface.
4. Tuning the individual cells by either CP (- 7 kHz per 1 µm surface removal) or by shortening the axial cell length by a mechanical power system (- 1.5 kHz per 1 µm shortage).
5. Welding the whole structure at the irises by an outside electron beam.
6. Grinding the inner iris weld to smooth the rf-sur face.
7. Final cleaning by chemical polishing.
8. Rinsing with demineralized and dust-free water and drying in a laminar flow environment.

Table 4 Experimental results of superconducting one cell and five cell cavities

Treatments	Q_o [10^8] at max.E_{acc} T = 4.2K	E_{acc} [MV/m]	Comments
single cell cavity delivered from the manufacturer, only rinsed with water*	1.2	1.5	max. E_{acc} limited by available power
iris weld ground, 50 µm CP, water* rinse	5.0	3.0	quench near upper iris
quench location ground, 50 µm CP, water* rinse	4.8	3.5	quench at the equator weld
quench location ground, rinsed with acetone, alcohol and water*	3.0	3.0	same quench location as before
20 µm CP, water* rinse	4.6	5.3	quench location near equator, not at the weld
five cell cavity delivered from the manufacturer, 20 µm CP, water* rinse	2.5	3.2	Q_o=4.5*10^8 at low E_{acc}. Temperature mapping system not yet available, so quench location not detected.

*water: deionized and dust-free

To gain experience with the manufacturing process a single cell, a 5 cell- and a 9 cell-unit have been produced as first series. Results of the superconducting tests of the single cell and the five cell cavity are given in table 4, the nine cell structure is at the state of final welding. The cavities are tested in a conventional vertical He cryostat. Temperature mapping at subcooled Helium is applied for quench diagnostics. A system of 20 rotating resistors per cell, a multiplexer unit at Helium temperature and a computer controlled digital voltmeter are used for instrumentation. The results in table 4 demonstrate that an aimed repair of quench locations (grinding and CP) is a necessary manufacturing step to reach high field values. The measured quality factor of the cavity Q_o, the theoretical value Q_{BCS} (according to BCS theory) and the residual quality factor Q_{Res} (representing normal-conducting losses) are related by

$$1/Q_o = 1/Q_{BCS} + 1/Q_{Res}$$

Our measurements show a value of $Q_{BCS,4.2K} = 7.5*10^8$ and typically $(1\text{-}2)*10^9$ for Q_{Res}.

Acknowledgement

During the development of our program we had many fruitful discussions with our colleagues at CERN, Cornell, KFK and in our houses. The instrumental support by the CERN superconducting rf-group and the engaged participation of Prof. Piel enabled an early start of our experiments. All these helpful contributions are gratefully acknowledged.

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