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BEAM TEST OF A 9-CELL SUPERCONDUCTING CAVITY IN THE PETRA STORAGE RING

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Summary

A 1 GHz 9-cell superconducting cavity was installed and tested in the PETRA electron-positron storage ring. 2 mA were injected at 7 GeV and stored by a superconducting cavity with a maximum gradient of 2.5 MV/m. With the addition of normal-conducting 500 MHz cavities the superconducting cavity transferred 27.5 kW to a 8 mA beam current. The resonator is kept at LHe temperature since February 1985 to gain long-time experience on superconducting cavities in the storage ring environment. The maximum achievable field and the quality factor have not changed up to now.

Introduction

A developement program for superconducting 1 GHz cavities was started at DESY in 1982 to explore the possibility of upgrading the energy of a storage ring by superconducting cavity technology.

The design, fabrication and final preparation of Niobium-resonators are described in[1,2]. Three nine-cell structures were tested in a vertical cryostat and showed maximum gradients of 5 MV/m at 4.2 K. Two of these structures were equipped with rectangular waveguides at the ends; one mainly for the fundamental mode input and the other for the extraction of the higher order modes. A leak in a weld near the explosive bounded Nb-SS flange at one output coupler necessitated a time consumpting repair, so that only one complete nine-cell cavity could be installed in time for the scheduled beam test in PETRA. The aim of this experiment is to gain system experience with a superconducting rf-module in a storage ring over a long as possible period of time.

Experimental Layout

Details of the cavity, couplers, tuners, input and output couplers and the cryostat are given in[3,4,5]. Rectangular waveguides at both ends of the resonator are used to feed the fundamental power and to extract the beam induced higher frequency energy. All microwave components are based on a broad band design including a 1 GHz filter absorber for the input pover line which absorbs all higher frequency beam induced power[4]. The resonator is tuned lenghthening or shortening the whole structure with a hydraulically driven system. The Nb-cavity is mounted inside a magnetic shielded horizontal LHe cryostat using metal seals (Helicoflex) for beam vacuum components and indium seals for isolation vacuum connections. A 100 W He refrigerator is used for cool down and steady state operation at 4.5 K (1.3 bar). Prior to cool down the cavity was evacuated by a 100 L/s turbomolecular pump and two 30 L/s ion getter pumps. The isolation and beam line vacuum were monitored by mass spectrum analysers.

110 normal-conducting 500 MHz cavities are installed in the PETRA storage ring which were tuned or detuned and powered according to the test program. A 1 GHz klystron with a modified 500 MHz power supply was used to drive the superconducting cavity.

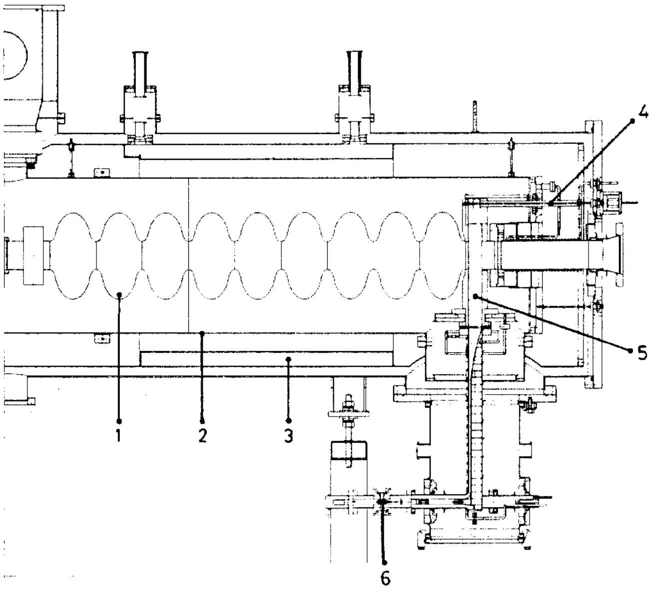

Fig.1: Main layout of the horizontal test cryostat (1: Nb-cavity, 2: LHe-vessel, 3: LN_2-shield, 4: tuning system, 5: higher order mode coupler, 6: window in line 5)

Resonance frequency	f_o (MHz)	999.334
Cavity diameter	2R (cm)	27.9
Iris diameter	2r (cm)	9.0
Length of active structure	L (m)	1.35
Coupling coefficient	K (%)	1.56
Shunt impedance	r/Q (Ω/m)	740.
Geometric factor	G (Ω)	259.
Peak electr. field ratio	E_p/E_{acc}	1.8
Peak magn.field ratio	B_p/E_{acc}(mT/MV/m)	4.3
Quality factor, BCS, 4.5K	$Q_o(10^8)$	7.0
Quality factor measured 4.5K	$Q_o(10^8)$	6.5
Loading of input line	$Q_{ext}(10^5)$	1.28
Tuning range	f(kHz)	+300/-130
Frequency	f/p(Hz/mbar)	-23

Table 1: Parameters of 1 GHz 9-cell cavity

Experimental Results

Input Line

The design of the input window and the feedline filter is described in detail in[4]. The window was high power tested under matched (mismatched) conditions with 50 kW (30 kW). Matched conditions are estab-

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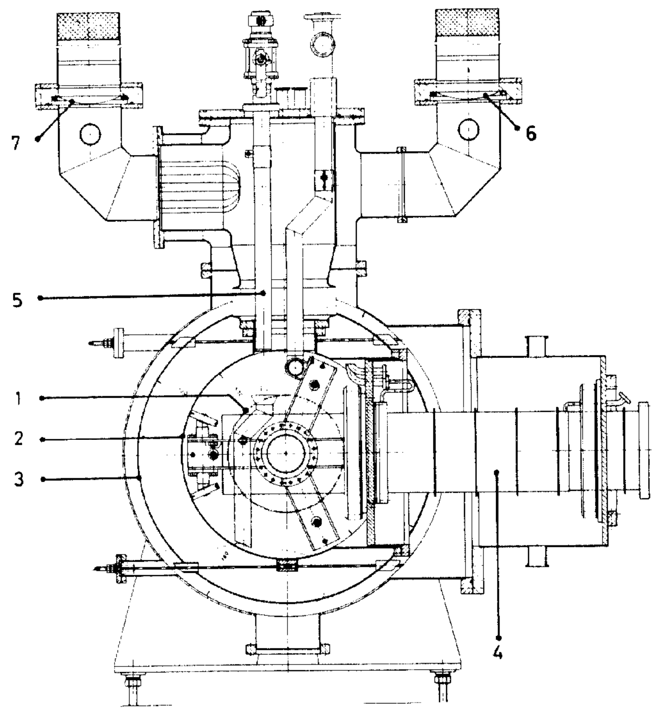

Fig. 2: Cross section of the cryostat at the input coupler (1: Nb-cavity, 2: LHe-vessel, 3: LN$_2$ shield, 4: input waveguide, 5: transfer lines to refrigerator, 6: burst valve isolation vacuum, 7:burst valve LHe-room)

lished for a beam current of 4x4 mA during the beam test. Lower beam currents result in a rf-mismatch with standing wave patterns in the input line. The window was placed in the region of maximum magnetic field and weakest absorption patterns on the ceramic obtained from the window test. A light detector monitoring the vacuum side of the window ceramic interlocks the rf-drive in case of discharge phenomena. The heat exchanger in the rf-input line was measured in a test cryostat and showed 2 W total rf-heat load to the 4.5 K He for 50 kW forward rf-power. The waveguide gasket at the connection flange to the cavity accounted only for 0.3 W of this total.

Cavity measurements

Before the installation in PETRA the cavity was measured outside the storage ring. Obvious discharge problems at the input window resulted in an operating mode with pulsed rf for 1 msec and increasing duty factor from 10 % to 95 %. Under those conditions an accelerating field of E_{acc} = 3 MV/m was reached at the limit of 30 kW forward power. The radiation level was lower than 1 mrem/h at a distance of 1.5 m from the cryostat. A warm up and cool down cycle during the installation of the resonator inside the PETRA tunnel did not change the rf and vacuum properties. Under cw operation however, the accelerating field was limited at 2.5 MV/m.

In case of a quench the complete cavity became normalconducting and absorbed all forward rf-power because of the matched rf-conditions. If the klystron is not switched off the consequences are a vacuum deterioration by 4 orders of magnitude, mainly due to desorbed H_2-gas from the warmed up inner cavity surface, and a considerable pressure increase in the LHe-room. In fact, the partial pressure of H_2 turned out to be the most sensitive detector for the onset of a quench. Using this signal as an interlock for the klystron drive, the cavity could be protected against quenches without any loss of LHe.

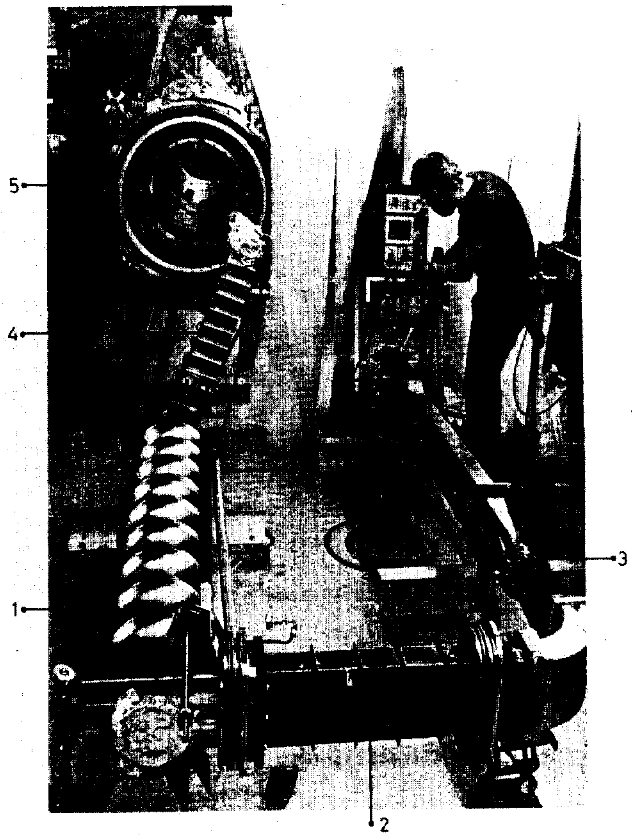

Fig. 3: 9-cell Nb-cavity during rf-measurement (1: Nb-cavity, 2: input coupler with heat exchanger, 3: input window, 4: higher order mode coupler, 5: horizontal cryostat)

The quality factor Q of the cavity was determined by measuring the transient response of the refrigeration system immediately after on/off switching of the resonator field. The calibration was made with a resistor immersed in the LHe cryostat.

Experiments with Beam Currents

At 7 GeV/c current of 4x0.5 mA with a beam lifetime τ = 3.2 h was injected and stored by the superconducting cavity. The other 110 normal conducting cavities were not powered and were detuned during this experiment. A measured synchrotron frequency of f_s = 5 kHz confirmed rf-calibration of a maximum acceleration field E_{acc} = 2.5 MV/m within 10 %. Additional circumferential voltage of 20 MV at 500 MHz allowed to increase the stored current to 4x2 mA. The relative phase of the 1 GHz superconducting cavity was tuned to transfer a maximum of 27.5 kW to this beam current. This value was limited by sparking in the ridged waveguide part of the feed line filter. A total of 280 W beam induced higher frequency power in both coupler lines was measured for a current of 4x3.2 mA with a bunch length of σ_{rms} = 1.6 cm. This is comparable with the 300 W predicted by TBCI calculation[3] but including the radiation along the beam pipe.

No evidence of a beam instability caused by the superconducting cavity could be found during all experiments. An exact analysis is difficult due to the presence of 110 normal conducting resonators. After a period of 12 dedicated shifts for the experiment with the superconducting cavity, the luminosity runs of the PETRA storage ring started 18th of March, 1985. The fundamental mode of the superconducting cavity was detuned by 40 kHz and the cryostat was kept at LHe tem-

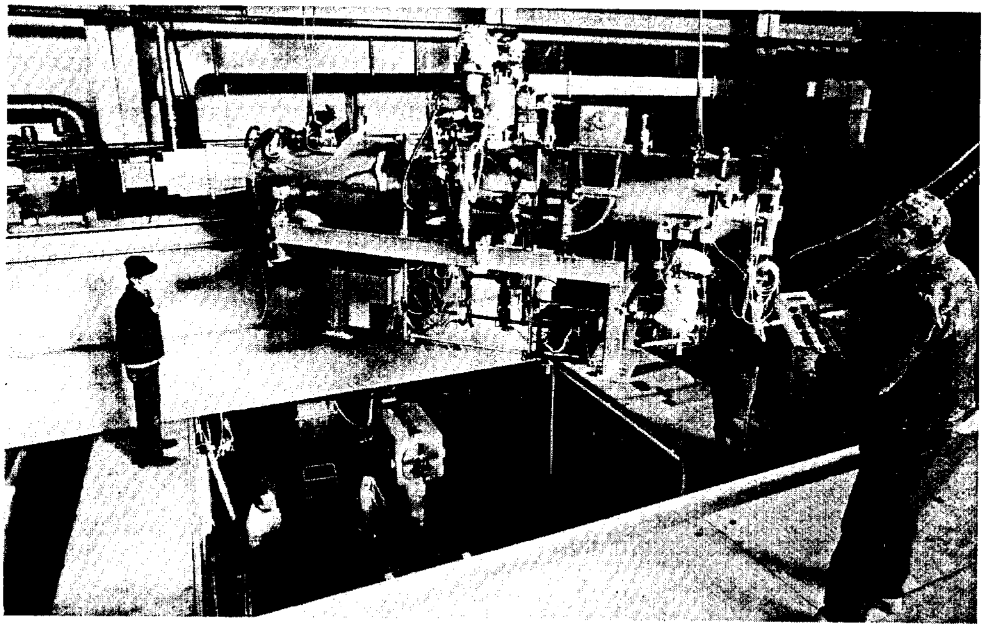

Fig. 4 Horizontal cryostat during installation in the PETRA storage ring

perature. At least every two weeks the cavity was resonance-tuned to measure the quality factor Q and the maximum accelerating field E_{acc}. No changes have been observed so far (middle of May 1985).

A lot of minor problems had to be solved during the tests with the superconducting cavity. Most of them are related to the refrigerator system which is not adapted to fast head load changes due to varying conditions of the superconducting cavity. A detailed report describing these problems is under preparation[6].

A problem appeared as the beam current was increased to 4x3.5 mA during ramping the PETRA energy from 7 GeV/c to the 21.8 GeV/c. At about 14 GeV/c a heat pulse disturbs the LHe cooling system and is accompanied by a detoriation of the beam pipe vacuum (mainly H_2 gas). Since the rf-frequency is slightly changed during the ramping procedure it cannot be excluded that a high Q cavity mode is excited by the beam. This phenomenon will be investigated in more details during a machine study shift.

Conclusion

This experiment with a superconducting 1 GHz resonator in PETRA confirmed the practicability of superconducting cavity thechnology in storage rings and is in agreement with previous tests (for a review see[7,8]). In addition, the ongoing long time test gave no hint of a deterioration of the cavity performance. Most technical problems were related to the refrigerator system which will be modified based on this experiment. The reduced accelerating gradient as compared to the tests in the vertical cryostat is possibly due to the complex geometry of a horizontal cryostat which makes an assembly under dustfree conditions very difficult. Accelerating gradients of 5 MV/m under working conditions should be possible with a modified cryostat design and the use of Niobium with higher thermal conductivity[9,10] to raise the quench threshold.

Acknowledgement

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