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SUPERCONDUCTING ACCELERATING CAVITIES FOR HIGH ENERGY e^+-e^--STORAGE RINGS

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Abstract

In electron storage rings the high demand of RF power contributes considerably to both construction and operating costs. A cost optimization shows, that a storage ring with superconducting cavities is smaller and cheaper than one with normal cavities. Exchanging normal into superconducting cavities in an existing storage ring can increase the end energy by about 40%. Open questions like performance, especially in presence of synchrotron radiation, effects of higher order modes and handling of high beam power need tests in an operating storage ring. The preparations and components of a test in DORIS are described.

I. Introduction

In high energy e^+-e^--storage rings the RF-power dissipated in the normal conducting cavity walls is of major concern. Superconducting cavities offer the possibility to reduce the cavity losses practically to zero, compared to the RF-power available for the beam. In addition, as the accelerating field gradient is no longer determined by cooling problems and cost considerations, higher fields become possible reducing the total length of the cavities and thereby lowering the construction costs inspite of the presumably higher costs/m of superconducting systems.

II. Expectations

1. The advantage of superconducting cavities can be considered in two ways. First, one might ask, by what amount the final energy of an existing storage ring could be increased replacing the normal conducting cavities by superconducting ones, using the previously installed RF-power. Fig. 1 shows the answer for the example PETRA[1], where 200 m of cavities and 8 MW of RF-power limit the energy at 23 GeV in the normal conducting case, whereas superconducting cavities would increase the energy into the 30 - 35 GeV range. [2]

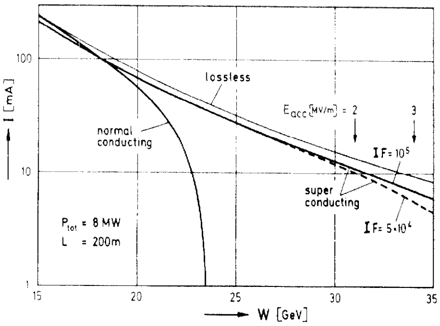

Fig. 1: Current I of one beam versus final energy W for PETRA for 8 MW RF-power and 200 m cavities. For normal conducting cavities the RF-power is shared between the beam and the losses in the cavity walls. For superconducting ones nearly all RF-power remains for the beam. The limitation in this case is due to the achievable accelerating fieldgradient E_{acc}. (IF: Improvement factor Nb/Cu)

2. If, on the other hand, one asks, how a storage ring design with superconducting cavities from the beginning would look like, an extension [3] of the usual cost optimizing procedure [4] for this case gives the result shown in Table I, where unit costs from ref. 4 have been used.

TABLE I
Comparison: normal (n) and superconducting LEP 70-100

	70 GeV (n)	70 GeV (s)	100 GeV (s)
bending radius ρ (m)	2469	1576	2355
cavity length L (m)	1491	629	1753
beam power P_b (MW)	18.9	29.6	25*
cavity power P_c (MW)	40.5	.005	0.013
luminosity $\mathcal{L}$ (cm^{-2} sec^{-1})	10^{32}	10^{32}	4×10^{31}*

* beam power restricted to 25 MW due to power-handling capability of the LEP-70 beam tube, limiting $\mathcal{L}$ to 4×10^{31}. (From ref. 6).

One may argue that this result should depend on the specific unit costs and that the costs of superconducting system are not yet well enough known. Fig. 2, however, shows the ratios (average radius and cavity length of a superconducting machine)/(radius and cavity length of a normal conducting one) as a function of the ratio of the unit costs for (superconducting)/(normal conducting) cavities. The lower curves indicate, that for the same energy the superconducting version has a smaller radius and a shorter cavity length than the normal conducting one. The upper part shows, that the dimensions which give a cost optimum for a normal conducting machine of 70 GeV are almost equal to those of an optimized superconducting machine of 100 GeV. This result, which is in agreement with ref. 5 depends very little on the specific unit prices used.

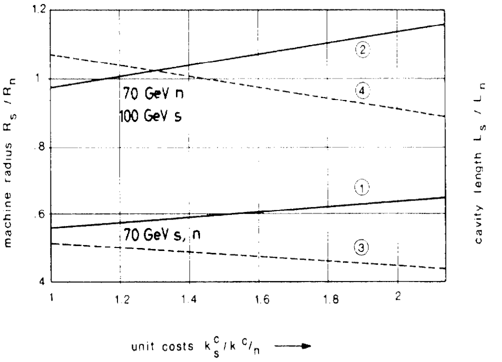

Fig. 2: Optimized geometry for normal (n) and superconducting (s) cavities. 1 and 2: Ratios R_s/R_n (average radius) versus ratio k^c_s/k^c_n (cavity costs/m) for n- and s-cavities, 1 for s and n 70 GeV, 2 for s 100 GeV, n 70 GeV. 3 and 4: Ratios L_s/L_n (cavity length). Unit costs for n cavities: $k^c_n = 80 \cdot 10^3$ \$/m.

3. What accelerating field gradients can be expected? As discussed in ref. 6 this question is closely related to the choice of the operating frequency. The main limitation of the achievable field in Nb cavities is electron loading [7]. This loading for oxide coated Nb seems to depend on frequency like $E_p \simeq 10^7 V/m/f(GHz)$.[7]

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Resulting from machine design considerations, however, operating frequencies $\leq$ 500 MHz have been chosen [1,8,9]. In this frequency range accelerating field gradients of about 2 - 3 MV/m can be expected [7]. In addition, other aspects of the superconducting technology like surface treatment, stability of cavities, helium consumption, size of cryostats and costs favour smaller cavities, i.e. higher frequencies.

4. The Q-value, governing the RF-losses and thereby the size of the required refrigerators seems less problematic. Improvement factors of the order 10^4 - 10^5 have been achieved regularly at 4.2 K [6]. Since at the frequencies considered the residual surface resistance of Niobium is of the same order of magnitude as the theoretical surface resistance at 4.2 K, a reduction of the operating temperature below 4.2 K does not lower the power consumption. Therefore the refrigerator can operate at athmospheric pressure and additional costs and difficulties with possible leaks from athmospheric to below athmospheric components of the He-circuit are avoided.

III. Questions typical for storage rings

1. Although the cavities are situated in straight sections, scattered synchrotron radiation may impinge on the surface. At DORIS about 1 W/m of synchrotron radiation has been measured [10], which generates about 10^{13} photoelectrons per second. Their effect on the cavity performance, especially over a longer period of time remains to be investigated.

2. The beam bunches generate higher order modes in the cavities, some of which have detrimental effects on the beam. In superconducting cavities not only these modes, but also all other modes have to be coupled out very effectively to dissipate their energy in a room temperature load rather than into the helium bath.

3. The design of an input coupling system which couples about 100 kW from outside into the cryostat and cavity without excessive heat losses is not a trivial task, and to obtain operating experience with such a system is necessary.

These questions can only be answered by experiments in an operating storage ring. We, therefore, designed an experiment with a single-cell-cavity to be tested in DORIS end of 1979. In the following paragraphs the present status of this experiment will be described.

IV. Description of the DORIS-Experiment

1. Table II shows the basic parameters of the cavity and its expected performance.

TABLE II
Parameters for the DORIS-Experiment

frequency	F (MHz)	500
shuntimpedance (300 K)	Z (MΩ/m)	25
Q-value (300 K)	Q_o	4.4×10^4
geometry factor	G (Ω)	255
peak electric field / E_{acc}	E_p/E_{acc}	1.67
assumed achievable Q(4.2 K)		10^9
assumed achievable acc. Field	E_{acc} (MV/m)	3
cavity power	P_c (W)	5
beam power	P_b (kW)	100

Fig. 3 shows a scetch of the cavity and its main dimensions. The geometry has been chosen according to the present knowledge about electron loading [7,11,12]. The cavity is fabricated from sheet niobium by pressing the endplates and rolling the cylinder wall. Coupling parts and flanges are machined from solid Nb. The parts are connected by TIG-welding.

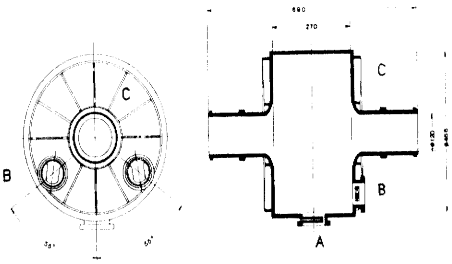

Fig. 3: Niobium test cavity for DORIS. A: input coupling; B: output coupling for higher modes; C: stiffening bars.

2. The principle of the input coupling system is shown in fig. 4. It consists of the following parts:

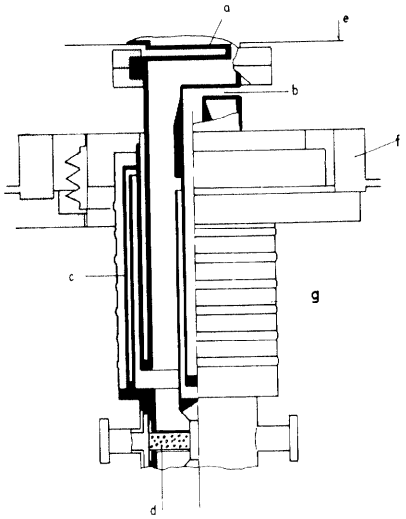

Fig. 4: 100 kW-input coupling system. e: cavity wall; f: helium tank; g: insulating vacuum; a: helium cooled field transformer (Nb); b: helium cooled coupling loop (Nb); c: capacitively separated inner and outer conductor of coaxial line (Cu); d: nitrogen cooled ceramic window. (Not shown: a similar separation and a water-cooled window at room temperature, and the coax-waveguide-transition outside the cryostat).

A "field transformer" [13] increases the coupling strength and keeps the field inside the cavity undistorted. The hollow coupling loop is flooded by liquid Helium. Inner and outer conductor of the coaxial line are separated capacitively to minimize heat influx. The cavity is separated from the outside world by a ceramic window at 80 K and a second window at 300 K.

3. Two higher mode output couplers as shown in fig. 5 are placed at the endplates to couple effectively also the azimutal unsymmetric modes. The exponential line is used to reject the fundamental mode and to match the impedances of all higher modes to the 50-Ω-coaxial line. This system has been tested at a room temperature model cavity; it couples out all modes up to 2 GHz with a coupling - $Q_{ext} \leq 10^4$. This system is described in detail in ref. 14.

4. For frequency tuning we made use of the fact, that the athmospheric pressure of the helium bath acts against the vacuum pressing the endplates inward. The tuner, as shown in fig. 6 pulls the endplates at the beam tubes outward. The tuner sensitivity is about 1 kHz/μ. The driving step motor is mounted outside the cryostat.

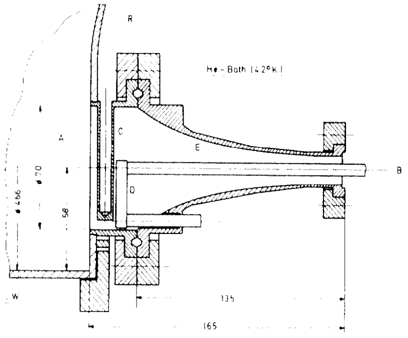

Fig. 5: Cross section of the higher mode output coupling system. R: cavity endplate; A: cavity; W: cavity cylinder wall; C: helium-cooled field transformer; D: helium-cooled coupling loop; E: exponential coaxial line; B: 7/16 mm coaxial output line.

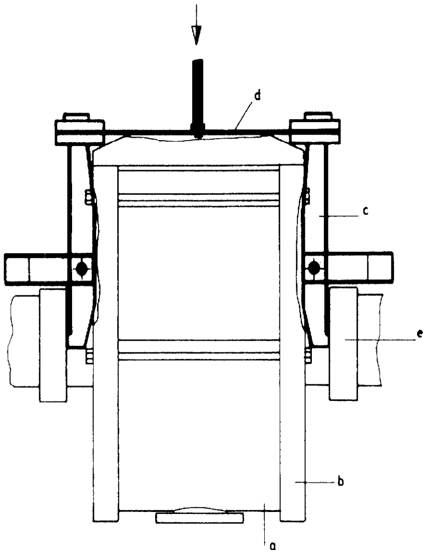

Fig. 6: Tuning system of the DORIS-cavity (a). The supporting frame (b) holds the movable bars (c). By pressing the connecting band (d) down, the bars pull the beam tubes outward against the athmospheric pressure.

5. The cavity is cooled in a bath cryostat which is connected to a LHe-transportcontainer. Beam pipes are cooled prior to the cavity and act as baffles. The evaporating cold Helium gas is used to precool the 80 K-shield, the beam tubes and the couplings. The 80 K-window of the input coupling and the Helium-transferline is cooled by LN_2 to obtain stable conditions for varying loads.

V. Conclusion

Superconducting accelerating cavities offer a possibility of reducing both construction and operating costs for e^+-e^--storage rings and allow an appreciable increase of the final energy in an existing machine Open technical and physical questions will be investigated in an experiment at DORIS, the basic design features of which have been described.

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