

INVESTIGATION OF A MODIFIED HELIX LOADED SUPERCONDUCTING  
 RESONATOR FOR ACCELERATION OF HEAVY IONS

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Summary

A modified helix loaded cavity was developed. The design is a compromise between a rather simple construction, rigidity and small size on one hand and a reasonably good acceleration of low velocity ions on the other hand. It contains a tapered helix to reduce the ratio of peak electric to effective accelerating field to  $\sim 7.1$  at an optimum relative charged particle velocity of  $\beta = 0.092$ . Field measurements at room temperature have been performed as well as first measurements at 4.2 K. The rigidity of the helix was increased resulting in a typical frequency noise smaller  $\pm 175$  Hz<sub>peak</sub> at the fundamental frequency of 142 MHz. The design accelerating field is 2.25 MV/m at a peak electric field of 16 MV/m leading to an optimum accelerating potential of 538 kV. In laboratory test measurements an effective accelerating field of 2.36 MV/m was achieved. This corresponds to an accelerating potential of 566 kV at a peak electric surface field of  $\sim 17$  MV/m.

Introduction

Superconducting helix loaded cavities were proposed and used in the past for accelerating low energy protons and heavy ions in test sections.<sup>1-4</sup> The helices in these experiments had cylindrical shape with constant pitch and diameter. The usual field limitation results from field emission due to the peak electric field. The goal of this investigation was to reduce the peak electric field relative to the effective accelerating field by changing the shape of the helix to something like a rotational hyperboloid. At the same time the rigidity of the helix should be increased by employing a larger diameter of the helix conductor. The tank diameter was limited to 0.2 m and the maximum acceleration should occur around a relative velocity of ions  $\beta = 0.1$  or lower.

Design Considerations

The maximum electric field in a cylindrically wound helix loaded cavity appears between the end turns of each shorted  $\lambda/2$ -helix or radially at the middle turn. In order to reduce this fields, the separation of the turns towards both ends was increased by moving the end turns into the corners of the tank, while the diameter of the middle turn was diminished.<sup>5</sup> At the same time the diameter of the helix conductor was increased to 15 mm to stiffen the helix. The wall thickness of the helix tube was 1 mm before surface treatment. Figure 1 shows the design of the test cavity. HF-power was coupled through the beam tubes.

Field Measurements at Room Temperature

The fundamental frequency of the resonator is 142 MHz and the first harmonic is at 168 MHz. The ratio of maximum electric field to effective accelerating field (cavity length 0.24 m) is 7.1. The accelerating potential at a reactive power of  $PQ = 10^8$  W is  $\Delta U = 246$  kV at a relative particle velocity of  $\beta = 0.092$ . Figure 2 shows the field distribution on the axis while figure 3 shows the design accelerating potential at an electric peak field of 16 MV/m. The quality factor of the Niobium resonator at a temperature of 297.7 K is  $Q_0 = 945$ .

From this the geometrical factor can be determined to be  $G = 8.8 \Omega$ .

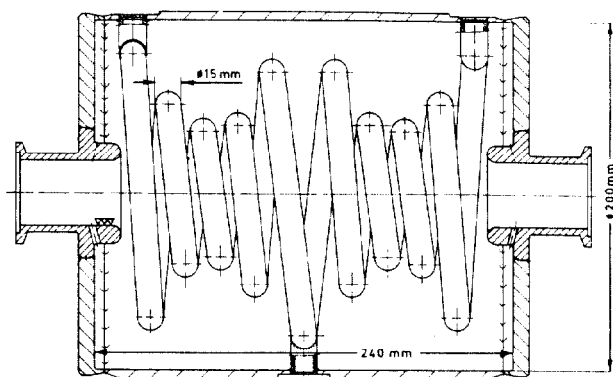


Fig. 1: Design of the Niobium test cavity with a ratio of the electric fields  $E_{\text{peak}}/E_{\text{trav. wave eff}} = 7.1$  and an optimum relative particle velocity  $\beta = 0.092$ .

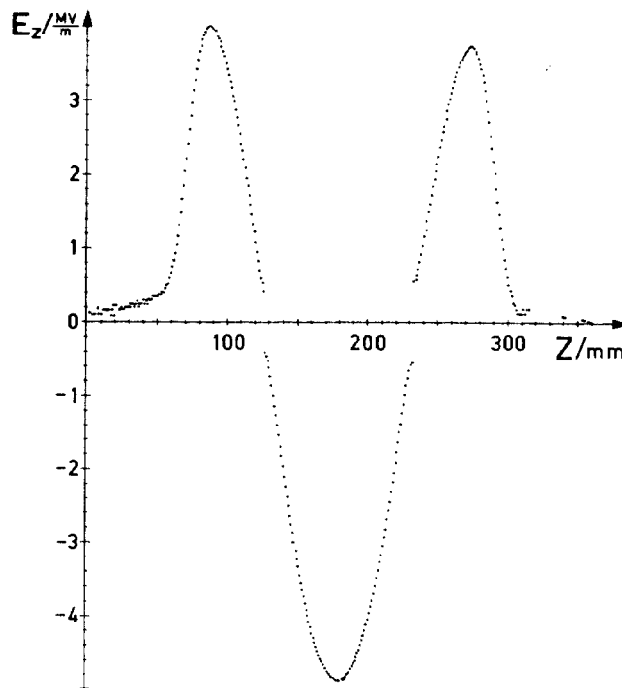


Fig. 2: Axial electric field distribution at  $PQ = 4.8 \times 10^8$  W determined by a dielectric bead disturbance measurement.

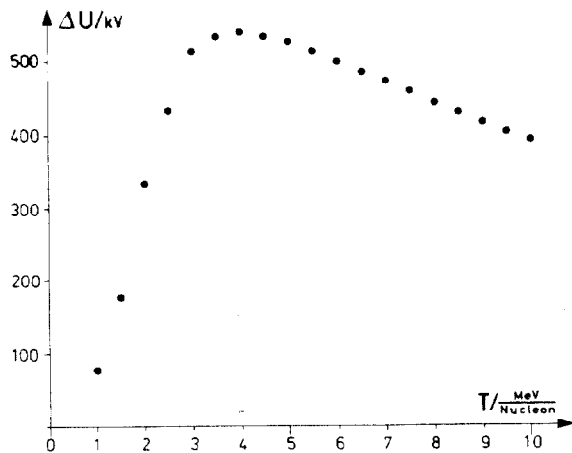


Fig. 3: Acceleration potential for ions with different specific injection energies at the design value  $PQ = 4.8 \times 10^8$  W.

#### Fabrication and Surface Treatment

The cavity has been built of Stanford Grade Niobium. Only inert gas welding was employed. The only intermediate heat treatment (900°C, 2 h) was performed after the flat material for the outer tank was patched together from two parts and before it was rolled. Accidentally there happened an air leak at the box when welding the joint between the endplates and the outer tank causing a grey coating (oxide) also inside the cavity near one of the helix legs. The oxide was chemically polished away before oxypolishing the cavity around 18-21°C at a voltage of about 14 Volts and a mean current of near 65 A for 315 minutes pure polishing time. The exposed surface area of the cavity is about 0.53 m<sup>2</sup>. If Nb<sup>I</sup> goes into solution then this would correspond to a removal of 200 μm. After electropolishing the cavity was cleaned with a 1 : 10 solution of perhydrol in water in an ultrasonic bath for a few minutes, dried with methyl and then baked in a furnace at 950°C for 2 h at a final pressure of  $2 \times 10^{-8}$  Torr. After a first test measurement at 4.2 K did not show the desired performance the cavity was subject to further electropolishing for 90 min at the same parameters as before followed again by the same rinsing procedures and heat treatment.

#### Test Measurements at 4.2 K

Right after the furnace had cooled down to room temperature the cavity was mounted with its axis vertically into the laboratory cryostat without employing protective gas. The vacuum was  $7 \times 10^{-8}$  Torr before the cryostat was cooled down to 4.2 K. In the subsequent HF-measurement the cavity could be brought up to an effective accelerating field of 1.5 MV/m. He-processing for 30 minutes at maximum achievable field and a pressure of  $4 \times 10^{-5}$  Torr raised the effective accelerating field to 1.85 MV/m still limited by field emission. After the second chemical and heat treatment of the cavity the accelerating field reached 1.3 MV/m. He-processing for 2 h raised the achievable accelerating field to 2.36 MV/m corresponding to a peak electric field of about 17 MV/m. At this power level the cavity is loaded by electrons. The accelerating potential at that field is 566 kV at an ion velocity of  $\beta = 0.092$  and the frequency shift due to ponderomotive forces is 53.1 kHz. Figure 4 shows the quality factor as a function of the effective accelerating field before and after He-processing.

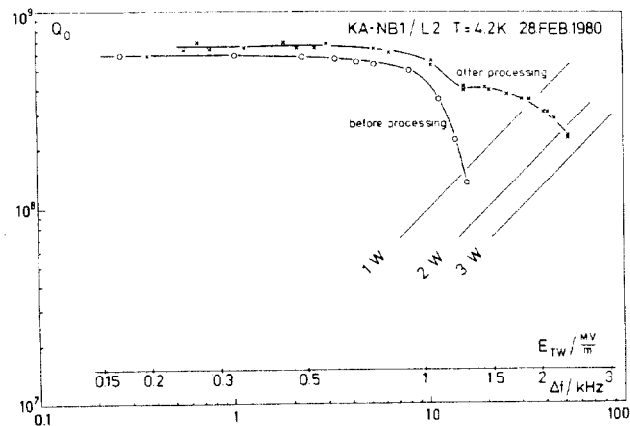


Fig. 4: Quality factor  $Q_0$  of the testcavity as a function of effective accelerating field  $E_{TW}$  before and after about 2 h of He-processing at the second low temperature test at 4.2 K.

The frequency noise was measured by phase locking a voltage controlled oscillator (HP 8654 A) to a self-excited loop containing the resonator and measurement of the calibrated VCO-drive voltage. The measurements indicate a predominant modulation frequency of 65 Hz upon knocking against the cryostat. The frequency oscillation decays with a time constant of  $2\tau = 4$  sec. The frequency noise at the achievable fields was typically smaller than  $\pm 175$  Hz<sub>peak</sub>.

#### Acknowledgement

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