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

DEVELOPMENT OF SUPERCONDUCTING CAVITIES OF CYLINDRICAL SYMMETRY AT CORNELL

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Abstract

The fabrication, processing and measurement of five single cell and one 5-cell L-band niobium cavities of elliptical shape are discussed. Q-values of 2 to 5x10^9 have typically been obtained without high temperature firing. In single cells magnetic surface fields as high as 56 mT corresponding to an accelerating field of 7 MV/m have been measured. In the 5-cell structure a gradient of 4.7 MV/m was achieved.

Introduction

For several years the Cornell group has been working on the design and fabrication of superconducting niobium cavities of the muffin-tin type.[1,2] The development focussed on the construction of cavities, which could be used as accelerator cavities in a storage ring. In spring 1982 a one meter long section was successfully tested in CESR.[3]

Since then the development of cylindrical symmetric cavities at 1500 MHz had been pursued for reasons of comparing both cavity types in their performance. Cylindrical symmetric cavities seem to promise - besides high mechanical stability and ease of fabrication - good rf-performances as reported in ref 4)-6).

Cavity Design

Guided by recently achieved results on elliptically shaped resonators[7] we have designed a cavity of the shape shown in Figure 1.

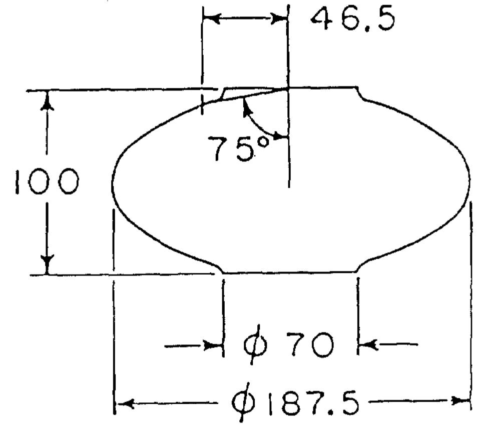

Figure 1: Elliptically shaped accelerating cavity resonating at 1500 MHz

The smooth continuous change in curvature is well suited for spinning, hydroforming or deep drawing techniques and yields a high mechanical stability. The tilting of the end-plates to an angle of 75° allows good access for chemical surface treatments. The rather large beam-hole diameter of 70 mm had to be chosen because of beam aperature considerations and is responsible for the relatively low effective shunt-impedance and the high ratio of $E_{peak,\ surf}/E_{acc}$ as can be seen from table 1.

Cavity Type	Single Cell	5 cell π - mode
Geometry factor [Ohm]	277	275
Z_{eff} [Ohm/m]	662	959
$E_{p,surf}/E_{acc}$	3.02	2.56
$H_{p,surf}/E_{acc}$ [mT/MV/m]	7.8	4.68

Table 1: RF-and Accelerator Properties of the cylindrical TM_{010} - Cavities as calculated by SUPERFISH; E_{acc} is the effective accelerating field including transit time factor

Cavity Fabrication and Processing

The cavities are fabricated out of 1/8" thick reactor grade niobium sheets by deep drawing round blanks in a single stage process into half cells. These cups are trimmed to the right length on a numerically controlled milling machine. In addition, the necessary machining for the preparation of the electron beam welds is done. No stress annealing of the half cells is carried out. Before welding the cups together with inside welds at the irises and full penetration welds from the outside at the large diameter, a thorough surface inspection including removal of surface irregularities by mechanical and chemical methods is carried out. Also about 50μm are chemically removed from the surface. Usual processing techniques[8] have been applied to the cavity surfaces as are listed in table 2 together with results of several tests. After the chemical processing intensive rinsing of the surfaces in distilled water and methanol is carried out. The rf-coupling probes are attached to the cavity in a clean room environment.

Measurement Methods

The low temperature measurements were made in a magnetically shielded dewar and consisted of measuring the rf-characteristics of the cavities (Q-value and peak fields) at 2.1K, temperature mapping of the outer cavity surface below and at break-down and measuring electron currents produced inside the cavities at higher field levels.

Temperature Mapping

Since the first use of carbon resistor thermometry at the outside wall of a superconducting cavity for quench detection,[9] the method has been developed to be a very powerful tool for detecting troublesome areas of increased energy losses in a cavity shedding more light onto loss mechanisms and field limitations encountered during the operation of superconducting cavities.[10,11] We have developed such a mapping system by adopting the basic design as reported in ref 11). The concept of the mapping system is a X-Y-array of wires forming a

0018-9499/83/0800-3348$01.00©1983 IEEE

pattern of nodes. A resistor is connected between each pair of nodes; a voltage is applied to one node and a current is measured at another node held at virtual ground. All other nodes are held at ground during the measurement. In this configuration the number of wires needed for N resistors and emerging from the cryostat is reduced to $(1 + \sqrt{(1 + 2N)})$.

A multiplexer at room temperature is switching the resistors as part of a data acquisition system. A chain of 19 carbon resistors in the case of a single cell and 81 resistors for the 5-cell cavity is moved around the outside wall of the resonators, which are immersed in subcooled helium at a temperature between 2.2K and 2.6K.. In the subcooled condition microconvection in the helium is not present, thus reducing the cooling capacity of the helium substantially. Therefore, larger temperature differences can be obtained at the thermometers[10]. The resistors are glued into small copper blocks which are mounted onto beryllium-copper springs providing a good thermal contact between cavity surface and thermometer.

Results and Discussion

Table 2 contains a summary of experimental results achieved with five single cell and one 5-cell cavities. The table does not list all test results, but from the test number given, one can extract the efforts involved in getting the final result. Listed are Q-values at low and high fields, maximum accelerating fields and the peak magnetic field at the surface as a measure of the quality of the niobium surface.

As can be seen from the table, the Q-values obtained in these cavities are mostly between 2 to 5 x 10^9 with the exception of the initial tests on LE1-2. This cavity showed a very pathological behaviour and neither mechanical treatment of the surface with abrasive powder ("tumbling") nor chemical or electrochemical polishing by a total material removal of 110µm improved the Q-value or the fields significantly. By a moderate firing at 1150°C, the highest Q-value of 10^{10} ever obtained in our tests was measured. It is believed that this abnormous behaviour is maybe related to hydride formation in the niobium during electron-beam welding, caused by large amounts of hydrogen being dissolved in the material during the initial electropolishing of the untrimmed cup. Cavity LE1-4 never showed this kind of behaviour; the electropolished cups had been hydrogen degassed prior to welding.

In several tests break-down was observed at the center weld close to the region of the peak magnetic surface field. By mechanically grinding these areas, the performance of the cavities could be improved and higher fields have been obtained. According to ref 12) defects of smaller size are becoming more important at higher field levels in limiting the cavity performance. Magnetic surface fields as high as 56 mT have been measured in a single cell cavity corresponding to an accelerating field of 7.3 MV/m. In the 5-cell cavity a gradient of 4.7 MV/m was obtained.
In many cases field emission loading above 2 to 3 MV/m was observed. Helium processing[13,14] was successfully applied and decreased the electron currents and the associated losses. Temperature mapping of the outer

Table 2: Summary of Experimental Results

(bcp = buffered chemical polishing; cp = cold polishing;
ep = electropolishing; wg = weld grinding; BD = breakdown)

Cavity/ Test #	Q_o [10^9]	Q_o (H_p) [10^9]	E_{acc} [MV/m]	$H_{p,\ surf}$ [mT]	Surface Treatment	Comment
LE-1/1	1.3	1.3	2.5	19.7	75µm bcp	low Q due to ss endplate atbeam-pipe
/3	3.8	2.8	2.3	17.8	80µm bcp	niobium end-plate attached at beam pipe, BD at center weld
/4	6.0	2.5	6.5	50.6	wg 78µm bcp	FE loading at 3.6 MV/m BD at center weld
LE1-2/1	0.04	0.04	2.3	17.8	75µm ep of cups, 60µm bcp "tumbling", 60µm + 50µm bcp	thermal limitation due to low Q; large parts of cavity warming up
/3	0.08	0.05	3.5	27		
/4	10.0	9.0	4.4	34.3	firing at 1150°C 8 hrs. 10^{-7} torr; 12µm cp	BD at center weld
LE1-3/1	3.6	2.4	4.8	37.4	50µm bcp	He processing 4.2 to 4.8 MV/m; BD at lower end-wall particle at BD location found
/3	4	1.3	5.4	41.8	40µm + 35µm bcp	processing 4.2 to 5.4 MV/m; BD on upper end-wall
LE1-4/1	3.6	1	7.3	56.4	75µm ep of cups, firing at 1 00 C wg 70µm bcp	He processing 4.2 to 7.3 MV/m; BD at center weld
LE5-1/2	5.3	3.8	3	14	70µm + 40µm bcp	BD at center weld of cell 1 and 4
/3a	4.8	3	4.2	19.6	wg at BD areas, 30µm bcp	He processing 2.1 to 4.2 MV/m; BD in cell 5
/3b	4.1	4.5	4.7	22	warmed up to room-temperature	He processing 4.2 to 4 .7 MV/m BD in cell 1 center weld

cavity surface allows one to recognize the disappearance of electron emitters and electron trajectories, which was generally accompanied with an increase in field. A typical example of an electron trajectory and its disappearance during helium-processing is shown in figure 2, which also includes the temperature map at the break-down field of 7.3 MV/m.

In the case of the 5-cell cavity the pumping system, which maintains a cavity vacuum below 10^{-7} torr, failed for some time during test 3a and some gas condensation occurred on the cold niobium surface. Strong field emission, starting at relatively low fields, was observed. After the resonator was warmed up to room-temperature, releasing the condensed gases, field emission was very much reduced.

Conclusion

The single and 5-cell L-band cavities were built to evaluate the features of the elliptical shape. Q-values between 2 to 5 x 10^9 and fields up to 7.3 MV/m corresponding to $H_{p,surf}$ = 56 mT have been obtained. In many cases, defects in the center welds caused field break-down, but mechanical grinding of the troublesome area improved the cavity performance. In this respect cavities made out of seamless tubing[15] seem to promise advantages over welded cavities.

Field emission was usually observed with surface electric fields above 6 to 10 MV/m and could be reduced by helium ion sputtering. Nevertheless, it seems to be a serious problem if one is interested in achieving higher gradients and a better understanding of the mechanisms involved is needed.

Acknowledgement

We would like to thank J. Brawley and A. Heidt for their technical assistance during the fabrication of the cavities as well as F. Palmer, H. Padamsee, J. Amato, and L. Phillips for valuable discussions.

For the UHV-firing, we are thankful to J. Turneaure of Stanford University and H. Baumgärtner of the Kernforschungszentrum Karlsruhe, West Germany.

The tests have been carried out with a cryogenic set-up which was donated to us by the Kernforschungszentrum Karlsruhe. We gratefully acknowledge this donation.

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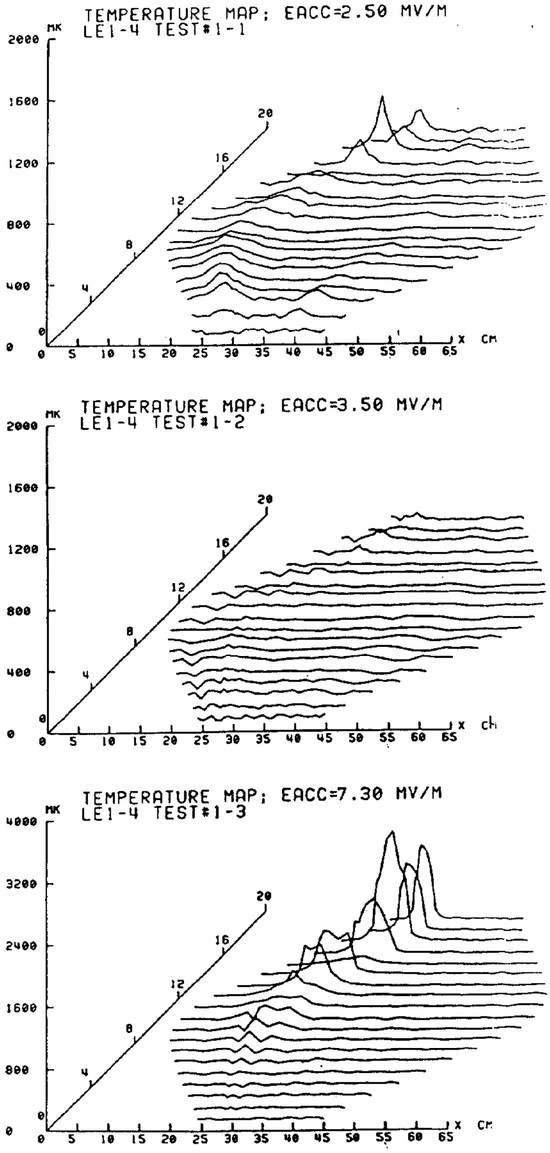

Figure 2: T-maps of the cavity surface at different field levels. Above: electron trajectory; Middle: after helium processing; Below: at break-down.

*Work supported by the National Science Foundation.