PRELIMINARY STUDIES OF ELECTRIC AND MAGNETIC FIELD EFFECTS IN SUPERCONDUCTING NIOBIUM CAVITIES*

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Abstract

Superconducting cavities made from high purity niobium with RRR > 200 often show pronounced features in the Q vs. E_{acc} dependence such as a peak at low gradients, a B²-slope at intermediate fields and a steep degradation of Q-values ("Q-drop") at gradients above E_{acc} ~ 20 MV/m without field emission loading.

Whereas the B²-slope is in line with 'global' heating [2] there are still different models to explain the observed "Q-drop". The model of ref. [1] is based on magnetic field enhancements at grain boundaries in the equator weld region of the cavity and local heating. These grain boundaries become normal conducting, when their critical magnetic field is reached and contribute gradually to the losses in the cavity as long as they are thermally stable.

The model proposed in ref. [2] is based on effects taking place in the metal-oxide interface on the niobium surface. The major contribution to the RF absorption is coming from interface tunnel exchange between electronic states of superconducting Nb with their energy gap and localized states of the dielectric Nb_2O_5.

An experimental program was started at JLab to settle the mechanisms behind B²-slope and the Q-drop. A modified CEBAF single cell cavity is excited in either TM_{010} or TE_{011} modes and the Q vs. E_{acc} dependences are measured as a function of various surface treatments such as BCP, electropolishing, high temperature heat treatment and "in-situ" baking. In addition, a special two-cell cavity was designed, which allows the excitation of the 0 – and π – modes of the TM_{010} passband, which "scan" different areas of the cavity surface with high electric and magnetic fields, respectively. This contribution reports about the design and first measurements with both types of cavities.

ELECTROMAGNETIC DESIGN

Other than the mode TM_{010}, used to accelerate a charged particles beam, the resonant mode TE_{011} in a cylindrical structure has the property of having a purely azimuthal electric field configuration, providing a way of measuring only the effect of the magnetic field on the surface resistance. A CEBAF single cell cavity with side-port coupling can be excited in both TM_{010} and TE_{011} modes by using a properly shaped inductive loop. The basic properties of these modes have been computed with SUPERFISH and are summarized in Table 1. Figure 1 shows the field distributions along the cavity surface. It can be seen that the magnetic field in the TE_{011} mode is localized in a region next to the cavity's iris. The shape of the loops used as an input coupler and a field probe for both modes have been optimised through few iterations.

Table 1: Electromagnetic parameters of the TM_{010} and TE_{011} modes for a CEBAF single cell.

	TM_{010}	**TE_{011}**
Frequency [MHz]	1472.599	2830.723
$E_{peak}/\bullet U$ [(MV/m)/•J]	24.1	0
$B_{peak}/\bullet U$ [mT/•J]	60.7	70.4
G (=$R_s Q_0$) [Ω]	271	701

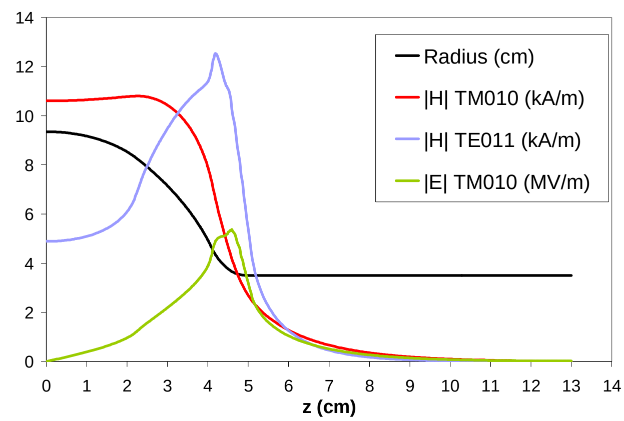

Figure 1: Surface fields for the two modes for 50mJ stored energy and cavity profile.

In addition to the CEBAF single cell, a two cells cavity was designed so that one mode would have a high ratio of peak magnetic to peak electric field and one that would have both high peak electric and magnetic fields. It was decided to have these two modes as close in frequency as possible, to reduce the effect of the frequency dependence of surface resistance.

The cavity was designed with the FEM code described in ref. [3] and the field configurations of choice are the TM_{010}-0 and -π modes. Their features are a large beam pipe that allows a large cell-to-cell coupling and steep curvatures at the equators and middle iris, confining the peak fields in these regions.

The electromagnetic parameters of the modes are indicated in table 2, while figures 2 and 3 shows the field distributions on the cavity surface.

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Table 2: Electromagnetic parameters of the TM_{010}-0 and TM_{010}-π for the 2-cells cavity.

	TM_{010}-0	TM_{010}-π
Frequency [MHz]	1381.848	1494.574
$E_{peak}/\sqrt{U}$ [(MV/m)/$\sqrt{J}$]	2.92	11.26
$B_{peak}/\sqrt{U}$ [mT/$\sqrt{J}$]	23.0	24.5
G (=$R_s Q_0$) [Ω]	406	426

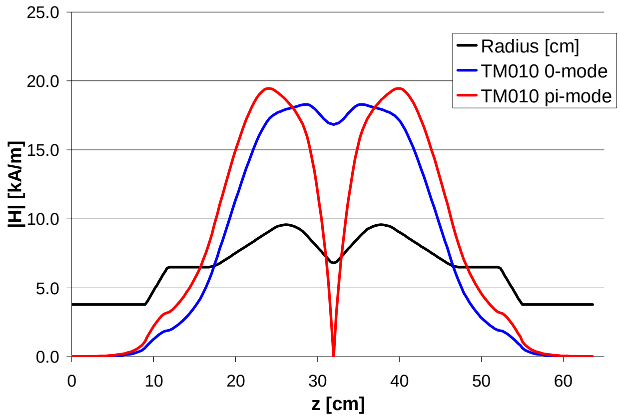

Figure 2: Surface magnetic fields in the TM_{010}-0 and π modes for 1J stored energy.

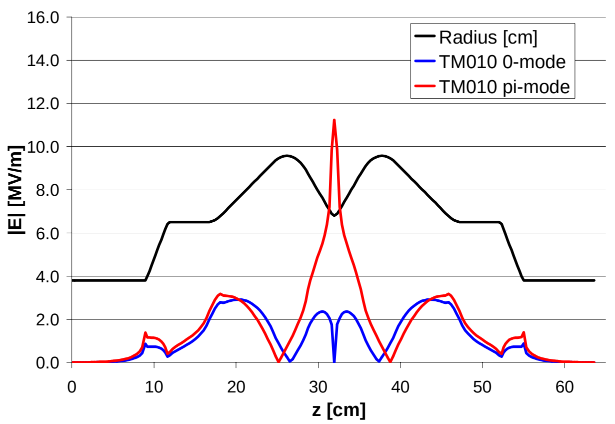

Figure 3: Surface electric fields in the TM_{010}-0 and π modes for 1J stored energy.

It can be seen that the combination of the TM_{010} modes offers the possibility of having high electric and magnetic fields mainly in the area where the electron beam welds are located.

Calculations with the FEM code MULTIPAC showed that the conditions for multipacting are not met for this cavity shape.

Both cavities were fabricated with RRR>250 niobium, using the standard procedure of deep-drawing half-cells followed by electron beam welding. The CEBAF single cell cavity has niobium flanges with indium seal, while the 2-cells cavity has Nb55Ti flanges with AlMg3 gaskets. The preparation for the vertical tests consists of buffered chemical polishing (BCP) with a mixture of HF, HNO_3, H_2PO_4 in a 1:1:1 ratio, removing a total amount of about 150μm from the internal surface. After drying, the cavities are assembled in a class 100 clean room and attached to the vertical stand where they are evacuated to about 10^{-8} mbar prior to cooldown.

Figure 4: 2-cells cavity (left) and CEBAF single cell (right) on the vertical test stand.

The measurement of the CEBAF single cell cavity in the vertical test (Fig. 5) showed a Q-drop in the TM_{010} mode starting at a peak magnetic field of about 110mT without field emission, but in the TE_{011} mode the cavity quenched at that field level. The surface resistance between 4.2K and 2K was measured and then fitted to the BCS theory to obtain values of residual resistance, mean free path and energy gap.

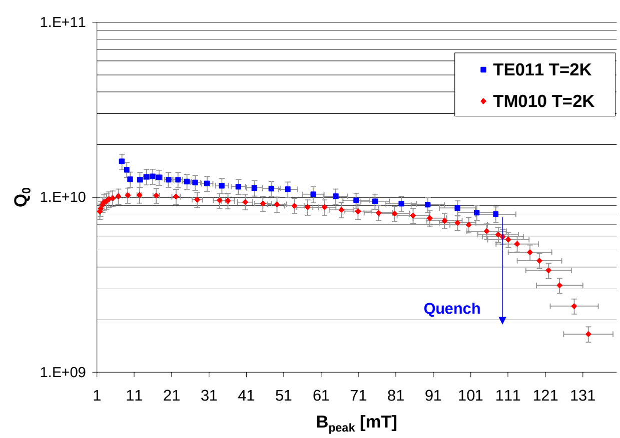

Figure 5: Q vs. B_{peak} in the TM_{010} and TE_{011} modes at 2K.

Subsequently the cavity was "in situ" baked for 20hr at 100C and tested again. The results are shown in figure 6. In the TM mode a strong Q-slope starting at a peak magnetic field of about 38mT was observed, while the test in the TE mode showed the same Q vs. field behavior as before baking, with a quench at 97mT. After baking, the residual resistance increased in both modes, together with a decrease in mean free path, whereas the BCS part of the surface resistance had changed to a lower value as typically observed.

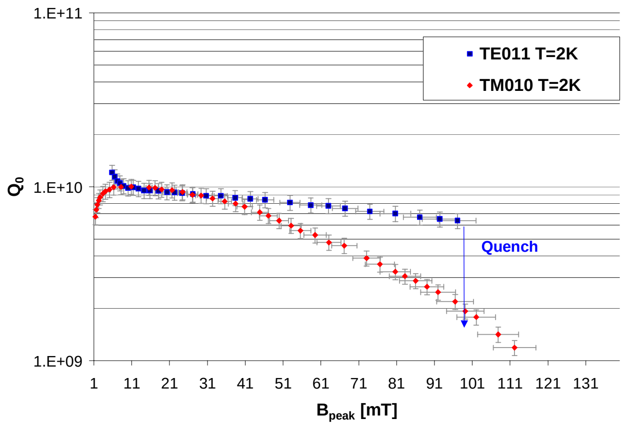

Figure 6: Q vs. B_{peak} at 2K after 100C, 20hr baking.

The results of the vertical test of the 2-cell cavity are shown in figure 7. Both -0 and -π mode show the same field dependence with Q-drop without field emission starting at a peak surface magnetic field of about 75mT. The maximum field of 100mT corresponds to a peak surface electric field of about 45MV/m in the -π mode, but it's only 13MV/m in the -0 mode. The residual resistance is extremely low in both modes. In a previous test, multipacting was seen at B_{peak} = 10mT in both modes and processed after about 30min of applying RF power to the cavity.

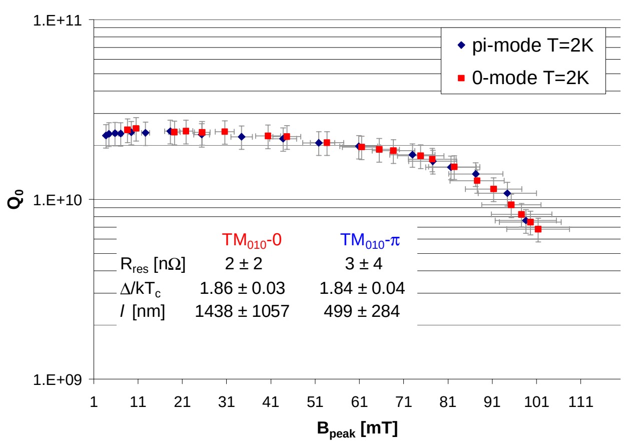

Figure 7: Q vs. B_{peak} in the TM_{010} modes at 2K.

The cavity was baked under vacuum at 80C for 24hr by a stream of heated nitrogen gas to avoid oxidation of the cavity outer surface. It was then tested again at 2K (figure 8) showing an increased residual resistance, reduced mean free path and a strong Q-slope beginning at very low fields. The field behavior of the two modes is again very similar. These results remain after warming up to room temperature and cooling down again to 2K. The same results were obtained in a previous test when the cavity was baked at 100C for 24hr.

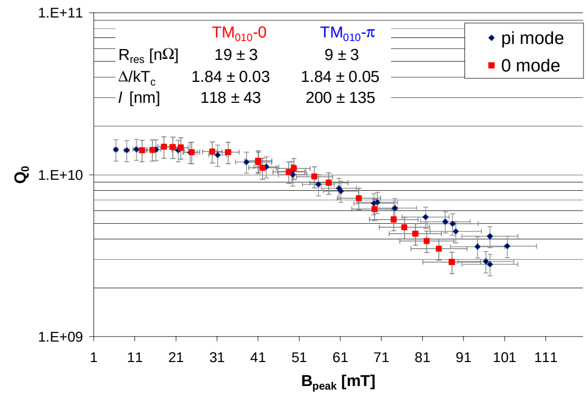

Figure 8: Q vs. B_{peak} at 2K after 80C, 20hr baking.

DISCUSSION

We believe that the quench in the TE_{011} mode is related to a surface defect and does not appear in the TM_{010} because of the different field location of the magnetic field. We plan to improve the quench behavior of the cavity by both "guided repair" and post purification of the niobium material. The Q vs. B_{peak} curves after baking were unexpected. In the single cell cavity the TE_{011} mode still presents a "normal" heating effect ($R_S(B_{peak}) \propto B_{peak}^2$) but the TM_{010} shows an exponential increase of surface resistance with B_{peak} above about 30mT. This was seen in both modes of the 2-cell cavity. The results on the TE/TM modes seem to be consistent with the model in ref. [2], however some ambiguity remains since the H-field limit in the TE_{011} mode happened close to the field level where the Q-drop happened in the TM_{010} mode. The results from the 2-cell cavity seem to indicate a magnetic field effect. The areas where the welds are located are high magnetic field regions and their large grain structure might play an important role. To better investigate this possibility, three seamless hydroformed NbCu 2-cell cavities have been made at DESY. Further tests on the single cell and 2-cell cavity will include high temperature heat treatment and electropolishing.

ACKNOWLEDGEMENT

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