SUPERCONDUCTING RF CAVITY DEVELOPMENT FOR ESS

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Abstract

We report first experimental results of a 5-cell elliptical cavity investigation (500 MHz, $\beta = v/c = 0.75$). This superconducting cavity has been designed and built by ACCEL Instruments in the frame of European Spallation Source project and preliminary tested in CERN. At present time the cavity with full-equipped cryostat is under operation for test in FZ Juelich. As the cavity has no stiffening the main task of investigation is measuring the cavity detuning caused by Lorentz forces and microphonics. A new 5-cell elliptic cavity (700 MHz, b=0.5) is under consideration and its design procedure and parameters are presented. The parameters are compared with alternative structure (spoke cavity) design data.

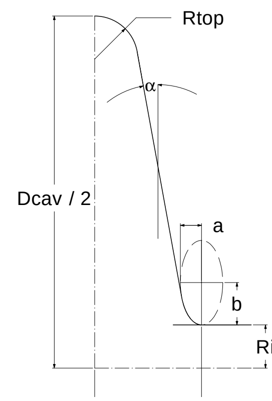

Figure 1: Elliptical Cavity Cell Geometry (1/4 part is shown)

1 MIDDLE CELL GEOMETRY OPTIMISATION

A well established sc "elliptical" cavity (Fig. 1) adapted for proton beams with $\beta = v/c$ range from 0.5 to 0.95 is accepted as a main accelerating structure for European Spallation Source (ESS) project[1]-[2]. At the same time from mechanical considerations such type cavity is accomplished with a need of serious mechanical structure stiffeners. That's why a spoke cavity is considered as an alternative structure for β's lower than 0.6[3]. Since about two years, at Forschungszentrum Juelich, we have been looking at the possibility to use SC cavities in ESS.

Making an elliptical cavity design[4] we restricted ourselves by the optimisation of two characteristics, which limit in principle the achievable value of accelerating field in cavity E_{acc} : the peak surface electric field (E_{pk}) and the peak surface magnetic field (H_{pk}).

From the point of the elliptical cavity cell design there are two types of cavities – "narrow" cavities for β less then about 0.7 and "wide" above it. The separation comes from the longitudinal cell dimension which equals $\beta\lambda/2$ and is strongly fixed. For the "wide" cells the decisive factor of optimisation is a dependence of ratio E_{pk}/E_{acc} on a cell slope angle α that has two sections – one more or less constant and one strongly increasing part (Fig. 2). It makes not much sense to increase α beyond this corner of the curve if one has to achieve minimum of E_{pk}/E_{acc}. And for these cavities $\alpha = 10^o$ is a quite good number in terms of cavity mechanical rigidity.

There is one more geometric limitation for a cavity cell that comes from the radius of the material curvature in the region of the cavity iris. The smallest radius estimated is to be 2-3 times bigger than a cavity wall thickness. Here we make a design for the Nb thickness of 4 mm. But this limitation is not an issue for "wide" cells as there are enough space for rather large ellipses.

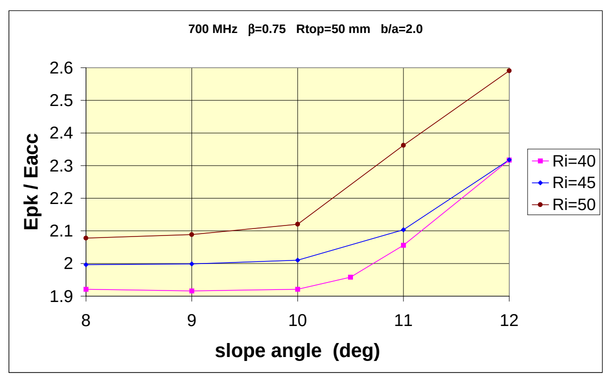

Figure 2: E_{pk}/E_{acc} vs. Cavity Slope Angle α ($\beta = 0.75$)

For the "narrow" cell ($\beta < 0.7$) the dependence E_{pk}/E_{acc} is similar but the change of the behaviour starts earlier in the range of $\alpha \simeq 5^o$ (Fig. 3). As the slope angle defines the cavity mechanical rigidity this 5^o are rather small and should be increased. This results definitely in the higher value of E_{pk}/E_{acc}. On the other hand the small ellipse axes and cell-to-cell coupling (say an iris radius R_i) limit the slope increase. An investigation of the plots presented on Fig. 4 helps to make a proper choice of cell geometry.

The next step is to find the minimum of E_{pk}/E_{acc} changing the ratio of big to small ellipse axis b/a (Fig. 5). For the "wide" cells the minimum stays at $b/a \simeq 2$.

Using the described procedure we made design for cavities with different $\beta's$. The results are summarised in Ta-

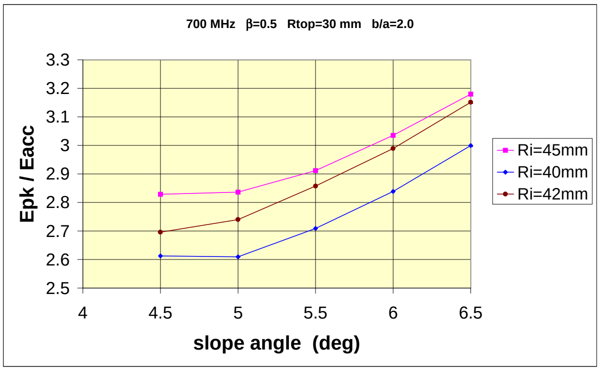

Figure 3: E_{pk}/E_{acc} vs. Cavity Slope Angle α ($\beta = 0.5$)

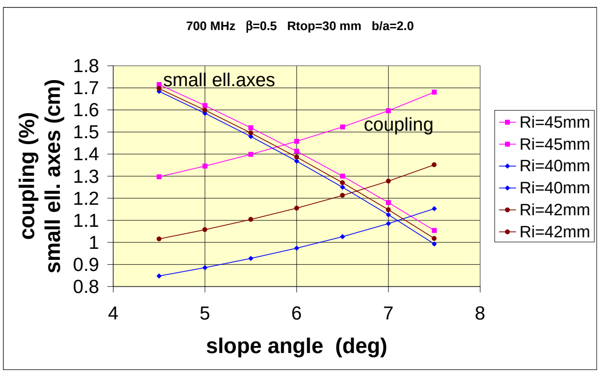

Figure 4: Cell-to-Cell Coupling vs. Cavity Slope Angle α ($\beta = 0.5$)

ble 1.

For comparison we simulated a spoke cavity for 350 MHz and β=0.5 with results of E_{pk}/E_{acc}=3.35 and H_{pk}/E_{acc}=83.5 Gs/MV/m. A detailed procedure of a spoke cavity geometry optimisation is published elsewhere[4].

2 MULTI-CELL CAVITY TUNE

A correction of the electric field distribution along a beam path is made in two steps:

- Keeping mid cell geometry constant for all cells we increase beam pipe radius (about 15%) to get an even E-field distribution.
- Open more beam pipe (up to 25%) on one side, as it is required for the coupler and change end cell geometry on this end (slope angle together with dome radius).

This procedure keeps the structure in best way homogeneous in terms of mechanical deformations. Although changes only of end cell geometry do not allow to get 100% even E-field distribution. Fig. 6 shows electric field values in the middle of cells relative to the electric field in the center of the cavity.

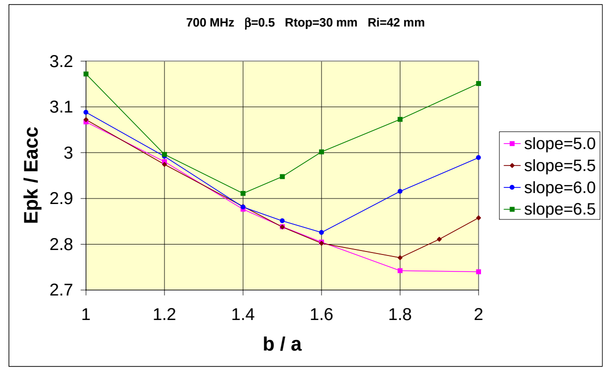

Figure 5: E_{pk}/E_{acc} vs. Ellipse Axes Ratio b/a

Table 1: Some Parameters to Compare Elliptical Cavities with Different $\beta = v/c$ (frequency=700 MHz)

β	0.5	0.6	0.75	0.9
cav. diam. D_{cav} (cm)	37.4	37.4	37.9	38.1
aperture R_i (cm)	4.2	4.5	5.0	5.5
dome R_{top} (cm)	3.0	4.0	5.0	6.5
slope α (deg)	6	7	10	12
cell-length (cm)	10.71	12.86	16.07	19.29
a (mm)	13.33	14.20	19.39	22.60
b (mm)	21.33	25.56	38.78	45.20
coupling %	1.117	1.20	1.152	1.216
E_{pk}/E_{acc}	2.83	2.54	2.12	1.92
H_{pk}/E_{acc} (Gs/MV/m)	58.85	51.74	47.49	42.93
$Q_0 * 10^{-10}$	.966	1.18	1.39	1.64
$R_s * Q_0$ (Ohm)	143.6	173.9	207.3	243.7
R_{sh}/Q_0 (Ohm/m)	572	693	808	914

3 ESS SC CAVITY TEST MODULE

A superconducting accelerating test module[5] has been delivered to FZ Juelich by ACCEL Instruments in February of this year. The module is equipped with 500 MHz 5-cell cavity. The parameters of the cavity are shown in Table 2.

At first, the cavity has been measured on the low power level. All five modes of a fundamental band have been allocated. In order to measure the high Q-value a new regulating circuit has been built (Fig. 7). The setup allows fast accurate measurements with an adjustable sensitivity. The results of measurements as a function of field level are shown on Fig. 8. No multipactor resonance discharge has been detected.

The mechanical stability evaluation of the cavity has been made semi-analytically and by means of numerical

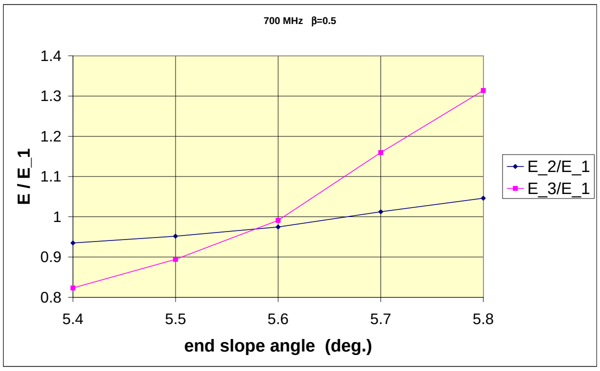

Figure 6: Electric Fields in Different Cells

Table 2: Some Parameters of FZJ SC Elliptical Cavity

β	0.75
cav. diam. D_{cav} (cm)	54.2
aperture R_i (cm)	8.5
dome R_{top} (cm)	6.5
slope α (deg)	10
$a(b = 2a)$ (mm)	35.4
coupling %	1.98
E_{pk}/E_{acc}	2.28
H_{pk}/E_{acc} (Gs/MV/m)	54.4
$R_s * Q_0$ (Ohm)	207
R_{sh}/Q_0 (Ohm/m)	450

simulations using Finite Element Method[6]. An experimental analysis of a mechanical cavity stability revealed the lowest resonance around 45 Hz and the second at 110 Hz (both supposed to be longitudinal) with 32.2 and 96 Hz analytical predictions.

Fig. 9 shows the data of the cavity Lorenz Force Detuning which results in $k = 3.7Hz/(MV/m)^2$.

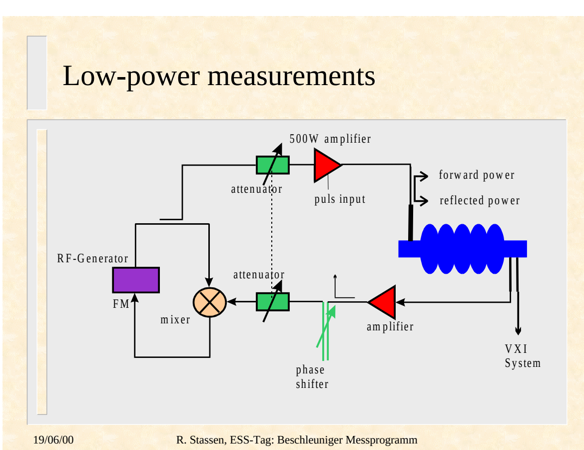

Figure 7: Setup for Low power Measurements

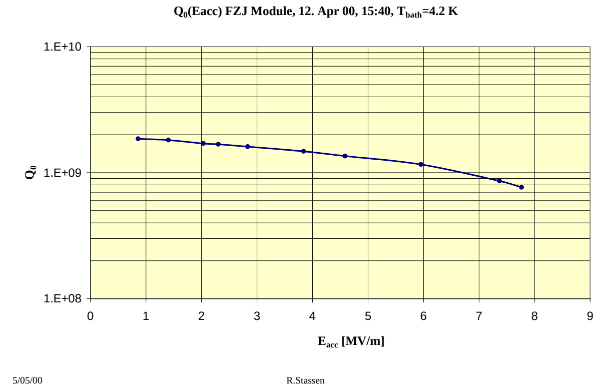

Figure 8: $Q_0(E_{acc})$ measured in FZJ Module

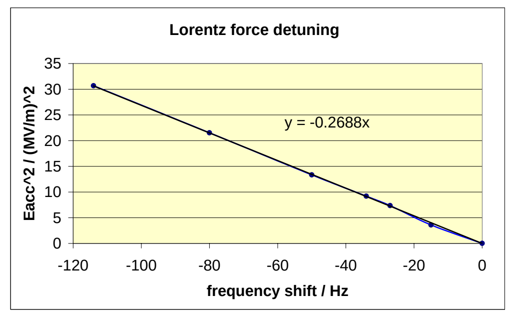

Figure 9: Lorenz Force FZJ Module Detuning

The further program of RF measurements is as follow:

- High power tests with a 25 kW power amplifier.
- Control of the coarse frequency adjustment system (stepper motor), building up a frequency control system with the piezo elements.
- Measurement of Q, E_{acc} with different coupling factors.
- Starting up of fast data acquisition system (1MHz, VXI-System) to measure and control amplitude and phase in pulse-mode operation.

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