EXPERIMENTAL CHARACTERIZATION OF A 700 MHZ β=0.47 5-CELL SUPERCONDUCTING CAVITY PROTOTYPE FOR PULSED PROTON LINAC

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Abstract

A 700 MHz 5-cell elliptical cavity has been developed to accelerate a high intensity proton beam in the lower energy part of a superconducting pulsed linac, starting at 80 MeV. This cavity is stiffened in order to minimize the Lorentz detuning which limits high field pulsed operation of the flatter, low beta cavities.

Cavity performance in vertical cryostat is reported. Measurements of the RF response to mechanical excitation are presented

INTRODUCTION

Future high intensity proton linacs will use elliptical superconducting (SC) cavities for high energy acceleration. For relative velocities β above 0.6, this technology is now applied on operating facilities like SNS. For the medium energy section of proton accelerators, it has to be proven that multicell elliptical SC cavities can provide efficient acceleration. The primary limitation for pulsed operation is the Lorentz force detuning which results from the flatter shape of cells. Mechanical stiffeners have to be designed in order to minimise the Lorentz detuning coefficient K_L while keeping the cavity adjustable in terms of field distribution and frequency. A 5-cell elliptical cavity optimised for pulsed operation at 2 K with a geometrical beta of 0.47 has been designed, concentrating on stiffening[1].

Table 1 : cavity design parameters

Frequency [MHz]	704.4
Epk/Eacc	3.36
Bpk/Eacc [mT/(MV/m)]	5.59
r/Q [Ω]	173
G [Ω]	161
Q_0 @ 2K Rs=8 nΩ	$2\ 10^{10}$
Optimal β	0.52
Geometrical β	0.47
Total length [mm]	832
Cavity stiffness [kN/mm]	2.25
Tuning sensitivity Δf/Δl [kHz/mm]	295
K_L @ k_{ext} = 30 kN/mm [Hz/(MV/m)²]	-3.9
Δf @ 12 MV/m, k_{ext} = 30kN/mm [Hz]	-560
K_L with fixed ends	-2.7
K_L with free ends	-20.3

The main characteristics of the cavity are summarized in table 1. The stiffening relies on expected 4 mm wall thickness and two sets of rings between cells. The cavity is symmetrical and the beam tubes are 130 mm in diameter so the end cells are sufficiently reinforced at the level of their irises. After fabrication, the wall thickness was measured using an ultrasonic probe. It varies from cell to cell, and the average thickness is 3.4 mm (excluding the weld region,).

CAVITY PREPARATION

After the first fabrication stage, the cavity was equipped with only one end cup of the He tank. The field flatness was adjusted to 92 % by plastic deformation of the structure. The cavity was then heat treated to prevent Q disease (650 °C, 24 h). It had to be adjusted to recover the field distribution. The chemical treatment consisted in buffered chemical polishing (BCP) using a 1:1:2.4 FNP mixture. First a 100 µm thickness has been removed before checking the field flatness. Then 20 extra µm were removed from the surface before the high pressure rinsing (HPR) and clean room assembly. The first cavity test was plagued by field emission. It was decided to proceed to the last steps of Helium tank welding. After this last fabrication step, the field flatness was checked again and it was reduced to 89 %. A new preparation was carried out, consisting of 20 µm BCP, a 2.5 h HPR in the clean room.

Figure 1: Cavity with helium tank and stiffening tube

CAVITY PERFORMANCE

The cavity was measured in a vertical cryostat after a fast cooldown. The $Q_0(E_{acc})$ characteristic curve at T = 1.8 K is shown on figure 2.

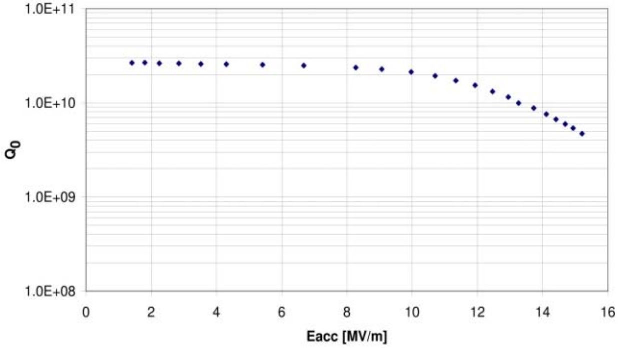

Figure 2 : $Q_0(E_{acc})$ curve before baking at 1.8 K

A multipactor (MP) barrier was encountered between 8 and 10 MV/m. It was processed in about 2 hours. The field emission onset field is 10 MV/m. The electron loading becomes significant (detuning observed) above 13 MV/m and could not be processed. The cavity operation was limited by a thermal quench. At the maximum Eacc=15 MV/m, the peak surface fields are Epk= 50 MV/m and Bpk=83 mT.

After this test, the cavity was vacuum baked using standard parameters [2] (115 °C for 70 h) inside the vertical cryostat and cooled down again without any venting or processing. The BCS surface resistance was reduced by 25%. The MP barrier reappeared, and the processing took 3 hours, longer than before baking, which might be explained by an increase in the SEE coefficient [3]. However, the cavity performance at 1.8 K was not changed by the baking process.

The cavity has been simulated with the MUPAC multipactor code [4]. The observed MP barrier corresponds to a 2 point resonant trajectory in the equator region starting at Eacc= 8.1 MV/m.

PRESSURE SENSITIVITY

In order to keep the cavity length as constant as possible, a stiffening tube linking the helium tank to the otherwise free cavity end was installed at the position of the tuning system (see fig.1). This spacer ensures a high external stiffness k_{ext} to allow the static K_L to be measured in optimal conditions. Its efficiency can first be assessed when pumping on the He bath to reach 1.5 K. The He pressure drops from atmospheric pressure to a few mbar. The cavity detuning is recorded during this phase (fig. 3). The pressure sensitivity df/dP is -14.5 Hz/mbar and is very sensitive to k_{ext}. In order to obtain an indirect estimation of k_{ext} coupled mechanical/RF FEM simulations have been carried on the cavity, tank, and stiffening tube system using CASTEM and a Slater perturbation method. The numerical model is axi-symmetric.

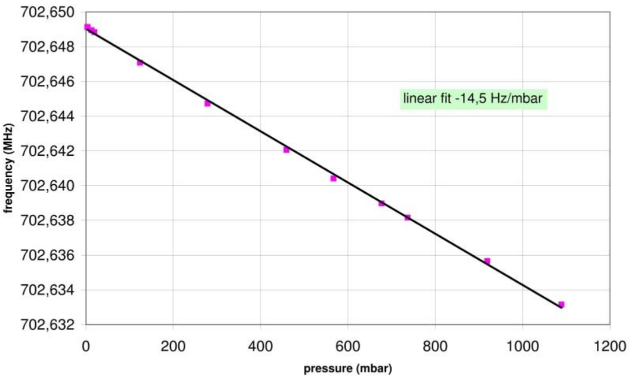

Figure 3: Helium pressure sensitivity measurement

For all calculations the thickness of the cavity is 3.3 mm (taking into account the average measured value and chemical etching). The calculation shows that the external stiffness has been improved by at least a 20-fold factor replacing the former rod stiffening system by the tube.

LORENTZ FORCE DETUNING

The measurement of the static K_L at 1.8 K is shown on figure 4. Due to slight temperature variations during the measurements, the He pressure was not constant, therefore the data have been corrected using the experimental df/dP coefficient. The data set is limited to E_{acc}<13 MV/m since above this value, the cavity is loaded with field emission electrons.

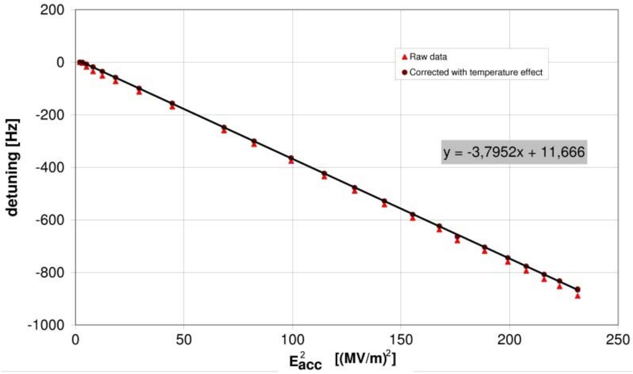

Figure 4 : Lorentz detuning measurement

The field measurement accuracy is estimated to 5% so K_L is evaluated at -3.8 ± 0.4 Hz/(MV/m)^2. It is very close to the design value of with k_{ext} = 30 kN of table 1. Comparing this more in details with simulations and taking into account the reduced thickness of the cavity walls, we can obtain another estimation of the actual external stiffness (fig. 5). The K_L curve for both design and 3.3 mm thickness are shown. The blue area corresponds to the k_{ext} range from 33 to 200 kN, values for which K_L is equal to -3.8 Hz/(MV/m)^2 for 4 and 3.3 mm thickness respectively. The design stiffness of the tank is 100 kN/mm. Thus the actual k_{ext} should be lower than 100 kN/mm. It leads us to think that K_L is in the lower range of -4 to -4.2 Hz/(MV/m)^2 compatible with the error bar of the measurements.

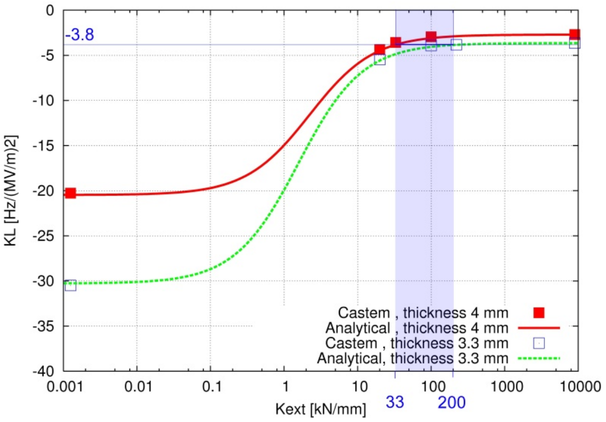

Figure 5 : K_L versus external stiffness calculations

MECHANICAL MODES MEASUREMENTS

In order to understand the cavity behaviour in pulsed mode, the mechanical modes have to be identified. A piezo actuator is installed between the tank and the stiffening tube, and acts on the cavity length in a similar way as a piezo tuner would. The transfer function between the piezo voltage and the RF frequency detuning has been measured at room temperature using a phase demodulation system (fig. 6).

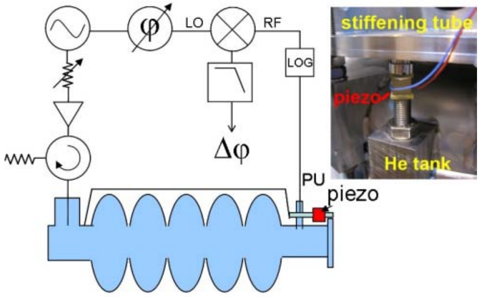

Figure 6 : piezo to detuning transfer function setup

The experimental data is fitted with a sum of 2nd order system transfer functions (fig. 7) to obtain the frequencies and quality factors (Q_m) of the mechanical modes summarized in table 2.

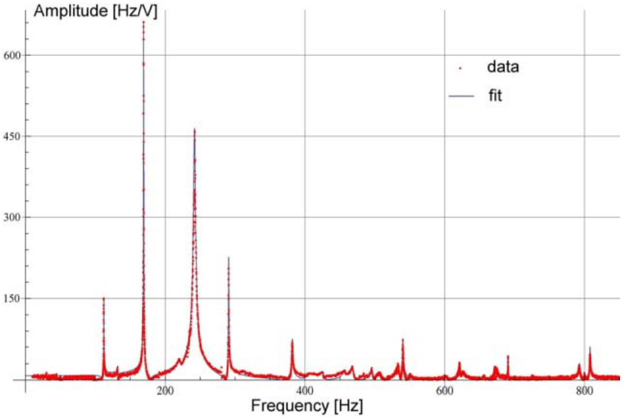

Figure 7 : piezo voltage to detuning transfer function

Table 2 : simulated and measured data of the main low frequency mechanical longitudinal modes

Frequency (simulation) [Hz]	Frequency (meas.) [Hz]	Q_m (meas.)
95	112	400
184	169	500
240	242	90
300	291	500
388	382	300
477	468	195
549	540	500
605	601	100
628	621	350
665	672	300
690	691	1000

The CASTEM eigenmode computations correspond to a 3.3 mm cavity thickness and k_{ext}=50 kN/mm. The mass distribution of the cavity, tank and stiffening tube have been taken into account carefully. Here, only longitudinal modes are computed. It has been checked experimentally that their frequency is not sensitive to a slight elongation of the cavity. The thickness distribution of the real cavity is not uniform, and the external stiffness of the real system is only an estimation. The combination of these factors can explain the discrepancy on frequencies between computations and measurements which are observed on several modes. Modes with very high quality factors appear in the list. Most of these high Q_ms are likely to be damped when the cavity is equipped with its piezo tuning system due to friction between in ball bearings.

AKNOWLEDGMENTS

We acknowledge the support of the European Community-Research Infrastructure Activity under the FP6 “Structuring the European Research Area” programme (CARE, contract number RII3-CT-2003-506395). Work carried out using the SUPRATech GIS infrastructures with the financial support from Region d’Ile de France.

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