TEST RESULTS OF THE 3.9 GHz CAVITY AT FERMILAB*

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Abstract

Two types of 3.9GHz superconducting RF cavities are under development at FNAL for using in the upgraded A0 photo-injector facility. A TM_{010} mode cavity (3rd harmonic of 1.3GHz, frequency of accelerating capture cavity) will be used to linearize energy distribution in the bunch before compression for better emittance. A TM_{110} mode cavity (deflecting or "CKM" cavity) will provide streak capability for bunch slice diagnostics. In paper we present current status of both cavities and results of testing niobium and copper prototypes.

INTRODUCTION

Both cavities have strong motivation for development [1,2]. The design of cavities, infrastructure development and material study can be found in [3,4], R&D work on both cavities were presented at PAC'03 and SRF'03 conferences [2,5]. Here we discuss status and latest results of high gradient test and studies of the high order modes.

STATUS

Before building final design of each type of the cavity a few prototypes were produced and tested to finalize cavity design. Below we discuss current status of design work and production activity at Fermilab.

3rd Harmonic Cavity

Cavity is made of 9 cells with elliptical shape in iris and equator areas. End-cells have bigger iris (r=20mm) from the tube side, than the regular cells (r=15mm). It allows increased coupling with main coupler and facilitates HOM damping [3]. Two HOM couplers mounted in both ends of the cavity provide good damping. To study HOM performances of the cavity and RF properties for accelerating mode we have built two full-scale copper models, each equipped with main and HOM couplers. We also built short 3-cell niobium cavity for the low temperature high gradient tests. Briefly the current status of 3rd harmonic cavity is the following:

- Cavity design is finished, including helium vessel, magnetic shielding and frequency blade-tuner.
- 9-cell cavity in production, all components are ready and partly welded.
- Helium vessels and blade tuners for two cavities are placed an order, stepper motors with controllers are in hand.
- Main coupler and cryomodule for installation on photo-injector A0 are under design.

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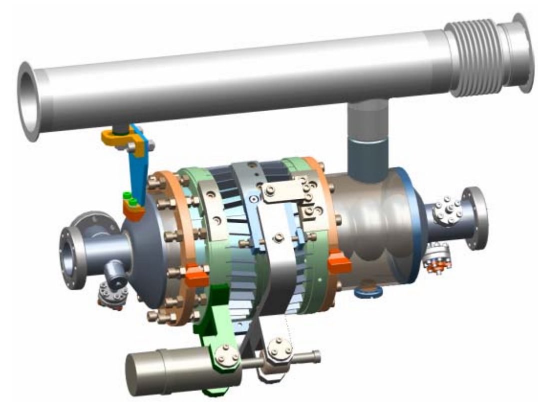

Figure 1: 3rd cavity, equipped with helium vessel and frequency tuner (design).

CKM Cavity

Eight TM_{110} mode cavities have been made, mostly shorter (3, 5 and 9 cells) structures, but there is one full 13-cell prototype. One more short structure is in production, and one more 13-cell is planned. First prototypes were made of 1.6mm niobium sheet, but cavity shape wasn't rigid enough. Last prototypes were built out of 2.2 mm niobium to improve mechanical properties. Helium vessel and frequency tuner are built, assembled and are under testing (see Fig.2). CKM cryomodule for two cavities are ready and will be tested soon. Small cryomodule (for single cavity) for A0 installation will be the same design as for 3rd harmonic cavity.

Figure 2: 13-cell CKM cavity, assembled with the helium vessel.

TEST RESULTS

Short niobium prototypes of both cavities were tested at helium temperature down to 1.6°K in a vertical dewar to investigate cavity performances and field limitations (fig.3). The results of cold tests are presented below.

Three Cell 3rd Harmonic Cavity

3rd harmonic cavity was tested several times. First test was done after production before any BCP etching. Second set of testing (2 thru 5) was done after cavity treatment at JLAB, which included ~20/140µm outside/inside BCP etching, high temperature treatment (10 hrs @ 600C) and 15min HPR at 1200psi. Visual inspection done after tests shown three "rust" spots on the iris in one of the end cells, which can explain high level of X-rays. Third set of the cold tests was done after additional 20µm BCP and 30min HPR.

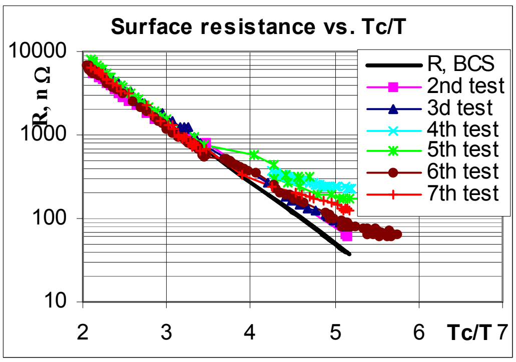

Figure 3: Surface resistance vs. T_c/T measured for few cold tests. T_c - critical temperature of niobium.

Fig.3 shows results of surface resistance measurements for all tests. In second test we have reached R_s~60 nΩ, not faraway from the theoretical limit. After working at high gradient with strong X-ray level, resistance dropped down on the following tests. After second BCP treatment surface resistance was restored again (test #6).

High gradient performances of 3-cell cavity measured at π-mode are shown in Fig.4. Achieved gradient ~12.5 MV/m was limited mostly by X-ray, not quench. The same set of measurements was done for 0 and π/2-modes in this cavity. For 0-mode fields in the mid-cell almost twice high than in end-cells, for π/2 mode mid-cell is empty, all fields are concentrated in end-cells.

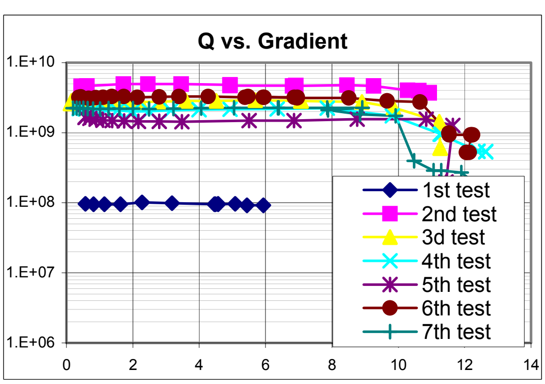

Figure 4: Q-value vs. Accelerating gradient in 3rd harmonic 3-cell cavity.

So, different cavity behaviour at these modes gives information, which cell causes problem. Measured surface magnetic fields before quench are 110;85;77mT for 0; π/2; π modes, which corresponds accelerating fields in 9-cell cavity E_{ACC} ~ 22;17;16MV/m (Design parameters: E=14 MV/m; B=68mT)

CKM TM$_{110}$ Cavity

Few prototypes have been tested at helium temperature, most of them are short 3-cell cavities. In earlier tests done for cavities made of 1.6mm niobium we have reached $P_\perp$ ~ 5.4 MV/m, R_s=160nΩ in TM_{110} mode (R_s ~65nΩ in TM_{010}, 2.8GHz), but gradient has decreased to ~ 3.5MV/m with repeated tests. Last test, done for 3-cell cavity made of 2.2 mm niobium demonstrated good performances (Fig.5 and 6). Beam pipe in this cavity is 20mm longer, than in previous prototypes. Cavity treatment was done at JLAB.

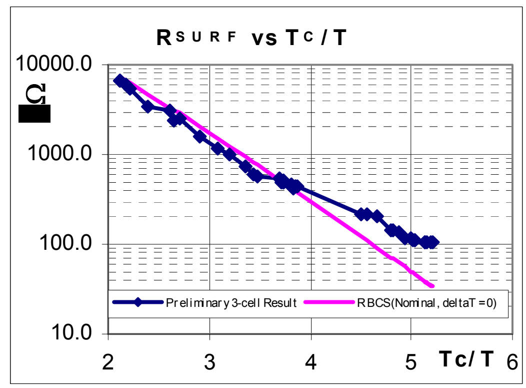

Figure 5: Surface resistance vs. T_c/T for CKM cavity.

In this test we measured surface resistance 100 nΩ @ 1.8°K. Fig.6 shows that we went up to 7.5MV/m kick, which is well above the 5MV/m goal. The second run shows that the performance remained after we ran up to the quench point in all the other cell coupled modes modes.

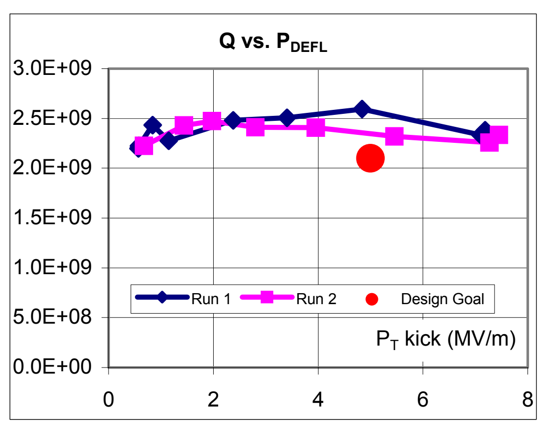

Figure 6: Q-value vs. kick gradient in CKM cavity.

We saw signs of multipacting in the other modes at high field levels. In all cases though it cleared up quickly. No X-rays. We never have seen them for deflecting modes. We do not see any sort of droop-off at high fields that one expects for a thermally loaded situation. Table 1 shows CKM design parameters compared to TESLA cavity parameters.

Table 1:

Cavity type	mode	Freq, GHz	Ea/ $P_\perp$ MV/m	Bmax mT	Emax MV/m
TESLA	TM010	1.3	25	105	50
CKM	TM110	3.9	5	80	18.5

HOM STUDIES

HOM studying and damping is a big issue for both accelerating and deflecting cavities. Each cavity has two HOM couplers with appropriate orientation to soak out both polarizations of the parasitic modes. Nevertheless calculations show that loaded Q-value for some of the modes is sensitive to the boundary conditions at the end of the tube[6]. In reality it means that the big reflection from the neighbour cavity can cause problems. To study HOM damping in 3rd harmonic cavity two copper models were built and tested (Fig.7). Rotatable flanges on HOM couplers and cavity to tube connection allow adjustment of coupler orientation to get maximum dissipations.

Figure 7: HOM studies of assembly of the two copper cavities on the bead-pull set-up in clean room.

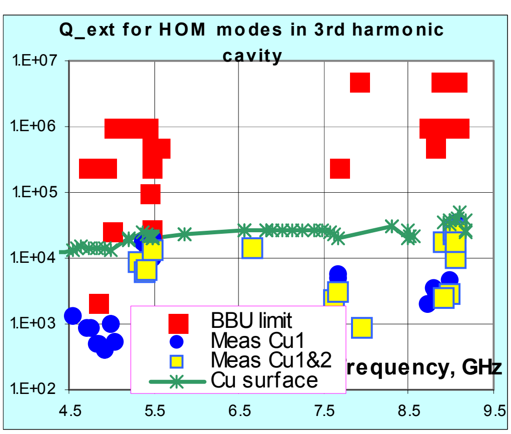

Figure 8: Q vs. frequency for HOM in TM_{010} cavity. Red-BBU limit, blue&yellow – measurements, green-Copper.

Fig.8 shows Q-value, measured in the single copper cavity and in chain of two assembled cavities. Red markers represent Beam Break Up (BBU) limits in photoinjector, calculated by P.Piot for more dangerous dipole modes with R/Q>1. Measured Q-values (blue and yellow) are well below limits for most of the modes up-to 10GHz. Green line shows Q for copper surface. As one can see from the plot, few modes from 2nd (f~5.5GHz) and 5th (f~9GHz) passbands have Q-value close to natural Q of the cavity. Calculation shows, that some modes from 5th passband might be trapped in cavity, but fortunately, they have low R/Q. Besides small perturbations in cell dimensions can easily disturb the field distribution for those modes. More precise measurements are needed to define the coupling of this mode to the HOM couplers.

Figure 9: HOM couplers.

HOM couplers developed for TM010 cavity are planned to use in deflecting cavity. The CKM cavity also needs a low mode coupler (LMC) to dump lowest accelerating mode at ~2.8GHz. Prototype of LMC is placed an on order. According to design, LMC will provide loaded Q~10^5 for the first monopole band and ~ 10^6 for 2nd and 3rd bands.

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