DEVELOPMENT OF THE SUPERCONDUCTING 3.9 GHZ ACCELERATING CAVITY AT FERMILAB*

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Abstract

A superconducting third harmonic 3.9 GHz accelerating cavity was proposed to improve the beam quality in the TTF-like photoinjector[1]. Fermilab has developed, built and tested several prototypes, including two copper 9-cell cavities, one niobium 3-cell cavity, and one 9-cell cavity. The helium vessel and frequency tuner for the 9-cell cavity was built and tested as well. In cold tests, we achieved a peak surface magnetic field of ~100mT, well above the 70mT specification. The accelerating gradient was likely limited by thermal breakdown. Studies of the higher order modes in the cavity revealed that the existing cavity design with two HOM couplers will provide sufficient damping of these modes. In this paper we discuss the cavity design, results of the studies and plans for further development.

INTRODUCTION

Fermilab is developing a third harmonic accelerating (3.9GHz) SC cavity and cryostat for a new generation of high brightness photo-injector [2-5]. This system will compensate the nonlinear distortion of the longitudinal phase space due to the RF curvature of the 1.3 GHz TESLA cavities prior to bunch compression. The first cryomodule, with four 3.9GHz cavities, will be installed in DESY's TTF-2 photoinjector behind the first eight cavity, 1.3 GHz cryomodule. A second, 3.9 GHz cryomodule will be installed in the SMTF photoinjector at Fermilab [6]. Four 3.9GHz cavities will provide the energy modulation, ~20 MV, needed for compensation.

CRYOSTAT AND CAVITY DESIGN

DESY Cryomodule

The cryomodule with four 3.9 GHz cavities will be connected to DESY's CRYO_1 vessel as an extension. Based on the DESY, CRYO_1 and CRYO_3 cryomodule designs, the Fermilab vessel will be a hybrid design (Fig.1). Its major components will be incorporated into the SMTF photoinjector as well. This new design will utilize the piping and vessel layout of the CRYO_1 vessel. It will also utilize the helium vessel, roller bearing supports and the cavity stabilizing invar rod features from the CRYO_3 vessel and will have two coldmass supports, one fixed and one sliding, with Taylor-Hobson fiducials. These supports are exact copies of the INFN design. The total length of the vessel, ~2m, is limited by the available space at the TTF-2 photoinjector. The space limitation affects the helium vessel and frequency tuner designs and impacts the positioning of the couplers in the cryomodule. The input couplers will be alternately mounted from both sides of the vessel. Two coupler ports are shown in fig.1. The other two, on the other side of vessel, are not visible.

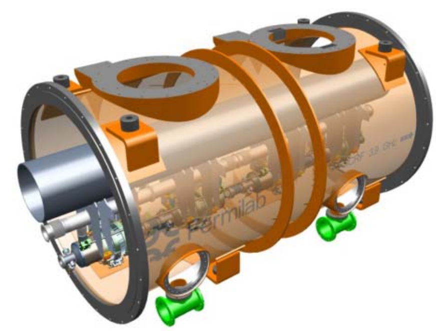

Figure 1: Cryomodule design for 4 cavities.

Cavity

The design and the basic parameters of the 9-cell cavity are described elsewhere [2,3,7] (see Fig.2). The design cavity parameters are presented in Table 1.

Table 1: Parameters of the 3.9GHz accelerating cavity.

Active Length	m	0.346
Gradient	MV/m	14
Phase	degree	-179
R/Q	Ohm	375
Qext for accelerating mode		9.5e+5
BBU limit for HOM, Q		<1.e+5
Beam current	mA	9
RF power/per cavity	kW	12.5

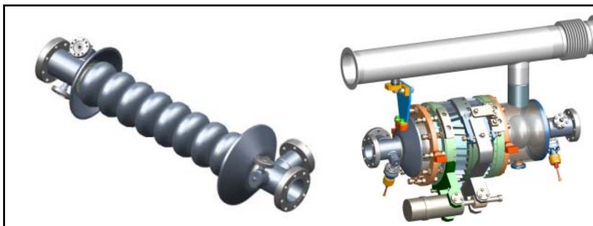

Figure 2: Naked and dressed 3rd harmonic cavity.

Two copper 9-cell cavity models were built, tuned and tested as proof of concept. The welding of our first niobium full size cavity was finished in December 2004. Unfortunately, the last weld failed and produced a hole on the equator (Fig.3). The cavity will be repaired and etched at JLAB and then tested at Fermilab this summer, 2005. The second cavity is being welded at Sciaky. The end-groups are ~90% complete and the rest of the welds will

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be finalized in May 2005 after the commissioning of Sciaky's new welding machine. The other 4 cavities are scheduled to be fabricated by the end of the 2005 calendar year by a collaboration between FNAL and JLAB. The individual parts will be produced by Fermilab and sent to JLAB for etching and e-beam welding.

Figure 3: First 9-cell SRF cavity.

Helium vessel

The titanium helium vessel design is shown in fig.4. Two flanges are used for mounting the bladetuner and for connection into the coldmass. The components for our first helium vessel have been fabricated, inspected, and are being welded. After the cavity has been welded into the vessel, the bladetuner will be installed and mechanically tested. The design will be reviewed prior to the fabrication of four additional vessels.

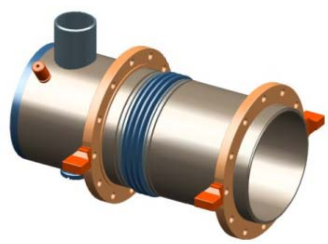

Figure 4: Helium vessel for 3rd harmonic cavity

Bladetuner

A cavity wall thickness of 2.8mm provides good mechanical stability and makes it unnecessary to use stiffening rings or a piezo tuner. A calculated Lorenz force detuning of 90 Hz at the operating accelerating gradient of 14 MV/m is only 2.3% of the 3900 Hz cavity bandwidth. The bladetuner was proposed for the adjustment of the resonant frequency of the cavity after cooling down to an operating temperature of 1.8K. (Fig.5). This bladetuner design was chosen because of the limitation of space between the cavities. The TESLA-style tuner could not be used.

Computer simulations of the mechanical properties of the entire system, including the cavity, helium vessel and bladetuner were performed. The cavity can lengthen by 92% of the total bladetuner expansion. The calculated stiffness of the 9-cell cavity is 5200 N/mm. Longitudinal deformations of the cavity by 0.1mm results in a 9 MPa Von Mises stress in the iris of the cavity, which is far from the 30 MPa yield point for annealed niobium. The cavity will remain in the elastic region even at a maximum 0.2mm cavity deformation imposed by the cryomodule design.

Figure 5: Bladetuner assembly.

A measurement of the sensitivity of the cavity resonance frequency to longitudinal elastic deformation was done on the copper 9-cell model. The measured coefficient was 2.2 MHz/mm. The elongation of the bladetuner was measured without load (fig 6).

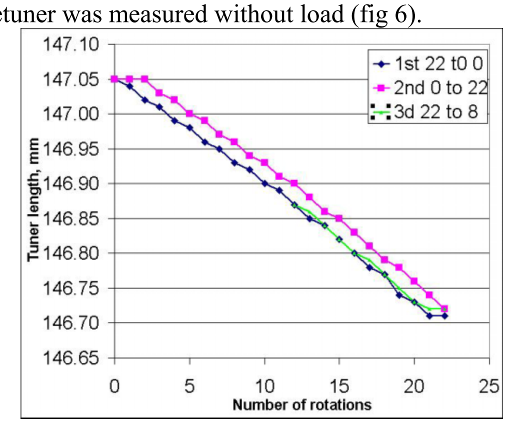

Figure 6: Blade tuner elongation measurement

A deformation of the cavity to ±0.1mm imposes a 200 kHz frequency pre-tuning accuracy. This value is easily achievable. We are planning to take measurements of the elongation of the loaded bladetuner as well.

Magnetic Shields

This is a unique design in that it puts the shield *under* the bladetuner for 100% shield coverage in this region. It is designed to allow for tuner movement with overlapping seams and a small diameter profile allowing better access to the bladetuner.

Input coupler

After a series of calculations of different coupler designs, the chosen concept of a non-adjustable coupler is shown (Fig.8). This is a 50Ω coaxial line with a 30mm OD to prevent excitation of the asymmetrical modes. For the cold window, we adopted the cylindrical ceramic window of the TESLA coupler. For the warm window, we are buying a waveguide window, designed by CPI for the 3.9GHz, 80kW klystron. A lower power level and a high frequency reduce the risk of multipacting problems in the coupler. Our simulations did not show any MP activity in the coaxial part of the coupler. All components of the coupler, cold window section, bellows, coax-to-waveguide transition, vacuum and diagnostic ports, were optimized by HFSS for low reflection (S11<0.02) at the operating frequency. FE analysis shows that the design will accommodate forces due to shrinkage and shifting of cavity centroid during cool-down to helium temperature. Static and dynamic heating loads for copper plated and non-copper plated SS tubes and bellows have been analyzed for the nominal RF power. Testing is planned to better understand the necessity for this copper plating.

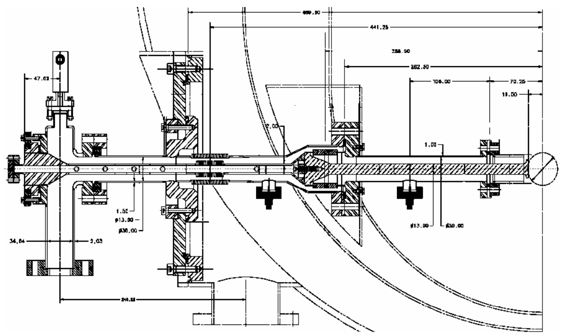

Figure 7: Main coupler design

HIGH GRADIENT TESTS

In the first tests of the 3-cell cavity, we achieved a surface resistance of Rs=60nΩ and an accelerating gradient of 12MV/m even without high pressure rinsing [8]. After an additional 5μm etch and ~2hrs HPR in ultra-pure water, the cavity performance improved. The new results: Rs~6nΩ, Eacc=19MV/m, Hpeak=103mT are shown in Fig.8 and Fig.9. The same value of peak magnetic field was measured for the other two modes in the 3-cell cavity. The 9-cell cavity will have a gradient of 21MV/m for the same surface magnetic field.

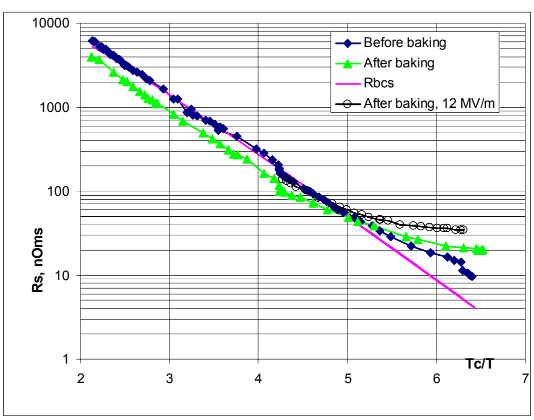

Figure 8: Resistance vs. Temperature

Thermal breakdown calculations done for this cavity show that the maximum achievable magnetic field in this cavity is limited to ~110mT at 1.8K [9]. Our model explained the Q-slope at high fields and predicted an increase in the magnetic field at a lower temperature, which was not supported by our experimental data. (Fig.9). A similar finding was measured by other groups[8]. One possible explanation is that, at low temperatures, residual resistance dominates compared with BCS resistance. Physics of the residual resistance is not well understood yet, but certainly it is field dependant as one can see from experiments (Fig.8).

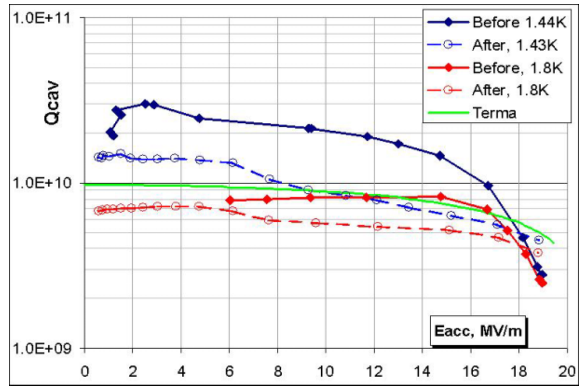

Figure 9: Q vs. accelerating gradient at different temperatures

An additional 120°C@48hrs bake reduces Q-slope, but increases residual surface resistance. The quench field, after baking, remains the same as before.

CONCLUSION

Fermilab has made significant progress in developing superconducting 3.9 GHz accelerating cavities. In the 3-cell cavity, the gradient of 19MV/m and a low surface resistance was demonstrated. Our first niobium model has been built. The next 5 cavities are scheduled for fabrication in 2005. Other cavity components such as the helium vessel and bladetuner are completed. The coupler and cryostat are still under development.

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