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THE PROGRESS IN DEVELOPING SUPERCONDUCTING THIRD HARMONIC CAVITY

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Abstract

The XFEL and TTF facilities are planning to use section with a few third harmonic cavities (3.9GHz) upstream of the bunch compressor to improve beam performance [1-2]. Fermilab is developing superconducting third harmonic section for the TTFII upgrade. This section will include four cavities equiped with couplers and blade tuners installed in cryostat. Up to now, two cavities are complete and one of them is under test. The status of the cavity development and preliminary test results are presented in this paper.

INTRODUCTION

The 3rd harmonic 3.9 GHz cavity was proposed to linearize energy distribution along the bunch before the bunch compressor [2]. These cavities operate in the TM010 mode and will be located downstream of the 1.3 GHz TESLA cavities. The required operating gradient is 14 MV/m [3-4]. Fermilab has agreed to provide DESY with a cryomodule containing a string of four of these cavities. In addition, a second cryomodule with one cavity will be fabricated for installation in the Fermilab photo-injector, which will be upgraded for the ILC accelerator test facility. In the scope of this project Fermilab is developing cavities, couplers, blade tuners and cryostat [4-8]. The construction and successful test results of copper and niobium cavity prototypes, helium vessels and blade tuners allowed us to start cavity production after several minor modifications in design. The status of the production and the first results of the cold test are discussed below.

STATUS OF CAVITY DEVELOPMENT

Cavities

The overall objective is to build eight 3rd harmonic cavities. The first cavity, a prototype design, was completed in December 2005. Lessons learned suggested several minor design changes that were incorporated into the remaining seven cavities. Fabrication of the cavities is a collaborative effort. Fermilab will build four cavities (including the prototype), and JLAB will build the remaining four cavities (using parts supplied by Fermilab).

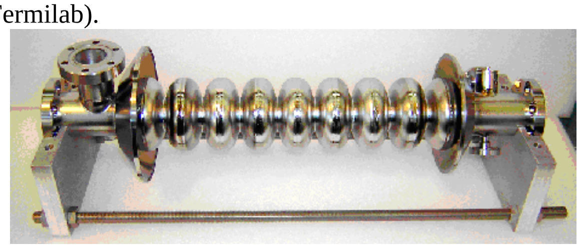

Figure 1: Cavity No.2 before etching

Cavity No. 2 was completed at Fermilab in January 2006. It is currently under test. Parts for the remaining six cavities are complete, and fabrication is in progress. Cavities No. 3-6 are approximately 80% welded at JLAB, while cavities No. 7-8 are approximately 40% welded at Fermilab. It is expected that cavities No. 3-6 will be completed by late June or early July. Cavities No. 7-8 are scheduled for completion by late August.

Main Coupler

Delivery of the first pair of 3.9GHz power input couplers is expected June 23, 2006 (fig.2). Upon receiving, the couplers will be mechanically measured, leak checked, tested, and processed. The station for coupler processing and test is assembled and ready. To reduce design complexity, the 3.9GHz couplers do not include a tuning mechanism for adjustment of antenna coupling to the cavity. As procured, the antenna length on the coupler's cold end assembly is 2mm longer than required by simulations to accommodate possible simulation errors and fabrication tolerances. As part of testing, antenna coupling to the cavity will be measured. Antennas will then be trimmed to final length using wire EDM. This coupling test will take place at ambient temperature and pressure and will use much of the same hardware as designed for the coupler processing station.

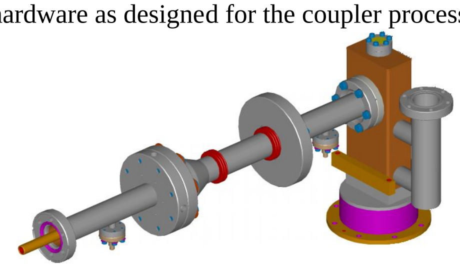

Figure 2: Coupler for 3.9GHz cavity.

Cryomodule

The design of the cryomodule has been completed (Figure 3). Components for the cryovessel, helium vessels, bladetuners, heat and magnetic shields, and cold mass supports have been ordered with delivery beginning in the summer of 2006. We are currently following up on the bid process for many of these main components and implementing some small design modifications as needed. DESY engineers will be designing and procuring the RF and vacuum systems.

Assembly tooling for the cavity string and the cold mass is well underway. Many of the fixtures are common to the 1.3 GHz cryomodule which are currently being assembled and installed at Fermilab. Others, like cavity support posts, will be slightly modified for the 3.9 GHz cavities.

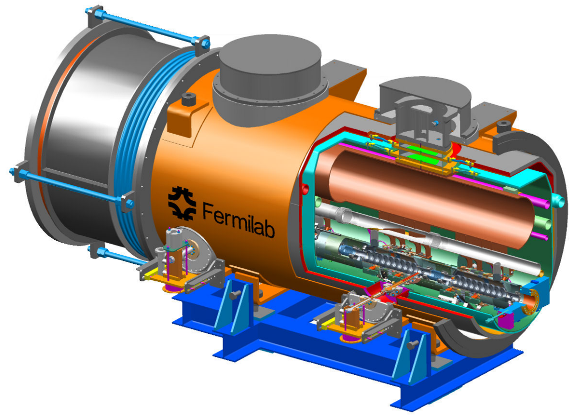

Figure 3: Layout of the cryostat.

The cavity string will be assembled at Fermilab but the cryomodule will be pre-assembled to check the fit of all components, disassembled, and then shipped to DESY for final assembly. Ultimately, the cryomodule will be installed in DESY's TTF in 2007.

COLD TEST RESULTS

Test of the 3-cell cavity.

The first niobium 3-cell prototype was built to test cavity performances and develop tooling and technology. There are no HOM or main couplers on this cavity. The first results of the cold tests were reported in [5-6]. A brief test history is shown in Table 1.

Table.1: History of cold tests of the 3-cell cavity

BCP; HT; HPWR	Test results
No treatment	R=2000nΩ, Ea=5.6 MV/m
BCP-140μm; 10hrs@600C; HPR:30'	R=60nΩ, Ea=11.5 MV/m; X-ray
BCP-30μm; HPR: 3x30	R=70nΩ; E=12.5 MV/m; X-ray
HPWR:1hrs, movable	R=60nΩ;E=12.8MV/m;NoX-ray
BCP:20μm;HPR:7x90'	E=15MV/m - coupler problem
BCP:5μm; HPR~2hrs	R=6 nΩ; Ea=19MV/m; NoX-ray
Bake: 48hrs@120C	R=16 nΩ, E=19MV/m; NoX-ray
BCP:10μm;HPR:2.5hrs	R=58 nΩ; Ea=12MV/m, X-ray
HPR:6.5 hrs, movable	R=15nΩ;Ea~19MV/m; NoX-ray

Initially the cavity was etched ~140 μm inside (measured by etching rate, not frequency) and 20 μm outside and then treated 10hrs at 600ºC. The first test showed a field emission problem, which was fixed after appropriate high pressure rinsing. The best achieved residual surface resistance was 6 nΩ (measured at 1.4°K). Typical resistance at 1.8 °K of ~50 nΩ corresponds Q_0~6.e+9. The cavity was quenched at accelerating gradient of ~19 MV/m (surface peak magnetic field of ~105mT) and this threshold can be explained by thermal breakdown model [9]. The 9-cell cavity will have a gradient of ~21MV/m for the same surface magnetic field achieved in the 3-cell cavity. This is well above design gradient of 14MV/m. We are planning to use this cavity as a reference cavity to check performances of the buffered chemical polishing (BCP) and high pressure water rinsing (HPWR) facilities.

Test results of the 9-cell cavity

The first 9-cell Nb cavity (prototype) failed during the deep BCP. After ~130μm etch a hole developed in one of the HOMs couplers, which has thinner wall thickness than in the final design. Cavity No. 2 was successfully manufactured, tuned and tested after BCP, high temperature treatment (10hrs at 600°K) and HPWR.

Initial measurements showed a very high residual resistance Rres=3000 nΩ. After operating with high fields in "π" and "0" modes, the residual resistance dropped off ~5 times to ~ 600 nΩ. After processing at high field level during the rest of the day, the next day showed a residual resistance of ~80 nΩ. Processing was done at pulsed power 120 W and different duty factor from 1% to CW. Additional high field processing for 2 more days improved residual resistance to 40 nΩ. The history of RvsT measurements is shown in figure 4.

In the cavity tests we observed strong multipactoring which causes Q-slope at small field level. After high fields "processing" Q improved for small fields and the multipacting level shifted from ~0.5 MV/m accelerating gradient to ~ 2.5 MV/m. In pulsed regime accelerating gradient was ~8-11 MV/m, limited by available RF power due to low Q. Some DC current was observed from pick-up antenna at the gradient higher than 10 MV/m (fig. 5).

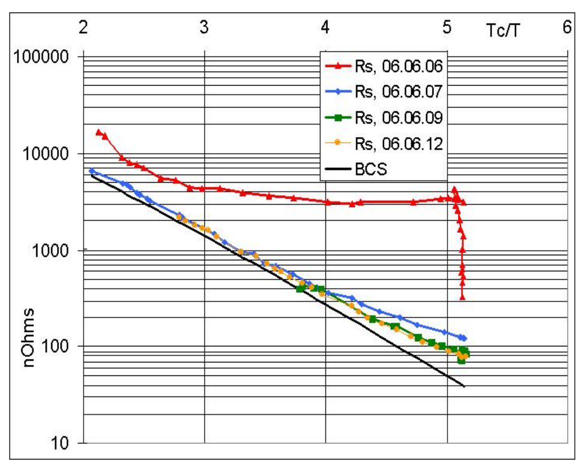

Figure 4: Resistance vs. Tc/T. Measurements were done in a few cold tests.

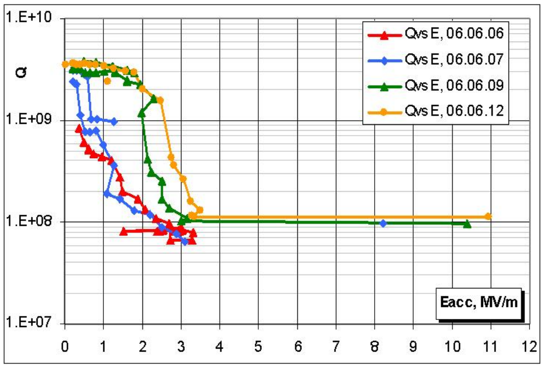

Figure 5: History of the QvsE measurements

"0"-mode measurements shows fairly high Q up to the quench level (Figure 6). Fields in the end cells of the cavity are much lower in this mode. The result clearly indicates that the problem is located in the cavity ends, not in the cells. Also some x-rays were observed in higher field operation. A temperature sensor installed in one of the HOM couplers showed heating during the pulse. In CW operation with a power level of ~100W the temperature at the sensor increased ~20K in one minute.

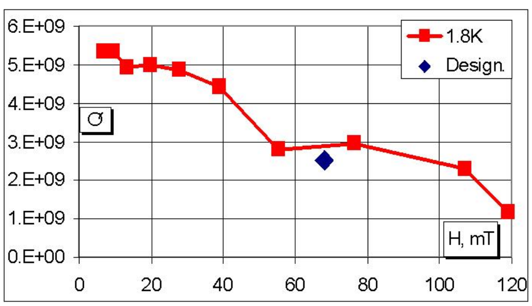

Figure 6: Q and surface magnetic field measured in "0"-mode.

Preliminary 3D multipacting (MP) calculations show possible problem in the HOM coupler in the range of ~10 mT surface fields at the inner conductor (Figure 7). MP activity is very sensitive to the shape of the conductor, for example, the increasing of the gap between the conductor and the HOM body will eliminate MP in the full of design fields range. This modification can hopefully be done without rebuilding the HOM coupler.

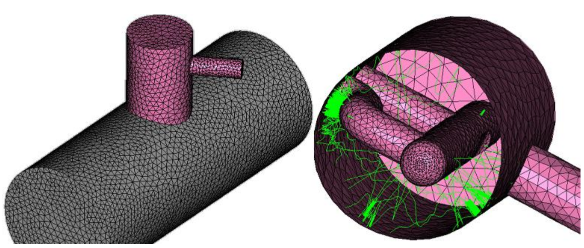

Figure 7: Multipacting 3D simulations.

Blade tuner design and tests

A blade tuner with a copper 9-cell full size prototype cavity was tested at room temperature. The measured sensitivity was ~2.5 MHz/mm [7]. This test was repeated with the blade tuner submerged in 4.2K liquid helium. The goal of this test was to measure tuner performances together with a 9-cell cavity in a cold environment. Because of helium inside the cavity, the frequency spectrum was lowered by 75 MHz and sensitivity of ~2 MHz/mm was measured. Due to fluctuations in helium pressure the frequency measurements were noisy. To reduce noise the major measurements were done with temporarily no helium supply to the dewar. A total of 30 full cycles of compressing and stretching were done. The tuner was carefully inspected after warm-up and no evidence of damage or cracks were found. Since during this test the stepping motor and gear system were submerged into liquid helium, we are going repeat this test in a horizontal test station under insulating vacuum.

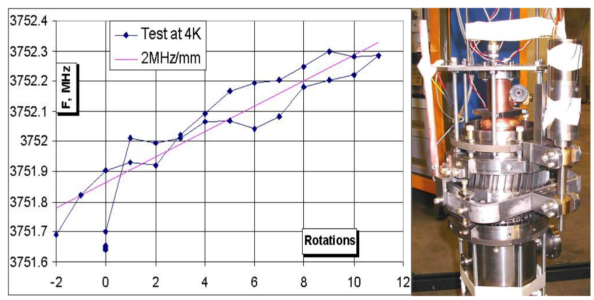

Figure 8: Blade Tuner Cold test results.

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