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CRYOGENIC TEST RESULTS OF THE SPS PROTOTYPE RF-DIPOLE CRABBING CAVITY WITH HIGHER ORDER MODE COUPLERS*

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Abstract

The rf-dipole crabbing cavity planned for the LHC High Luminosity Upgrade is designed to deliver a transverse kick of 3.34 MV; crabbing the proton beam in the horizontal plane. The proton beams of the LHC machine operating at 7 TeV each sets high impedance thresholds on the crabbing cavity systems. The rf-dipole crabbing cavity is designed with a two higher order mode couplers to suppress those HOMs. The first prototype of the HOM couplers are fabricated at Jefferson Lab. This paper reports the cryogenic test results of the HOM couplers with the SPS prototype rf-dipole cavity.

INTRODUCTION

Crabbing cavity systems are an essential component in the LHC High Luminosity Upgrade in recovering the loss of luminosity due to the crossing angle of the colliding bunches [1]. These crabbing systems allow head-on collision of bunches compensating the loss of luminosity. Novel compact crabbing cavities have been designed to meet the tight dimensional constraints in LHC [2]. The SPS prototype rf-dipole crabbing cavity shown in Fig. 1 is one of the cavities that is being designed and fabricated with all the ancillary components including the fundamental power coupler, higher order mode (HOM) couplers, and tuning and He vessel interfaces.

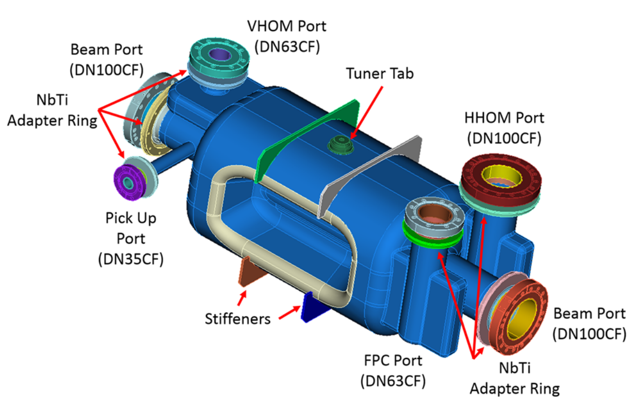

Figure 1: 400 MHz SPS prototype rf-dipole cavity.

The rf-dipole cavity has been designed to operate in a TE_{11}-like mode where the primary contribution to the kick is given by the transverse electric field between the poles [3]. The poles and outer body are optimized to minimize the peak surface field ratios for given transverse kick.

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SPS PROTOTYPE RF-DIPOLE CRABBING CAVITY

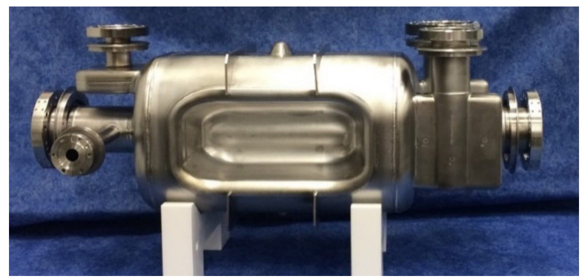

Figure 2: Fabricated Nb rf-dipole cavity.

Two prototype cavities were fabricated by Niowave Inc. and completed at Jefferson Lab under US-LARP. Figure 2 shows the fabricated full prototype rf-dipole crabbing cavity. The cavities were bulk BCPed followed by heat treatment at 600 C for 10 hours. Then the cavities were light BCPed, high pressure rinsed and assembled for rf testing. Prior to rf test the cavity was baked at low temperature of 120 C. The details of the fabrication and cavity processing are given in Ref. [4].

Bare Cavity Test Results

The two cavities were rf tested at Jefferson Lab with performance exceeding the design specifications [5]. Figure 3 shows the measured Q curves of the RFD-CAV-002. The same cavity was rf tested with the HOM couplers following the bare cavity test.

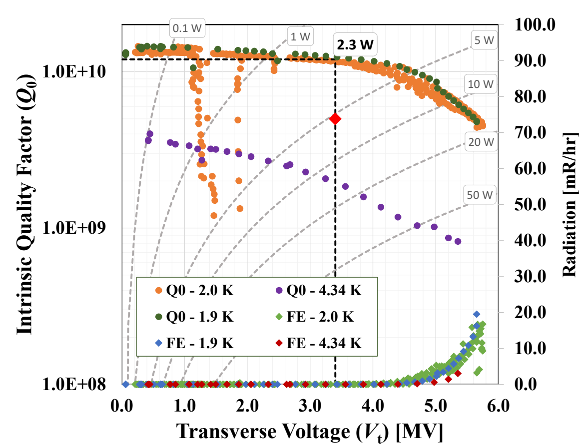

Figure 3: Q curves of the bare RFD-CAV-002.

The cavity achieved a maximum transverse kick of 5.8 MV with peak surface fields of E_p = 56 MV/m and B_p = 96 mT and low field Q_0 is greater than 1.3×10^{10}. The

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cavity had no field emission below 4.5 MV. Low field multipacting was processed completely and didn't reappear. The cavity Q_0 at operating voltage of 3.4 MV is 1.24×10^{10} with a power dissipation of 2.3 W.

HIGHER ORDER MODE COUPLERS

The rf-dipole cavity is designed with two HOM couplers named Horizontal-HOM (HHOM) coupler and Vertical-HOM (VHOM) coupler as shown in Fig. 4 [6]. These couplers are placed at the ends of the cavity in the low field region and are designed to damp the HOMs up to 2 GHz. The HHOM coupler is a high pass filter designed to cut off the fundamental mode and to damp the horizontal dipole modes where the VHOM coupler damps the vertical dipole modes. The VHOM coupler is designed as a coax-antenna with an asymmetric probe head to strongly damp few modes at higher frequencies.

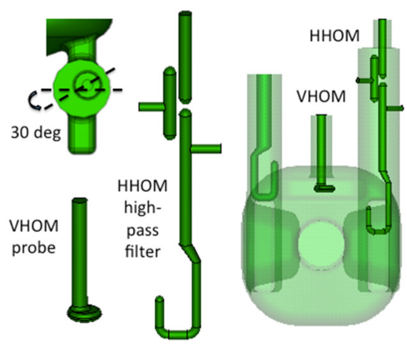

Figure 4: HHOM and VHOM couplers for the rf-dipole crabbing cavity.

Two sets of HOM couplers for the rf-dipole cavity have been fabricated at Jefferson Lab as shown in Fig. 5. The HHOM coupler is a demountable Nb coupler where the probe and VHOM coupler antenna is made out of Cu.

Figure 5: Nb HHOM high pass filter with hook and T (top), HHOM coupler probe (bottom left) and VHOM coupler (bottom right).

The HHOM high pass filter is designed with a separate stainless steel He jacket. However, the HHOM coupler used for the tests doesn't have the He jacket welded. The HOM coupler set, which was used for the cryogenic rf tests with the RFD-CAV-002 was processed and rf tested as follows.

- Light BCP of 24 microns
- Low temperature bake at 120 C for 12 hours after cavity assembly
- First RF test (Test 1) at 2 K
- Additional light BCP of 13 microns
- Low temperature bake at 120 C for 12 hours again after cavity assembly

RF TESTS WITH HOM COUPLERS

A series of rf tests have been performed on the RFD-CAV-002 with HOM couplers. The RF Test 1 of the rf-dipole cavity with HOM couplers were tested with both the HHOM and VHOM couplers and the Q curve is shown in Fig. 6.

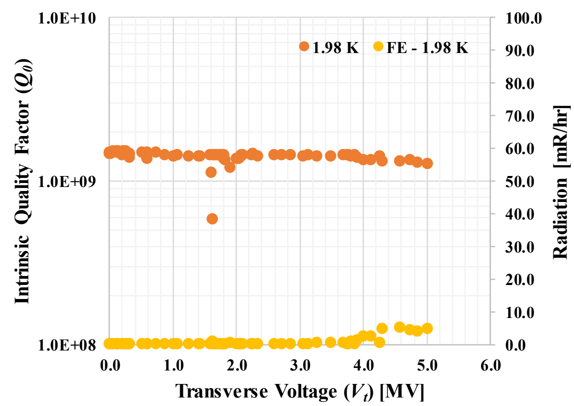

Figure 6: Q curve of the RFD-CAV-002 with both HHOM and VHOM couplers (Test 1).

The cavity reached a transverse kick of 5 MV where cavity had no quench issues and was rf power limited. No new multipacting levels were observed at the cavity or at the couplers and the cavity showed very low field emission similar to that of the bare cavity test.

The cavity showed a low Q_0 compared to that of the bare cavity test. Also, a strong coupling with $Q_{ext} = 2\times10^9$ with equivalent transmitted power of ~13 W was measured at the fundamental mode through the VHOM coupler. It was determined that fabrication imperfections of the waveguide stub of the VHOM port reference to cavity poles results in this strong coupling to the fundamental mode. This also limits the available rf power during the rf test and also increases the error in the measured Q_0.

Additional light BCP was done on the HHOM coupler with the assumption that the reduced Q_0 was due to inadequate removal of the damaged Nb layer at the coupler. In the second RF test (Test 2) the cavity was tested with only the HHOM coupler and the Q curve is shown in Fig. 7. The multipacting and field emission levels are similar to that in RF Test 1 with both HOM couplers. However, the cavity Q_0 was lower than that in RF Test 1.

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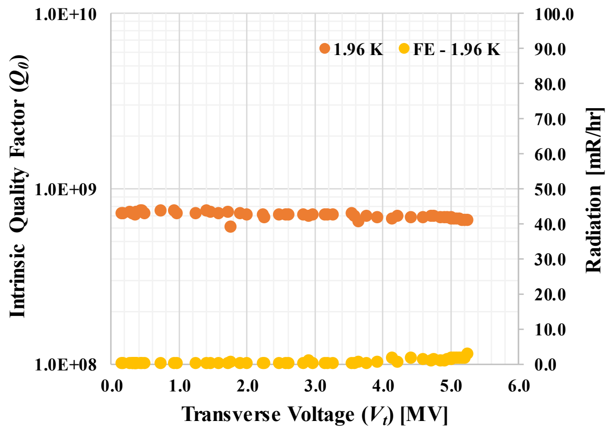

Figure 7: Q curve of the RFD-CAV-002 with only HHOM coupler (Test 2).

A set of Cernox sensors were placed at the HHOM coupler and temperature was recorded during the test. The various locations of the Cernox sensors on the HHOM coupler are shown in Fig. 8.

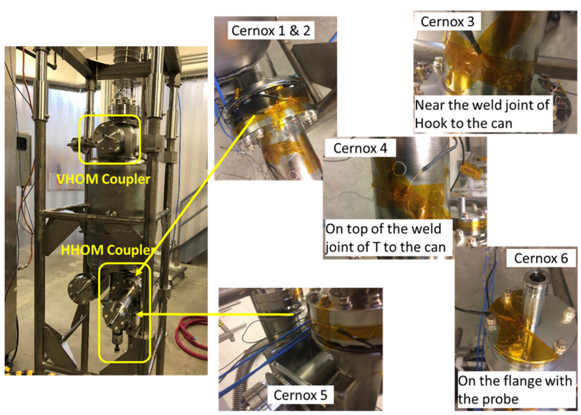

Figure 8: Locations of the Cernox sensors on the HHOM coupler.

The Cernox sensors 4, 5, and 6 show no significant change in the temperature. However, Cernox sensors 1, 2, and 3 show an increase in temperature as shown in Fig. 9.

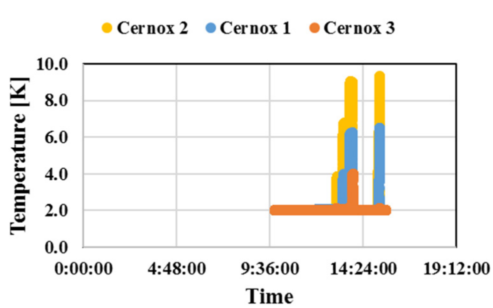

Figure 9: Measured temperature change in Cernox sensors.

The heating (Cernox sensors 1&2) is at stainless steel flanges of both the cavity and couplers facing the cavity body with no heating shown on the stainless steel flange facing the cavity beam pipe (Cernox sensor 5). Also there is heating at the weld joint of Nb hook to the outer can (Cernox sensor 3). This clearly indicates that there is a constant loss present at the HHOM coupler due to rf losses that degrades cavity Q_0 yet doesn't cause cavity to quench. Detailed analysis done with the rf simulation estimated a low Q_0 of 7×10^8 due to the incorrectly sized Cu gasket, which exposed the stainless steel surfaces at both cavity and coupler to rf currents generated by the presence of the hook. Figure 10 shows the Cu gasket location and the corresponding rf losses at the stainless steel flange. In order to recover the cavity Q_0 and to eliminate the rf loses at the exposed stainless steel surfaces; an rf gasket will be used in the future rf tests.

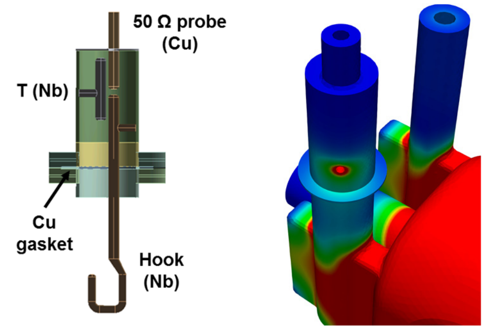

Figure 10: Cu gasket location at the HHOM coupler (left) and rf losses at the stainless steel flange (right).

CONCLUSIONS

Cryogenic tests have been carried out on RFD-CAV-002 to validate the performance of the RFD cavity with HOM couplers. Initial tests (Test 1) were carried out with both the HOM couplers and Test 2 was done only with the HHOM coupler. The cavity achieved a transverse kick of 5 MV and didn't quench in both the rf tests. No new multipacting levels or field emission levels were observed. The cavity Q_0 was low in all the rf tests with the HOM couplers. The reduced Q_0 was caused by the rf losses at the exposed stainless steel surfaces due to incorrectly sized Cu gasket. Next the cavity will be re-tested with only the HHOM coupler and with an rf gaskets to recover the cavity Q_0. Currently new RF gaskets for the HHOM coupler are under fabrication.

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