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INSTRUMENTATION FOR CHARACTERIZING 201-MHZ MICE CAVITY AT FERMILAB*

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Abstract

A 201-MHz single cavity module is installed in the Mucool Test Area (MTA) of Fermilab to test the performance of the cavity at the design parameters for the International Muon Ionization Cooling Experiment (MICE) particularly in multi-Tesla external magnetic fields. To monitor various aspects of the cavity and to understand detailed physics involved in RF breakdown and multipacting, numerous instrumentation is installed on the cavity module and also in the experimental hall, which includes thermocouples, infrared sensors, electron pickups, fiber light guides, and radiation detectors. In this paper, we will present details of each diagnostic and initial test results.

INTRODUCTION

The International Muon Ionization Cooling Experiment (MICE) is a proof-of-principle experiment of ionization cooling, which is under construction at Rutherford Appleton Laboratory (RAL) in the United Kingdom. Eight 201-MHz RF cavities are needed in the MICE cooling channel. Each pairs of the cavities will be driven by a 2-MW RF power source for a gradient of 8 MV/m per cavity. Ten RF cavities have been manufactured using techniques developed at LBNL, and one prototype cavity has been shipped to Fermilab after electropolishing, in order to evaluate the assembly procedure and to test cavity performance, particularly in a strong magnetic field [1]. The prototype cavity is housed in a special vacuum vessel, and tuner system and RF couplers have recently been installed. Table 1 summarizes the nominal parameters of the 201-MHz cavity, and Fig. 1 shows the picture of the single module cavity assembly in the Mucool Test Area (MTA) of Fermilab.

INSTRUMENTATION SETUP

To characterize the performance of the cavity in a systematic way, various instrumentation has been considered and installed. This instrumentation will give detailed engineering information and also provide valuable physics of RF breakdown in a strong magnetic field. Since the MTA experimental hall is located about 100 m away from the control room in the Fermilab linac gallery (LK8), each instrumentation should be operating and monitored remotely. In addition, signal attenuation and noise pickup should be reasonably minimized. Another consideration is that the instrumentation should work in the strong magnetic field environment. The MTA instrumentation can be categorized into three parts: for cavity and vacuum vessel, for RF couplers, and for miscellaneous system (air, water, SF6, cavity interior etc.). Up-to-date status and more detailed description of the MTA instrumentation can be found in the MTA website [2].

Table 1: Nominal Parameters for the 201-MHz Cavity

Parameter	Value
Radius	610 mm
Length	430 mm
Shunt impedance per unit length	22 MΩ/m
Quality factor, Q_0	54,000
Be window diameter	42 cm
Be window thickness	0.38 mm
Peak accelerating field	8 MV/m
Peak input RF power	1 MW
Duty factor	0.1%
Pulse length / Rep. rate	1 ms / 1 Hz
Average RF power	1 kW
Vacuum (cavity)	$\sim 10^{-7}$ Torr
Vacuum (vessel)	$\sim 10^{-5}$ Torr
Maximum B-field at MTA	5 T ($\sim$ 0.25 T @ cavity)

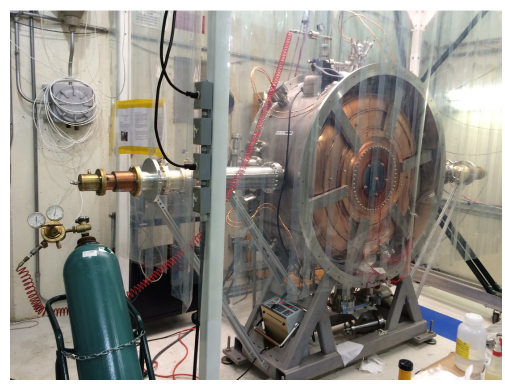

Figure 1: Single cavity module assembly in the MTA clean room, showing the cavity body, vacuum vessel body, two couplers, six tuning forks, actuators, water cooling pipes, and various instrumentation.

Cavity Body and Vacuum Vessel

RF pickups To monitor the cavity RF fields, two magnetic pickup loops are installed on top of the cavity equato-

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rial plane (Fig. 2). The RF pickup signals will be delivered through heliax cables to the envelope detectors in the LK8 station, and fed into the LabVIEW program. Based on the magnitude of the RF pickup signal, the LabVIEW program determines whether the cavity is on resonance, and adjust the tuning folks. To study RF breakdown physics, e.g., decay time of the RF magnitude and modulation of the RF frequency etc., the RF pickup signals may also be directly fed into the fast scope.

Figure 2: RF pickup probes installed through the top hat of the cavity. SMA connectors are used.

Vacuum gauges Three ion gauges are installed to monitor pressures at various components of the experimental setup (Fig. 3). Pressure rise is often correlated with RF breakdown or multi-pacting, however, ion gauges are not working properly in the presence of strong magnetic fields.

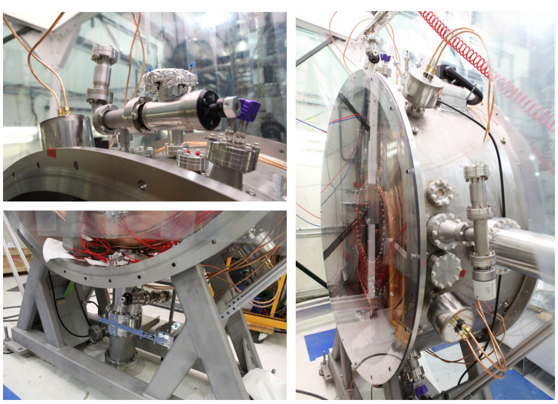

Figure 3: Vacuum gauges for cavity (top), vessel (right), and pumping line (bottom).

Fiber light guides To detect breakdown light, we installed fiber light guides (Fig. 4). Considering the space limitation and bending radius requirement, we choose 400 μm fiber with numerical aperture of 0.22. A custom-made ferrule inside the Swagelok fitting holds four fibers tightly. Light signals are detected by high-gain (4×10^6) and high-speed (0.78-ns rise time) PMT's (H10720-110).

Microphones An array of microphones (acoustic transducers) are attached to the outside of the cavity (12 on cavity body and 12 on windows) to localize sparks inside the cavity

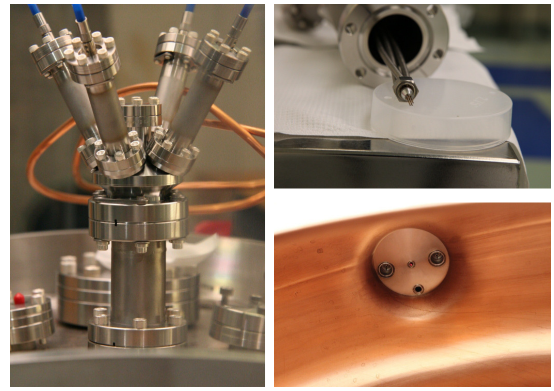

Figure 4: Light detection system; Vacuum fiber feedthrough on top of the vessel (left), fibers in ferrule (top), and fiber testing with laser pulse (bottom).

(Fig. 5). Sound signals are pre-amplified and then fed into NI DAQ Ethernet chassis.

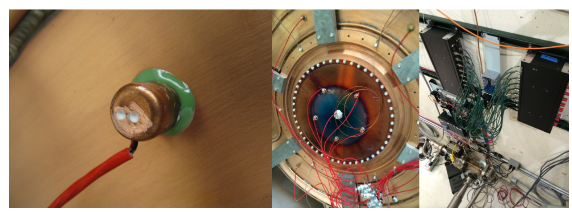

Figure 5: A special vacuum-compatible epoxy (left) is used to place the microphones on the cavity (center). Signals are handled remotely through Ethernet chassis (right).

Thermocouples Temperature rise often causes resonance frequency change during the cavity operation. Type-E thermocouples (non-magnetic) are installed to monitor temperature changes: 12 on the cavity body, 1 on vessel cylinder, and 2 on cover plate (Fig. 6). Three thermocouple feedthroughs are installed on the vacuum vessel.

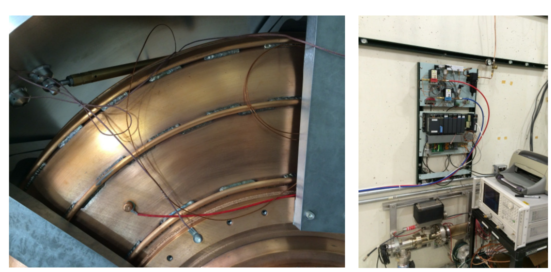

Figure 6: The thermocouple attached on the cavity body (left) is monitored through PLC (right).

Faraday cup To measure dark current from the cavity surface, a Faraday cup has been designed and tested (Fig. 7). To measure possible fast signals, the geometry of the

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Faraday cup has been designed to yield 50 Ω impedance. A copper plug has been installed inside the inner conductor of the Faraday cup to collect more electrons, and a thin CF Ti window will be placed on the vacuum vessel to allow electrons to come out easily.

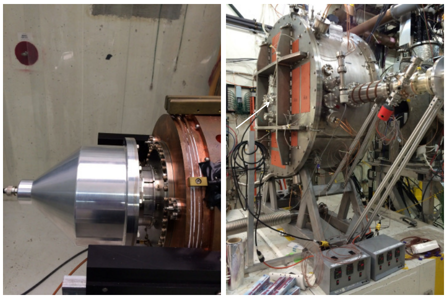

Figure 7: The Faraday cup can be mounted both on 805-MHz (left) and 201-MHz (right) cavities when 4-5/8" flanges are available.

Coupler

New RF couplers, designed and manufactured by LBNL, have been installed. A conventional coaxial type loop coupler is adopted and a disk type RF window is integrated. To commission and characterize the coupler, we installed several dedicated diagnostics. In particular, we note that there are some concerns about multi-pacting and gas discharge when the coupler is operating in a strong magnetic field.

Directional couplers Dual directional coupler in each side of the coupler measures forward and reflected power waveforms.

View ports and vacuum gauges To aid coupler commissioning, we installed ion and cold-cathode (CC) vacuum gauges on each coupler (Fig. 8). To detect possible arcing in the coupler, we employed a mini-CF viewport. Light signals are collected by a collimating lens which is mounted on top of the viewport via custom-made adapter [Fig. 8 (top)]. When it is necessary to minimize background light, we may turn off the ion gauges and use only CC gauges, or may adjust field of view of the lens.

Electron pickups To detect electron activity in the coupler ceramic vacuum window regions, we installed electron pickup probes [Fig. 8 (bottom)]. A bias voltage (≤ 20 V) is applied through the signal cable. The pickup signals are delivered through heliax cables to the VME module in the LK8 for processing.

Experimental Hall

Several other instrumentation is installed around the MTA hall (outside the B-field range). Air pressures (main supply, and stretch and squeeze lines for tuner actuators) are monitored by electronic pressure gauges (PX319 by Omega) [3].

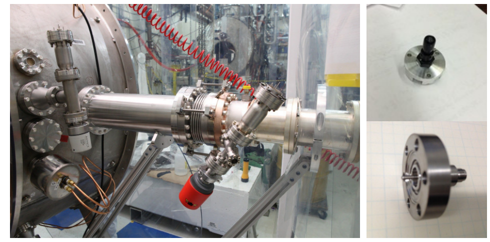

Figure 8: Several diagnostic instrumentation is employed to understand coupler performance: vacuum gauges and viewport (left), collimating lens with adapter (top), and electron pickup probe (bottom).

The current outputs of the gauges are readout by the PLC, and then fed into LabVIEW or ACNET.

There are five cooling tubes in this experimental setup: one for the cavity body, two for the coupler loops, and two for the RF windows. Water pressure, temperature, and flow rate will be monitored by the PLC.

There are several radiation detectors as well. Ionization chambers provide overall dose rate and scintillation counters measure X-ray rates. A NaI crystal counter is also available for X-ray spectra measurements.

A cavity interior inspection system is also being developed to keep track of the surface condition changes during the experiments.

EXPERIMENTAL PLAN

Baking of the cavity and vessel assembly is in progress. Once the required vacuum level is achieved, we will start commissioning of the cavity with flat Copper windows. For the initial suit of experiments, about 3 MW of RF power is required, which will be provided by 7835 PA tube in the Fermilab linac station RF7. First, we will apply minimum RF power to test LabVIEW tuning program and check various diagnostic signals. Then we plan to run the cavity up to 3 MV/m carefully to identify and overcome multi-pacting at low power. Over 3 MV/m, we will increase the RF gradient by 10% (e.g., 0.3 MV/m) only when there is no spark for 0.1 M pulses. We will repeat this procedure until we reach 8 MV/m. To test cavity performance under the magnetic field, fringe field of the MTA solenoid (5 T maximum on axis) will be applied. Cavity body and couple region will be inspected after one-month of operation.

REFERENCES

[1] Y. Torun et al.,"Assembly and Testing of the First 201-MHz MICE Cavity at Fermilab", NA-PAC2013, Pasadena, WEPMA16, p 1016.

[2] http://mice.iit.edu/mta/rf/201/inst/List.html

[3] L. Somaschini, "Test of the Fermilab Radio Frequency Accelerating Unit for the Mice Experiment at Rutherford Laboratory", MS Thesis, University of Milan (2014).