MICE CAVITY INSTALLATION AND COMMISSIONING/OPERATION AT MTA*

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Abstract

A first electropolished 201-MHz RF cavity for the international Muon Ionization Cooling Experiment (MICE) has been assembled inside a special vacuum vessel and installed at the Fermilab's MuCool Test Area (MTA). The cavity and the MTA hall have been equipped with numerous instrumentation to characterize cavity operation. The cavity has been commissioned to run at 14 MV/m gradient with no external magnetic field; it is also being commissioned in presence of fringe field of a multi-Tesla superconducting solenoid magnet, the condition in which cavity modules will be operated in the MICE cooling channel. The assembly, installation and operation of the Single-Cavity Module gave valuable experience for operation of full-sized modules at MICE.

INTRODUCTION

The International Muon Ionization Cooling Experiment (MICE) is under construction at Rutherford Appleton Laboratory (RAL, UK). It is designed to demonstrate feasibility of an ionization cooling channel for use in such high-intensity muon sources like a Neutrino Factory or a Muon Collider [1].

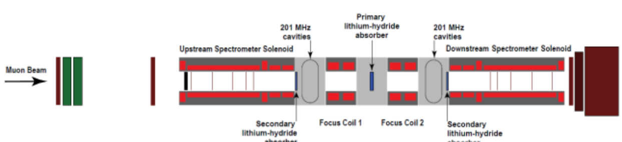

Figure 1: Final configuration of MICE cooling channel, showing two RF cavity modules.

Final MICE channel configuration [2] contains two RF Assembly (RFA) modules very similar to the module being tested at the MuCool Test Area (MTA). Each cavity will be driven by a 2-MW amplifier system to operate at a gradient of at 10.3 MV/m. The cavities also need to operate in fringe fields of multi-tesla solenoidal magnets.

MTA has a 5-T superconducting solenoid that provides operational conditions very similar to MICE channel. MTA Hall is also equipped with numerous detectors to monitor cavity environment and radiation levels, since radiation from RF cavities would affect various components of MICE channel [3] (e.g., radiation damage to detectors, thermal load on liquid hydrogen vessel, etc.). The cavity has also been equipped with instrumentation to characterize its behaviour during operation.

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CAVITY INSTALLATION

RF Cavity body was manufactured in industry using techniques developed at LBNL, it was electropolished at LBNL and sent to Fermilab for installation and testing in a special vacuum vessel designed by LBNL, which is very similar to the final design to be used in MICE [4].

The cavity was initially installed and equipped with all the instrumentation in Lab 6 area, which has a class 100 (ISO 5) clean environment. All instrumentation, including the tuning system has been fully tested.

The tuner system consists of 6 stainless steel tuner forks driven by pneumatic actuators. Pneumatic system has a release valve at pressure of 120 PSI, and setup was tested up to 100 PSI at Lab 6, providing "pull" and "squeeze" with ~ 4 KHz/PSI tuning sensitivity [5].

The cavity was then moved to the MTA hall. It was removed from its vacuum vessel to reduce the dimensions during transport. The assembly installation in the vacuum vessel was finished in the MTA clean room [6].

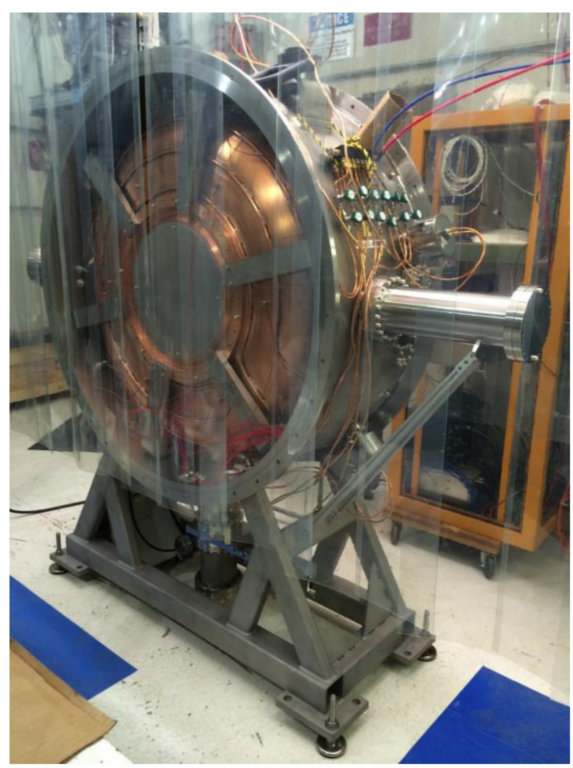

Figure 2: MICE Cavity in the MTA clean room, shortly after it was moved from Lab 6.

Instrumentation

The following instrumentation has been installed on the cavity, couplers, vacuum vessel and in the MTA Hall:

- two Pick Up loops (PU1 and PU2) to monitor RF fields
- four Cavity Light (CL) signals consisting of optical fibers + PMT to detect breakdown in the cavity
- Piezoelectric acoustic sensors on cavity body to detect and localize breakdown through acoustic signals
- Forward and Reflected power waveforms from directional couplers near cavity on Left and Right Coupler arms, and near Klystron station
- viewports on Left and Right couplers to detect light signals
- Field Emission Probes in Left and Right couplers to monitor coupler conditioning
- Faraday Cup
- Radiation detectors:
  - ionization chambers for overall dose rate
  - 4 scintillator + PMT counters in the Hall for X-ray rates
  - two small plastic scintillators (SPS): up- and downstream of the cavity, directly on vacuum vessel
  - NaI crystal
- water flow and pressure
- thermocouples on cavity body and infrared sensors to look at Be windows
- gas pressure for tuner actuators
- vacuum pressure at various gages
- solenoid: current, voltage, temperature, LHe level
- many more

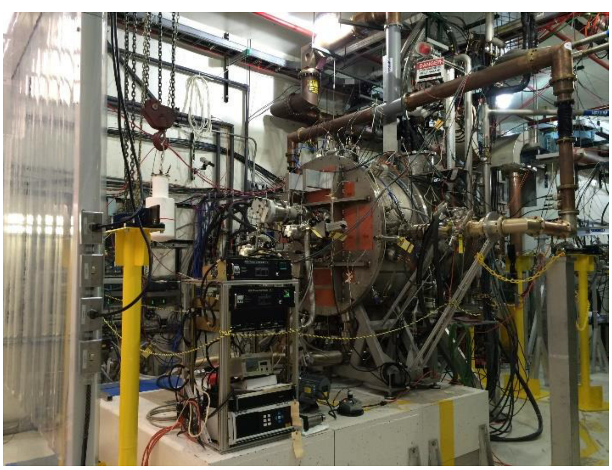

Figure 3: MICE Cavity Module installed next to 5-T solenoid in the MTA Hall.

CAVITY COMISSIONNING/OPERATION

Run with Cu Windows with No Magnetic Field

We had a run with temporary flat copper windows with no magnetic field present (Sep. 15 – Nov. 26 2014). We used this run as a "shakedown" for instrumentation, data acquisition and control systems. RF power station controls have been upgraded and commissioned first with a test load [7], and frequency tuning was incorporated into the control software before the run.

We had achieved gradients of 13.5 MV/m with breakdown probability ~ 10^{-6}, collecting 32 breakdown events overall, during conditioning and hold at high gradient.

We performed a preliminary Tuner System Test at MICE operation frequencies, with only 5 out of 6 actuators operational. We applied pressures up to 40 PSI in "pull" and "squeeze" directions, confirming ~4 Hz/PSI tuning sensitivity. Going beyond 40 PSI was not possible because it took cavity out of frequencies range available from the power station. We also tested tuner system response to thermal drift of the cavity, see figure 4.

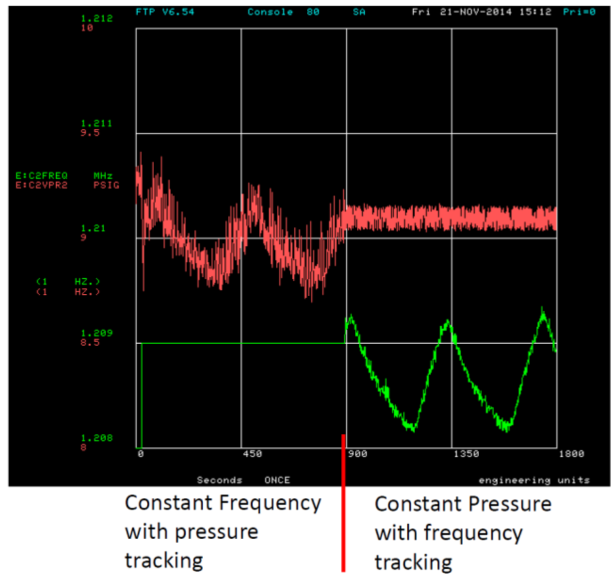

Figure 4: MICE Cavity Module installed next to 5-T solenoid in the MTA Hall.

It shows that the system can successfully hold constant cavity frequency by adjusting pressure.

Run with Be Windows with No Magnetic Field

The cavity has been fitted with curved beryllium windows, also, parts of data acquisition system have been rebuilt and improved [8]. We had a run with no magnetic field present (March 18 – April 6). The cavity successfully went through couple of Multipacting (MP) bands at low gradients [9], and reached >11 MV/m gradient without breakdown events. We have collected more than 0.5 million pulses holding at constant gradient of 11 MV/m (corresponding to ~1.8 MW power in the cavity) with no breakdown events.

During the periods when cavity went through MP, and at the final hold at high gradient, we operated the cavity at 10 Hz, while for the slow ramp up of the gradient we operated at 5 Hz. This was to insure that our DAQ system has sufficient time to record any breakdown events, if any were to happen. The cavities would operate at 1 Hz in MICE cooling channel, but with long flattop, which is not possible at MTA. At 10 Hz operation, we have the same

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duty factor and supply the same average power to the cavity, thus, we can conclusively test cooling performance and radiation levels. The dose rate for 10 Hz operation stayed comfortably below tracker damage threshold.

Cavity gradient went up to 14 MV/m for short periods, due to tuning of the modulator at the RF station, no breakdown events have been observed. We also had no issues with the cavity or services (vacuum, water) and all instrumentation and DAQ worked well.

Run with Be Windows in Fringe Field of a 5-T Solenoid

The vessel was moved against the 5-T solenoid magnet, placing the cavity in the fringe field of the MTA solenoid, which was operated at 5 T, providing fields similar to those the cavities would see in MICE channel. Small plastic detectors were rebuilt to operate in the magnetic field (optical fibres were added to move PMTs out of magnetic field), also, some detectors had to be moved and gauges had to be turned off. We are continuing the run with Be windows in magnetic field (April 24 – ongoing). The cavity successfully went through the MP bands at low gradients, and reached >11 MV/m gradient without breakdown events. We have collected more than 1 million pulses holding at constant gradient of >8 MV/m (~1.2MW input power), and 3 million pulses at 11 MV/m (~1.8MW input power) with no breakdown events.

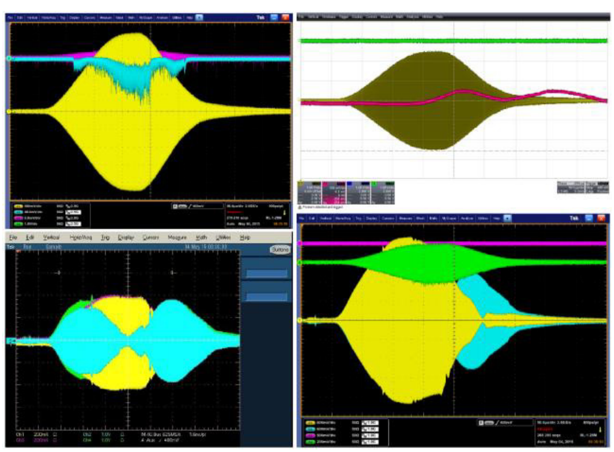

Figure 5: Scope signals during B=5 T run at ~11MV/m. Top Left: PU2, SPS upstream, SPS downstream, Light#3; Top Right: PU1, Faraday Cup, Light #1 and #2; Bot. Left: Forward and Reflected powers from Right and Left Coupler arms;
Bot. Right: Forward and Reflected powers at Klystron, Light #4, NaI crystal.

The dose rate stayed comfortably below tracker damage threshold for 10 Hz cavity operation. Cavity gradient went up to 12.6 MV/m for very short period due to tuning of the modulator at the RF station. We had no issues with systems, DAQ, cavity or magnet operation.

Tests at MTA provided valuable operational experience for all RF Cavity Module components, leading to some design improvements [4].

CONCLUSIONS

We have successfully demonstrated that the RF Cavity Module can be operated in MICE channel at gradient of 10.3 MV/m in presence of magnetic field.

Remaining Steps

We need to perform full Tuner System Test at MICE operation frequencies, collecting 0.25M+ pulses at ~ 1MW power, and 0.5M+ pulses at ~2MW power. We also plan to have “physics runs” to calibrate radiation detectors. We then may proceed to try push cavity to operation at higher gradient and observation of cavity breakdown, this is conditional on many external factors, such as availability of power form RF station, and on time/personal resources, since MTA has extensive testing program with multiple cavities, and breakdown studies are not essential for MICE cavity operation demonstration. Indeed, they are part of Modular Cavity program [10].

ACKNOWLEDGMENT

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