

INSTALLATION AND COMMISSIONING OF THE MICE RF MODULE PROTOTYPE*

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Abstract

A special vacuum vessel prototype was built [1] to house the first electropolished 201-MHz RF cavity for the International Muon Ionization Cooling Experiment (MICE) [2]. The resulting prototype RF module has been assembled, instrumented, installed and commissioned at Fermilab's MuCool Test Area (MTA) [3] and the effort has provided valuable experience for design and assembly of modules that will be used in the cooling channel for the experiment.

MECHANICAL ASSEMBLY AND INSTALLATION

Cavity Insertion

There is little clearance between the dressed cavity assembly (with the tuner forks installed) and the vacuum vessel. The cavity was inserted into the vacuum vessel using a material lift with a custom fabricated attachment to match the stiffener ring. The setup is shown in Fig. 1. During adjustment of the suspension struts that form the six-axis platform to center the cavity in the vessel, several of the rod ends seized. This was most likely due to the lubricant film on the threaded rods being removed during cleaning or stripped during adjustment under load. The strut bodies and threaded rods were both made of stainless steel which increases the likelihood of galling. New strut bodies were machined out of aluminum bronze to avoid this problem. Magnetic permeability of the new parts were measured to confirm that they would be acceptable for use in a strong magnetic field. In addition, a test fixture was designed and built in order to gain some familiarity with the adjustment procedure without



Figure 1: Left to right: cavity insertion, lift, test fixture with the new struts, and an alignment rod on the test fixture seen from inside (top) and outside (bottom) the vessel.

a heavy load. This fixture consisted of a hoop with identical attachment points as the cavity so it could be used with the same struts and fasteners. After successful testing of the system with the fixture, the cavity was reinstalled in the vessel using the new struts and adjustments could be made easily by turning the strut bodies by hand while the full weight of the cavity assembly was suspended.

Tuner System

Initial tests of the pneumatic actuators were made on a separate fixture [4]. Alignment rods screwed into the tuner forks were used to center the tuner actuator shafts with respect to the corresponding vessel ports while adjusting the cavity position. Each actuator consists of a concentric inner and outer shaft pair with threaded sections at their tips. The shafts have identical thread spacing and are screwed into corresponding holes in the fork body. Initial installation of the actuators on the vessel revealed another issue; most actuator vacuum flanges would not mate up with the vessel port flanges before the inner actuator shafts bottomed out on the forks. This was resolved by removing a short section (about one thread) from the end of each inner shaft. After the cavity was aligned inside the vessel, detailed measurements of the mechanical (pressure to displacement) and RF control (pressure to frequency) transfer functions were carried out [5, 6] (Fig. 2). While the vessel was under vacuum in the MTA experimental hall, one of the actuators developed a vacuum leak during testing. No spare unit was available at the time, so the faulty actuator was removed and the corresponding port blocked off. This unit was repaired and reinstalled during reconfiguration of the module. Testing under vacuum revealed a vacuum leak in another unit which was replaced with a spare. The actuator design was modified to eliminate the weak joint responsible for the leak.

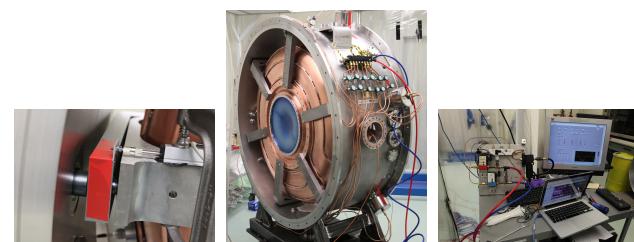


Figure 2: Tuner test setup: potentiometer on tuner fork (left) for displacement measurement, dressed cavity inside vessel (center), actuator pressure control (right).

* Work supported by the US Department of Energy Office of Science through the Muon Accelerator Program.

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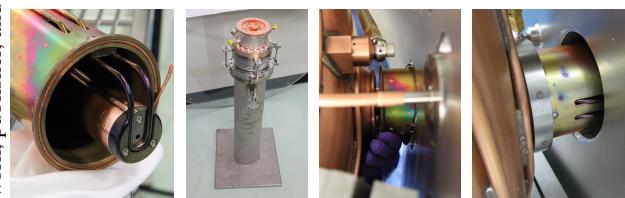


Figure 3: Left to right: coupling loop during assembly, partial coupler assembly in leak check fixture, completed assembly during, after attachment to cavity body.

Couplers

The first pair of prototype coaxial loop couplers were fabricated, assembled and vacuum leak checked at LBNL before being partially disassembled and shipped to Fermilab. They were reassembled, vacuum leak checked, installed on the cavity and adjusted for critical coupling at Fermilab's Lab-6 (Fig. 3). Coupling adjustment requires rotating the entire coupler assembly to change the coupling loop angle within the cavity. These adjustments proved difficult in practice. The coupler design has been modified to provide better mechanical support and maintain alignment of the flange connection at the cavity during adjustment. Each coupler assembly includes a ceramic window forming a barrier between the cavity vacuum volume and the coaxial input waveguide which was pressurized with about 1 atm of N₂ gas during cavity operation. Each window assembly has two tubes with instrumentation flanges connected to the vacuum side. One of the tube-to-flange joints developed a vacuum leak just before operation in magnetic field. The leak was plugged using an epoxy compound and the repair has held up so far.

VACUUM SYSTEM

Requirements

The pressure inside the RF cavities should be kept below 0.1 μ Torr during operation. The module volume outside the cavities is part of a common vacuum space for the cooling channel which will be maintained at several μ Torr. This suggests maintaining isolation between the inside and outside of the cavity volumes. However, these volumes can not be pumped down independently as the 0.38-mm-thick Be windows are not rated for a substantial pressure differential. The vacuum conductance between the inside and outside of cavities should be low for molecular flow but high for viscous flow at all times in order to protect the Be windows. In addition, the vacuum system has to be operable in a strong external magnetic field. The only available port for pump-down of the cavity interior is the flange at the bottom of the cavity with 4" inner diameter. The main pumping port for the prototype vessel is an extension tube at the bottom with 6" inner diameter. The outer conductor in each coupler assembly also separates the inner (cavity) and outer (vessel) vacuum spaces. However, there is a pair of slots in the outer conductor (visible in Fig. 3) to allow the cooling tube for the coupling loop to go through and these slots have substantial

conductance. The coupler design has been modified to plug these holes for production units.

Configuration Sequence

The interior surfaces of both the cavity and the vessel are electropolished. However, the vessel was open to (clean-room) atmosphere for several months during assembly work. The vacuum system for the prototype module was built and tested in several stages. After installation in the MTA hall and initial pump-down, the vessel was baked under vacuum at 100-110° C for several days to accelerate removal of adsorbed water. The vessel had to be let up to atmospheric pressure afterward for removal of the leaking actuator. The vacuum system was reconfigured at the same time to install additional pumping on one of the cover plates. Initial commissioning of the cavity with Cu endplates and no magnetic field was carried out in this configuration. The vessel was opened again by removing the flange plates for access to inspect the cavity interior and install the Be windows. Testing with Be windows and in external magnetic field was performed in this final configuration. In both cases, the vessel was opened for a limited period (2-3 days) while covered by a portable clean room with the cavity under N₂ gas purge.

Test Setup

The original design had a small diameter tube connected to the bottom flange of the cavity to provide an annular region with large conductance between the inside and the outside of the cavity satisfying the Be window safety requirement. The system was initially tested with a non-evaporable getter (NEG) pump at the bottom of the vessel and a turbo pump connected through a relatively low-conductance path. A larger diameter tube was fabricated and installed at the bottom of the cavity to block most of the conductance between the vessel and the cavity at that location so the NEG pump capacity could be used mainly for the cavity interior volume. A separate bypass line was installed between the vessel and the cavity with large viscous and small molecular flow conductance to maintain protection for the windows. It was clear that the NEG pump alone would not be enough to maintain adequate vacuum in the cavity for long periods. In order to move ahead with cavity commissioning quickly, an interim configuration was devised. A set of turbo pumps were mounted on one of the vessel cover plates providing large pumping speed for the vessel to keep its pressure low and reduce leakage into the cavity volume through the coupler slots. In this configuration, the system provided operational vacuum levels in the cavity within a few days and baseline pressures as low as of 35/50 nTorr were achieved in the cavity/vessel after 3 weeks. A high-speed, large capacity, high-vacuum rated NEG pump was purchased for the next stage of testing and installed on the vessel cover plate to be used in place of the turbo pumps during operation with the external magnetic field on. In this configuration, operational vacuum in the cavity was achieved within 10 days and baseline pressures were within a factor of 2 of



Figure 4: Cavity inspection fixture mounted on the vessel cover plate with the camera outside the vessel (left) and the mirror inside the cavity (right).

the interim configuration. The system was heavily instrumented [7] with vacuum gauges to characterize the behavior in detail. Ionization gauges were installed near the top and bottom of the cavity, at the outer ends of the couplers, in the vessel and manifolds. These were supplemented by cold cathode gauges. In preparation for operation in magnetic field, the cold cathode gauges were relocated away from the magnetic field using small-diameter tubing. This causes a background pressure due to outgassing in the tubes but still enabled us to monitor cavity vacuum with the magnetic field on. Measurements made in different configurations during these tests helped confirm outgassing loads and conductances and provided useful data that will be incorporated into the final vacuum system design.

CAVITY INSPECTION

A thorough inspection of the RF surfaces before and after high-power operation was one of the goals of the test program. This is not an easy task due to the dimensions of the cavity and vessel and strict cleanliness requirements to avoid contamination. Coupler parts, Cu endplates and Be windows were inspected during assembly. The interior surface of the cavity was photographed inside the MTA clean room while the vessel cover plates were off. A custom fixture was built allowing a camera to be mounted outside the vessel and view the interior of the cavity through a mirror mounted inside. The fixture is rotatable and includes provision for automated drive although manual control was adequate during initial use. The camera was operated by computer control and the (several hundred) images saved directly to computer storage during the inspection. The system is shown in Fig. 4.

LOW-LEVEL RF MEASUREMENTS

The resonant frequency and quality factor of the cavity as well as the response of the field probes were measured several times throughout installation and commissioning. Sample results are shown in Table 1. Note that some of the frequency variation is due to temperature (expected to be around $3.4 \text{ kHz}/^\circ\text{C}$) which isn't the same in both cases.

Table 1: Cavity parameters.

Configuration	f_0 [MHz]	Q [10^4]
Cu endplates	201.24	4.9
Be windows	200.81	4.7

The response of the tuner system is about $+3/-4 \text{ kHz}/\text{psi}$ in stretch/squeeze mode for a total range of 560 kHz with 80 psi of input pressure. In addition, spacer rings of various thicknesses were built and used under one of the Be windows (the convex side) to explore the sensitivity of the frequency to window position and the measured value of 52 kHz/mm is consistent with simulation results.

STATUS AND PLANS

The module has been assembled and successfully operated and the cavity exceeds MICE operational specifications [8]. Assembly procedures have been fully worked out and will be used for the production modules. Many fixtures built for assembly of the prototype will be reused for production units. Several issues identified during assembly and commissioning were addressed by design changes for the production vessels, couplers and tuner actuators. Most of the other components for the production modules are in hand [9]. Further tests of the cavity and tuner system will be carried out at high power at the MTA. When the first production coupler is available, it can be installed in place of the prototype with the repaired window and the system operated again to qualify the performance of the final design. Another inspection of the cavity interior as well as the removed prototype coupler can be done at the same time.

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