PROGRESS ON THE MICE RF SYSTEM*

A. Moss, J. Orrett, P. McIntosh, P. Corlett, A. Wheelhouse, C. White, STFC, Daresbury Laboratory, Warrington, UK

Abstract

The Muon Ionisation Cooling Experiment (MICE) is being constructed at Rutherford Appleton Laboratory in the UK. A muon beam will be cooled through a process of absorption using hydrogen absorbers then accelerated using 200MHz copper RF cavities. This paper describes the RF power source used to accelerate the muon beam, testing of the high voltage power supplies and amplifiers to date and progress on the RF distribution scheme to the accelerating cavities.

INTRODUCTION

The development of a neutrino factory requires low emittance muon beams. The only practical method that could produce a low emittance muon beam is ionisation cooling. An experiment at Rutherford Appleton Laboratory (RAL) is being built to test this approach. The Muon Ionisation Cooling Experiment (MICE) consists of a cooling channel that accepts a muon beam generated by plunging a target into the proton beam on the ISIS facility at RAL.

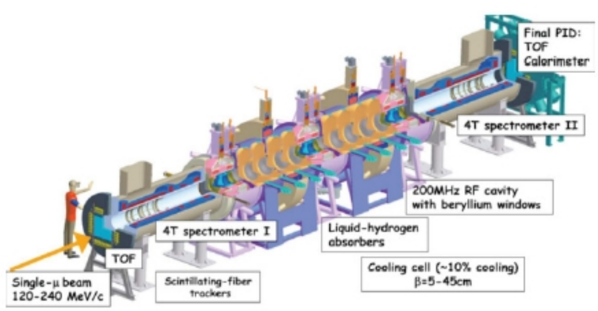

Figure 1: MICE cooling channel.

The initial muon beam emittance is measured in the first detector of the experiment. The beam then enters the first absorber focus coil (AFC) where its emittance is reduced in both longitudinal and transverse momentum using hydrogen absorbers. The RF Coupling Coil (RFCC) is used to restore the longitudinal momentum using RF cavities. The beam emittance is then measured again at the end of the cooling channel. In practice there are three absorbers equipped with superconducting focus coils, these are interspaced with eight RF cavities. The cavities are constructed in two banks of four, which are immersed in a 2.5 Tesla field generated by a superconducting magnet. An accelerating gradient of up to 8 MV/m is possible across the cooling channel, with each cavity powered by 1 MW of RF power. A prototype cavity [1] has been tested at the MuCool Test Area (MTA) test stand at Fermilab. A further five cavities have now been fabricated and are undergoing frequency tuning by Lawrence Berkeley National Laboratory (LBNL) staff.

MICE is an experiment to test the feasibility, performance, and technical challenges of ionization cooling. The close proximity of RF cavities, liquid hydrogen and superconducting magnets call for advanced engineering solutions.

Test Area Progress

A test facility has been constructed at Daresbury Laboratory (DL) to test all of the RF components and power supplies necessary for this amplifier chain. A program of testing will be carried out so that each component of the RF power supply system can be commissioned while the amplifier under test is connected to a dummy load. The power supplies used for the amplifiers are essentially a replication of the units used in the RAL ISIS linac. A coolant pumping station has been installed next to the test area to provide a glycol cooling circuit for the RF load. The amplifier chain contains a 4 kW Dressler solid state amplifier (SSA), a 4616 tetrode amplifier circuit and a 2 MW TH116 amplifier circuit. Each tube amplifier requires a HT supply, capacitor storage bank and auxiliary power supplies to give the correct operating conditions. Protection for the tubes in case of an arc is done by monitoring the peak current, should an over current be detected (internal tube arc) then the crowbar is fired, removing from the tube rapidly. A detailed explanation of the power supplies can be found reported elsewhere [2].

Amplifier Testing

The amplifier circuits are 'tuned' using a variety of adjustable devices. For the 4616, the input cavity is equipped with a variable capacitor that moves the resonant frequency, also the 'N' type connections to the cavity are adjustable to change the coupling factor on both the input and load side. On the output of the amplifier, the cavity length and hence its resonant frequency can be changed using a hand wheel, a stub tuner is located in the output coax section to alter coupling factor into the output coax. When first operating the amplifier into a matched load, all of these adjustors are used in succession to maximise the power output.

We have already tested the first 4616 amplifier; using an old tube we gradually brought the power level up to 170 kW with a 1 mSec pulse at 1 Hz, these tests will be repeated with a new tube to assess the ultimate performance of this system.

In the case of the TH116 amplifier systems, a moveable ¼ wavelength short is used on the input to set the match, the 'grid' and 'anode' taps of the cavity amplifier are moveable and now motor driven and finally the output

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capacitor can be moved by hand to set the coupling into the output coax. The final commissioning of electrical systems is taking place for the first 116 amplifier system. A supervisory PLC has been installed and tested; this will monitor all the interlocks of auxiliary power supplies, the water and air cooling systems and remove the HT if a problem occurs. A thyristor power controller has been used to supply the filament power for this amplifier, this is able to ramp up the power in a controlled manner up to the level of 500 Amps, feedback is then used to stabilise the controller at the required set point. Testing of the first refurbished 116 amplifier system will commence very shortly.

The procedure will be to start off at the lowest HT possible <10 kV, drive the system with the 4616 amplifier at 1 kW, then adjust the 116 circuit to find the conditions under which the circuit will start to amplify. This is likely to be quite a slow process to start with as systems such as these have a tendency to self oscillate. Given the amount of work that has gone into refurbishment of the systems great care must be taken to avoid damage. Much of the circuit relies on beryllium copper spring fingers to make good contact with moving surfaces, should these fingers not make an acceptable contact, breakdown is likely to occur. In an attempt to prevent this we will install arc detectors in critical areas, the HT tank is the most likely area of concern, together with the area around the output capacitor, any sparking will trip the system off and hopefully prevent serious damage taking place. Inspection of the tube socket will take place after initial testing; this requires removal of the 116 tube to asses any contact issues, this may be repeated as the power level is increased as damage in the socket would require a strip down of the circuit to repair the finger strip and silver plated metalwork.

The tube amplifier circuits have been gifted to the MICE collaboration from LBNL and CERN [3]. In the case of the CERN amplifiers, the systems were fully refurbished prior to their delivery. The LBNL units however were in need of substantial repair and refurbishment which necessitated a total strip down and rebuild.

MICE Experimental Hall

The systems will be transported and installed in the MICE experimental hall ready for step five of the project. This is when the first RF power will be needed. The amplifier systems will be located behind a magnetic shield wall. The coax outputs from the amplifiers will be routed and suspended from the floor. The space available for the RF equipment is limited; a mezzanine will be built over the top of the RF coax equipment, leaving a space of less than half a metre so careful planning and the use of 3D CAD imaging will be used to understand and optimise the layout of components, and ensure that the sequence of installation matches the space and timeline of the rest of the MICE hall.

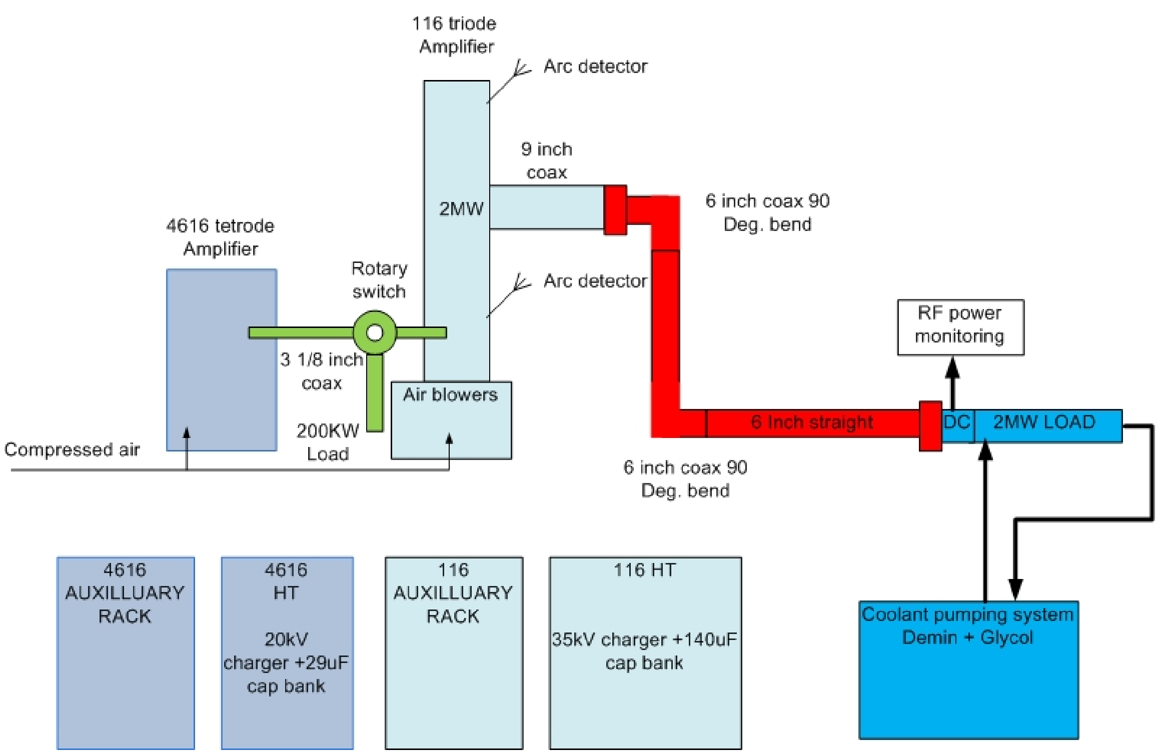

Figure 2: Daresbury Test Area

Coax Components

The components that will be installed between the amplifiers and the RFCC will be based on 6 1/8 inch coax pressurised with dry nitrogen. A gas barrier at the amplifier will be used to pressurise the system all the way to the cavity input couplers. This will do two things, increase the voltage standoff of the coax sections by keeping moisture and dust to a minimum and provide an interlock to the control system that the coax guide is complete.

The 116 amplifiers from LBNL differ in one respect from the CERN units, in that the LBNL amplifiers have one 9 inch capacitive output, the power from this will be split two ways using a 3 dB power splitter. The CERN amplifiers have two 6 1/8 inch coax outputs from taps directly on the grid circuit, as the power is already spilt on this amplifier it negates the need for a power splitting device.

The next piece of coax equipment will be a phase shifter. This will be used to move the reflected power away from the amplifier. This is standard practice at both Femilab and Brookhaven when using amplifiers of this type. Trombone style phase shifters are large devices however and it will be a challenge to find the space to fit a device like this on each amplifier feed.

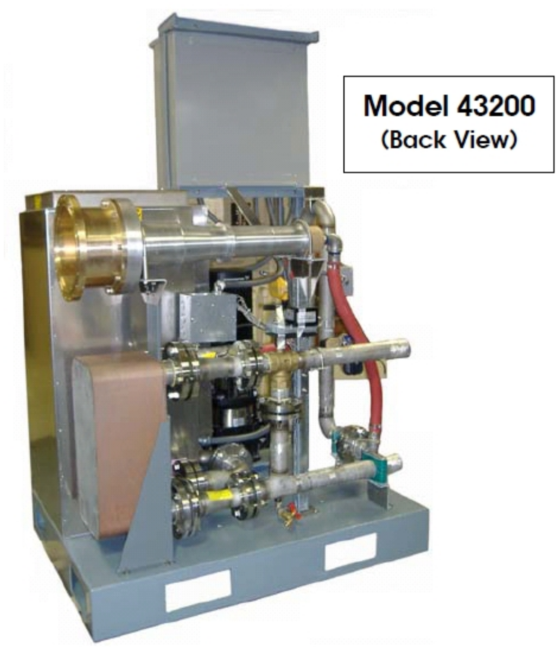

Figure 3: Altronic 43200 RF load and coolant pumping station

As each cavity in the RFCC has two input couplers the power from each amplifier has to be split to provide 500 kW of power into each coupler. This will be done using a hybrid power splitter. The reason to use such a device is that the isolation between the two output ports is significantly increased over a 3 dB power splitter for example. The use of a circulator was considered, however at 200 MHz these devices become unfeasibly large and will simply not fit in the hall space. This isolation factor may become an important issue during setup and operation if one power coupler starts to reject power. As the hybrid splitter uses a reject load on its reflected power stub, any reflected power will be split equally between the reject load and the input port of the device. This system will provide the best solution for isolating the cavity from the amplifier, should some sort of imbalance occur. The RF load itself could be the model shown in Figure 3 from Altronic Research Inc. The system uses a relatively small RF load which is important for the hall layout, coupled to a cooling plant. Given the relatively low average power of the MICE RF system, it may be possible to have a number of these loads connected to one remote mounted cooling plant to save on the space required.

The cavity input couplers need to be supplied with RF power at the correct phase to ensure that power is added inside the cavity. Careful design of the path lengths of the coax system will need to be made to ensure this occurs. A small phase mismatch can be removed using probe style phase shifters; these devices have been built by Mega Industries LLC and have a phase range of 15 degrees.

At positions in the coax run where power is split, it is intended to install directional couplers to monitor forward and reflected power. These signals will be digitised by the LLRF system along with the cavity probe signals to provide closed loop operation and a monitoring of the system performance. The LLRF will have an EPICS interface to link into the MICE control system. This will enable full remote control and archiving of all monitored parameters

CONCLUSION

Testing of the first high power amplifier is imminent, with electrical system tests underway right now. The test area that has been constructed will allow power supplies and amplifiers to be tested in a known system so that any issues can be isolated and solved before equipment is transferring to the MICE experiment itself.

The layout of coax and components to be used in the experimental hall has been discussed and a design is being refined to optimise the system to fit inside the space available in the MICE hall.

REFERENCES

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