Progress in the Construction of the MICE Cooling Channel

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Abstract. The international Muon Ionization Cooling Experiment (MICE) aims to build and test one section of an ionization cooling channel. It is sited at the Rutherford Appleton Laboratory in the UK, utilizing the pulsed muon beam from the ISIS rapid cycling synchrotron. The major parts of MICE include two Spectrometer Solenoid (SS) modules, three Absorber-Focus-Coil (AFC) modules and two RF Coupling-Coil (RFCC) modules. The compact integration of large superconducting magnets, high gradient normal conducting RF system, strong magnetic field and a safe liquid hydrogen system makes this experiment technically challenging. In this paper we will introduce the recent construction progress on various components and the latest schedule for MICE.

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INTRODUCTION

The international Muon Ionization Cooling Experiment (MICE) at Rutherford Appleton Laboratory (RAL) [1, 2], shown in Figure 1, aims to build and test one cell of an ionization cooling lattice and is designed to achieve a 10% transverse emittance reduction. It mainly consists of three kinds of modules: two Spectrometer Solenoid (SS) modules to track the incoming and outgoing muon beams, three Absorber Focus Coil (AFC) modules to reduce the beam momentum in both longitudinal and transverse directions, and two RF Coupling Coil (RFCC) modules to compensate the longitudinal momentum loss. Both learning through engineering experience and benchmarking the ionization simulation code from MICE will be beneficial for building a future neutrino factory and muon collider.

The latest plan of MICE construction is divided into three steps, as shown in Figure 2, with data taken at each step. In Step I, the incoming muon beam is measured directly without any solenoid focusing, cooling or re-accelerating. The emittance measurement results and detailed discussions are presented in [3]. In Step IV, with the upstream and downstream SS module, and one AFC module in between, one can measure the beam emittance before and after the absorber and evaluate the ionization process. In Step VI, the full system is set up by adding two more AFC modules for more ionizing effect and two RFCC modules to compensate the longitudinal momentum loss in the AFC modules. The designed transverse emittance reduction is $\approx$10%, depending on the initial emittance. As of June 2012, Step I has been completed and Step IV and Step VI are now under construction.

MICE STEP IV

The goal of Step IV is to measure the ratio of emittances before and after the absorber. The major instruments needed for this step are one AFC module and two SS modules.With two fiber trackers and liquid absorbers ready, solid absorbers and Electron Muon Ranger (EMR) installation almost ready, the construction work is focused on the AFC focus coil, liquid hydrogen (LH_2) system and two spectrometer solenoids.

The AFC focus coil, as shown in Figure 3, provides the guiding magnetic field in the liquid hydrogen absorber. It consists of two superconducting coils which can be operated with the same (“solenoid mode”) or opposite (“flip mode”) polarities. As of June 2012, the radiation shields have been fitted and the cold mass has been installed and aligned. The first AFC focus coil is scheduled to arrive at RAL in July and the absorber integration will take another 3 months.

The liquid hydrogen (LH_2) system provides the hydrogen for the absorber. The system layout is shown in Figure 4. As of June 2012, all the hardware has been completed, as well as the vacuum check, helium check and heater-chiller check. Before being connected to the absorber, the LH_2 system will be connected to a test cryostat for a system test. The preparation of the system test is in progress.

The spectrometer solenoid provides a guiding magnetic field in the fiber tracker, which bends the muons to allow measurement of their momenta. Learning from the previous magnet training experience [4], modifications have been done to reduce the heat leak to the cold mass, increase the available cooling power and stabi-

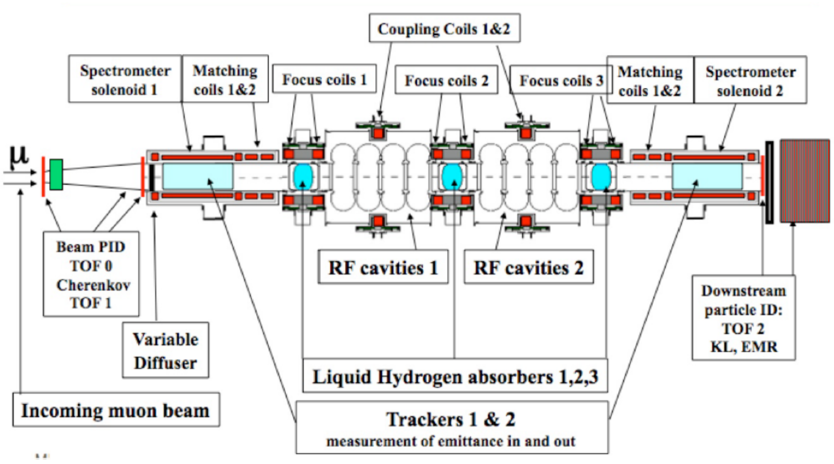

FIGURE 1. MICE layout.

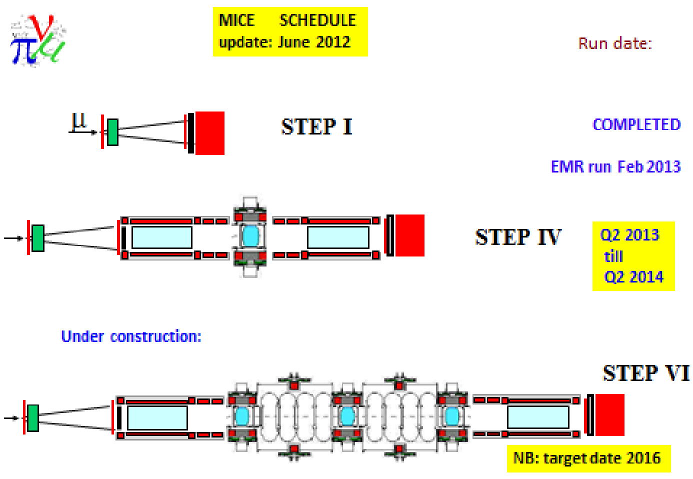

FIGURE 2. MICE schedule, updated in June 2012.

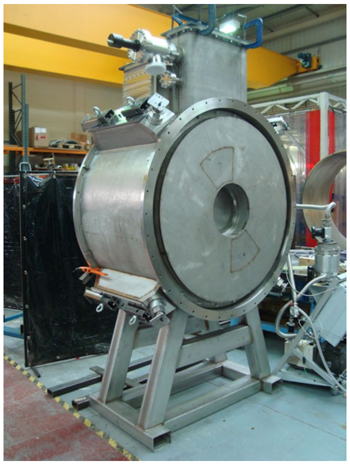

FIGURE 3. Absorber focus coil.

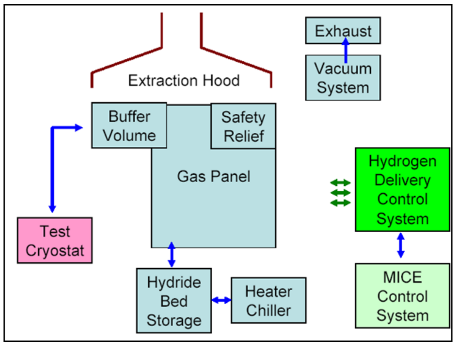

FIGURE 4. LH$_2$ system layout.

lize the LTS (low temperature superconducting) leads. For the first SS, the LTS and HTS (high temperature superconducting) leads which were burnt in the previous training have been replaced. After assembling the SS and cooling down the cold mass, the magnet training has resumed at the vendor, Wang NMR, in Livermore, California, as shown in Figures 5, 6 and 7. A DAQ quench protection system has been implemented by Fermilab, which can detect the quench initiation and propagation in the solenoids by measuring the voltage drop across each coil. It also monitors all the LTS and HTS leads for any possible lead failure. As of June 2012, the quench current of magnet training is going up steadily and on schedule.

The second SS is under assembly at Wang NMR. Its training will start after the training of the first SS is done.

MICE STEP IV

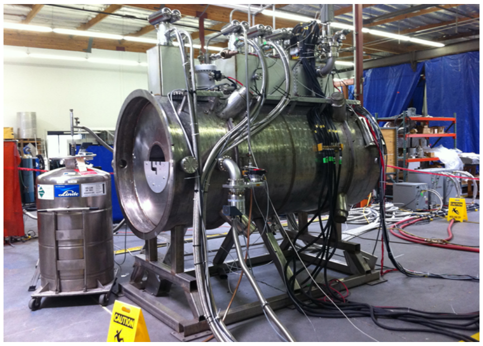

FIGURE 5. Spectrometer Solenoid training at Wang NMR.

FIGURE 6. Quench protection DAQ, instrumentation and power supply control.

From Step IV to Step VI, two RFCC modules are implemented to compensate the longitudinal momentum loss, and two more AFC modules are installed for more ionization effect with the total transverse emittance reduction estimated to be about 10%. The emittance measurement accuracy is required to be within 0.1%.

Each RFCC module [5] consists of four 201 MHz normal conducting RF cavities and one coupling coil. To improve the acceleration efficiency and suppress RF breakdown, beryllium windows are installed on the irises of the cavity. Ten cavities, eleven beryllium windows and ten RF windows have been manufactured and shipped to Lawrence Berkeley National Lab (LBNL). RF break-

FIGURE 7. Magnet quench.

down in the strong magnetic field is associated with the field emission electrons [6]. To suppress field emission, electropolishing (EP) has been carried out on one cavity, shown in Figure 8, to reduce the number of surface emitters. This cavity will be shipped to Fermilab, installed in a single cavity vacuum vessel, and tested in a strong magnetic field. EP of the rest cavities is planned to start at the end of 2012 at LBNL.

FIGURE 8. Setup of Electropolishing for the 201 MHz cavity.

The coupling coil (CC) provides the guiding magnetic field in the RF cavity. It is the largest superconducting coil in MICE. An external review of the CC design was held at LBNL in March 2012 and the detailed design was finished by June 2012. The first cold mass manufactured by Harbin Institute of Technology (HIT) has arrived at LBNL, shown in Figure 9. LBNL and Fermilab are now preparing the full current test of the cold mass. At LBNL, work on the cooling tube, quench protection circuit, vacuum potting and interface with the Fermilab test facility are underway. A cryostat, shown in Figure 10, has been shipped from the National High Magnetic Field Laboratory (NHMFL) to Fermilab. It will be modified and installed for the CC cold mass full current test. Fabrication of the CC cryostat has been planned and will be carried out at LBNL.

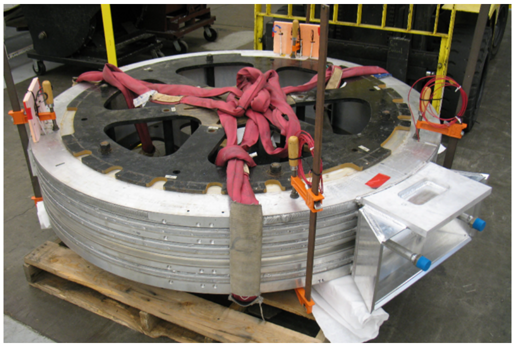

FIGURE 9. Coupling Coil cold mass at LBNL.

FIGURE 10. Cryostat from NHMFL for Coupling Coil cold mass test.

CONCLUSIONS

The construction of the MICE cooling channel is making good progress. An updated schedule stages the construction process into three steps, with physics carried out in each step. We aim to complete the construction of Step IV in Q2 2013 and run the experiment from Q2 2013 to Q3 2014. The target date for Step VI is 2016, when we will fully demonstrate the muon ionization cooling.

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