ACOUSTIC SPARK LOCALIZATION FOR THE 201 MHZ RF CAVITY*

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Abstract

Current designs for muon cooling channels require high-gradient RF cavities to be placed in solenoidal magnetic fields in order to contain muons with large transverse emittances. It has been found that doing so reduces the threshold at which RF cavity breakdown occurs. To aid the effort to study RF cavity breakdown in magnetic fields it would be helpful to have a diagnostic tool which can detect breakdown and localize the source of the breakdown inside the cavity. We report here on the experiment setup for localizing sparks in an RF cavity by using piezoelectric transducers and on preparation for data collection on a 201.25 MHz vacuum cavity.

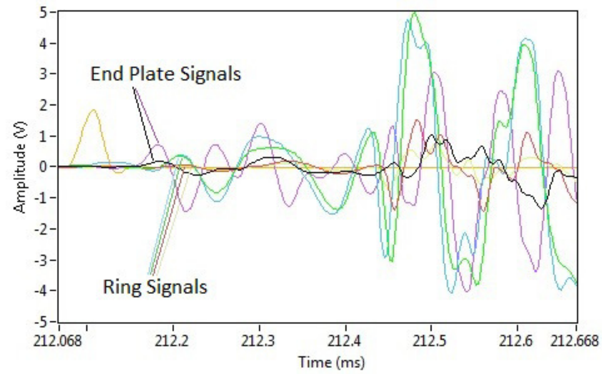

Figure 1: 600 μs of conditioned spark signals.

INTRODUCTION

Muon beams are desired for use in future particle physics experiments. Muon colliders could compliment hadron machines like the LHC without the need for prohibitively long accelerators that are proposed for electron-positron machines such as the ILC or CLIC. Neutrino physics would also benefit from having a neutrino factory which generates a neutrino beam from the decay of muons.

The main challenge with using muons for colliders and neutrino factories is creating tight muon beams. Muons are created from the decay of pions which themselves come from proton collisions with fixed targets. The resultant spray of muons must be collected, focused, and accelerated well within the muon lifetime (2.2 μs in the rest frame). The only feasible method that has been conceived for reducing the beam size prior to accelerating it is ionization cooling.

Ionization cooling uses low-Z materials as energy absorbers to reduce the overall momentum of muons. The muons are then subjected to electric fields which accelerate them only along the beam axis [1]. To corral the muons as they are cooled transversely, strong solenoidal magnetic fields are used. Unfortunately it has been found that the maximum accelerating gradient a cavity can produce without breaking down is significantly reduced in the presence of strong magnetic fields [2].

In order to improve the performance of accelerating cavities in strong magnetic fields, it would be useful to have a diagnostic tool that would indicate where breakdown sparks are occurring without having to shutdown the experiment and open the cavity to inspect damage. Currently the Muon Ionization Cooling Experiment's 201.25 MHz RF cavity is being tested in the MuCool Test Area (MTA) at Fermilab. We have demonstrated the feasibility of acoustic localization of breakdown spark sources with other cavities, and we present here our progress in instrumenting the MICE cavity with an acoustic transducer microphone array and the setup of the associated DAQ system.

PREVIOUS FEASIBILITY STUDIES

Previously we reported on our attempts to demonstrate acoustic localization of breakdown by instrumenting two similar RF cavities with microphones on the outer surfaces in various physical configurations [3]. We developed software in LabVIEW that conditions the signals and then applies the Accumulated Correlation algorithm borrowed from free-space acoustic localization. Like other time delay estimation techniques, this algorithm utilizes at its core the cross-correlation between each pair of signals to determine their separation in time and thus the relative distances of the corresponding microphones from the sound source [4].

The original microphones that we used were a design borrowed directly from the COUPP dark matter experiment. These had an on-board amplifier that easily clipped the signals due to the much louder nature of our breakdown events. We then built prototype microphones with various lower gain amplifiers. Since the cross-correlation of two signals is largely unaffected by amplitude differences, using amplifiers with different gains was not a concern.

The cavities we used were cylindrical with their axis of symmetry aligned with the beam axis. The cavities are in general composed of a ring capped off with end plates. We started out by placing a single microphone on each end plate (upstream and downstream surfaces) and between three and four microphones on the outer diameter of the ring. As can be seen from Fig. 1, we were able to distinguish at least by sight in a brief period at the very beginning of the spark signals between end plate and ring wavefronts.

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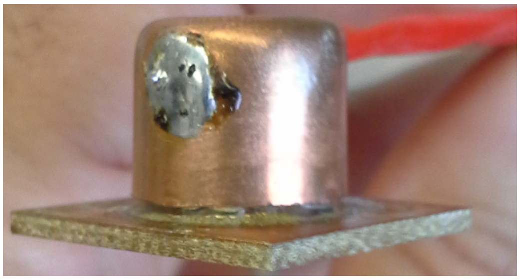

Figure 2: The passive acoustic transducer design for instrumenting the MICE Single-Cavity Module.

Since the cross-correlation is designed to work on two signals that are different only in their phase, the signals were often not similar enough to apply the localization algorithm and expect a reasonable position estimate. Considering also space limitations of cavities mounted inside a solenoidal magnet and preliminary simulation results, we decided it would be better to mount all of the microphones on the upstream and downstream surfaces. Our first attempt at data taking using the "all-seasons cavity" (ASC) and this microphone configuration was plagued by an electrical anomaly that destroyed the acoustic signal in the region useful for applying the localization algorithm. A later attempt saw no such interference, but time ran out for experiments on the ASC without recording any useful acoustic breakdown signatures.

MICE CAVITY SETUP

At the time of publication, testing will have begun on the first of the Muon Ionization Cooling Experiment's 201.25 MHz Single-Cavity Modules (SCM). It was decided that the next step in developing an acoustic breakdown localization system would be to instrument the SCM. This cavity is much larger than the previous test cavities (48.5 inches in diameter compared to 12 and 14.5 inches) allowing us to attach many more transducers. The increased number of inputs results in more statistics that should yield a better prediction of the breakdown source locations.

The previous cavities were built of thick stainless steel which allowed them to be either evacuated or pressurized without deforming. The SCM is made of relatively thin annealed copper with the option of various thin windows to reduce the amount of material a particle would have to encounter before and after acceleration inside the cavity. The cavity is evacuated, so to compensate for pressure forces that could deform the cavity it also sits in an evacuated vessel. No power is allowed inside the vacuum vessel, so a new passive acoustic transducer design was created. The design has a piezo attached to PCB board and surrounded by a 3/8 inch copper pipe cap as the Faraday cage (see Fig. 2).

Passive Transducer Construction

In addition to the limitation on power in the vacuum vessel, there were other requirements due to the low pressure environment as well as the eventual use of strong magnetic fields. All parts are joined using either lead-free solder or vacuum-compatible epoxy. The base of the transducer (a short section of 3/8 inch copper pipe) is soldered to the PCB board using solder paste and an oven. We originally tried to use solder paste as well to attach the bottom terminal of the piezo to the PCB board as well as to attach wire to the top terminal of the piezo, but we experienced problems with the silver terminal pads delaminating during the high-temperature bake needed to melt the solder paste. Thus we use EPO-TEK H21D silver-filled epoxy from Epoxy Technology to make connections to the piezo terminals. A piece of copper foil is epoxied to the top terminal which can then be readily soldered to without overheating and delaminating the pad. H21D is also used to attach a negative lead to the base, the cap to the base, and secure the cable shield drain wire to the outside of the cap. Before the cap is secured the base is potted with Loctite Hysol 1C epoxy for structural strength.

Transducer Installation

The initial configuration of the SCM includes 24 transducers, 12 for each of the upstream and downstream sides of the cavity. Six transducers were placed at about 3/4 of the radius from the center with 120 degree separation. The remaining six transducers are placed on the copper windows with one transducer in the middle surrounded by five equally spaced transducers at 1/2 the window radius. Since these are passive devices, the plan is to attempt to use one of the center transducers as a signal source to calibrate the other transducers. This transducer is much larger than the others due to the fact that the smaller piezos are incapable of putting out sufficient volume. Eventually the copper windows will be swapped out for berilium windows at which time there will only be 12 transducers on the main cavity body. Additional transducers may be placed on the external surface of the RF coupler pipes to help distinguish any spark sources that may come from the RF copuler.

The transducer cables were terminated with four-pin Burndy connectors for negative, positive, and shield drain (the last pin is unused). Two umbilical cable bundles were created feeding into two 41-pin feed-through ports in on the inside of the vacuum vessel with matching Burndy connectors at the opposite ends for attaching to the transducer cables. The Burndy connectors had springy washers for the locking machanism that is feromagnetic. These were removed and replaced with plastic washers to avoid interaction with magnetic fields. To adhere the transducers to the cavity body we used Scotchweld 1838 epoxy. To keep the transducers in place on the vertical surfaces while the epoxy cured we had simple clamps machined that attached to the tension ring on the cavity by a single bolt. The other end had a screw that advances toward the cavity surface and holds the transducer in place. On the copper windows we used Easypoxy K-20 and simply used wieghts to hold the transducers in place since the windows could be removed and laid on a flat surface.

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Data Acquisition Hardware

The DAQ hardware consists of a National Instruments cDAQ-9188 Ethernet chassis with four NI 9221, 8-channel, 100 kS/s (per channel), 12-bit analog input modules. Though the sampling rate is lower than we would have liked, this was the best compromise for our budget. Fortunately the larger size of the SCM requires less spatial resolution, and consequently less temporal resolution in the signals, to distinguish between transducers. In lieu of the on-board amplifiers, a set of eight-channel Programable Gain Amplifier receiver boards were fabricated at Fermilab. The receiver boards have been configured with a 50 kHz (the Nyquist frequency of the analog input modules) and four independently selectable gains between 2 and 200. The receiver boards and DAQ chassis are placed as close as possible to the cavity to minimize signal losses in the cable while being safely outside of the high-field zone of the 5 T solenoid magnet used for studies of RF cavity breakdown in magnetic fields. The DAQ modules are then controlled through a gigabit Ethernet LAN connection from the MTA control station located along the Fermilab linac gallery.

Signal Interference Mitigation

The PGA receiver boards sit inside a metal box with, initially, eight BNC inputs and eight BNC outputs. We discovered that the box components were coated with a non-conductive finish which prevented the sides from being electrically connected, preventing the box from being an effective Faraday cage. To complete the Faraday cage we dismantled the box and scraped enough of the finish away at the attachment points to ensure all parts of the box were at the same potential. To further improve interference shielding we decided to bypass the BNC connectors for the differential inputs and use a shielded, multi-twisted-pair cable. The cable has fifteen pairs, so we removed the boxes' top panels and created brackets to attach the boxes top-to-top giving us two boxes each containing a pair of receiver boards. Finally, the drain wires from the multiple twisted pair wires were bundled together and bolted to the metal cable strain relief bar. See Fig. 3 to see the boxes after modification. The BNC connectors all have their ground conductor isolated from the box. Upon testing we discovered this allowed significant interference on the single-ended outputs into the DAQ modules. To remedy this we used the washers removed from the Burndy connectors inside the vacuum vessel to create an electrical connection between the isolated mount of the box BNC connectors and the outer ground conductor of the BNC connectors of the cables leading to the DAQ modules.

SOFTWARE

As the SCM begins its initial test runs the software used in previous acoustic breakdown localization experiments will be updated to the specfic geometry and properties of the cavity as well as the configuration of the transducers. The algorithm will be modified to first localize on the upstream and downstream surfaces separately. Additional information can be obtained by comparing the time of the upstream event with the time of the downstream event. It will hopefully be possible to determine the direction of the breakdown spark if it is unipolar or whether the spark is bipolar. Additional analysis of the signals will be provided through comparisons with acoustic simulations that have begun using COMSOL Multiphysics.

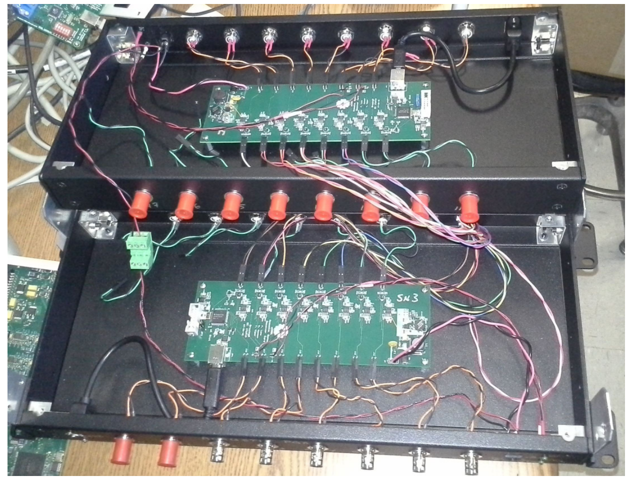

Figure 3: The PGA reciever boxes after modification.

CONCLUSION

We have successfully instrumented the first MICE Single Cavity Module with 24 passive acoustic transducer microphones and completed a DAQ system for processing their signals. With localization software updated based on conclusions from previous experience and the beginning of RF tests with the SCM, we expect to soon be in a position to demonstrate a complete vialbe system for acoustically localizing the source of RF cavity breakdown.

ACKNOWLEDGMENT

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