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Experimental analysis of surface finish in normal conducting cavities

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ABSTRACT

A normal conducting 805 MHz test cavity with an in built button shaped sample is used to conduct a series of surface treatment experiments. The button enhances the local fields and influences the likelihood of an RF breakdown event. Because of their smaller sizes, compared to the whole cavity surface, they allow practical investigations of the effects of cavity surface preparation in relation to RF breakdown. Manufacturing techniques and steps for preparing the buttons to improve the surface quality are described in detail. It was observed that even after the final stage of the surface treatment, defects on the surface of the cavities still could be found.

1. Introduction

In a Neutrino Factory complex pions are created by bombarding a target by protons and are captured by a magnetic field at low energy where they decay to muons [1,2]. The phase space of the muons is controlled and shrunk through bunching and cooling. They would be accelerated later and injected into storage rings with long straight sections where muons decay to produce neutrinos that are directed towards the detectors [1,2].

The reduction in the transverse emittance of muons is achieved through a technique known as ionisation cooling where muon beam is cooled through energy loss at absorbers [3–5]. Existing techniques such as stochastic, electron and laser cooling for transverse emittance reduction are not feasible due to the muon's short lifetime of 2.2 μs [4]. The net effect of transverse cooling can be achieved if the longitudinal momentum is restored through re-acceleration. The Muon Ionisation Cooling Experiment (MICE) is essentially a proof of this principle and is based at the Rutherford Appleton Laboratory (RAL) [3–7]. The MICE experiment consists of a cooling section positioned between a pair of particle spectrometers. The 200 MeV muon beam is generated from the ISIS 800 MeV proton beam at Rutherford Appleton Laboratory (RAL). The cooling cell is made out of two 201 MHz cavities, one primary and two secondary LiH absorbers placed between two superconducting focusing coil modules. The cooling cell is also sandwiched between two spectrometer solenoid modules [5].

The MuCool Test Area (MTA) is a dedicated facility built at Fermilab [6] to support the technology development for muon ionisation cooling channels. The main purpose is to assess the characteristics of an RF cavity under the same conditions as those experienced in an ionisation cooling channel. The principal components at the MTA are the 201 MHz MICE test cavity and a higher frequency (and smaller size) 805 MHz button test cavity. The 805 MHz test cavity is positioned inside a 4 Tesla (T) superconducting solenoid, and closely resembles a cylindrical pillbox cavity with Beryllium windows covering the irises. The experiment has been designed to allow for demountable windows to be installed. As a result, various physics are being investigated through different tests, such as those involving button samples. The cavity parameters are given in Table 1.

A major goal of the MTA program is to test and investigate the performance of different materials and surface treatments in the presence of high electric and magnetic fields. The prime interest is the manufacture of 201 MHz, which demands sheet metal processing. The 201 MHz cavities, however, do not accommodate button samples. The 805 MHz cavities are small enough to be manufactured by machining from solid bulk and accommodate button samples. New buttons had to be designed, which could be manufactured using sheet metal techniques and tested in the 805 MHz cavity. The button shape enhances the field locally, ensuring any possible breakdown occurring on the button surface. The performance of the sample is analysed by increasing the field strength in steps until RF breakdown has occurs. The buttons allow for a wide variety of materials to be tested with quick and easy changeover between the samples. They also provide a practical way to use small samples instead of the whole cavities for the purpose of testing the cavity surface

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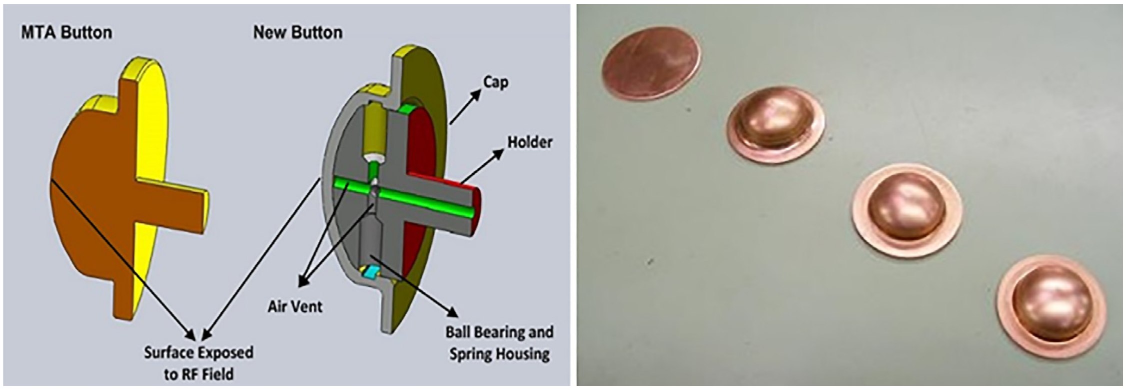

Fig. 1. Cross sectional view of the current MTA button (far left) and new design (left); four stages of Cap piece fabrication (right).

Table 1
Main MTA 805 MHz cavity parameters.

Parameter	Value	Unit
Frequency	805	MHz
Cavity radius	15.62	cm
Gap length	8.1	cm
Be windows thickness	0.127	mm
Cavity shunt Impedance	32	MΩ/m
Cavity quality factor Q	18,800	

preparation. This forms the basis for the surface roughness measurement experiment, where button samples are produced and treated using a series of manufacturing and preparation techniques. RF breakdown with external magnetic field in 201 MHz and 805 MHz cavities were studied at the MTA [8]. The MTA group has investigated the field emission characteristics of various materials and the effects of an externally applied magnetic field on such emissions [9,10]. The quality of the RF surface has been identified as a major factor contributing to RF breakdown [8]. Hence this research has focused on the quality of the RF surface and how various production and surface treatment techniques alter the final surface finish. A new button testing program was defined focusing on manufacturing techniques instead of material. While the button design was changed, the overall size and shape was kept similar to the MTA button. This was to allow complete compatibility with the testing equipment available at the MTA testing area.

The structure of the paper is as follows. Section 2 introduces fabrication setup used to manufacture each button sample. This is followed by the introduction of the processing setup used to treat the surface of each button in Section 3. The main methods employed for the surface treatment are hand polishing, chemical etching, electro polishing (EP) and electro plating (EPL). A detailed investigation in to the quality of the RF surface is presented in Section 4, highlighting the changes observed during various stages of production. Surface roughness [11] for each button is investigated quantitatively in terms of Average and Root Mean Square (RMS) surface roughness. Finally, we summarise our results in the conclusions made in Section 5.

2. Button fabrication techniques

During the production of an RF cavity, the metallic surface experiences both mechanical and chemical alterations. Hence the quality of the RF surface is directly influenced by the manufacturing techniques employed during production. The quality of the RF surface can influence the probability of an RF breakdown event.

In order to enhance the performance of the cavity, production methods need to be improved and further investigated. The MTA research program has been performing a series of high power tests on button shaped samples using an 805 MHz copper cavity. The aim is to investigate the RF breakdown limit of various materials by exposing each to high E and B fields [12–18]. Our focus, however, is on the manufacturing techniques rather than material properties of the buttons [19–21].

The new design of the button test piece is shown in left panel of Fig. 1. Although the overall shape is similar to the MTA design (Fig. 1 far left), the new design consists of two separate detachable parts. The upper part known as the cap is subject to RF fields inside the cavity and is held in the correct position by the holder. A major benefit of such a design is the ability to use a wider range of fabrication techniques due to simpler design. During testing, the cap and holder need to stay as one unit. This was achieved by drilling six equally spaced holes in the holder, each housing a ball bearing and spring mechanism. When in position, the springs generate the necessary friction between the cap and the holder by pushing the ball bearings towards the internal walls of the cap. A series of air vents are incorporated in the holder to ensure no air pockets are trapped when operating in vacuum.

To replicate the processes used for the production of the MICE 201 MHz cavity, sheet metal drawing was used as the fabrication method. The cap is made out of a 1 mm thick copper sheet. As shown in Fig. 1 (right), the cap was pressed in four different stages, achieving the final shape. The staged deformation process was designed to avoid possible rupture when stretching the material. The material of choice for normal conducting cavities is Oxygen-Free High Conductivity (OFHC) copper. This generally refers to a group of wrought, high conductivity a copper that has been refined to reduce oxygen levels.

The cap was manufactured using OFHC to match the characteristics of MICE and MTA cavities. The oxygen purity level of the OFHC used in this research was 99.99% [22]. The holder on the other hand, is not subject to RF fields but needs to be operated in the presence of high magnetic fields. To fulfil such requirement, the holder was made out of aluminium alloy with high mechanical strength and ability for easy machining. Furthermore, attention was paid to choose austenite stainless steel for each ball bearing and spring mechanism.

Optical profiling measurement system was used to take the necessary surface roughness measurements. The apparatus used is WYKO NT1100, which is a 3D optical profiling measurement system. The scanning measurement area is 736 by 480 μm. In order to provide a better characterisation of the surface of each sample, measurements were taken at various locations. A total of 16 data points on 4 concentric circles were chosen for the purpose of measurement. As shown in Fig. 2, the apex is counted four times. The overall surface roughness parameters were derived by averaging the roughness of the all sixteen data points. To preserve the accuracy of measurements the incident light was kept orthogonal to the cap surface. This was achieved by designing and manufacturing a scanning holder tool.

The RF surface was prepared using different surface treatment methods. An X-ray Photoelectron Spectroscopy (XPS) was utilised to analyse the chemical composition of the button samples. By taking measurements after each major stage of production, it was possible to identify the changes of the surface characteristics for each sample.