EFFECT OF HIGH SOLENOIDAL MAGNETIC FIELDS ON BREAKDOWN VOLTAGES OF HIGH VACUUM 805 MHZ CAVITIES

A. Moretti, A. Bross, S. Geer, Z. Qian, (FNAL) , J. Norem, (ANL), D. Li, M. Zisman, (LBNL), Y. Torun, (IIT), R. Rimmer, (TJNAL), D. Errede, (UIUC)

Highlights:

The aim of the study is to do R&D on Linac cavities suitable for a muon collider or neutrino factory. The cavitiesfor MuCool need to be immersed in very large solenoidal magnetic field.

There is an on going international collaborative study on the feasibility and cost a collider or neutrino factory.

The study has shown that the peak achievable accelerating gradient is reduced by a factor greater than 2 when solenoidal fields of greater than 2 T are applied to the cavity.

RF is one of the major cost drivers of MuCool. Increasing the achievable accelerating gradient would reduce one of the major cost drivers of a future collider or neutrino factory.

Studies have taken place in Fermilab Facility Lab G.

The Lab G Test Facility:

a Fermilab upgrade Linac modulator and controls,

a 12 MW pulsed klystron and its waveguide system,

a 5 T superconducting magnet with a large warm bore,

a cooling water and high vacuum systems for the test cavity

and a radiation shielded interlocked test cave.

The facility permits research and development on methods and materials to increase the breakdown limit and reduce dark current emissions. It also allows us to test RF components and qualify RF technology for a future muon collider, neutrino factory.

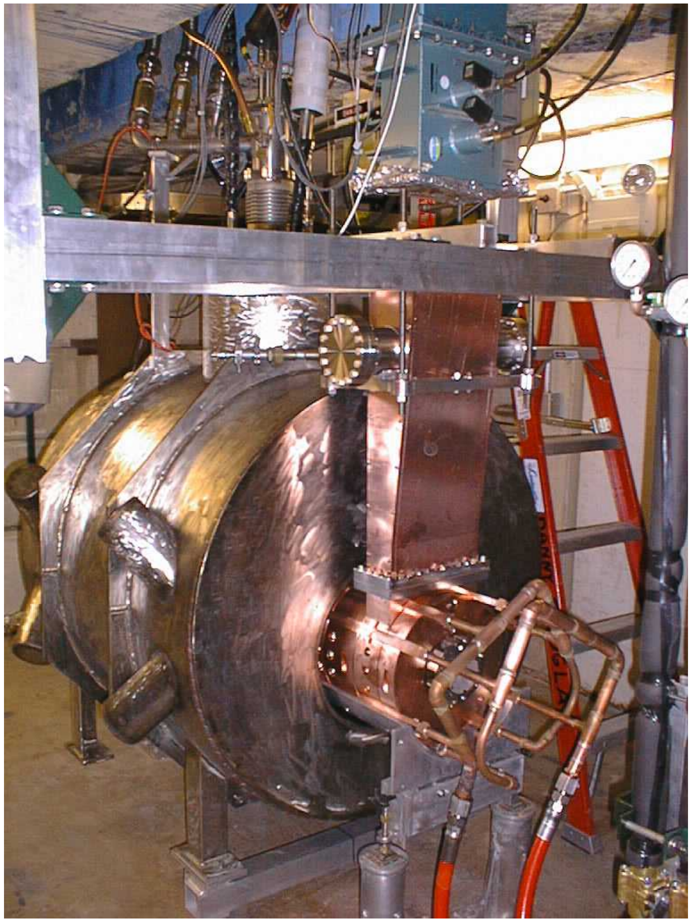

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Figure 1 shows a picture of the 5 T superconducting solenoid with the first test cavity (an open cell cavity) being tested in the facility [4]. At its ends are shown thin 125 µm Ti vacuum windows for dark current and x-ray measurements

Figure 1.

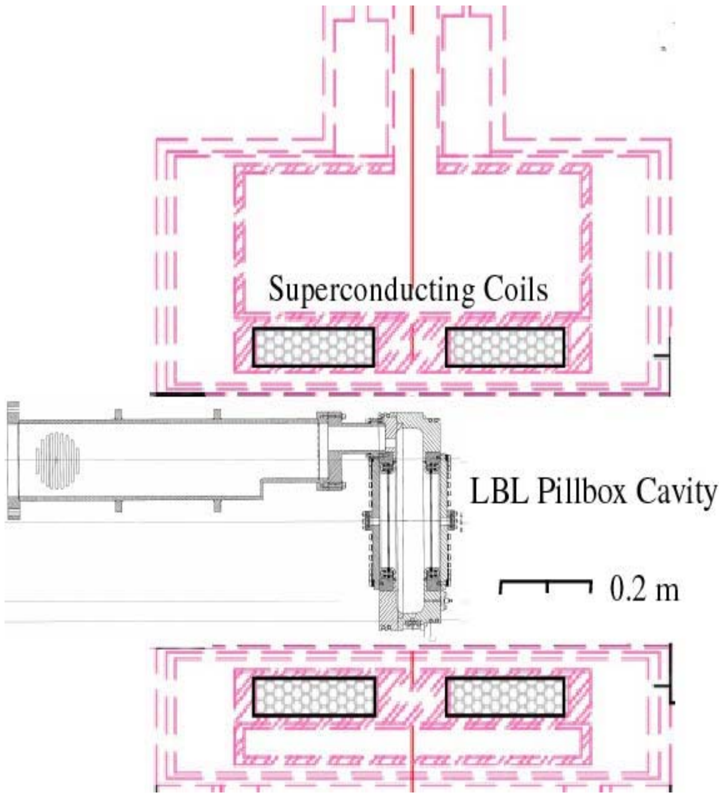

Figure 2. The single cell cavity in the superconducting 5 T solenoid

The arrangement for the second set of measurements on the LBL Pill box cavity is shown in Figure 2. The single cell LBL cavity is shown in the center of figure 2, [5,6]. It has been designed with removable vacuum end pieces and thin windows for dark current measurement.

Note: the solenoid has two separate coils. They can be powered to aid (solenoid mode), opposed (gradient mode), or one coil alone (single coil mode).

EXPERIMENTAL RESULTS ON THE LBL SINGLE CELL CAVITY :

The chart, Figure 3, presents the breakdown limit versus magnetic field results from about a 2 year period of study.

The graph shows the limit above which surface damaging sparks occur during a relatively short RF commissioning period of time. Spending long periods, hours, above this limit results in a very large permanent increase in dark current and x-ray emissions.

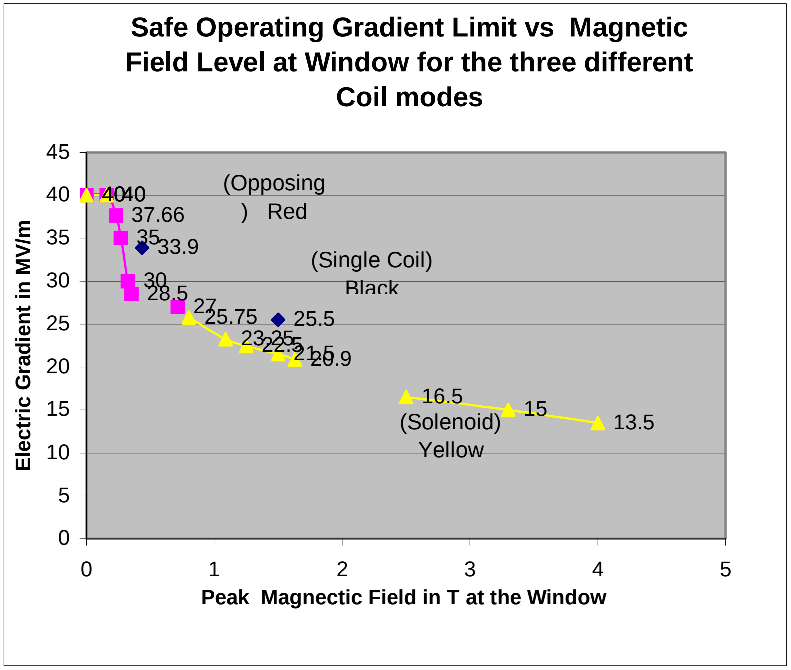

Figure 3. Safe operating electric gradient for the three different coils excitations. Operating above these limits produced damaging sparks that produce large increases in x-ray levels which never fully recover.

Safe Operating Limit Continued:

The graph shows the safe gradient operating limit in a magnetic field. Operating near this or at this limit results in little increase in dark current and x-ray emissions over time. The data were taken with the three magnetic field configurations as parameters and are plotted as a function of the field level at the window.

This shows that the breakdown limit is strongly correlated with the value of the magnetic field at the site of the window. It also shows a reduction in the breakdown limit of greater than a factor two above 2 T.

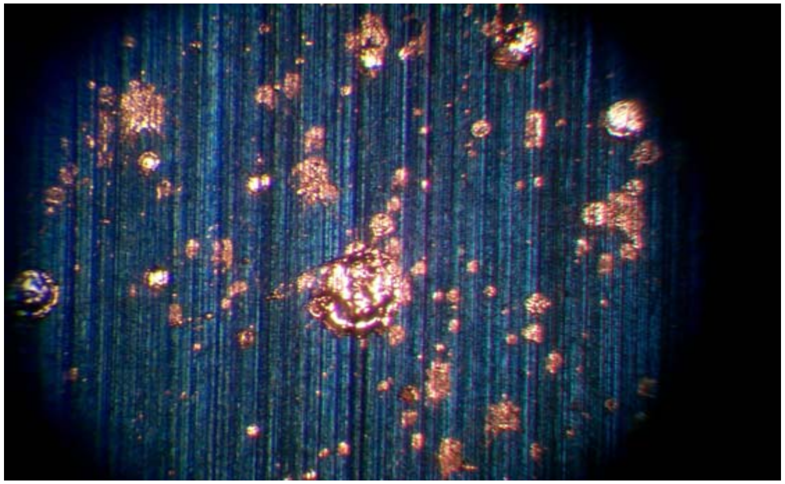

Figure 4. Copper Splatter on Be Window

Examination of the damage by SEM and optical microscope showed molten copper disks 100 to 125 µm in diameter scattered over the Be window surface.

There was no spark damage observed in the Be or in the TiN coating of the window. Spark damage was only observed in the copper parts of the cavity.

The SEM analysis of the molten copper spots indicate they were mainly composed of copper with just a small trace of other elements.

This demonstrates that copper is the weak link in reaching high gradient in large magnetic fields and that Be has a greater intrinsic breakdown limit.

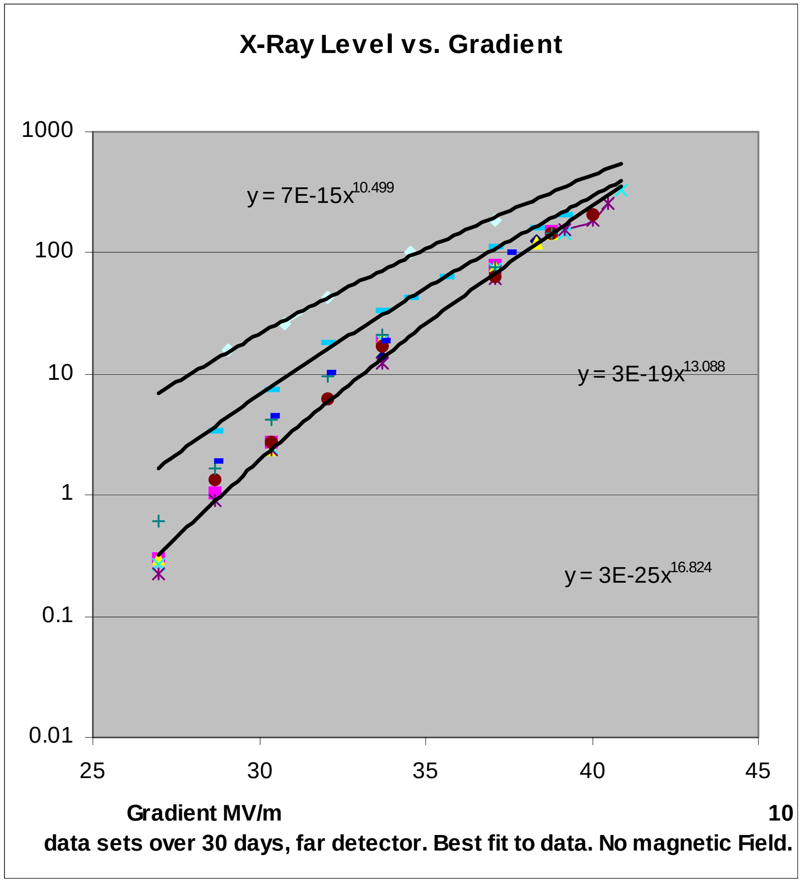

Figure 5. X-ray level in far detector 3 m away from the cavity [vertical scale mrem/hr].

Figure 5, shows typical x-ray level measurements as a function of gradient without magnetic field over a period of 30 days. Time starts with the top curve and ends 30 days later at the bottom curve.

This is called the curing effect. As the RF commissioning time goes on the x-ray levels go down as long as the breakdown limit is not exceeded.

However, as soon as a damaging spark occurs, the x-ray emission greatly increases and never recovers to the previous low background level.

The curves end just below the breakdown limit and indicates that breakdown is determined by the dark current emission.

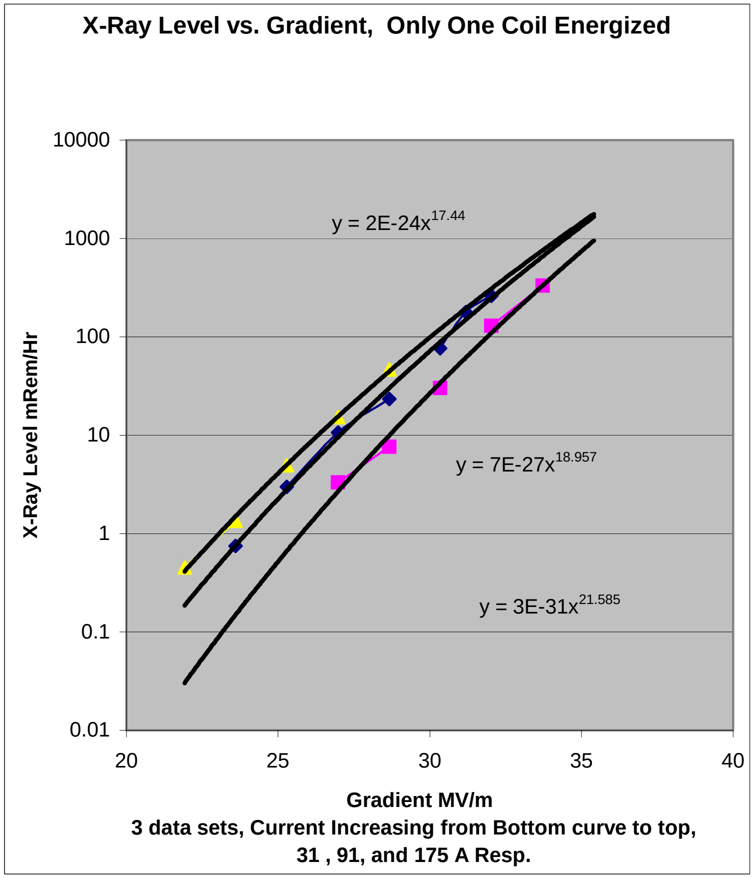

Figure 6. X-ray level in far detector 3 m away from the cavity with magnetic field levels of 0.3 T, 9.1 T and 1.7 T respectively.

Figure 6, shows typical x-ray level measurements as a function of gradient with the magnetic field as a parameter for three field levels. The magnetic field levels increase from bottom to top.

This demonstrates a large increase in x-ray levels with increasing magnetic field. The x-ray background levels are also higher than without the magnetic field because of the focusing effect of the magnet.

As the RF commissioning time goes on, the x-ray levels go down as long as the breakdown limit is not exceeded. However, as soon as a damaging spark occurs, the x-ray emission greatly increase.

SUMMARY AND FUTURE PLANS

In general the breakdown limit is much lower when a solenoidal magnetic field is applied.

The dark current and x-ray emissions are much larger after the occurrence of sparking at very high electric and magnetic field level.

The Lab G facility has been recently shut down and the equipment is being moved to the new Fermilab MuCool Test Area (MTA) Figure 7, [7].

Figure 7. Picture of the MTA at the south end of the Fermilab linac comples.

A modification of the cavity which will allow for the insertion of small button size sample pieces has been designed and is under construction.

Materials under consideration for study are chromium, tungsten, and molybdenum by themselves or as coatings[8].

A research effort is being planned to find a coating that can protect and therefore greatly enhance the breakdown limit of copper.

Figure 8. Picture of the installation of the 805 MHz waveguide and 201 MHz 0.233 m Coax hardline on top of linac berm looking away from linac towards the MTA.