805 MHz Breakdown Studies with Be Windows in Large DC magnetic Field

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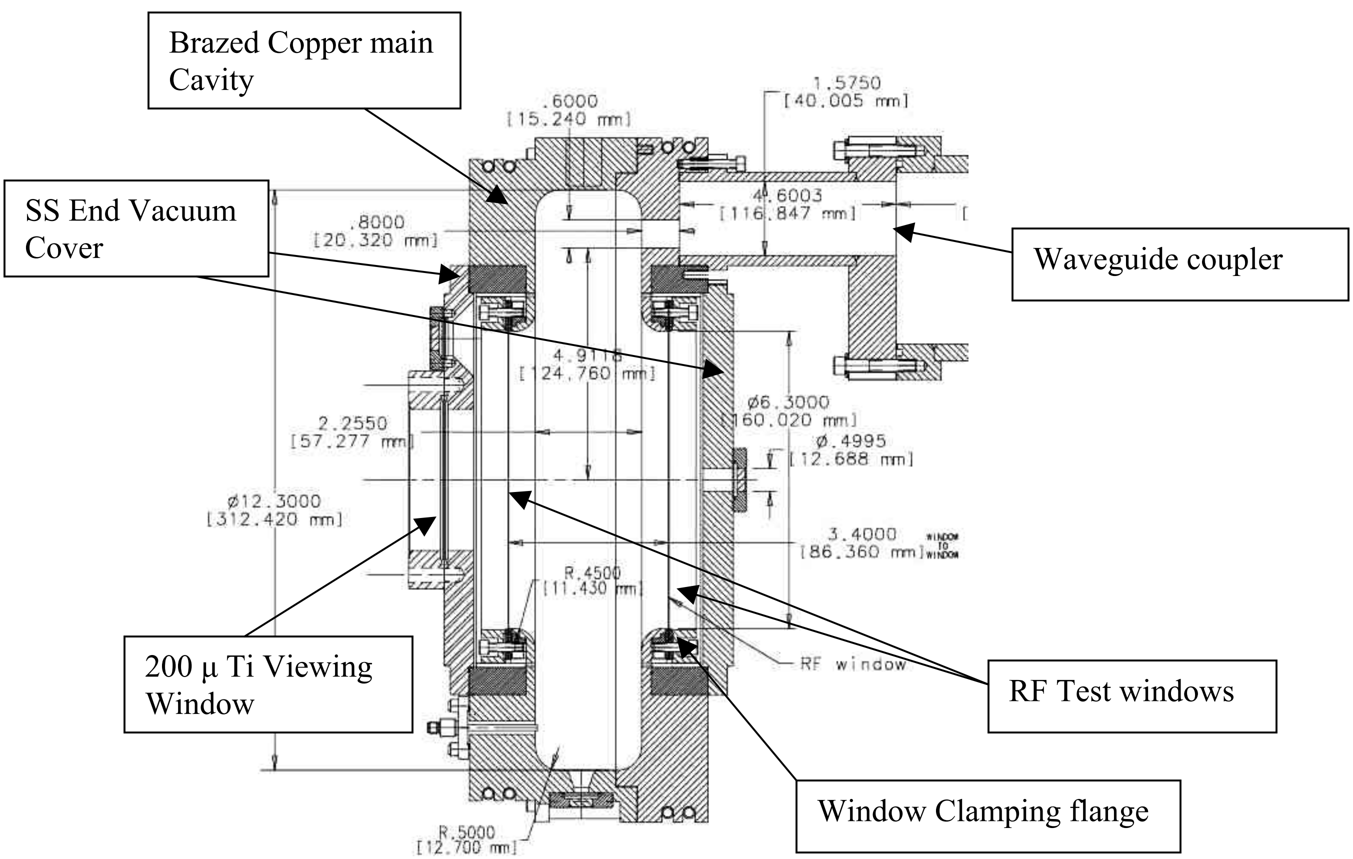
Talk: On experimental Results from LAB G and explanation
Of cavity frequency stability with thin windows.

The LBL cavity, figure 1, has been under study nearly two years.

- *The results of this study with Be window inserts coated with several hundred A of TiN for secondary electron emission and multipactoring reduction are presented.*
- *Figures 1 and 2, show the cavity and the LBL 5 T magnet and its mode of operation.*
- *Figure 3, shows optical microscope image of spark damage on the Be window.*
- *Figure 4, are of the first RF commissioning breakdown limit as function of central coil magnetic field level.*
- *Figure 5, shows the Second RF commissioning breakdown limit as a function of magnetic field at the window for the 3 modes of operation of the magnet. It shows strong correlations with the magnetic field level at the window.*
- *Figures 6, the X-Ray level on the far detector vs. gradient and its exponential dependence.*



Brazed Copper main Cavity
SS End Vacuum Cover
Waveguide coupler
200 µ Ti Viewing Window
RF Test windows
Window Clamping flange
RF window
.6000 [15.240 mm]
1.5750 [40.005 mm]
4.6003 [116.847 mm]
.8000 [20.320 mm]
4.9118 [124.760 mm]
ø6.3000 [160.020 mm]
2.2550 [57.277 mm]
ø.4995 [12.688 mm]
ø12.3000 [312.420 mm]
3.4000 [86.360 mm] WINDOW TO WINDOW
R.4500 [11.430 mm]
R.5000 [12.700 mm]

Figure 1, Single Cell LBL Cavity

Note, the RF Test windows can be removed. They are held in place with 24 small Bolts. They can be removed and another set inserted and tested.

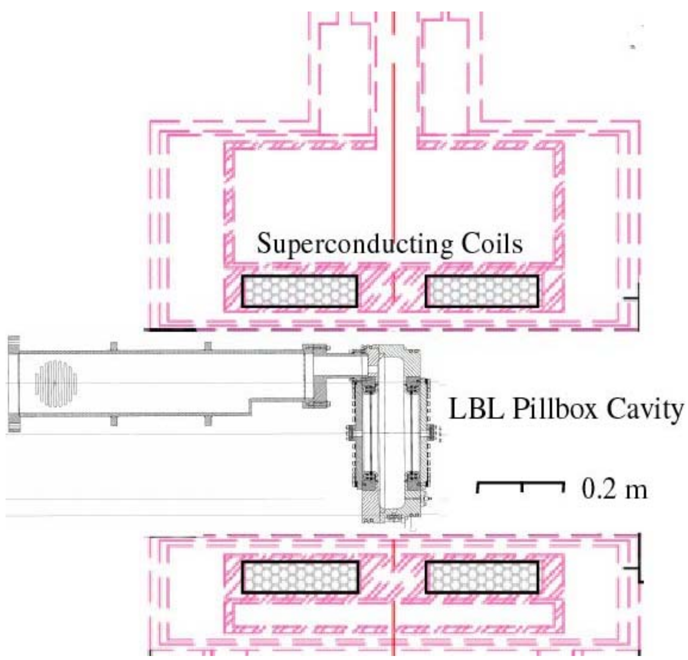


Figure 2, The LBL Single Cell Cavity in the Lab G 5 T superconducting magnet.
<u>Note</u>, the magnet has two separate Coils. They can be powered to aid, solenoid mode; opposed, gradient mode; or one coil alone, single coil mode. Also, the magnetic field at the window sites differ. It is the highest in the solenoid mode; intermediate in single coil mode; and lowest in the gradient mode; about a factor 2 respectively.

The first RF commissioning studying of the LBL Cavity was conducted with Be windows coated with about 500 angstroms of TiN to reduce multipactoring and dark current emissions. The downstream window facing the dark current measuring apparatus was 250 μ in thickness, the other 500 μ. The intent of this study was to determine the breakdown limit of Be with magnet field turned on. It was decided to keep the first part of the RF commissioning to a low gradient of 24 MV/m without the magnetic field on so that any damage observed could be attributed to the field on, condition. The commissioning without the magnetic field went well as before (our test case was a previous run with copper windows) with little sparking and X-Ray emissions low.

The rf commissioning study was extended to 4 T. Conditions changed when the magnetic field was turned on. It behaved much as a previous copper window experiment with the magnetic field on. At gradients of 21 MV/m and 2.5 T and 18.5 MV/m and 4 T, the sparking became severe and the X-Ray emissions greatly increased. After operating at these level for several hours, it was necessary to back the gradient lower to 16.5 MV/m and 13.5 MV/m respectively, to achieve stable operation. The X-ray emissions were also greatly increased. This is what I call the safe operating gradient limit with magnetic field on.

Results of the first commissioning study with the Be windows with magnetic field on at 2.5 T and 4 T are:

* *Reached 21 MV/m at 2.5 T and 18.5 MV/m at 4 T for short time could not maintain; Sparking rate high had to reduce gradient to 16.5 MV/m and 13.5 MV/m, respectiveley for stable operation; Could not increase gradient any higher without high sparking rate and high dark current emission;*
* *Ending Radiation emissions levels were 10 times larger than previous run without magnetic field. However this Run was cut short to inspect and analyse the windows;*
* *Observed a "curing effect" when running without*

Magnetic field on at high RF gradients for several days.

* *Multipactoring was greatly reduced as expected with TiN.*
* *Severe sparking damage observed on copper cavity parts; No spark damage observed on TiN coated Be windows.*
* *After removal and microscope and SEM examination (molten copper found on inside copper support area of the Be windows. Figure 3, shows molten copper splatter, typically 125μ diameter, on the Be windows.*

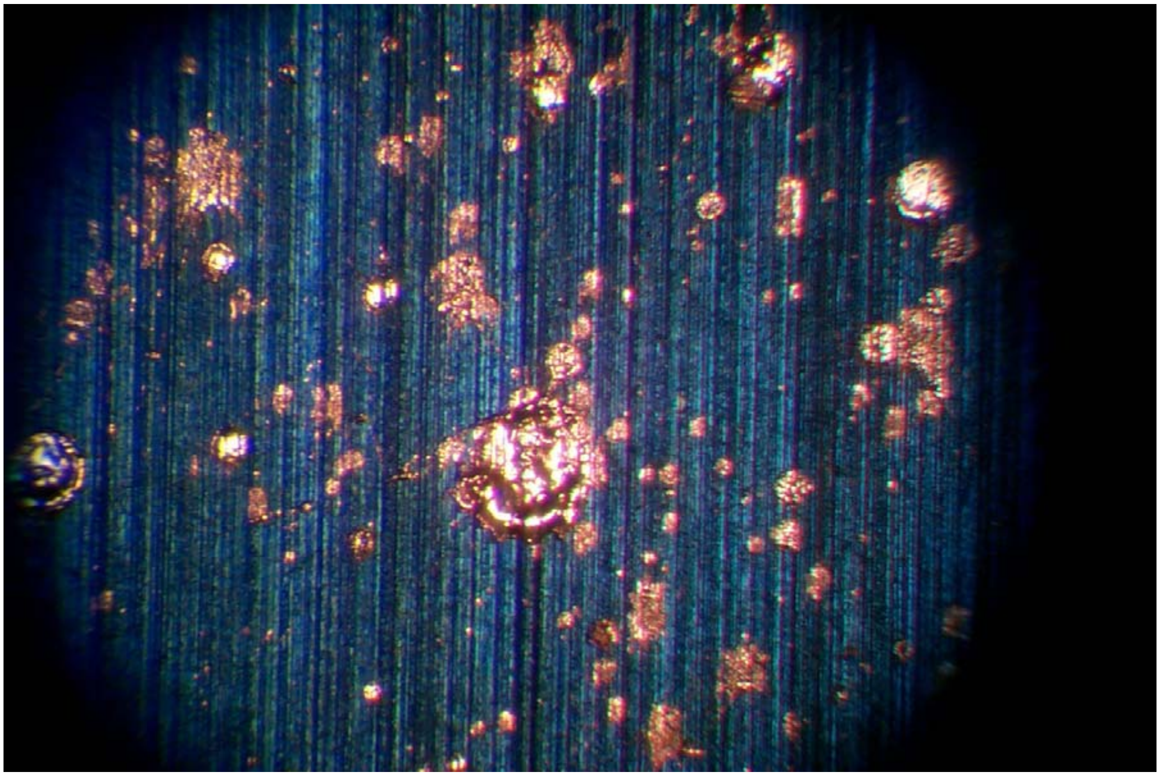


Figure 3, Copper Splatter on Be Window

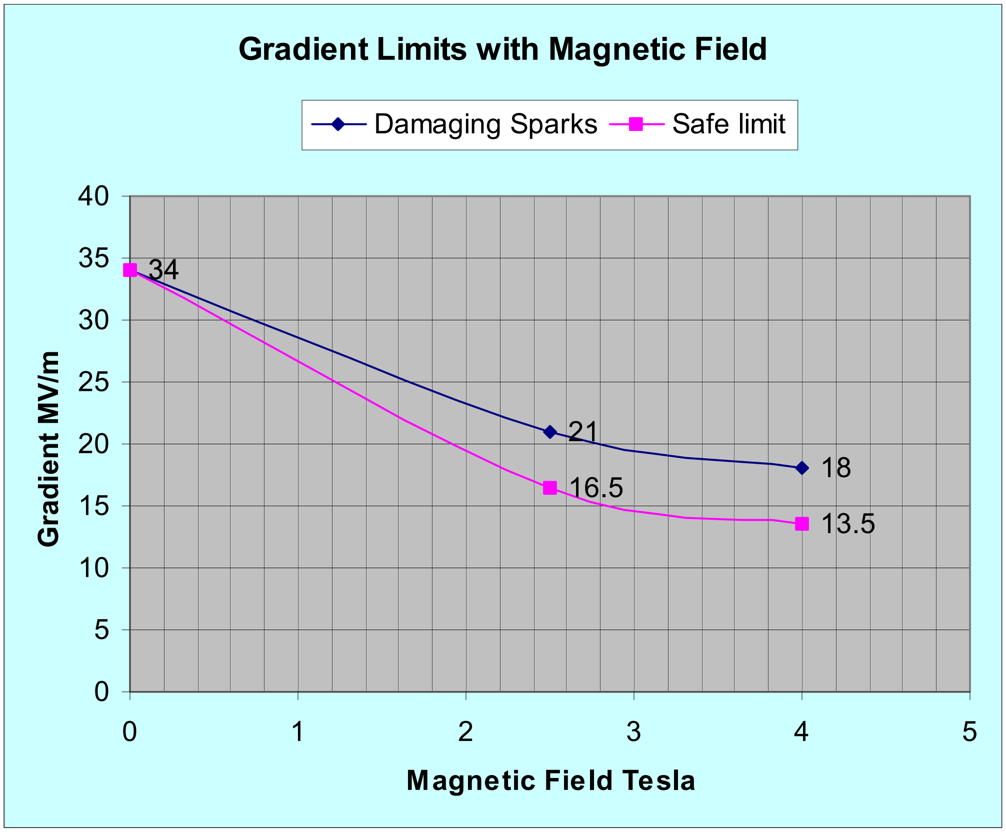


Figure 4, Gradient Limit with Magnetic Field, first Commissioning Study.

The second and current RF commissioning studying with the LBL Cavity is being conducted with 125 µ Be windows replacing the previously damaged Be windows.

The coils were operated in the three modes explained above. The Results are shown in figure 5.

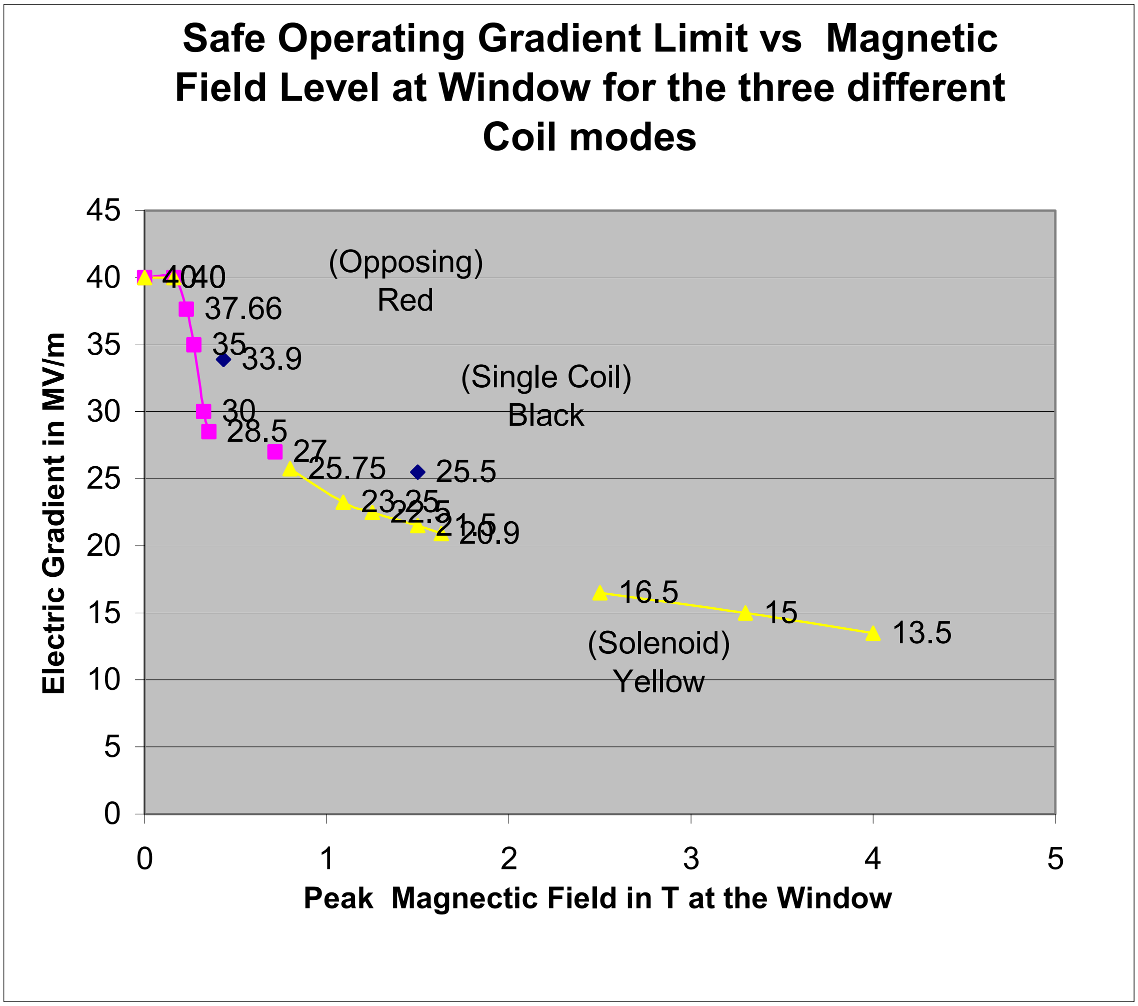


Figure 5, Safe operating gradient limit for the three different Coils excitations.
Operating above these limits produced damaging sparks which required a long time to recover again to the safe limit. One can also see the strong correlation of the limit with the magnetic field level at the window.

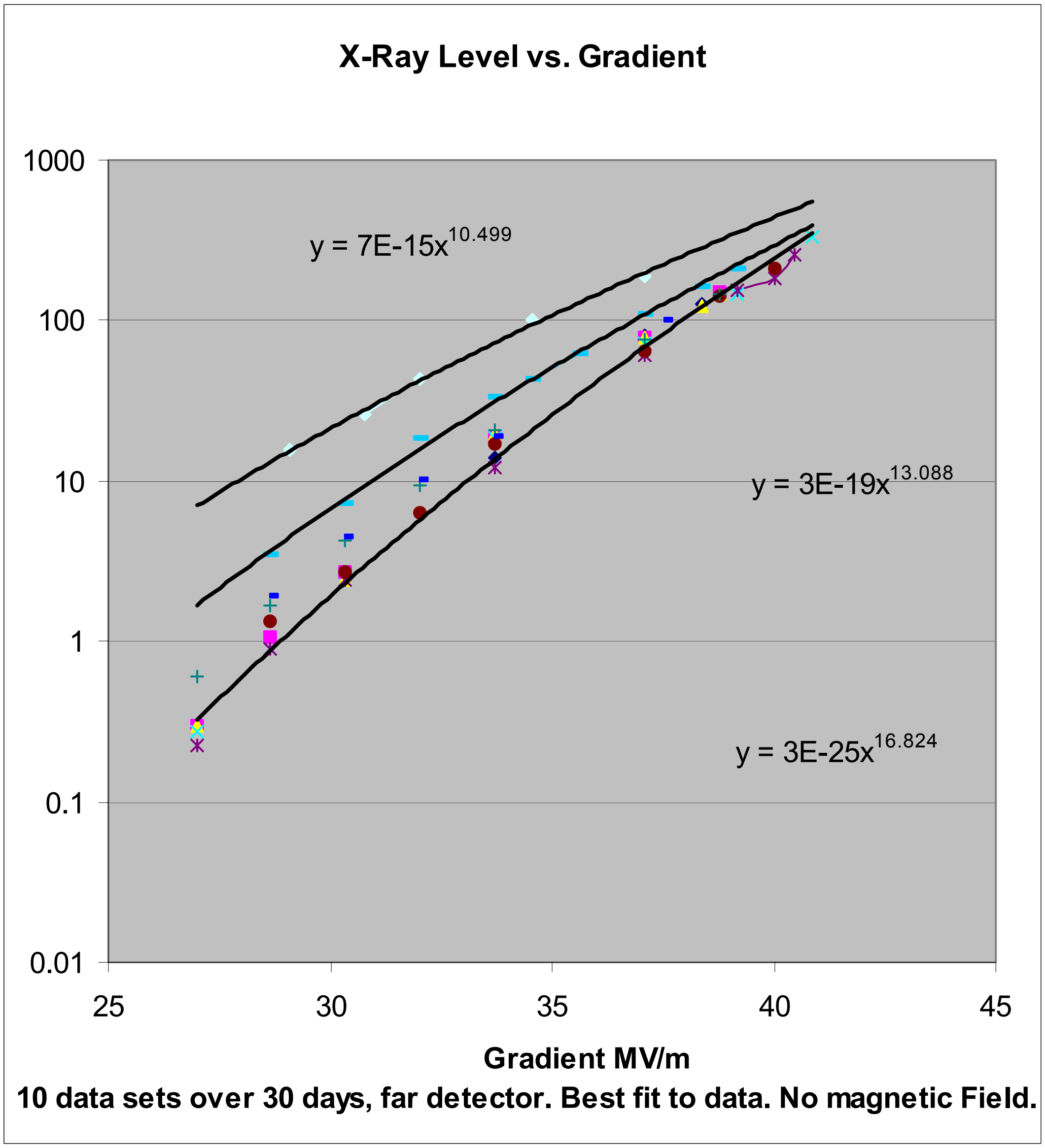


Figure 6, X-ray level in far detector 3 m away from the cavity.

Summary of LBL Single Cell Cavity Results:

The study of the breakdown limit of the LBL single cell cavity with large applied solenoidal fields has been going for about 2 years in Lab G. Studies were conducted with copper window inserts and for the last year with Be windows coated with TiN. In general the breakdown limit is much lower with increase in applied magnetic field. In addition, the dark current and X-Ray emissions are much larger after the occurrence of some sparking at very high electric and magnetic fields.

The chart, Figure 4, presents the accumulated results over this period of study. The top graph shows the limit at which surface damaging sparks occur during relatively short RF commissioning period of time. Spending long periods say hours results in very large permanent increase in dark current and X-Ray emissions. Examination of the damage by SEM and optical microscope showed molten copper disks 100 to 125 μ in diameter scattered over the Be window surface, Figure 1. There was no spark damage observed in the Be, TiN coated windows. Spark damage was only observed in the copper parts of the Cavity. The copper windows inserts were observed to behaved in similar manner. This demonstrates that copper is the weak link in reaching high gradient in large magnetic fields. A research effort is being planned to find a coating that can greatly enhance the breakdown limit of copper.

The lower plot in Figure 4 is the safe operating gradient limit in a magnetic field. Operating near this or at this limit results in little increase in dark current and X-Ray emissions.

Again, examination of the Be window damage showed no occurrence of spark damage to the TiN coating or into the Be. However, because all of the occurrences of damage showed the presents of copper, the gradient limit in a high magnetic field could be determined by copper. The breakdown limit will probability increase if we can find the magic copper coating that will suppress RF breakdown. The first choice in the planned research study will be TiN. It has demonstrated higher gradient breakdown limit than copper in the completed Be window study. Future studies of different materials and coatings are currently being planned.

Frequency Stability: 1. The cavity was very unstable in frequency with high Power RF pulsing. The frequency at high peak RF Power changed by +/- 25 kHz per pulse. This was Due to instantaneous heating and thermal expansion Of the window. This frequency change corresponds The window moving about +/- 4 mm.

2. The frequency was very unstable in the solenoid mode; very stable in the gradient and single coil modes.

3. The eddy currents in the gradient and single coil mode acted as a brake to prevent the movement of the thin window to the impulse heating effect described above.