BEAM INDUCED HEATING OF FERRITE MAGNETS*

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ABSTRACT

Alerted by impedance measurements of ferrite kicker magnets[1] and by apparent beam induced pressure increase in the neighborhood of window frame kicker magnets, bench measurements of magnet heating have been done. They confirmed the necessity of interrupting the ferrite yoke. Another method, which can be applied for existing magnets, will be described.

OBSERVATIONS AND MEASUREMENTS

Figure 1 shows a vacuum scan in the AGS at the A-10 straight section, where window frame kicker magnets are located. The scan was taken during a high intensity running period and includes a scheduled maintenance shutdown. The horizontal line indicates the period without circulating beam. At the beginning of that shutdown, it was seen that the vacuum decreases by an order of magnitude and that it increases again when the AGS resumed running. Measurements of beam impedance of ferrite magnets[1] led to the assumption that the ferrite is outgassing due to beam induced heating.

Figure 1. Vacuum scan at A-10 straight section in the AGS ring.

To investigate this phenomena further, a bench measurement was set up in which an rf power amplifier (ENI A-500) was used to simulate the beam. Ferrite bricks (C2050), similar to the ones in the kicker magnets, were stacked to form a one-foot long window frame magnet with 8" x 5" outside and 6" x 3" inside dimensions and the power amplifier was connected via a copper rod through the magnet into a dummy load. The transmitted current was monitored with a current transformer. The temperature of the ferrite bricks was measured with thermocouples. Figure 2 shows the temperature of the ferrite as a function of time after the power amplifier was turned on for two different frequencies. The starting temperatures are slightly different, reflecting that the curves were obtained on different days. The heating of the ferrite is seen to increase strongly with frequency. Especially the behavior at the higher frequency explains the observed pressure rise in the vicinity of the kicker magnet in the AGS, since Fourier analysis of the circulating beam shows that all harmonics of the rf frequency show up in the spectra.

The measurements have been repeated for the case in which the ferrite yoke has been interrupted by a 1 mm

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copper sheet as a diamagnetic barrier in the magnetic path. Even with a current of 3.5 A at 12 MHz through the magnet for many hours, no temperature change of the ferrite has been observed.

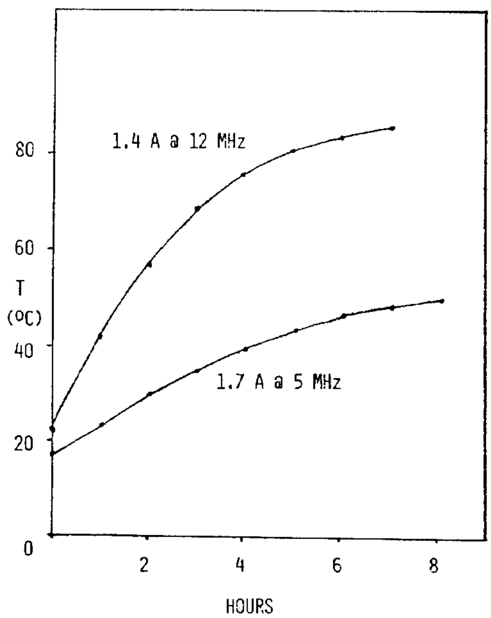

Figure 2. Temperature of ferrite as a function of time at two rf frequencies.

Another way to prevent flux being coupled into the ferrite is to wrap a shorted coil around the ferrite yoke. Such a coil will generate a current such that the next flux remains zero to fulfill the boundary condition, that there cannot be any voltage drop across the short circuit. Actually due to the finite resistance of such a coil, some residual flux may flow. With R the resistance of the coil and L the inductance of the magnet, it can be shown that with a current $I \times \sin(\omega t)$ in the primary winding, the induced current in the coil is within the limit $\omega L >> R$:

$$I \times [R/\omega L \cos(\omega t) + \sin(\omega t)].$$

For the magnets under investigation, the contribution to the flux due to this effect is negligible.

With a current of 3.5 A at 12 MHz, the experiment was repeated. A temperature increase of 4°C was observed after a period of 8 hours. Apparently some flux leaks around the short circuit. Nevertheless, since the test showed so much improvement and since a shorted coil can be installed so easily on the existing magnets, it was decided to install shorted coils in the symmetry plane of the kicker magnets in the AGS during the summer shutdown of 1989. Figure 3 shows a vacuum scan similar to Figure 1 during the high intensity run following the installation of the shorted coils on the kicker magnets. It is seen that there is still interaction between the beam and the vacuum, but it should be noted that the operating pressure in the AGS improved by an order of magnitude, thereby significantly increasing the sensitivity for outgassing.

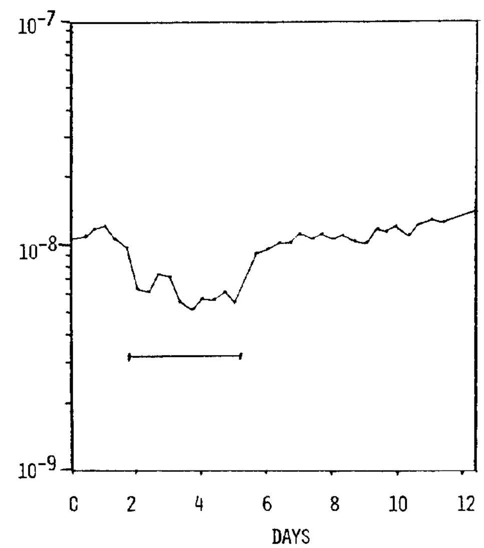

Figure 3. Vacuum scan during high intensity running after installation of shorted turns.

The ferrite (CMD5005), which has been selected for all the fast kicker magnets for the AGS Booster, has good vacuum properties and a high permeability. A sample of the ferrite was obtained and tested in a similar way. Figure 4 gives the temperature measurement for a current of 1 A at three different frequencies. It is seen that in all three cases, the surface temperature of the ferrite rises to above 120°C, which is so close to the Curie temperature of the ferrite that the magnetic properties of the ferrite will have changed drastically. Although the dimensions of the sample were different, 4" x 4" outside and 2" x 2" inside, the higher permeability leads to an increased sensitivity for induced heating.

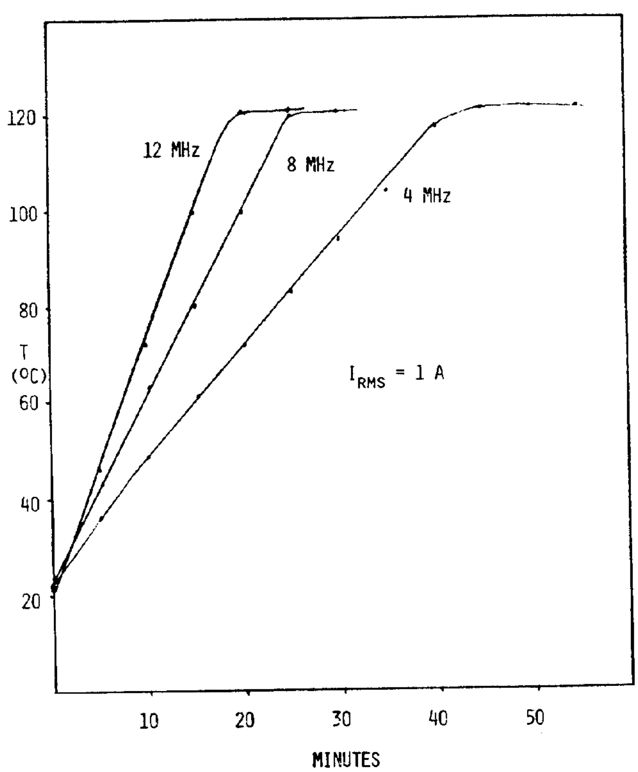

Figure 4. Temperature measurement for a current of 1 A at three different rf frequencies.

With the sample CMD5005 ferrite, the tests with the copper interruption and the shorted coil have been done. With the copper interruption, no temperature rise has been detected with a current of 2 A at 8 MHz during a period of many hours. Under the same conditions, a temperature rise of 1-2 degrees was measured at the end of a 5-hour period for the case of a shorted coil.

CONCLUSIONS

To reduce the impedance to the beam, a diamagnetic barrier in window frame ferrite magnets has proven to be very effective and it is shown that it is necessary for two other reasons; namely, for maintaining the quality of the vacuum and for preserving the magnetic properties of the ferrite.

Equipping window frame magnets with a shorted coil, which can be executed rather easily on existing magnets, has been shown to serve the same purpose, although not as effectively as the diamagnetic barrier.

REFERENCE

[1] F. Voelker, G. Lambertson, Proc. 1989 PAC, p. 851.