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DIFFERENCES BETWEEN THE GRADIENTS IN THE F AND D MAIN RING QUADRUPOLES AT INJECTION DUE TO REMANENT FIELD

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The main ring quadrupoles, after being assembled from essentially non-magnetized steel, are subjected to measurements to determine the uniformity in the gradient of the magnetic field. These measurements are made while pulsing the current from zero to approximately 6700 A. During a normal measuring cycle, a quadrupole will be pulsed to this maximum current several hundred times, and all the quadrupoles are excited with identical polarity. This shall be referred to herein as positive polarity. Once installed in the ring, the F quadrupoles retain this same positive polarity, while the D quadrupoles require negative polarity. It is of interest then to ask what the difference is between the gradients in an F and D magnet, particularly at the injection field where remanent field effects can be expected to be most pronounced; and also since the remanent field depends on the excitation history of a magnet, what is the minimum current required in the D quadrupoles to reverse the remanent field to the point where the difference between injection fields in the F and D magnets is negligible.

The quantity measured for purposes of this study was $\int_{-\infty}^{+\infty} B' dZ$

using the same field sensing probe that is used for the production tests. This probe consists of two loops of wire that extend well past the ends of the magnet. The injection current is nominally 86 A; the power supply stability is ± .05%. The probe is moved across the horizontal aperture in steps of 1 in. The integrated voltage from the coil is proportional to the change in flux. With this technique measurements were made on three 7 ft. quadrupoles. The measurements on a given magnet were repeatable to within ± 0.1% and the variations from magnet to magnet (with obviously poor statistics) were within ± 0.25%. The results at various currents are shown in the table below. The plus and minus currents correspond to the positive and negative polarities mentioned earlier. The internal gradient is calculated by assuming an effective gradient length equal to the length of the steel (84 in.). The difference between the injection fields of the F and D magnets is approximately 7.5% which is due, of course, to the remanent field established during production testing.

TABLE

Measurements of Main Ring 7 ft. Quadrupole Gradient

I (A)	$\int B'dz$ (kG)	B' (kG/m)
+76	9.606	4.502
+86	10.772	5.049
+96	11.947	5.600
-76	8.832	4.140
-86	9.990	4.682
-96	11.223	5.261
+1000	121.92	57.15
+2000	243.50	114.14
+3000	364.56	170.88

An attempt was then made to determine what procedures could be employed to make the gradients in the F and D magnets equal in magnitude given the fact that both types are tested with positive polarity. Two procedures were investigated, each giving satisfactory results. In all probability variations of these procedures would give equally good results. The first technique was to simply degauss the magnet using the following procedure:

i) Pulse the magnet to $\pm$ 1500 A for 10 cycles.

ii) Use the normal degaussing procedure of reversing the polarity and at the same time reducing the amplitude. (The amplitude was reduced in steps of 100, 10, 5, and finally 2.5 A)

After degaussing in this manner it was observed that the remanent field at x= $\pm$ 2 in. was less than $\pm$ 1.5 gauss. Before degaussing, but after production testing, it is typically 10 gauss at x = + 2.0 in. After degaussing it was found that the difference between injection fields for positive and negative polarity was on the order of 0.01% and that the injection gradients would remain essentially equal provided that the history of excitation of the F and D magnets remained identical. There is a point at which the strength of the remanent field remains essentially constant. This point was found to be approximately 3200 A. In fact, in searching for this current, it was observed that a complete degaussing procedure such as that described above did not appear to be necessary in order to insure equal injection gradients. By simply pulsing the quadrupole to a current in excess of 3200 A, the maximum remanent field is established and the injection gradients in the F and D quadrupoles have been observed to be equal to a few parts in 10^4.

Another technique of degaussing the magnet was attempted but did not produce particularly good results. This involved charging up a capacitor bank of .004 F to 1200 V and discharging this into the magnet. Even though the remanent fields were again reduced to values comparable to those resulting from the degaussing procedure described above, there remained a difference greater than .3% between the injection gradients.