BROOKHAVEN NATIONAL LABORATORY
Associated Universities, Inc.
Upton, New York

ACCELERATOR DEPARTMENT
Informal Report

MAGNETIC FORCES IN THE SIX-BLOCK ISABELLE MAGNET

G. H. Morgan

March 30, 1972

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CRISP 72-20
 ISABELLE PROJECT

INTERSECTING STORAGE ACCELERATOR NOTES

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An approximation to the final (as yet undecided) current block configuration has 14, 13, 12, 9, 6 and 3 turns per block, in blocks numbered 1 through 6, respectively, from the midplane to the poles. The block dimensions are 1.905 cm radially by 0.924 cm azimuthally, and the blocks are located on an inner circle of radius 3.81 cm. An iron shell has inner radius 6.0325 cm. If the iron had infinite permeability, a current of 3209 A would produce 40 kG; the expected current will be about 3% higher due to saturation effects. The magnetic forces on each block in the first quadrant are given in Table I as computed by program MAGFLD for the infinite μ case. The actual forces will be the same 3% higher. An 8 cm i.d. would lead to forces 5% higher in proportion to the consequent increase in turns.

TABLE I

Block No.	1	2	3	4	5	6
F_x , lb/ft	5273.0	5538.0	6963.0	5609.0	4268.0	2308.0
F_y , lb/ft	-760.7	-1909.0	-2533.0	-2037.0	-1099.0	-303.4
Torque, lb	1.31	3.63	5.51	5.81	4.72	2.70

A positive F_x is horizontally out, F_y is positive upwards, and the torque at the block center is positive counterclockwise.

To obtain the force on the iron, it is sufficient to note that at an infinite- μ , iron-air interface, the force per unit area is normal to the interface and of magnitude $B^2/2\mu_0$. At an iron-iron flux-normal interface the correct expression is $BH/2$.

A proposed method of construction involves a vertical split of the iron. It is then necessary to know, if the coil forces are taken up by the iron, the net force on the bolts holding the iron together. Since there is no field in the split, there is no attractive force between halves there. There is an attractive force between the coils and the iron, however, which can be calculated from the field at the air-iron interface. When MAGFLD is used to Fourier analyze the field, the field is printed out at 4° intervals on the specified circle. The energy density $B^2/2\mu_0$ at 8° intervals on a circle of radius 6.03 cm with a field 40 kG is given in Table II.

TABLE II

u		u		u	
θ , deg	10^6 J/m^3	θ , deg	10^6 J/m^3	θ , deg	10^6 J/m^3
0	0.0	32	0.9544	64	3.0940
8	0.0848	40	1.7229	72	3.1979
16	0.2364	48	2.0808	80	3.5680
24	0.7038	56	2.5981	88	3.5327

The horizontal attractive force on the iron per unit height is $\partial F_x / \partial y = u \cos \theta$, and the total force per unit length of magnet is

$$\int_{-6.03}^{6.03} u \cos \theta dy = 2 \int_0^{\pi/2} u x d\theta .$$

Using Table II this is found to be $1.515 \times 10^5 \text{ N/m} = 10,383 \text{ lb/ft}$. The net tension on the bolts is then the sum of the forces on the coils minus this or 49,536 lb/ft.

The vertical attractive force on the iron per unit length along the iron-air interface is given by $\partial F_y / \partial x = u \sin \theta$. The total force per unit length of magnet is

$$\int_{-6.03}^{6.03} u \sin \theta dx = 2 \int_0^{\pi/2} u y d\theta = 2.338 \times 10^5 \text{ N/m} = 22,874 \text{ lb/ft}.$$

The field in a median-plane split is not given by MAGFLD, but an estimate can be made on the basis of saturable-iron program runs on previous similar magnets, which show that the field is almost constant along the median plane. The average

field can be obtained from the total flux computed by MAGFLD, 0.18422 Wb/m, and the proposed iron thickness, $3\frac{1}{2}$ in. = 8.255 cm, which gives $B_{av} = 22.316$ kG. From the data of McInturff and Claus (AADD-162) the relative permeability at this field is 26, which could be used in computing the stress $BH/2$ in the iron in the absence of a midplane split. With a split, the attractive force is computed from $B^2/2\mu_0 = 1.9815 \times 10^6$ J/m³. With the proposed thickness this gives 3.2715×10^5 N/m = 22,417 lb/ft. The total attractive force is then 45,291 lb/ft.

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