Fermilab

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FIELD QUALITY IMPROVEMENT OF PICTURE-FRAME MAGNETS

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Picture-frame magnets have great appeal because of their simplicity and low utilization of iron. The principal problem with their use as accelerator bending magnets as compared with poled magnets arises from the effects of coil positioning errors. These errors cause error fields, and derivatives of field, which die out as

$$\Delta B \sim \exp\left(-\frac{\pi x}{g}\right),$$

where x is the distance into the gap from the coil and g is the gap.[1] Since the errors are random from magnet to magnet, all harmonics of field and derivatives exist, so that driving terms exist for resonances. One is then forced to leave space next to the coil for these errors to die out, and the magnet is less attractive.

It is possible to "short out" these random errors with iron sheets placed between coil layers as in Fig. 1, and precisely positioned in the gap with spacers. (The sheets need not be precisely positioned in the coil.) Each coil layer is now in an iron slot of height g/n, where n is the number of coil layers. Field errors die out as $\exp - [(n\pi x)/g]$, so the necessary space is reduced by a factor of n. The ends of the iron

[1] See, for example, B. Hague, Principles of Electromagnetism Applied to Electrical Machines (Dover, New York, 1962).

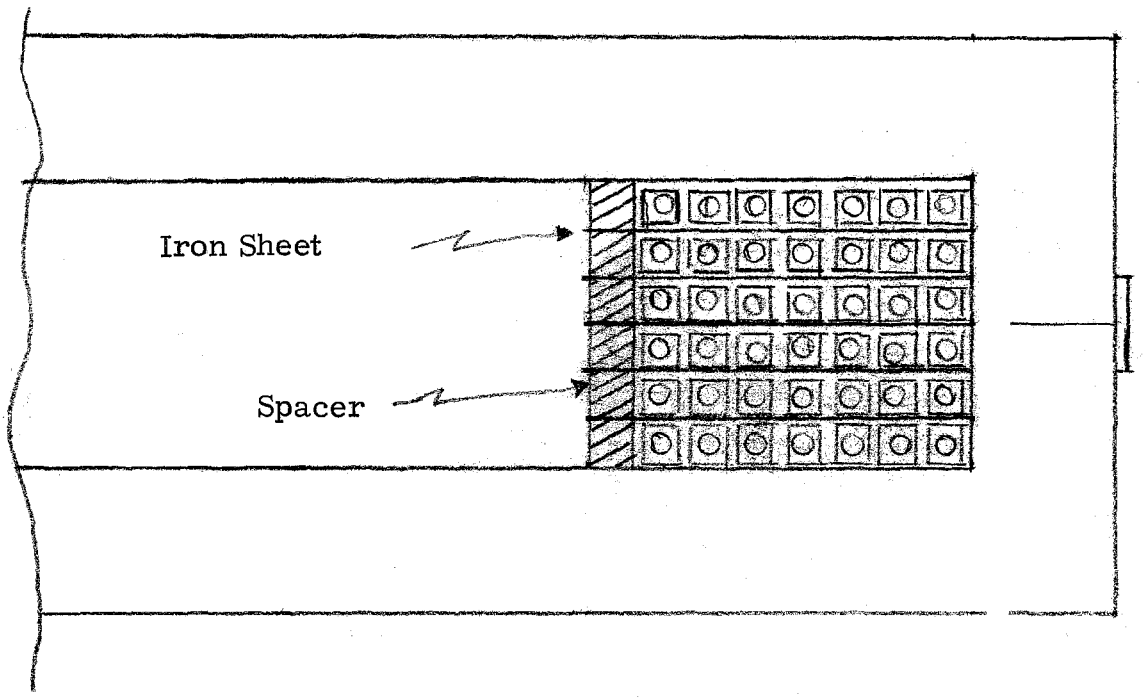
sheets now present uniformly spaced magnetic potential surfaces which match the potential surfaces of the uniform gap field. In fact, there is a slight systematic error of order $\Delta B/B = (n - 1)t/g$, where t is the thickness of the iron sheets. This systematic error can be reduced by cutting back the magnet iron by a distance $(n - 1)t$ in the coil region.

The thickness of the sheets is determined by the amount of error flux caused by the coil errors. It is easy to show[1] that the error flux per unit length in the sheet is given by

$$\Delta\psi = \frac{\mu_0 I \epsilon n}{2g},$$

where I is the individual conductor current and ϵ is its position error. If the sheet is allowed to carry a flux density B_I, then the required thickness is $t = B\epsilon / 2B_I m$, where m is the number of conductors in a coil layer. Here ϵ should include the effects of conductor lumpiness, water cooling holes, etc. as well as the random errors. For example, if ϵ = 1mm, B = 5 kg, B± = 10 kg, m = 7, t ≃ 0.03 mm ≃ 0.001 in. This should be doubled to allow for simultaneous errors in neighboring slots. If there are six coil layers, then the systematic error field would be $\Delta B/B \simeq 0.4\%$ for a 3-in. gap.

More complicated coil shapes, such as the main-ring magnet T-coils, can only be corrected with thin sheets where the field has symmetry in the coil region, so the improvement in such cases is less. One sheet on the mid-plane would, however, improve such magnets.



Picture-frame magnet corrected with potential sheets.