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A MAGNETIC FIELD CLAMP WITH BENEFICIAL SATURATION EFFECTS

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A MAGNETIC FIELD CLAMP WITH BENEFICIAL SATURATION EFFECTS†

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Abstract:

It is shown that a certain amount of saturation is desirable in some magnetic field clamps. A specific field clamp design is given that allows precise adjustment of the saturation in the field clamp.

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Whenever it is important to have a well defined and field level-independent effective field boundary (EFB), one usually incorporates into the magnet design field clamps at both ends of the magnet. There are two basic types of field clamps in general use:

1) Field clamps of the "windowframe" type, where the flux that enters the field clamp is carried by the clamp itself. This type of clamp does not have a flux carrying low reluctance connection to the magnet itself, except possibly a very desirable low reluctance connection of the midplane of the clamp to the midplane of the magnet yoke to make the performance of the clamp less sensitive to its alignment.

2) Field clamps consisting of two symmetric parts that are not magnetically connected to each other, but to their respective yokes, as indicated in fig. 1.

In order to obtain a nearly field independent shape and location of the EFB, most field clamps are designed to contain sufficient amounts of steel to make saturation of the steel negligible. While this is a necessary design criterion for field clamps of type 1), and often leads to clamps with formidable dimensions, negligible saturation of the field clamp is not a desirable feature of clamps of type 2). The purpose of this note is to point out that in field clamps of type 2), some saturation is desirable, and then show how one can obtain the benefit of the exactly correct amount of saturation in a simple manner.

In order to develop the concept, fig. 1 shows schematically the upper half of the end of a bending magnet with a field clamp of type 2). (Beam in or parallel to plane of paper) The arrows show crudely the direction of the field lines. If I_{00} indicates the number of Ampere-turns of the coil, and I_n equals $\int \vec{H} \cdot d\vec{s}$ along the indicated paths, Ampere's law gives:

$$I_{00} = I_1 + I_2 + I_3 + I_4 . \tag{1}$$

Similarly, fig. 2 shows a cross section of the upper half of the same magnet, with the beam prependicular to the plane of the paper. Field lines and integration paths are indicated as in fig. 1, with the paths that are common with paths in fig. 1 identified by the same numerals. Application of Ampere's law to the configuration shown in fig. 2 gives

$$I_{00} = I_1 + I_2 + I_5 . \tag{2}$$

From eqs. (1) and (2) one obtains

$$I_4 = I_5 - I_3 . \tag{3}$$

This equation follows, of course, also directly from Ampere's law if one chooses as the integration path paths 4, 3, 5, and the connecting line in the midplane.

According to figs. 1 and 2, I_5 and I_3 will have the same sign. The desired goal of making $I_4 = 0$ can be accomplished by compensating at the highest operating field level the necessarily nonzero contribution I_5 by a nonzero I_3. To get a good compensation also at lower field levels, it is desirable to use the same steel for the field clamp that is used for the yoke, and to make the field level and saturation path length in the clamp the same as they are in the yoke. In most cases the path length in the clamp cannot be made quite as large as it is in the yoke, requiring a design that has a field level in the clamp that is somewhat higher than it is in the yoke along path 5. Since it is only the nonlinearity of the steel that then makes the compensation imperfect at lower field levels, one can expect that the compensation is quite good for all field levels, unless the path lengths are quite different, and a numerical analysis confirms this.

Since in real life a magnet rarely behaves in every detail exactly as one predicts, it is advantageous to choose a design of the field clamp that allows an adjustment of the finished magnet that makes $I_4 \equiv 0$ at a chosen field level. Figure 3 shows the concept of such a design. The clamp consists of two parts. The main flux carrying clamp is intentionally designed to have a little more saturation than would be necessary for perfect compensation at the chosen field level, i.e., it alone would over-compensate I_5. That means that along that clamp, there must be a point that has exactly the same scalar potential as the midplane of the magnet. The other part of the clamp is bolted with nonmagnetic bolts to the top and bottom of the main clamp, with a magnetic spacer separating the two parts of the clamp. By moving that spacer, one then can obviously connect the two parts of the clamp magnetically so that at the reference field level, the outer part of the clamp is exactly at the desired scalar potential.

Fig. 1. Upper half of magnet end with single field clamp (beam in plane of paper).

Fig. 2. Upper half of magnet (beam perpendicular to plane of paper).

Fig. 3. Upper half of magnet end with double field clamp (beam in plane of paper).

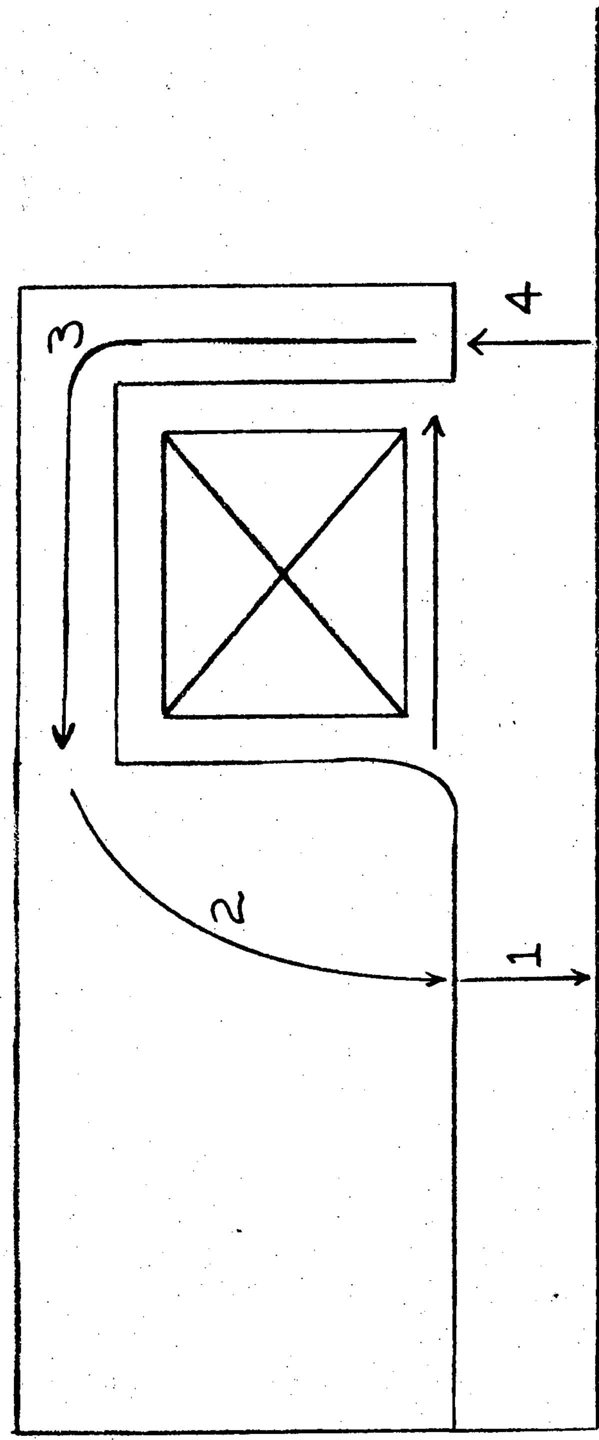

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Fig. 1

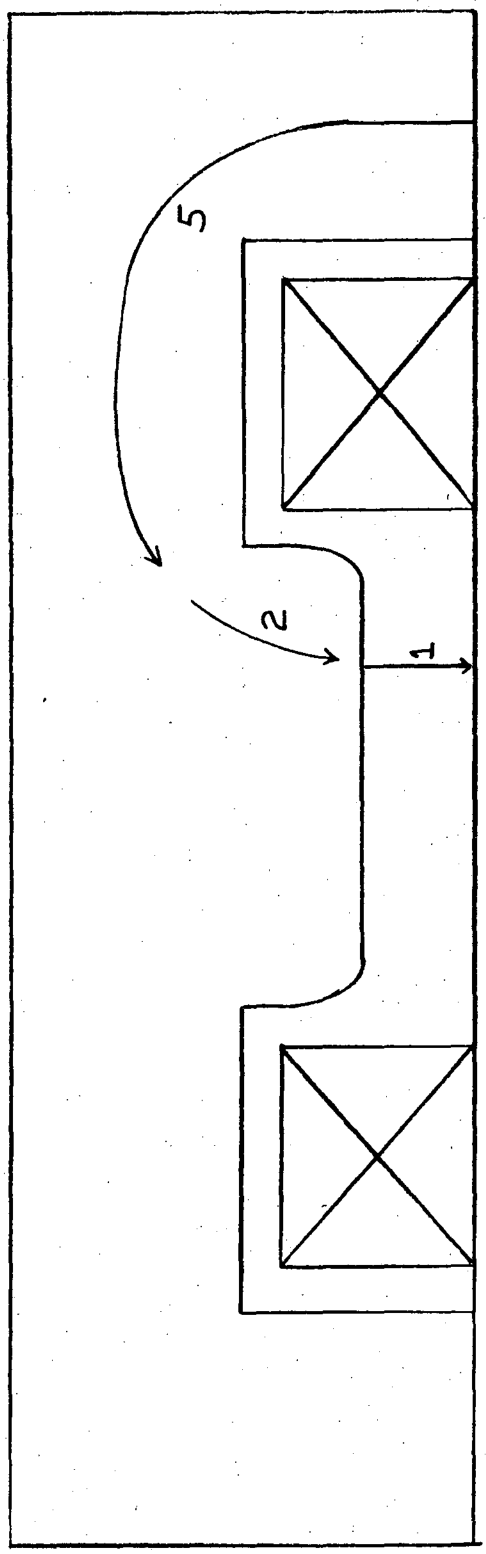

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Fig. 2

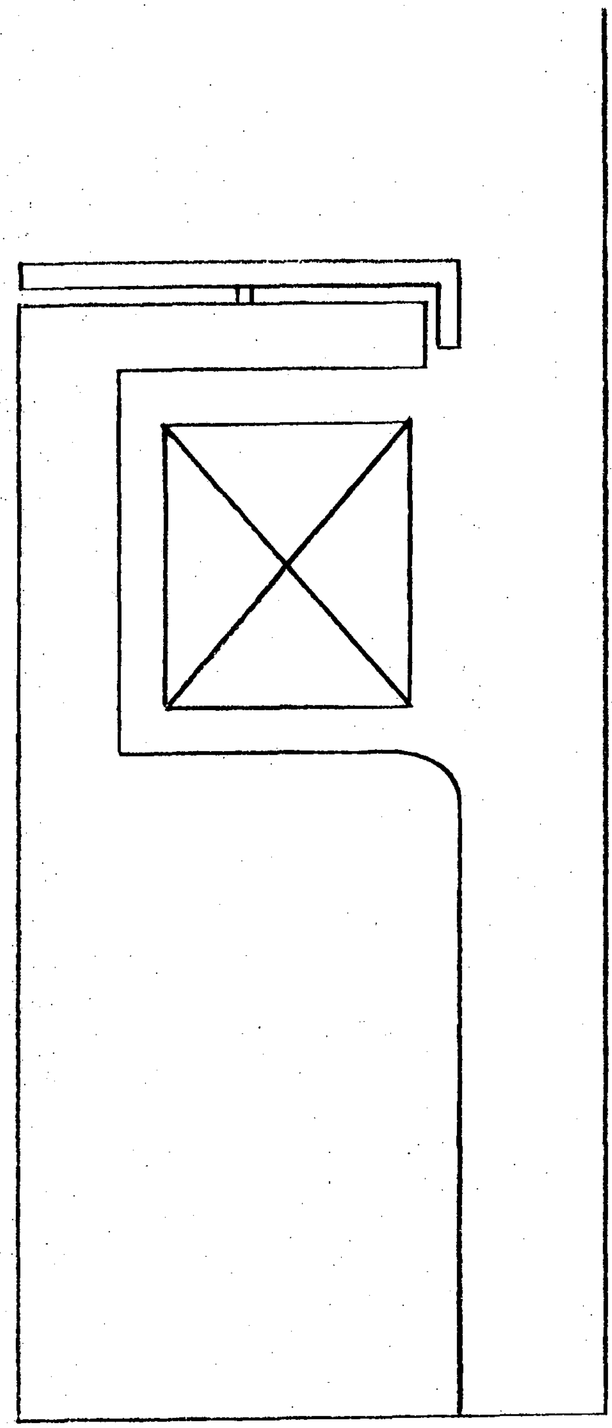

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Fig. 3

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