MAGNETIC LEAKAGE FIELD CAUSED BY A RECTANGULAR SLOT ON THE WORKPIECE SURFACE

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Abstract: The objective of this study was seeking the analytical expression of the magnetic leakage field caused by a rectangular slot on the surface of a cuboid block.
An item analysis was conducted on the magnetic charges distribution along all edges of the sample and the magnetic leakage field yielded by these linear magnetic charges.
The principle findings of this item analysis was an approximate analytic expression of the magnetic leakage field caused by a rectangular slot on the block surface and the plot of the spatial distribution of them along the symmetrical axis of the slot, gained through digital calculation.
On the basis of these findings, the present theoretical characteristic curves basically conform to the classical experimental result made by Dr. F. Förster in 1985. And the effect of the slot width on the magnitude and distribution of the magnetic leakage field yielded by the slot is explained naturally.

The magnetic leakage field caused by a rectangular slot on the workpiece surface is the basis of the magnetic non-destructive testing. This has been already paid great attention to by the NDT personnels from around the globe[1~4]. The characteristic curves given by the reference[5, 6] (Figure 1) becomes a classics of the experimental investigation on the magnetic leakage field yielded by a discontinuity. It's really a pity that the author has never read a theoretical analysis about this experimental result for 18 years. For seeking its regularity, the present paper is writen particularly to remedy this deficiency.

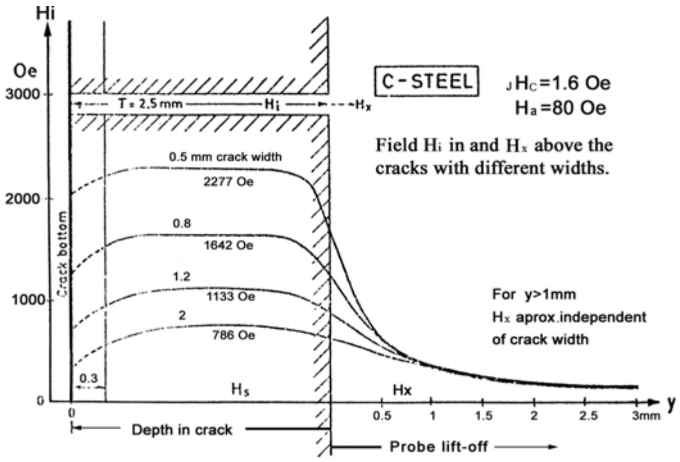


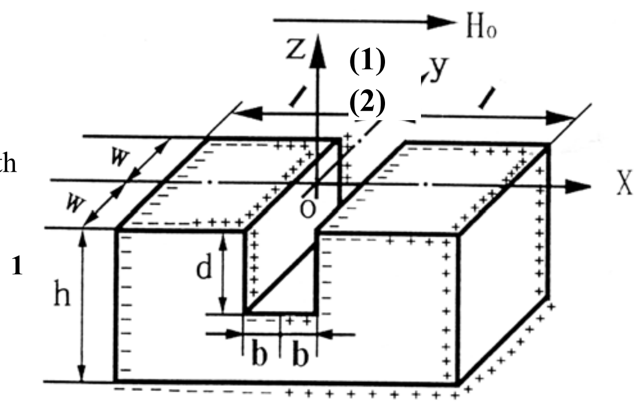
Figure 1 Representation of the normal behavior of the field H_l inside a defect and H_x in outer space of a series of crack widths without the effect of a detour flux dipole. Convergency of flux leakage amplitudes in outer space with different crack widths[5].

1. Magnetic leakage field caused by a rectangular slot on the workpiece surface

The author clarified long ago that the magnetic leakage field caused by a slot on the workpiece surface depends on the size of the slot, the shape of the sample and the type of magnetization[7]. When a square steel component with a rectangular slot on its surface (Figure 2) is magnetized longitudinally, an uniformly distributing linear magnetic charge will be excited out along its all edges , and the linear magnetic charge density σ_l (Wb/m)is[8]

$$\sigma_l = \frac{4w(lh-bd)\cdot C_s \chi_m \mu_0 H_0}{8lw-4bw-4bd+3l^2+3b^2-2lb+4lh}$$

$$C_s = C_s(H_0, l, w, h, b, d, x, y, z)$$



In which, 2l, 2w, h is respectively the length, width

and height of the square steel component (m).
2b,d is respectively the width and the depth of the slot (m).
χ_m is the magnetic susceptibility of the material of the sample, and it's a pure number without dimension .
μ_o is the magnetic permeability in the vacuum, and equal to $4\pi\times10^{-7}$H/m.
H_o is the strength of the magnetizing field (A/m).
C_s is a function related to the magnetizing field strength, the dimension of the square steel component, the size of the solt and the location of the field spot(x,y,z). As a rough approximation it can be considered as a constant.

Figure 2 The longitudinal magnetization of a square steel component with a rectangular slot

At the initial transient monment of longitudinal magnetization of a aquare steel component with a rectangular slot and at the active magnetization of the sample mentioned above an uniformly distributing areal magnetic charges will be excited out over the two end surfaces of the square steel component and over the two lateral surfaces of the slot perpendicular to the magnetizing field. Their magnetic charges areal densityσ_s(Wb/m^2)is[8]:

$$\sigma_s=C_s\chi_m\mu_oH_o \qquad (3)$$

When the sample mentioned above is magnetized longitudinally and actively, the magnetic leakage field H yielded by the slot shall be:

$$H=H(\sigma_l)+H(\sigma_s) \qquad (4)$$

here, $H(\sigma_l)$ is the magnetic leakage field yielded by the linear magnetic charges uniformly distributing along all edges.
$H(\sigma_s)$is the magnetic leakage field yielded by the areal magnetic charges uniformly distributing over the lateral surfaces of the slot.

2. An approximate analytic expression for the Dr. Förster's experiment

The references[5,6] didn't give out the shape and dimensions (l, w, h) of the tested block, so in the present paper an approximate analysis for the classical experiment made by Dr. Förster may be only carried out under the hypothesis that his tested block was shown as Figure 2—only consider the magnetic leakage field caused by the rectangular slot, that is, to find the solution of the H in following expression.

$$H=H_1(\sigma_l)+H_2(\sigma_l)+H_3(\sigma_s) \qquad (5)$$

in which, $H_1(\sigma_l)$ is the magnetic leakage field caused by the magnetic charges along the top edges and the vertical edges.
$H_2(\sigma_l)$ is the magnetic leakage field caused by the magnetic charges uniformly distributing along the bottom edges of the rectangular slot.
$H_3(\sigma_s)$ is the magnetic leakage field caused by the areal magnetic charges uniformly distributing over the tow lateral surfaces of the slot, perpendicular to the magnetizing field.
The expression (1) in the reference [9] is $H_1(\sigma_l)$. As this paper has limited space, only the value of magnetic field along the symmetrical axis of the slot is set out as follows{that is the expression (2) in reference [9]}:

$$H_{1x}(\sigma_1)\Big|_{\substack{x=0\\y=0}} = \frac{\sigma_1}{\pi\mu_0}\left[\frac{bw}{(b^2+z^2)\sqrt{b^2+w^2+z^2}} + \frac{b(z+d)}{(b^2+w^2)\sqrt{b^2+w^2+(z+d)^2}} - \frac{bz}{(b^2+w^2)\sqrt{b^2+w^2+z^2}}\right] \qquad \textbf{(6)}$$

$H_{2x}(\sigma_1)\Big|_{\substack{x=0\\y=0}}$ ...m references[10,11] as follows:

$$H_{2x}(\sigma_1)\Big|_{\substack{x=0\\y=0}} = \frac{\sigma_1}{\pi\mu_0}\left[\frac{1}{\sqrt{b^2+w^2+(z+d)^2}} - \frac{1}{\sqrt{w^2+(z+d)^2}}\right] \qquad \textbf{(7)}$$

And $H_3(\sigma_s)|_{x=0, y=0}$ obtained from expression (1) in the reference [12] as follows:

$$H_{3x}(\sigma_s)|_{x=0, y=0} = \frac{\sigma_s}{\pi\mu_0}\left[tg^{-1}\frac{w(z+d)}{b\sqrt{b^2+w^2+(z+d)^2}} - tg^{-1}\frac{wz}{b\sqrt{b^2+w^2+z^2}}\right] \quad \textbf{(8)}$$

3. The relation betweenσ_l andσ_s

From expression (1) and (3) it can be known that

$$\frac{\sigma_l}{\sigma_s} = \frac{4w(lh-bd)}{8lw-4bw-4bd+3l^2+3b^2-2lb+4lh} \quad \textbf{(9)}$$

If b, d<<l, w , h, then

$$\frac{\sigma_l}{\sigma_s} \approx \frac{4wlh}{8lw+3l^2+4lh} = \frac{4wh}{3l+8w+4h} \quad \textbf{(10)}$$

And from the reference [8] we know that on a square steel component without slot, there is relation as follows:

$$\frac{\sigma_l}{\sigma_s} = \frac{wh}{l+2w+h} \quad \text{□11□}$$

That is , at longitudinal magnetization of a square steel component, there exists a fixed proportional relation between the linear magnetic charge density along all the edges and the areal magnetic charge density over the two end surfaces excited. The proportional coefficient is equal to the proportion of the end surface area to a certain combination of the lengths of its all edges.

4. Calculation and discussion:

The references [5,6] only give the following data:

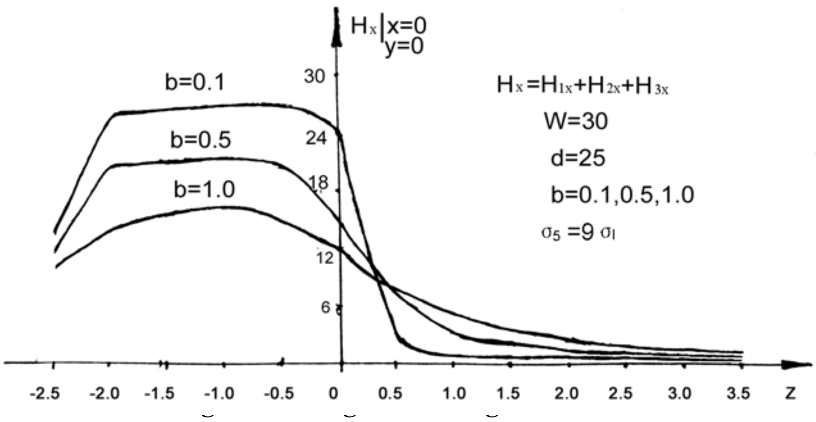
d=2.5mm; b=0.1,0.25,0.4,0.6,1.0mm.

In order to preliminarily verify the theoretical analysis mentioned above, there's nothing the author can do but arbitrarily hypothesizes the dimensions of the tested block by Dr. Förster at first. That is order

W=30mm

$\sigma_l/\sigma_s=9$

From expressions (5)~(8) the Z direction distribution of X component of the magnetic leakage field along the central axis of the slot can be calculated out as shown in Figure 3. It may be seen that Figure 3 is basically similar to Figure 1 as follows:



by a rectangular slot

(characteristic curves through theoretical calculation)

(1) The magnetic field strength is high and smooth in the slot, it is low and slanting near the breaking point of the slot, it drops rapidly out of the slot , and approaches to zero with the increasing of the distance from the breaking point of the slot.

(2) The wider the slot , the lower the magnetic field strength in the slot, and the higher the magnetic field strength out of the slot.

5. Conclusion

5.1 The distribution of the magnetic leakage field for a rectangular slot derived and calculated by the magnetic dipole theory given above basically conforms to the classical experimental result of Dr. Förster.

5.2 The digital calculating result of magnetic dipole theory clarifies naturally the influence of the slot width upon the magnitude and distribution of the magnetic leakage field caused by the slot.
5.3 The certain hypotheses proposed beforehand in present paper basically accord with the physical practice of this problem.
5.4 Due to the lack of the full experimental data in the original reference, the author had to use the simplest model, thence led to some discrepancy between theoretical characteristics and experimental curves. So the investigation on the exact theory for this classical experiment must be furthered on and deepened.

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