Numerical analysis and experimental study of the error of magnetic field strength measurements with single sheet testers

N. Nakata
Okayama University

N. Takahashi
Okayama University

Y. Kawase
Okayama University

Masanori Nakano
Okayama University

M. Miura
Okayama University

J. D. Sievert
Phys. -Techn,Bundesanstalt

NUMERICAL ANALYSIS AND EXPERIMENTAL STUDY OF THE ERROR OF MAGNETIC FIELD STRENGTH MEASUREMENTS WITH SINGLE SHEET TESTERS

T.Nakata*, N.Takahashi*, Y.Kawase*, M.Nakano*, M.Miura* and J.D.Sievert**

*Dept. of Electrical Engng., Okayama University, Japan

**Phys.-Techn.Bundesanstalt, 3300 Braunschweig, F.R.Germany

Abstract

The error of the measurement of the magnetic field strength with a single sheet tester has been studied. Two different methods, determination by means of field sensing coils (1) and from the magnetizing current (2), have been compared. The errors of methods (1) and (2) were calculated by the finite element method (FEM), different parameters having been varied, and method (2) was additionally studied experimentally. SSTs with wound yokes and stacked yokes were considered. The results will help to decide whether the more complicated and more accurate H coil method or the easier to handle, but less accurate m.c.method is chosen.

1. INTRODUCTION

Due to a considerably easier sample preparation and substantial saving of material, the Single Sheet Tester (SST) with yokes is increasingly replacing the Epstein frame. Two versions of the SST are in use with different methods for the determination of the magnetic field strength H: (1) using tangential field sensing coils (H coil method)/1/; (2) from the magnetizing (primary) current (m.c.method), whereby the latter needs the fixation of the effective magnetic path length l_m, for instance by setting l_m equal to the inner width of the yokes as practised here, or by tracing it back to H coil results (l_{mH}), or, as prescribed by an IEC standard/2/, by adaption to Epstein measurements. With method (1), the measured value of the field strength is influenced by stray fields, and thus is different from the value inside the material, in particular with high-grade oriented and with amorphous material. However, with method (2), the magnetizing current from which the field strength and then the losses are determined, depends on the yoke material, on the construction of the SST and on the air gaps between specimen and yokes. For those reasons one expects to find greater uncertainties with this method in comparison with the H coil method. Despite this, method (2) should be taken into consideration, as this simpler method is the same as that used with the widely used Epstein frame.

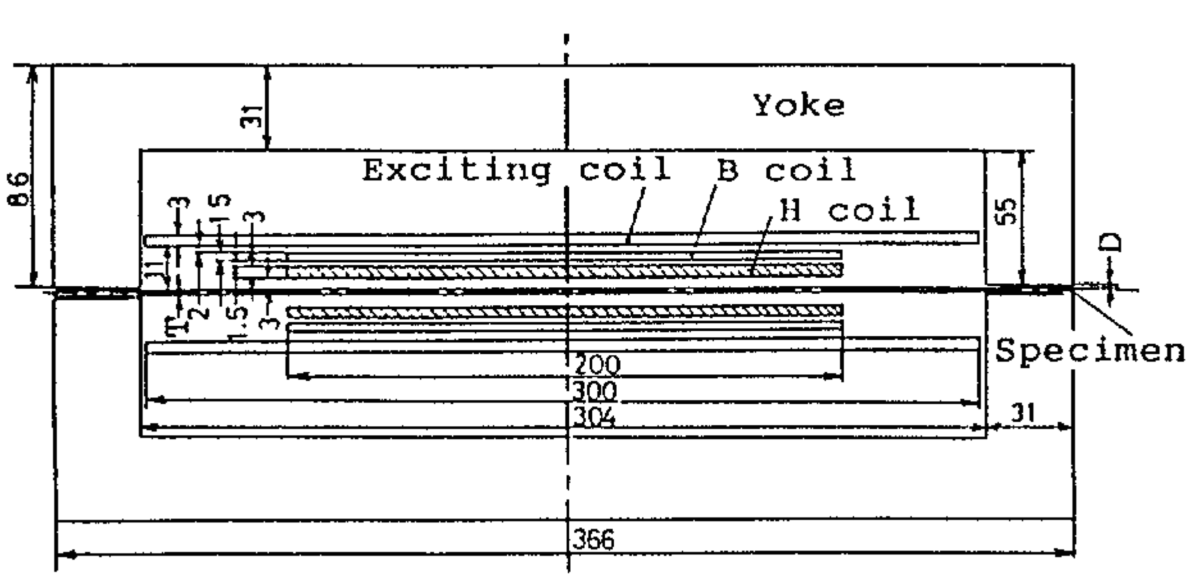
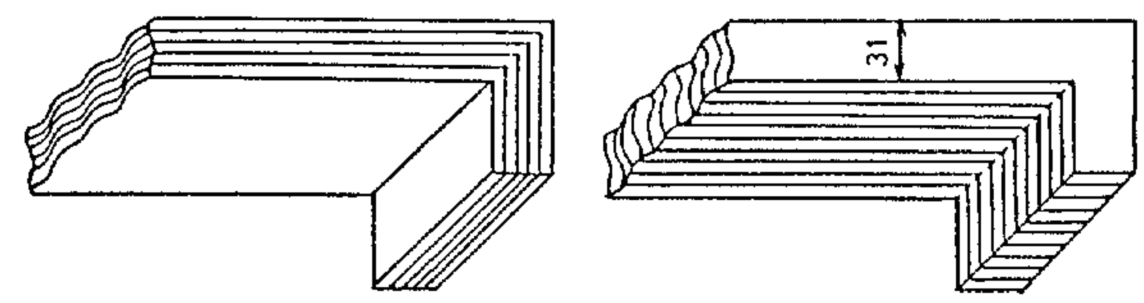


Fig.1 Single sheet tester.

A former paper /3/ dealt with the influence of the H coil position and dimension on the error of method (1). In this paper the error of method (1) and (2) is calculated by the finite element method (FEM), the influence of the material, its thickness, the air gap width and of the lamination being considered. Method (2) is additionally studied experimentally.



(a) Wound yoke (b) Stacked yoke

Fig.2 Yoke laminations.

2. MODEL AND METHOD OF THE NUMERICAL ANALYSIS

Fig.1 shows a sectional view of the SST with T being the thickness of the specimen and D the air gap width. The influence of the edge region of the SST is small, so that the calculation can be confined to two dimensions and, due to symmetry, to a quarter of the total cross section. We start from a given flux inside the B coil, since with all SST's the magnetizing current is controlled by means of the B coil output. The initial magnetization curve of the yokes material is used to represent the non-linearity.

Fig. 2a and b show the two versions of yokes considered here. Since it is difficult to simulate the lamination of the wound yokes (Fig.2a) exactly, we assume that the yokes are homogeneous with regard to the magnetic properties. If ν_T means the overall reluctivity in the vertical direction to the sheets,

$$\nu_T = (T \cdot \nu_n + T_g \cdot \nu_o)/(T + T_g)$$

with T the thickness of the material, T_g the width of the air gaps inside the yokes, ν_n the reluctivity of the material vertical to the surface and ν_o the field constant. The yoke material was assumed to be conventional grain oriented steel sheet, type G10, the thickness of the sheet 0.35mm and the space factor 96%.

3. ANALYSIS OF THE INFLUENCES ON THE H MEASUREMENT

3.1 Material of the specimen

The permeability curves of the material considered are shown in Fig. 3, and the flux distributions in the space between the wound yoke and the specimen in Figs. 4 to 6 for a specimen thickness of 0.3mm and an air gap width of 0.0035mm. One flux line represents $\Delta\Phi$(Wb/m). In Figs. 4-6(b) the material is almost saturated, and the field distributions in the region of the H coil are almost the same, whereas in Figs. 4-6(a) at lower induc-

0018-9464/86/0900-0400$01.00©1986 IEEE

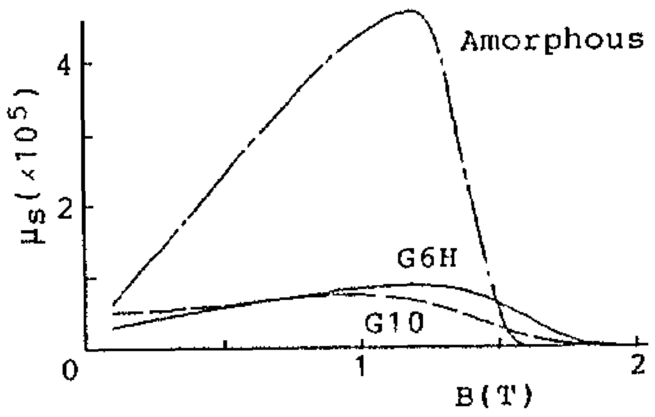
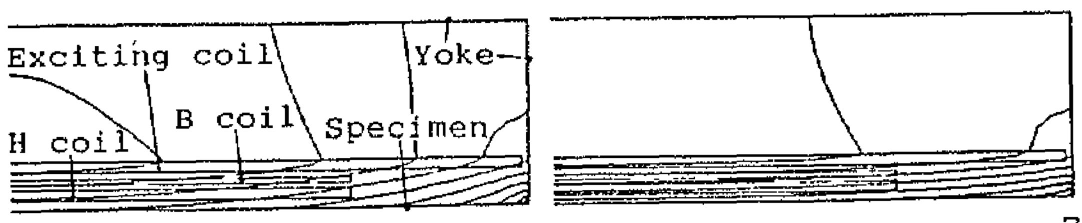
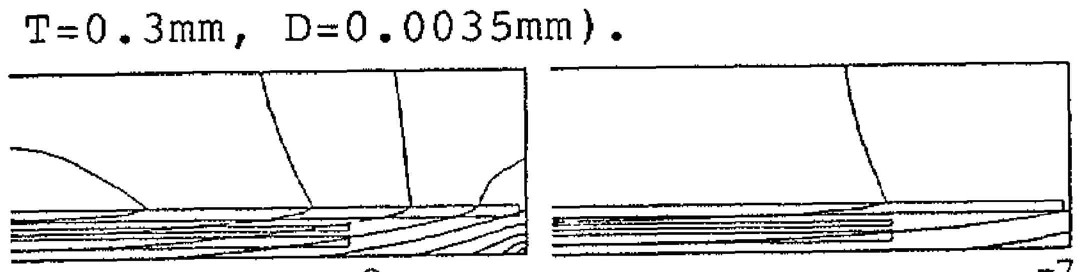


Fig.3 Relative permeability versus flux density.



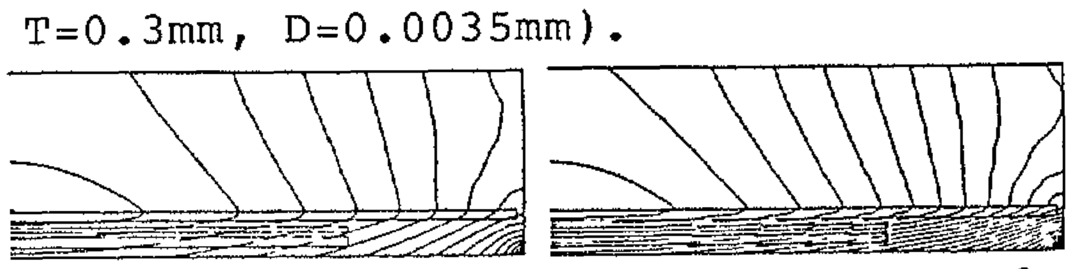
(a) B=1.0T($\Delta\Phi$=5·10^{-8}Wb/m) (b) B=1.7T($\Delta\Phi$=5·10^{-7}Wb/m)

Fig.4 Flux distributions (G10 material, T=0.3mm, D=0.0035mm).



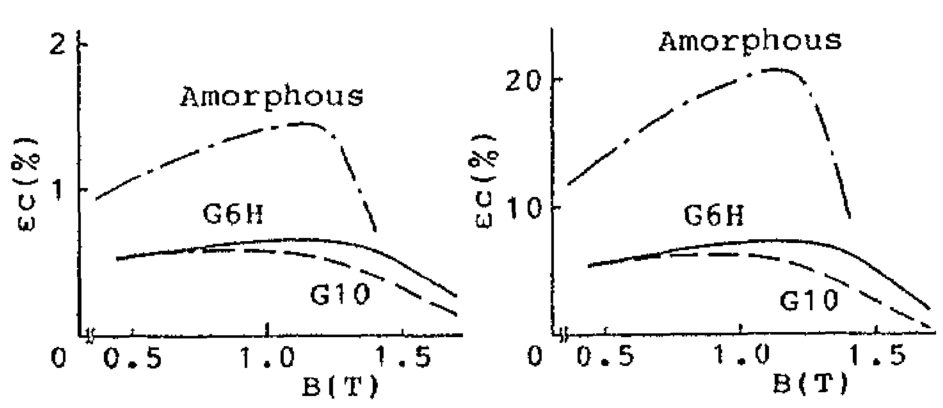
(a) B=1.0T($\Delta\Phi$=5·10^{-8}Wb/m) (b) B=1.7T($\Delta\Phi$=5·10^{-7}Wb/m)

Fig.5 Flux distributions (G6H material, T=0.3mm, D=0.0035mm).



(a) B=1.0T($\Delta\Phi$=10^{-8}Wb/m) (b) B=1.4T($\Delta\Phi$=10^{-8}Wb/m)

Fig.6 Flux distrobutions (Amorphous material, T=0.3mm, D=0.0035mm).



(a) H coil method (b) m.c. method

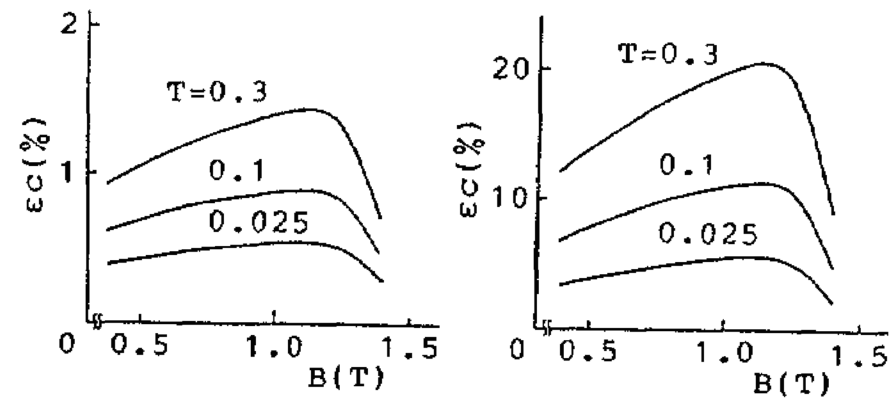
Fig.7 Errors of magnetic field strength (T=0.3mm, D=0.0035mm, Wound yoke).

tion, the permeability is high and the distribution is markedly different. It is important that in this case, the flux component vertical to the surface of the specimen is substantially higher, in particular with the high permeability material.

Fig. 7 shows the calculated error ε_c of the H measurement for both H coil and m.c. method. ε_c is defined accordingly

$$\varepsilon_c = (H_m - H_o) \cdot 100/H_o (\%).$$

H_o is the value at the surface of the specimen averaged over the length corresponding to that of the H coil, and H_m the value as measured. With the m.c. method, H_m is obtained from the total magnetizing current by dividing the actual ampere-turns by the length of the specimen between the yoke limbs, thus neglecting the magnetic resistance of yokes and air gaps. For the m.c. method, the error is about ten times higher than for the H coil method (Fig.7), and it is correlated to the permeability value (Fig. 3) in both cases, which is due to the inhomogeneity of the field at the surface in the case of the H coil, and to the significant ratio of the magnetic resistance



(a) H coil method (b) m.c. method

Fig.8 Errors of magnetic field strength (Amorphous material, D=0.0035mm, Wound yoke).

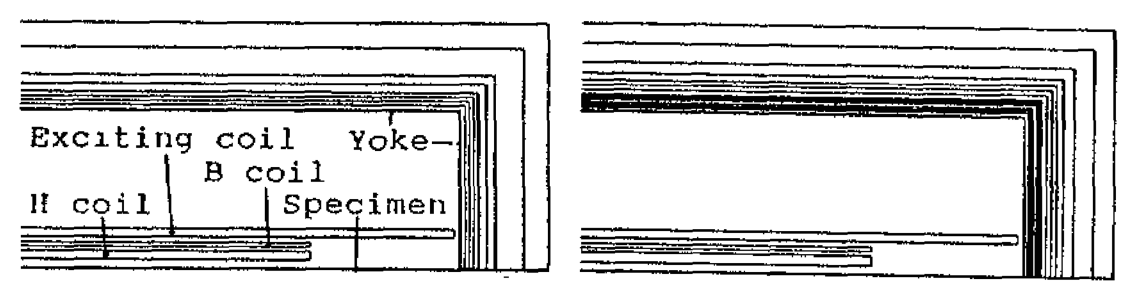
of the yokes to that of the specimen with the m.c. method.

3.2 Thickness of the specimen

The higher the permeability of the specimen the greater is this influence. This can be seen from Fig. 8 which shows the error ε_c for the cases of amorphous material of various thicknesses T with wound yokes. The increase with the thickness is due to the greater demagnetizing field (H coil),and again is caused by the magnetic resistance ratio of yoke to specimen (m.c. method).

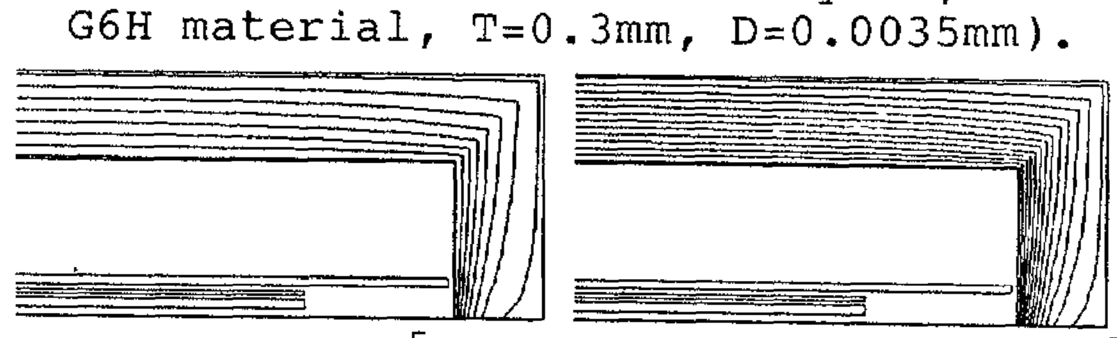
3.3 Lamination methods of the yokes

Figs. 9 and 10 show the flux distributions with the two kinds of lamination (G6H material, thickness of the specimen T = 0.3mm, air gap width D = 0.0035mm). As can be seen from Fig.11, the error is almost independent of the lamination with the H coil method, whereas with the m.c. method, the error is greater with the wound yoke due to a more inhomogeneous flux distribution.



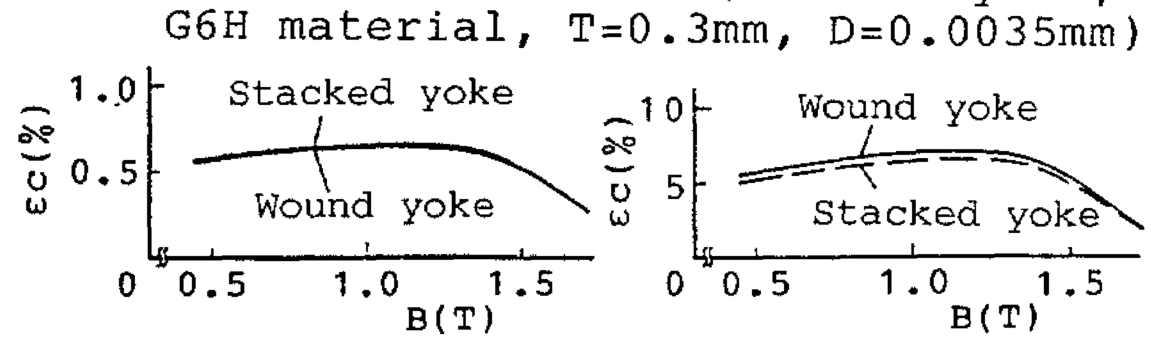
(a) B=1.0T($\Delta\Phi$=2·10^{-5}Wb/m) (b) B=1.7T($\Delta\Phi$=2·10^{-5}Wb/m)

Fig.9 Flux distributions (Wound yoke, G6H material, T=0.3mm, D=0.0035mm).



(a) B=1.0T($\Delta\Phi$=2·10^{-5}Wb/m) (b) B=1.7T($\Delta\Phi$=2·10^{-5}Wb/m)

Fig.10 Flux distributions (Stacked yoke, G6H material, T=0.3mm, D=0.0035mm).

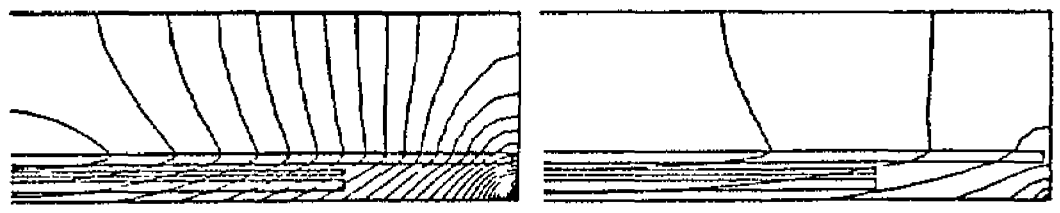


(a) H coil method (b) m.c. method

Fig.11 Errors of magnetic field strength (G6H material, T=0.3mm, D=0.0035mm).

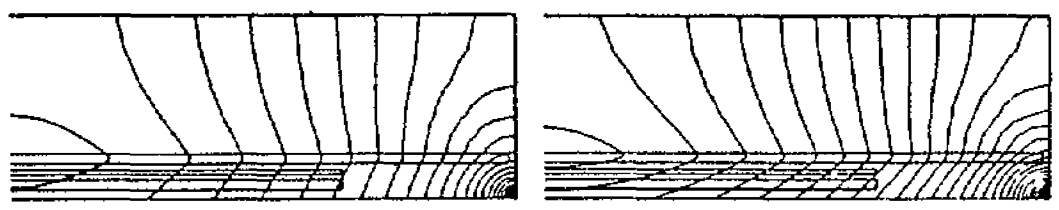
3.4 Air gaps between specimen and yokes

For the wound yoke and a specimen of 0.3mm thickness, Figs.12 and 13 show the flux distribution for the G6H type and amorphous material, respectively, at an air gap width of D = 0.075mm instead of 0.0035mm as in Fig. 5. Comparing Fig. 5 with Fig.12 and Fig. 6 with Fig.13 we find, that the inhomogeneity of the flux distribution increases with the widening



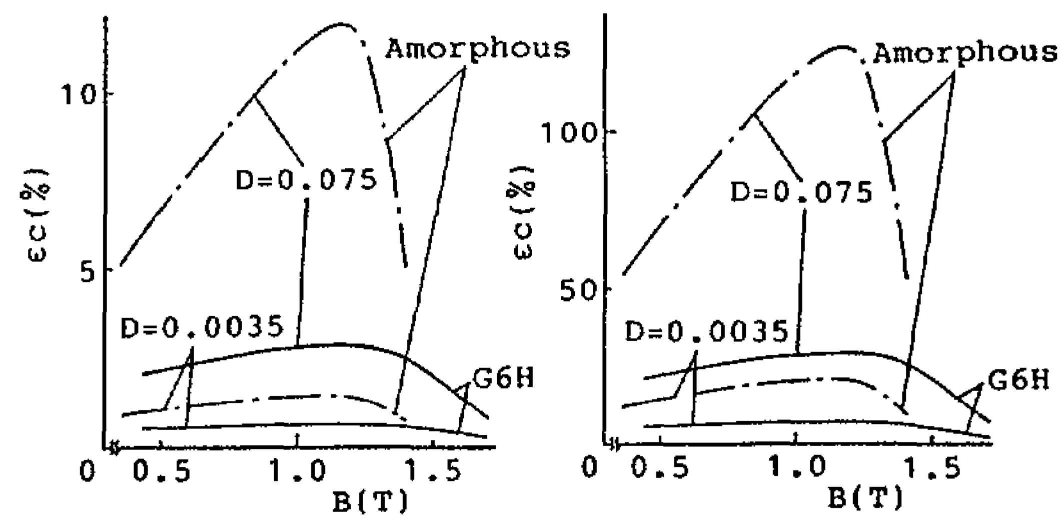
(a) $B=1.0T(\Delta\Phi=5\cdot10^{-8}Wb/m)$ (b) $B=1.7T(\Delta\Phi=5\cdot10^{-7}Wb/m)$

Fig.12 Flux distributions (G6H material, T=0.3mm, D=0.075mm).



(a) $B=1.0T(\Delta\Phi=5\cdot10^{-8}Wb/m)$ (b) $B=1.4T(\Delta\Phi=5\cdot10^{-8}Wb/m)$

Fig.13 Flux distributions (Amorphous material, T=0.3mm, D=0.075mm).



(a) H coil method (b) m.c. method

Fig.14 Errors of magnetic field strength (T=0.3mm, Wound yoke).

of the air gap, which also increases the error (see Fig.14). However, with the m.c. method with which we neglected the contribution of the air gaps, the magnetic potential drop in the widened air gap is actually increased, and so is the error, in particular with highly permeable material. Here the wider air gap increases the ratio of the magnetic resistances of the air gap and specimen.

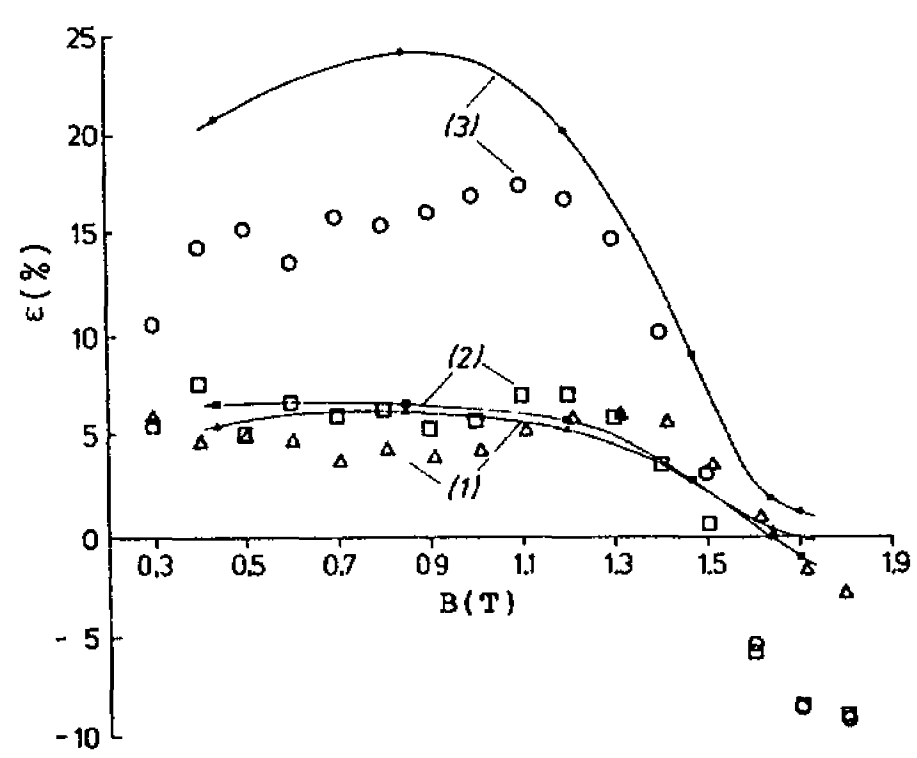


Fig.15 Relative difference $\varepsilon = 100\mathrm{x}(H_{mc}-H_c)/H_c$, versus B; H_{mc} from magnetizing current, H_c by means of H coil;

—— calculated (FEM); △,□,○ measured values

(1)▲— △ stacked yokes, air gap width 0.0035mm

(2)□— □ wound yokes, air gap width 0.0035mm

(3)○— ○ wound yokes, air gap width 0.075mm

4. COMPARISON BETWEEN CALCULATIONS AND MEASUREMENTS

The measurements were carried out using a single sheet tester of smaller dimensions (wound yoke) and an SST with an inner width of 38cm (stacked yoke)/4/, in both cases the geometrical ratios were similar to the calculated cases. To study the influence of the air gap its width was increased by inserting paper of 0.075mm thickness. The air gap width without paper and the space factor were assumed to be similar to the value used with the calculation. Grain oriented steel sheet of a type similar to G10 which was 0.3mm thick, has been used for the comparison. Fig.15 shows the calculated differences between H obtained from the m.c. method and from the H coil method, related to the latter. The agreement, particularly for the slope of the curves, is good considering the complicated magnetic circuit.

5. CONCLUSIONS

It has been shown that the accuracy of the H coil method in all cases considered here is remarkably greater than with the m.c. method. The latter becomes unsuitable in the case of high permeability material at wider air gaps. The results will help to decide whether the more complicated and more accurate H coil method or the easier to handle, but less accurate m.c. method is chosen.

It should be mentioned that, with the m.c. method, measurements of the magnetic loss seem to be less erroneous /4/ compared with the H measurements, due to the fact that the potential drop in the air gaps does not contribute to the loss. This problem will be studied later.

References

/1/ T.Yamamoto and Y.Ohya, IEEE Trans.MAG-10 (1974)157

/2/ IEC publication 404-3 (1983)

/3/ T.Nakata, Y.Ishihara, N.Takahashi and Y.Kawase, JMMM,26 (1982)179

/4/ J.D.Sievert, IEEE Trans.MAG-20 (1984)1702