Charts for Estimating the Axial Shielding Factors of Open-Ended Cylindrical Shields

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***Abstract*—Axial shielding factors of single and double-shell open-ended cylindrical magnetic shields are calculated numerically and represented by charts. It is assumed that the thickness of the shells is small (1%) compared to the largest diameter and the permeability is independent of magnetic induction. Dependencies of the axial shielding factors on the shields' geometry and permeability are calculated numerically and represented finally as logarithmic-scale contour plots. Single-shell shields are described by one chart only where the length-to-diameter ratio (1 to 10) and the permeability (10^1 to 10^4) normalized to the thickness-to-diameter ratio are variable parameters. Double-shell shields are described by a set of charts where the ratio of the shells' lengths (0 to 1) and the normalized permeability are variable parameters while the outer shell length to diameter ratio (3, 4, and 5) and the ratio of the shells' diameters (0.5, 0.6...0.9) are fixed parameters.**

***Index Terms*—Axial (longitudinal) shielding factor, charts, magnetic shielding, open-ended cylindrical shields.**

I. INTRODUCTION

EXISTING theory does not suggest an exact analytical description of axial magnetic shielding with finite length, finite permeability cylindrical shields. Approximate, quasi-theoretical equations developed in [1]–[3] seem to need more detailed experimental verification, especially in the case of double and multi-shell open-ended axial shields. Moreover, the employment of existing analytical formulas for a general analysis of the shielding efficiency in a wide range of shield dimensions and permeability is time-consuming.

Numerical description of axial magnetic shielding by finite element methods yields, apparently, more precise results [4]. Unfortunately, existing software such as the ANSYS and Vector Fields packages is rather expensive and not available for many potential users. A general analysis of magnetic shielding by using existing software is also relatively time-consuming. On the other hand, employing special charts describing magnetic shielding with the most widely applicable, canonical shielding structures can be a convenient and time-saving alternative for many shield designers. Representation by charts is successfully and traditionally used for solving many engineering problems and it is surprising that such charts have not yet been developed for describing magnetic shielding. The present work is aimed at filling in this gap.

II. DEVELOPING THE CHARTS

There are three parameters affecting the axial shielding factor, S_a (defined as the ratio of the external uniform field to the field at the shield's center), of single-shell open-ended cylindrical shields [Fig. 1 (a)]: the cylinders' length-to-diameter ratio, L/D, thickness-to-diameter ratio, t/D, and permeability, μ. The number of parameters can be reduced to

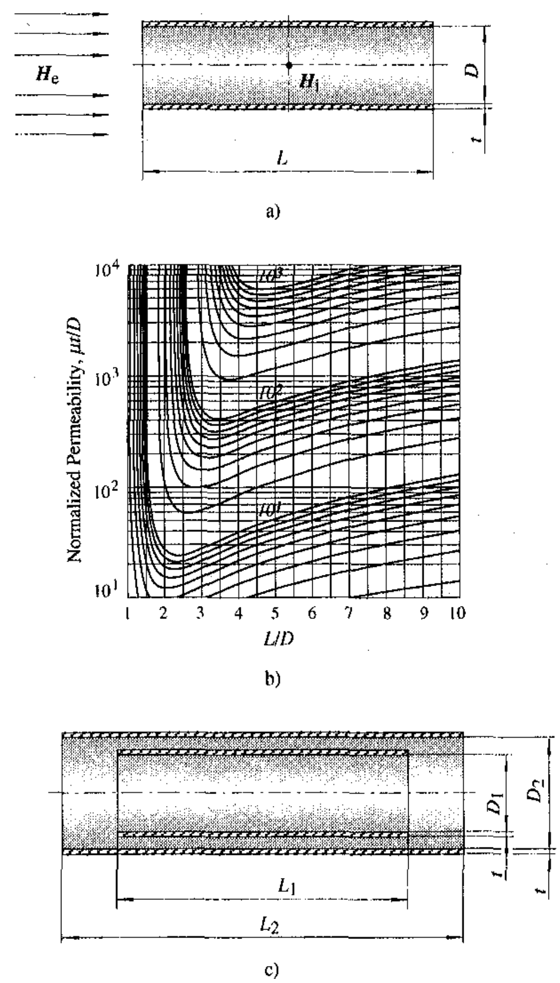

Fig. 1. Open-ended cylindrical shields. a) Single-shell shield. b) Chart for estimating the axial shielding factors of single-shell open-ended cylindrical shields. c) Double-shell shield (for charts see Fig. 2).

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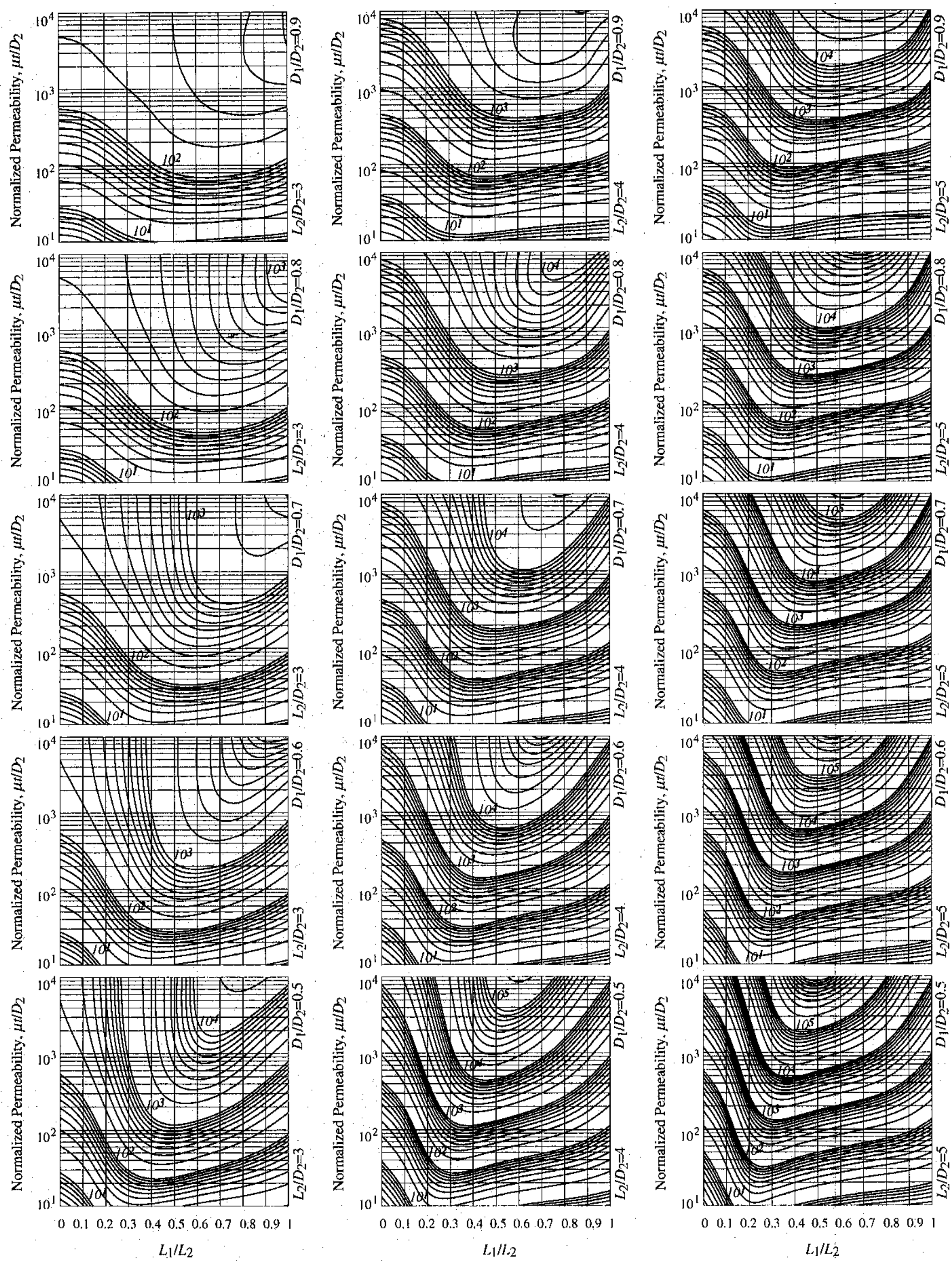

Fig. 2. Charts for estimating the axial shielding factors of double-shell open-ended cylindrical shields.

two, the L/D ratio and the normalized permeability, $\mu_{norm}=\mu t/D$, by assuming that the thickness of the cylinders is small compared to the diameter. A single chart can be used for describing $S_{a\ single}=f(L/D, \mu_{norm})$ dependence in this case.

In order to develop the chart, the shielding factors of single open-ended cylindrical shields exposed to a uniform axial magnetic field are calculated numerically by employing an ANSYS 5.3 software package. (It is assumed that the permeability is independent of the ambient magnetic field.) In order to improve the resolution of the charts, the results of computations are interpolated by standard numerical procedures. Finally, a three-dimensional function $S_{a\ single}=f(L/D, \mu_{norm})$ is represented as a contour plot [see Fig. 1 (b)] with contour lines drawn through the points corresponding to the same values of the axial shielding factor according to logarithmic scale.

In the case of double-shell shields [see Fig. 2 (c)], two new parameters, the ratio of the lengths, L_1/L_2, and the ratio of the diameters, D_1/D_2, of the inner and outer shells, affect the axial shielding factor $S_{a\ double}$. (It is assumed that the inner and outer shells are of equal permeability and thickness, and the μ_{norm} is defined as $\mu_{norm}=\mu t/D_2$.) Since the number of parameters is larger than two in this case, several charts are needed to describe $S_{a\ double}=f(L_2/D_2, \mu_{norm}, L_1/L_2, D_1/D_2)$ dependence.

It is generally important to estimate how the μ_{norm} and distance between the shells, $\Delta\propto 1/(D_1/D_2)$, affect the axial shielding factor $S_{a\ double}$ for various values of the L_1/L_2 ratio. As a result, a set of charts describing $S_{a\ double}=f(L_1/L_2, \mu_{norm})$ for fixed L_2/D_2 and D_1/D_2 should be calculated. In order to develop these charts, a procedure that is similar to the above-mentioned one, employed for single-shell shields, was used. Finally, the following three-dimensional functions $S_{a\ double}=f(L_1/L_2, \mu_{norm})$ for fixed L_2/D_2=3, 4, 5, and D_1/D_2=0.9, 0.8, 0.7, 0.6, 0.5 are represented as logarithmic-scale contour plots (see Fig. 2).

Charts developed illustrate behaviour of the shielding performance as being affected by the shields' geometry and permeability. The two following geometry related effects cause deterioration of the shielding performance of both single and double-shell shields, namely: the effect of the openings and decreasing the axial shielding efficiency with increasing the length of the shell. In the case of double-shell shields, two new geometry related effects that cause enhancement of the shielding performance should be taken into account, namely: decoupling the shells due to introducing interspaces, $\Delta\propto 1/(D_1/D_2)$, between them; and screening the ends of a shorter inner shell by a longer outer shell.

The chart in Fig. 1 (b) shows that in the case of single-shell shields, the effect of openings is a dominant factor for shields having L/D ratios that are smaller than those providing maximum axial shielding factors. The charts in Fig. 2 show that in the case of double-shell shields, decoupling the shells, $\Delta\propto 1/(D_1/D_2)=1/0.9-1/0.5$, is an important parameter increasing the axial shielding factor.

It is interesting on the other hand that reducing length of the inner shell in order to screen its ends by a longer outer shell is not always effective. For instance, it is worth to chose the same length for both the inner and outer shell for shields with L_2/D_2=3, D_1/D_2=0.8 or 0.9, and $\mu t/D_2>1{,}000$ (see Fig. 2) since for such relatively short shields it is more important to reduce the effect of the openings by increasing the inner shell L/D ratio rather than to screen the inner shell ends.

III. CONCLUSION

Axial shielding factors of single and double-shell open-ended cylindrical magnetic shields are calculated numerically and represented by charts. Charts computed allow a quick and relatively accurate estimating of the axial shielding factors in a wide range of the shields' dimensional ratios and permeability. Employing the charts also allows one to visualize and represent the results of calculations in a compact and comprehensive form. It can assist in a general study of axial shielding performance for axial cylindrical shields.

The present work is the first attempt of the author to describe magnetic shielding by special charts. This work was actually initiated in order to stimulate analytical or quasi-analytical magnetic shield modeling. For this reason, it is important to describe numerically magnetic shielding with shells having an equal thickness and a constant permeability. The charts describing axial shielding factors of triple-shell open-ended cylindrical magnetic shields can be of an academic interest as well, and the author is about to complete calculation of such charts.

In order to increase practical significance of the charts, it is important to take into account the variations in permeability caused by applied magnetic field, and the author hopes to address this issue in his future work.

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