Optimal screen width for field reduction applications of low frequency magnetic fields in three-phase conductors

H.Beltran[1], V.Fuster[1], C.García[2], V.Ferrer[1], I.Piqueras[1]

[1]Institut de Tecnologia Elèctrica.
Avda. Juan de la Cierva, 24 – Parc Tecnològic Paterna
46980 Paterna (Valencia). Spain
Phone: +34961366670 Fax: +34961366680 E-mail: Vicente.Fuster@itenergia.com, Hector.Beltran@itenergia.com , Vicente.Ferrer@itenergia.com , Ignacio.Piqueras@itenergia.com

[2]UNION FENOSA - Distribución.
Avda. Arteijo, 171
15007 A Coruña. Spain
Phone: +34981178700 Fax: +34981178828 E-mail: cjgarcia@unionfenosa.es

Abstract. Shielding of low frequency magnetic fields has been investigated by computation and experimentation. Plane shape ferromagnetic and conductive materials (Fe, Al and Cu) have been considered in order to prove the efficiency of different widths facing the same magnetic field. The results of the measurements validate those of the simulations. The graphics exposed provide an idea of the limitation phenomenon appearing on the different materials which shows shielding effect is not infinitely improved by the increasing of the screen width. The optimal dimension is analyzed for each of the materials.

Keywords

Magnetic shielding, extremely low-frequency electro-magnetic fields, screen width, finite elements technique.

1. Introduction

In the last years, an increasing number of people have become concerned about the possible health effects related with the electromagnetic fields generated by electric infrastructures such as high voltage transmission lines or power substations. After the Rio Environmental International Conference the European Union starts regulating over environment focusing on the domain of magnetic fields with the Directive 2004/40/CE.

From there on, limitations on magnetic field permanent or punctual exposure have been established. New installations will have to be kept under limits and old ones must be controlled to check they agree with the legislation. Many of these old infrastructures are placed close to residential areas or public access zones. Those producing magnetic field levels above the limits will have to be modified. Thus, one of the ways to reduce the electro-magnetic radiation emitted by electrical components is the magnetic shielding, although there are several ways to reduce it, both active and passive (screening) methods ([1],[2]). Traditionally, ferromagnetic materials have been considered to be the best solution for magnetic screening due to their high permeability, but several studies performed lately on this topic have shown up that shielding by means of conductive sheets, such as aluminium ones, has some advantages with respect to ferromagnetic foils ([3],[4]).

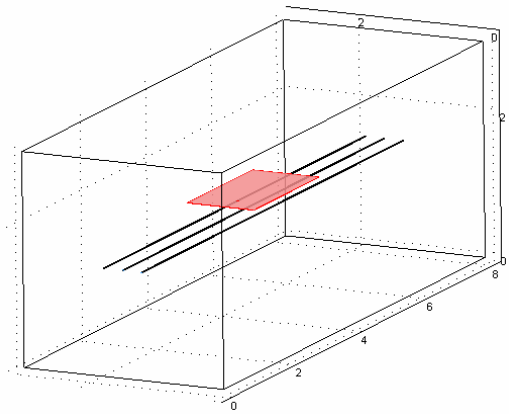

Figure 1 - 3D view superior screening.

The main aim of this paper is the study of screening effect performed with several widths of different kind of materials, conductive (Al and Cu) and ferromagnetic (Fe). The knowledge of the optimal width in connection with the rest of dimensions ([5],[6]) will help for the correct design of magnetic screens.

2. Mathematical formulation

The magnetic field produced by a three-phase conductor system with the presence of magnetic screens in the surroundings can be determined by numerical methods.

For the calculations the Finite Elements method has been used. 2D models have been used in order to simplify the 3D problems depicted in figures 1 and 2.

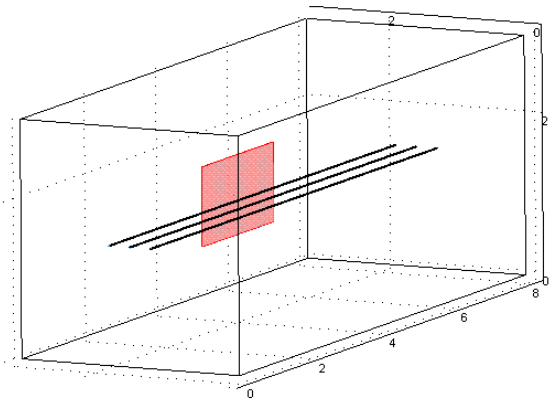

Figure 2 - 3d view lateral screening.

In conductive materials, currents are induced as a consequence of the exposure to time varying magnetic fields. These magnetic fields induce electric fields along the material which can originate voltage gradients inside the material that produce circulation of currents. The equation describing such a phenomenon is Faraday's law:

$$\nabla x E = -\frac{\partial B}{\partial t}$$

The appearance of these eddy currents has to be assumed as one of the causes of magnetic field reduction [7]. They generate an opposed magnetic field. The 2D eddy current problem yields the equation:

$$\sigma \frac{\partial A_Z}{\partial t} = -J_0$$

This will be solved knowing that J_0, the exciting current density, has only one component in the z-direction due to the model in two-dimensions.

On the other hand, in ferromagnetic materials, the flux shunting mechanism is observed and used for magnetic screening. Microscopic domains of the material tend to align themselves with external magnetic fields creating a secondary magnetic field which couples with the original one. The total field is the addition of the two fields. This adding yields flux lines to be drawn into, and shunted through, the material, reducing the field intensity beyond the material.

This ability to reduce the magnetic field is directly dependant on the permeability of the material and it is taken into account in the simulations varying the value of this property for each of the different materials.

The dependent variable used for the resolution of the problem in this application is the z component of the magnetic vector potential, A_z, which obeys the following relation. It is this equation which solves the numerical model considering all the properties:

$$\left(j\omega\sigma - \omega^2\varepsilon\right)A_Z + \nabla \times \left(\mu^{-1}\nabla \times A_Z\right) = J^e$$

Where ω is the angular frequency, σ is the conductivity, μ is the permeability, ε is the permittivity, and J_e denotes the current density due to an external source.

Three materials have been used during the analysis and the properties used for their representation are:

	Conductivity (S/m)	Relative Permeability
Aluminium	3.774e7	1
Copper	5.998e7	1
Iron	1.12e7	4000

3. Experimental procedure

A three-phase conductor distribution as that one showed in fig 1 was installed in the laboratory. The three phase copper conductors were 6m long, with a section of 240mm^2 and 285mm as reference distance among centres. The current circulating through them was established as 500A. A current generator was used to feed the system from the electric power network. From this installation, a series of measurements were carried out getting values of magnetic field generated around the conductors comparing them with the values obtained by means of the simulations.

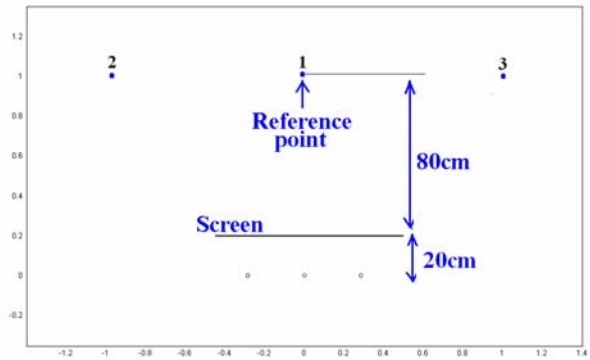

Figure 3 - Conductors distribution.

The simulation of the problem was done using a 2D model, representing a section of the distribution, and applying the finite elements method (FEM). Comparing the results of both procedures, simulation and measurements, it could be assured that the computer modelling had been done in a proper way. For this comparison of magnetic field three places were selected as reference points. Taking the central conductor as the (0,0) coordinates in the 2D view, the three points are situated at the coordinates: Point 1, 1m above the conductors on their vertical (0,1); point 2, 1m above and 1m left (-1,1); and point 3, at 1m to the right (1,1). The situation of the points can be observed on the figure 3. The cases measured and simulated were:

- Without any kind of shielding.
- With an iron screen.
- With an aluminium screen.
- With a copper screen.

The width of the screens used in these initial simulations was 1 meter and the thickness 2mm for the 3 materials.

The values of magnetic field (in μT) registered on the different cases were:

Point 1:

	Without screen	Iron screen	Aluminium screen	Copper screen
Measured	4,248E-05	2,926E-05	1,738E-05	1,569E-05
Simulated	4,546E-05	2,969E-05	1,456E-05	1,156E-05

Point 2:

	Without screen	Iron screen	Aluminium screen	Copper screen
Measured	2,319E-05	2,037E-05	1,494E-05	1,425E-05
Simulated	2,486E-05	2,146E-05	1,058E-05	9,261E-06

Point 3:

	Without screen	Iron screen	Aluminium screen	Copper screen
Measured	2,304E-05	1,924E-05	1,473E-05	1,395E-05
Simulated	2,472E-05	2,033E-05	1,041E-05	9,291E-06

From the values above, it can be checked the equivalence of the results. Nevertheless, there are some differences on the lateral points which have deviations of around 20%. These differences can be justified from the precision of the measurement method which can vary the lecture in this range within a displacement of the instrument of 3cm. Considering the size of the measurement windings, around 10cm, the error is acceptable.

Figures 1 and 2 show the two different screening arrangements that were considered: the superior and lateral screening. For the analysis of the effect of the width of the plates in these 2 positions, some parameters were forced to be constant. In this way, the thickness was established to be 2mm for all the plates. The distance between the conductors and the plates was always 20cm and the plates were centred referred to the three phase distribution.

4. Simulations

A. Superior screening

Superior screening, corresponding to the arrangement depicted in figures 1 and 3, produces a distortion of the magnetic flux lines as the one showed in the following figure.

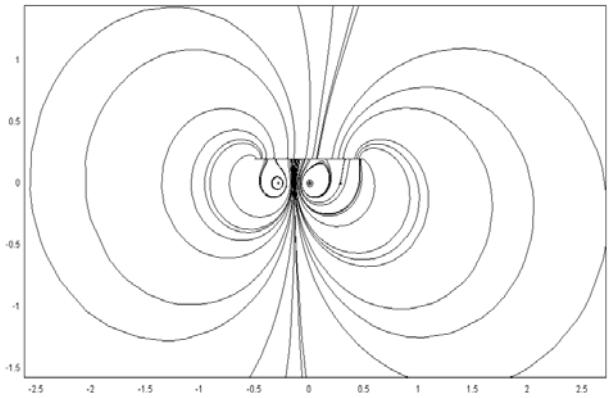

Figure 4 - Magnetic flux lines using aluminium screen.

The simulations check the magnetic field registered in a point situated 1 meter above the conductors when different width screens are placed as shown in figure 3. The values considered are 0.3m, 0.5m, 0.8m, 1m, 2m, 3m and 4m wide.

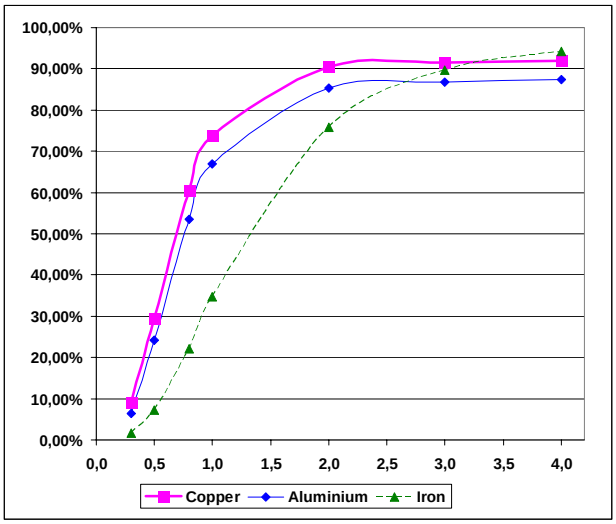

Figure 5 - Percentage of field reduction as a function of the screen width in metres.

From the previous graphics it can be deduced that aluminium or copper have better response than iron in these conditions of magnetic field since magnetic flux lines impact mostly perpendicularly the surface of the plate, enhancing in this way the creation of eddy currents in conductive materials (aluminium and copper), this corresponds with the explanations in [8].

B. Lateral screening

In order to complement the width influence registered on the screening effect, a second disposition was considered and simulations with lateral screening performed. The shield was now situated 20cm right of the lateral conductor and the point controlled was established to be 1m right of the central conductor. Since the lateral conductor is 285mm away from the centre of the distribution and the plate is located at 200mm away from this, the reference point is separated just 515mm from the screen. Next 2D view clarifies the disposition of the system corresponding to one section of the 3D view showed in figure 2.

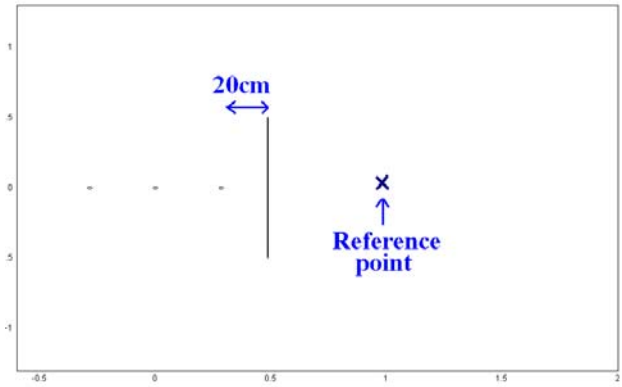

Figure 6 - 2D scheme for lateral screening.

As for the case previously analyzed with superior screening, a view of the deformation of the magnetic field can clarify the effect introduced by the screen. The

field resulting from the insertion of a 2 metres iron plate on the side of the conductor's distribution is as follows:

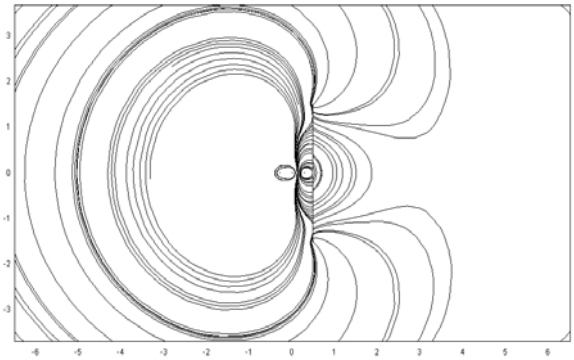

Figure 7 - Magnetic flux lines with lateral screening.

The simulations done in this new arrangement are quite the same as for the previous case. Measuring the magnetic field in the reference point multiple dimension plates have been inserted. The sizes simulated are: 0.3m, 0.5m, 0.8m, 1m, 2m, 3m and 4m wide. From these simulations a new graphic can be obtained with the magnetic field reduction observed as a function of the width of the plate inserted.

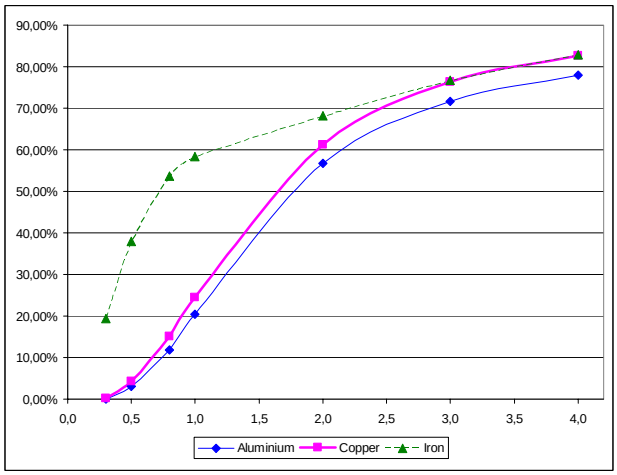

Figure 8 - Percentage of field reduction as a function of the screen width in metres.

In this position iron had a good behaviour, better than aluminium or copper. This is due to the fact that in this second position analyzed for the screen, the magnetic flux lines are not perpendicular to the surface of the plate. In this case they are mostly parallel to the surfaces and then, it is the permeability of the material which disturbs the trajectory of the flux lines in this region of the space. Even though, it can be observed that conductive materials have also a good performance for widths greater than 2m.

So, in the superior screening, they were the Eddy currents what had the most important influence whilst in the lateral screening it is the permeability of the material the most determinant characteristic.

This remarks the big importance of the electromagnetic source and the shield orientation, which determines the shielding effectiveness as a function of the relative position, confirming previous studies [9].

Apart from those considerations, regarding the width of the plates, it is reflected on the graphics that it has a limitation in the way that beyond certain values the increase in width is not proportional to the reduction of magnetic field. So there are optimal values and limits in width for the screening efficiency in relation with the cost and weight of the structures. This limit varies for the different materials and could be approximated from the results as: around 1m large on each side of the magnetic field source with conductive materials, and from 0.5m to 1.5m large on each side for magnetic materials such as iron depending on the relative position of the plate regarding the magnetic field source.

These results come from the graphics where it can be observed that the best point of functioning is with the 2m wide plates, which is approximately 1m wide on every side of the three-phase distribution.

5. Conclusions

The influence of the material width on the screening efficiency has been studied. Both measurements and simulations have been performed. The measurements validate the results of the simulations. Through extended simulations it has been shown that the wider the screen is the most important the field reduction we get. However, there is a limitation point on the width effect for each of the materials. For the iron, increasing it beyond 1m or 3m, depending on the relative position to the conductors, will bring no great improvement. On the other hand, the limitation width for both cupper and aluminium is situated around 2m. These are the optimal widths to be used in the different screening applications and that should be applied, spitted into 2 parts on the sides of any magnetic field source.

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