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Some aspects of electromagnetic field shielding

Abstract. *The paper deals with the electromagnetic field shielding both at low and high frequency. At the low frequency the goal of shielding is to regulate the distribution of electromagnetic field in order to either minimizing the power losses in the iron (steel) parts of the device in question. The main practical aim of the shielding at the low frequency electromagnetic field is to avoid the state of overheating. At the high frequency the shielding is mainly dedicated to limit the radiation from the electromagnetic sources and the protection of electronic devices. In some extreme cases the shielding has to protect the humans against electromagnetic field.*

Streszczenie: *Artykuł dotyczy problematyki ekranowania pola elektromagnetycznego, zarówno dla niskich jak i wysokich częstotliwości. W problemach niskoczęstotliwościowych celem ekranowania jest właściwe sterowanie polem elektromagnetycznym w celu zminimalizowania strat energii w urządzeniu, co praktycznie sprowadza się do unikania stanu przegrzania elementów metalowych. W sytuacjach wysokoczęstotliwościowych ekranowanie ma na celu ograniczenie emisji pola elektromagnetycznego , a także ochrony urządzeń elektronicznych przed działaniem pola elektromagnetycznego. W sytuacjach ekstremalnych ochrona tak może dotyczyć ludzi* ***(Wybrane aspekty ekranowania pola elektromagnetycznego)***

Keywords: electromagnetic shielding, electromagnetic field , power losses, electromagnetic interferences
Słowa kluczowe: ekranowanie elektromagnetyczne, pole elektromagnetyczne, straty mocy, interferencje elektromagnetyczne,

Introduction

Electromagnetic field (EMF) has many applications in engineering, medicine, biology, computer and data engineering and other areas of technology, science and life. Hence, its role is mainly positive. But, there are cases where electromagnetic field has to be limited in magnitude or/and in space. The main reasons of these limitations are usually overheating and parasitic interferences. The limitation of EMF is realized by means of various manners but the main method is supposed the use of the shield.

Electromagnetic field shielding is the intentional control of EMF to reduce electromagnetic energy in electrical, electronic and telecommunication installations. The electromagnetic field is a physical phenomenon that is produced to generate and using electrical energy (generators, motors, transformers, heating devices, electromedicine) and it applies to low frequencies, basically 50 Hz, and to generate and transmit information (wireless communications, audiovisual media, radars, military and medical techniques). They mainly apply to high-frequency and ultra-high-frequency EMF.

The effectiveness of reducing the EMF level results from:

- the construction of the device,
- the geometry of the device,
- materials used,
- the final goals of this shielding.

Shielding of the ELF EMF (extremely low frequency electromagnetic field)

According to the Commission on Non-Ionizing Radiation Protection) guidelines [1], ELF EFM is at the range of frequency (1 Hz – 100 kHz). These frequencies are mainly linked with the electricity used in the home appliances, power generators substations (transformers, switchgears, bus bars etc.), electric networks (power transmission systems), medical equipment, and some others. While this range of frequency is being considered the problem of shielding is focused on the minimization of electric energy at some chosen places. It can be the problems of saving energy or the problems connected with overheating. The shielding (screening) of EMF consists in conscious steering EMF by using electric materials. The protection of transformer tank against overheating due the leakage magnetic flux is one of the good examples of shielding technology.

The reduction of the magnetic field in the transformer tank, is obtained by using:

1. magnetic shield, i.e. material with very high magnetic permeability (ferromagnetic sheets),
2. highly conductive material (copper, aluminum).

In the first case, the shield is used to properly route of the magnetic field force lines, so that the magnetic field will not penetrate the steel of the tank and the magnetic field will be confined to the shield area. Due to the material properties of magnetic sheets the power losses will be minimized.

In the second case, a significant part of the energy resulting from the existence of eddy currents will remain in the conductive shield, which will result in energy losses, due to the high conductivity of the shield, smaller than in a steel tank.

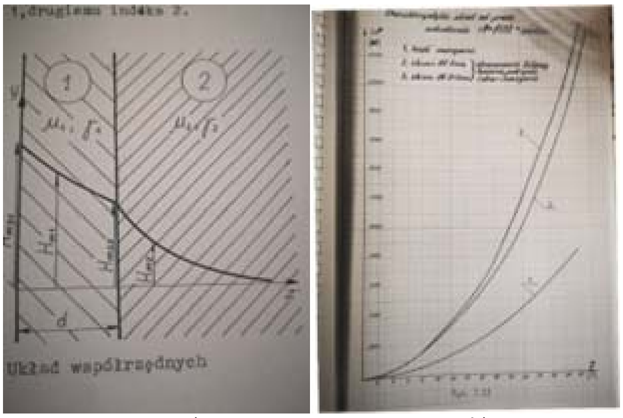
The second solution see to be more often applied, especially for large power transformers. But the attention should be put on the final energy balance. In the case of improper shield using, the situation can be changed for worse. False selection of the shield thickness can cause the magnetic field weakly damped in the shield and fully penetrate the steel tank, and therefore energy losses in the steel (almost the same as without the shield + energy losses in the shield) worsen the energy situation of the entire facility

a) b)

Fig.1 a) the measuring set, b) the coil [2]

More than fifty years ago two diploma students of the Faculty of Electrical Engineering at the Łódź University of Technology discovered the above mentioned fact [2]. They

investigated the effectiveness of shielding the steel tank by the shields made of aluminum of various thicknesses, The magnetic field, representing the leakage flux in transformer, was generated by the coil (Fig.1).
The experiment showed that the total energy losses (tank&shield) is much bigger than the energy losses in the tank standalone.



a) b)

Fig. 2 a) the illustrative distribution of magnetic field strength in the measured object , b) the measured power loss (1- tank standalone, 2 – shielded by 1 mm aluminum shield, 3 – shielded by two 1 mm shields) [2] [1].

It should be added that the thickness of aluminum shield which ensure the effective shielding is about 8 mm. It results from the coefficient of penetration $\boldsymbol{\delta}$ which binds material conductivity, material magnetic permeability and frequency of electromagnetic field and physically determines the effectiveness of dumping electromagnetic field (1).

(1) $$\delta = \sqrt{(2/\mu\omega\gamma)}$$

Where: $\boldsymbol{\omega}$ – angular frequency; µ – magnetic permeability; $\boldsymbol{\gamma}$ – electric conductivity.

Other cases of shielding relate to the protection of MV / LV switchgears (medium and low voltage), especially those located in close proximity to residents. The main task of such shielding is to limit the emission of the electromagnetic field outside the substation from the point of view of electromagnetic compatibility. The source of EMF in this case are mainly busbars, which lead the current of relatively high intensity. The implementation of the shielding can be done in a similar manner to the transformer tank shielding techniques discussed above.

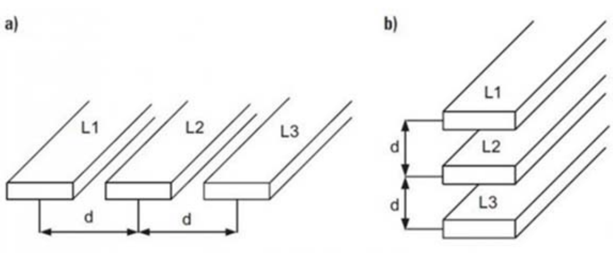


Fig.3 The alternative arrangements of busbars [3]

It is worth mentioning here that the reducing of EMF emitted by the busbars can be realized by simpler and then less expensive methods. One of them, which is becoming more and more popular, is the use of a compact coil. This technique uses Faraday's law of electromagnetic induction and Lenz's principle: the current induced in the compact coil generates a magnetic field directed opposite to the primary, reducing it severely. Another way is to create an appropriate configuration of the three-phase busbar system, e.g. by changing their horizontal position to vertical (Fig.3) [3].

[1] As the Fig. 2 is copied directly from the original typescript [21] its quality is pour and the descriptions are in Polish

Shielding of the RF EMF (radio frequency electromagnetic field)

The term shield / shielding usually refers to the metal housing that completely surrounds the electronic product or part of that product. There are two targets of the shield as shown below in Fig.4 [4].

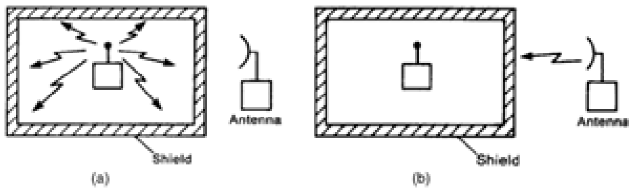


Fig.4 Two possibilities of shielding: a) internal b) external [4]

The first is to prevent the product electronics from radiating beyond the product boundary. The motivation here is either to prevent these emissions from causing the product to fail to comply with radiated emission limits, or to prevent the product from causing interference with other electronic products. The second purpose of the shield is to prevent radiation emissions outside the product from coupling with the product electronics, which may cause interference in the product. As an example, shielding can be used to reduce susceptibility to external signals such as high power radars or radio and television transmissions.

To put it synthetically, it can be said that the screen is a barrier to the transmission of the electromagnetic field. The shielding effectiveness is expressed as a ratio of magnitude A_1 of the electric (magnetic) field that falls on the screen to the magnitude A_2 of the electric (magnetic) field that has penetrated the screen. Shielding effectiveness (SE) is measured in decibels (dB).

(2) $$SE = 20 \log_{10} (A_1 / A_2)$$

For example, reducing the magnetic or electrical component of the EMF by 10^5 times expressed in decibels gives a value of 100 dB.

Effectiveness of shielding strongly depends on the geometrical and physical properties of the shield.

The thickness of the shield, its shape, the physical parameters of the material and the EMF frequency have a great influence on the effectiveness of the shielding. As with low frequencies, a poorly designed shield can lead to the opposite effect to what is expected. For example, a shield with a geometric defect (gaps, cracks, cuts) poorly designed may lead to an increase in the EMF intensity in the protected area. Clayton R. Paul writes in his book [4]:

The shield must completely cover the electronics and must not have any disturbances in the structure such as holes, seams, sockets or cables. Any discontinuities in the shield structure, unless properly handled, can drastically reduce the effectiveness of the shield.

The materials most often used in the high frequency shielding are metal materials, especially copper, aluminum and some alloys and the carbon materials, like graphite or graphene. From the metal materials the most known are [7.8]:

- Copper is often considered the most reliable of all EMI shielding materials because it reduces electrical and magnetic waves. It is not easy to find a piece of electronic hospital equipment that does not have some copper EMI shielding. Copper does cost more than other materials and pre-tin-plated steel, but it is the most conductive of all EMI shielding materials.

- Aluminum works well because it boasts a high strength-to-weight ratio while remaining highly conductive. It is important to keep in mind that aluminum is prone to corrosion, and it has oxidation properties. Oxidation compromises the structural integrity of the metal.
- Nickel Silver / Copper Alloy 770 is often referred to as alloy 770 and the other name is German silver. Its name comes from the bright metallic silvery appearance of the alloy. Although the mentioned alloy do not contain true silver. It consists varying amounts of 27% of zinc, 55% of copper, and 18% of nickel. this material exhibits exceptional mechanical properties. Nickel silver has good electrical properties and excellent solderability. The susceptibility of the alloy to oxyacetylene and spot welding are rated as good. This material is an excellent alternative to post-plated parts. This alloy is ideal for use in environments where corrosion is a problem. The material is also very useful for EMF of GHz frequencies.

As the carbon material a good example is the recent discovery made by the group of Polish scientists from the Faculty of Physics of the Warsaw University of Technology, who have started research on new carbon materials with high shielding efficiency, mainly while using in the microwave and terahertz frequencies. These materials are nanocomposites based on graphene. Project leader, prof. Zdrojek describes the started research project as follows [5]:

Metals are usually used for protection against electromagnetic field. But they have many disadvantages, most of all they are heavy and not very plastic, and most importantly they reflect electromagnetic field instead of eliminating it. Therefore, we decided to develop a non-metallic material that absorbs electromagnetic radiation.

The special attention in the process of external shielding should be paid to the medical instruments which generate the electromagnetic field of very low magnitude. This situation is mostly faced in magnetocardiography (MCG) or magnetoencephalography (MEG) diagnostic systems. The magnetic field which is used there is in the range of 100 pT (MCG) and a few picoteslas (MEG), thus its measuring is possible only by the use of SQUID (superconducting quantum interference device), In Fig. 5 the shielded room for MEG diagnostics under preparation is shown [9].

Fig. 5 The assembling of room for MEG diagnostics [9]

Personal shields as the protection against EMF emitted by mobile phone systems

In recent years, there has been an eruption of the production of electromagnetic shields to protect the living area, but also people from "dangerous electromagnetic radiation". The production of protective elements such as paints, wallpapers, bedding, protective sticks or clothing items does not provide for certified effectiveness tests and is a classic example of eliminating human anxiety using the placebo method. The examples of items of clothing and other products are shown in Fig.6.

The pathological form of this approach to EMF is presented by people called tin foil hatters. These people, by putting on the head protection in the form of an aluminum foil cap, protect themselves against EMF, which causes, in their opinions, mind control, changes in consciousness, and other dangerous interference with the human mind as well as generate various illnesses and dysfunctions. The foliar views gained popularity during the introduction of 5G technology to the telecommunications market.

Fig. 6 Examples of personal screening [10,11]

Conclusions

EMF shielding is most often used to reduce the energy produced by EMF in electrical devices and to minimize electromagnetic interferences in electronic, automatic and tele/radio communication systems. In other words, the aim of shielding is to avoid any undesirable electromagnetic influences and interferences. Some people believe that shielding can protect against the allegedly negative impact of EMF on human organisms. As contemporary research does not indicate a negative impact of electromagnetic field on human health and life, within the limits allowed by the international and national standards, the production of such protective shields also seems to be superfluous.

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