XXVI Seminarium

ZASTOSOWANIE KOMPUTERÓW W NAUCE I TECHNICE 2016

Oddział Gdański PTETiS

ANALYSIS OF ELECTROMAGNETIC FIELD DAMPING EFFICIENCY BY USAGE OF SHIELDING WITH DIFFERENT PARAMETERS

Maciej KUNIEWSKI[1], Jakub PLUCIŃSKI[2]

1. AGH University of Science and Technology
   tel.: +48 12 617 44 e-mail: maciej.kuniewski@agh.edu.pl
2. AGH University of Science and Technology
   tel.: +48 606 358 396 e-mail: j.plucinski44@gmail.com

Abstract: This paper presents measurement of shielding effectiveness for 50Hz electric and magnetic field while using different materials (ferromagnetic/diamagnetic), that varies between structure (net/solid sheet; open/close shields), intensity of EM field (phenomenon of saturation to magnetic materials) and frequency spectrum (50Hz field with higher spectrum). Wide-range frequency analysis for EM field was also taken into account in order to present distortions in measurements, caused by High Voltage Impulse Generator.

Keywords: shielding effectiveness; electromagnetic field; shielding.

1. INTRODUCTION

During work, electrical power devices produces electromagnetic (EM) field around their structures [1,2]. Intensity of EM field is determined by values of the current and voltage of the source, field level in particular places may exceed permitted level exposing human body to risk. On the other hand, electronic and scientific devices such as electron microscope are highly vulnerable to external EM field which may disrupt proper work. That forces designers to attenuate EM field for which basic method is shielding [1-4].

1.1. Shielding effectiveness

Effectiveness of used shielding is determined by three coefficients: absorption coefficient *A* reflection coefficient *B* and multiple reflection coefficient *C* (fig. 1). Shielding coefficient K_s is related to ratio of electric and magnetic field intensity measured with and without shielding [1].

Shielding effectiveness may calculated in diversified ways, considering shielding parameters:

$$SE = A + B + C \ \ [dB] \quad (1)$$

$$SE = 15{,}4d\sqrt{f\mu\sigma} + 168{,}16\frac{\mu_r f}{\sigma_r} + 20\log(1 - e^{2d/\delta})$$

To use relation (1), knowledge of cofactors as: material thickness *d*, electrical conductivity of shielding material σ, magnetic permeability of shielding material μ, frequency *f*, depth of wave penetration δ, is required [1].

The multiple reflection factor *C* can be neglected if absorption factor *A* is higher than 9 dB. Therefore shielding effectiveness *SE* may be calculated as (2).

$$SE = A + B \ \ [dB]$$

$$SE = 8{,}69t\left(\frac{2}{\omega\mu\sigma}\right)^{1/2} + 20\log\left(0{,}25\left(\frac{\sigma}{\omega\mu_r\varepsilon_0}\right)^{-1/2}\right) \quad (2)$$

Figure 1 presents visualization of shielding coefficients and their interpretation in wave attenuation.

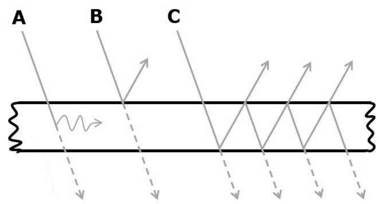

Fig. 1. Visual representation of shielding quality coefficients, A – absorption, B – reflection , C – multiple reflection cofactor

2. NEAR AND FAR FIELD

The properties of EM field are determined by the source, media surrounding it and distance between source and observation point [2]. In points close to the source, characteristics are mainly determined by source attributes, whereas points far from the antenna highly depend on media through which field is propagated. Therefore EM field can be divided into two regions: near and far field, depending on the critical distance $x_c = \lambda/2\pi$, from source and signal properties, where λ is wavelength of the main frequency in analyzed signal spectrum.

We talk about far (radiation) field, when observing distance is greater than x_c, in which field properties are constant and equal to characteristic impedance of the medium (air characteristic impedance (3)).

$$Z_0 = \frac{E}{H} = 377\Omega \quad (3)$$

In radiation filed, both, magnetic and electric components are being attenuated as r^{-1}.

Space close to (3) is a transition region in which wave properties cannot be determined exactly.

Near (induction) field exists in distance closer than x_c from the source. Its properties are not constant and varies due to current and voltage level of source. If source has small current and high voltage $(Z > Z_0 = 377\Omega)$, field is dominated by electric component, such wave is called high-impedance wave, its value decreases with distance reaching (3) at x_c. With increasing distance electric component loses are gained as complementary magnetic component is being generated. In induction field, electric component attenuates as r^{-3}, whereas magnetic component attenuates as r^{-2}. On the other hand, if source has high current and low voltage $(Z < Z_0 = 377\Omega)$, we might say about predomination of magnetic component, such wave is called low-impedance wave, its impedance increases until reaching Z_0 impedance in the distance of x_c. Magnetic component loses are gained with distance as electric component is being generated. First of them attenuates as r^{-3}, while second one as r^{-2}. Characteristics of wave impedance due to distance from source is visualized in fig. 2.[1]

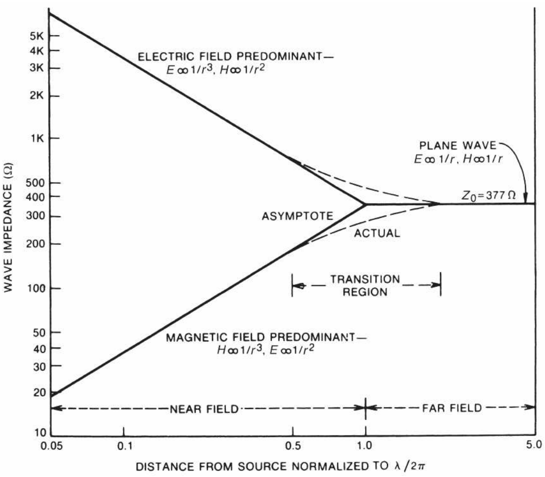

Fig. 2. Characteristics of EM wave in near and far field [1]

Due to non constant relation between magnetic and electric components in near field, they should be considered separately. Each measure presented in this paper has been made within the range of near field with high impedance wave.

3. RESULTS OF THE EXPERIMENT

3.1. Electric field

Experiment was carried out in a High Voltage Laboratory at AGH, University of Science and Technology. Installed shields placed around each *HV* test station were under investigation. As test stations have different shields configurations, we were able to make a comparison of shielding effectiveness due to shield design. Test design of shielding were: aluminum net with mesh 1x1 cm and solid plates, aluminum net shield designs have open structure up to 1.8 m high and close structure. Measurements have been performed with electric dipole meter [2] at distance 1.8 m above ground.

To calculate shielding effectiveness for electric field produced by HV test transformers (U_n up to 250 kV), we took series of measures in points 3-7 (Fig. 3)

Average shielding effectiveness for net structure (up to 1.8m high) around 110 kV test transformer is 26 dB, whereas for both, shielded tunnel (point 3, field produced by 250 kV test transformer) and solid structure (produced by 110 kV test transformer), *SE* is more than 61 dB (due to reaching of maximum dipole sensitivity). Electric field intensity was rising linearly with the raise of voltage, referring to this, it may be said, that *SE* is constant in the measured range of produced field.

Obtained results shows that shields with closed structures are damping electrical field efficiently, even if observer is standing next to HV source behind shield. Shielding of electrical field with open structures is less efficient because of field lines, which are closing on grounded elements not in 100 %, and are pushed out of shield, in closed structures electrical field lines don't leave out Faraday cage. Efficiency of open shields are determined by geometry (i.e. height of shield and measuring place) and placement of HV source inside pole.

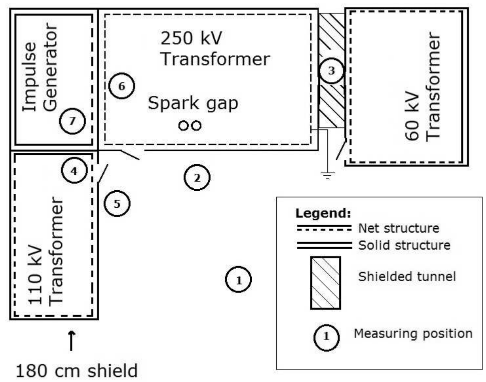

Fig. 3. HV laboratory scheme

3.2. Magnetic field

This part of experiment was performed in setup shown in Fig. 4. Magnetic field produced by coil L, was measured by tri-axis pole meter placed in symmetry axis of coil. Shielding structure was placed between source and measuring point. Properties of analyzed shields are presented in table 1. Four of them had open structure in form of one side wall, one of shield had closed structure around source of magnetic field. Shield 1 and 2 was made from diamagnetic material with high conductivity σ and almost air permeability ($\mu_r \approx 1$). Shields 3-5 was made from ferromagnetic materials, with high μ_r. Variable magnetic field generates in materials, with high σ, eddy currents, which counteract to magnetic field according to Lenz's law.

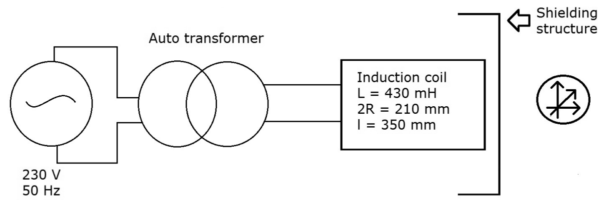

Fig. 4 Magnetic field test stand scheme

Table 1. Properties of used shield models

Shield (fig. 3 and 4) symbol	Material	Structure	Properties,
1. Cu	Copper net, mesh 1x1 mm	Open, wall	Diamagnetic,
2. Al	Aluminum net, mesh 5x5 mm	Open, wall	Diamagnetic,
3. Fe	Stainless steel, solid sheet	Open, wall	Ferromagnetic,
4. Si 1 wall	Cold rolled silicon steel	Open, wall	Ferromagnetic
5. Si 4 wall	Cold rolled silicon steel	Closed around source	As above

Measurements of magnetic flux density *B* in distance *B(x)* and in excitation current *B(i)* domain were performed. Measurements were basis for analysis of shielding efficiency of each used models. Magnetic field meter during first experiment (fig. 5) was placed constantly in the distance of 25cm from the coil axis. During *B(x)* measurements (fig. 6), meter changed its position between 20 and 100 cm, same for every used current level. Shield models were placed in distance 12.5 cm from coil.

Figure 5 presents results of magnetic field measured in distance of 25 cm, produced by 50 Hz current I flowing in coil in case with no shielding. As we observe, B raises linearly with growth of current, which proves that anything affects distribution of magnetic field in measurement stand.

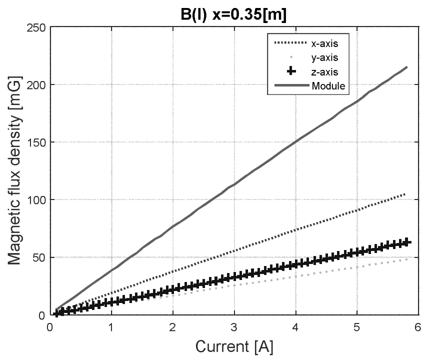

Fig. 5. Magnetic flux density in current analysis

Figure 6 presents results of magnetic field in distance *x* from coil in case with no shielding, for various excitation currents.

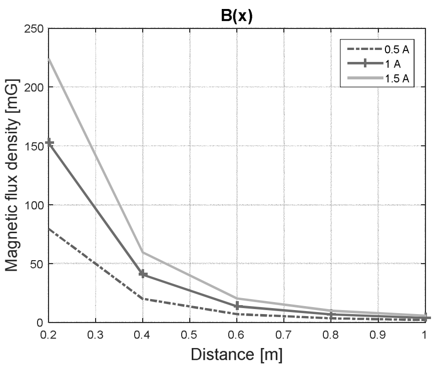

Fig. 6. Magnetic flux density in distance

On the basis on data from fig. 8, we were able to determine characteristics of shielding effectiveness for examined materials (Table 1). Measurement results of shielding efficiency for different analyzed shields are presented in Fig. 7.

Analysis of results shows that, despite the exponential fall of magnetic flux density in distance domain, shielding effectiveness remains relatively constant in the experimental range. Highest attenuation of magnetic field has been obtained, while using ferromagnetic materials, especially for cold rolled silicon steel (SE = 32 dB),whereas field becomes unchanged while shielding material is diamagnetic e.g. copper or aluminum (SE ≈ 0 dB). Usage of high conductive materials δ with low permeability μ_r doesn't impact on magnetic field distribution around analyzed coil in terms of eddy current effect and Lenz Law.

Worth mentioning is considerable difference in shielding effectiveness for closed loop of silicon steel shield and single wall of such material. In this case, magnetic circuit becomes closed, what influence of reluctance reduction. That gives an opportunity for the magnetic field to change its propagation way and penetrate into shielding material. In the second case, only some of field lines are closing in shielding material, the rest are pushing around shielding object, causing lower attenuation, magnetic field is distorted.

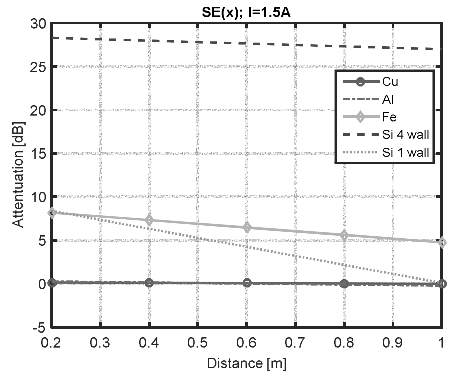

Fig. 7. Shielding effectiveness in distance for examined materials

One of the problem occurring while shielding with ferromagnetic material is saturation phenomenon of such materials. Saturation causes reduction of material permeability which influence on reluctance rise. In high saturation state, ferromagnetic shield is transparent to magnetic field. Fall of shielding effectiveness due to saturation is more visible for closed structures. Figure 8 presents shielding effectiveness of closed 4 wall shield made with cold rolled silicon steel, due to rise of current in coil SE of this shield is changing. Measurements were taken in 25 cm distance from coil. This change is similar to change of material permeability due to magnetic field strength [5].

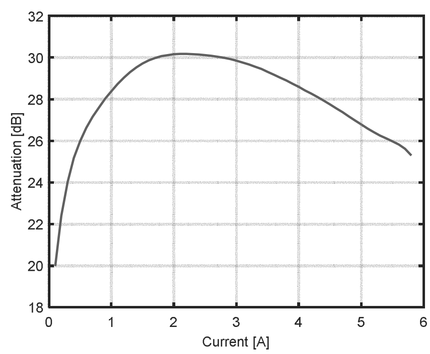

Fig. 8. Shielding effectiveness for Si-Fe material in current

Maximal attenuation (30.5 dB) is observed for current approx. 2 A, this current provides such magnetic field strength in this geometry in material for which magnetic domains are fully ordered. Reduction of saturation effect in magnetic field shields is achieved by equipment of such shields with small air gaps.

3.3. Wide range frequency-domain analysis for EM field

Third group of measurements covered analysis of signals, received from HV sources as 250 kV test transformer and HV Impulse Generator, measured by antenna. This part of investigation covered analysis of frequency spectrum of distortions provided by work of HV equipment and damping effectiveness for higher frequencies by different shields design. Signal measured by antenna was converted to frequency domain by Fourier Transform in MATLAB®. Measurements were taken in different places (Fig. 3), due to that highest analyzed frequency is 1 MHz it is assumed that measured field is near field, and reflections form other elements are neglected. There is assumed that measurements performed in different places of HV laboratory reflects efficiency of shielding which is next to measurement unit.

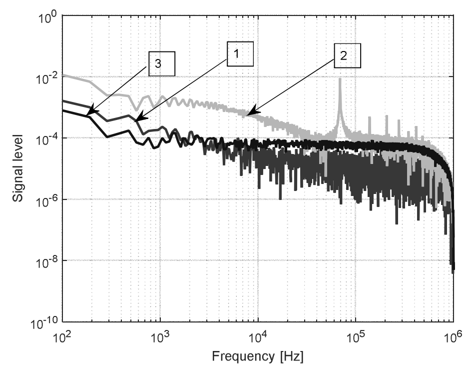

Fig. 9. Recorded signals for HV impulse generator, 1 – far measurement from shielding, 2 – next aluminum mesh (2x2 cm), 3 – next to solid stainless steel shield

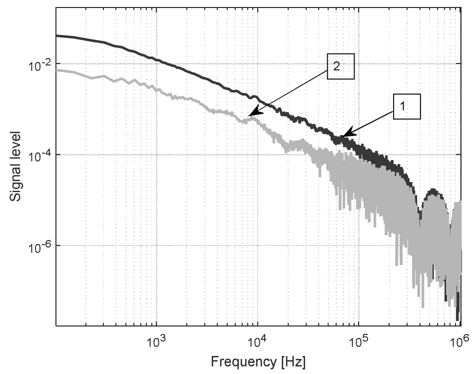

Fig. 10. Recorded signal for 250 kV cascade 1 – measurement point 1, 2 – measurement point 2 (fig. 5)

Figure 9 presents signals recorded in different position of antenna, signals 1, 2 and 3 were measured, in points 1, 6, 4 respectively (fig. 3), measurement point covers analysis of damping of signal, structures such as aluminum net with 2x2 cm mesh, solid stainless steel wall and far measurement from source. Source of distortions were impulses from HV 400 kV Impulse Generator which provides Lightning Impulses 1.2/50 µs. Analysis of results shows that highest signal is measured in point no. 6 which is placed near source and next to aluminum mesh, better damping for lower frequencies is observed in measuring point no. 4 which corresponds to solid wall shielding. Measured signal in this point (4) is relatively constant for higher frequencies and converge to signal no. 2, the same distance of antenna from source for point 4 and 6 determine that on measured signal affect only properties of shield which is placed between. Results obtained in point 1 shows that measured signal is highly damped with distance because of high impedance measured wave (paragraph 2.), for lower frequencies signal is higher than in point 4 but above 2 kHz amplitude of signal is the lowest.

Second analysis based on measurements of distractions occurring form 250 kV cascade during sparks ignitions between round electrodes. Measured signals were mostly investigated under the influence of shielding structure, measurements taken further (signal 1) are outside shielding net which corresponds to higher measured signal (Fig 10).

Measurements taken near source have smaller amplitude despite of shielding is carried out by 1.5 cm mesh.

4. CONCLUSION

Results shown in article proves that electromagnetic field EMF shielding effectiveness is determined by several factors as material properties, design and properties of EMF source. Higher effectiveness in wide frequency spectrum is achieved by solid shields. Most effective shielding of magnetic field is performed by high permeability materials, only unfavorable effect is saturation which can decrease SE.

High Voltage equipment can be source of high frequency distortions, because of discharge phenomena in air.

5. LITERATURE

1. Ott H. W.: "Electromagnetic Compatibility Engineering", J.Wiley & Sons, Hoboken, New Jersey 2009
2. Florkowska B.: Wytrzymałość elektryczna gazowych układów izolacyjnych wysokiego napięcia, Wydawnictwa AGH, Kraków 2003
3. Augustyniak L., Laboratorium Kompatybilności Elektromagnetycznej, Pol. Białostocka, Białystok 2010
4. Adamczyk B., Florkowska B. „Analiza warunków sterowania pola elektrycznego w wysokonapięciowych izolatorach przepustowych", Zeszyty Naukowe Wydz. EiA Politechniki Gdańskiej Nr 30, s. 13-16, Gdańsk 2011.
5. Cold rolled electrical steel & toroidal cores, Catalogue, Stalprodukt S.A., 2016

ANALIZA SKUTECZNOŚCI TŁUMIENIA POLA ELEKTROMAGNETYCZNEGO POPRZEZ ZASTOSOWANIE EKRANOWANIA O ZRÓŻNICOWANYCH PARAMETRACH

Jednym ze skutków działania wysokonapięciowych urządzeń elektroenergetycznych jest wytwarzanie pól elektromagnetycznych wokół swoich konstrukcji. Pola te mogą negatywnie wpływać na organizmy żywe oraz zakłócać funkcjonowanie innych urządzeń elektrycznych i elektronicznych znajdujących się w pobliżu. Rozwiązaniem tego problemu jest zastosowanie odpowiednich układów ekranujących urządzenia wytwarzające pole elektromagnetyczne lub osób i urządzeń które są narażone na oddziaływanie pola. Ze względu na swoje przeznaczenie, klatki ekranujące pole mają różne formy konstrukcyjne i są wykonane z różnych materiałów w celu zapewnienia wymaganych parametrów przy obniżeniu kosztów ich wykonania. Problemy związane z występowaniem nienilowych zależności w stosowanych materiałach, duże gabaryty urządzeń oraz wymagania dotyczące kompatybilności elektromagnetycznej powodują iż projektowanie takich klatek jest skomplikowanym zagadnieniem technicznym. W artykule przedstawiono możliwości ekranowania pól elektromagnetycznych, wytwarzanych przez różne urządzenia elektroenergetyczne. Porównano wyniki pomiarów tłumienia, wykonane dla ekranów o różnych konstrukcjach i zbudowanych z różnych materiałów.

Słowa kluczowe: skuteczność ekranowania, fala elektromagnetyczna, ekranowanie.