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Shielding of Electric Reactor Magnetic Field

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Introduction

Recently it is developed great number new materials with unique magnetic properties. By this the shielding becomes one of the most perspective means to decrease an electromagnetic field to admissible level.

The magnetic field of industrial frequency (50 Hz) is the most large–scale and constantly operating harmful factor for the person. The screens of conductive crystalline ferromagnetics are not working in considered area. In this case the amorphous magnetic soft alloys can be used [1].

One of sources of a large magnetic field is air current–limiting reactor, i.e. reactor without the ferromagnetic core. The magnetic field of current–limiting reactor often exceeds maximum permissible levels near the reactor. Reduction of magnetic field in the surrounding space of the reactor is important task.

The properties of the electric reactor and ways of protection against its magnetic field

In high–voltage networks short circuit currents can reach such sizes what to pick up installations which could sustain the electrodynamic forces arising owing to course of these currents, it is not obviously possible. Current–limiting reactors are mainly used to limit short–circuit current, i.e. to prevent fault currents from rising to values dangerous for the equipment. The reactor is a coil with the constant inductive resistance, included in a circuit in series.

In a normal mode on the reactor the power failure is observed of an order 3 – 4 % that is quite admissible. The value of the maximum shock current of short circuit can be calculated by this expression:

$$i_m = 2{,}54 I_N \frac{100}{X_p\%}, \qquad (1)$$

where I_N – network rated current; X_p – reactance of the reactor. Therefore the maximum shock current increases with decrease of reactance which is proportional to the coil inductivity.

The big current saturates coil steel core that sharply reduces reactance, and, as consequence, the reactor loses the current limiting properties. For this reason reactor carries out without steel core. But it is necessary to do them of the big sizes and weight for maintenance of the same inductance value.

Fig. 1. Current–limiting reactor

There are two ways of magnetic field protection: to situate the protected objects in distance at source and to shield of a field source by materials with high magnetic properties. In modern power plants degree of integration increases and, as consequence, high consolidation of means can be on the limited areas. Therefore, it is not a possibility always to transfer the technical equipment or to remove biological objects on distance at which a field level is below the maximum permissible value. In this case shielding of a field source must be applied or the protective clothes for human must be used.

The use of the electric reactor cell screen is represented to be the most perspective. The screen will provide the magnetic field decrease in a human zone to the values satisfying to operating standard documents.

Electromagnetic calculation of the screen

The investigated space shares on three parts for carrying out of the shield electromagnetic calculation:
I – a shielded internal zone;
II – an interior of the shield walls;
III – an infinite zone outside the shield.
In the first and third parts electric conductivity $\gamma = 0$ and the Laplace equation for the scalar magnetic potential V_m computation can be used:

$$\left(\nabla^2 V_m = 0\right). \qquad (2)$$

The shield wall II is conductive ($\gamma \neq 0$). The Helmholtz equation must be used for the magnetic field strength computation:

$$\nabla^2 H = \alpha^2 H \, , \tag{3}$$

where α is a constant which is defined by expression:

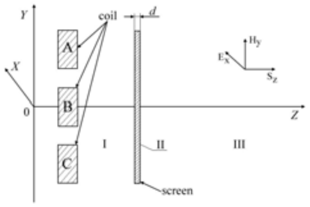


Fig. 2. Zones of shielding of the electric reactor

$$\alpha = \sqrt{j\omega\mu\gamma} = (1 + j)k = \sqrt{2}ke^{j\frac{\pi}{4}} \, , \tag{4}$$

where ω – a cyclic frequency of the field variation; μ – permeability of the shield material; k – a constant of attenuation of a wave in metal, m^{-1}:

$$k = \frac{1}{\delta} = \sqrt{\frac{\omega\mu\gamma}{2}} \, , \tag{5}$$

where δ – the depth of the wave penetration in metal on which the field strength amplitude decreases in e times (H_{ms}/e) [1].

It is convenient to characterize shielding effect of eddy currents in size of equivalent depth of penetration δ. The δ is less, the greater current flows in the shield superficial layer and the major opposite magnetic field will be created by it. The current density is constant in a layer δ and its maximum value is equal to

$$I_{m1} = \frac{1}{\sqrt{2}} J_{ms} \, . \tag{6}$$

Accepting that the magnetic flux density is constant in a layer δ and it is equal to $\frac{1}{\sqrt{2}} B_{ms}$, the magnetic flux is [1]

$$\left| \Phi_{m1} \right| = \frac{B_{ms}}{\sqrt{2}} \delta \, . \tag{7}$$

When the environment is linear (μ = *const* and γ = *const*), the equation (3) is correct for the sinusoidal magnetic wave in the shield.

In the flat magnetic shield amplitudes of the magnetic field strength and the current density decrease with the penetration distance z according to the equation

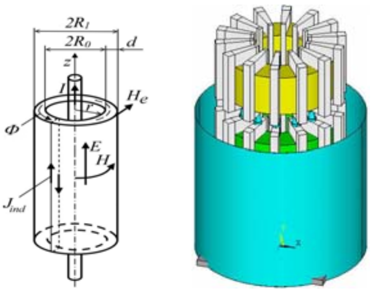
$$\left| \frac{H_m}{H_{ms}} \right| = \left| \frac{J_m}{J_{ms}} \right| = e^{-kz} \, . \tag{8}$$

When the cylindrical shield is used for protection against the electric reactor magnetic fields, it is under the influence of the own reactor field and the outer fields.

For the open shield of limited length, at $r = R_1$

$$H_m = I / \left(\sqrt{2} \pi R_1 \right) \tag{9}$$

The shielding efficiency can be characterized by the shielding factor defined as the ratio of the magnetic field strength in shielded area H_1 and the magnetic field strength in the absence of shield H_2 in the same point of space.



a b

Fig. 3. The electromagnetic cylindrical shield: a – in a peripheral field; b – around the electric reactor [1]

Two factors can vary the efficiency of shielding by eddy currents: the value of opposite magnetic field created by eddy currents and superficial effect in a shield material. The superficial effect is insignificant for the low frequencies ($d<\delta = \sqrt{2/(\omega\mu\gamma)}$), the shielding operates practically by the first factor and shielding efficiency can be defined this way [1]

$$a = \ln\left|\frac{H_1}{H_2}\right| = \ln\frac{1}{|p_H|} = \frac{1}{2}\ln\left[1 + \left(\frac{\omega\mu_0\gamma D d}{2m}\right)^2\right], \tag{10}$$

where m – factor of the shield shape (for cylindrical shield $m = 2$).

Using (10) we can find the thickness of the shield d when there are set the shielding efficiency a and the diameter D. The shielding factor (K_e) of the cylindrical shield is calculated as follows:

$$K_e = \mu \, (d/D), \tag{11}$$

where μ – magnetic permeability of a material of the shield; d – a thickness of a wall of the shield; D – diameter of the cylindrical shield.

It is obviously from the resulted formula that we obtain the better shielding using the material with the better magnetic permeability.

Properties of screens from amorphous soft magnetic materials

Materials for protection against magnetic fields of 50 Hz industrial frequency should possess as much as possible high magnetic properties. Amorphous soft magnetic alloys satisfy such requirements. Amorphous soft magnetic materials (ASMM) are magnetic with a disorder arrangement of the atoms, received as a result of fast training liquid with speed of cooling 10^4 – 10^6 $^0C/s$. Metal amorphous alloys contain 75–85 % of one or several ferromagnetic metals (Fe, Co, Ni) and 15–25 % glass–forming elements (B, C, Si, P) [1].

Magnetic properties of ASMM are close to that of the electrical steels and the permalloys. The optimal magnetic properties are obtained by applying of thermo magnetic processing. That increases the B_s and orthogonality of hysteresis loop. The specific resistance of ASMM is the 3–5 times more, than at the crystal.

Efficiency of shielding can be enlarged by use of multilayered shields from materials with various characteristics. Thus primary shielding is made by the layers located more close to leads with current. Materials of these layers should possess higher magnetic flux density saturation in comparison with materials of external layers which should possess higher magnetic permeability. Thus, for the multilayer shield of two different materials it is expedient to choose an alloy on a basis of iron and an alloy on the basis of cobalt for internal and for external layers of the shield, accordingly. It is necessary to provide electric isolation of separate layers of the shield, too.

Shielding of the electric reactor amorphous soft magnetic alloy

By means of software ANSYS modeling of the electric three–phase reactor is spent and electromagnetic calculation is carried out [2, 3]. The distribution of three–dimensional magnetic field was obtained in surroundings of reactor without shield.

The system possesses the full symmetry to any plane passing through an axis *z*. Therefore the simpler model can be used when shielding problems are investigated. For reduction of quantity of final elements the model was created in the form of sector with the central corner 180°. The current density equal to J = 162730 A/m^2 was put to platforms of cross–section section of a winding. The condition of magnetic flux parallelism was put to all external lines of model. Internal radius of a reactor winding was accepted equal to R_0 = 0,46518 m, and external radius– equal to R_1 = 0,85982 m [4].

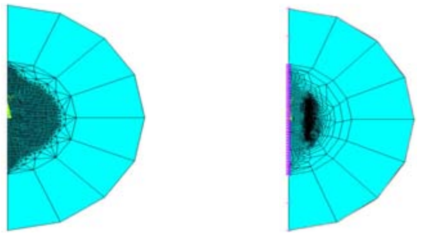
The electric reactor was modeled both with the shield, and without it. The modeled shield consists of 4 layers: two of amorphous soft magnetic material 5БДСР (type B) and two of amorphous soft magnetic material ГМ501. Magnetic properties of materials are presented in the Table 1. The thickness of the one screen layer and the interval between the screen layers are accepted equal to 1 mm.

Table 1. Magnetic properties of the soft magnetic alloys

Alloy	$\mu_{0,08}$	μ_{max}	B_s, T	H_c, A/m
5БДСР (type B)	100000	200000	1,3	0,6
ГМ 501	150000	600000	0,43	0,15

Analysis type was stationary, two–dimensional, magnetic, with open borders. Calculation was spent by a method of vector magnetic potential (MVP).

Parameter of meshing quality was *SmS* = 4. Number of finite elements of the model was obtained $n_{f.e.}$= 14634 and the number of nodes – $n_{n.}$= 29367.

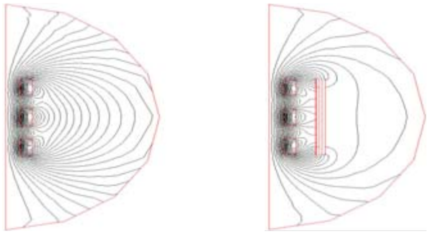


a) b)

Fig. 4. Finite element mesh of the two–dimensional model of electric reactor: a – the reactor without the screen; b – the reactor with the screen

8–nodial axisymmetric final elements PLANE53 were used. The external infinitely extended space was modeled by special 8–nodial quadrilateral axisymmetric final element INFIN110 [2, 4]. The distribution of a magnetic field is obtained according to boundary conditions both in the reactor and behind its limits (Fig. 4).

The magnetic flux lines of calculated field are presented in Fig. 5.



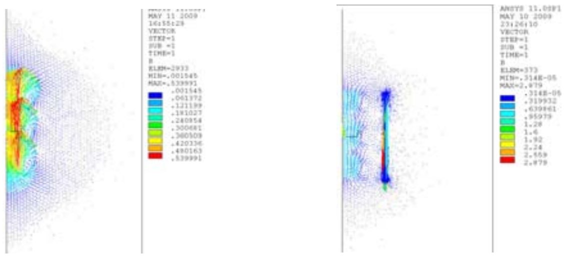
a b

Fig. 5. Magnetic flux distribution: a – the electric reactor without shield; b – the electric reactor with the shield

In the case of the reactor without the shield (Fig.5, a), the value of a magnetic flux on distance of 1,6 m from a reactor axis is equal to Φ = 0,07557 Wb.

In case of the reactor with the shield (Fig.5, b), the value of a magnetic flux on distance of 1,6 m from a reactor axis is equal to Φ = 0,02313 Wb, i.e. it is less almost in 3,3 times. We can see on Fig.5, b that the most part of a flux lines are closed in the shield and only their insignificant part are closed outside of the shield.

The distribution of the magnetic flux density is presented on Fig. 6.

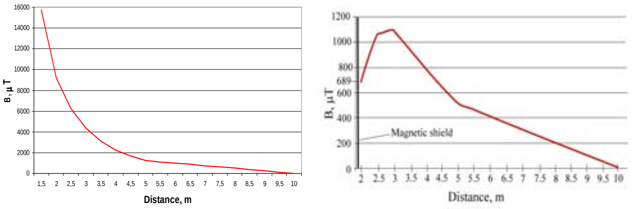


a) b)

Fig. 6. Magnetic flux density distribution of the electric reactor model: a – without the shield; b – with the shield

In the case of the reactor without the shield (Fig. 6, a) the greatest values and the most concentration of the magnetic flux density are in a zone of windings of the electric reactor. In case of the reactor with the shield (Fig. 6, b) the greatest values and the most concentration of the magnetic flux density are in a zone of the first shield layer. In the shield these values have decreased in 3 times.

In Fig.7 there are presented time dependences of magnetic flux density on the *x* axis without the screen and with the shield. In the case without the shield (Fig.7, a) the magnetic flux density is equal to B = 9,2 mT on distance of 2 m from the reactor axis. On distance 5 m this value is B = 1248,3 μT and corresponds to hygienic norm of Lithuania HN110:2001 for 8 hour working day. On distance 8 m this value is $B \cong 500$ μT and corresponds to norm specified in the Parliament and Council of Europe Instruction 2004/40/EB from 2004.04.29.



a) b)

Fig. 7. The variation of a total magnetic induction along an axis *x* at *y* and = *z* = 0: a – the electric reactor without shield; b – the electric reactor with the shield

In the case with the shield (Fig. 7, b) the magnetic flux density on the distance (2 – 4) m from the reactor axis, is interval B = (689–1100) µT that much less than that by hygienic norm of Lithuania HN110:2001 for 8 hour working days. The norm specified in the Parliament and Council of Europe Instruction 2004/40/EB from 2004.04.29 is agreed beginning at 5 meters.

Therefore, when the multilayered shields from amorphous soft magnetic alloys are used, the mean value of magnetic flux density decreases more than ten times and the workplaces can be approached to electric reactor.

Conclusions

1. Current–limiting reactor creates in surrounding space the intensive magnetic field which exceeds maximum permissible level for human and equipment.
2. Materials for protection against magnetic fields of industrial frequency of 50 Hz should possess as much as possible high magnetic properties. Amorphous soft magnetic alloys satisfy this requirement.
3. Application of multilayered shields from amorphous soft magnetic alloys reduces considerably the magnetic flux density in the reactor surroundings.

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Concerning protection of the person the area of magnetic fields of industrial frequency (50 *Hz*) is the most large–scale and constantly operating harmful factor. In considered area, the shields from usual conducting materials are not effective. It is recommended the use of multilayer screens produced of amorphous magnetic soft alloys. The expressions are presented for the shielding efficiency calculation. The air current–limiting reactor is the source of the large magnetic field. The modeling by finite element method was performed to compare the magnetic field in the air reactor surroundings with magnetic screen and without it. The obtained results show that magnetic screen of amorphous magnetic soft materials allows to diminish the magnetic field in reactor surroundings more than 10 times. Ill. 7, bibl. 4, tabl. 1 (in English; abstracts in English, Russian and Lithuanian).

Е. Морозенков, Ю. А. Вирбалис. Экранирование магнитного поля электрического реактора // Электроника и электротехника. – Каунас: Технология, 2009. – № 8(96). – С. 15–18.

С точки зрения защиты человека область магнитных полей промышленной частоты (50 Hz) является наиболее широкомасштабным и постоянно действующим вредным фактором. В рассматриваемой области экраны из обычных проводящих материалов недостаточно работоспособны. Предлагается использовать многослойные экраны из аморфных магнитомягких сплавов. Представлены выражения для расчета эффективности экранирования. Одним из источников сильного магнитного поля является воздушный токоограничительный реактор. Методом конечных элементов было исследовано магнитное поле вокруг реактора с магнитным экраном и без него. Полученные результаты показали, что магнитный экран из аморфных магнитомягких материалов уменьшает плотность магнитного потока вокруг реактора более 10 раз. Ил. 7, библ. 4, табл. 1 (на английском языке; рефераты на английском, русском и литовском яз.).

J. Morozionkov, J. A. Virbalis. Elektrinio reaktoriaus magnetinio lauko ekranavimas // Elektronika ir elektrotechnika. – Kaunas: Technologija, 2009. – Nr. 8(96). – P. 15–18.

Žmogaus saugos požiūriu pramoninio dažnio (50 Hz) magnetiniai laukai yra ypatingas ir nuolatinis kenksmingas faktorius. Esant šiam dažniui ekranai iš įprastinių medžiagų nelabai veiksmingi. Siūloma naudoti kelių sluoksnių ekranus, pagamintus iš magnetiniu požiūriu minkštų amorfinių lydinių. Pateiktos išraiškos ekranavimo efektyvumui apskaičiuoti. Ypač didelius pramoninio dažnio magnetinius laukus sukuria oriniai srovę ribojantys reaktoriai. Buvo atliktas modeliavimas baigtinių elementų metodu, siekiant palyginti magnetinius laukus šalia reaktoriaus be magnetinio ekrano ir su juo. Gautieji rezultatai parodė, kad daugiasluoksnis magnetinis ekranas iš magnetiniu požiūriu minkštų amorfinių medžiagų leidžia sumažinti magnetinio srauto tankį daugiau kaip 10 kartų. Il. 7, bibl. 4, lent. 1 (anglų kalba; santraukos anglų, rusų ir lietuvių k.).