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ERASURE OF PARASITIC MAGNETIC FIELDS ON EMERGENCY MEDICAL UNITS

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ABSTRACT
The presence of an external time varying magnetic field in a conductive loop, creates induction voltage. If the loop is closed, current will flow. Many fittings of contemporary electrical engineering are based on this phenomenon. However, undesirable results seem to appear in some cases. Such cases are the parasitic currents in perimetrical grounds and conductive floors in medical and intensive care units. Limitation of those parasitic currents is imposed due to the presence of patients but also of high sensitivity devices in these room areas. In this work the creation of parasitic currents in perimetrical grounds and conductive floor is described and also a way to restrict them by using Bithreaded winding (double wounded wire) is suggested. Lastly the use of Bithreaded winding is examined as a way to restrict undesirable magnetic fields in other devices.

KEY WORDS
Magnetic field, Induction, Bithreaded winding, ground

1. Introduction

The perimetrical ground and the conductive floor are protection systems and are widely applicable in electric installations. The perimetrical ground, protects from short circuits occurring in the metal cover of a device and guides short circuit currents towards the ground. The conductive floor protects from static charges accumulating in a room mostly due to friction. The perimetrical ground is a conductive strip (usually made by copper) that runs perimetrically a buildings walls. According to the new regulations [1,2] its installation is compulsory in all buildings. The conductive floor, is constructed of special plates or cast conductive material. The conductive floor's installation is done over a mesh of copper wire (of i.e. 30x1mm^2 section). The copper wire should not necessarily be weld together and the mesh is grounded in a specific spot with a different ground electrode that should be relevant to another ground net in the same building [3]. The basic form of the conductive floor is shown in figures 1 and 2.

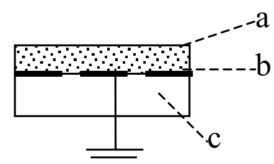

Figure 1: General arrangement of a conductive floor
a) Conductive floor, b) ground mesh, c) floor of the building

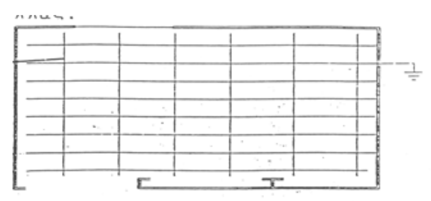

Figure 2: Grounded mesh of the conductive floor.

The conductive floor should be installed in places, where static charges are expected and there exist sensitive electric devices as oscillographs and computers.

Thus, the installation is essential in laboratories, high voltage test rooms, places that computers exist but also into Hospitals and emergency medical units. Despite undisputable utility of the above two systems (perimetrical ground and conductive floor) the presence of a time varying magnetic field near them, may cause undesirable induction voltages and currents. The basic principle of creating the parasitic currents is seen on the case of a simple loop and mesh (see figure 3). The perimetrical ground is simplified described with the single turn loop while the conductive floor with the mesh.
Particularly in the case of conductive floor the figures 3b and c, show that whether there is an external loop or a mesh, the current runs only into the external loop. Meaning that the superposition of the currents in the inner sides of the knitting gives no current[4].

Consequently the phenomenon concludes to be like in the perimetrical ground and finally in the simple loop. This current's creation flowing around the loop, can affect near situated devices or people if an inductive coupling occurs.

One way to prevent this inductive coupling is by using a Bithreaded winding showed in figure 4a that in contrast to common coils (figure 4b) introduces magnetic lines only to the entrance e and exit a of the coil.

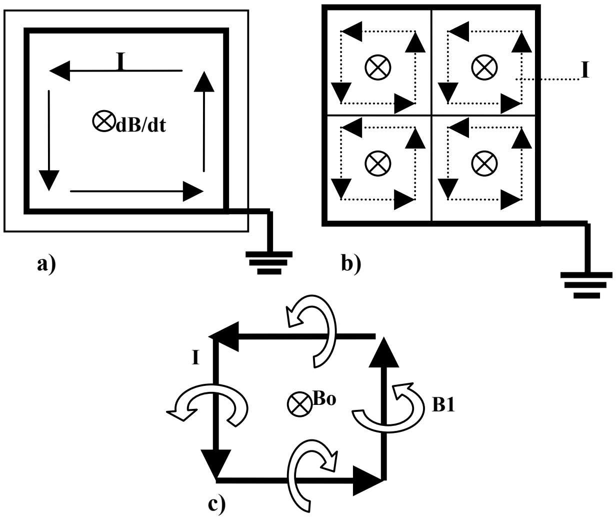

Figure 3: Appearance of currents due to external time varying magnetic field ($dB/dt \neq 0$) to a) perimetrical ground and b) conductive floor's knitting. The currents are drawing in agreement to the Lenz's law. c) Only the external loop will be carrying current. This current could create a secondary magnetic field B1.

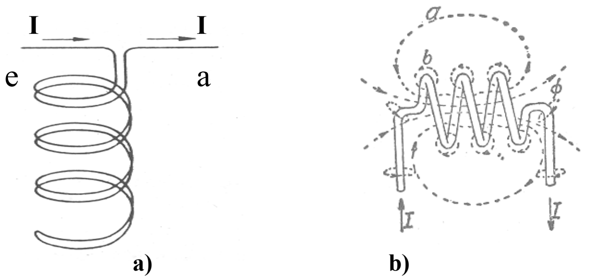

Figure 4: a)Bithreaded winding with entrance e and exit a, b) Magnetic flux in a common winding with current I.

In the Bithreaded winding, currents flow opposed to each other. In this way magnetic field does not derive from these currents, so inductive coupling with nearby conductive loops such as devices and or even humans, can not exist.

Consequently if the perimetrical ground and the conductive floor are formed as Bithreaded winding even if parasitic currents appear at this point, they do not create secondary magnetic fields and inductance phenomena in nearby conductive loops. In other words, Bithreaded winding reacts as a parasitic currents shielding. How this occurs in practice, can be explained later but before that, a theoretical analysis of a simple loop and a loop with opposite to each other side currents (meaning a Bithreaded winding) should be done, according to the classical electromagnetic theory.

2. Theoretical Analysis

According to the induction's law, voltage occurs in a conductive loop when a time varying magnetic field exists. Current will flow when the loop is closed. Current's direction is opposed to the magnetic field that caused it, according to Lenz's law.
So the valid equations are:

$$\Phi o = \iint_s B_o ds \quad (1)$$

$$Ui_1 = -N_1 \, d\Phi o/dt \quad (2)$$

$$I_1 = Ui_1/R_1 \quad (3)$$

Where Φo, Bo are the magnetic flux and the magnetic induction, Ui_1 the induction voltage, N_1 the number of turns, I_1 the developed in the loop by induction current and R_1 the loop's ohmic resistance.

The picture of the magnetic flux and the magnetic induction has been given with the "o" indicator to be distinguished from the magnetic flux and the magnetic induction that will be secondarily created by current I_1. Indeed the current I_1 (created by the magnetic field Bo) forms a magnetic field around it. So if a second loop is installed in the space near the loop leaked by current I_1 it will be involved by magnetic lines from this current. In this way, induction voltage in the second loop will appear and if it is closed, current I_2 will flow. The induction voltage in the second loop is given by the equation:

$$Ui_2 = -N_2 \, d\Phi_{12}/dt \quad (4)$$

Where now Ui_2 is the induction voltage into the second loop, N_2 the turns of the second loop and Φ_{12} the magnetic flux running through the second loop created by the first loop. For this flux that involves inductively both loops the equation is:

$$\Phi_{12} = M_{21} I_1 \quad (5)$$

Where M_{21} is the mutual inductance factor that involves both loops. This factor depends on the geometrical order but also on the material in which the loops exist.

In figure 5 it is designed in a section, the coupling of two conductive loops, as well as the magnetic flux that will pass from the first loop to the second one. For the mutual inductance factor the Neumann's relation (6) is valid [5, 6]:

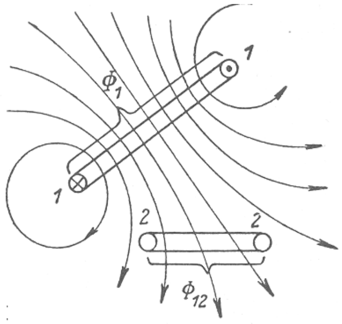

Figure 5: Magnetic coupling between two conductive loops

$$M_{21} = \frac{\mu_o \mu_r}{4\pi} \oint_1 \oint_2 \frac{dl_1 dl_2}{r_{12}} \quad (6)$$

In this relation μ_o is the magnetic permeability of the vacuum and μ_r the relative magnetic permeability of the medium between the two. The line integrals are closed and r_{12} is the distance between the differential lengths dl_1 and dl_2. It may be noticed that $M_{21}=M_{12}$ when $\mu_{r1}=\mu_{r2}$ and that is when between two loops there is the same material (i.e air). In figure 5 the second loop has been designed without current of course if $dB/dt \neq 0$, current will appear that will be:

$$I_2 = Ui_2/R_2 \quad (7)$$

Where R_2 the ohmic resistance of the second loop. The equation combing the magnetic field's strength H with the magnetic field's density B (induction) is the following:

$$B = \mu_o \mu_r H \quad (8)$$

The finding of the magnetic field's strength H created in a room by a current I_1 is a rather difficult procedure. Can be done following the "point by point method" [4] and basically the solving of the Laplace's differential equation for the scalar magnetic potential ψ, where:

$$H = -\mathrm{grad}\psi \quad (9)$$

Is the equation involves the magnetic field H (vector) with the scalar magnetic potential ψ, where for ψ the Laplace's differential equation is:

$$\nabla^2 \psi = 0 \quad (10)$$

From (9) and (10) the magnetic field can be found all over the place around a conductor. For simplicity and without damage of the generalization, continuously the finding of the magnetic field is examined, not all over the area, but in the centre of a carrying current loop. Two cases are to be examined and the one of them is basically a closed loop while the other is basically the Bithreaded winding. The solving of the problem is done with the Biot-Savart's law:

$$H = \frac{I}{4\pi} \oint_c \frac{dl \times r}{r^3} \quad (11)$$

Where dl is the differential length of the conductor crossing by current I and creates in a r distance, a magnetic field H. Supposing the following devices are given:

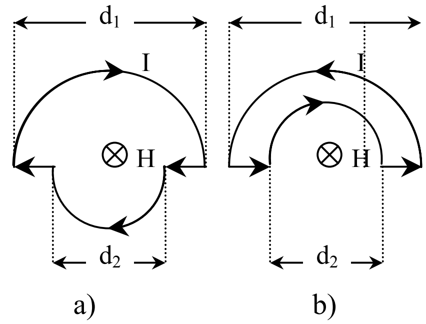

Figure 6: Two devices consisted by the composition of two semicircles flowing by current I.

The magnetic field H in the centre of the devices occurs from the superposition of the fields, creating each separate semicircle with current I.

In the device labelled a) in figure 6 it is:

$$H = H_1 + H_2 \quad (12)$$

Where H_1 is the field produced into the semicircle with diameter d_1 and H_2 the field produced into the semicircle with diameter d_2.

In the device labelled b) in figure 6 it is:

$$H = H_2 - H_1 \quad (13)$$

The negative sign in this case is due to the field created into the first semicircle that is opposite to the one created into the second semicircle. From (11) it is proved [7] that for the first and second semicircle the following are valid:

$$H_1 = I/4r_1 \quad (14a)$$
$$H_2 = I/4r_2 \quad (14b)$$

Where r_1 and r_2 are the radius of the previous semicircles. From (12), (14a) and (14b) concerning the device labelled a) in figure 6, the following is valid:

$$H = \frac{I}{4}\left(\frac{1}{r_1} + \frac{1}{r_2}\right) \quad (15)$$

For the device labelled b) in figure 6 it is:

$$H = \frac{I}{4}\left(\frac{1}{r_2} - \frac{1}{r_1}\right) \quad (16)$$

As it can be seen from the (16) when the r_1-r_2 tends to reach zero, meaning that the two semicircles are very close to each other, the magnetic field H in the center tends to reach zero as well.

The device labelled b) in figure 6 is a kind of Bithreaded winding with only one turn.

3. Application of the Bithreaded winding for the erasure of the magnetic field

Since the theoretical analysis for the case of a simple loop has been given, as well as the one for loop with different side currents (Bithreaded winding) the realization of the arrangement and the limitation of the magnetic field for the cases of perimetrical grounding and conductance floor is presented.

For the case of perimetrical ground the copper strip needs to be given by the factory in a double winding as it is shown in the figure7.

Figure 7: Wounded copper strip in the form of Bithreaded winding

In this way during installation, the ground wire has the form of a Bithreaded winding. Figure 8 shows the currents being able to appear in the sideways conductors of such a ground wire. Because of the opposed currents magnetic fields does not appear outside of the loop. On the other hand, the operation of the ground is done normally meaning that the movement of the current towards the earth is not prevented by the double threaded winding. Exactly the same applies for the conductance floor as well. Since it consisted by grounding knitting so that the static charges will be guided towards the earth and an external loop by double winding (Bithreaded winding), in order to the magnetic field will not created.
In figure 9 the movement of a positive static charge towards the earth, can be seen. The figure 9 shows that the forming of the external loop of double winding does not affect the operation of the antistatic floor. On the other hand in case of appearance of parasitic current because of the shape of the external loop, magnetic field will not be created and the case will be as in the perimetrical ground, depicted in figure 8.

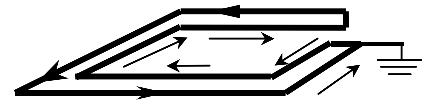

Figure 8: Perimetrical ground in the form of Bithreaded winding. In the sides of the conductor, the magnetic field does not appear, due to the opposed currents.

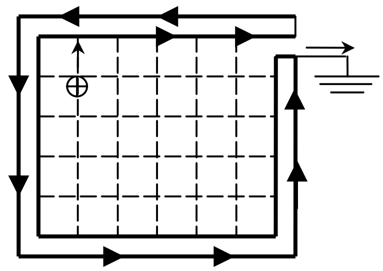

Figure 9: Grounded Mesh of conductive (antistatic) floor with external loop by double winding. The movement of a positive electrostatic charge to the earth is depicted.

4. Current's calculation in a conductive loop, inside a medical unit

In the case of a medical care ward and perimetrical ground or with conductive floor (antistatic) with the same surface and the presence of a magnetic field, voltage will appear in the grounded loop and current according to that mentioned in the above paragraphs.

Because of the loop being rectangular and the magnetic field sinusoidal, using the equation (2), the induction voltage in rms value is given by the equation [8]:

$$U = 4{,}44\, N \hat{\Phi} f \quad (17)$$

where N the number of turns, $\hat{\Phi}$ the maximum value of the magnetic flux for which the (1) is valid and furthermore

$$\Phi = \hat{\Phi} \cos(\omega t) \quad (18)$$

Where

$$\omega = 2\pi f \quad (19)$$

the relation between frequency f and circular frequency ω
For a surface of 3x3= 9m^2 the (1) combing the above data, will finally give:

$\hat{\Phi}$ = 900μWb

Let us assume the presence of a magnetic field with amplitude $\hat{B}$ = 1Gauss=100μT and frequency f=50Hz. The value of the magnetic field in this case it is equal to the national reference limit for the human's exposure to magnetic field and especially the limit for the general population [9]. Fields of this rate are realistic in power and energy systems [10, 11].

In the case of a simple loop N=1 and combing the above data for f and $\hat{\Phi}$ and (17) the result will be U= 0.2V=200mV.

The current that will be developed will derive from the equation (3) and because generally in these ground wires it is desirable for the resistance to be as low as it possible [3], the current to be produced will not be negligible. According to the standards [1, 12, 13] the earthing resistance should be R<1 Ω.

In this case the current will be I>0.2A according to (3).

If the resistance is 0.1Ω (an attainable value in grounds) then this current will become 2A .

The resistance that the ground strip (the electrode resistance) have in the antistatic floor's knitting is quiet minor than 1Ω, if it is considered that the mesh's loop is a separately circuit and the resistance to earth (depending on the ground's nature) is not considered. For a copper conductor with 12m length (the perimeter of a 3x3 room), and section of 30x1mm^2, the resistance will be R= 7mΩ as it is occurs from the equation:

$$R=\rho l/A \qquad (20)$$

Where ρ= 0,0175 x 10^{-6} Ωm the specific resistance of copper [6], l the length and A the conductor's section. If U=0.2V and R=7mΩ then the current will be according to Ohm's law: I=28.57 A

In the following discussion part, the above results should be examined.

5. Discussion

After the current's calculation, the magnitude of this kind of current and its influence should be examined, as we take into account that nearby the conductive loop are sensitive medical and electronic devices such as electrocardiograph ECG and electroencephalograph EEG. The cardiogram's and the encephalogram's signals are of the mV and μV equivalent rates [3]. Consequently a parasite signal of a mV rate in the protection ground of these equipment will cause undesirable noise in the signals that should be scanned. The calculation of the voltage in a case of a simple loop and a room of 9m^2, under the presence of a magnetic field of 100μT and 50Hz, shows that this voltage is of a mV range meaning that it will cause problems in equipments such as the ECG an the EEG. This kind of voltage developed near devices such as the ECG and EEG, seems to be important in medical units and it should be taken into consideration.

Furthermore the value of the created current is not negligible. That is because of the very low resistance of the grounded conductors. The standards suggest that the grounded conductor's resistance should be in a minimum especially in hospital installation [3]. Nevertheless the example in the previous paragraph shows that the minimum the resistance is, the maximum the current will be in the loop. Therefore it has been suggested that no perimetrical ground should be installed in intensive care units but other special ground arrangements [3]. But even if all these happen and the presence of a perimetrical ground is rejected, the phenomenon will appear at the external loop of the conductive floor which is irreplaceable especially in hospital installations [3]. That is because there is no any other similar device like the conductive floor which can drive static charges towards the ground. On the other hand if the resistance to earth (depending on the ground's nature) is not considered a current of almost 30A occurs. This value can not be ignored.This magnitude is comparable to a short circuit current in the low voltage nets. But because this big value has been estimated without taking into account the resistance towards the earth, it is a transient current that will appear with just a small duration until it leaves the loop and moves towards the earth following the same performance as in a short circuit. It may be considered that such a current may appear even as transient phenomenon and its magnitude is comparable to the one of a short circuit; although also the opposite can be presumed; which is the possibility that such a current may cause short circuit or other damage in a nearby device, passing through the ground conductor to the metal cover of the device.

But even if it may be considered as a permanent parasitic current in the loop with value I= 0.2A as it has been calculated above for a resistance R= 1Ω, it can still cause a secondary magnetic field that should not be avoided. Those parasitic currents and magnetic fields, can possibly lead to secret errors that can be difficulty registered. In any case whether the appearing current is big or not, either it is transitional or it has some duration, what causes side effects, is the created magnetic field and even more the mutual inductance phenomenon. The Bithreaded winding is considered a satisfactory way of limiting the magnetic field as it does not produce the mutual inductance phenomenon since its self inductance is close to zero [14, 15] and for the case of the ground and the conductive floor it does not abrogate their action but rather improves it. For hospital installations which are those of increased sensitivity, the ground in Bithreaded winding form is estimated to contribute to a better safety of patients and the reliability of medical registered measurements.

6. Conclusion

In this work the possibility of limiting the magnetic field in hospital installation grounds was presented.

Nevertheless, it can be mentioned that the same applies also for grounds in general installations. The use of Bithreaded winding as a way of limiting magnetic fields is generally something that has to be examined in other electrical equipments and devices.

Acknowledgements

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