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Benjamin Vincent, Olivier Chadebec, Jean-Luc Schanen, Kévin Berger, Ronan Perrussel, et al.. Identification of equivalent multipolar electromagnetic sources by space filtering. Compumag 2009, Nov 2009, Florianópolis, Brazil. pp.512. hal-00412226

HAL Id: hal-00412226
https://hal.science/hal-00412226

Submitted on 1 Sep 2009

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Identification of equivalent multipolar electromagnetic sources by space filtering

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***Abstract* — New sensors of magnetic induction in near field, dedicated to studies of electromagnetic compatibility, are proposed according to the principle of the Standard CISPR16-1 coils. The new coil shape allows the sensors to be sensitive to only some specific components of the multipolar expansion, which is similar to a spatial filtering. Our proposition follows previous works. By means of rotations of the spherical harmonics functions, our aim is to simplify the geometry of the sensor coils introduced before. After a description of the tools required, the design method is described. Comparative robustness studies end the article.**

I. Introduction

For electromagnetic compatibility studies, a compact model of the stray magnetic field generated by power electronic systems enables to reduce the design cost. To determine this model, our works focus on experimental approach. In this case, the use of large loop antenna offers advantages, especially by reducing the effect positioning inaccuracies. For instance, to identify the first order of a multipolar expansion (dipole) [1], Standard CISPR 16-1 [2], proposes to use three orthogonal loops (Fig. 1, on the right hand side). This standard applies for the medium frequency range: 9 kHz to 30 MHz.

The problem is that no source is composed of pure dipoles. Therefore, even the standard method can lead to errors. In previous works, we have proposed to take into account higher order terms in the expansion leading to a new and original coils sensors design and improving the accuracy [3]. Here, we introduce a simplification of the sensor design. The principle of this design and some improvements are reminded and a comparative robustness studies are proposed.

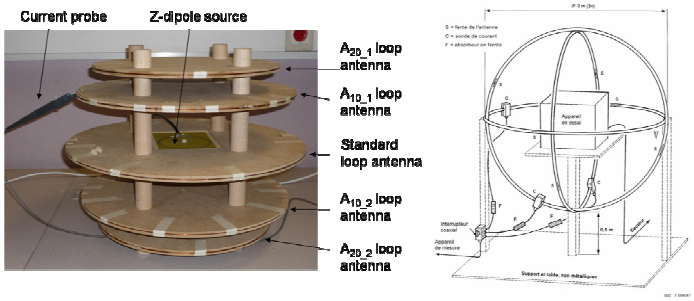


Fig. 1. On the left hand side, the whole system of loop antennas ('A_{10}', 'A_{20}' and 'Standard'). On the right hand side, the loop-antenna system from Standard CISPR 16-1 consisting of three orthogonal loop-antennas

II. Multipolar expansion

For near field studies and the standard frequency range, the quasi-static approximation is suitable. Outside a sphere including all radiation sources, the magnetic field can be fully described by its magnetic scalar potential ψ solution of the Laplace equation. For each frequency and in a given spherical coordinate system, the unique multipolar expansion solution is:

$$\mathbf{B} = -\nabla\Psi \quad \text{with:} \quad \Psi(r,\theta,\varphi) = \sum_{n=1}^{+\infty}\sum_{m=-n}^{+n} \mathrm{A_{nm}} \cdot \frac{1}{r^{n+1}} \cdot \mathrm{Y_{nm}}(\theta,\varphi) \qquad (1)$$

where Y_{nm} is real harmonic spherical function of order n and degree m, (r, θ, φ) are the spherical coordinates whose origin is the centre of expansion and A_{nm} the unknown coefficients. This development is hierarchical: for elements of order n the field decreases as $1/r^{n+2}$. A decomposition limited to the order 2 gives a precision considered as sufficient beyond the distance of measurement. There are 8 coefficients to measure (3 for order 1, 5 for order 2).

III. Sensor design

The measurement principle is similar to a spatial filtering: according to the coil shape, each sensor is just sensitive to its specific component of the multipolar expansion. Thanks to a rigorous approach, we proposed a system of coils, allowing the identification of the two first orders (n = 1 and 2) and not sensitive to the two followings (3 and 4). It leads to the realisation of 8 flux coils sensors topology located on a measurement sphere (radius r_{mes}). The method is detailed in [3]. The 8 sensors are presented on Fig. 2. These first shapes are linked to spherical coordinates: outlines within θ or φ constant. But this solution is too complex in order to make a practical realisation. Loosing the build constraint allows finding simpler possibilities.

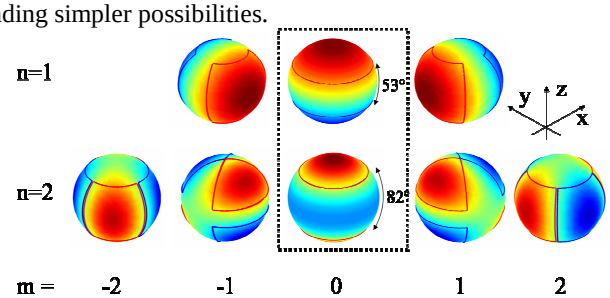


Fig. 2. 8 coils sensors for the identification of 1 and 2 orders. The flux is counted as positive for the red coils and negative for the blue ones

A. *Rotation properties of Y_{nm}*

We want to simplify this solution in order to build a practical sensor. The basis idea comes from properties of spherical harmonic functions. Indeed, thanks to rotations, it is possible to produce all components of the same *n* order with only one. Examples are given on Fig. 3. The first order rotation dependency is evident. This is more complex for the second order case. Idea is that it is possible to generalise this property to design sensors. Thus, to reach the simplification, we must to start from simpler sensor coils. The A_{10} and A_{20} loop antennas are just constituted of coplanar coils (black frame on Fig. 2).

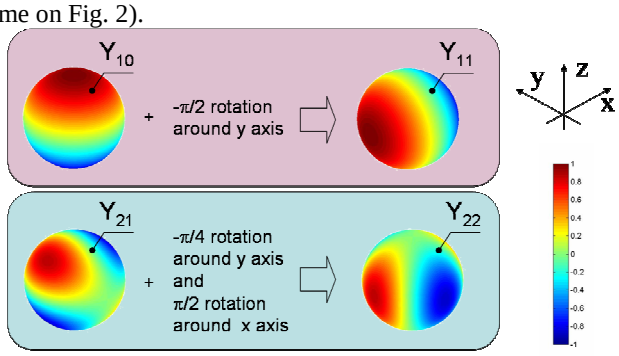


Fig. 3. By n order, same shape.

B. *Sensor design*

The full set and method are presented on Fig. 4. For the first order, the A_{10} loop antenna direction is just lined with targeted component. The second order case needs A_{20} sensor rotations and composition of the measured fluxes. We demonstrate that the totality of filtering capability is conserved with this new solution. Thus, 2 only different and simple shapes allow identifying the 8 first components of the multipolar expansion.

The complete validation is reached thanks to numerical (by Finite Elements Method) and experimental experiences. Our prototype is presented on Fig 1, on the left hand side. It concerns just the identification of A_{10} and A_{20} components. To these 4 coils, a loop-antenna (r_{mes}= 0.225 m) located on the middle plan is added to demonstrate the robustness of our new approach. It corresponds to the initial *z*-dipole sensor proposed in [2].

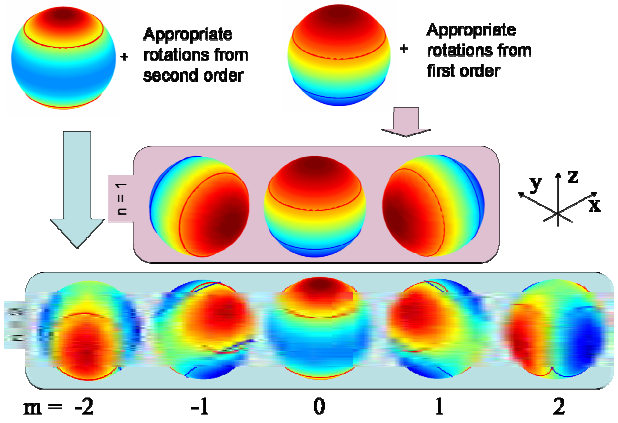


Fig. 4. Sensor set and the design process

C. *Comparative robustness*

Several cases have been studied. First, numerical experiences allow demonstrating the efficiency of our solution toward punctual measurements. This integral method is more accurate. Furthermore, complete measurement process is faster than 3D mapping solutions with one punctual sensor.

Secondly, we check the robustness of the sensor in comparison with the solution proposed by the standard. This is achieved thanks to the shifting of the source loop versus the center of sensors itself. Only the dipole identification is concerned in this experiment. The measurement results on Fig. 5 show that an error on the dipole determination occurs. In our sensor cases, despite the source shifting, identification error keeps stationary and reasonable (less than 2% of error). With Standard sensor, the error raises to 11%. A decentered dipole implies a more complex field (i.e. higher orders in the decomposition). The error is mainly attributed to the contribution of order 3 multipolar induction term in Standard sensor. In contrary, our sensors are designed to filter this third order term.

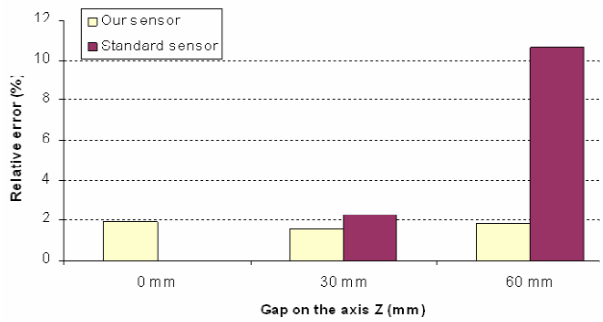


Fig. 5. Comparison between Standard and our sensor identifications: relative error compared to the actual and theoretical *z*-dipole with different gaps

IV. Conclusion

We have showed that it is possible to improve the dipole components measurement of the Standard device. It is also possible to create simple systems of coils which measure di- and quadri-polar components by filtering exactly both high orders.

Furthermore, our identification method is validated by experimental and numerical results. Comparative robustness studies show the interest of using dedicated multipolar component sensors, which are more robust than punctual measurement solution. Calibration and loop-antennas modelling must be completed for the complete frequency band. So, in future work, we can focus on the realization of the full coils system including rotation. It will be tested on a real industrial case.

V. References

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