Electromagnetic relay modelling: a multi physics problem. Part 2: Dynamical behavior of the relay

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Abstract — In order to ensure life safety, differential circuits breakers are employed. These devices are usually made of different parts. One of the parts that will be described in this paper is the electromagnetic relay. The actuator must be modeled with a great accuracy in order to predict if the circuit breaker will open of an eventual fault occurs. In this paper, the dynamical behavior of the relay is studied. Two accurate dynamical laws of the magnetic material are taken into account and tested.

I. INTRODUCTION

The differential circuit breaker is essential to ensure life safety. The device is composed of three parts: the differential current sensor [1], the electronic circuit and the electromagnetic relay. To reduce the problem, we focus on the relay. The elaboration of a new prototype requires accurate models [2]. The study of the relay leads to a multi physics problem; it links magnetic, electrical and mechanical equations. In the aim to simplify the problem, the relay is studied by considering its mobile vane closed.

The establishment of the flux density in the core of the relay depends on the magnetic material behavior. This flux density allows to estimate the force created on the mobile vane.

An accurate representation of the relay would require a 3D field calculation with dynamical material laws and a coupling with the electrical circuit. In the aim to deal with these requirements, an approach with dynamical flux tubes is chosen.

II. ELABORATION OF THE MODELLING

This elaboration uses two successive steps. The first one is presented in detail in a first submitted paper. This step concerns the elaboration of the flux tubes network. To obtain this network, the static behavior of the relay is studied. The topology and geometrical specifications of the network are obtained to respect to satisfy essential criteria associated to the relay.

The static flux tubes network elaborated is used to represent the dynamical behavior of the relay on condition that a dynamical material law is introduced in the magnetic flux tubes. This work constitutes the second step of the relay modeling.

III. DYNAMICAL MODEL OF THE RELAY

A. The flux tubes network

The static study of the relay allows designing the flux tubes network which respects the main criteria associated to the device.

This network contains three kinds of flux tubes:

Air flux tube (to represent air gaps or leakage fluxes)

Magnet flux tube (to represent the magnet)

Magnetic flux tube which allows describing the core of the relay.

Each flux tube constitutes a “magnetic circuit component” which must be linked to other magnetic or electrical circuit components [3]. This association respects the nodes law (1) and the Ampère’s theorem (2) obtained by analogy between magnetic and electric circuits. The coupling variables are $d\Phi/dt$ and H.l (where Φ is the flux, H is the excitation field on the surface of the flux tube, l is this mean length and $N_k.i_k$ represents the MMF source numbered k).

$$\sum_{i=1}^{n}\frac{d\phi_i}{dt}=0 \tag{1}$$

$$\sum_{j=1}^{jn} H_j.l_j = \sum_{k=1}^{nk} N_k.i_k \tag{2}$$

B. The magnetic component

The so called component represents a magnetic flux tube. The input and output which allow the different coupling are $d\Phi/dt$ and H.l. A dynamical behavioral material model must be considered to define the relation between these input and output.

The core which constitutes the considered relay is thick and the magnetic material is hardly excited (high frequency), a lot of dynamical effects induced in the core can expand. In view of the circuit thickness, Eddy currents are developed in the majority in the circuit. An accurate and appropriate material law has to be taken into account.

Two different models for representing the dynamical effects due to the Eddy currents are considered.

The starting point of the first model comes from the equation (3) defined for a rectangular magnetic lamination and the second one is associated to the magnetic field diffusion equation (4). The elaborations and foundations of both models are presented in a lot of works [4], [5], their assumptions are only reminded in this paper.

Same assumptions for both models can be defined:

The study domain is a rectangular lamination where edge effects are neglected, the thickness of the lamination noted d is much littler than the width, the magnetic field is unidirectional (along the length). The material is isotropic, the conductivity is noted σ. B_a in the equation (3) represents the flux density averaged over the cross section of the lamination and H_{edd} represents the excitation field on the surface of the lamination, H_{stat} is the magnetization field associated to B_a calculated from the static material law (the relation between B_a and H_{stat} can be given using the Jiles Atherton's static hysteresis model). These assumptions define a flux tube. A minor transformation of the equation (3) leads to obtain the first dynamical magnetic component.

$$H_{edd} = H_{stat} + \frac{\sigma.d^2}{12}.\frac{\partial B_a}{\partial t} \qquad (3)$$

The equation (4), formulated with finite element or finite difference methods is numerically solved on the thickness d of the cross section of the lamination.

$$curl(curl.H) = -\sigma.\frac{\partial B}{\partial t} \qquad (4)$$

The formulation is reduced to a 1D problem in the aim to allow a comparison with the first model. The resolution of the diffusion problem allows obtaining local information in the section which is not available by measurement. The first model, called "global" model, neglects the skin effect on the contrary of the second one called "local" model.

IV. EXPERIMENTAL VALIDATION

Two dynamical magnetic components are available. In the aim to choose the more suitable magnetic component to model the problem, tests of both models are performed on a sample made of the same material as the relay core.

The sample is made of a stack of rings. The thickness of each ring is the same as the thickness of the core building the relay in the aim to respect the development of dynamical effects. The material of the ring is made of NiFe, its conductivity is 2080.10^3S, the thickness is higher than 1mm.

Tests are performed by considering a 150 Hz frequency sinusoidal magnetization field applied on the surface of the sample.

The Fig.1 compares the dynamical loops measured and calculated with "global" and "local" models.

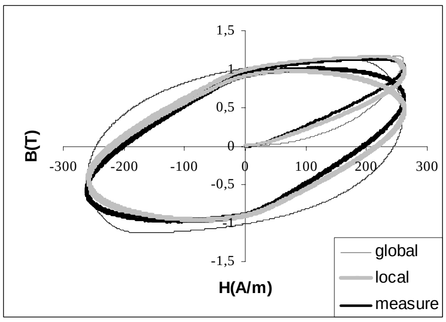

Fig.1. Dynamical loops: measured and calculated (with "local" and "global" models), 150Hz frequency operation

The "local" magnetic component obviously suits the best to represent the dynamical behavior of the sample. The skin depth can be estimated to 0.2 mm. In this case, the magnitude of the field is not homogeneous in the cross section of the sample. The validity domain of the "global" model is overshot. The Fig.2 confirms this result by comparing the temporal values of the magnetization fields applied on the surface of the sample and calculated in the middle of the section (d/2) with the "local" model.

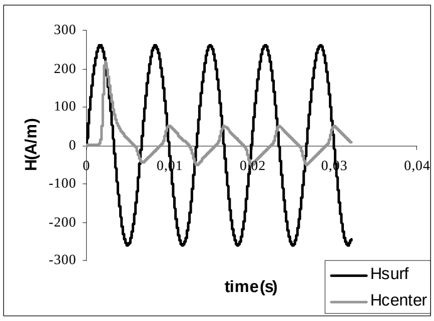

Fig.2. Temporal evolutions of the magnetization fields on the surface and in the center of the depth for a 150Hz frequency operation

V. CONCLUSION

A dynamical model of an electromagnetic relay is analyzed in this paper. This relay has to be associated to a differential circuit breaker. In the aim to allow the coupling between the relay model and the electrical circuit equations, an approach of the problem with flux tubes network is chosen.

The dynamical material behavior must be taken into account with accuracy. Two different dynamic magnetic components, both able to represent dynamic behavior of a flux tube are presented and tested on a sample.

Works about the application of the proposed model to represent the dynamical behavior of an industrial relay are carried out. Experimental validations of the relay model will be presented in detail in an extended paper.

VI. REFERENCES

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