Electromagnetic relay modelling: a multi-physics problem
Part 1: Modelling of the geometry

F. Sixdenier*, M.A. Raulet*, R. Marion*, R. Goyet*, G. Clerc*, F. Allab†
*Université de Lyon, F69622, France ; Université Lyon 1, F69622, France;
CNRS UMR5005 AMPERE, 43, Boulevard du 11 Novembre 1918, Villeurbanne, F-69622, France.
Email: name@cegely.univ-lyon1.fr
†Schneider Electric, Grenoble, 38EQI,
31,rue Pierre Mends France, 38320 Eybens
Email: farid.allab@fr.schneider-electric.com

***Abstract*— In order to ensure life safety, differential circuit breakers are employed. These devices are usually made of different parts. One of the part that will be described in this paper is the electromagnetic relay. This actuator must be modeled with a great accuracy in order to predict if the circuit breaker will open if an eventual fault occurs. In this paper, we focus on the modelling of the geometry of the electromagnetic relay and of its static behaviour. A tripping criterium and different optimization results of the model parameters will be discussed.**

I. Introduction

Differential circuit breakers are devices which ensure protection of life and property safety. Such devices are usually made of three parts: the differential current sensor [1], an electronic circuit for the signal processing and an actuator (linked to the tripping mechanism). A model able to represent the whole system can't be started without studying independently the different parts. In this paper, we focus on the actuator which is an electromagnetic relay, notably on the modelling of its geometry and of its static behaviour [2]. Nethertheless, the model used will be able to describe the dynamic representation of the relay. Particularly, the model will take into account the dynamic effects of the massive magnetic circuit [3] (eddy currents, wall motion…). Different parameters which have a great importance on the conditions of tripping are optimized with several criteria in order to be as closest as possible, with the type of model used, of the reality.

II. Description of the relay

The electromagnetic relay is composed of a magnet, a massive magnetic circuit, a mobile vane linked to a spring and a coil. The Fig. 1 shows the geometry of the relay (the scales are not respected) with its different parts.

The initial configuration, is when the mobile vane is closed (horizontal). The mobile vane is hold in this position thanks to the magnet attraction. When there's no current circulating in the coil the flux produced by the magnet separates itself into two parts. The first part goes to the pole where the coil is wound and the other part goes to the opposite one. When a current appears in the coil, it tends to reduce the flux and consequently the force between the mobile vane and the pole where the coil is wound. If the force created by the spring becomes superior to the one created by the magnet and the coil, then the relay trips.

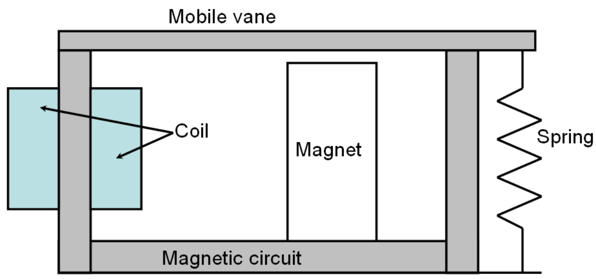

Fig. 1. Geometry of the relay

III. Analysis of the problem

A. Choice of the method of modelling

In order to predict when the relay will trip, the model requires to know how the magnetic flux splits up in the different parts of the relay. A 3D finite element model (FE) [4] would be the best choice in terms of accuracy. Nethertheless the model specifications stipulates that the model of the relay should be able to be linked to the whole system (differential current sensor and electronic circuit) in its dynamical representation. A 3D FE model would lead to prohibitive calculation times. It is not a suitable solution which satisfies the specifications of such a model. Nethertheless, a 3D FE model can be very helpful to know how the magnetic flux splits up in the different parts of the relay.

Another way to model the relay is the method of the Magnetic Equivalent Circuit (MEC) [5]. The magnetic circuit, the magnet and the air-gaps are described with several flux tubes linked together. Saturation of the magnetic material and dynamical effects can be easily introduced in the model (see part 2). This method uses the same variables as the bond-graph theory [6] for modelling magnetic systems.

B. Modelling of the device

Thanks to a 3D nonlinear FE model results, an a priori magnetic equivalent circuit is defined. The Fig. 2 shows the topology of the flux tubes network. Each part of the relay (Magnet, magnetic circuit, air-gaps,…) is described as a component. Each component requires a set of data. Each flux tube is parameterized by its dimensions (length, section, depth) and its magnetic behaviour (linear, nonlinear, reversible or not).

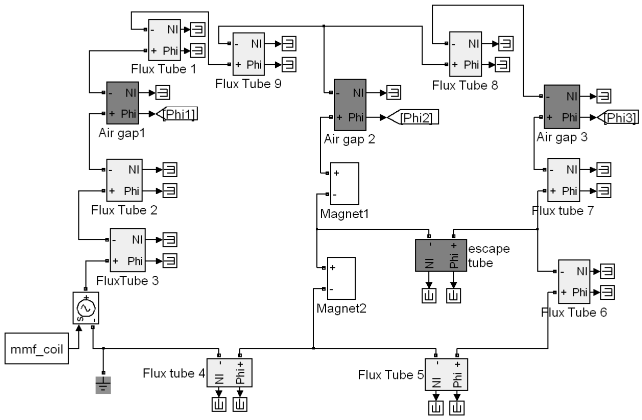

Fig. 2. magnetic equivalent circuit of the relay

The magnet characteristics (remanent flux density B_r, relative permeability μ_r) is a first set of data that are predominant in the conditions of tripping. If this first set of data is known, then the major criteria are the dimensions of the air-gaps and leakage flux tubes.

C. Optimization of the model parameters

In order to determine these parameters, optimization algorithms are used (simplex, genetic). The objective function is the quadratic error for the simplex between the resultant mechanical force exerced on the mobile vane calculated by the 3D FE model seen before and the MEC model. The sections of the air gaps and leakage flux tubes are adjusted in order to minimize the objective function (Simplex). The objective function for the genetic algorithm is the inverse of the quadratic error.

1) Simplex algorithm: The Nelder-Mead simplex method (NMS) is a very powerful local descent direct search method for minimizing a real-valued function $f(x)$ for $x \in \Re$. In each iteration, NMS begins with a simplex, specified by its $n+1$ vertices and the associated function values. One or more test points are computed along with their function values, and the iteration terminates with such a new (different) simplex that the function values at its vertices satisfy some descent conditions compared to the previous simplex. This search process is realized by a series of transformation of the simplex: (reflection, expansion, contraction and shrinkage).

2) Genetic algorithm: At first, N individuals, called *Population*, are created according to a random process. Then, in an iterative way, by modifying these individuals' genes with genetic operators, the optimization solutions will be obtained. The genetic operators are *selection*, *crossover* and *mutation*.

IV. RESULTS

In this paper, only the results of the simplex algorithm will be presented. The results given by the GA will be given in the extended paper. The Fig. 3 presents the resultant mechanical force versus the magnetomotive force of the coil calculated with the 3D FE model, with the flux tube model with initial sections (non-optimized parameters) and with the flux tube model with the sections determined by the simplex algorithm.

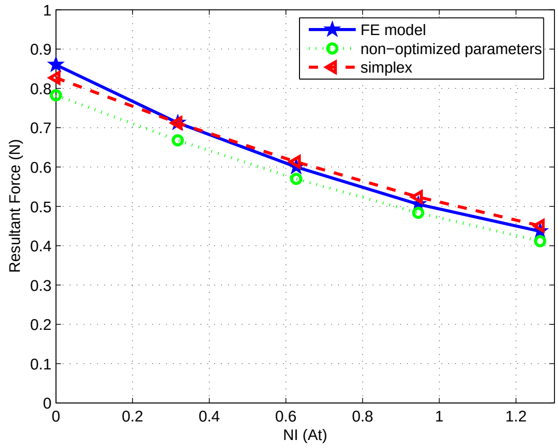

Fig. 3. Force versus magnetomotive force of the coil

The Fig. 3 shows clearly that the NMS increase the accuracy of the model. Indeed, the quadratic error between the force calculated with the FE model and the flux tube model has gone up from $4.02\ \%$ (non-optimized parameters) to $2.2\ \%$ (simplex) justifying the fact that the model parameters must be optimized.

V. CONCLUSION

A simple model of an electromagnetic relay has been analysed here and optimized thanks to a 3D FE model of this one. Thanks to the use of a Nelder-Mead simplex method, the parameters of the relay have been adjusted in order to be as closest as possible of the reality (3D FE model). In the extended paper, the model will be more explained and the Genetic algorithm will also be tested and compared with the NMS.

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