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Dynamic model for AC and DC contactors – Simulation and experimental validation

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A B S T R A C T

Electromagnetic contactors have a non-linear behavior due to the magnetic force. This paper develops a robust and low time-consuming parametric model to describe the dynamic behavior of both AC and DC contactors. The proposed model solves simultaneously the mechanic, electric and magnetic coupled differential equations that govern its dynamic response. This model takes into account the fringing flux, an effect that greatly influences the dynamic behavior. In case of AC contactors, the model deals with the shading rings. First, the electric and magnetic equations of an AC contactor – which are more complex due to the effect of the shading rings – are introduced. After that, by simplifying this set of equations, the ones of a DC contactor are derived. Conversely, mechanical equations are the same for both, AC and DC powered contactors. Data from simulations carried out by applying the presented parametric model are compared with experimental data, being demonstrated its accuracy and effectiveness.

1. Introduction

Electromechanical contactors are utilized in applications that require circuit making and breaking, such as electrical automatisms, railways, electric vehicles, circuits containing starter motors, heaters, and lighting applications. Nowadays millions of them are in use and they cannot be replaced in the foreseeable future by electronic switches. There are many reasons for this, such as their large overload capacity, large isolation capability of the switching gap and insensitiveness to voltage spikes which can lead to the destruction of the electronic switches. Unlike electronic switches, electromechanical contactors have the disadvantage of the mechanical displacement of some of their components and the wear related with that. This mechanical movement causes the contacts to impact during closure. The contact closing velocity and the velocity of the movable core during impact have a great importance on the behavior of the device [1]. This impact during closure is the origin of the contact bounce, also known as chatter. It is an undesirable phenomenon, which results in a re-opening of the contacts, causing the apparition of an electric arc until the contact makes definitely [2]. The arc can cause severe contact erosion, and therefore the electrical life and reliability of the contacts are dramatically reduced [3,4].

A rise in the contact temperature causes a greater increase in the contact resistance. This process may degrade the contact [5].

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Nomenclature

d_{A_0}	initial pre-compression of the return spring
d_A	resting position of the movable core
$x,\ \dot{x},\ \ddot{x}$	instantaneous position, velocity and acceleration of the movable core
x:	air gap length
m_A	mass of the movable core
d_{C_0}	initial pre-compression of the phase springs
d_C	resting position of the movable contacts
$x_C,\ \dot{x}_C,\ \ddot{x}_C$	instantaneous position, velocity and acceleration of the movable contacts
m_C	mass of each movable contact
k_1	elastic constant of the return spring
k_2	elastic constant of each phase spring
b	friction constant
ε	restitution coefficient
F_{k_1}	force of the return spring
F_{nk_2}	resultant force of the n phase springs
n	number of power contacts/phase springs
F_f	force of friction
F	fringing factor >1
R_1	electrical resistance of the main coil
R_2	electrical resistance of each shading ring
N_1	number of turns in the main coil
$N_2 = 1$	number of turns in each shading ring
u	voltage applied across the main coil terminals
i_1	current through the main coil
i_2	current through each shading ring
ϕ_1	magnetic flux through the main coil
$\phi_2/2$	magnetic flux through each shading ring
S	cross-section of the magnetic core
$\Re$	reluctance of the magnetic circuit

The coil of the contactor can be powered by an AC or a DC supply. DC powered coils generate a constant magnetic field that guarantees an appropriate closing of the contacts. Conversely, AC powered coils generate sin wave magnetic fields which produce a force that drops to zero twice in each cycle (50/60 Hz), giving rise to an undesired chatter of the contacts, because of the opposing force of both, the return and phase springs. This effect can be overcome by placing a metal shading ring in the contactor core. This ring, called shading ring, acts as a secondary winding. The current flowing through it generates a magnetic field that is out of phase with the one generated by the contactor coil. This setup produces a resultant force that does not drop to zero, thus eliminating the vibrations of contacts.

Hence, there are two types of contactors, those powered by DC magnets or those powered by AC magnets. DC powered contactors are used in applications where several hundred amps must be switched. This is why for a given pole face area, the average force on an AC powered magnet is only half that obtained with DC feeding. Consequently, for a given force and path, the AC magnet will be much heavier than the DC magnet. Moreover, DC magnets can be designed to achieve the same mechanical power with a smaller peak volt–ampere input than an equivalent AC magnet. In applications requiring a current lower than 100 A, the abovementioned limitations do not necessarily offer serious objection to the use of AC magnets.

If the contactor is powered by an adequate voltage source, a sufficient current can flow through the coil generating a magnetic field that attracts the movable core, and in this way causing the closure of the contacts.

Improvement of the dynamic characteristics of electromagnetic actuators centers the efforts of many research groups [6,7]. Today, dynamic modeling and simulation of electromechanical systems have become essential tools for design verification, operation studies and design and behavior improvement [8–10].

This paper presents an accurate parametric model in order to predict the dynamic behavior of whatever contactor, either AC or DC powered. This model is capable to predict important parameters of the contactor, such as power consumption, movable core closing time, contacts closing time, as well as their impact velocity. Because electromechanical contactors are non-linear devices, their dynamic behavior is not easy to predict. In order to determine the forces that explain their dynamic response, it is necessary to solve coupled electric, magnetic and mechanical equations, which make it a complex problem.

Firstly, a parametric model of an AC contactor with an especially difficult geometry is obtained in order to prove that the suitability of the model can be extended to any geometry of AC contactors. This model is explained in the first section of this paper and avoids simplification assumptions found in other parametric models [11]. It deals with the shading rings from an