CONTROL OF MAGNETIC ACTUATORS IN ELECTRIC CONTACTORS BY CURRENT SHAPING.

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Abstract
Most of present electric contactors use magnetic actuators of reluctant type (so called electromagnets) that are supplied with a simple voltage source. The use of a reluctant actuator in this condition leads to a considerable force increase when the magnetic circuit is closing, which creates damaging rebounds of the electrical contacts. To have a better control of the closing dynamics, we develop an electric drive method to reduce impact speed and to improve the closing dynamics. In this method, the reluctant actuator structure is unchanged. The appropriate current shape to be injected into the actuator is determined using a calculation method

Keywords: electromechanic, actuator, open loop, dynamic, control

Introduction
Most of present electric contactors use magnetic actuators of reluctant type that are supplied with a DC source voltage. These reluctant actuators run in binary mode (on-off position) because their physical principles are based on reluctance minimization ($F = \frac{1}{2}\frac{d\Lambda}{dx}\Theta^2$.) The closing of these contactors is provided by the supplying of the coil and the opening is provided by pull-off springs. Electronics associated with their coil are studied in order to minimize energy consumption.
In the present situation, conception of these contactors is carried out with a finite elements method using a static resolution. In this method, we assume that geometry and shape air gap are variable parameters. If all the points of the curve (force versus stroke) in static mode are above the resistant force curve, we suppose that the contactor is well designed. The final step consists of performing a dynamic resolution with respect of dynamic and Lenz's laws to provide good results (see figure 1).

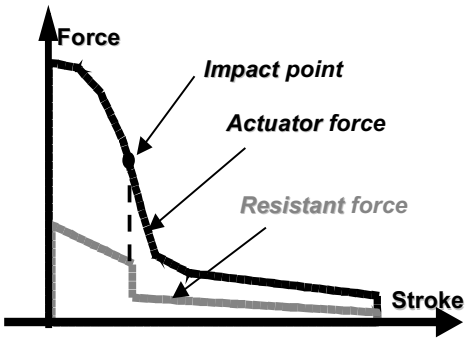


Figure 1

The analysis of this characteristic shows us several interesting points. The use of a reluctant actuator in this condition leads to a considerable force increasing when the magnetic circuit is closing. As the kinetic energy is important at the moment of the impact of poles, damaging rebounds of electrical contacts are generated. At this stage, the dynamic of contactor is out of our control.
To get a better control of the dynamic, we developed an electric drive method to reduce impact speed and to improve the closing dynamics. This method is called "Current shaping method".

Description of the Current shape method:
The current shape method consists of imposing the dynamic of contactor. We impose the shape of the curve Force versus stroke (see figure 2)

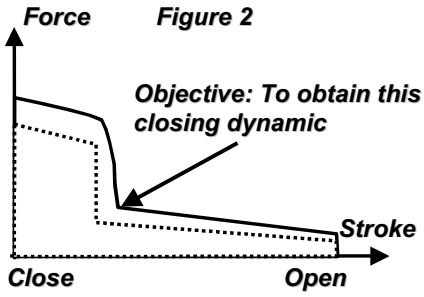
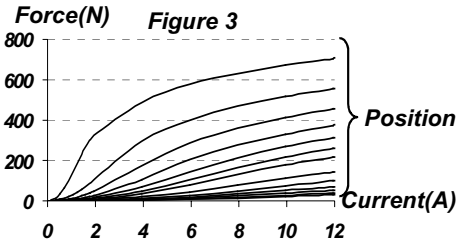
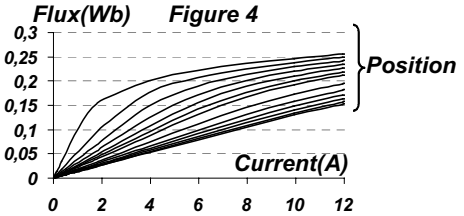


Figure 2

In a first stage, a multistatic approach with a 3D(or2D) finite elements simulation allows to obtain two characteristics which are the force and the flux versus current curves for each position values (see figures 3&4.)





In a second step, we use these results to recompute for each stroke the current value, which allows to obtain the good force at this position, and finally we obtain a characteristic of current versus stroke. Then this characteristic is parametrized in a finite elements software (FLUX 2D/3D) by taking into account the fundamental dynamics law and the coupling circuit. The results of this last simulation give us the coil current, the coil voltage, the velocity, and the acceleration versus time. We specify that it is possible to obtain these last results with a Matlab/Simulink model using some look-up tables.

Simulation results:
The simulations have been made on an existing contactor with a 24 VDC power supply.

-Coil characteristics:
-Voltage: 24VDC.
-Resistance: 2 Ohms.
-Number of turn: 222

-Contactor characteristics:
-Nominal Current: 115A.
-Nominal Power: 55Kw.

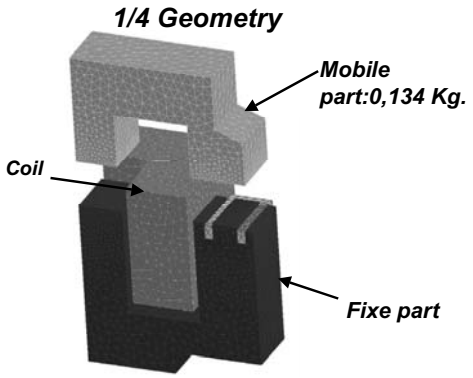


Figure 5

Curves below show us comparisons between the case where the coil would be supplied by a 24VDC-source voltage and the case where the current shape method would be applied.

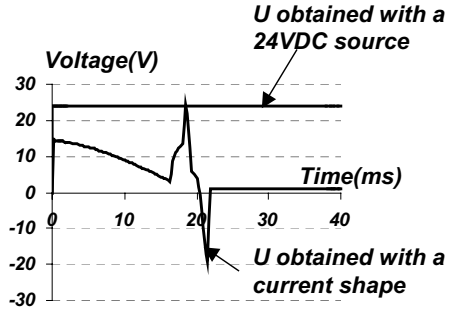


Fig 5b – Voltages versus time in the case of a Constant Voltage and in the case of a Voltage determined by current shape

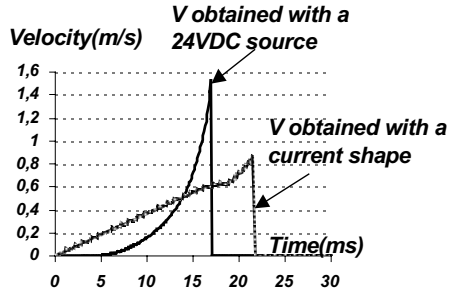


Fig 5c – Velocity versus time in the case of a Constant Voltage and in the case of a Voltage determined by current shape

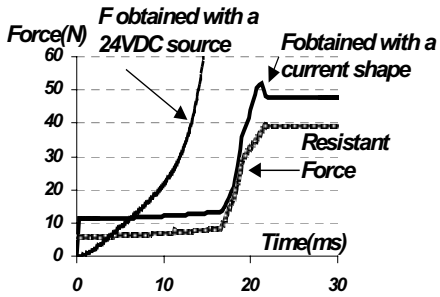


Fig 5d – Force versus time in the case of a Constant Voltage and in the case of a Voltage determined by current shape

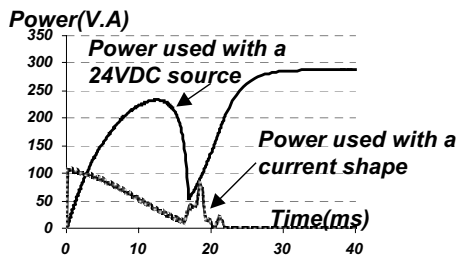


Fig 5e – Force versus time in the case of a Constant Voltage and in the case of a Voltage determined by current shape

The analysis of these curves shows us several interesting points.
In a first time, we can see that the impact velocity reach 1,5m/s in 17ms when the coil is supplied by a 24VDC source voltage whereas this velocity reaches 0,85m/s in 21,75ms when the coil is supplied by a current shape. The impact velocity is divided by 1,8. An other interesting point is that the current shape, injected in the coil, allows obtaining the expected closing dynamic.
It is shown by the force and the velocity characteristics above. These two curves allow us to say that acceleration is a constant during the displacement. The last interesting point is the analysis of energy used. As we saw the closing time increases of 4,75ms when the coil is supplied by this current shape. We compute for these two cases the mean power by:

$$< P >= \frac{1}{T}\int_0^t UIdt$$

and we consider that integration times for each cases are respectively 17ms and 21,75ms. The results of these computations give respectively 168W when the coil is supplied by a 24VDC-source and only 52W in the other case. The mean power is divided by 3,2.

Experimental results:
We developed a MATLAB/SIMULINK model in order to implement the current shape into the contactor. The MATLAB/SIMULIK model allows to generate a selected signal current shape using look-up tables. A DC power supply associated with a servo amplifier allow generating the real current shape to inject in the coil (see figure 6&7.)

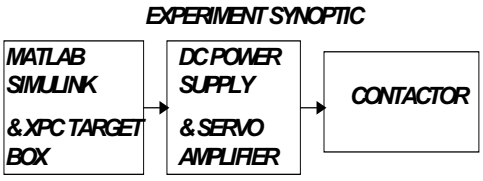


Figure 6

We specify that this method allows working in open loop mode. One sensor is used to measure the position of the mobile part for visualisation. The velocity is computed using a derivative function. The current coil is measured with a current sensor for visualisation.
In a first stage, we performed some measurements when a 24VDC-source voltage supplies the coil in order to measure the impact velocity. Measurements give an impact velocity equal to 1,2m/s and a closing time equal to 22ms(see figure 7.)

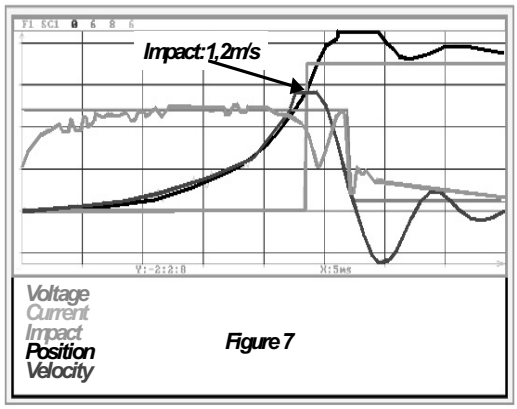


Figure 7

In a second stage, we wished to obtain a closing dynamic, divided in two phases; a constant acceleration phase at the beginning and a constant velocity before the impact to minimize the impact energy. Figure 8 shows how the characteristic force versus stroke must be to obtain this particular dynamic.

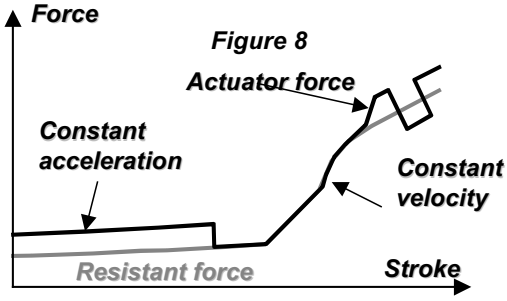


Figure 9 shows the experimental measurements obtained.

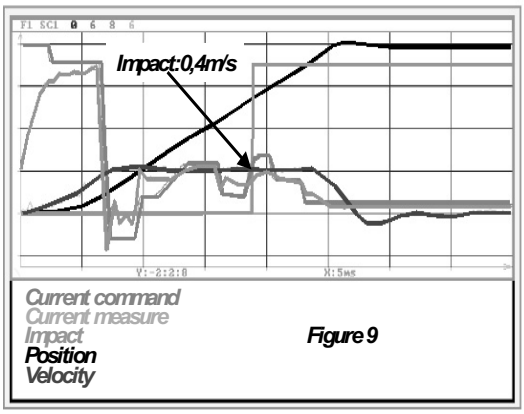


Figure 9

We can see that we obtain the expected dynamic. For this particular case, the impact velocity is equal to 0,4m/s and we can see how the current evolves. The Matlab/Simulink model associated with look up tables allows directly computing the new current shape to inject in the coil.
The closing time is not increased and it is equal to 22ms(This is the same time when the coil is supplied by a 24VDC voltage source.)

These results are obtained in open loop and we can see that the impact kinetic energy is divided by 9 and that the impact velocity is divided by 3.

Conclusion:

The current shape method allows to impose some closing dynamics of a contactor without changing the actuator structure.
The advantage of this method is that it can be led in open loop and doesn't need any sensor.
A dedicated electronic has been developed to implement the results of finite elements simulation in a microprocessor (characteristics force and flux versus current for each position values) and to supply the coil(power electronic). As the impact velocity is considerably reduced, the current shape method will allow to increase mechanic and electric performances of contactors(impact mechanics, reduction of electric arcs etc..)
Finally the current shape method has been tested with success by simulation on voice coil, moving magnet and polarised reluctant actuators and allows to compute current shapes in case of closing dynamics.

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