

On the modeling of a stepper reluctant linear motor by neural approach

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Abstract: - A classical model of electrical machines is generated by a specified identification shows a discrepancy between the simulation results and those obtained practically. Being a second-order model of a stepper linear motor, the method adopted for the identification of parameters of the machine does not detect an adequate quantification values for the simulation tests, because for which use of new methods seems more reliable. The goal was to identify a mathematical model defining as finely as possible the behavior of the studied machine based on modeling by neural networks for the quality of their contributions in learning ability to better estimate the dynamic behavior of the considered motor.

Key-Words: -Neural Networks, incremental linear machine, Modeling.

1 Introduction

Modeling an electromechanical system represents the objective of this work, usually expressed in two different ways;

-Electromagnetic modeling based on the use of the operating equations of the machine to model electromagnetic effects,

-Electromechanical modeling that considers a mathematical model with simplifying assumptions,

-The ferromagnetic materials are ideal ($\mu_r = \infty$).

-The notch effect is neglected.

-The effect of the induced currents is neglected.

-The Effect of mutual inductance is neglected.

Inspecting the defects in electromechanical devices is generally limited to the analysis of voltage, current, speed, temperature and vibration magnitudes. The growing demand in terms of robustness of the diagnostic tools required the development of new solutions based on the analysis of new magnitudes and exploring new complementary approaches to existing ones.

In this regard, we consider the results of identification and modeling obtained on a laboratory

test prototype of a linear stepping reluctant motor to four supply phases.

2 Modeling tubular 4-phase stepping motor

The test prototype is a variable reluctance linear motor shown in Figure 1. [1]

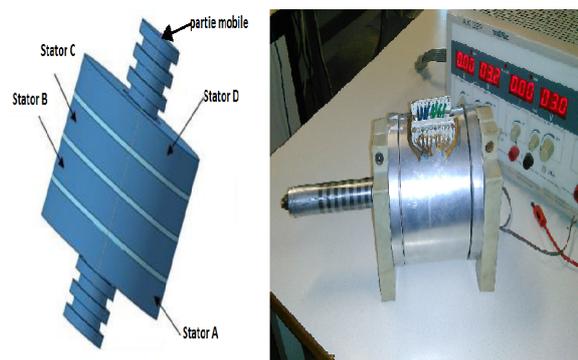


Figure 1 Schematic prototype of the SLRM

This relates to a linear motor provided with a tubular structure, with a smooth moving portion, formed of an alternation of identical dimension

rings with materials of different magnetic behavior, guided in translation by linear bearings.

The toothed stator comprises four statoric modules, where house the windings of phases A, B, C and D in their magnetic circuit.

Spacers of non-magnetic materials, of thickness λ_p , are interposed between the phase modules to ensure magnetic separation and the regular operation of the machine.

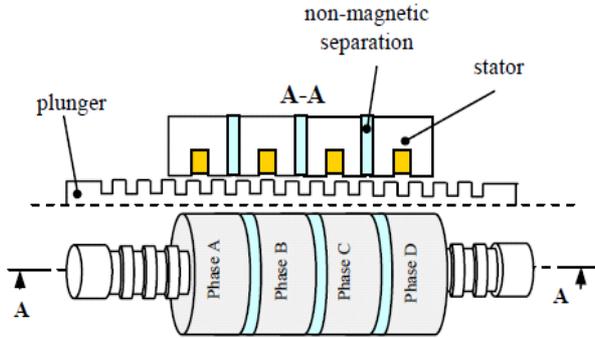


Figure 2 Elements of the test Motor

The exploitation of results obtained by practical tests performed on the prototype test, were permitted to identify and then to model the behavior of the machine.

For reasons of convenience of calculation, the works in [3] for the general study of the linear stepper machine were limited to the unsaturated state. For this, the following simplifying assumptions are made:

- Excluding the saturation
- Excluding the magnetic relaxation (insignificant hysteresis effect)
- Infinite permeability and resistivity of iron,
- Insignificant leakage flux,
- Insignificant fringe and ends effects.

A stepper machine in pure variable reluctance is naturally devoid of magnets. The generalized model is obtained by canceling the terms relating to the magnet. It comes then:

$$F_m = \frac{1}{2} \sum_j \sum_p \frac{\partial L_{jp}}{\partial x} \quad (1)$$

$$m \frac{d^2x}{dt^2} = F_m - \xi V - F_c - F_{0\text{signe}(V)} \quad (2)$$

$$u_j = R_j i_j + L_{jj} \frac{di_j}{dt} - L_{jp} \frac{di_p}{dt} + (i_j M_{jj} + i_p M_{jp}) V \quad (3)$$

The system inductance in both phases of the machine is expressed by the following relationship:

$$\begin{aligned} L_{AA} &= L_0 + L_1 \cos\left(\frac{2\pi x}{\lambda}\right) \\ L_{BB} &= L_0 - L_1 \cos\left(\frac{2\pi x}{\lambda}\right) \end{aligned} \quad (4)$$

With:

$$L_0 = \frac{L_q + L_a}{2} \text{ et } L_1 = \frac{L_q - L_a}{2} \quad (5)$$

It has the following expressions of M_{AA} and M_{BB} :

$$\begin{aligned} M_{AA} &= -\frac{2\pi}{\lambda} L_1 \sin\left(\frac{2\pi x}{\lambda}\right) \\ M_{BB} &= \frac{2\pi}{\lambda} L_1 \sin\left(\frac{2\pi x}{\lambda}\right) \end{aligned} \quad (6)$$

For the linear multicircuit structure proposed, the mutual influence of the phases can be neglected. The system of equations (1), (2) and (3), on this structure, is then reduced to the following equations:

$$\begin{aligned} U_B &= R i_B + L_0 \frac{di_B}{dt} + L_1 \cos\left(\frac{2\pi x}{\lambda} - \frac{\pi}{2}\right) \frac{di_B}{dt} \\ &\quad + \frac{2\pi}{\lambda} L_1 \sin\left(\frac{2\pi x}{\lambda} - \frac{\pi}{2}\right) V i_B \end{aligned} \quad (7)$$

$$\begin{aligned} U_C &= R i_C + L_0 \frac{di_C}{dt} + L_1 \cos\left(\frac{2\pi x}{\lambda} - \pi\right) \frac{di_C}{dt} \\ &\quad + \frac{2\pi}{\lambda} L_1 \sin\left(\frac{2\pi x}{\lambda} - \pi\right) V i_C \end{aligned} \quad (8)$$

$$\begin{aligned} U_D &= R i_D + L_0 \frac{di_D}{dt} + L_1 \cos\left(\frac{2\pi x}{\lambda} - \frac{3\pi}{2}\right) \frac{di_D}{dt} \\ &\quad + \frac{2\pi}{\lambda} L_1 \sin\left(\frac{2\pi x}{\lambda} - \frac{3\pi}{2}\right) V i_D \end{aligned} \quad (9)$$

$$\begin{aligned} U_A &= R i_A + L_0 \frac{di_A}{dt} + L_1 \cos\left(\frac{2\pi x}{\lambda}\right) \frac{di_A}{dt} \\ &\quad + \frac{2\pi}{\lambda} L_1 \sin\left(\frac{2\pi x}{\lambda}\right) V i_A \end{aligned} \quad (10)$$

$$\begin{aligned} \frac{dV}{dt} &= -\frac{\pi L_1}{m\lambda} \left[i_A^2 \sin\left(\frac{2\pi x}{\lambda}\right) + i_B^2 \sin\left(\frac{2\pi x}{\lambda} - \frac{\pi}{2}\right) + i_C^2 \sin\left(\frac{2\pi x}{\lambda} - \pi\right) \right] \\ &\quad - \frac{\pi L_1}{m\lambda} \left[i_D^2 \sin\left(\frac{2\pi x}{\lambda} - \frac{3\pi}{2}\right) \right] - \frac{F_0 \text{signe}(V)}{m} - \frac{\varepsilon}{m} - \frac{F_c}{m} \end{aligned}$$

(11)

The theoretical model of the machine concerned by this study is given by the equations of electrical and mechanical system (7), (8), (9), (10) and (11).

With:

- F_m: Developed electromagnetic force.
- F₀: Dry friction force.
- F_c: Resisting force.
- V=dx/dt: Linear speed of the movable part.
- x: Armature position.
- m: Armature mass.
- ζ: Dynamic viscosity coefficient.
- R: Statoric resistant.

U_k, i_k: Voltage and current in one phase (k=A, B,C, and D).

λ : rotor and stator tooth pitch.

The studied motor is characterized by the following parameters;
 m=0.47Kg ; ζ=21Nm/s ; R=7.34Ω ; U_k=15V ; F₀=0.1N; F₀= 0N.

On the other hand, the system is considered to two time scales. It includes fast variables related to electrical parameters and other slow variables, those related to mechanical parameters of the system. Thus in [3] only equation (11), relative to the mechanical equation, was chosen for the model simulation.

The simulation is made by taking into account all the electrical and mechanical equations. The physical model of the machine is established by means of „Matlab“ and „Matlab/simulink“. [2] Was carried out by only the equation (1), the mechanical equation, for the model simulation. Indeed, it has neglected the electrical parameters (the fastest), the delay is neglected and the simulation is made by taking into consideration of all the electrical and mechanical equations. The physical model of the machine is established by means of “Matlab” and “Matlab/simulink”.

Concerning the motor control, we excite a phase at a time as shown in the following table 1:

Table 1 Motor drive’s table.

Excitation	2.54mm	5.08mm	7.62mm	10.16mm
Phase A				
Phase B				
Phase C				
Phase D				

The results obtained are illustrated in the following figures:

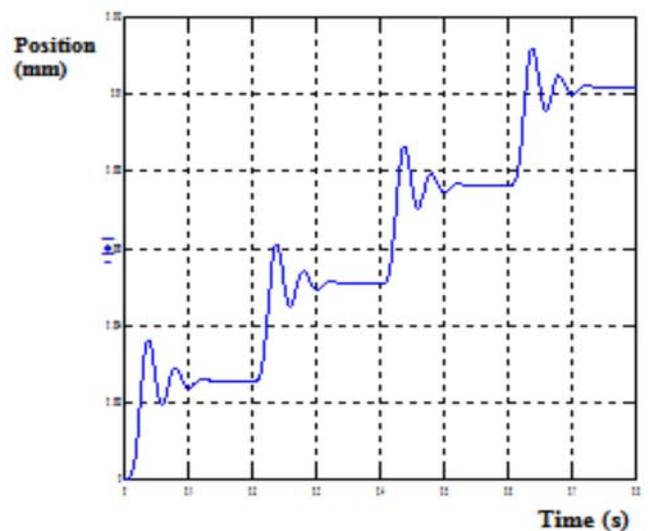


Figure 3 Simulated dynamic response of the motor

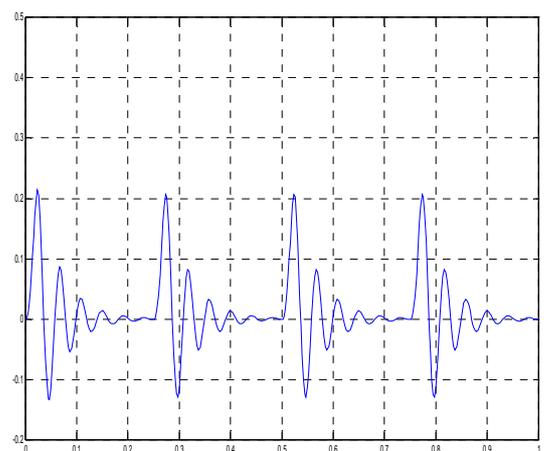


Figure 4 simulated Motor speed

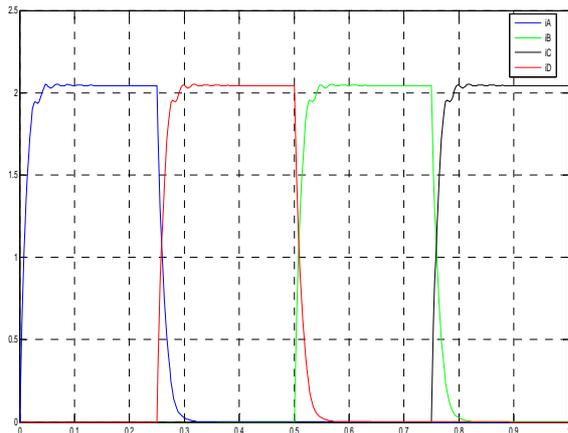


Figure 5 Currents in different phases

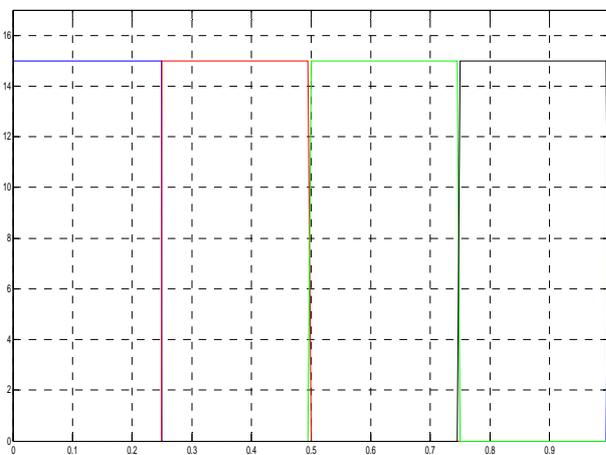


Figure 6 Voltages in different phases

Single phase is energized for 0.25s as shown in figure 6. When Phase A is powered, motor makes a step of 2.54mm, then the next phase, phase B, for another step of 2.54mm to reach the position of 5.08mm, and phase C and then phase D to arrive at the end to make a complete dental step 10.16mm.

In the case, in theory, of a problem while choosing the parametric identification method of testing motor, we try in this work to adopt a neural network approach, for the quality of their contributions in learning ability to better estimate the dynamic behavior of the considered motor. The work is limited to the neural network detection phase for their better approximation capabilities of nonlinear functions.

3 Neuronal Approaches

The neuron-fuzzy diagnosis ensures generation of residues by neural networks and their subsequent analysis by fuzzy logic.

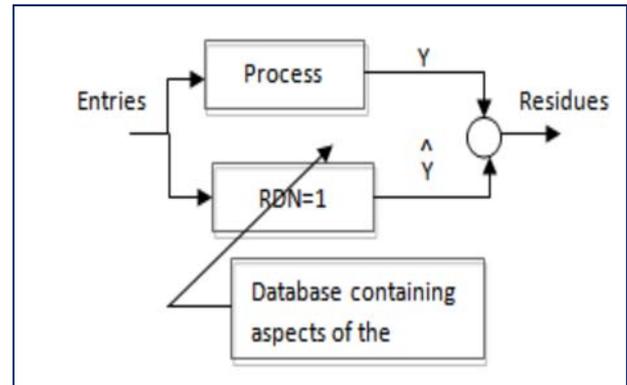


Figure 7 Neuro-fuzzy patterns for diagnosis

The steps for creating a neural network can be thus summarized:

Creating the database

- ✓ Expert knowledge,
- ✓ Key features of the process

Choice of neural network structure

- ✓ Layers number
- ✓ Neurons number
- ✓ The activation functions

Learning

- ✓ Network Initialization
- ✓ Back propagation of error
- ✓ Levenberg-Marquardt algorithm

Neural network validation

- ✓ Network evaluation
- ✓ Network tests

if unsatisfactory network:

- Change in the network structure
- Increasing the number of iterations of the learning phase
- Changing the initial values of the weights and biases

The desired algorithm followed this approach is well illustrated in the following diagram:

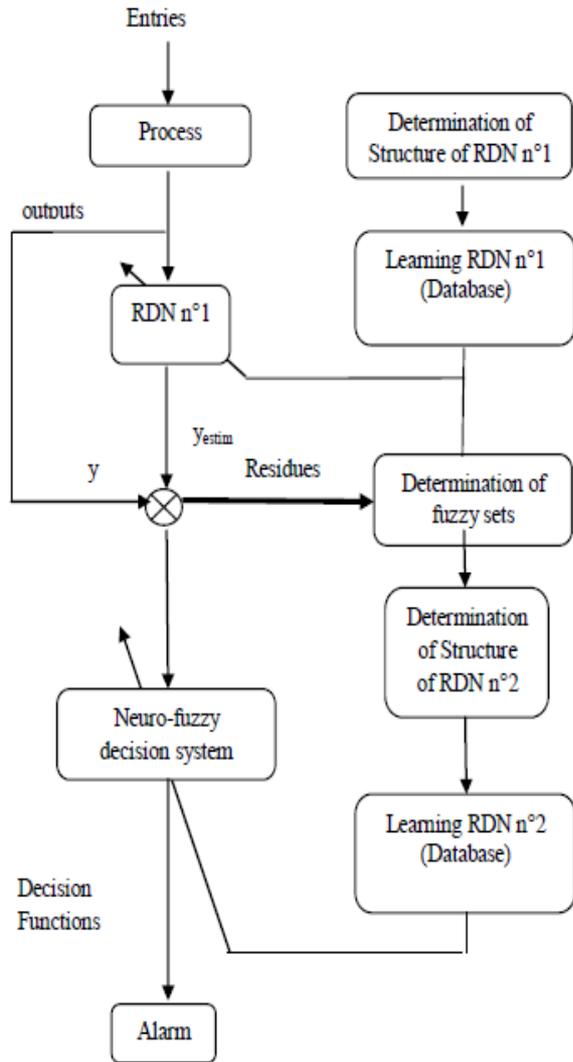


Figure 8 Neuro- fuzzy patterns for diagnosis

Our work was focused mainly on the step of neuronal estimation.

4 Validation based on an experimental response of the developed neural estimator

A method for the characterization of the achieved model which has been proposed in [3], which intends the development of a technique for estimating motor parameters studied based on the approximate feedback of speed, (\dot{x}), and the acceleration (\ddot{x}), and using the least squares method to determine the best parameters characterizing the motor.

The implementation of this technique for a pitch of 3.2 ms discretization and a position vector (X) : $X = [0 \ 0 \ 0 \ 1.5 \ 2.5 \ 4 \ 6.5 \ 11.5 \ 17.5 \ 26.5 \ 38.5 \ 46.5 \ 47 \ 46.5 \ 41.5 \ 36.5 \ 29.5 \ 25 \ 25 \ 27 \ 31.5 \ 35.5 \ 37 \ 35.5 \ 35 \ 32.5 \ 30 \ 30 \ 30.5 \ 32 \ 32.5 \ 32.5]^T$ leads to the response of the new model in Figure 7.

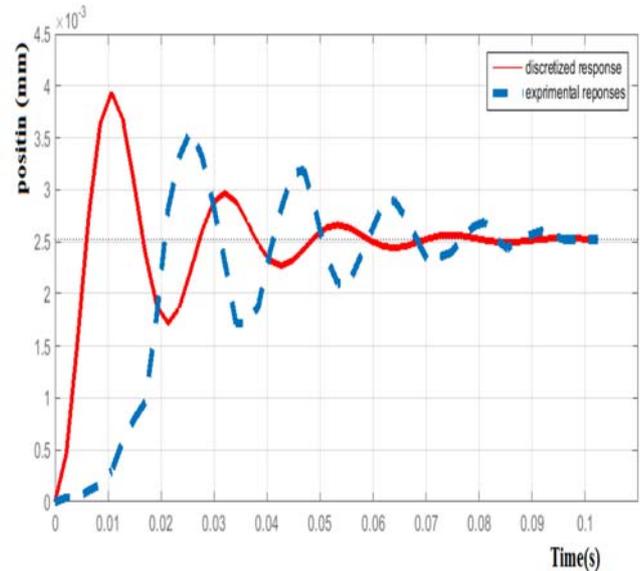


Figure 9 Unit-step responses for the new model

This experimental study of simulation allowed us to characterize a nonlinear dynamic model of reduced order. We note that during the preparation of this study, only the evolution of the variable of position was taken into account whereby generating the difference between the result of the model and that of experience. A model, which coincides exactly with the practical one, will be very effective for identifying the parameters of model that take into account any non-linearity of the studied system.

Using "Neural Network Toolbox" of Matlab, a neural network, having as activation function for the hidden layers, the "tangent sigmoid" and the "linear" functions for the output layer, is prepared.

We came up with an estimate, using a neural network, the response which coincides much better with the discrete response than the simulated one performed in [3].

Initially we worked on the phase A of the studied motor later we developed an own neural estimator for each phases B, C and D.

The results for phase A are illustrated in Figures 10 and 11.

- **number of Iterations =500**

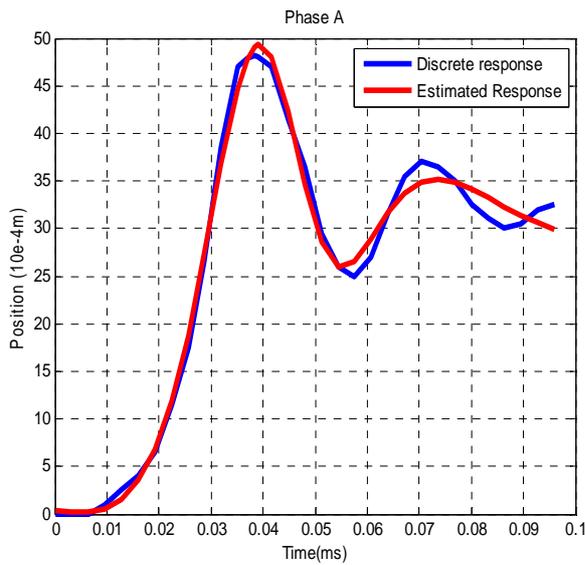


Figure 10 The estimated response for a number of iterations = 500

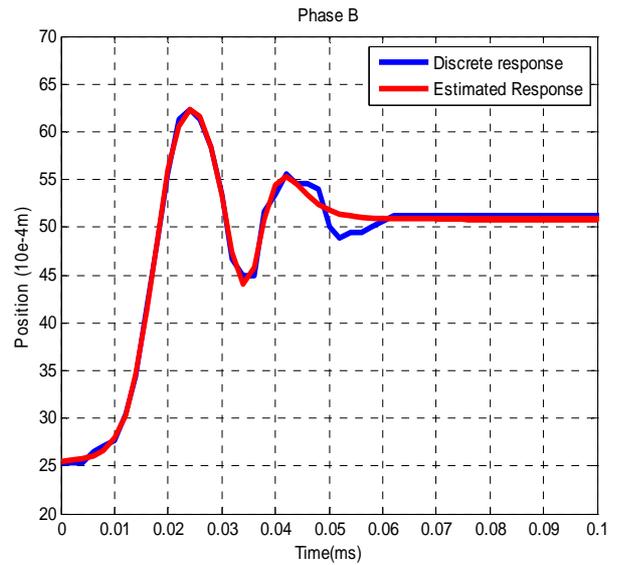


Figure 12 The estimated response for a number of iterations = 500 (Phase B)

- **number of Iterations =1000**

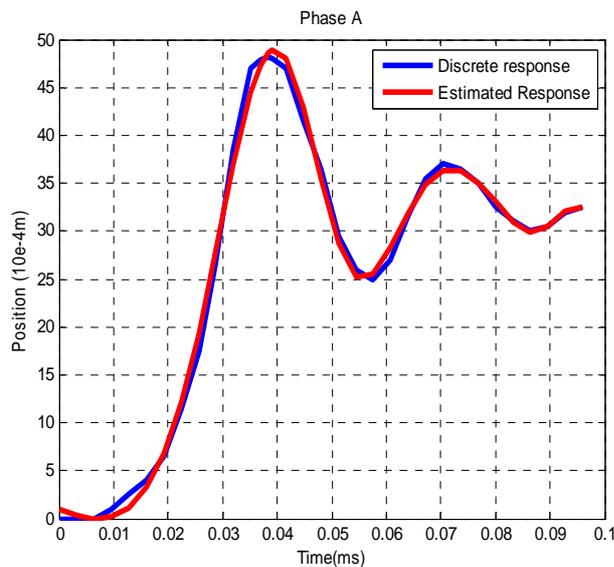


Figure 11 The estimated response for a number of iterations = 1000

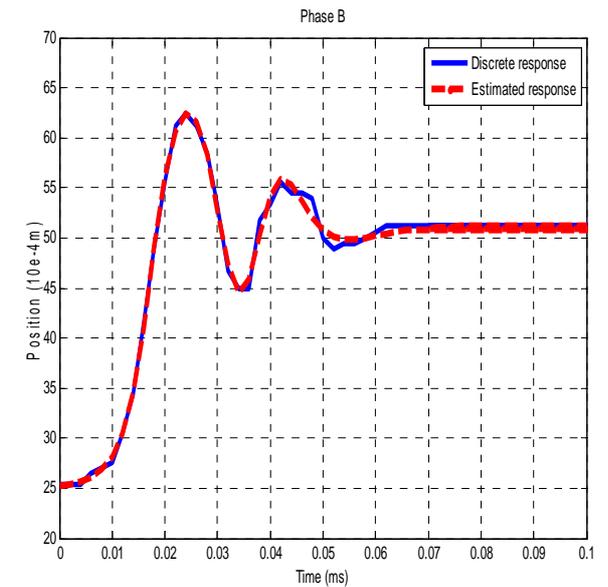


Figure 13 The estimated response for a number of iterations = 1000 (Phase B)

The results obtained (of the simulation model and of the neural estimator) for phase A satisfy well the aimed objectives.

The results for phase B are illustrated in Figures 12 and 13.

The results for phase C are illustrated in Figures 14 and 15.

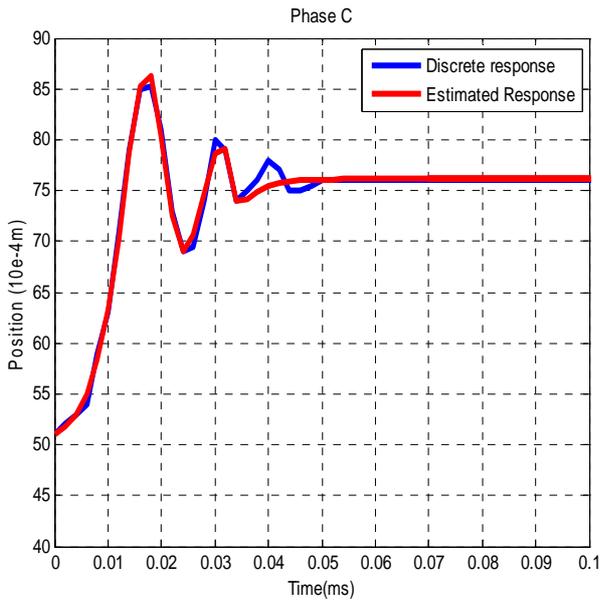


Figure 14 The estimated response for a number of iterations = 500 (Phase C)

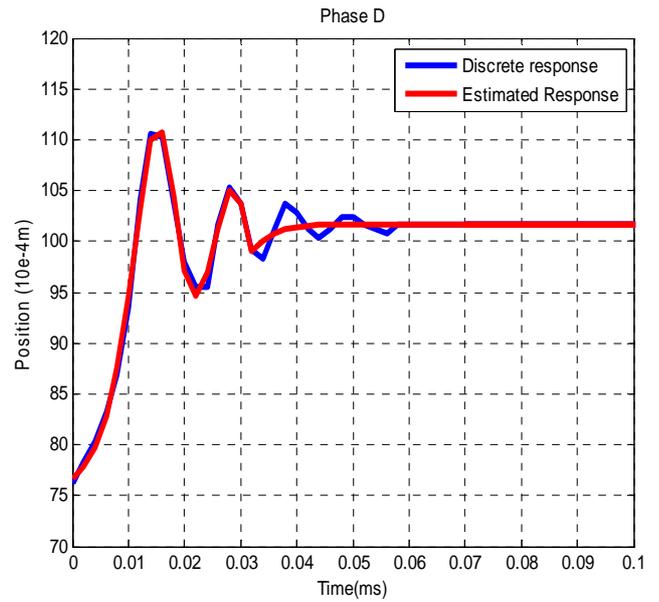


Figure 16 The estimated response for a number of iterations = 500 (Phase D)

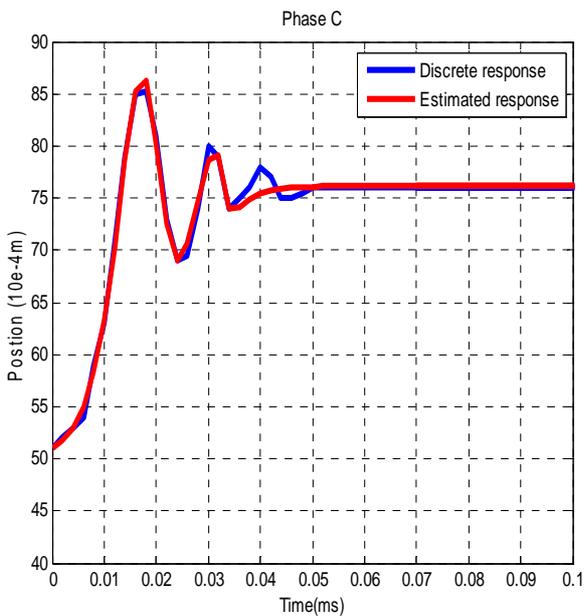


Figure 15 The estimated response for a number of iterations = 1000 (Phase C)

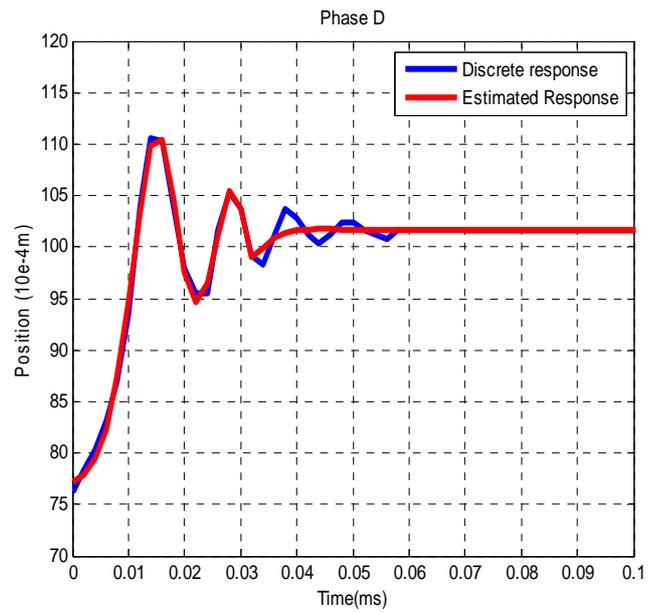


Figure 17 The estimated response for a number of iterations = 1000 (Phase D)

The results for phase D are illustrated in Figures 16 and 17.

Initially, during the model simulation based on the four electrical equations and the mechanical one, we obtained the expected responses verifying that the generalized model of the test motor, developed in the work of the document [3], show this limitations and that the method adopted for the identification of the machine parameters do not result in adequate values for the simulation of the actual operation of the designed motor. Then, using a neural network, an estimate based on an experimental unit-step response of the machine is developed. The simulation showed that for a large number of iterations of the implementation of the network we reach a response that perfectly follows the experimental response.

The number of iterations of the implementation of the developed neural network affects the results of the simulation. Thus, for a higher number of iterations to thousand, the results were conclusive.

5 Conclusion

Our study presents a modeling more appropriate to the dynamic behavior of such a stepping motor.

In fact, since the first approach is not reliable; we have proceeded by a neural networks-developed estimator proceeding. The adoption of the selected neural network tool is argued by its learning capacity. Due to the non-linear nature of the model to be studied, such adopted tool seems, well adequate in respect of its excellent approximation of nonlinear functions.

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