Proceedings of the 6th WSEAS Int. Conf. on FUZZY SYSTEMS, Lisbon, Portugal, June 16-18, 2005 (pp1-6)

Reference Variables Generation Using a Fuzzy Trajectory Controller for PM Tubular Linear Synchronous Motor Drive

R. LUÍS J.C. QUADRADO

ISEL, R. Conselheiro Emídio Navarro, 1950-072 LISBOA
CAUTL, R. Rovisco Pais, 1049-001 LISBOA
PORTUGAL

Abstract: The usage of linear permanent-magnet (PM) actuators, and their associated controllers, increases in a wide variety of applications, due to the exhibited high force density, robustness, and accuracy. The s-curve motion profiling is the motion trajectory usually employed in common industrial applications. In this control scheme, the trajectory shape is determined by maximum acceleration, maximum speed, and the target distance. The values of speed and acceleration must be chosen carefully. If they are chosen excessively large or very small, it may not be possible for the system to track the generated trajectory with good accuracy. This paper, considers the control of a single degree-of-freedom (DOF) mechanical system, in which a PM Tubular Linear Synchronous Motor (PM-TLSM) is used as the actuator. Since the fuzzy logic control controllers are based on heuristics are therefore able to incorporate human intuition and experience. The resulting motion trajectory obtained from the fuzzy logic is particularly suited to high accuracy applications such as parallels manipulators, robotics systems and factory automation. Computer simulation results verify the effectiveness of the proposed scheme.

Key-Words: Fuzzy logic control, Trajectory tracking, Modelling and Simulation.

1 Introduction

In recent years, the fuzzy control has been increasely developed and has become one of the most successful tools in the industry.

Fuzzy logic control provides a formal methodology for representing, manipulating and implementing a human's heuristic knowledge on how to control a system [1].

Figure 1 shows the main components of the fuzzy controller.

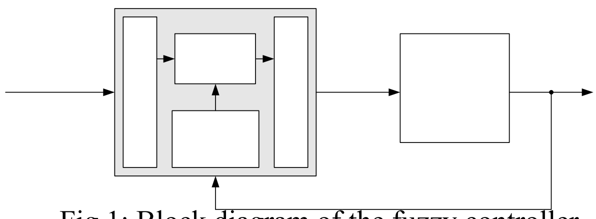

Fig.1: Block diagram of the fuzzy controller embedded in the closed-loop control system.

The "rule-base" holds the knowledge, in the form of a set of rules, i.e. the way to control the system.

The "inference engine" evaluates which control rules are appropriate at the current time and then decides what the input to the process should be.

The "fuzzification" interface modifies the inputs so that, they can understand and activate the rules in the "rule-base". The "defuzzification" interface converts the conclusions reached by "inference engine" into the process inputs.

The Fuzzy logic incorporates a simple, rule-based "IF X AND Y THEN Z" approach to solve the control problem rather than attempting to model a system mathematically. The fuzzy logic model is empirically-based, relying on the operator's experience rather than its technical understanding of the system.

2 System description

This paper uses two fuzzy logic controllers to predict the necessary speed and acceleration references allowing the system to track the position reference correctly.

Another possible approach relies on the theory and application of the time-optimal control of the linear actuators, which is obtained in feedback form via a three-dimensional state-space analysis, [2].

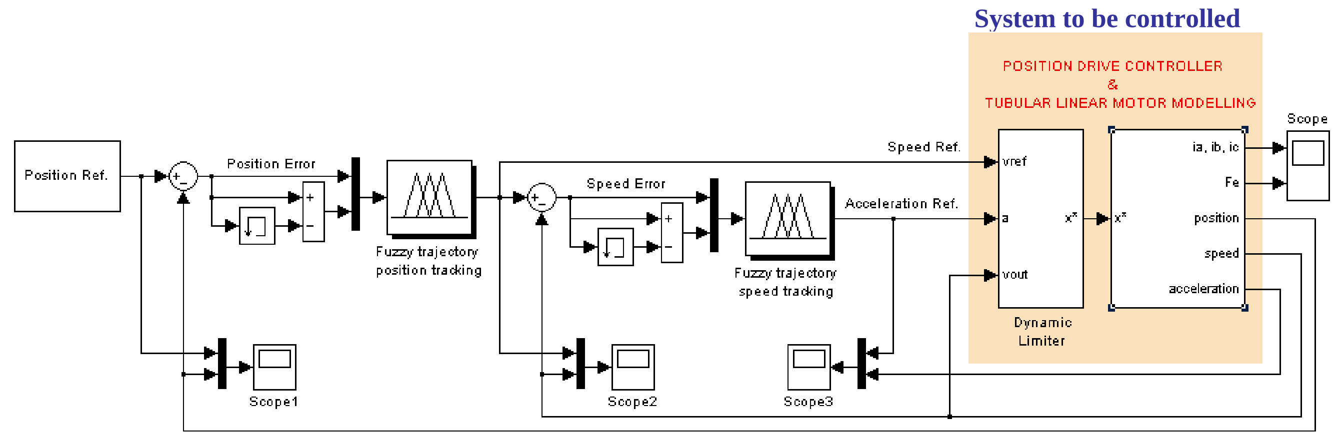

Fig.2: Global scheme of the fuzzy trajectory controllers.

The proposed control structure, using fuzzy logic controllers is shown in figure 2. The proposed controllers have been implemented on the Matlab® environment, using Fuzzy Logic Toolbox, Stateflow® and Simulink®.

The system model to be controlled incorporates two main parts: a dynamic limiter and a cascade position loop controller for the PM-TLSM. The Maltab® implementations of these models are presented in Appendix to this paper.

The dynamic limiter has three reference inputs: speed, v_{ref}, acceleration, a_{ref}, and deceleration, d_{ref}. These values will allow the dynamic limiter to generate an internal motion trajectory reference for the poison controller. The basic principle of the dynamic limiter implementation follows the expressions described by (1).

$$\begin{cases} \text{If} \quad v_{ref} > v_{out} \quad \text{then} \quad a_{out} = a_{ref} \\ \text{If} \quad v_{ref} < v_{out} \quad \text{then} \quad a_{out} = d_{ref} \\ \text{If} \quad v_{ref} = v_{out} \quad \text{then} \quad a_{out} = 0 \end{cases} \qquad (1)$$

In (1), v_{out} and a_{out} represent the actual speed and the actual acceleration of the system, respectively.

The position control scheme includes a speed loop within a position loop. The position loop has a proportional controller and a proportional-integral with anti-windup compensation which is used in the speed loop. The tuning of the different controllers has been evaluated using the integral of time multiplied by the absolute value of the error (ITAE) criterion.

The stator currents strategy of the PM-TLSM used employs a hysteretic vectorial control in αβ coordinates, as it is reported in [2].

The mathematical model of the PM-TLSM used in this paper is reported in [3].

3 Design of the Fuzzy logic controllers

3.1 Definition of the system parameters

The variables to control are the system speed and acceleration references. As it is shown on figure 2, the system's speed reference is the output of the fuzzy trajectory position tracking block. Also from the figure 2, it can be seen that acceleration reference value is the output of the fuzzy trajectory speed tracking block. In the control loop, the fuzzy input variables are the position error, e_p, and the change of position error, Δe_p. The speed error, e_s, and the change of the speed error, Δe_s, are the fuzzy inputs variables on the speed control loop.

The fuzzy linguistic inputs (e_p, Δe_p, e_s and Δe_s) are divided into seven fuzzy sets: Negative Big (NB), Negative Medium (NM), Negative Small (NS), Zero (ZE), Positive Small (PS), Positive Medium (PM) and Positive Big (PB).

For the fuzzy linguistic outputs (position and speed references) two more fuzzy sets are used: Negative Enormous (NE) and Positive Enormous (PE).

In order to assure the simplicity of the fuzzy controllers, the shapes of the membership functions adopted for the fuzzification of the inputs are triangular and trapezoidal, as show in figure 3.

The fuzzy inference engine used is the MAX-MIN method which tests the magnitudes of each rule and selects the highest one.

The defuzzification method employed is the COG (center of gravity).

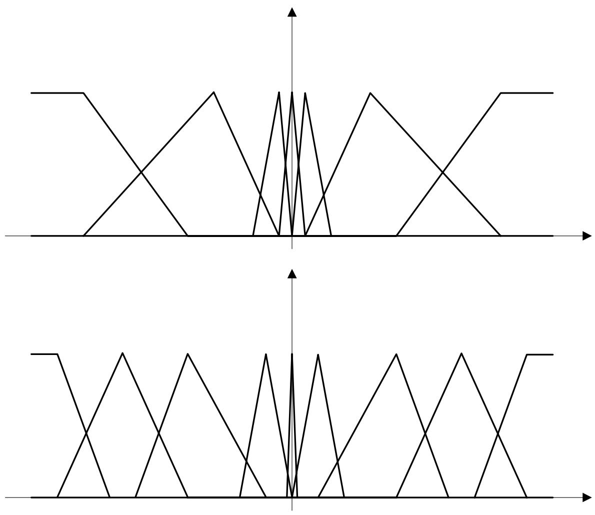

Fig.3: Membership functions of fuzzy controllers.

3.2 Formulation of the control rules

To obtain the control rules formulation, a typical second order dynamic system response to a step input is taking into account, as seen in figure 4.

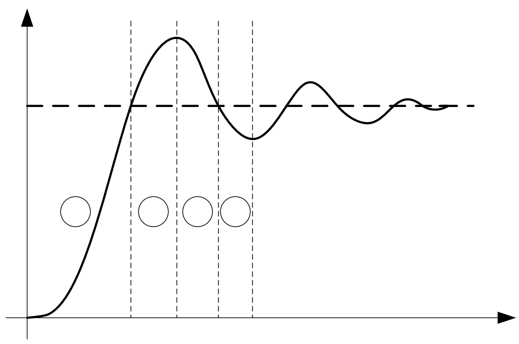

Fig.4: Typical second order system response.

Figure 4 is splited into four distinct sectors. The differences of each sector can be evaluated by the error (e) and the change of error (Δe) signals. For the first sector the error and the change of error signals are described by (2).

$$\text{sector 1}: \quad e > 0,\ \Delta e < 0 \qquad (2)$$

For the remaining sectors, the error and the change of error signals are given from (3) to (5).

$$\text{sector 2}: \quad e < 0,\ \Delta e < 0 \qquad (3)$$

$$\text{sector 3}: \quad e < 0,\ \Delta e > 0 \qquad (4)$$

$$\text{sector 4}: \quad e > 0,\ \Delta e > 0 \qquad (5)$$

The control strategy is achieved by building the rule bases. This rule bases consider the desired dynamic system behaviour, i.e. considers overshoot, rising time, settling time, position and speed errors and the respective error changes.

The number of the rules for each fuzzy controller is 49, presented in Tables 1 and 2.

Using the linguist fuzzy terms the highlighted rules in Tables 1 and 2, can be read, respectively, as follows, by (5) and (6).

$$\textbf{IF } e_p \textbf{ is } \text{PM} \textbf{ and } \Delta e_p \textbf{ is } \text{NS} \textbf{ then } \textit{Speed Ref.} \textbf{ is } \text{PE} \qquad (5)$$

$$\textbf{IF } e_s \textbf{ is } \text{ZE} \textbf{ and } \Delta e_s \textbf{ is } \text{PM} \textbf{ then } \textit{Acceleration Ref.} \textbf{ is } \text{PS} \qquad (6)$$

Table 1: Rule table for the Fuzzy Position Controller.

Speed Ref. — e_p \ Δe_p	PB	PM	PS	ZE	NS	NM	NB
PB	PE	PE	PE	PE	PE	PE	PE
PM	PE	PE	PE	PE	PE	PB	PM
PS	PE	PB	PM	PM	PM	PS	PS
ZE	PM	PS	PS	ZE	NS	NS	NM
NS	NS	NS	NM	NM	NM	NB	NE
NM	NM	NB	NE	NE	NE	NE	NE
NB	NE	NE	NE	NE	NE	NE	NE

Table 2: Rule table for the Fuzzy Speed Controller.

Acceleration Ref. — e_s \ Δe_s	PB	PM	PS	ZE	NS	NM	NB
PB	PE	PE	PE	PB	PB	PB	PB
PM	PE	PB	PB	PB	PB	PM	PM
PS	PM	PM	PS	PS	PS	PS	PS
ZE	PS	PS	ZE	ZE	ZE	NS	NS
NS	NS	NS	NS	NS	NS	NM	NM
NM	NM	NM	NB	NB	NB	NB	NE
NB	NB	NB	NB	NB	NE	NE	NE

Figure 5 shows a three-dimensional plot of the Fuzzy Position Controller Speed Reference, with respect to e_p and Δe_p whose ranges are [-2, 2], [-0.3, 0.3] and [-0.6, 0.6], respectively.

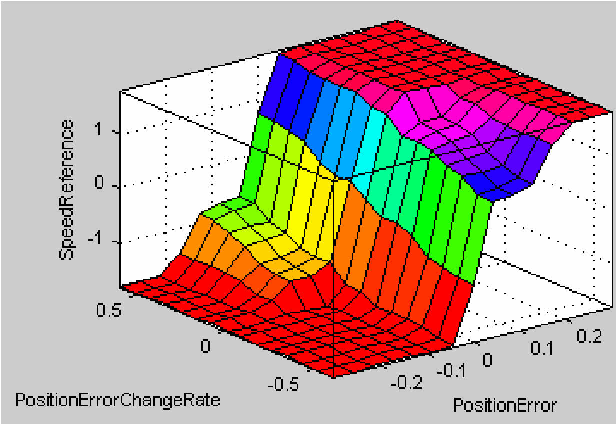

Fig.5: Control surface of the Fuzzy Position Controller.

Figure 6 shows a three-dimensional plot of the Fuzzy Speed Controller Acceleration Reference with respect to e_s and Δe_s whose ranges are [-50, 50], [-2, 2] and [-4, 4], respectively.

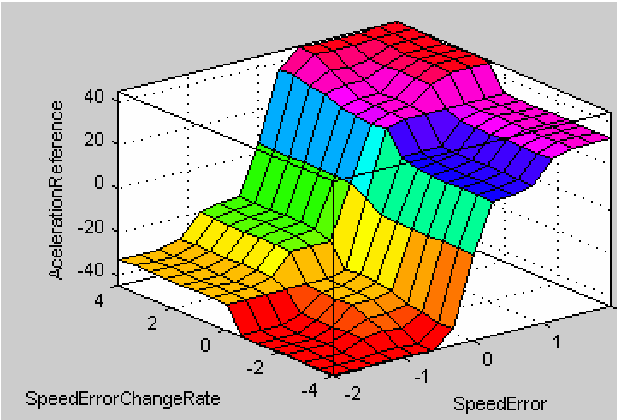

Fig.6: Control surface of the Fuzzy Speed Controller.

4 Simulation results

The simulations have been carried out using the mathematical model of a position controller drive of a PM-TLSM implemented in Simulink®.

Figures 7 to 9 show the simulations results obtained for a sinusoidal position reference.

Figures 10 to 12 show the simulations results obtained for a square-wave position reference.

These results demonstrate the applicability of the proposed fuzzy logic controllers.

The differences founded between the references and the actual values can not be neglected. These results denote that it will be necessary improvements in the design of the fuzzy trajectory controllers to achieve higher precision motion control.

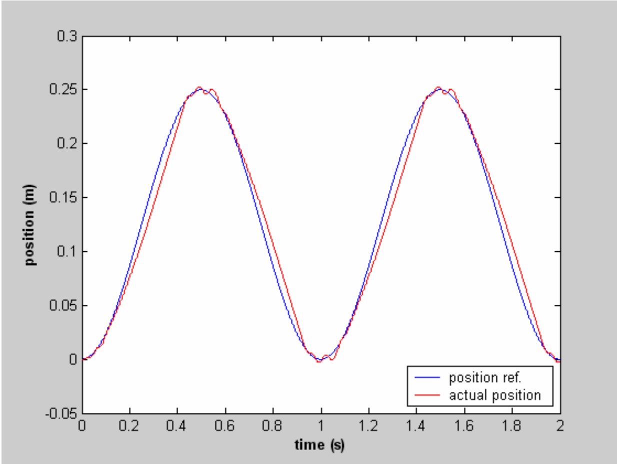

Fig.7: Position response to a sinusoidal position reference.

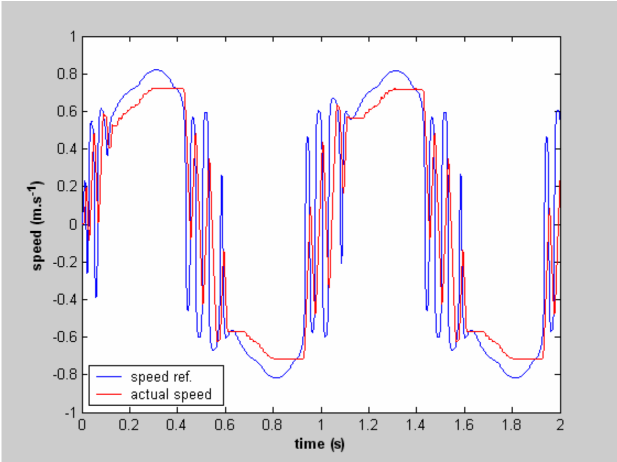

Fig.8: Speed response to a sinusoidal position reference.

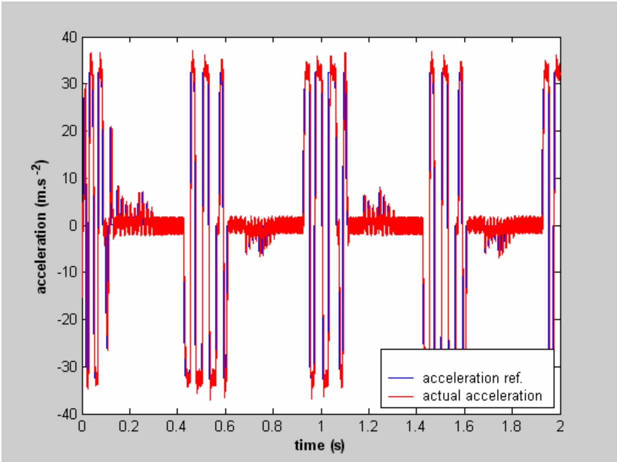

Fig.9: Acceleration response to a sinusoidal position reference.

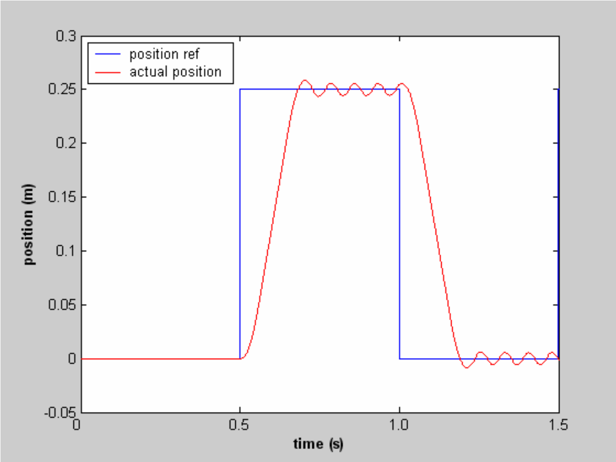

Fig.10: Position response to a square-wave position reference.

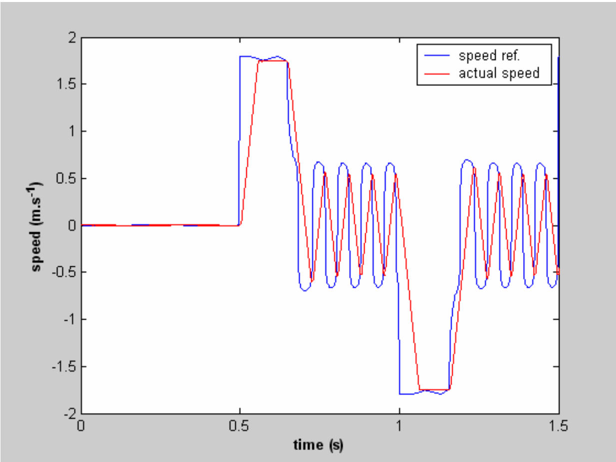

Fig.11: Speed response to a square-wave position reference.

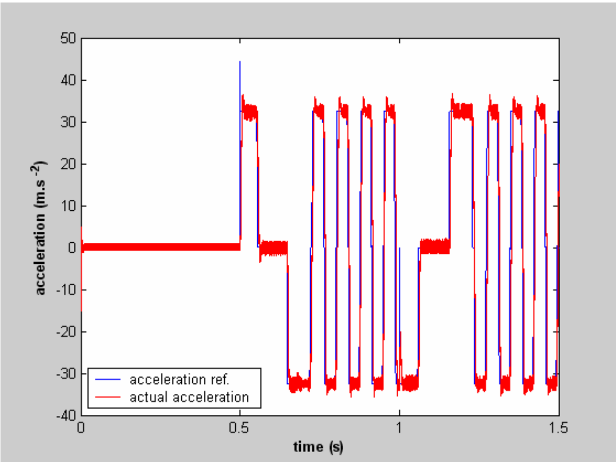

Fig.12: Acceleration response to a square-wave position reference.

5 Conclusions and further developments

In this paper the design of the fuzzy logic controllers to predict the speed and the acceleration references to an electromechanical system that incorporate a position controller drive and a PM-TLSM was developed.

In conclusion, it is important to recognize the large potential that fuzzy logic has to offer in this application. With this control tool it is not necessary to build a detailed mathematical model of the system and the human knowledge can be easily incorporated.

These are only preliminary results further work is needed to consolidate this approach

Future work includes experimental validation of this approach. Among other further development, it is foreseen the implementation of a fuzzy supervisory control to improve the accuracy of the system.

References:

[1] Passino, K.M., Yurkovich, S., *Fuzzy Control*, Addinson-Wesley Longman, 1998.

[2] Yang-O Kim and In-Joong Ha, Time-Optimal Control of a Single-DOF Mechanical System Considering Actuator Dynamics, *IEEE Trans. On Control Systems Technology*, Vol.11, No.6, 2003, pp.919-932

[3] Barata, F.A., Quadrado, J.C., Brushless DC Motor Position Linear Control Simulation (*to be published*)

[4] Luís, R., Quadrado, J.C., On PM Linear Synchronous Motor Modelling, *WSEAS Trans. on Circuits and Systems*, Vol.3, No.9, 2004, pp. 1852-1857.

Appendix

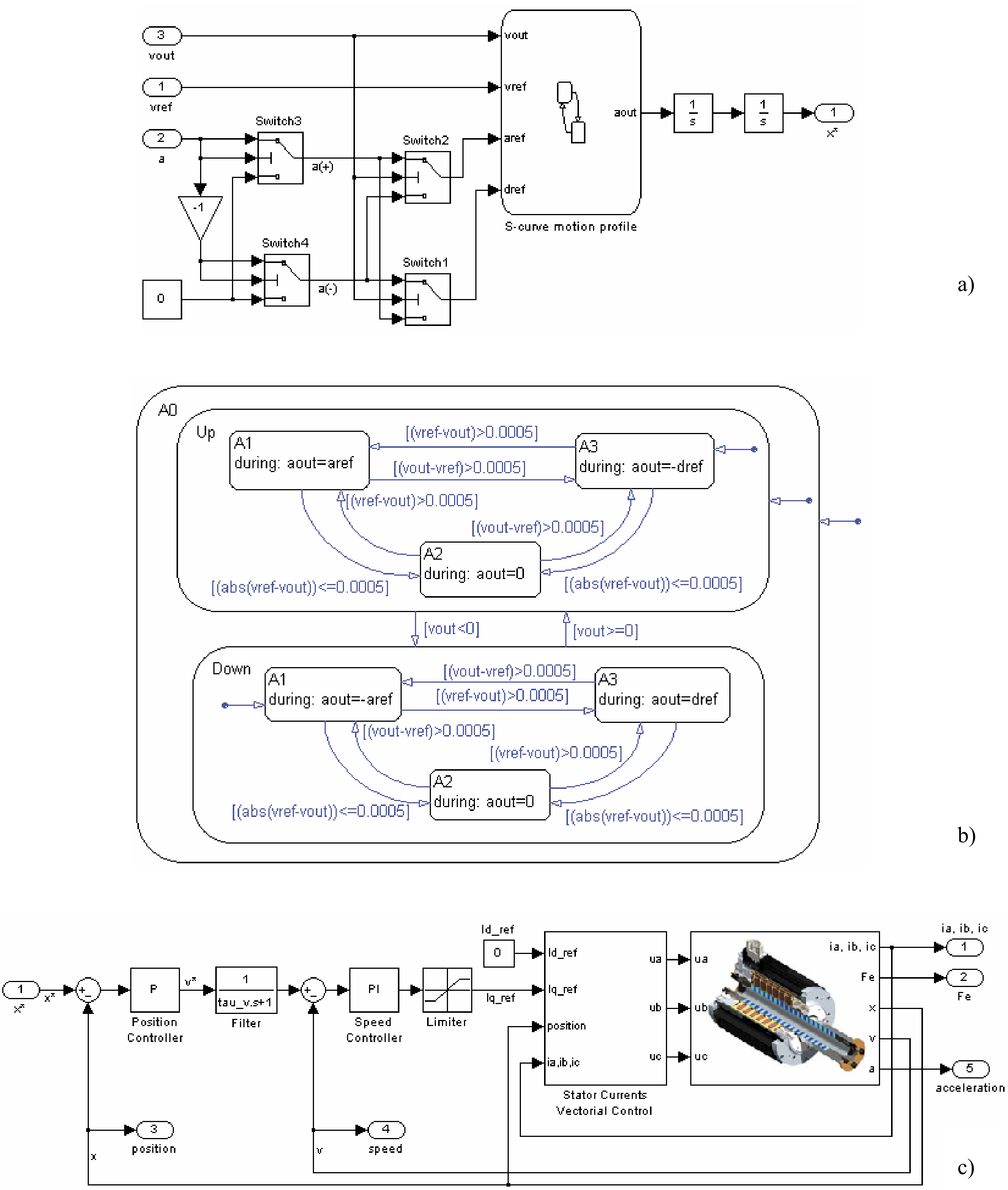

Fig.13: Main parts of the position drive controller modelling: a) Dynamic limiter; b) State flow chart; c) Loop controls of position and speed of the PM-TLSM Drive.