MULTI-LAYER FUZZY CONTROL BASED POSITION TRACKING OF VARIABLE RELUCTANCE DRIVE SYSTEM

التحكم التتابعى للموضع باستخدام المنطق اللامحدد المتعدد الطبقات
فى نظم المحركات ذو الممانعه المتغيرة

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خلاصه:

فى هذا البحث تم استخدام المنطق اللامحدد المتعدد الطبقات للتحكم التتابعى للموضع فى نظم المحركات ذو الممانعه المتغيرة و التى تستخدم فى التطبيقات الصناعية العالية الاداء. يتكون هذا المتحكم من طبقتين أساسيتين: الأولى مسئولة عن تقسيم منحنى تتابع الموضع الى مناطق تبعا لطبيعة التشغيل. والطبقة الثانية هى المسئولة عن تحديد المنطقة المناسبة للتشغيل. و يقدم البحث النتائج التى توضح أهمية و فاعلية هذا المتحكم المتقدم.

ABSTRACT.

In this paper, A multi-layer fuzzy control (MLFC) is used on position tracking of variable reluctance motor (VRM) drive system. The MLFC is an extension to fuzzy control concept. This type of high performance drives system, is essential in applications such as robotic, actuation, and guided manipulation where precise movements are required and very essential. In this work, there are two main layers in the MLFC tracking system; the first layer is responsible of dividing the position trajectory into ranges according to operating conditions. The second layer is the supervisory layer which is responsible of determining the present or actual range of operation. A simulation result has been provided to show the effectiveness of this advanced controller.

1. INTRODUCTION.

Precise position tracking control is being studied in many manufacturing fields in order to improve the accuracy and performance of manufacturing process and manipulator driving systems which demand more precise, robust and efficient control systems every time. Certain behavior is desired in position tracking control systems: fast response and convergence, zero tracking error and robustness against changes in the system itself and /or its environment. The classical way to solve the tracking control problem for linear time invariant system has been design to a one-

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degree of freedom, or better, two degree of freedom controller which achieve the desired performance as close as possible [1]. However, when the structure of the problem is nonlinear, unknown or the parameter variation is excessive the effectiveness of the classical way diminishes. Even if it is possible to develop a reasonably accurate model, the resulting control is so computationally intensive that it becomes infeasible to implement it in a real time control environment [2].

In recent years, considerable attention has been given to computational intelligent techniques such as fuzzy logic control (FLC) [3]. The fuzzy controller is simple and straight-forward technique. The controller design dose not depend on the accurate model of the system, but it is based on heuristics about controlled process behavior [4]. More rules can be added to deal with design objectives and to overcome varying operating conditions. However, with the increased number of rules, the tuning of the system become more tedious. An extension to fuzzy control, the multi-layer fuzzy control (MLFC), which is proposed here to overcome this problem.

In this paper, A multi-layer fuzzy control (MLFC) is used on position tracking of variable reluctance motor (VRM) drive system. The high performance position tracking of VRM system is highly complex non-linear control problem. So, this problem is divided into sub -problems. Each of this sub-problem is smaller and simpler in nature and therefore easy to solve. A track or trajectory is a desired time history of the particular controlled variable. One of the main difficulties with conventional tracking controller for electric drives is their inability to perform over a wide range of operating conditions [5]. There are two layers in the MLFC which are shown in fig. 1. The first layer is the execution layer (ELFCs). It is made up of sub-controllers each designed for a control sub-problem or a region of operation. The second layer is the supervisor layer which combines the ELFCs such that the control problem is solved.

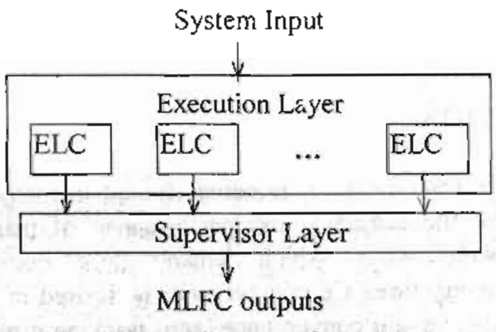

Fig. 1 Block diagram of an MLFC.

2. STATE SPACE MODEL OF VRM.

The state space representation of the VRM as given in [6] is:

$$\dot{X} = Ax + Bu \tag{1}$$

$$y = cx \tag{2}$$

$$x = [i\,\theta\,\dot{\theta}] \tag{3}$$

$$A = \begin{bmatrix} -\dfrac{r+k_b}{L} & 0 & 0 \\ \dfrac{k_T}{J} & 0 & -\dfrac{D}{J} \\ 0 & 0 & 1 \end{bmatrix} \tag{4}$$

$$B = \begin{bmatrix} \dfrac{1}{L} & 0 & 0 \end{bmatrix}^T \tag{5}$$

$$c = \begin{bmatrix} 0 & 1 & 0 \end{bmatrix} \tag{6}$$

Where:
i: phase current.
u: input voltage.
L: phase inductance is function in θ.
r: phase resistance.
k_b: back EMF coefficient, it is function in θ.
θ : rotor position.
K_T: torque constant, J and D are the moment of inertia and viscous coefficient.

3. TRACKING CONTROLLER.

The selection of the trajectory is critical to the performance of the tracking system. An abrupt change in any system variable may translate into excessive stress to the system both mechanical and electrical. A sigmoidal function is the best choice of track because it does not have abrupt changes. Figure 2 shows the sigmoidal function and its derivative. The equations describe the sigmoidal function and its derivative are given by:

$$Sig\ (t) = \frac{z}{1 + e^{-(t-t_o)/\tau}} \tag{7}$$

$$\frac{d}{dt} Sig(t) = \frac{z e^{-(t-t_o)/\tau}}{\tau [1 + e^{-(t-t_o)/\tau}]^2} \tag{8}$$

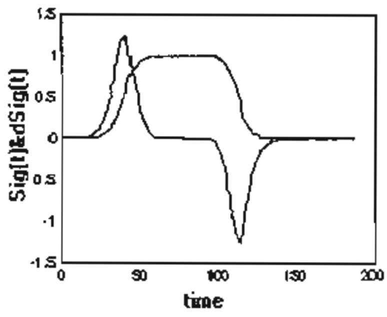

Fig. 2 Sigmoidal function and its derivative.

4. MLFC POSITION TRACKING.

In tracking applications, the trajectory is known before. the preselected position trajectory is a sigmoidal function as shown in fig. 2. It is clear that the different segments of a sigmoidal position trajectory have different characteristics and therefore require different control strategies. A MLFC based position tracking controller is developed for this purpose. The inputs to the MLFC position tracking controller are the position trajectory, acceleration trajectory actual rotor position and the error. The controller output is conduction angle command. Figure 3 shows the block diagram of the MLFC for position tracking of the VRM drive system.

The trajectory is divided into five regions according to its acceleration; this acceleration is indication of how fast or slow the transition from different range of operation changes. These ranges are constant-speed, slow and fast acceleration, and slow and fast declaration. There is an ELFC for each range. The supervisor layer uses the acceleration track to determine the present range of operation.

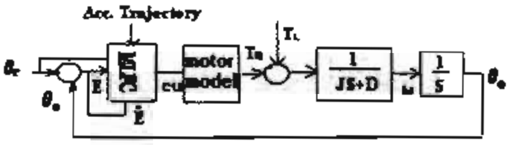

Fig. 3 MLFC of position tracking VRM.

The position error and acceleration can be obtained from the following forms:

$$E = G_{er}\left[\theta_r(T+1) - \theta_o(T)\right] \qquad (9)$$

$$Acc = G_{ac}\left[\omega_r(T) - \omega_o(T-1)\right] \qquad (10)$$

Where:

θ_r : the desired position track given by the sigmoid trajectory shown in fig. 2.

θ_o : actual position at given time interval T.

ω_r :the desired speed as given by the derivative of sigmoidal position trajectory.

G_{er} G_{ac} : are the scaling factors.

The fuzzy decision rules table of the supervisor layer is given by:

Table 1, Fuzzy rules of supervisor layer.

If acc is FP	Then ELFC1
If acc is SP	Then ELFC2
If acc is ZE	Then ELFC3
If acc is FN	Then ELFC4
If acc is SN	Then ELFC5

Where: FP,SP are set for fast positive, and slow positive. FN,SN are set for fast negative, and slow negative. Ze set for zero acceleration (constant-speed).

The fuzzy rule table of each ELFC controller is obtained by examining the error signal and the acceleration trajectory for each region, they are given in tables 2,3 &4 as follows:

Table 2, Fuzzy set rules of ELFC1,2.

		CE				
		LN	SN	ZE	SP	LP
E	LN	LN	LN	LN	LN	LN
	SN	SN	SN	SN	ZE	SP
	ZE	SN	ZE	ZE	ZE	SP
	SP	SN	SN	SP	SP	SP
	LP	LP	LP	LP	LP	LP

Table 3, Fuzzy set rules of ELFC3.

		CE				
		LN	SN	ZE	SP	LP
E	LN	LN	LN	LN	LN	LN
	SN	SN	SN	SN	ZE	SP
	ZE	SN	ZE	ZE	ZE	SP
	SP	SN	ZE	SP	SP	LP
	LP	LP	LP	LP	LP	LP

Table 4, Fuzzy set rules of ELFC4,5.

		CE				
		LN	SN	ZE	SP	LP
	LN	LN	LN	LN	LN	LN
E	SN	LN	SN	SN	ZE	SN
	ZE	SN	ZE	ZE	ZE	SP
	SP	SN	SN	SP	SP	LP
	LP	LP	LP	LP	LP	LP

It is clear that the fuzzy rule tables for slow and fast acceleration ELFC1 &ELFC2 share the same set of rules, which is shown in table 2. likewise, the rules for for slow and fast deceleration ELFC4 &ELFC5 share the same fuzzy rule sets, as shown in table 4. The rule table for the constant- speed ELFC3 is similar to that of a typical fuzzy regulator and is shown in table 3. It is designed to maintain the speed

5. SIMULATION RESULTS.

The results of the MLFC tracking system are given in figs. 4,5,6 and 7. There is a high position error shown in fig. 5. The maximum position error is 0.04 radian. By tuning of the ELFCs fuzzy rules, the position error diminishes and the output matched the desired position trajectory as shown in fig. 6. The tracking error exhibits a smaller value of 0.02 radian as shown in fig. 7, more tuning will leads for better response.

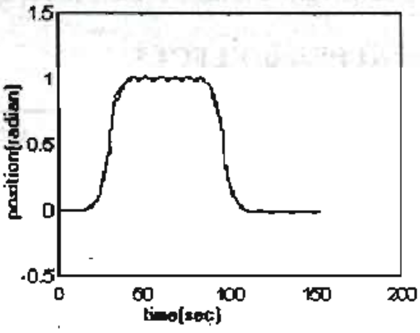

Fig. 4 Position tracking of VRM.

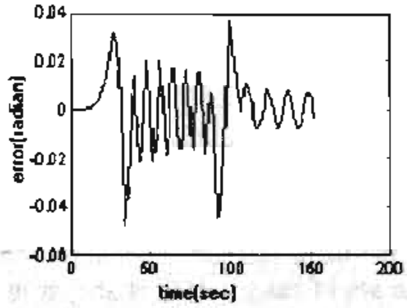

Fig .5 The tracking position error.

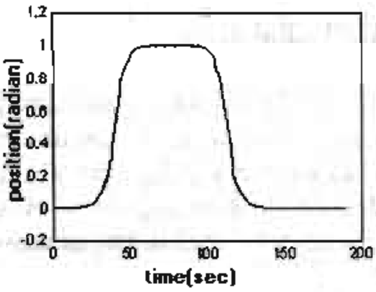

Fig. 6 Position tracking of VRM After Tuning of MLFC.

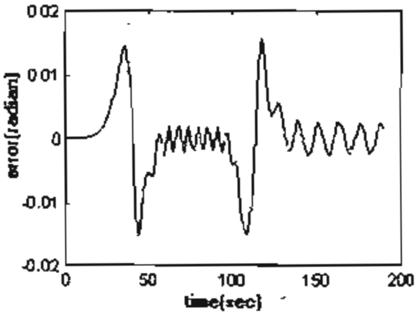

Fig. 7 Position error after tuning of MLFC.

6. CONCLUSION.

The MLFC based position tracking of VRM drive system has been described in this work. The high performance position tracking of VRM system is highly complex non-linear control problem. So, this problem is divided into sub-problems. Each of this sub-problem is smaller and simpler in nature and therefore easy to solve. In this controller more rules can be added to deal with design objectives and to overcome varying operating conditions. The simulation results show the high performance of the system with the proposed controller. The MLFC based tracking controller is easy to design and tune.

7. REFERENCES.

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APPENDIX (A)

VRM Data:

A three phase VRM of 6/4 poles in stator and rotor respectively with the following parameters, is given by:

Base speed	ω_b = 4700	rpm
Base electrical frequency	f_b = 313.3	Hz
Base torque	T_b =121.9	Nm
Base power	P_b = 60	Kw
No load speed	ω_o = 12500	rpm
Primary resistance	R_a = 0.069	Ohm
Secondary resistance	R_s = 0.069	Ohm
Minimum inductance	L_{min}=0.667	mH
Maximum inductance	L_{max} = 16.8	mH