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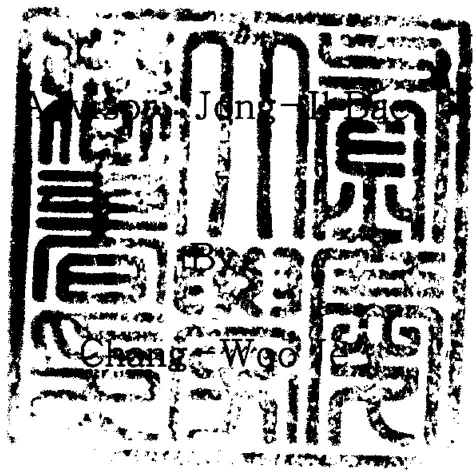
Speed Control of DC Series Wound Motor Using a Genetic Algorithm with Self-Tuning Method

유전알고리즘의 자기동조 방법에 의한 DC 모터 속도제어



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Speed Control of DC Series Wound Motor Using a Genetic Algorithm with Self-Tuning Method

A Dissertation

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1. INTRODUCTION

The adaptive control which adjusts the gain of PID controller according to the change in a system is used in order to control the speed of an electric forklift. Under this adaptive control, however, it is practically hard to make a due to complication of algorithm and any other reasons. Also the variable structure control is applied as a nonlinearity control but it may cause high frequency characteristics ignoring high speed modeling on a sliding surface[1].

In order to solve this problem a fuzzy controller under the genetic algorithm with self-tuning is applied, which will perform high efficiency speed control. The efficiency of control algorithm is presented through the experiments and compared with the quality of PID controller[2].

2. METHODS

2.1 DC series wound motor in transfer function

The DC series wound motor in an electric forklift needs huge force of traction, which steady-state speed is determined by friction and force of traction. And rated speed of the motor, the highest terminal voltage, is controlled in a uniform torque or current by regulating terminal voltage[3].

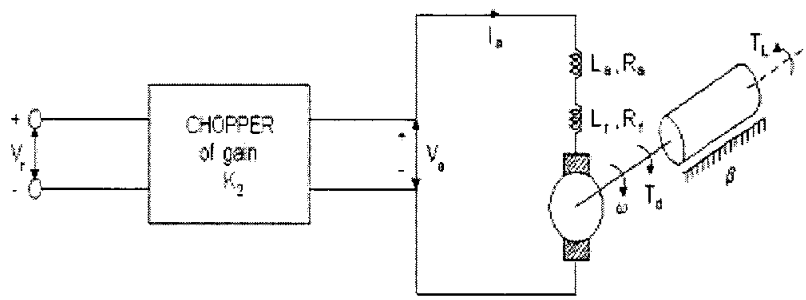


Fig. 1 Chopper-fed DC series motor drive

As Fig. 1 indicates, the terminal voltage is related with the standard voltage on chopper's linearity gain k_2. Supposing that k_v, electro motive force coefficient is fixed regardless of armature (or field) current, the DC series wound motor equation for motor system including load is induced as a formula,

$$V_a = K_2 V_r\ , \quad e_g = K_v i_a \omega$$

$$V_a = R_m i_a + L_m \frac{di_a}{dt} + e_g \qquad (1)$$

$$T_d = K_t i_a^2$$

$$T_d = J\frac{d\omega}{dt} + B\omega + T_L \qquad (2)$$

In the equation $T_d = k_t i_a^2$, it is characteristic of variable-type nonlinear, controller is designed on limited range of operation transforming the non-linear system into the linearity system on the purpose of applying transfer function. So define system parameters at operating point as follows,

$$e_g = E_{go} + \Delta e_g \quad , \quad i_a = I_{ao} + \Delta i_a$$

$$v_a = V_{ao} + \Delta v_a \quad , \quad T_d = T_{do} + \Delta T_d \qquad (3)$$

$$\omega = \omega_o + \Delta\omega \quad , \quad v_r = V_{ro} + \Delta v_r$$

$$T_L = T_{Lo} + \Delta T_L \qquad (4)$$

where, we can find that Δi_a, $\Delta\omega$ are entirely small.

The equation(2) from equation(1) can be linearization as follows.

$$\Delta v_a = K_2 \Delta v_r \quad \Delta e_g = K_v (I_{ao}\Delta\omega + \omega_o \Delta i_a) \qquad (5)$$

$$\Delta v_a = R_m i_a + L_m \frac{d(\Delta\omega)}{dt} + B\Delta e_g \qquad (6)$$

$$\Delta T_d = 2K_v I_{ao} \Delta I_a$$

$$\Delta T_d = J \frac{d(\Delta\omega)}{dt} + B\Delta\omega + \Delta T_L \tag{7}$$

Which are written in the transform of Laplace space as follows[3].

$$\Delta V_a(s) = K_2 \Delta V_r(s) \tag{8}$$

$$\Delta E_g(s) = K_v[I_{ao}\Delta\omega(s) + \omega_o \Delta I_a(s)] \tag{9}$$

$$\Delta V_a(s) = R_m \Delta I_a(s) + sL_m \Delta I_a(s) + \Delta E_g(s) \tag{10}$$

$$\Delta T_d(s) = 2K_v I_{ao} \Delta I_a(s) \tag{11}$$

$$\Delta T_d(s) = sJ\Delta\omega(s) + B\Delta\omega(s) + \Delta T_L(s) \tag{12}$$

Which mean that the change of either reference voltage or load torque is the change of the speed block diagram for the change of reference voltage and load torque is drawn in Fig. 2 and Fig. 3.

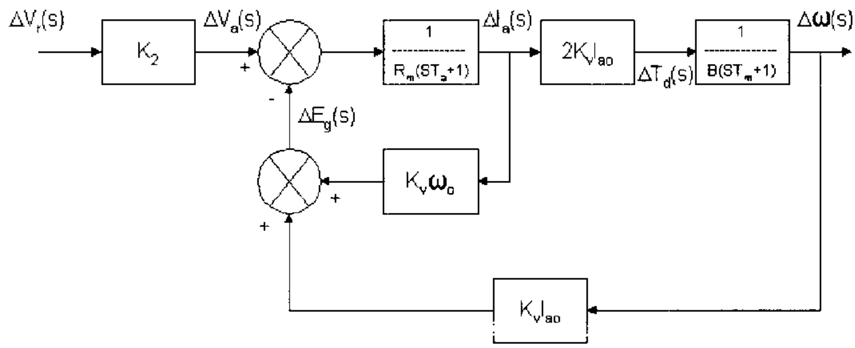


Fig. 2 Block diagram for reference voltage

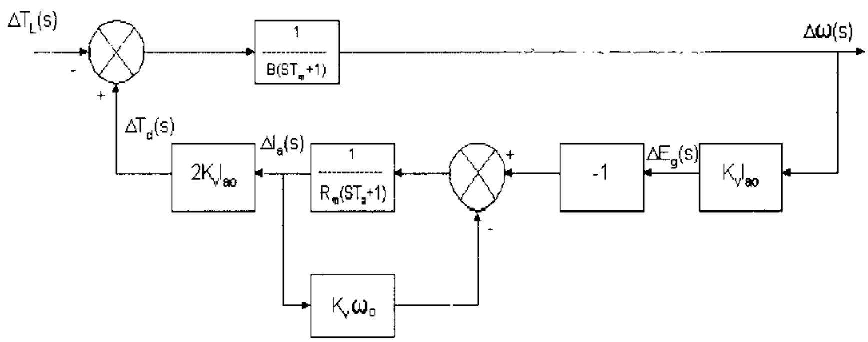
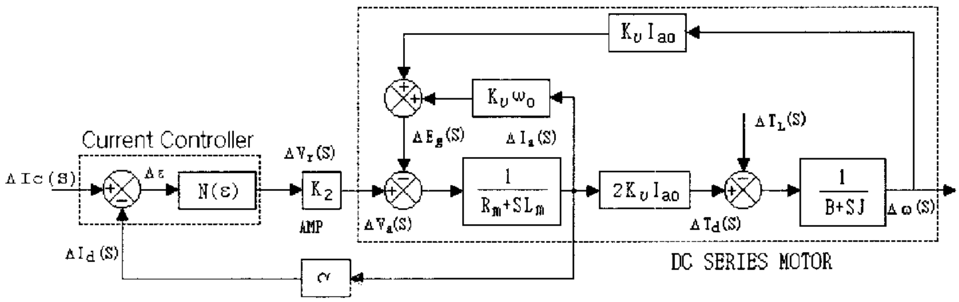


Fig. 3 Block diagram for load torque disturbances

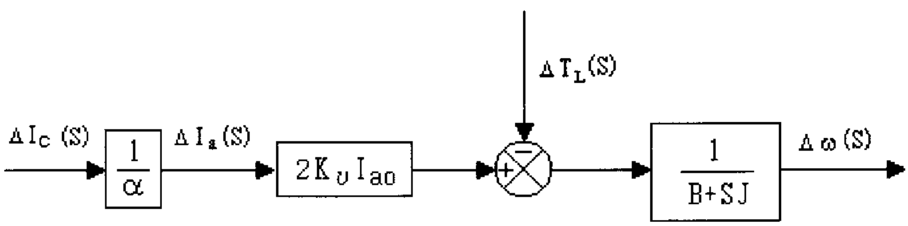
2.2 Current controller with closed transfer function

We can get the dynamic equation of an electric motor as Kirchhoff's voltage equation is applied to armature field system circuits and easily obtain the dynamic equation through Newton's dynamic laws that are applied to rotation machinery part as the electric and mechanical combined relation equation is applied to motor current and generation torque.

In section 2.1, the current sensor is connected to power circuit to convert closed-loop system into closed-loop system, so the output of sensor is amplified in proportion to supply current of rotor by α-factor and generates error voltage ($\Delta\varepsilon$) comparing it with current ($\Delta I_c(s)$)



(a) Block diagram of DC series wound motor



(b) Simple equation block diagram

Fig. 4 Closed-loop block diagram of DC series wound motor

(1) Let us solve that closed-loop step response (Δω(s)) caused change of reference current in the block diagram

$$\frac{\Delta\omega(s)}{\Delta I_c(s)}=\frac{N(\varepsilon)K_2 2K_v I_{ao}}{(R_m+sL_m)(B+sJ)+N(\varepsilon)K_2\alpha(B+sJ)+K_v\omega_o(B+sJ)+sK_v^2I_{ao}^2}$$

according to final value theorem

$$\lim_{s\to o}\frac{\Delta\omega(s)}{\Delta I_c(s)}=\frac{N(\varepsilon)K_2 2K_v I_{ao}}{(R_m B+N(\varepsilon)K_2\alpha B+K_v\omega_o B)}$$

(2)speed change in normal operating-Δω(s)

$$\lim_{s\to o}\frac{\Delta\omega(s)}{\Delta T_L(s)}=\frac{R+K_2N(\varepsilon)\alpha+K_v\omega_o}{B(R_m+K_2N(\varepsilon)+K_v\omega_o)+2K_v^2I_{ao}^2}$$

$$\frac{\Delta\omega(s)}{\Delta T_L(s)}=\frac{(R_m+sL_m)+K_2N(\varepsilon)\alpha+K_v\omega_o}{(B+Js)[(R_m+sL_m)+K_2N(\varepsilon)\alpha+K_v\omega_o]+2K_v^2I_{ao}^2}$$

2.3 Self-tuning of fuzzy controller using a genetic algorithm

Fig.5 shows total hardware diagram for tuning membership function of the fuzzy controller using a genetic algorithm. IBM PC tune membership function of the fuzzy controller using a genetic algorithm. 818 Lab card will transfer a signal. and the DSP board will control current[4, 5].

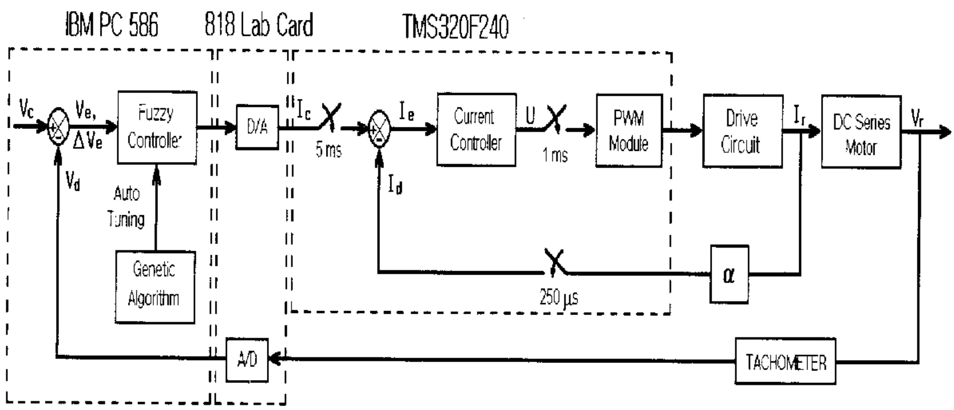


Fig. 5 Total hardware diagram for magnetic tuning fuzzy controller using PC

2.4 A genetic algorithm for self-tuning of membership function

2.4.1 Condition of a genetic algorithm

A genetic algorithm for self-tuning applied 7 levels to the flowchart of Fig.6, install basic coefficient, a population chrom-length is 12, 1 generation has 10 population. and will evolution for 50 generation. P-Cross is 80%, P-Mutation is 5%[6, 7].

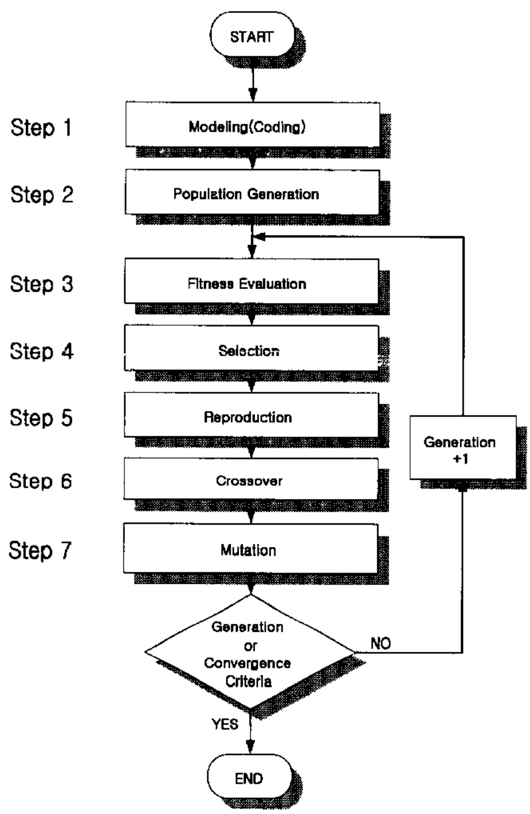


Fig. 6 Flowchart of genetic algorithm

2.4.2 Genetic structure initialization and Decoding

Fig. 7 is total 12 chromatins, and include every membership function of a population.

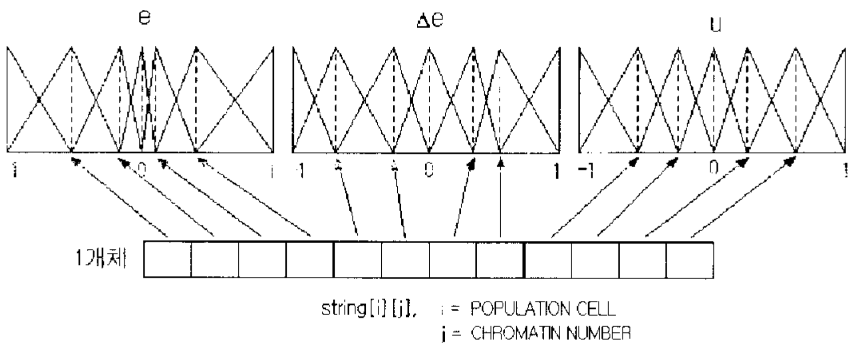


Fig. 7 Genetic structure of an individual

A decoding of membership function to adapt gene in the Fig. 7 to the fuzzy controller is as follows[8].

$$MemPt[i][j] = string[pop][k] \tag{13}$$

2.4.3 Result of tuning

Fig. 8 and 9 show growth, variety of compatibility when the above suggestion is applied to the system. In the figures, exact condition through the growth rate is the time reaching at 1.000 ~ 1.005 under the testing condition with reference speed 1500[rpm], load 100[A]

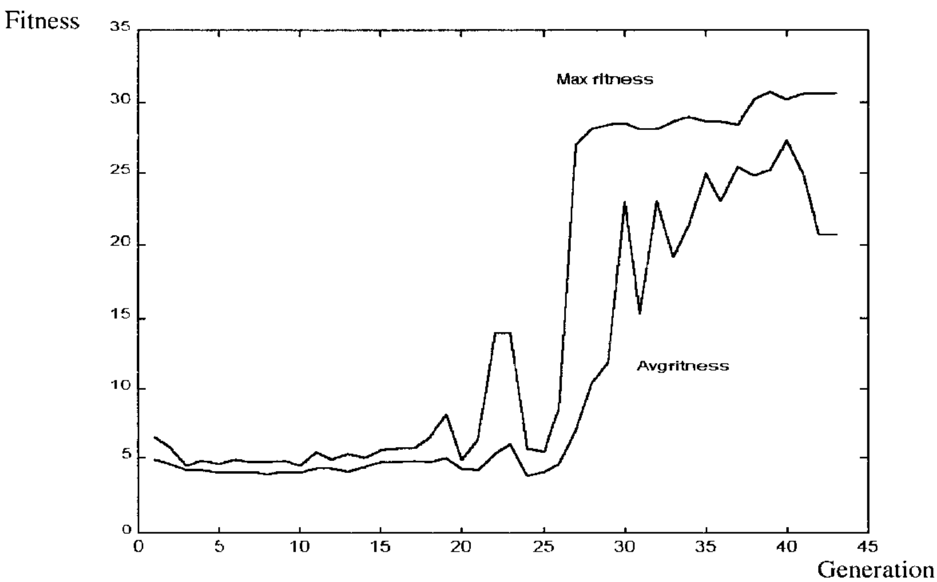


Fig. 8 Fitness variation

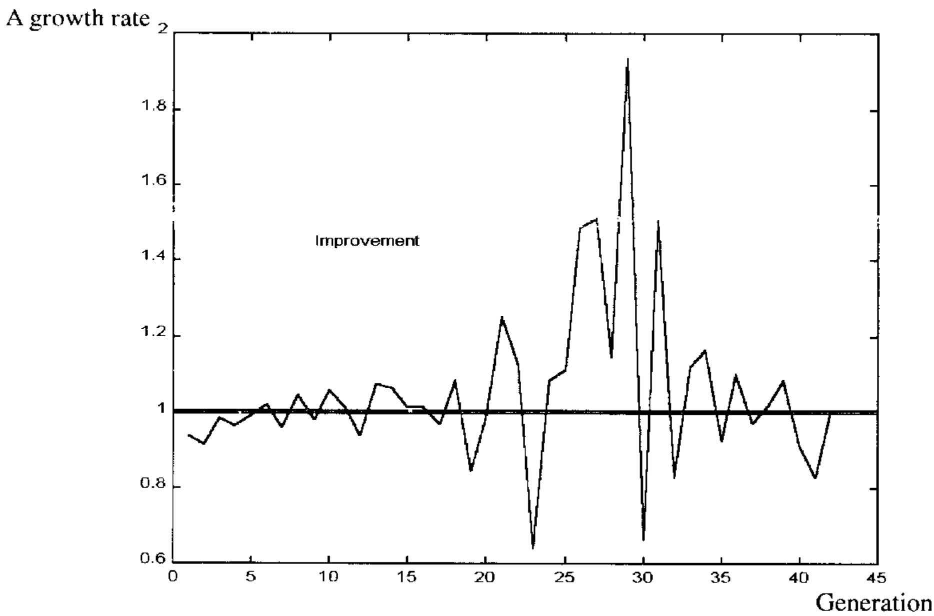


Fig. 9 Convergence at each generation

This result shows that growth rate is generally over 1 through the whole generation, converge at 42 generations. It means that output is better.

3. THE SPEED CONTROL OF DC SERIES WOUND MOTOR USING DSP (TMS320F240)

3.1 Configuration of total hardware

We use the PI current controller for internal loop to control the DC series wound motor as Fig. 10.

Configuration of hardware system shows in the Fig.11.

The internal loop is consist of the current controller, PWM, motor driver circuit and a current sensor. The external loop is consist of the speed controller, DC series wound motor, tachometer which is used as speed sensor.

As the Fig. 12, the speed controller changes current commend every 5 [ms]. Setups about interrupt, PWM follow the one of PI current controller[9, 10].

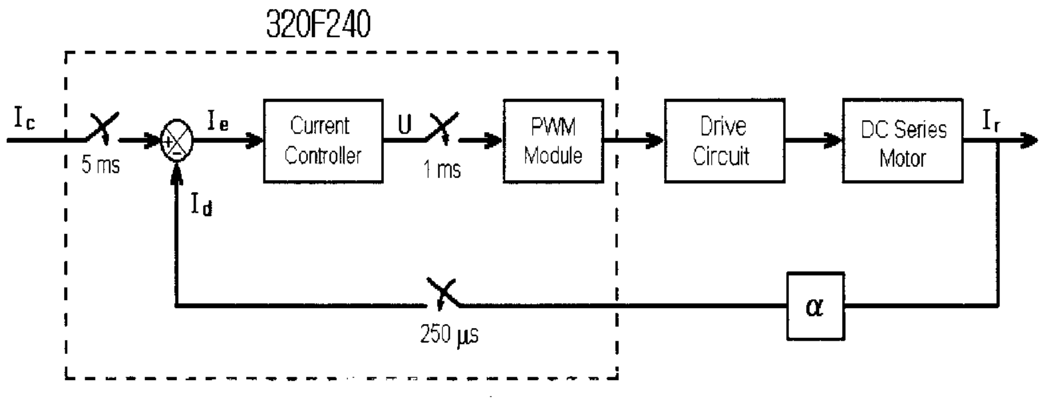


Fig. 10 Total hardware diagram for current control of real system

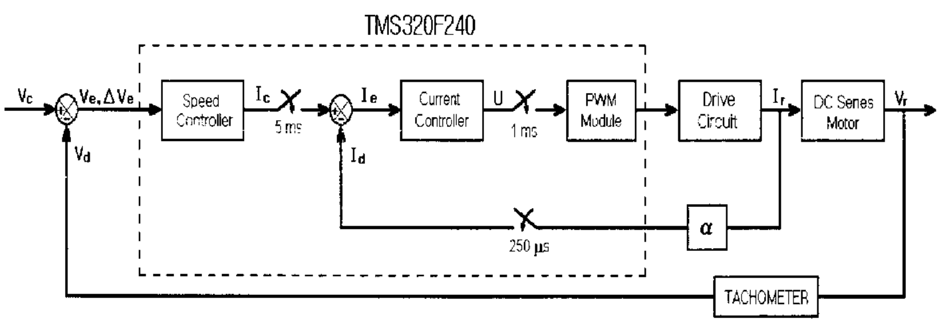


Fig. 11 Total hardware diagram for speed control of DC series wound motor

3.2 The speed control using PI controller

(1) The architecture of controller

It is possible to control speed with the PI controller substituting speed controller to the PI controller in the Fig. 12. The input value of speed control is the gap between reference speed command and feedback value from the tachometer. Out put value is current command from current controller which is internal loop. The equation used in the PI controller is equation(14)[10].

$$u = k_P \times e + k_I \times \int e \; dt$$

$$= k_P \times e + k_I \times \sum e \cdot \Delta t \qquad (14)$$

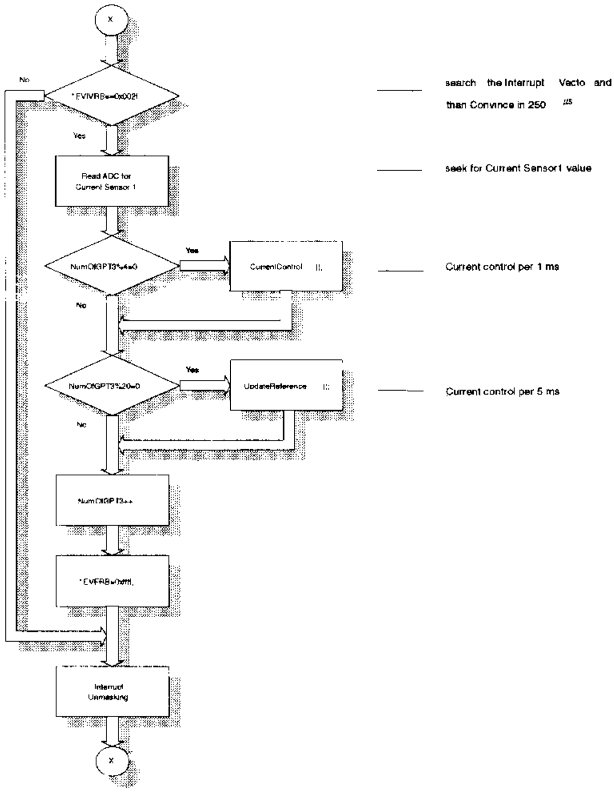


Fig. 12 Flow chart of 250[μs] interrupt subprogram

It is possible to remove the noise from the tachometer, a current sensor and a potentiometer by taking five simple moving mean value using speed information every 5[ms], current every 1ms and pedal every 1[ms].

The moving mean method correspond with digital low-pass filter and represented equation (15). If weight is uniform, it can be simple movement mean method[10].

$$y(i) = \frac{1}{w}\sum_{j=-m}^{0}\omega(j)x(i+j) \qquad (15)$$

(2) The control of PI speed controller gain

At the graph of test results, the speed response of the top side is that 1[V] shows 500[rpm] and the current of the low side means that 1[V] shows 100[A].

The current scale of downward oscilloscope Channel 2 means that 100[mV] represents 1[V/div]. It shows the load of the weight of electric forklift body concerning that Load becomes 100[A] and the 160[A] Load shows the load of weights of an electric forklift body and something loaded.

a) Response in changing a proportional gain

At Fig.13, the response is showed as K_p changes when speed command value K_I, K_p are equal to 1500[rpm], 1, 100[A] respectively.

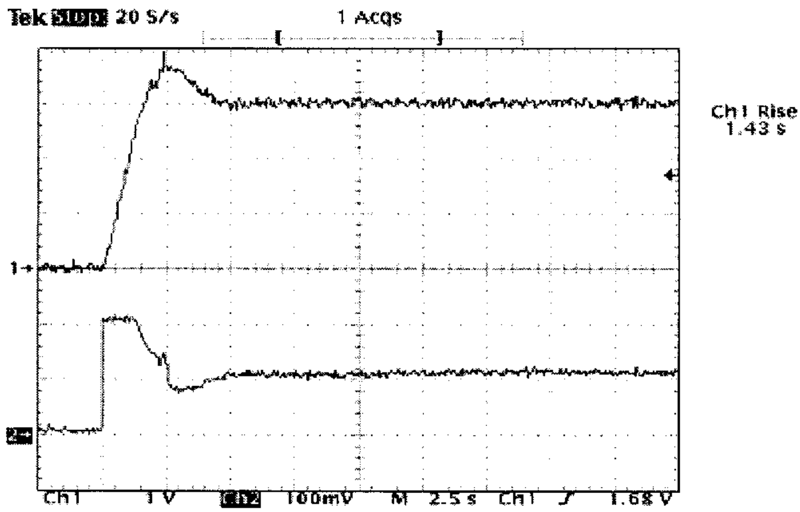
b) Response in changing an integral gain

Fig.14 shows response of changing K_I when speed command value is 1500[rpm], K_p is 5.0 and Load is 100[A].

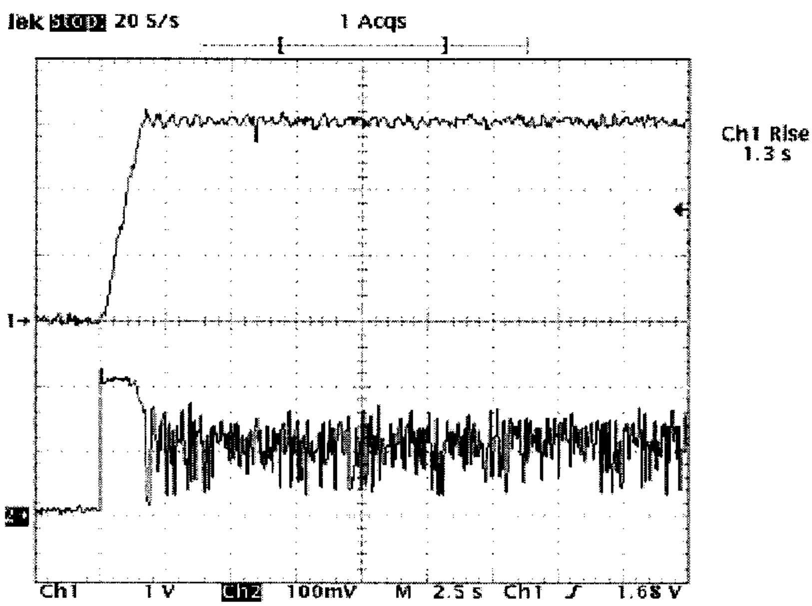
(3) Result of Test

When load's being kept at 100[A], Fig.15 shows the response of changing reference speed at $K_p = 5.0$, $K_I = 0.5$

Due to such limits, the wrong response appears like steady-state error and at asymptotic slope increases with keeping the load in 160[A].



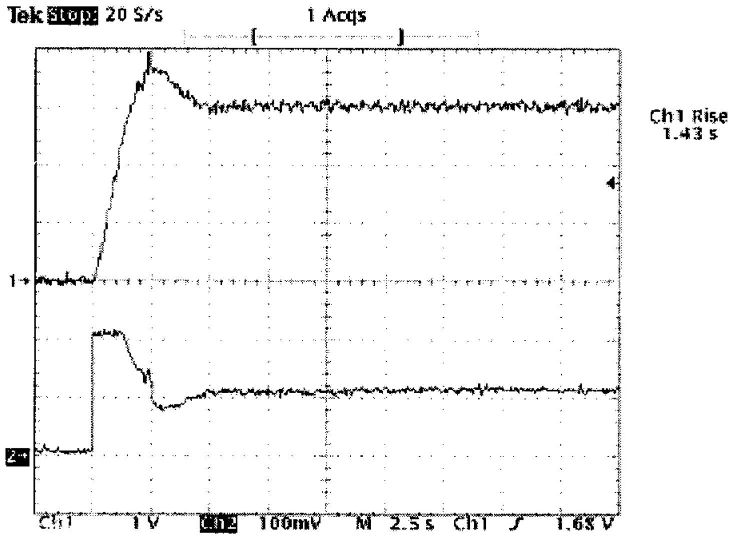
(a) $K_p = 1.0$



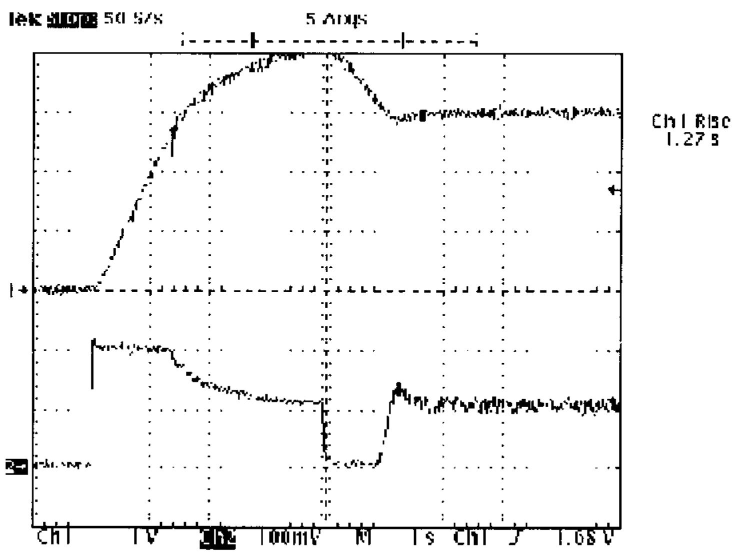
(b) $K_p = 20.0$

Fig. 13 Experiment results 1 of PI speed controller

($K_I = 1$, load 100[A], reference speed 1500[rpm])



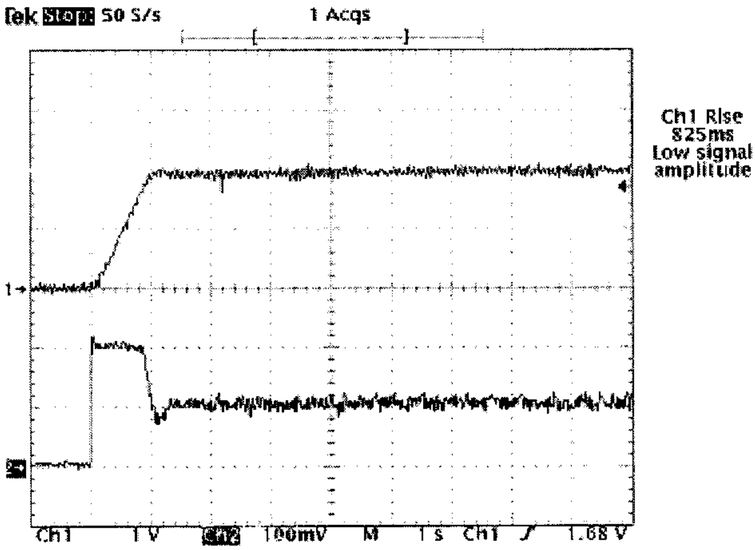
(a) $K_I = 0.1$



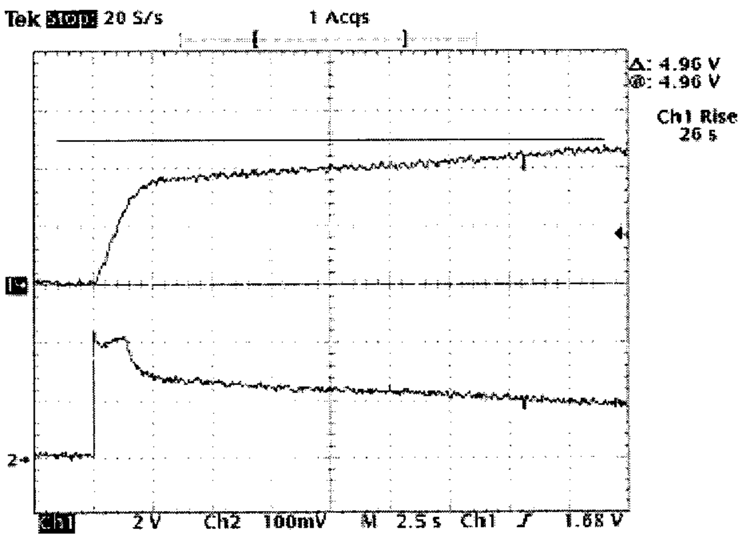
(b) $K_I = 4.0$

Fig. 14 Experiment results 2 of PI speed controller

($K_I = 1$, load 100[A], reference speed 1500[rpm])



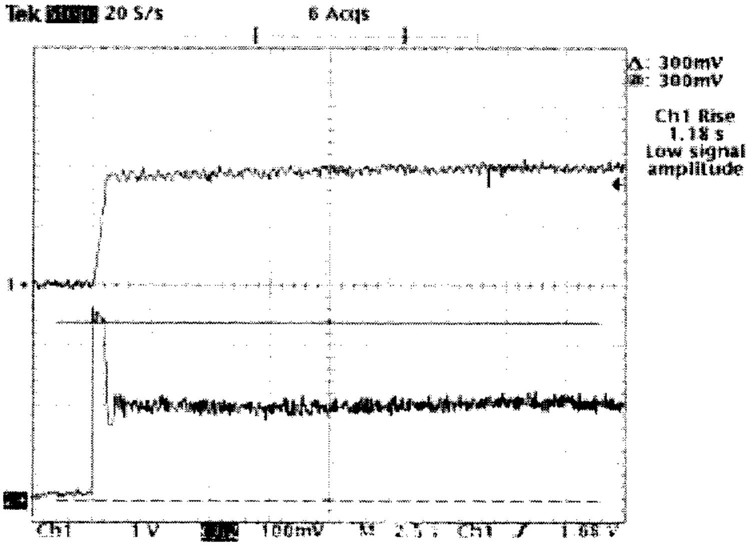
(a) Reference speed 1000[rpm]



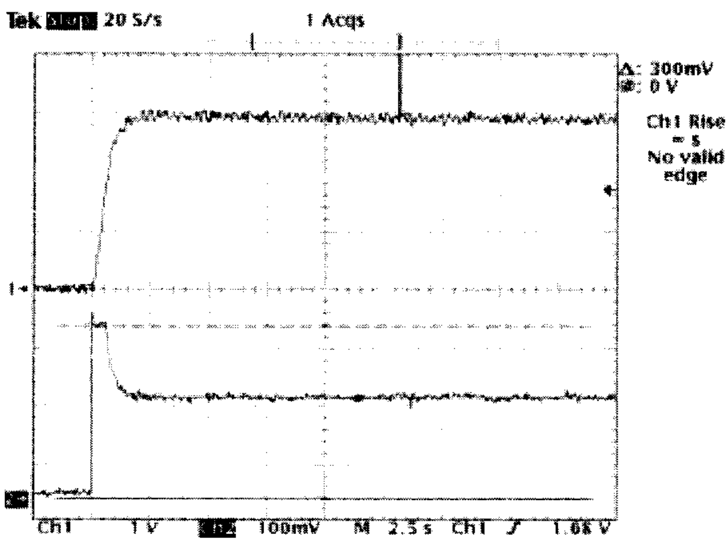
(b) Reference speed 2500[rpm]

Fig. 15 Experiment results of PI speed controller

when load 100[A] (max. 200[A])



(a) Reference speed 1000[rpm]



(b) Reference speed 2500[rpm]

Fig. 16 Experiment results of PI speed controller

when load 160[A] (max. 300[A])

3.3 Speed controller using fuzzy controller

3.3.1 Configuration of controller

We constitute the fussy controller from the speed controller in Fig. 11 for speed control. Inputs of fuzzy controller become the reference command value, the error and the change ratio of the feed-back speed value from tachometer, so output has the command value of reference current of current controller like initial loop[10].

3.3.2 Speed control of fussy controller of using tuned belonging function

As we consider the condition used for the fussy controller fussy rule uses the value in Table 1 based on phase plane and belonging function uses the value in Table 2 tuned by a genetic algorithm. Because all the belonging functions in Table 2 are normalized, we need scale values, so let's speed error scale, error change rate and output go to 0.5, 1.0 and 2.5 respectively. Here, speed error and error change rate mean 500[rpm] when they are 1.0 and output means 100[A] when it is 1.0.

Table 1 Table of 49 control rules

Δe \ e	NB	NM	NS	ZO	PS	PM	PB
NB	NB	NB	NB	NB	NM	NS	ZO
NM	NB	NB	NB	NM	NS	ZO	PS
NS	NB	NB	NM	NS	ZO	PS	PM
ZO	NB	NM	NS	ZO	PS	PM	PB
PS	NM	NS	ZO	PS	PM	PB	PB
PM	NS	ZO	PS	PM	PB	PB	PB
PB	ZO	PS	PM	PB	PB	PB	PB

Language Value

NB : Negative big, PS : Positive small

NM : Negative medium, PU : Positive medium

NS : Negative small, PB : Positive big

Table 2 Belonging function of tuning fuzzy controller

Kind	NB	NM	NS	ZO	PS	PM	PB
e	-1.00	-0.42	-0.08	0.00	0.03	0.21	1.00
Δe	-1.00	-0.61	-0.25	0.00	0.31	0.74	1.00
u	-1.00	-0.62	-0.35	0.00	0.32	0.57	1.00

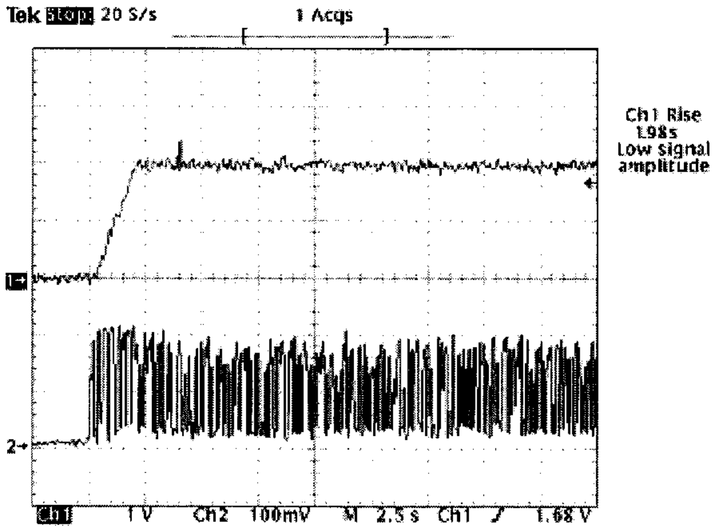
(1) Test when load 100[A]

a) Classification fuzzy controller

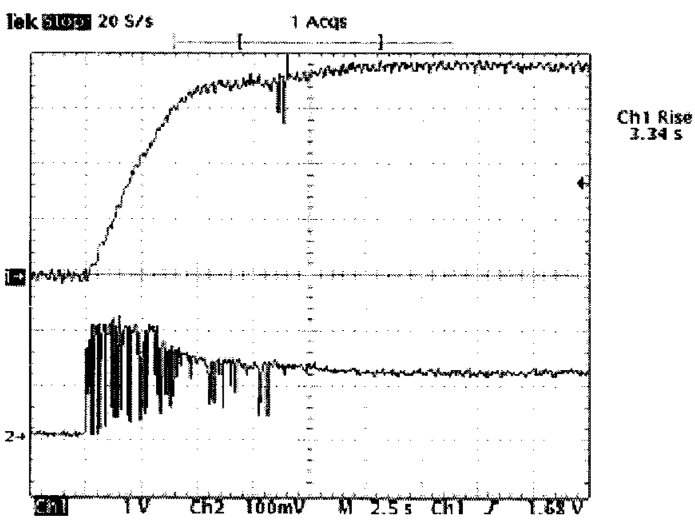
The result is showed in Fig. 17 when fussy controller with self-tuning belonging function is executed by a genetic algorithm and load is 100[A].

Here, the speed information is the value from five moving mean method every 5[ms] and we get error and error rate by using that. As the response, steady-state error doesn't occur at reference speed of 1000[rpm] and the asymptotic slope to steady state reaches zero[10].

But steady state error occurs at 2000 [rpm] because output fuzzy scale doesn't match.



(a) Reference speed 1000[rpm]

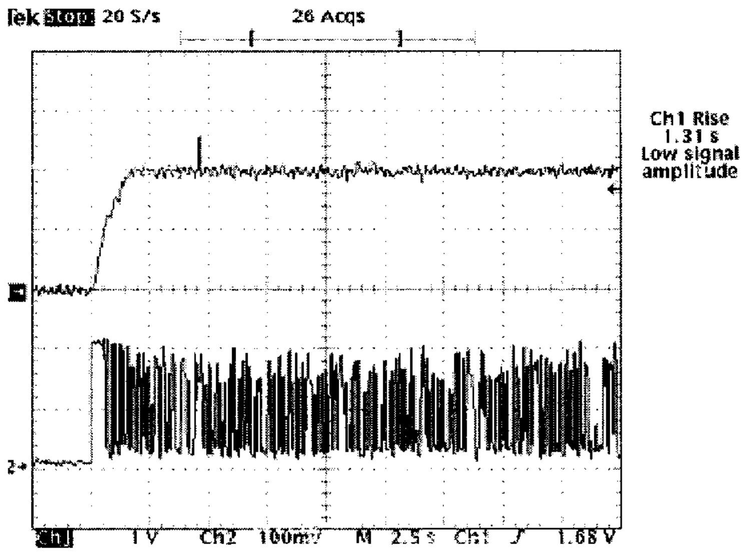


(b) Reference speed 2000[rpm]

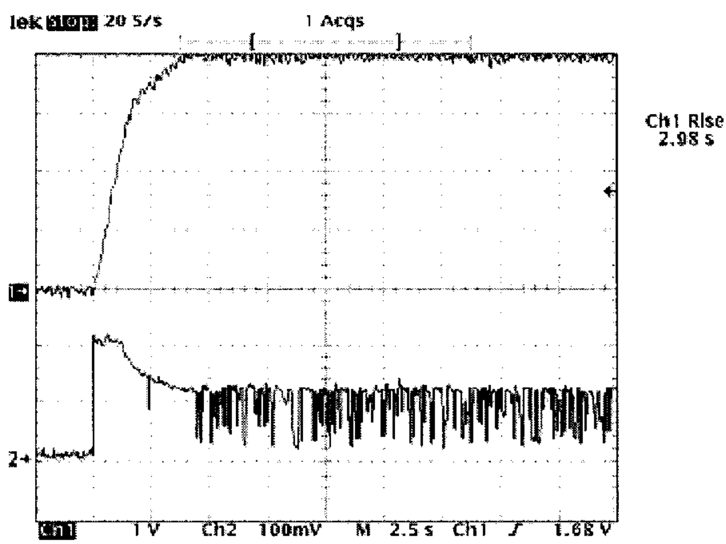
Fig. 17 Outputs of basic fuzzy controller (load 100[A])

b) The fuzzy controller using fuzzy singleton.

The fuzzy singleton generates ON-OFF signal not like general fuzzy group. The Fig. 18(a) shows that the quick response becomes slow because of using the fuzzy controller from the transition response. The Fig. 18(b) represent that the quick response time is improved comparing with existing the fuzzy controller and steady-state error, asymptotic slope disappear[10].



(a) Reference speed 1000[rpm]

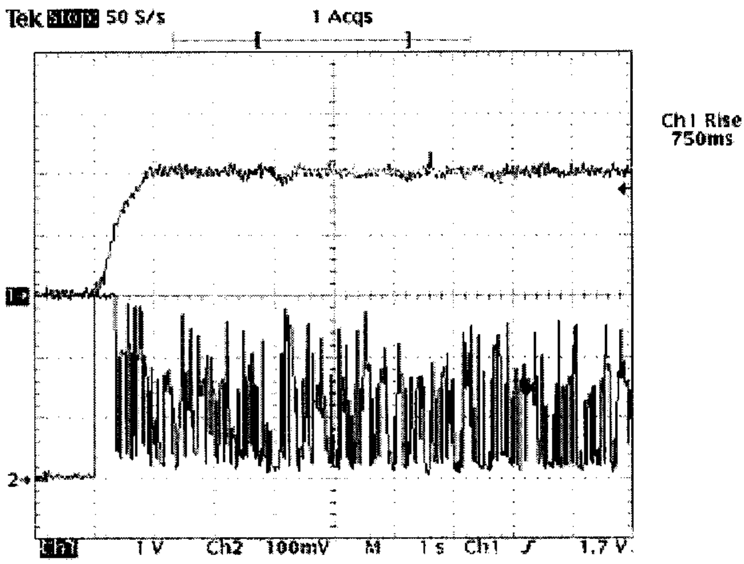


(b) Reference speed 2000[rpm]

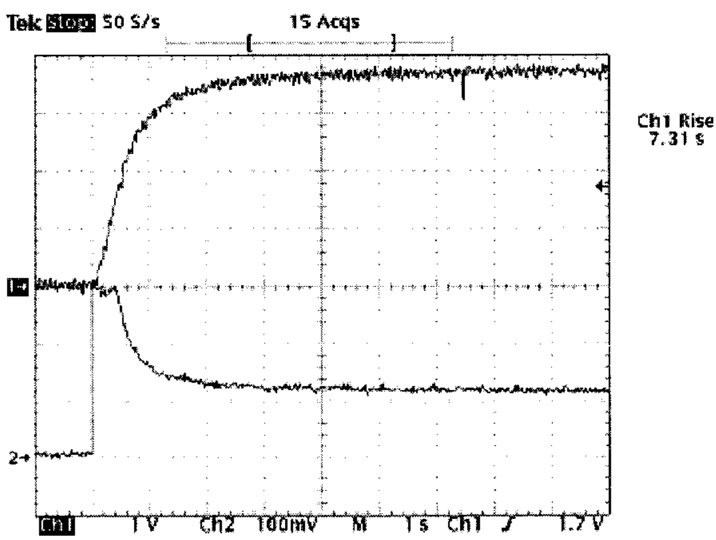
Fig. 18 Fuzzy controller output using fuzzy singleton (load 100[A])

c) Fuzzy controller using individual moving mean method.

We get speed error and error rate from five moving mean value every 5 [ms] using fuzzy singleton. Individual means taking five moving mean every 5 [ms] from the speed information and error rate every 1 [ms]. The speed error can be taken from the moving mean of speed information. As the response, quick response improves much at the reference speed 1000 [rpm] but the steady-state error occurs at 2000 [rpm]. because of not matching output fuzzy scale as the Fig. 19(a).



(a) Reference speed 1000[rpm]



(b) Reference speed 2000[rpm]

Fig. 19 Outputs of fuzzy controller using individual moving mean method (load 100[A])

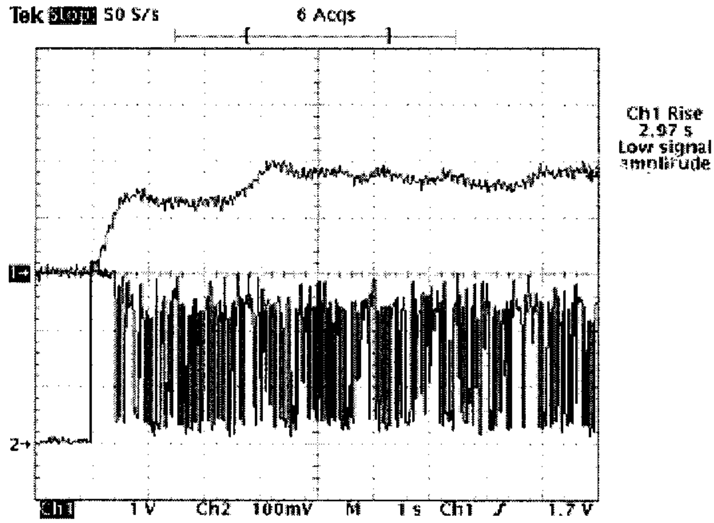
(2) The response following output scale at 160[A] load.

In this part, it shows response from other kind of digital filter after take all of fuzzy singleton.

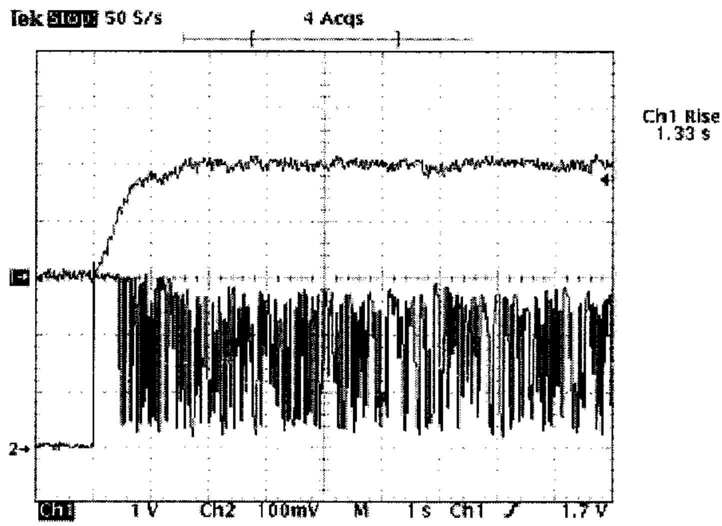
We examine the reference speed 1000 [rpm] following characteristics curve of motor because load is 160[A]. As a result, the speed response doesn't follow reference speed command when the output scale is 2.5 and steady-state error disappear as scale increase. But the respect of the quick response, it is worse over the specific scale value.

The Fig. 20 shows response of changing scale when the load is 160[A], the fuzzy controller is standard and the reference speed is 1000 [rpm].

The Fig. 21 shows the response of changing scale using the fuzzy controller with individual mean method when the load is 160[A], the reference speed is 1000 [rpm].



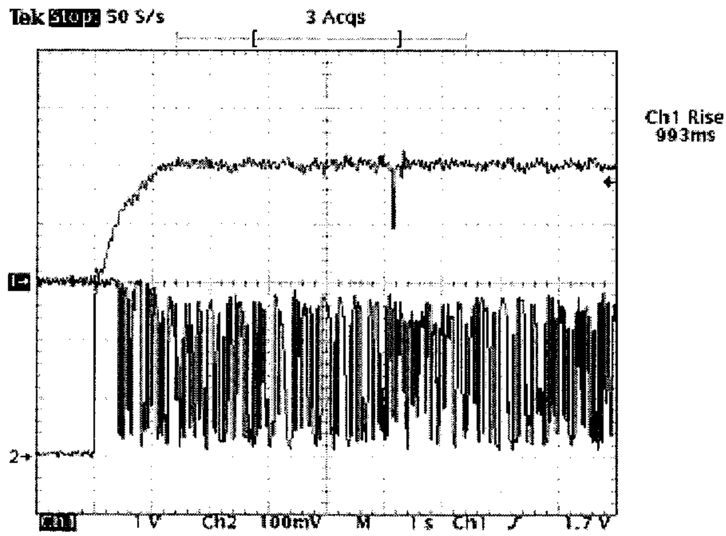
(a) Output scale = 2.5



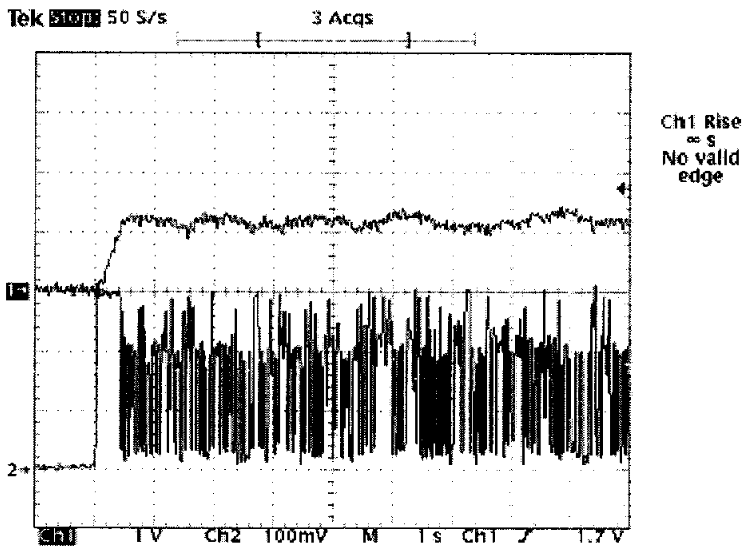
(b) Output scale = 7.0

Fig. 20 Outputs of basic fuzzy controller

(load 160[A], reference speed 1000[rpm])

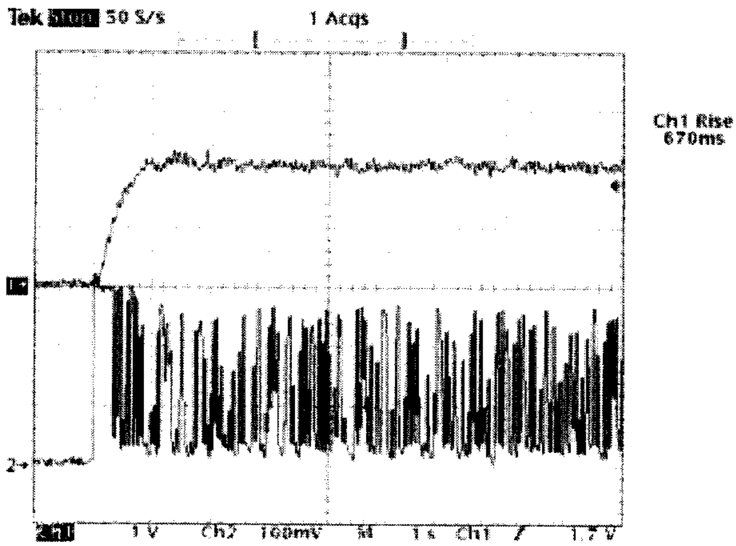


(a) Output scale = 2.5

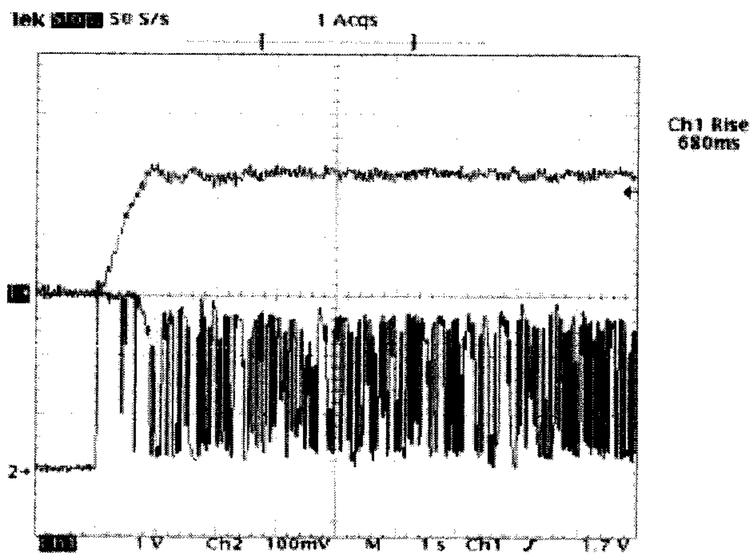


(b) Output scale = 7.0

Fig. 21 Outputs of fuzzy controller using individual moving mean method (load 160[A], reference speed 1000[rpm])



(a) load 100[A], reference speed 1000[rpm]



(b) load 160[A], reference speed 1000[rpm]

Fig. 22 Responses of fuzzy controller using individual moving method

4. RESULT

When load changes, the fuzzy controller didn't need tuned belonging function to be recontrolled and met with the change of the load only as controlling output scale.

The fuzzy controller influences the change rate of error as noise exists in speed feedback, so current ripple occurs. In this paper, we apply the simple moving mean method and the individual moving mean method to decrease the effect of the noise. The result shows that the individual moving mean method is most effective performance. We need more study of the PI type fuzzy controller to decrease current ripple occurring at the fuzzy controller[10].

Table 3 is comparison of PI controller response(Fig. 15(a), Fig. 16(a)) when reference speed is 1000[rpm], the load is 100[A]. It shows the fuzzy controller is better quick response and characteristics of steady-state than the PI controller.

Table 3 Result comparison of PI control and fuzzy

(reference speed 1000[rpm])

Controller / Function	PI controller		Fuzzy controller	
	100 [A]	160 [A]	100 [A]	160 [A]
Rising time(sec)	0.825	1.18	0.670	0.680
steady State error(rpm)	20	50	0	0
asymptotic slope rate(rpm/sec)	0	3.63	0	0

5. REFERENCE

[1] Y. F. Li and C. C. Lau, "Development of fuzzy algorithm for servo systems," *IEEE Control System Magazine*, pp. 65-71, April. 1989

[2] G. C. D. Sousa and B. K. Bose, "A fuzzy set theory based control of a phase controlled converter DC machine drive," *Conf. Rec, IEEE IAS Ann. Meeting*, pp. 854-861, October, 1991

[3] Sang-Rae Lee and Kwang-Won Lee, "A new variable structure position control for DC motor using fuzzy logic," *KIEE Trans*, Vol. 41, No. 6, pp. 625-632, 1992

[4] *TMS320C24X DSP Controllers Reference Set-Volume 1*, Texas Instruments, 1997

[5] *TMS320C24X DSP Controllers Reference Set-Volume 2*, Texas Instruments, 1997

[6] Chae-suk, Young-Sik Oh, *Fuzzy Theory and Control*, Chung Moon Kag, 1995

[7] Rainer Palm, Dimiter Driankov, Hans Hellendoorn, *Model Based Fuzzy Control*, Springer, 1997

[8] David B. fogel, *Evolutionary Computation*, IEEE PRESS, 1995

[9] Dimiter Driankov, Hans Hellendoorn, Michael Reinfrank, *An Introduction to Fuzzy Control*, Springer, 1996

[10] B. Kosko, *Neural Networks and Fuzzy Systems*, Prentice Hall, 1992

[11] *TMS320C2x/C2xx/C5x Optimizing C Compiler-User's Guide*, Texas Instrument, 1995

[12] *TMS320C5x C Source Debugger-User's Guide*, Texas Instrument, 1994

[13] *TMS320C1x/C2x/C2xx/C5x Assembly Language Tools-User's Guide*, Texas Instrument, 1995

유전알고리즘의 자기동조 방법에 의한 DC 모터 속도제어

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요 약

일반적으로, 전동지개자의 속도제어를 위하여는 PID 제어기의 이득을 시스템 변화에 따라 조정하는 적응 제어 방법이 사용하고 있으나 알고리즘의 복잡성 및 여러 가지 이유로 인하여 실제로 원활한 제어기를 구현하기가 힘든 단점을 가지고 있다. 또한 비선형제어 방법으로 가변구조제어(Variable Structure Control)방법이 사용되고 있으나 슬라이딩 평면에서 고속 모델링이 무시되었던 고주파 동특성을 야기시킬 수 있는 문제점을 가지고 있다.

이러한 문제점을 해결하기 위하여 유전알고리즘(Genetic Algorithm)에 의한 자기동조(Self-tuning) 방법을 도입하여 퍼지 제어기에 적용하고 유전알고리즘의 속도제어 적용에 대한 고효율성의 제어가 가능하다는 것을 실험을 통하여 제어 알고리즘 성능평가와 기존의 PI 제어기와의 성능비교를 나타내었다.

감 사 의 글

오늘의 결실이 있기까지 저의 부족한 점을 감싸주시고 세심한 배려와 아낌 없는 충고로 논문을 지도 해주신 배종일 지도교수님께 깊은 감사를 드립니다. 그리고 심사위원장을 맡아주시고 인자하신 충고와 아낌없는 지도를 해주신 이동철 교수님께 깊은 감사를 드립니다. 그리고 본 논문이 완성되기까지 성심 성의껏 심사해 주시고 좋은 논문이 되도록 지도해주신 조봉관 교수님께도 깊은 감사를 드립니다.

또한, 어렵고 힘이 들 때마다 늘 힘이 되어준 대학원 동기 정동훈과 김성훈에게 고마움을 전하고, 실험실에서 갖은 잡무를 다 맡아서 수고 하여준 김영훈에게 깊은 고마움을 전합니다. 그리고 실험실에서 든든한 응원자가 되어준 이재철, 손동완, 한성호, 이병호에게도 고마움을 느낍니다.

오늘의 영광이 있기까지 늘 언제나 든든한 버팀목으로 되어주신 아버지, 그리고 늘 언제나 헌신하며 자상한 격려와 용기를 불어 넣어 주신 어머니께 이 영광을 돌리고자 합니다. 그리고 늘 언제나 동생의 선택을 믿고 든든한 지원자가 되어주신 형님과 형수님께도 이 영광을 돌립니다.

끝으로, 다년간의 수학을 한 권의 책으로 마무리 지으며, 새로운 도약의 계기로 삼고자 합니다.

2003. 12. 5

제 창 우 올림