Proceedings of the Fifth IASTED International Conference
POWER AND ENERGY SYSTEMS
June 15-17, 2005, Benalmádena, Spain

SCALE FACTOR SELF TUNING FUZZY CONTROLLER

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Abstract
This paper presents a scale factor self tuning fuzzy controller (SFFC) which applies for separately excited d.c. motor speed controller. The objective is to build a scale factor self tuning Fuzzy controller for d.c. motor speed control. The advantages of using fuzzy controller are to acquire the optimal scale factor from each motor without testing the electrical and mechanical parameters and the transfer function of d.c. motor. The value of scaling factor self tuning is evaluated during the iterative operation. The performance of speed response is evaluated and create the new scale factor to use in the next loop until the optimal scale factor obtained. For the experimental results, the proposed method has been tested with a 1 kw. separately excited d.c. motor for both step response and various step loads.

Key Words
scale factor self tuning fuzzy controller (SFFC), separately excited d.c. motor.

1. Introduction

Fuzzy controller is most widely applied to many works especially the non linear complex system. From the previous works, fuzzy controller is used in data base for decision making and the scaling factor fuzzy controller is developed to adjust the parameters of the fuzzy controller. There are several ways to develop fuzzy controller as the self tuning fuzzy controller [1-2] namely, the hierarchical fuzzy system [3] and the sliding mode fuzzy controller [4].

This paper presents the scale factor self tuning fuzzy controller with the application for speed control of the medium size d.c. motor. We utilize a simple principle and easy to implementation method of fuzzy controller to find the optimal scaling factor from each motor without having to test both electrical parameter and mechanical parameter, and also to decrease the starting current.

The fuzzy controller structure has simple component and mathematic model. The scaling factor is obtained from the fuzzy IF-THEN rules: 1) between the error in the speed response's overshoot and the error in scale factor and 2) between the change of error in the speed response's overshoot and the change of error in scale factor.

2. The structure of SFFC

The structure of SFFC consists of the followings [5-6]**:**

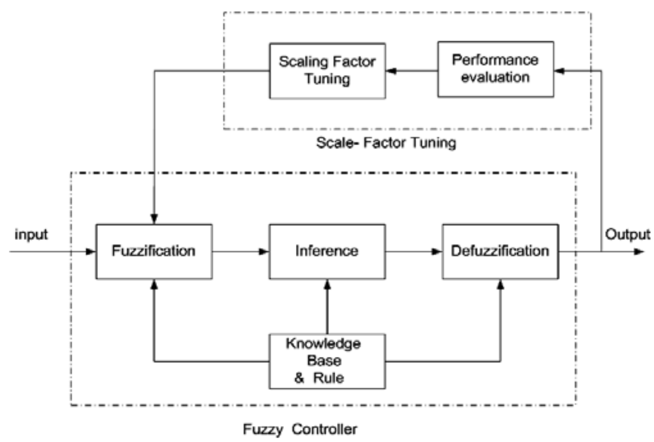


Fig. 1. The structure of SFFC

2.1. Fuzzy Controller

The PI fuzzy controller is applied in the form of fuzzy rules. There are two inputs, e(k),ce(k) and one output, u(k), in which **:**

$$e(k) = setpoint - y(k) \quad (1)$$
$$ce(k) = e(k) - e(k-1) \quad (2)$$
$$u(k) = u(k-1) + \Delta u(k) \quad (3)$$

where

e(k) = motor speed error,
ce(k) = change of error,
$\Delta u(k)$ = change output in the k^{th} loop

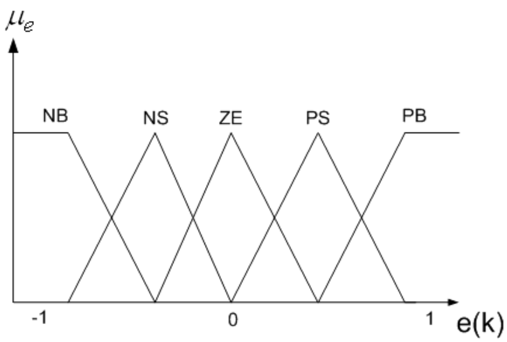
The fuzzy control rule is in the form:

IF e(k) is antecedent AND ce(k) is antecedent
THEN $\Delta u(k)$ is consequent

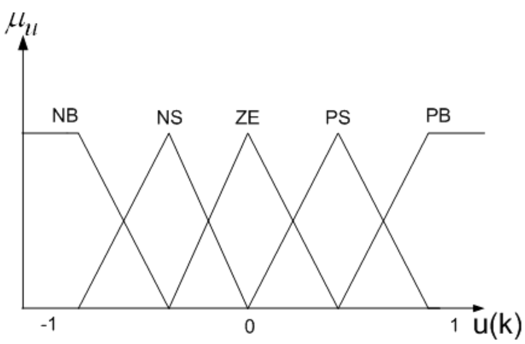
The basic fuzzy logic controller has three components which are fuzzification, fuzzy rule, and defuzzification.

2.1.1. Fuzzification

The input variable e(k), ce(k) and u(k) are converted to the corresponding fuzzy linguistic term as follows: PB = Positive, PS = Positive Small, ZE = Zero NS = Negative Small, and NB = Negative Big, see Fig. 2.



(a.)



(b.)

Fig. 2. (a) The membership function of input (e(k), ce(k)) The membership function of output (u(k))

2.1.2. Fuzzy Rule

Table 1 is the 25 fuzzy rules to control the excitation voltage which can be interpreted. For example:

IF e(k) is NS AND ce(k) is PS THEN $\Delta u(k)$ is ZE

Table 1. Fuzzy controller rules.

ce \ e	NB	NS	ZE	PS	PB
NB	PB	PB	PS	PS	ZE
NS	PB	PS	PS	ZE	NS
ZE	PS	PS	ZE	NS	NS
PS	PS	ZE	NS	NS	NB
PB	ZE	NS	NS	NB	NB

2.1.3. Defuzzification

The objective of the defuzzification is to convert the inferred fuzzy control action into the required crisp value which controls the excitation voltage. The Center of Gravity is used as defuzzification method.[7]

$$\Delta u(k) = \frac{\sum_{r=1}^{m} \bar{y}_r \left[\prod_{i=1}^{n} \mu_i(\Delta u(k))\right]}{\sum_{r=1}^{m} \left[\prod_{i=1}^{n} \mu_i(\Delta u(k))\right]} \qquad (4)$$

where $\bar{y}_r$ = averages crisp value of r^{th} rule,
$\mu_i(\Delta u(k))$ = degree of membership function.

2.2 Scale Factor Tuning

2.2.1. Performance Evaluation

The speed outputare measured and evaluated by comparison with desired value. In our case, we use only overshoot (OV) as a performance measure.

$$\Delta OV = OV - OV_{desired} \qquad (5)$$

where

ΔOV = speed overshoot error,
OV = speed overshoot measured, and
$OV_{desired}$ = speed overshoot desired.

The membership function of overshoot (OV) is divided into 3 terms (see Fig. 4): N = negative, Z = zero, and P = positive.

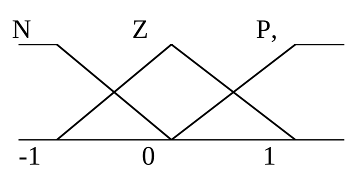


Fig. 4. The membership function of OV, ΔOV, ΔS_e, and ΔS_{ce}.

2.2.2. Scale Factor Tuning Rules

The rules for adjusting the scale factor of speed error (Δs_e) are :

IF OV is P THEN Δs_e is P
IF OV is Z THEN Δs_e is Z
IF OV is N THEN Δs_e is N

The rules for modification the scale factor of change in speed error (Δs_{ce}) are:

IF ΔOV(T) - ΔOV(T-1) is P THEN Δs_{ce} is P
IF ΔOV(T) - ΔOV(T-1) is Z THEN Δs_{ce} is Z
IF ΔOV(T) - ΔOV(T-1) is N THEN Δs_{ce} is N

$$s_e(T+1) = s_e(T-1) + \Delta s_e(T) \quad (6)$$

$$s_{ce}(T+1) = s_{ce}(T-1) + \Delta s_{ce}(T) \quad (7)$$

where

$s_e(T+1)$ = current scale factor of speed error,
$s_{ce}(T+1)$ = current scale factor of change in speed error,
$s_e(T-1)$ = Previous scale factor of speed error, and
T = period of iteration.

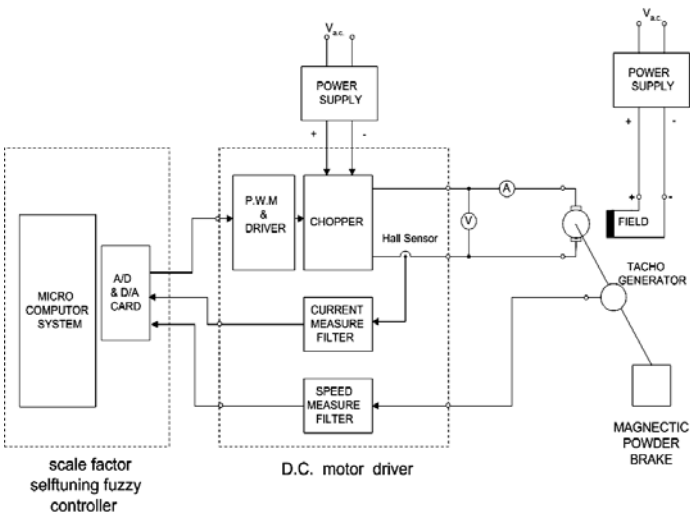


Fig. 5. The d.c. motor speed control by SFFC

3. The experimental results

There are three cases of experiments; find the optimal scale factor, test of step response of motor speed, and step load. Fig. 5 shows a separately excited d.c. motor speed control by SFFC. Some of the specification are:

1 D.C. shunt wound motor separately excited: 220 volt, 1kW. , 6.2 Amp., rated speed 2000 r.p.m.
2. Tachogenerator: a.c. tacho generator 10 volt, 1.5 watt, 6000 r.p.m.
3. Mechanic Brake - Magnetic Powder Brake.
4. D.C. power supply for armature circuits 2 kw. 220 volt; D.C. power supply for excited circuit: 500 w. 220 volt.
5. Digital storage oscilloscope : 150 MHz.

Detail of experiment are as follows:

3.1. Initialize the scale factor with large value to provide a slow speed response while the parameters of the motor are unknown. This is because if the fuzzy controller operate fast in the initial state, the motor will start operating fast too resulting in high starting current. 3.2. Define the desired overshoot of speed response which in this paper is limited within 5-6 % of the speed set point. 3.3. Test the control motor by operating in short period (approximately 10 seconds) of 7 iterations. The SFFC evaluates the speed response and modifies the scale factor in order to obtain the measured overshoot below the desired overshoot. Fig. 6 shows the speed response of d.c. motor in 7 iterations and the corresponding relation between RT (rise time) and OV (overshoot) in Table 2.The overshoot of speed response is increasing gradually which the last value is 5.04 %. And the scale factor of speed error, and the scale factor of change in speed error for 7 iterations are shown in Table 3. As seen, the scale factor decreases then sensitivity of controller increases. Finally, this scale factor will be used in the next step for the test of step response of speed and step load response.

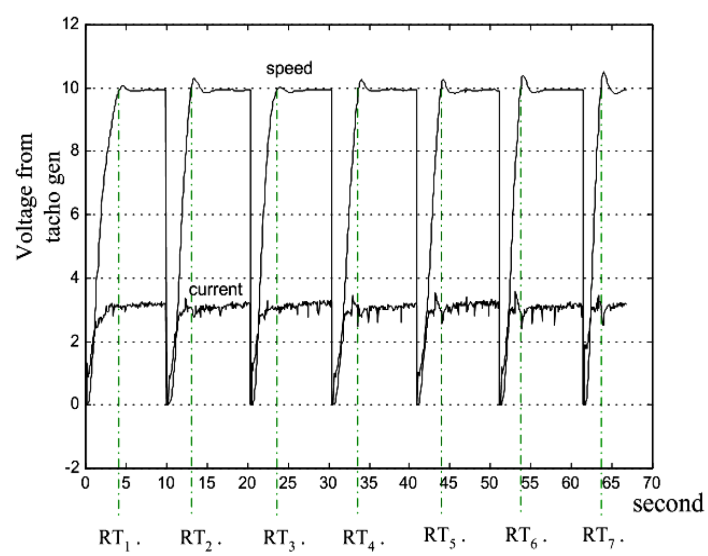


Fig. 6. The result of scale factor self tuning 7 iteration

Table 2. The OV and RT for 7 iteration where RT = rise time(sec.) and OV = overshoot of speed response.

RT_1	RT_2	RT_3	RT_4	RT_5	RT_6	RT_7
4.29	3.02	3.35	3.19	3.02	2.64	2.03
OV_1	OV_2	OV_3	OV_4	OV_5	OV_6	OV_7

0.8	3.04	0.48	2,56	2.8	4.16	5.04

Table 3. The scale factor of speed error, and the scale factor of change in speed error for 7 iterations.

Se_1	Se_2	Se_3	Se_4	Se_5	Se_6	Se_7
5	4.2	4.35	4.2	3.7	2.9	2.85
Sce_1	Sce_2	Sce_3	Sce_4	Sce_5	Sce_6	Sce_7
1	0.92	0.9	0.82	0.78	0.7	0.66

3.4. Next, operate the step response of speed at 1500 rpm. Then, measure the speed response from tacho generator and armature current by digital storage scope (with the scale 1 volt/DIV and 2 sec./DIV). In Fig. 7,

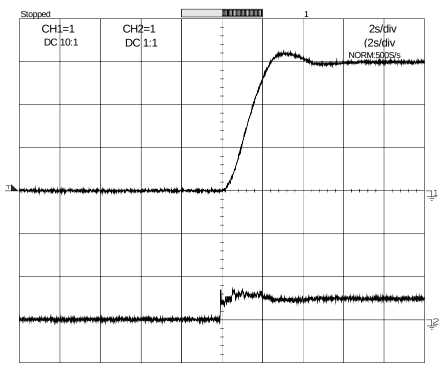


Fig. 7. Step response of speed at 1500 r.p.m.

the overshoot is not over 5 % and also the starting current is low.

3.5. Repeat the experiment in 3.4 in order to confirm the optimum scale factor, which is shown in Fig. 8.

3.6.Test the step load by 50 % and 100 % of motor capacity. Fig. 9 and Fig. 10 show speed response of the motor while taking and releasing mechanical load at 50 % and 100 % respectively. The result shows the motor is in speed regulation condition when mechanical load is taking rapidly.

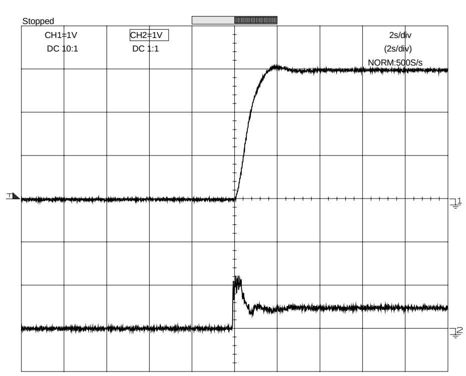


Fig. 8. step response of speed.

3.6. Next experiment is to test the step load in 50% and 100% of rated of motor. As seen in figure 9, 10 the speed response of motor while taking and releasing load.

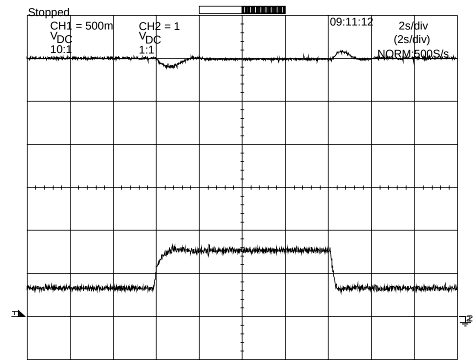


Fig. 9. Step load at 50 % of motor capacity.

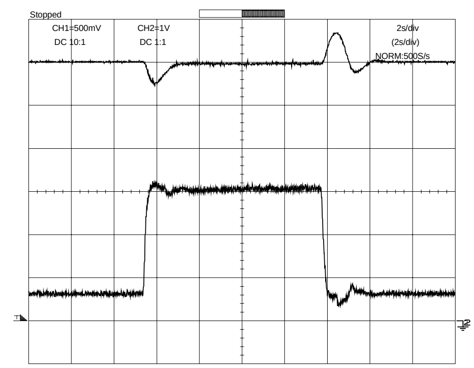


Fig. 10. Step load at 100 % of motor capacity.

4. Conclusion

The result of experiment shows the scale factor self tuning which can find the optimal scale factor by operation approximately 7 iterations. Also, the performance of step response of motor speed and step load are satisfactory. The advantage of SFFC is ultilized for the separately excited d.c. motor speed controller without knowing the motor parameters in comparison with conventional controller. This proposed method is simply and not complicated. And can apply to variation of motor sizes.

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