FUZZY-PID BASED PERFORMANCE ANALYSIS OF DC MOTOR

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Abstract: In this paper, a comparative performance analysis is worked out between fuzzy and conventional PID based control systems for dc motor. Initially, separately-excited dc motor is mathematically modelled. Then, fuzzy logic controller is used to control the speed of separately-excited dc motor. The rule-based fuzzy logic controller does this by armature voltage speed control method of dc motor. The controller and motor system is simulated in MATLAB/SIMULINK. The FLC is designed by using the difference of reference speed and actual speed i.e. the error as an input and rate of change of error as another input. The membership function and rule-base are used to generate the control signal as output of controller in such a way so as to reduce the error. This control signal varies the armature voltage of the dc motor so that motor runs at desired or reference speed input. Secondly, PID controller is used to perform the action of speed control. PID controller is also simulated on SIMULINK/MATLAB and its parameter values i.e. proportional, integral and derivative gains are tuned so as to get the required control signal which can maintain the dc motor speed according to the reference speed input variations. The simulation results obtained from both fuzzy and PID controllers are studied and compared. The response of dc motor to the variations in reference speed was observed & compared based on certain parameters such as overshoot, less settling time, etc.

1. Introduction

PID (proportional integral derivative) control scheme is one of the earlier control strategies. Earlier it was implemented in pneumatic devices, followed by vacuum and solid state analog electronics, before arriving at today's digital implementation of microprocessors. Although being a simple control strategy, it gives satisfactory results. Due to its this simplicity and satisfactory performance it has been widely used in industrial applications as a process controller. If the PID parameters are tuned properly they provide robust and reliable performance for most systems[2].However, PID controllers suffer from certain limitations as they require exact mathematical modelling of the plant to control the process. But for many systems it is not possible to define exact mathematical model as certain approximations are made to arrive at mathematical model. Due to these deviations from exact model, PID controllers are not able to give desired performance as their performance deteriorates.[3]-[5] Also it is not possible to use PID controllers in non-linear system. Hence for such systems, fuzzy logic was introduced by L.A. Zadeh in 1973. A new type of controller called fuzzy logic controller used the same fuzzy logic to control the process. They are able to overcome the limitations of PID controller as fuzzy controller is able to precisely and quickly follow the changes in reference speed with minimum overshoot and minimum steady-state error.[8]

2. Mathematical Model of DC Motor

In armature voltage control scheme for separately excited dc motors, voltage applied to armature is varied without varying the voltage applied to the field. Equivalent model of dc motor is shown in following figure..

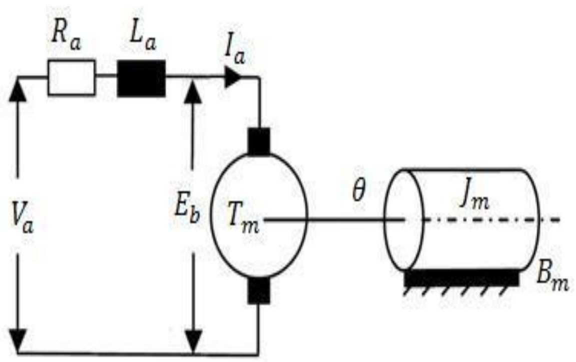

Fig. 1: DC motor model

$$v_a = R_a . i_a(t) + L_a . \frac{di_a(t)}{dt} + e_b(t) \quad (1)$$

$$e_b(t) = K_b . w(t) \quad (2)$$

$$T_m(t) = K_t . i_a(t) \quad (3)$$

$$T_m(t) = J_m . \frac{dw(t)}{dt} + B_m . w(t) \quad (4)$$

Where, V_a = armature voltage (V)
R_a = armature resistance(Ω)
L_a = armature inductance (H)
I_a = armature current (A)
E_b = back emf (V)
W = angular speed (rad/s)
T_m= motor torque (Nm)
θ = angular position of rotor shaft (rad)
J_m = inertia of rotor (Kg-m^2)
B_m = viscous friction coefficient (Nms/rad)
K_T = torque constant (N-m/A)
K_b = back emf constant (V/rad)

Let us combine the upper equations together:

$$v_a = R_a . i_a(t) + L_a . \frac{di_a(t)}{dt} + K_b . w(t) \quad (5)$$

$$K_t . i_a(t) = J_m . \frac{dw(t)}{dt} + B_m . w(t) \quad (6)$$

Laplace transforms of (5) and (6) are

$$V_a(s) = R_a(s) . I_a(s) + L_a . I_a(s) . s + K_b . W(s) \quad (7)$$

$$K_t . I_a(s) = J_m . W(s) . s + B_m . W(s) \quad (8)$$

If current is obtained from (8) and substituted in (7) we have

$$V_a(s) = W(s) . \frac{1}{K_t} . [L_a . J_m . s^2 + (R_a . J_m + L_a B_m) . s + (R_a . B_m + K_b . K_t)] \quad (9)$$

Then the transfer function which relates rotor speed and applied armature voltage is given as:

$$\frac{W(s)}{V_a(s)} = \frac{K_t}{[L_a . J_m . s^2 + (R_a . J_m + L_a . B_m) . s + (R_a . B_m + K_b . K_t)]} \quad (10)$$

The relation between position and speed is:

$$\theta(s) = \frac{1}{s} . W(s) \quad (11)$$

Then the transfer function between shaft position and armature voltage at no-load is:

$$\frac{\theta(s)}{V_a(s)} = \frac{K_t}{[L_a . J_m . s^3 + (R_a . J_m + L_a B_m) . s^2 + (R_a . B_m + K_b . K_t) . s]}$$

3. PID controller

Although being an old control technique, PID control scheme is extensively used in control systems for various control applications. The combination of proportional, integral and derivative control action is called PID control action and the controller is called three action controllers [7]. Although PD control deals neatly with the overshoot and rising problems associated with proportional control it does not reduce the problem with the steady-state error. Hence, PID controllers are used to reduce the steady-state error apart having the advantages of PD controllers. In PID controllers, we need to adjust three parameters i.e. proportional gain (K_P), integral gain (K_I) and derivative gain (K_D) to achieve the desired control performance. The PID controller system block diagram of this paper is shown in Fig 3 [5].

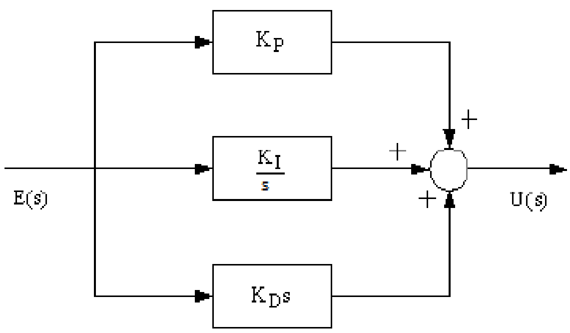

Fig 2: PID controller system block diagram.

The relationship between the input e(t) and output u(t) can be formulated in the following

$$U(t) = K_P e(t) + K_I \int_0^t e(t)\,dt + K_D \frac{de(t)}{dt} \tag{12}$$

The transfer function is expressed as follows

$$C(s) = K_P + \frac{K_I}{s} + K_D s = \frac{U(s)}{E(s)} \tag{13}$$

The DC motor speed control using PID controller system block diagram is shown in Figure a that indicate the flow of system

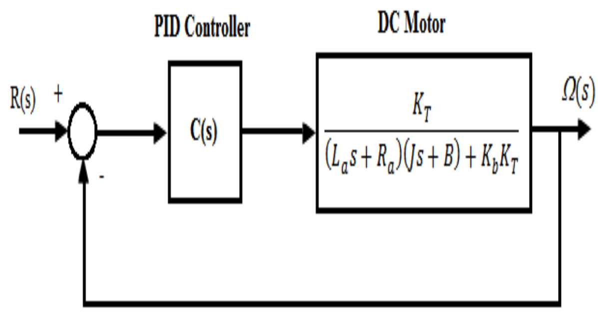

Fig. 3: PID DC motor speed control system block diagram

4. Fuzzy Logic Controller

The fuzzy logic control is based on the simulation of how people work and anticipate to any problem in real world. A complex problem or system may be simplified by allowing some degree of imprecision, vagueness and uncertainty up to some extent. An expert operator develops A flexible control mechanism can be developed by using one’s expertise with the words like "suitable, not very suitable, high, little high, much and far too much" that are frequent and obvious words in people's life[14].In the classical control paradigm, much stress is laid on the precision of the input, the intermediate steps that process them, and the modelling of the system in question.Whereas a fuzzy logic solution is tolerant to the imprecision in the inputs and the model of the system and still produces an output that is desired out of the system. This was put in a more effective way by Lofti A. Zadeh, the father of fuzzy set theory, “when he said most applications of fuzzy logic exploit its tolerance for imprecision.”[1]

4.1 Fuzzy Logic Controller (FLC)

The principal design parameters for a fuzzy logic controller are as given below. Figure 4 shows the controller between the pre-processing block and post processing block.

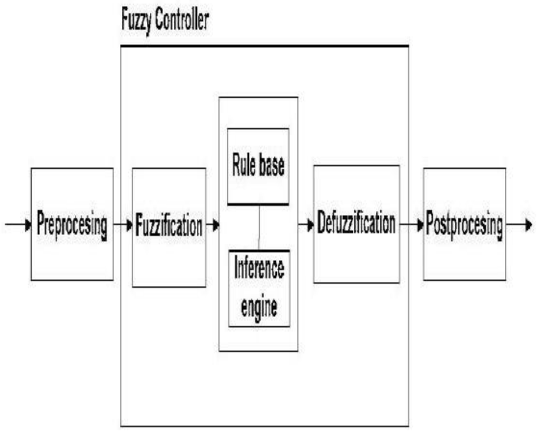

Fig.4:Process blocks of fuzzy logic

4.2 Pre-processing

This block represents the measurement stage where the crisp values of the input variables are measured using some measurement system. So in fuzzy control applications, observed data are usually crisp.[15]

4.3 Fuzzification

Fuzzification is related to the vagueness and imprecision in anatural language. It is subjective valuation which transforms a measuremet into a valuation of a objective value, hence it could be defined as a mapping from an observed input space to fuzzy sets in certain input universes of discourse.Hence fuzzification module performs a scale transformation which maps the current values of input process state variables into a normalised universe of discourse.[15]

4.4 Rule Base

The basic function of rule base is to represent in a structured the control policy of an experienced process operator and/or control engineer in the form of a set of production rules such as

If (Process state) *then* (control output)

The *if* part of such rule is called rule antecedent and is a description of a process state in terms of a logic combination of atomic fuzzy prepositions. The *then* part of the rule is called rule consequent and is a description of a control output in terms of a logic combination of atomic fuzzy prepositions. Hence a fuzzy control rule is a fuzzy conditional statement in which the antecedent is a condition in its application domain and the consequent is a control action for the system under control.[4]

4.5 Defuzzification

Defuzzification module performs following functions:

- Performs the defuzzification which converts the set of modified control output values into a single point-wise values.
- Performs an output denormalization which maps the point wise values of the control output onto its physical domain.

A defuzzification strategy aims at producing a non-fuzzy control action that best represents the possibility of an inferred fuzzy control action.[11]

4.6 Post processing

The block after defuzzification is a post processing block which consists of often an output gain that can be tuned and also become as an integrator.

5.1 Design of PID controller

A feedback control system measures the output speed and compares it with the reference speed. The error between reference and actual speed behaves as input to the controller and the controller generates the out control signal according to this input signal so as to reduce the error.[14]

A simple tuning procedure is as follows:

1. Remove derivative and integral actions by setting K_D =0 and K_I =0.

2. Tune K_P such that it gives the desired response except the final offset value from the set point

3. Increase K_P slightly and adjust K_D to dampen the overshoot

4. Tune K_I such that final offset is removed

5. Repeat steps from 3 until K_P is as large as possible:[9]

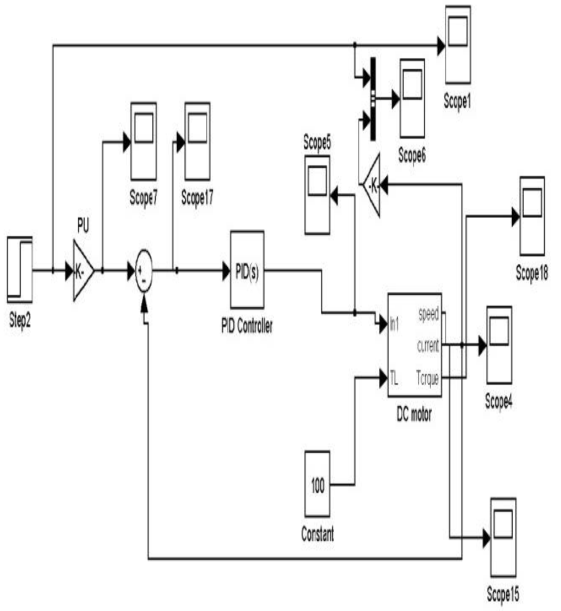

Fig.5: Simulation model for PID controlled dc motor

5.2 Design of fuzzy controller

The goal of designed FLC in this study is to minimize speed error. The bigger speed error the bigger controller input is expected. In addition, the change of error plays an important role to define controller input. Consequently, three linguistic variables are used for FLC:

1. error (e)=reference-actual speed
2. Change of error(cherror) = $\frac{de}{dt}$

The inputs are connected to the output through the rule-base which is defined as:

1. IF (Error is PM) THEN (Control is PM)
2. IF (Error is NM) THEN (Control is NM)
3. IF (Error is Z) AND (Cherror is N) THEN (Control is NS).
4. IF (Error is Z) AND (Cherror is P) THEN (Control is PS)
5. IF (Error is NS) THEN (Control is NS)
6. IF (Error is PS) THEN (Control is PS)

6. Simulation Results and Discussions

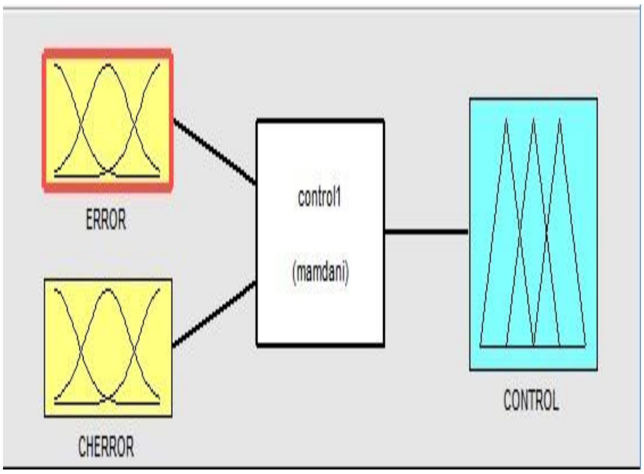

Fig. 6: Mamdani fuzzy inference system developed for fuzzy controller

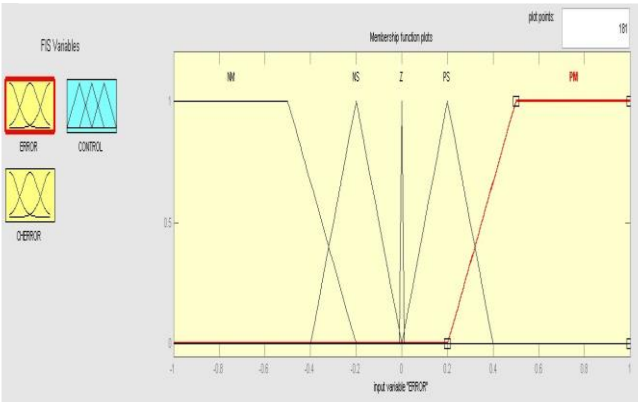

Fig.7:Membership function for input (error)

Error input variable has five membership functions i.e. Negative medium(NM), Negative small(NS), Zero(Z), Positive small(PS), Positive medium(PM).

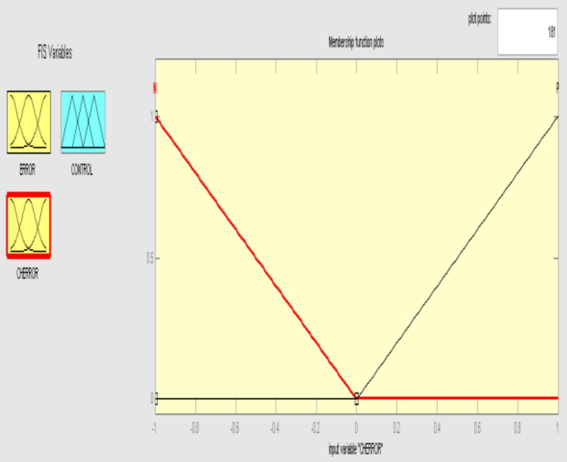

Fig.8:Membership function for input (change of error)

Change of error input variable has two mambership functions i.e. Negative(N), Positive(P).

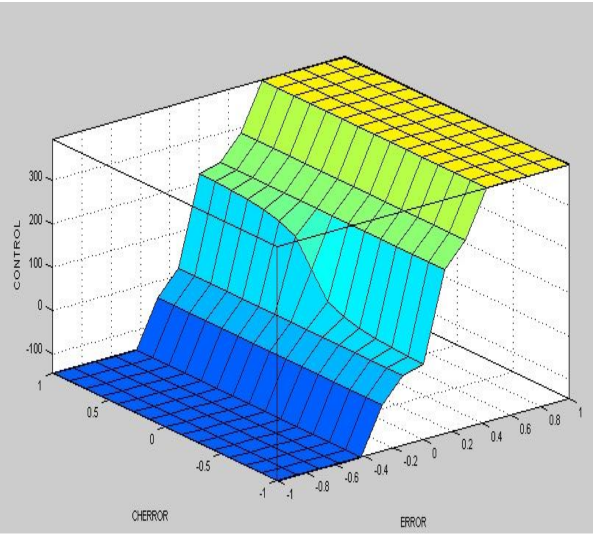

Fig.10:Surface view of FIS

Above figure shows the rule surface i.e. the dependency of the control output on the two inputs, error and change of error.

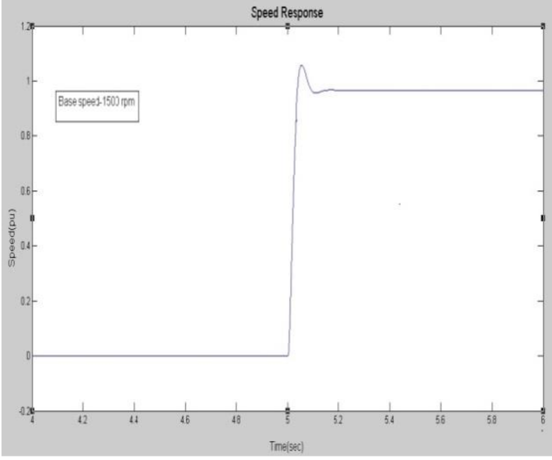

Fig.11:Step responseof dc motor with PID controller

The step response of PID controlled dc motor shows overshoot and certain oscillations before it settles down to steady-state value.

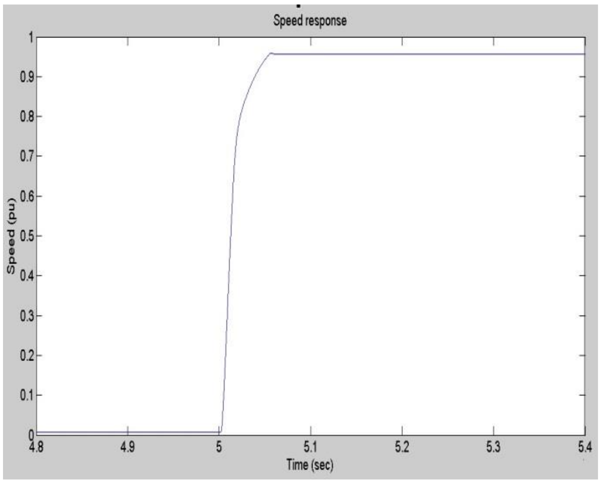

Fig.12:Step response of dc motor with PID controller

To overcome the overshoot and other limitations of PID controller, fuzzy controller is employed to control the dc motor. It is evident from the step response of fuzzy controller that dc motor smoothly follows reference speed and considerably reduces overshoot and oscillations.

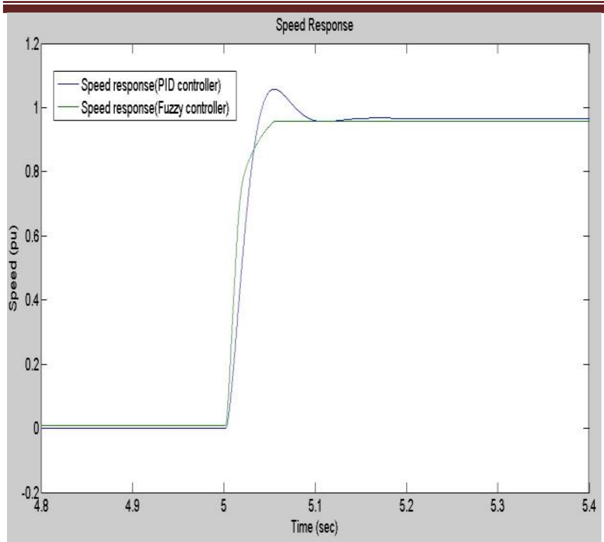

Fig.13:Comparison of speed response of dc motor using fuzzy controller and PID controller

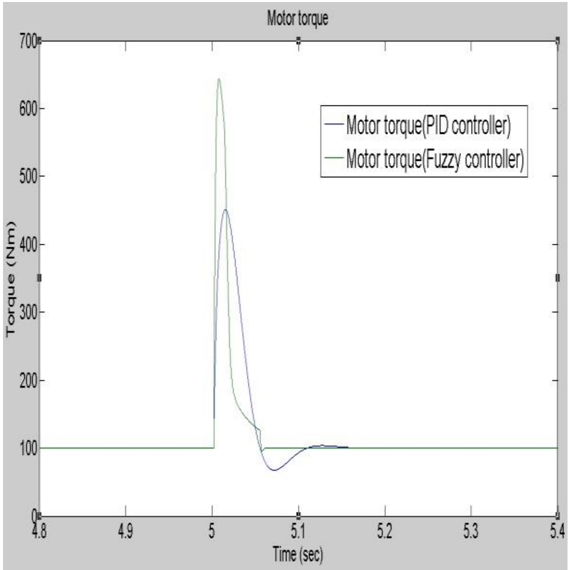

Fig.14:Torque characteristics of dc motor with fuzzy and PID controller

As is clearly visible in the curve that fuzzy controlled dc motor has high starting torque, hence speed quickly reaches its final value, however PID controlled motor torque oscillates around final steady-state value hence resulting in oscillations in motor speed.

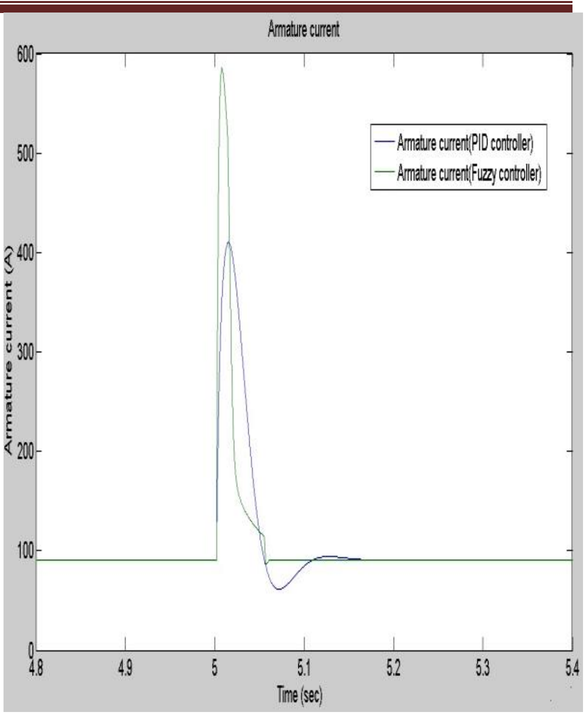

Fig.15:Armature current characteristics of dc motor using fuzzy and PID controller

Above characteristics show that fuzzy controlled dc motor has smaller transient period as the transient current quicklt settles down to its steady-state value.

7. Conclusions

In this paper speed control of dc motor is done using Fuzzy and PID controllers. The simulation results as obtained show that step response of PID controlled dc motor has overshoot and certain oscillations. Hence, a fuzzy logic controller is then employed to control the same dc motor. As it as evident from the above graphs that in step response of dc motor using fuzzy controller, overshoot has been considerably reduced and there is no oscillation. Also the fuzzy controller provides the dc motor with larger starting torque and transient period during speed variation has been considerably reduced. Hence, the comparison of responses of dc motor with fuzzy and PID shows that fuzzycontroller provides a better control of the motor parameters.

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