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Block diagram analysis of speed time characteristics of a simple DC motor and modeling of a PID controller in fuzzy systems engineering

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Abstract

In this paper, we discuss various techniques for changing the armature voltage to control the speed of a DC motor drive. Due to the ability to provide a variable DC output voltage from a fixed AC voltage, rectifiers are used. DC motors have variable characteristics and are used extensively in variable-speed drives in fuzzy systems engineering. The two most popular PID techniques are the step reaction curve experiment and a closed-loop “cycling” experiment under proportional control around the nominal operating point. In the absence of knowledge of the underlying process, our aim to consider a PID controller as the historically best controller.

Keywords: DC motor; PID controller; Fuzzy systems; Governing Equation; Simulink Diagram.

1. Introduction

Some people object, on principle, to using fuzzy systems instead of a more familiar model-based approach to design. To dispel the notion of crispness (i.e., dual-valued concepts, which either are true or are not true), in fuzzy system engineering that are widely used in PID control, signal processing and DC motors. While we frequently strive for crisp values of these terms, we usually use them in fuzzy contexts, where they actually convey more useful information than would a crisp value. Correlation is an interesting example, because it can be defined mathematically so that, for a given set of data, we can compute a crisp number for it. Let's assume that correlation has been normalized so that it can range between zero and unity, and that for a given set of data we compute the correlation value as 0.15. When explaining the amount of data correlation to someone else, it is usually more meaningful to explain it as "this data has low correlation." When we do this, we are actually fuzzifying the crisp value of 0.15 into the fuzzy set "low correlation." Stability is another very interesting example. A system either is or is not stable; there is nothing fuzzy about this. However, if the system is stable, we frequently describe its degree of relative stability, using any of the terms listed in Table 1. These terms may be more meaningful than the following description: "The system has four complex poles and the effective damping ratio for the system is 0.3." We just describe the response of such a system as "lightly damped." Once again, we are fuzzifying the crisp value of 0.3 into the fuzzy set "lightly damped." For interesting historical perspectives on FL, including its earlier origins (when it was called continuous-valued logic) see [2], and, for philosophical interpretations of FL, see [1].

Over the years, work in electric motor control systems has been expanded into a wide range. Various systems have been designed to control motor parameters such as speed, torque, etc. Various strategies for adjusting the armature voltage to regulate the speed of a DC motor drive are discussed in this paper. Rectifiers are utilized because they can produce a variable DC output voltage from a fixed AC supply. DC motors have changeable properties and are often utilized in variable-speed drives. Motor speed can be varied by controlling: armature voltage, field current, and torque demand. DC machines are of three kinds: separately excited, shunt excited, and series excited.

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A proportional-integral-derivative controller (PID controller) is a control loop feedback mechanism, also known as a controller, widely used in industrial control systems. A PID controller calculates an error value as the difference between a measured process variable and a desired set point. It is one of the earlier control strategies. Its early implementation was in pneumatic devices, followed by vacuum and solid-state analog electronics, before arriving at today's digital implementation of microprocessors. It has a simple control structure that was understood by plant operators and that they found relatively easy to tune. Since many control systems using PID control have proved satisfactory, it still has a wide range of applications in industrial control [4]. According to a survey for process control systems conducted in 1989, more than 90 of the control loops were of the PID type. PID control has been an active research topic for many years. Since many process plants controlled by PID controllers have similar dynamics, it has been found possible to set satisfactory controller parameters from less plant information than a complete mathematical model. These techniques came about because of the desire to adjust controller parameters in situ with a minimum of effort and also because of the possible difficulty and poor cost-benefit of obtaining mathematical models. The step response curve experiment and a closed-loop "cycling" experiment under proportional control around the nominal operating point were the two most common PID procedures. A PID controller has traditionally been thought to be the best controller in the lack of understanding of the underlying process. By tuning the three parameters in the PID controller algorithm, the controller can provide control actions designed for specific process requirements. The response of the controller can be described in terms of the responsiveness of the controller to an error, the degree to which the controller overshoots the set point, and the degree of system oscillation. Note that the use of the PID algorithm for control does not guarantee optimal control of the system or system stability.

2. Methodology of DC Motor and PID Controller in Fuzzy Systems:

2.1. Equivalent circuit of a DC motor

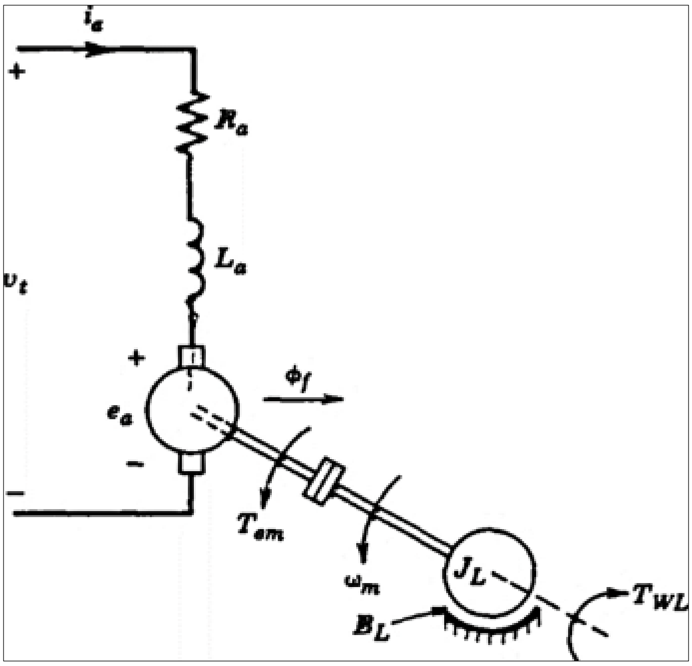

Figure 1 Equivalent circuit of a DC motor [5]

Vt is the armature voltage (In volt)
motor (In volt)
Ia is the armature current (In ampere)
Ra is the armature resistance (In ohm)
La is the armature inductance (In henry)
Tm is the mechanical torque developed (In Nm)
Jm is moment of inertia (In kg/m^2)
Bm is friction coefficient of the motor (In Nm/ (rad/sec))
ω is angular velocity (In rad/sec)

2.2. Modelling of DC Motor

The equations governing a DC motor are shown below.

As there are two parts of our proposed DC model, one is electrical part and the otherone is mechanical part. Equations are separated as follows.

For electrical Model:

$$V_t(t) = R_a i_a(t) + L_a \frac{di_a}{dt}(t) + e_a(t) \quad (1)$$

$$or, \quad \frac{di_a}{dt}(t) = \frac{1}{L_a}[V_t(t) - R_a i_a(t) - e_a(t)].$$

Therefore, $i_a(t) = \int \frac{1}{L_a}[V_t(t) - R_a i_a(t) - e_a(t)]dt.$ (2)

where, $e_a(t) = k_b w_m(t).$ (3)

For mechanical modeling,

$$T_{em}(t) = k_m i_a(t) \quad (4)$$

$$T_{em}(t) = J_L \frac{dw_m}{dt}(t) + B_L w_m(t) + T_{wL}(t). \quad (5)$$

$$or \ \frac{dw_m}{dt}(t) = \frac{1}{J_L}[T_{em}(t) - B_L w_m(t) - T_{wL}(t)].$$

Therefore, $w_m(t) = \int [\frac{1}{J_L}[T_{em}(t) - B_L w_m(t) - T_{wL}(t)]dt.$ (6)

2.3. Specifications and Parameters

The parameters of the DC motor used for the simulations in this paper are as follows:Armature resistance (Ra) = 0.5Ω

Armature inductance (La) = 0.02H
Armature voltage (Vt) = 200 V
Mechanical inertia (JL) = 0.1 Kg.m2
Friction coefficient (BL) = 0.008 N-m/rad/sec
Back emf constant (Kb) = 1.25 V/rad/sec
Rated speed = 3000 r.p.m
Motor torque constant (Km) = 1 N-m/A

Initially motor runs at no-load. A load torque is added after 15 seconds from start andremains till end of simulation.

Value of load torque $T\omega L$ = 100 N-m

2.4. PID Controller

Proportional-Integral-Derivative (PID) control is the most common control algorithm used in industry and has been universally accepted in industrial control. The popularityof PID controllers can be attributed partly to their robust performance in a wide range of operating conditions and partly to their functional simplicity, which allows engineersto operate them in a simple, straightforward manner for our given proposed model. Asthe name suggests, PID algorithm consists of three basic coefficients; proportional, integral and derivative which are varied to get optimal response [08].

2.4.1. Proportional response

The proportional component depends only on the difference between the set point and the process variable. This difference is referred to as the Error term. The proportional gain determines the ratio of output response to the error signal. For instance, if the errorterm has a magnitude of 10, a proportional gain of 5 would produce a proportional response of 50. In general, increasing the proportional gain will increase the speed of the control system response. However, if the proportional gain is too large, the processvariable will begin to oscillate. If Kp is increased further, the oscillations will become larger and the system will become unstable and may even oscillate out of control.

2.4.2. Integral response

The integral component sums the error term over total time. The result is that even a small error term will cause the integral component to increase slowly. The integral response will continually increase over time unless the error is zero, so the effect is to drive the Steady-State error to zero. Steady-State error is the final difference between the process variable and set point. A phenomenon called integral windup results when integral action saturates a controller without the controller driving the error signal toward zero meaning difference between input and output should be as low as possible.

2.4.3. Derivative response

The derivative component causes the output to decrease if the process variable is increasing rapidly. The derivative response is proportional to the rate of change of the process variable. Increasing the derivative time parameter will cause the control system to react more strongly to changes in the error term and will increase the speed of the overall control system response. Most practical control systems use very small derivative time, because the derivative response is highly sensitive to noise in the process variable signal. If the sensor feedback signal is noisy or if the control loop rate is too slow, the derivative response can make the control system unstable. So we need to take a good care of this one.

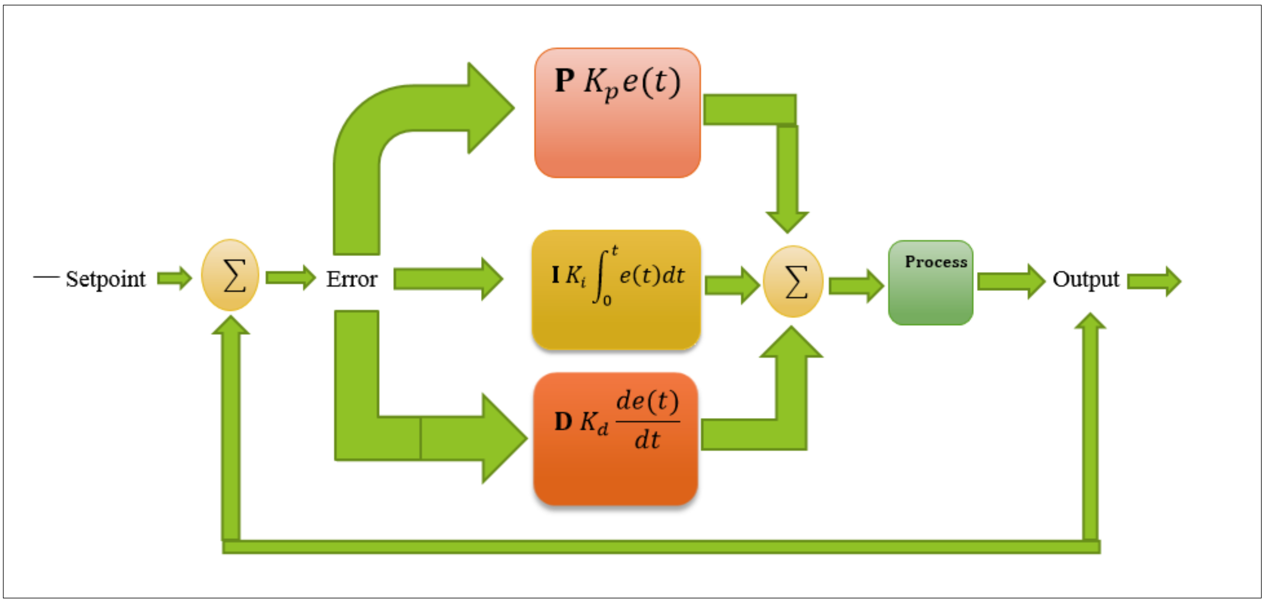

Figure 2 Block diagram of PID Controller

2.5. Modelling of a PID Controller

A PID Controller consists of three parts named as proportional gain, integral gain and derivative gain. And it calculates the measured data and desired data at the output. It tries to minimize the difference between them as well as have a good control over speed[07].

2.5.1. Governing equation

Three parameters are named k_p, k_i *and* k_d are the gain of proportional, integral andderivate. So the governing equation would be as followed:

$$P_{out} = k_p e(t) + k_i \int_0^t e(t)dt + k_d \frac{d}{dt} e(t)$$

The “p” stands for proportional control gain, “i” for integral control gain and “d”stands for derivative control. This is also what is called a three term controller.

2.5.2. Effect of changing parameters

A proportional controller (k_p) will have the effect of reducing the rise time andwill reduce, but never eliminate, the Steady state error

An integral control (k_i) will have the effect of eliminating the steady-state error,but it may make the transient response worse.

A derivative control (k_d) will have the effect of increasing the stability of thesystem, reducing the overshoot and improving the transient response.

The following would give us a good idea of the effect of parameters in PID.

Table 1 Effects of changing PID parameters on an output response [6].

Parameters	Rise time	Overshoot	Settling time	Steady state error
k_p	Decrease	Increase	Small Change	Decrease
k_i	Decrease	Increase	Increase	Eliminate
k_d	Small Change	Decrease	Decrease	Small Change

3. Result and Discussion

3.1. DC Motor in Simulink

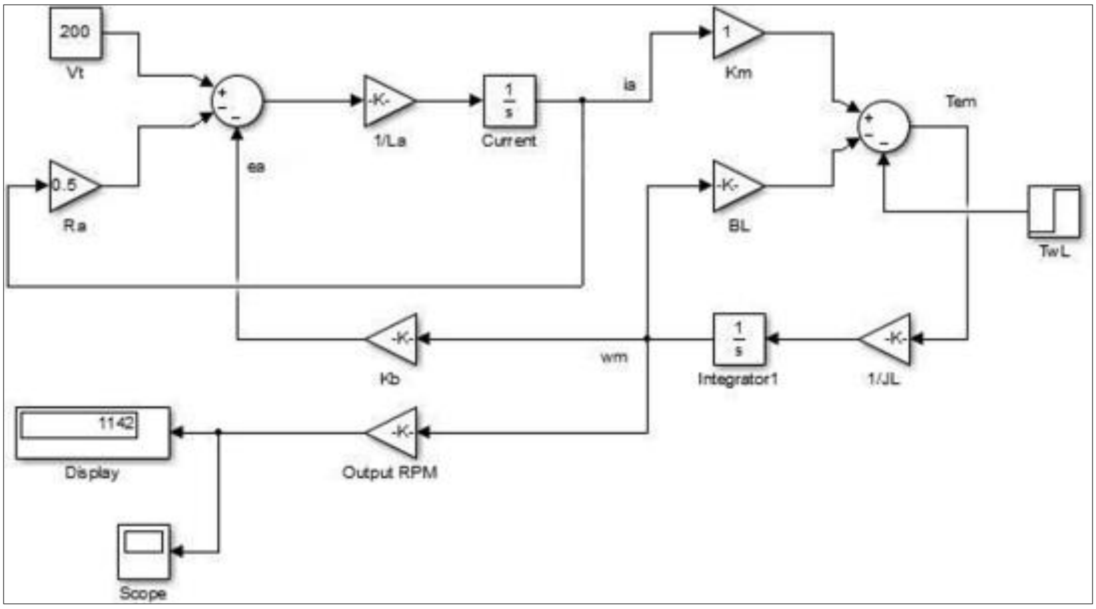

Figure 3 Simulink block diagram of a simple DC motor

Simulink diagrams are synonymous to block diagrams familiar in control systems engineering. The “scopes” and “displays” shown in the Simulink diagram are placed inorder to check the variables at each stage they are placed.

The Simulink block diagram based on the above equations is as follows. The values ofthe parameters are as listed as above.

And on the basis of this Simulink diagram shown below, we then use it in MATLAB Simulink and get our result of speed-time characteristics to find the wave shape and compare this with the other used controllers used in the next section.

Initially, motor is at rest. When an armature voltage of 200V is applied, the speed immediately tries to reach the value set by the voltage. There is high short circuit currentflow at the beginning so the speed goes higher than the speed that was supposed to be set for 200V. Because of mechanical inertial and friction, there are overshoot and undershoot. Finally, the speed settles at 1523 r.p.m. After 15 seconds, a load torque of100 N-m is added. As a result, speed falls to a new value of 1142 r.p.m., after some undershoot and overshoot caused by the same reasons.

Overshoot and undershoot is unwanted, and overshoot particularly is dangerous because high speed may cause the motor to be damaged. It is necessary to reduce theseeffects so that the more smoothly.

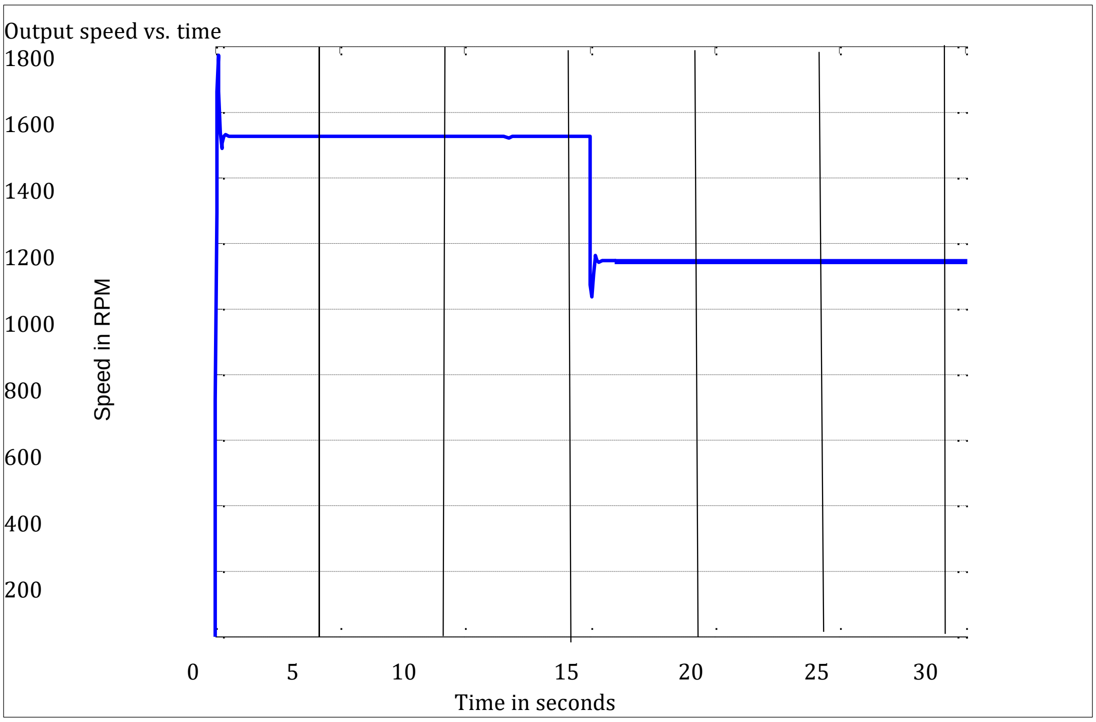

Figure 4 Speed-time characteristics of a simple DC motor

3.1.1. Working Principle of PID

The job of a PID controller is to maintain the output at a level so that there is no difference (error) between the process variable (PV) and the set point (SP).

In the diagram shown below the valve could be controlling the gas going to a heater, the chilling of a cooler, the pressure in a pipe, the flow through a pipe, the level in a tank or any other process control system. PID controller is looking at is the difference (or "error") between the PV and the SP. It looks at the absolute error and the rate of change of error. Absolute error means -- is there a big difference in the PV and SP or a little difference? Rate of change of error means -- is the difference between the PV or SP getting smaller or larger as time goes on. When there is a "process upset", meaning, when the process variable or the set point quickly changes - the PID controllerhas to quickly change the output to get the process variable back equal to the setpoint. If you have a walk-in cooler with a PID controller and someone opens the doorand walks in, the temperature (process variable) could rise very quickly. Therefore thePID controller has to increase the cooling (output) to compensate for this rise in temperature. Once the PID controller has the process variable equal to the set point, a good PID controller will not vary the output. You want the output to be very steady (not changing). If the valves (motor or other control element) are constantly changing,instead of maintaining a constant value, this could case more wear on the control element. So there are these two contradictory goals. Fast response (fast change in output) when there is a "process upset", but slow response (steady output) when the PVis close to the set point.

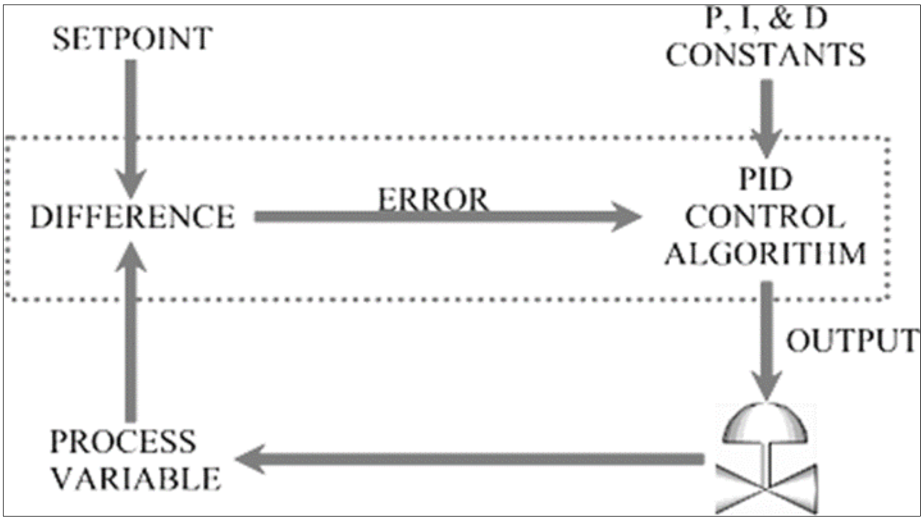

Figure 5 Working procedure of PID controller

4. Conclusion

In this project different method for speed control of DC motor are studied with great care. The speed-time characteristics, steady state and dynamic response of the DC motor output speed, and its torque-speeds, torque-current characteristics are studied. This project introduces a design method of two inputs and three outputs PID controller and make use of MATLAB toolbox to design controller. The fuzzy controller adjusted the proportional, integral and derivate (k_p, k_i and k_d) gains of the PID controller according to both speed error and change in speed error in fuzzy system engineering.

Compliance with ethical standards

Disclosure of conflict of interest

No conflict of interest to be disclosed.

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