Modeling & Simulation of Transient Response of a Armature-Controlled Direct Current Motor Using MATLAB/SIMULINK

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***Abstract*:   In this paper the experimental implementation of a separately excited DC motor are presented. The models of speed control of the DC motor are implemented in MATLAB/SIMULINK. Simulation can be very helpful for motor behaviour under different operating conditions which are helpful in designing more advanced protective devices precautionary equipments., For simulation of motor, some data is also required like torque constant which is obtained by experimental investigations. Output is varying corresponding to change in input variable. The input variables are armature current, filed resistance and armature voltage. By testing of actual motor simulating and modelling we will get our required output.**

***Index Terms*—Transient response, DC Motor, Motor Modelling**

1 INTRODUCTION

The different techniques used to control speed of a separately excited DC motor. By varying armature voltage the speed of a separately excited dc motor could be varied from zero to rated speed in the constant torque region. The speed of the motor will get above the rated speed by reducing the flux in constant power region. The mechanical load characterized by motor drives: inertia J, friction coefficient D_m, and load torque T_L.

2.PROPOSED WORK

Control of speed can be achieved by use of different methods:

A. *Armature voltage control*

"In separately excited motors, the voltage applied to the motor can be varied with the field remaining constant. Different voltages then give different intercepts (different no load speeds), and result in a family of parallel (i.e. same slope) mechanical c/s. To obtain variable DC voltage , the simplest method is to use a voltage divider, but this method is impractical and uneconomical; it is used only for testing. In modern applications, variable DC voltage for the armature is

often obtained from a solid-state controlled rectifier, with the

field fed from an uncontrolled rectifier. Another effective method for obtaining smooth voltage control is the Ward- Leonard system. The motor field is fed from an exciter (small DC generator) or rectifier at constant voltage. The Ward-Leonard system is generally more expensive than a solid-state drive, but has compensating advantages for certain applications.

B. *Field control*

If the field circuit resistance is increased, the field current, and hence the main field, will be reduced, and the speed will

increase. The higher the field resistance, the higher the intercept and the greater the slope (i.e. the c/s becomes softer). The flux cannot be reduced indefinitely because the speed becomes too high and may damage the motor. Moreover, if the main field becomes too weak, the demagnetizing effect of armature reaction becomes prominent (relatively large) which may lead to instability". [11]

3. MODEL DEVELOPMENT

In modeling the armature controlled DC motor for this study, simple electrical circuit of armature controlled DC motor diagram as shown in Figure 3 was employed while the activities involved were broken down into four stages. The four stages involved are presented in the following sub-sections as follows.

3.1 ARMATURE CONTROLLED DC MOTOR CIRCUIT DIAGRAM REPRESENTATION

This stage focus was on development of an armature controlled DC motor as shown in Fig.1 with torque and rotor angle.
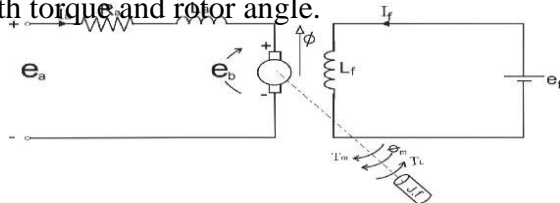

Fig.1: Armature-controlled DC motor

In Fig.1, R_a is the resistance of the armature, L_a is the inductance of the armature winding, i_a is the armature current, i_f is the field current, e_a is the applied armature voltage, e_b is the back emf, T_M is the torque developed by the motor, is the angular displacement of motor-shaft, J is the equivalent moment of inertia of motor shaft and load referred to the motor while f is the equivalent coefficient of motor and load referred to the motor shaft.

3.2 DERIVATION OF THE SYSTEM EQUATION

The activity in this stage involves the development of both the electrical and mechanical variables in Figure 3.1. The variables of interest on the electrical side are voltage and current while the variables of interest on the mechanical side are torque and speed. The two basic equations relate these four variables and form the foundation of armature controlled DC motor analysis

The developed torque by motor is defined mathematically as

$$T = \frac{Z_p i_a \emptyset_p}{2\pi a} \tag{1}$$

Where $\frac{Z_p}{2\pi a}$ was denoted as K_t

Similarly, the authors defined the back electromotive force e_b mathematically as;

$$e_b = \frac{Z_p}{60a} n \emptyset_p \tag{2}$$

However, since; $\quad n = \frac{60\omega}{2\pi}$
(3)

Substitute (3) in (2)
$$e_b = \frac{Z_p}{60a} \frac{60\omega}{2\pi} \emptyset_p = \frac{Z_p \omega}{2\pi a} \emptyset_p = K_b \omega \varphi_p$$
(4)

$$K_b = \frac{Z_p}{2\pi a}$$

The factor K_b is frequently referred to as torque constant K_t in (1) and voltage constant K_b in equation (4). Since $K_b K_t$, a newconstant, K^1, which is defined in [6] as;

$$K' = K_t = K_b = \frac{Z_p}{2\pi a}$$
(5)

Since the field strength is fixed, the flux per pole φ_p is merged with K' to yield another constant, K, which is expressed mathematically as;

$$K = \frac{Z_p}{2\pi a}$$
(6)

where K is referred to as the machine constant. Hence, (1) can be re-expressed as;

$$T = K i_a$$
(7)

Likewise, (4) can be re-expressed as;

$$e_b = K\omega$$
(8)

For clarity purposes so that it will be easy to

differentiate between electrical and mechanical Variables, the constant K in (8) and (9) are replaced with K_t and K_b to obtain (9) and(10) respectively giving as follows

$$T = K_t i_a$$
(9)

And

$$e_b = K_b \omega$$
(10)

Applying Kirchhoff Voltage Law (KVL) in Figure 3, the differential equation of the armature circuit is;

$$L_a \frac{di_a}{dt} + R_a i_a + e_b = e_a$$
(11)

Similarly, the armature current produces the torque that is applied to the inertia and friction to obtain the torque equation;

$$J \frac{d^2\theta}{dt^2} + B \frac{d\theta}{dt} = T = K_t i_a$$
(12)

3.3 MODELLING OF THE SYSTEM

Taking the Laplace transform of (10), (11) and (12) respectively, assuming zero initial conditions;

$$E_b(S) = K_b s\theta(S)$$
(13)

$$(L_a s + R_a)I_a(S) = E(S) - E_b(s)$$
(14)

$$(Js^2 + Bs)\theta(S) = T(S) = K_t I_a(S)$$
(15)

Substitute E_b(S) in (14) to obtain

$$(L_a s + R_a)I_a(S) = E(S) - K_b s\theta(s)$$
(16)

Make Ia(S) the subject of the formula in (16) to obtain

$$I_a(S) = \frac{E(S) - K_b s\theta(s)}{(L_a s + R_a)}$$
(17)

Substitute (17) in in (15) to obtain

$$(Js^2 + Bs)\theta(S) = K_t I_a(S) \frac{E(S) - K_b s\theta(s)}{(L_a s + R_a)}$$
(18)

$$[(Js^2 + Bs)(L_a s + R_a)]\theta(S) + K_t K_b s\theta(s) = K_t E(S)$$

Hence ,the system transfer function is expressed mathematically as; the transfer function from the input voltage, E (s), to the output angle,ө(S), directly follows

$$\frac{\theta(S)}{E(S)} = \frac{K_t}{s([(Js+B)(L_a s+R_a)]+K_t k_b)}$$
(19)

From the block diagram in Fig..2, it is easy to see that the transfer function from the input voltage, V (s), tothe angular velocity, w, is:

$$\frac{\omega(S)}{E(S)} = \frac{K_t}{[(Js + B)(L_a s + R_a)] + K_t K_b}$$

3.4 CONVERSION OF TRANSFER FUNCTION TO MODEL BLOCK

From (19), the block diagram for the armature controlled DC motor was developed. The block diagram is shown in Figure 2. The block diagram of the armature controlled DC motor was implemented in the simulink environment in the MATLAB. The model created in simulink toolbox of MATLAB is shown in Figure 2
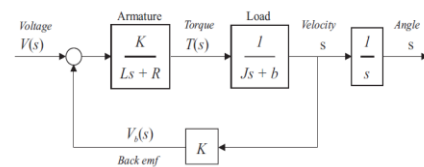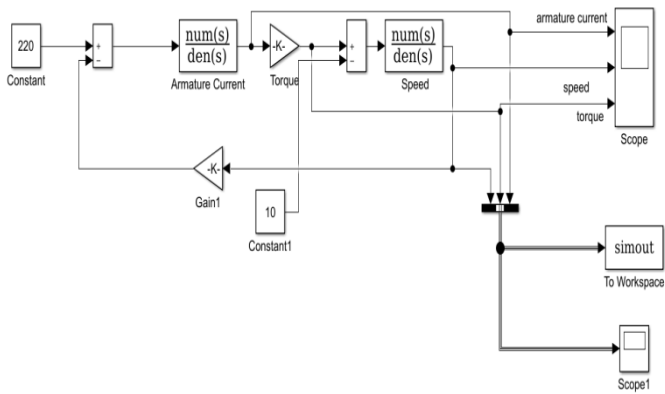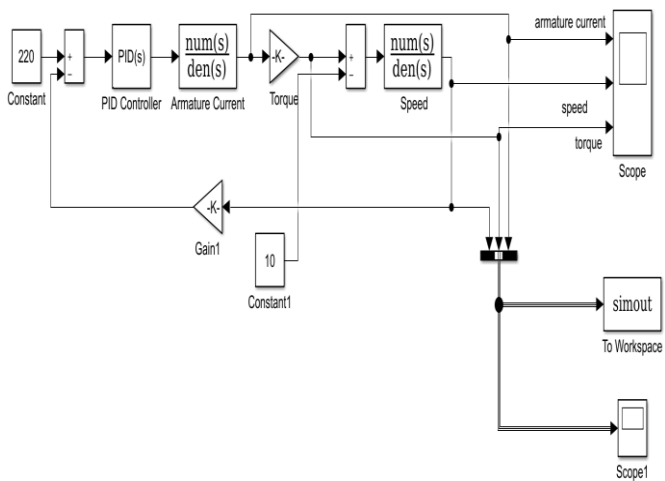

Fig.2 Block Diagram of an Armature controlled DC Motor

SIMULINK Model
The block diagram from Fig 2 can be directly implemented in SIMULINK, as shown in the Fig 3 & Fig 4

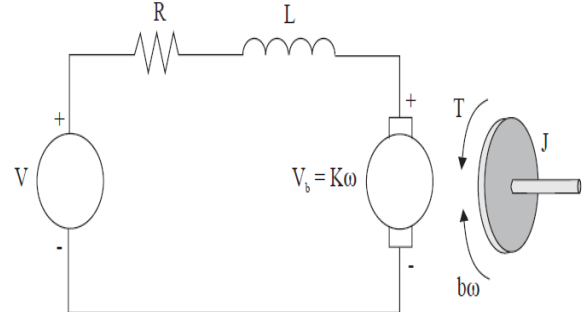**Fig 3** Modelling of Dc Motor Armature control Method

Fig 4 Modelling of D C Motor Armature control Method with PID Controller

4. RESULTS AND DISCUSSION

4.1. SIMULATION RESULTS AND DISCUSSIONS

The simulated model was analyzed based on its transient and steady state responses. The standard test input signals for transient response were step function and impulse function. However, for the steady state response, the graphs of torque-speed characteristics for different armature voltages and armature speed characteristics were considered.

Consider a DC motor, whose electric circuit of the armature and the free body diagram of the rotor are shown in Fig.5

Fig 5 Schematic representation of the considered DC motor

Consider the following values for the physical parameters:

moment of inertia of the rotor J =0.01 kg_ m2
damping (friction) of the mechanical system b =0.1 Nms
(back-)electromotive force constant K =0.01 Nm/A
electric resistance R = 1
electric inductance L = 0.5 H

The *input* is the armature voltage V in Volts (driven by a voltage source). Measured variables are the angular velocity of the shaft ω in radians per second, and the shaft angle θ in radians

4.2 PARAMETER EXTRACTION

To produce a good design, there needs to be some amount of modeling or simulations done to avoid aimless trial and error techniques with the actual equipment (the DC motor).For this purpose , a number of specifications are needed to be obtained and established. The specifications of the DC motor like Voltage, Current, Power, Field Voltage, Field Current are noted from the name plate details. Specifications:
Type Shunt
Voltage: 220v
Current :19A
Power :5 H.P
Field Voltage :220V
Field Current: 3A
Insulation: B

There is other specification that is required for the modelling of the DC motor and it is measured using test equipments in the laboratory and through mathematical calculations
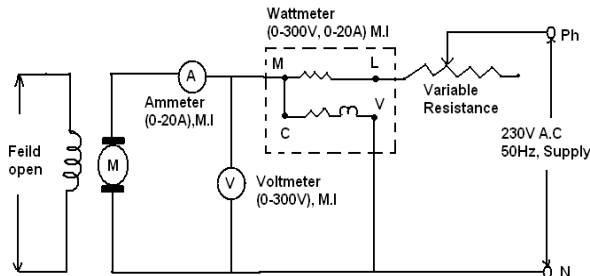

Fig.6: Experimental setup for testing the Armature side

Observations from test:

Table 1: Test result of DC motor parameter

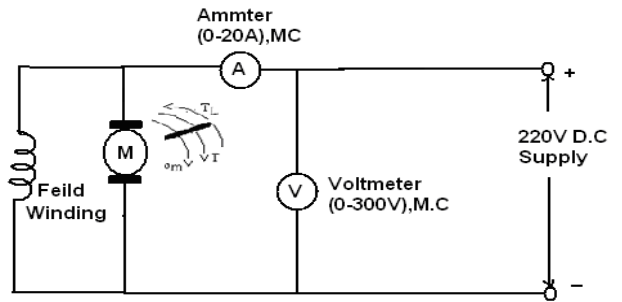| L = $X/2\Pi f$ H	Voltage (v) Volts	Current (I) Amps	Power (w) Watts	Phase angle (Φ) = cos^{-1} (W/(V*I))	Z= V/I	Resistance (R) = (W/I^2)	reactance (X) = $X = \sqrt{Z^2 -}$
0.013	12.5	2.75	12	69.568	4.54	1.58	4.256
0.013	17.5	3.75	30	62.8	4.67	2.13	4.156
0.014	22.5	4.80	34	71.65	4.68	1.47	4.443
0.133					**4.63**	**1.72**	**4.285**

Test for Finding Torque Constant (Km)

Fig. 7 Circuit for finding Km of DC motor

Table 2: To find the Average Torque constant of DC motor

Terminal Voltage, V_t (Volts)	Internal EMF, E_a (Volts)	Load Current, I_L (Amps)	Speed, N(rpm)	Speed, W_m in (rad/s)	Torque constant, K_m $K_m = E_a / W_m$
220	219.7.	0.65	1500	157.08	1.398
220	219.2	5.5	1454	152.26	1.439
220	218.8	7.5	1446	151.42	1.481
220	218.4	10	1426	149.33	1.462

From the above table data can be used to calculate Coefficient of viscous friction includes all rotation losses like friction and windage losses (B) and the moment of inertia of the motor (J) is calculated .and value of B and J is found to be
B=0.0251
J= 0.0759

V **SIMULATION RESULTS and Discussion:**
A. STEADY STATE RESPONSE

The performance of of DC Motor can be studied for different operating condition. The steady state responses are: armature voltage speed characteristics and torque speed characteristics for

different armature voltages. The results of the simulation for a supply voltage of 180V and load torque is zero as shown in Fig. 7while the simulations for a supply voltage of 220V with & laod torque is zero shown in Fig 8

Voltage increases with increase in speed as shown in Fig. 6.

The speed-voltage characteristics is as shown in Fig.7 It is observed that speed is directly proportional to armature voltage.
For different armature voltage to study the speed-torque characteristics of DC Motor is shown in Fig.7. It is observed that torque is low with higher speed. It means voltages are inversely proportional to the torque.

Fig. 8 shows the simulation output with an input voltage of 220V. The transient current, speed and torque were observed to be approximately72.43A, 150.9 and 102 N-M respectively while the transient period was for 0.872 seconds. It was observed that speed reaches to study values 1.632 sec. The transient current was about 3.812 times the rated current.
Similarly for input voltage 180V, the transient current and torque were approximately 59.43A and 83.44 N-M respectively for a transient period of about 0.94 seconds
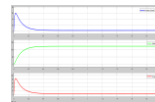
1. V=180 Volts, T_L=0

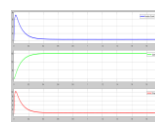Fig. 7: Armature Current, Torque-speed characteristics

V=220 Volts, T_L=0 N

Fig. 8: Armature Current, Torque-speed characteristics

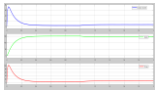V=220, Load Torque T_L=10 N (Without PID Controller)

Fig. 9: Armature Current, Torque-speed characteristics

B STEADY STATE RESPONSE USING PID CONTROLLER

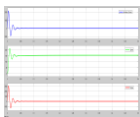PID controller: P=20,I=1,D=1.Torque=10

Fig.10 Steady state response Using PID controller

It was Observe the Results using PID Controller settling time reduced by 0.038 sec and rise time was reduced by 70.29 ms to 2.18ms

V. CONCLUSION

In this paper, the simulation model of an armature controlled DC motor was developed using MATLAB/Simulink. The analysis and performance evaluation of the developed motor show that the simulated motor correctly predicts the effect of armature voltage on the armature voltage-speed characteristics and torque-speed characteristics of the armature controlled dc motor. Furthermore, the results of the study show that the speed of the DC motor is directly proportional to the armature voltage.

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