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A Comparative Study of DC Motor for Optimal Performance Using LAG Compensator and PID Controller Implemented by MATLAB

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Abstract: DC motors are used in many industrial and commercial applications require higher performance, reliability, variable speed, easier controlling stability, accuracy, speed and position control of motor is required. In this research paper we have taken an unstable DC motor model and work on LAG compensator and PID controller to obtain a stable model of DC motor for optimal performance. The LAG compensator and PID controller parameter is tested with an actual motor. In this paper is a simulation and experimental investigation of the development of LAG compensator and PID controller by using MATLAB. DC motor system performance are studied by Root Locus plot, Bode plot and step response that contains transient response and steady state response is drawn to analyze the DC motor performance. An optimal model is made for the DC motor and comparative study has done for DC motor for achieving optimal performance specification using LAG compensator and PID controller.

Keywords: DC Motor, MATLAB, LEAD Compensator, LAG Compensator, ON-OFF Controller, PID Controller.

I. INTRODUCTION

DC motor has been popular in the industry control area for a long time because they have good characteristics that is high starting torque characteristics, high response performance and easier to be linear control. These motors are commonly used to provide rotary (or linear) motion to a variety of electromechanical devices and servo systems. DC motor has been widely used in industry even though its maintenance costs are higher than the induction motor DC motor has good control response, wide speed control range and it is widely used in systems which need high control requirements, such as rolling mill, double-hulled tanker, high precision digital tools, etc. There are several well-known methods to control DC motors such as Compensation Technique and Controller Method.

Despite a lot of researches and the huge number of different solutions proposed. The purpose of developing a control system is to enable stable and reliable control. Once the control system has been specified and the type of control has been decided, then the design and analysis are done. There are three major objectives of system analysis and design: producing the desired transient response, reducing steady-state error, and achieving stability.

The objective of this paper is to perform comparative analysis of the motor using LAG compensator and PID controller for optimizing the performance and design an optimal model for DC motor.

The control system has overall response that is transient response and steady state response is analyzed and to evaluate the performance of the optimal model of DC motor time response analysis and frequency response analysis are obtained.

II. D.C MOTOR

DC motor is one of the first devices to convert electrical power into mechanical power motor. Its origin, according to, can be traced to disc-type machines conceived and tested by Michael Faraday, who has formulated fundamental concepts of electromagnetism.

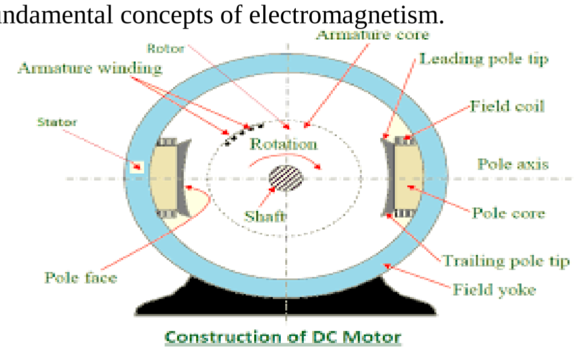

Fig 2 (a) Construction of DC Motor

DC motor uses electricity and a magnetic field to produce torque, which causes it to turn. It requires two magnets of opposite polarity and an electric coil, which acts as an electromagnet. The repellent and attractive Electromagnetic forces of the magnets provide the torque that causes the motor to turn.

It also consists of one set of coils, called armature winding, inside a set of permanent magnets, called the stator. Applying a voltage to the coils produces a torque in the armature, resulting in motion. DC motors provide excellent control of speed for acceleration and deceleration. DC drives are normally less expensive for most horsepower ratings. DC motors have a long tradition

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of use as adjustable speed machines and a wide range of options have evolved for this purpose.

III. MATHEMATICAL MODEL FOR DC MOTOR

To simulate a system, an appropriate model needs to be established. This paper has described the system contains a DC motor based on the motor specifications needs to be obtained. This is achieved by developing the open loop transfer function of a DC motor with the use of the system equations of the motor as given by variable supply voltage, resistors or electronic controls. The design method uses the concepts of the system theory, such as signals and systems, transfer functions, direct and inverse Laplace transforms. It requires building the appropriate Laplace model for each component of the whole control system. In order to build DC motor's transfer function, its simplified mathematical model has been used. This model consists of differential equations for the electrical part, mechanical part and the interconnection between them.

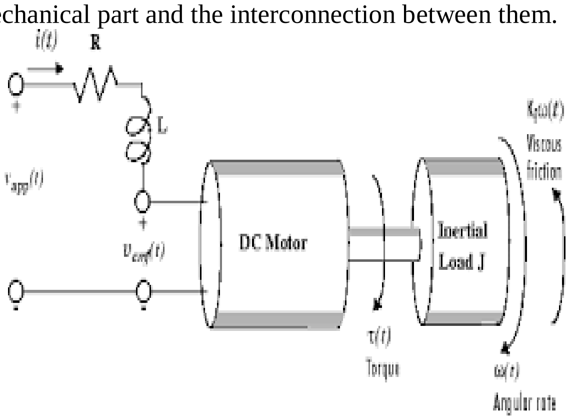

Fig 3 (a) Mathematical Modeling For DC Motor

Where,
i (t) =Field current (ampere)
Vemf (t) =Back emf (voltage)
Vapp (t) =Applied voltage (voltage)
R= Armature resistance (Ohms)
L= Armature self-inductance (Henrys)
K_m= Armature constant
K_b = Back emf constant
J= Moment of inertia (kg.m2/s^2)

In Field current controlled DC motor, the armature current must maintained constant i a (t) = ia=constant, and the field current, if varies with time, t, to cause the motor to rotate, this yields; the air-gap flux, Φ is proportional to the Field current.

The torque τ seen at the shaft of the motor is proportional to the current i induced by the applied voltage,

$$\tau(t) = K_m i(t) \quad \text{………………. (1)}$$

where K_m, the armature constant, is related to physical properties of the motor, such as magnetic field strength, the number of turns of wire around the conductor coil, and the emf can be given as

$$v_{emf}(t) = K_b \omega(t) \quad \text{......................(2)}$$

Where K_b, the emf constant, also depends on certain physical properties of the motor. So R, L, K_m and K_b are parameters which be given by the datasheet of the motor. The mechanical part of the motor equations is derived using Newton's law, which states that the inertial load J times the derivative of angular rate sum of all the torques about the motor shaft. The result of the system equation is as follows,

$$J\frac{d\omega}{dt} = \sum \tau_i = -K_f \omega(t) + K_m i(t) \quad \text{….(3)}$$

Finally, the electrical part of the motor equations can be described as

$$v_{app}(t) - v_{emf}(t) = L\frac{di}{dt} + Ri(t) \quad \text{………(4)}$$

or, solving for the applied voltage and substituting for

$$v_{app}(t) = L\frac{di}{dt} + Ri(t) + K_b \omega(t) \quad \text{………..(5)}$$

The sequence of equations leads to a set of two differential equations that describe the behavior of the motor, the first for the induced current,

$$\frac{di}{dt} = -\frac{R}{L}i(t) - \frac{K_b}{L}\omega(t) + \frac{1}{L}v_{app}(t) \quad \text{……(6)}$$

and the second for the resulting angular rate,

$$\frac{d\omega}{dt} = -\frac{1}{J}K_f \omega(t) + \frac{1}{J}K_m i(t) \quad \text{……… (7)}$$

By using Laplace transform and substituting the value of i(s), we will get the differential equation for input V_{app}(s) and the output is the speed of the motor W(s)

$$\frac{W(s)}{V(s)} = \frac{K_m}{(LS+R)(JS+K_f)+K_m K_b} \quad \text{… (8)}$$

This T.F. describes the relation between the input voltage and the speed and by plotting the step response of it we will see how the speed will be change and behavior of the motor. But if you don't want the speed as output, instead of it you want the angle of rotation to be the output then we think about what is the relation between the angular displacement (angle θ) and the state variable (i or w) and we found that

$$\frac{\partial\theta(t)}{\partial t} = w(t) \rightarrow S\,\theta(s) = W(s) \quad \text{……….. (9).}$$

So that the transfer function that relates the voltage (input) with angle (position) is

$$\frac{\theta(s)}{V(s)} = \frac{K_m}{S((LS+R)(JS+K_f)+K_m K_b)} = \frac{k_M}{S(1+S\tau_m)} \quad \text{… (10)}$$

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IV. CONTROL SYSTEM

The control system means by which any quantity of interest in a machine, mechanism, or other equipment is maintained or altered in accordance with a desired manner. The control systems basically are two types - Open loop system and Closed loop system. Open loop system is a physical system which does not automatically correct for variation in its output. In these systems for a constant input signal and unaltered external conditions, the output signal remains constant. General requirements on a system include: The system has to be stable, adequately damped, capable of rejecting disturbance and quick to respond, less sensitive to parametric variations. While open loop systems may fail to satisfy the above requirements, feedback systems provide a very good solution. The block diagram of the open loop system is

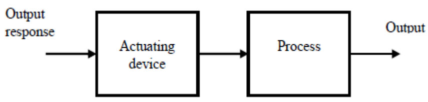

Figure 2 Open-loop control system (no feedback)

Fig 4(a) Open loop control system

A closed-loop control system utilizes an additional measure of the actual output to compare the actual output with the desired output response. The measure of the output is called the feedback signal. A feedback control system is a control system that tends to maintain a relationship of one system variable to another by comparing functions of these variables and using the difference as a means of control. As the system is becoming more complex, the interrelationship of many controlled variables may be considered in the control scheme. An example of closed-loop control system is a person steering an automobile by looking at the auto's location on the road and making the appropriate adjustments for desired response.

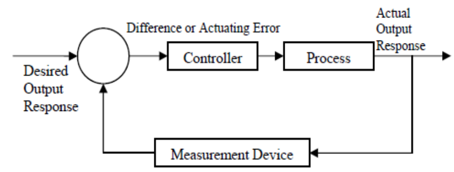

Figure 3 Closed-loop feedback system.

Fig 4(b) Closed loop control system

V. CONTROLTECHNIQUES

In order to obtain the optimal performance of DC motor there are many control techniques. But here we are implementing the control technique such as:

5.1. COMPENSATION TECHNIQUE

Compensation is the modification of the system dynamics to satisfy the given system performance. It is used to make the unstable system to become stable by introducing poles and zeros at suitable places. The compensation technique depends upon location of compensation network that is series compensation and feedback compensation, load compensation for improving the system specification. The compensation techniques used are such as:-

5.1. (a) LEAD COMPENSSATION.
5.1. (b) LAG COMPENSATION.
5.1. (c) LEAD-LAG COMPENSATION.

As per the system response need of Lag compensation network for improving the system responses towards stable steady state performance.

5.1. b. LAG COMPENSATION

Compensation is the modification of the system dynamics to satisfy the given specifications. Setting the gain is the first step in adjusting the system for satisfactory performance. In many cases, increasing the gain value will improve the steady-state behavior but will result in poor stability or even instability.

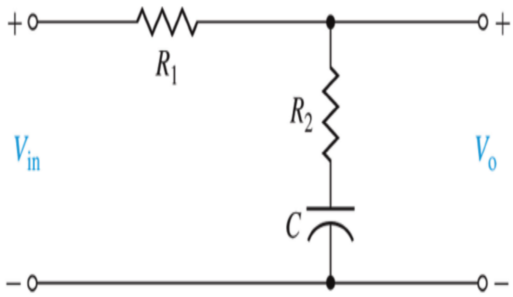

Fig 5.1 .b (a) Lag Compensation Network

The transfer function for a LAG compensator may be given as,

$$G_c(S) = \beta \frac{(\tau S + 1)}{(\beta \tau S + 1)}$$

$$\text{Where } \beta = \frac{R_2 + R}{R_2} > 1, \tau = C_2 R_2 \quad \ldots\ldots (11)$$

5.2. CONTROLLER TECHNIQUE

The controller works on determining the controlled variable and compares the actual value to desired value for providing a control action required to provide the desired output. The controller attempts to correct the error between a measured process variable and desired set-point by calculating the difference and then performing a corrective action to adjust the process accordingly.

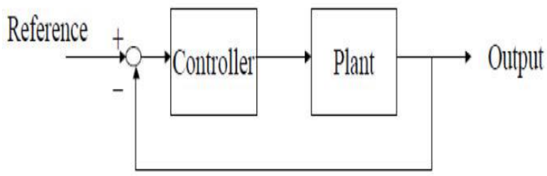

Fig 5.2. (a) Controller Network

Depending on the types of Control action controllers are classified as:

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5.2. (a) ON-OFF Controller.
5.2. (b) Proportional Controller.
5.2. (c) Integral Controller.
5.2. (d) PID controller.

As per the system requirement there is the need of PID Controller network for improving the system response towards transient and steady state performance of system.

5.2. (d) PID CONTROLLER

The PID controller is the most common form of feedback. It was an essential element of early governors and it became the standard tool when process control emerged in the 1940s. In process control today, more than 95% of the control loops are of PID type. The transfer function of PID controller is given as:

$$u(t) = K_p \left[e(t) + \frac{1}{T_i} \int_0^t e(\tau) d\tau + T_d \frac{de(t)}{dt} \right] \quad \text{........ (12)}$$

Proportional plus Integral plus Derivative control action is a combination of all three types of control methods. PID-control is most commonly used because it combines the advantages of each type of control. This includes a quicker response time because of the P-only control, along with the decreased/zero offset from the combined derivative and integral controllers. The offset was removed by additionally using the I-control. The addition of D-control greatly increases the controller's response when used in combination because it predicts disturbances to the system by measuring the change in error. On the contrary, as mentioned previously, when used individually, it has a slower response time compared to the quicker P-only control. However, although the PID controller seems to be the most adequate controller.

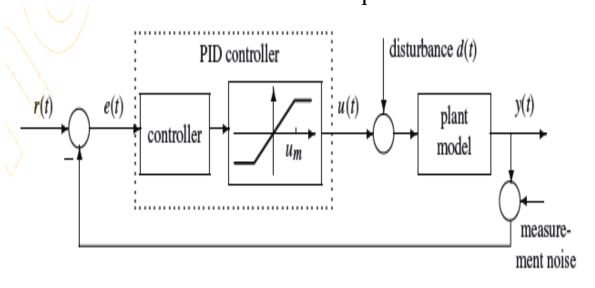

Figure *A typical PID control structure.*

Fig 5.2 .d (a) PID Controller Network

VI. MATLAB

MATLAB (**Mat**rix **Lab**oratory) is a numerical-computing environment and fourth generation programming language developed by MATHWORK. MATLAB allows matrix manipulations, plotting of functions and data, implementation of algorithms, creation of user interface by using MATLAB we can draw mathematical equations, transfer function and system response to study and also evaluate the system performance.

The system is evaluate by MATLAB and coding for DC Motor for obtaining optimal performance is done using Lag compensator and PID Controller. An optimal model is designed through MATLAB for obtaining optimal performance specification and comparative study is done for Lag compensator and PID controller.

VII. RESULT AND COMPARITIVE ANALYSIS OF SYSTEM RESPONSES

An optimal model is made for the DC motor and comparative study is done for DC motor for achieving optimal performance specification using LAG compensator and PID controller.

DC motor is modeled for mathematical transfer function and their characteristic has been observed by using MATLAB. The DC Motor system specifications are as:

R= 2 Armature resistance (Ohms)
L= 0.4 Armature self-inductance (Henrys)
K_t=0.01Armature constant
K_b = 0.2 Back emf constant
J= 0.02 Moment of inertia (kg.m2/s^2)

DC Motor has drawn for transfer function and the system specification is observed. The system response that is transient response and steady state response are analyzed and drawn. For obtaining the optimal performance specifications the LAG compensator and PID controller are tuned to the DC motor system. This improved system response. Hence system parameter is made to obtain the accuracy and stability.

DC motor system performance are studied by Root Locus plot, Bode plot and step response that contain transient response and steady state response is drawn to analyze the DC motor performance.

7.1. ROOT –LOCUS PLOT

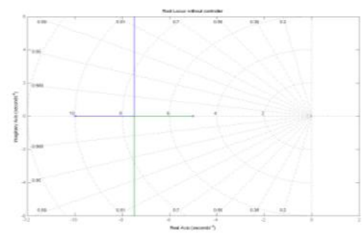

Fig 7.1 (a) Root Locus Plot Without Controller

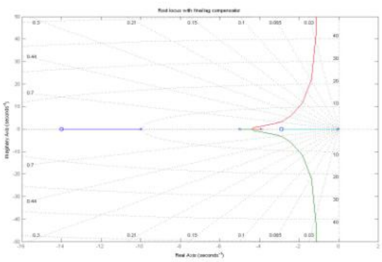

Fig 7.1 (b) Root Locus Plot with Final LAG Compensator

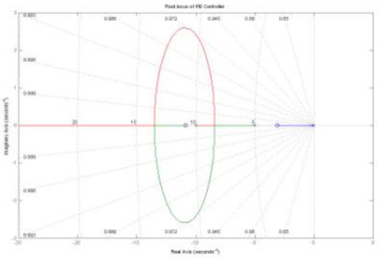

Fig 7.1 (b) Root Locus Plot with PID Controller

7.2. BODE PLOT

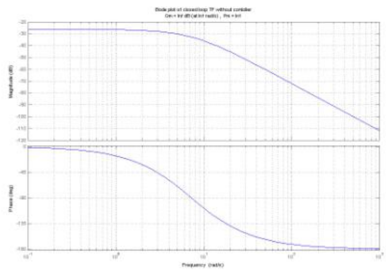

Fig 7.2 (a) Bode Plot without Controller

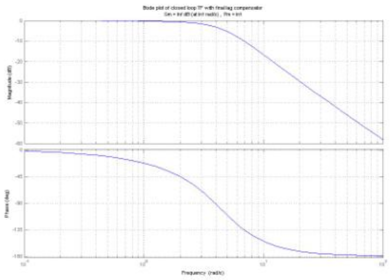

Fig 7.2 (b) Bode Plot LAG Compensator

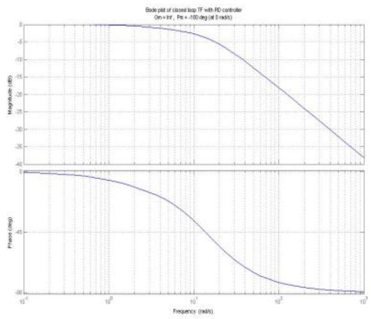

Fig 7.2 (c) Bode Plot PID Controller

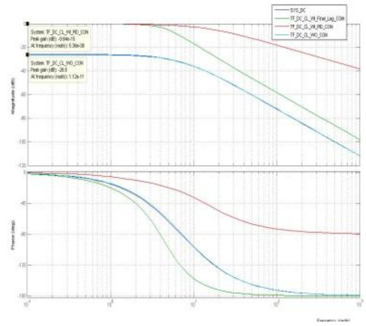

Fig 7.2 (d) Bode Plot of Without controller and LAG Compensator PID Controller

7.3. STEP RESPONSE

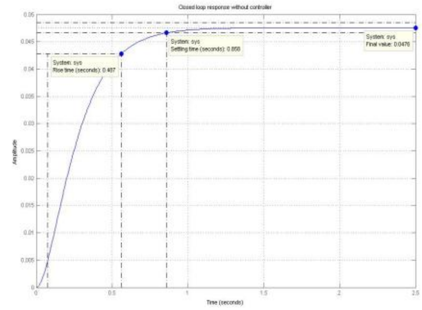

Fig 7.3 (a) Step Response without Controller

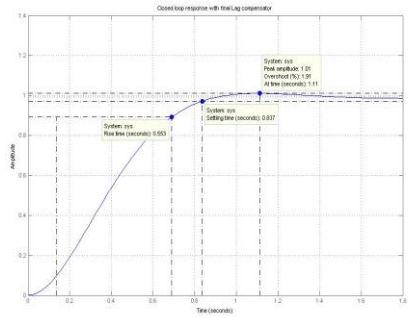

Fig 7.3 (b) Step Response with LAG Compensator

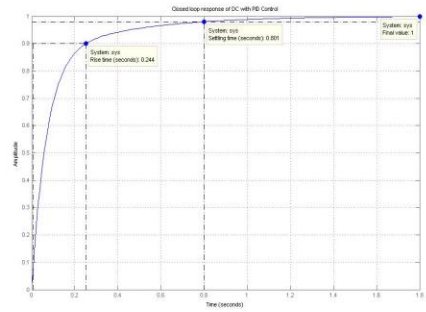

Fig 7.3 (b) Step Response with PID Controller

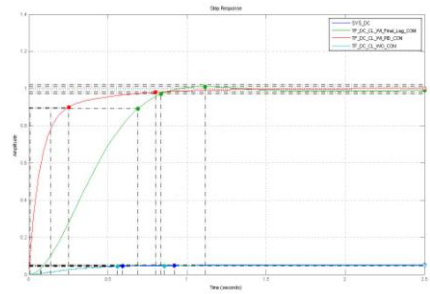

Fig 7.3 (d) Step Response of Without controller and LAG Compensator PID Controller

T. No. 1.
A COMPARITIVE PERFORMANCE ANALYSIS OF DC MOTOR CONTROL SYSTEM

Control System		PERFORMANCE ANALYSIS PARAMETERS				Overshoot (%)
Types		Rise Time	Settling Time	Steady State Value	Peak Response	
1.	Closed Loop Response Without Controller	0.587 s	0.858 s	1	0.0476	1.91
2.	Closed Loop Response With Lag Compensator	0.553 s	0.837 s	0.991	1.01	0.91
3.	Closed Loop Response PID Controller	0.244 s	0.801 s	1	0.999	0

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VIII. CONCLUSION

Comparative study of DC motor for optimal performance using LAG compensator and PID controller has done. It is concluded that LAG compensator improves steady state response but PID controller rectify the overall performance of system that and it improves transient as well as steady state response. The LAG compensator reduces the phase shift hence decreases the gain cross over frequency, bandwidth decreases and rise time and settling time become large and response become slower whereas PID controller rectifies the reduces the overshoot and rise time and settling time hence the response become faster and improves stability and accuracy of system. It has better future scope in industrial applications and also reduces the operational cost and improves the overall performance of system.

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BIOGRAPHIES

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