# Compensator Design for Speed Control of DC Motor by Root Locus Approach using MATLAB

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**Abstract -** *In this paper we focus on stability and performance of the System. Motors do not give full stability in its running operations. So as to maintain maximum accuracy and to get desired response the compensator circuit is use with system i.e. DC motor. Thus to get desired output from system it is necessary to introduce a compensator in system. This can be done by reducing overshoots and time domain parameters. It is not possible to study a practical system and evaluate all minor and major parameters, hence all the study is done on the basis of Laplace domain. Another problem encountered is that it becomes difficult to evaluate all the responses on the basis of first order system. Therefore to control speed of DC motor we have assumed the system to be performing on position control. In this paper compensator is designed by using MATLAB programming.*

*Key Words: Compensators, Computer Aided Design, Desired Response Specifications, MATLAB, Root Locus.*

## 1. INTRODUCTION

Today control systems are playing an important role in development of modern civilization and technology. Every system we come across today has some type of control engineering involved in it. In any sector of industry, you will find control systems everywhere. Say, inventory controlled of manufactured products, automatic assembly line, machine tool control, the space technology and weapon systems, the robotics, the power plants all are the industrial sectors. The system to be controlled is given different names. The most common being a process or a plant or the controlled system itself.

No system can be ideal and hence there are some power consuming elements. These causes the fall in efficiency and performance of the system. The system do not gives its actual performance. In a DC motor as considered has various power consuming elements such as inductance, resistance, friction, inertia, etc. It becomes possible to use a controller with the system which helps in providing desired response at the output. This can help to maintain speed, accuracy and performance of device (motor, etc.). In this project we are concentrating on compensator as a

controller to a DC motor. A compensator is a component in a control system that improves an undesirable frequency response in a feedback and control system. It is a fundamental building block in classical control theory. There are two general types of compensators: Lead Compensators, and Lag Compensators. If we combine the two types, we can get a special Lead-Lag Compensator system.

## 2. PROBLEM STATEMENT

To control the speed of DC motor, primary task is calculate the transfer function of motor. The transfer function obtained will be in the form of first order as given below,

$$\frac{w(s)}{V(s)} = \frac{1}{\tau s + 1} \qquad (1)$$

Where,

$w(s)$ =Speed of rotation (Output) $V(s)$ =Voltage (Input)

Calculating the response and time domain parameters is difficult. Thus to make it easier converting the above equation in second order,

$$\frac{\theta(s)}{V(s)} = \frac{1}{s(\tau s + 1)} \qquad (2)$$

After calculating responses by considering position control the model will again be converted to velocity control by using derivative block as stated below,
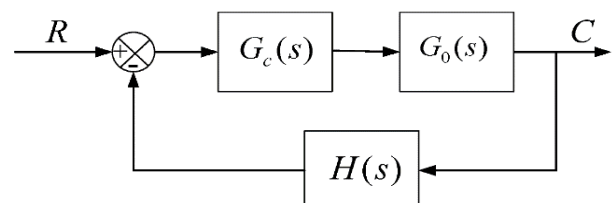


**Fig-1**: System block diagram of compensated system

In root locus technique, graphical calculations are more and becomes a long process to obtain a compensator

model. Thus here we have formed a complete program for which makes it easy to calculate.

## 3. DESIGNING PROCEDURE:

### 3.1 Lead Compensator:

1. Compute the transfer function of the system. Here computed is,

$$\frac{\theta(s)}{V(s)} = \frac{17.146}{s(0.043s + 1)} \qquad (3)$$

2. Get required or available value of ζ and ωn through responses of system or from given parameters and decide required Ts and Mp and then calculate $\xi$ and ωn which is required for designing as per specifications.
3. Plot root locus of open loop T.F. of the system computed and Plot 'Sd'= $-\zeta.\omega n \pm \omega n \sqrt{1 - \xi^2}$.
4. Calculate φ=$-180 - \angle G(s)$.
5. Plot compensating zero by assuming it (Assume it just after system pole).OR Find the $\gamma, \beta, \theta$ by triangle inequality theorem, from root locus graph.
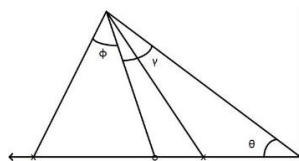


**Fig-2**: Root Locus graph for calculation of pole and zero

6. Taking angle φ plot compensating pole to the left of compensating zero. Find value of gain k by using formula,

$$\frac{K(compensating\ zero)}{(system\ pole)(compensating\ pole)} = 1$$

and Form the final transfer function for the lead compensated system.

### 3.2 Lag Compensator:

The procedure of lag compensator design is same as lead only the change in procedure is of calculations for poles and zeros. So we will use steps of lead upto step 5 as shown in 3.1. Following are the remaining steps.

1. Calculation for velocity error constant of system by using,

$$Kv(uncompensated) = \lim_{s \to 0} \frac{s(398.74)}{s(s + 23.26)}$$

2. Value of $\beta$ = Assumed greater than factor.

$$Factor = \frac{Kv\ compensated}{Kv\ uncompensated}$$

3. Compensating zero is assumed at an angle of less than 10° i.e. 6° taken with ζ line. Calculate compensating pole by triangle inequality, then find value of gain k and form the transfer function.

### 3.3 Lag-Lead Compensator:

The procedure of lag-lead compensator design is same as lead and lag compensators designed individually. Following are the steps which give a sequential idea for designing Lag-Lead compensator.

1. Compute the transfer function of the system. Here computed is,

$$\frac{\theta(s)}{V(s)} = \frac{17.146}{s(0.043s + 1)} \qquad (4)$$

2. Get required or available value of ζ and ωn through responses of system or from given parameters and decide required Ts and Mp and then calculate $\xi$ and ωn which is required for designing as per specifications.
3. Plot root locus of open loop T.F. of the system computed and Plot 'Sd'= $-\zeta.\omega n \pm \omega n \sqrt{1 - \xi^2}$.
4. Calculate φ=$-180 - \angle G(s)$.
5. Now, calculate lead branch as per part (3.1) and lag branch as per part (3.2), then calculate combined gain to compensate and form the final compensated system.
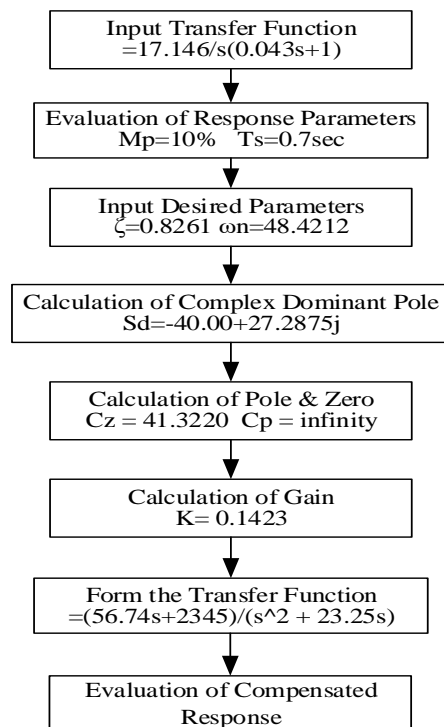
## 4. PROGRAM FLOW CHART:



**Fig-3** Algorithm for Lead Compensator

Figure 3 shows the algorithm flow chart for the lead compensator. In that explained step by step procedure for evaluation of parameter for lead compensator. Similarly figure 4 and figure 5 shows the algorithm flow charts for lag and lag-lead compensator respectively.
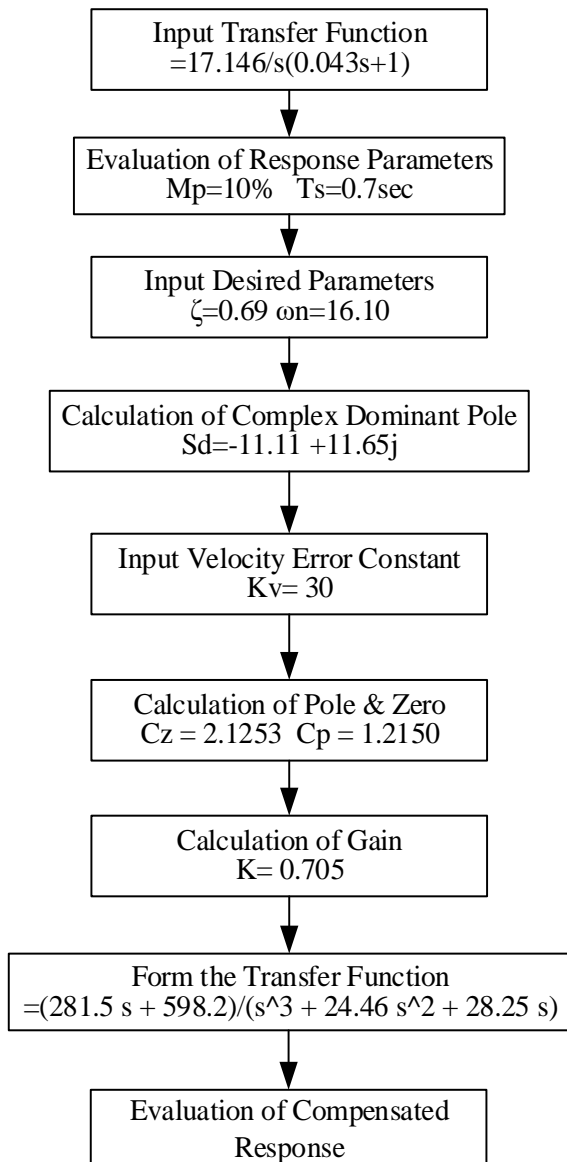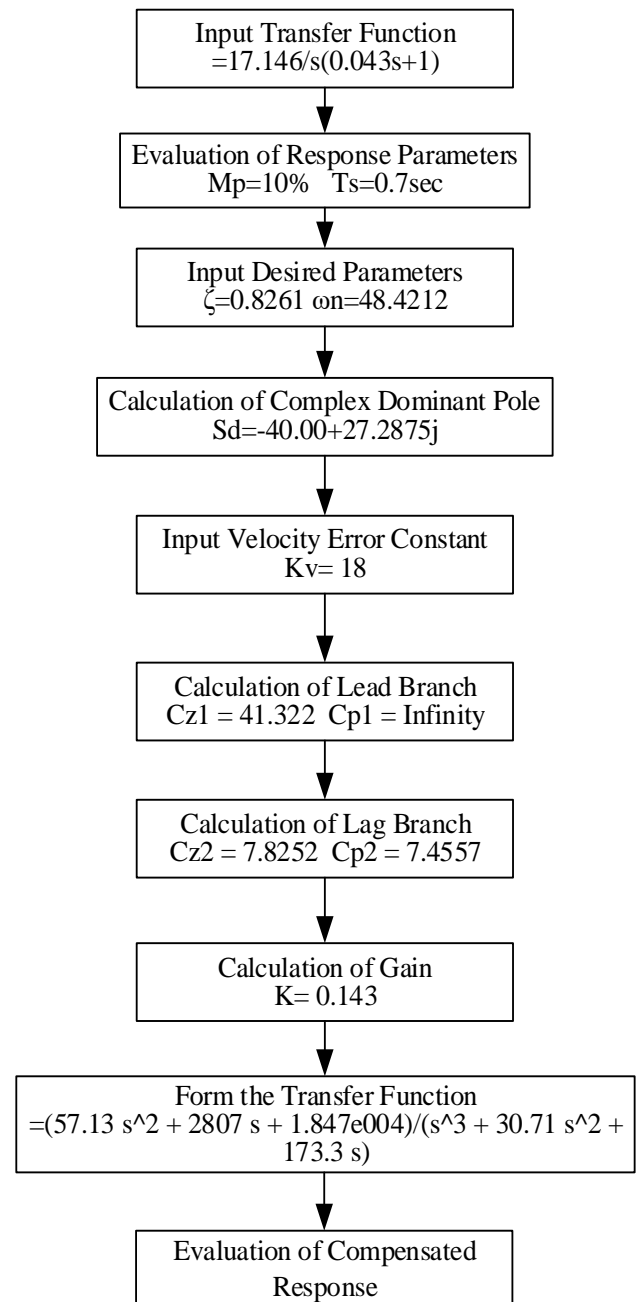


**Fig-4** Algorithm for Lag Compensator



**Fig-5** Algorithm for Lag-Lead Compensator

## 5. RESULTS AND DISCUSSION

The responses obtained for Lead Compensator are plotted as shown in figure 6 and the performance parameters calculated and compared in table 1 which is directly calculated from MATLAB program designed as per the flow chart shown in figure 3. In lead compensator the pole obtained by the formula for solving triangle is found to be infinity, as this value is not possible we considered its impedance to be infinity and behaves as open circuit.

The response obtained for Lag compensated system with comparison to original one is shown in figure 7. The evaluated values of different performance parameters of responses is tabulated in table 1. Also figure 4 shows the flow chart for the MATLAB program through which it is evaluated. Lag compensator reduces the distortion but takes a large settling time in compare to lead, thus this proves that lag improves steady state time of response. The steps as evaluated are as similar to lead. As per the study it is found that the response of lag is not very flexible which proves that lag is invalid for higher order systems.

In Lag-Lead compensator the respective response and the evaluated results of different performance parameters is as shown in the figure 8 and table 1 with respect to results evaluated as per MATLAB program as per flow chart figure 5. From the response it is clear that lag-lead compensator is having both properties of lag of improving steady state and lead for improving transient response.
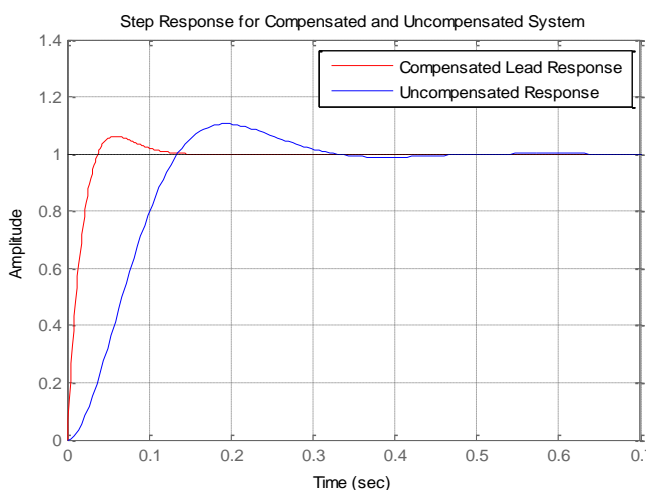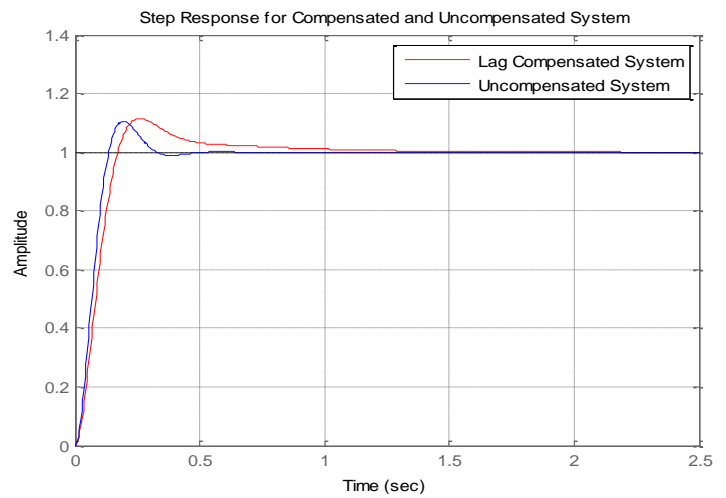


**Fig-7** Step response for compensated and uncompensated system. (Lag Compensator)



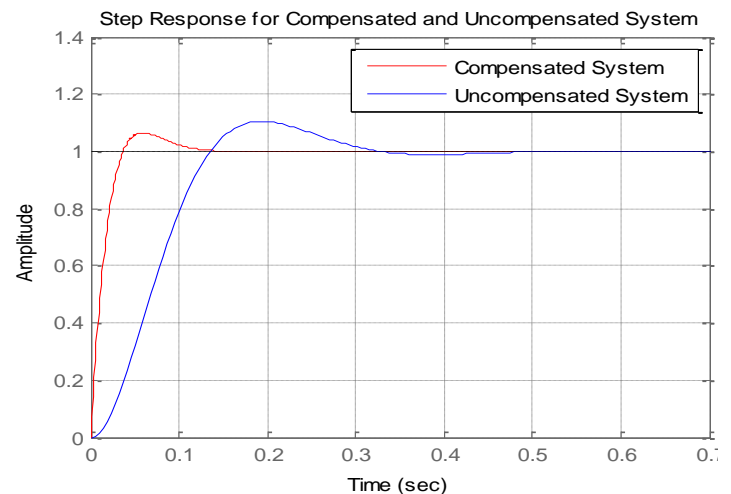**Fig-8** Step response for compensated and uncompensated system. (Lag-Lead Compensator)



**Fig-6** Step response for compensated and uncompensated system. (Lead Compensator)

| Parameters | Uncompensated System | Lead Compensated System | Lag Compensated System | Lag-Lead Compensated System |
|---|---|---|---|---|
| Peak overshoot | 10% | 6% | 12% | 7% |
| Settling time (sec) | 0.7 | 0.129 | 1.5 | 0.131 |
| Rise time (sec) | 0.135 | 0.038 | 0.2 | 0.037 |
| Peak time (sec) | 0.194 | 0.06 | 0.25 | 0.057 |

**Table: 1:** Comparison between parameters of Lead, Lag and Lag-Lead compensator.

## 6. CONCLUSIONS

From the above results, the program is giving optimum value of compensation. After obtaining the compensated values it can be added with derivative block to get speed control response. From the evaluation it is found that the value of lead compensator can be varied as per conditions, but choosing value of lag compensation is limited to certain proportion only. From the simulation result of lead and lag compensator it's seen that lead compensator improves the transient response and lag compensator improves the steady state response.

As the lag-lead compensator response shown in figure 8 is giving improved as compared to lag and lead compensators acting individually and improves both transient and steady state response.

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