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BASICS OF STUDYING MODEL FOR A DIRECT CURRENT MOTOR USING CONTROL ANALYSIS METHODS

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Abstract:
This study focuses on the control analysis methods used to implement mathematical equations for Direct Current Motor (DCM) parameters. It involves an examination of the analysis methods through computer simulations aimed at providing a comprehensive account of the nature of simulations for direct current electrical machine in education. In this way, the aim is to visually, analyze and capture the effect of DC motor parameters with mathematical equations by changing those DCM parameter values by using symbolic Mathematica language. Finally, the implications of the knowledge of analysis models for DC motors and control units is studied, which is a fundamental factor in teaching the nature of DC electrical motors.

Keywords: direct current motor, control analysis, transfer function, step response, bode diagrams

1. Introduction

In this study, the simulation of control analysis examples with the software development has been created using Mathematica software, due to its strong symbolic language and the available tools it provides. The most commonly used analysis methods are simulated on separately excited DCM transfer functions. The simulations are created and modified as a small graphical area representing manipulation of the s-plane. The studied circuits have been used to analyze separately excited DCMs, which are shown in Figure 1, using a step response method and Bode diagrams, with and without a proportional–integral–derivative (PID) controller [1] to [5].

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2. Model-Based on Transfer Functions for Separately Excited DCM

The mathematical modeling of separately excited DCMs to obtain the transfer function between command input and output is shown in Figure 1.

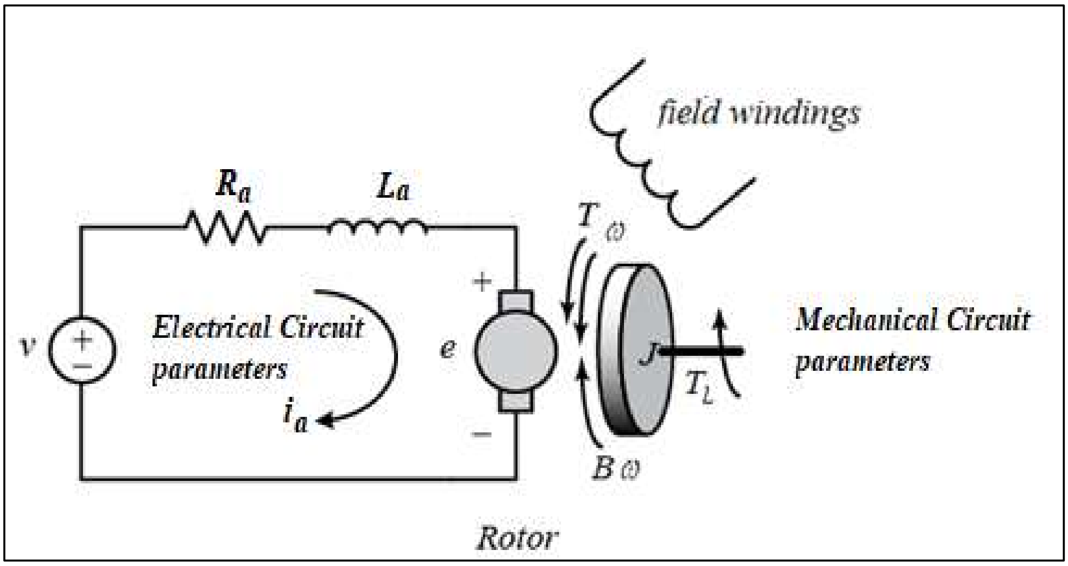


Figure 1: Separately excited DCM standard schematic diagram

According to Fig.1 where Kirchhoff's Voltage Law and mechanical equations are applied, the transfer function is derived as follows:

$$\frac{k_f}{(Js+B)(L_a s+R_a)+k_f^2} \tag{1}$$

where k_f is the motor constant, the armature coil is represented by an inductance $L_a\,(H)$ and a resistance $R_a\,(\Omega)$, $B(Nm.s/rad)$ is the friction coefficient and $J(kg.m^2)$ is the inertia torque. The control transfer function for a PID is shown in equation 2:

$$k_p s+\frac{k_i}{s}+k_p \tag{2}$$

where k_p, k_d, k_i are the proportional, derivative and integral gains respectively. Numerically, the rotor inertia value is J = 0.01 $kg.m^2/s^2$, the friction of the mechanical system, is B=0.1 Nms/rad,, back emf and torque constant is $k_f = 0.01\ Nm/A$, the electrical circuit resistance is $R_a = 1\,\Omega$, and the inductance is $L_a = 0.5\ H$.

3. Results and Discussion on the Control Analysis Methods

Equations (1) and (2) is the transfer functions to illustrate the step response and bode diagrams .Fig.2 (a) [1], [2] and Fig.2(b) correspond to the closed loop with control, the closed loop without control and the open loop transfer function, respectively, when unit step voltage is applied. The commands on this is given in appendix (also see figure 4). In this way, the aim is to be able to explore how the locations of poles and zeros in the s-plane are affected by the step response.

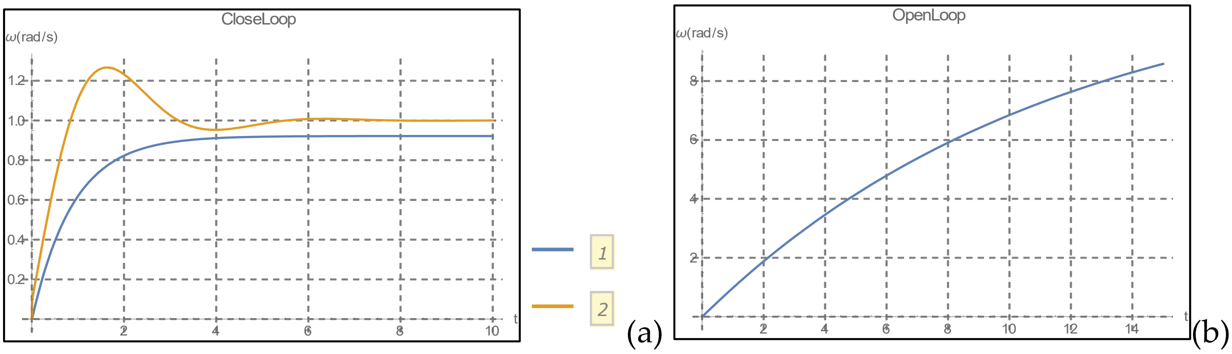
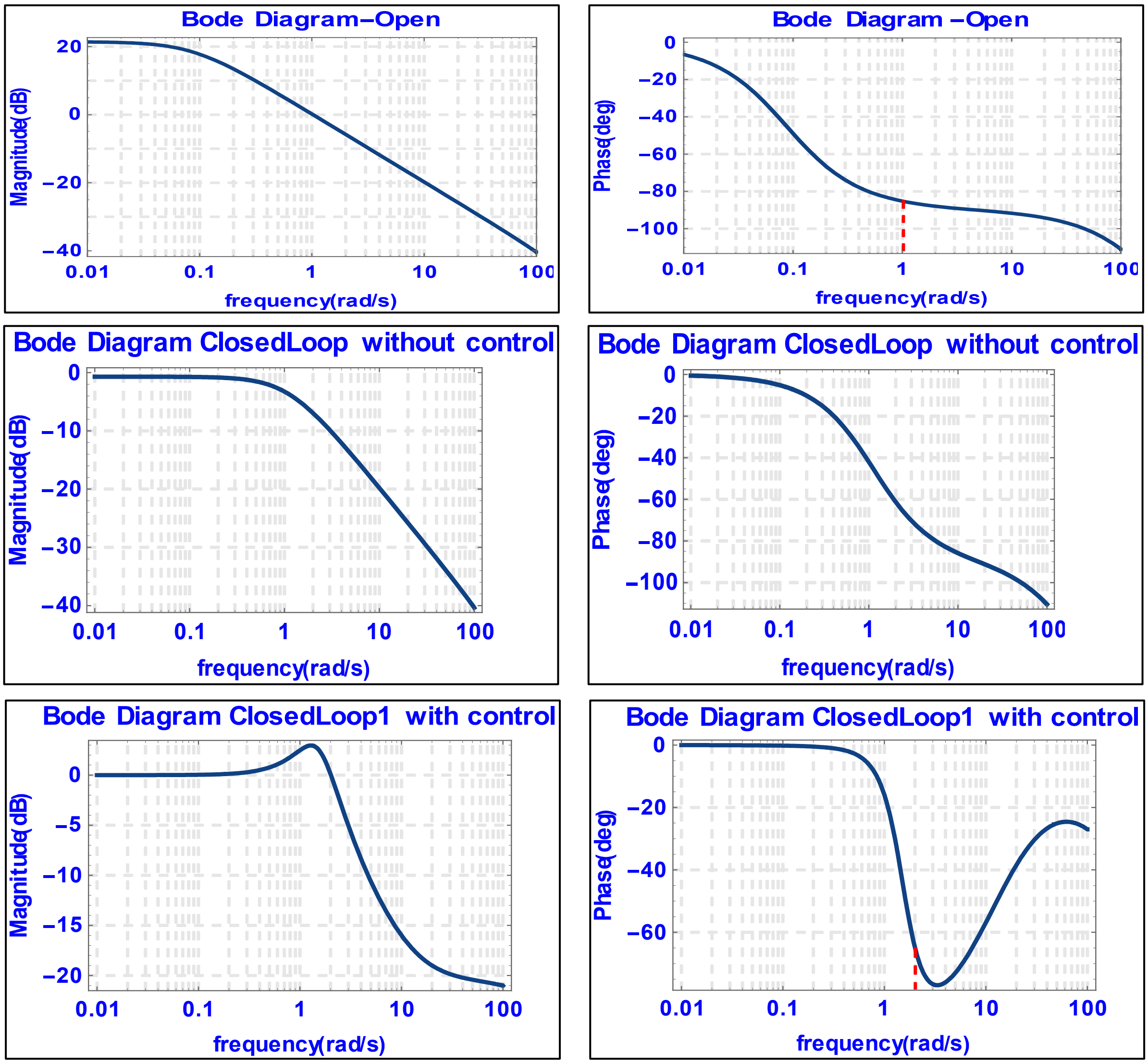


Figure 2: Step response of DCM (a) closed loop response 1 without control and 2 with control system, (b) open loop plot

The frequency response (Bode) diagrams show the magnitude in dBs and the phase differences between the input and output. Adding a controller to the system changes the open-loop Bode plot, thereby changing the closed-loop response. With a given software service, students can check to see if the control meets the requirement specifications and can take part exercise provided by the lecturer. If so, the students are ready to move their project to the implementation and testing phases. The limits of angular frequency define the horizontal axis obtained in the plot, and changes in the form of these limits are determined automatically by Mathematica [6]. The commands to use transfer function is given in applet window below first line, the constants of the motor are given in the second line:

$$\text{dcmotor[Kt\_, Kf\_, J\_, B\_, L\_, R\_]} := \text{TransferFunctionModel}\left[\frac{\text{Kt}}{(Js+B)(Ls+R)+\text{KtKf}}, s\right]$$
$$\text{dcmotor[0.02,0.02,0.015,0.001,0.005,1.3];}$$

With this exercises users can easily integrate, improve and compare their knowledge. To teach the effectively interest of the subject, some software program tools and commands, which has been used here, are given in appendix in detail. The Bode plots are given in detail with stability margins in Figure 3(a),(b) and(c). The red-dashed line indicates the stability of the margins [6].



(a)
(b)
(c)

Figure 3: Bode Plots of transfer function open (a) and closed (b) and with control (c).

4. Recommendations

This study can be widened with the other control analysis which is Nycuist and Nicolas Methods and comparison can be considered with their advantage and disadvantage by using computer simulations.

5. Conclusion

In this study, basic DCM analysis methods are shown for the control process of a DCM. Two different dynamic performance methods are presented with their features and then examined by using Mathematica software tools. It is thought that the study performed here is useful to control-related engineers and students to understand the effects of the analysis methods.

About the Author

N. Fusun Oyman Serteller received B.S. degree in Electrical Engineering from ITU (Istanbul Technical University) and MSc. degree from ITU and Ph.D. from Marmara University, in 1996 and 2000 respectively. She lectured in the department of Electrical Education department between 2001 and 2012. She has been as a lecturer in Electrical Engineering Department of Marmara University, Technology Faculty since 2012. Her research interests include electrical machines, electromagnetic fields, numerical analysis and education analysis via computer on interest area.

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[5] Antanio (2012). Research Trends for PID Controllers, ACTA, Polytechnica Vol 52,No.5.

[6] Wolfram Mathematica, version 12.

Appendix

Using PID coefficients:

```
kip=1.5;ki=2.5;kid=0.1;
pid=TransferFunctionModel[(kip*s+ki+kid*s^2)/s,s];

input=UnitStep[t];
output=OutputResponse[closedLoop,input,t];*)
dcmotor[Kt_,Kf_,J_,B_,L_,R_]:=TransferFunctionModel[ Kt/((J  s+B )(L s+R)+Kt Kf ),s]

tmf=dcmotor[0.02,0.02,0.015,0.001,0.005,1.3];
CloseLoop=SystemsModelFeedbackConnect[tmf];
openLoop=SystemsModelSeriesConnect[TransferFunctionModel[tmf],pid];
closedLoop1=SystemsModelFeedbackConnect[openLoop];
```

Using tune activities (alternative to pid coefficients):

```
openLoop1=PIDTune[tmf,"PID","PIDData"]
```

Gain and Phase Stability Tools:

```
GainPhaseMargins[CloseLoop]
GainPhaseMargins[openLoop]
gpm=GainPhaseMargins[closedLoop1]
GainMargins[CloseLoop]
PhaseMargins[CloseLoop]
Map[{#[[1]],#[[1]]/Degree}&,%%%]
```

Bode Plot;

```
Bode Plot[tmf,{.01,100},PlotLabel->"Bode Diagram-Open",LabelStyle-
>Directive[Blue,Bold],PlotStyle-
{Directive[Thick,ColorData[20,1]],Directive[Thick,ColorData[20,9]]},GridLines-
>Automatic,GridLinesStyle-Directive[GrayLevel[0.9],Dashed],StabilityMargins-
>True,StabilityMarginsStyle-{Green,Directive[Red,Dashed]},ImageSize->250,Frame-
>True,PlotStyle-
{Directive[Thick,ColorData[20,1]],Directive[Thick,ColorData[20,9]]},Frame-
>True,FrameLabel-
{{"frequency(rad/s)","Magnitude(dB)"},{"frequency(rad/s)","Phase(deg)"}},PlotLayout-
>"List"]
BodePlot[CloseLoop,{.01,100},PlotLabel->"Bode Diagram ClosedLoop without
control",LabelStyle-Directive[Blue,Bold],PlotStyle-
{Directive[Thick,ColorData[20,1]],Directive[Thick,ColorData[20,9]]},GridLines-
>Automatic,GridLinesStyle-Directive[GrayLevel[0.9],Dashed],StabilityMargins-
>True,StabilityMarginsStyle-{Green,Directive[Red,Dashed]},ImageSize->250,Frame-
>True,PlotStyle-
{Directive[Thick,ColorData[20,1]],Directive[Thick,ColorData[20,9]]},Frame-
```

>True,FrameLabel-
{{"frequency(rad/s)","Magnitude(dB)"},{"frequency(rad/s)","Phase(deg)"}},PlotLayout-
>"List"]

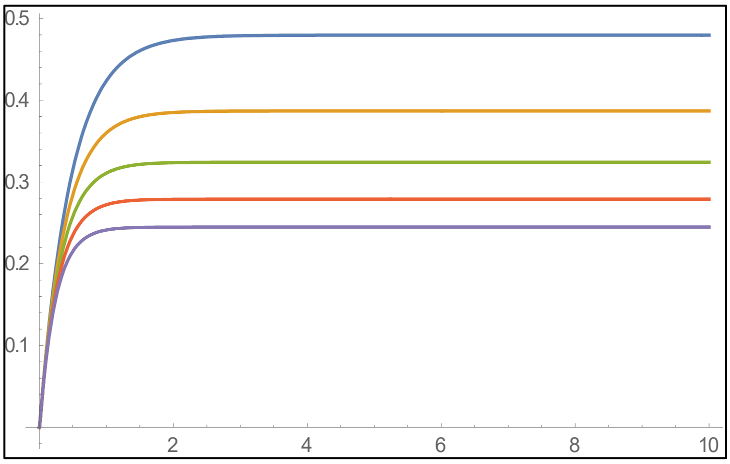

Figure 4: Step response of DCM for closed loop without control system