Second Homework, Motor Loop Shaping using Mixed Synthesis Design

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Abstract

The aim of this paper is to study the dynamics of a DC motor, construct the exteneded plant, obtain a robust controller using mixed synthesis design method and compare the result obtained with H-infinity sysnthesis.
Then, we will analyze the effect of the inductance term and related high frequency dynamics on the plant, neglect them and build a controller on the plant with neglected dynamics. The controller will be applied to both plants and results will be compared.
In the end, we will study the effect of uncertainties on the open loop plant in feedback loop with the robust controller synthetized before, based on the knowledge of the nominal plant and the range of the uncertainties.

Keywords: Motor, Mixsyn, Hinfsyn, MIMO, Uncertainties, Neglected Dynamics

1. Augmented Plant and Controller Synthesis

The DC motor has an internally stable open loop dynamics, this imply that since we have two poles, no one belongs to R.H.P., and at the same time the system is also minimum phase. From the analysis of its transfer function we can deduce that the motor dynamics depends only on the pole that is closer to the Imaginary Axis.

To synthetize the controller we will first build the augmented plant in Matlab by using *augw()* after having specified the three weights. These weights that penalize the error signal, the control signal and the output signal and their inverse times gamma are bounds for the H-infinity norm of the sensitivity function, control sensitivity function and complementary sensitivity functions respectively. Since the loop function, far away from its crossover frequency, can be approximated with the inverse of the sensitivity and complementary sensitivity, in order to achieve good reference tracking and distrubance rejections we choose W1 large in the control bandwidth and to attenuate the effects of the disturbances, that are modeled in simulink, and to achieve a good robustness and noise attenuation, we will choose W3 large at high frequency. W2 will be considered as a pure gain. Below are shown the following choiches and the resulting loop function.

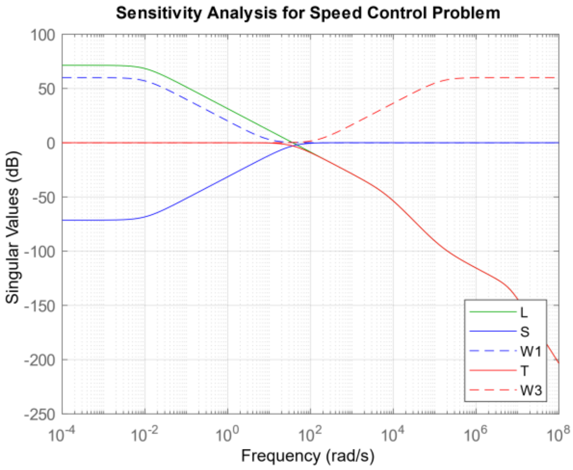

Fig.1 Mixed Synthesis Results

In the figure below we show the angular speed obtained with the controllers built with *mixsyn* and *hinfsyn* Matlab commands.

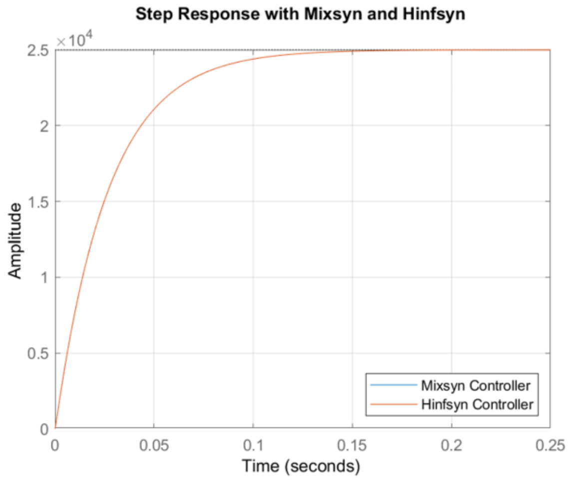

Fig.2 Step Responses Comparison

The responses are similar and in both cases the system reach the reference value of 25000 rpm, while penalizing the control effort. The step input is chosen to be smoother in simulink.

Before proceeding we would like to investigate how the control input is affected by this choice of the weights, and since there is a nominal voltage of 6 Volts, it should converge to that and shouldn't have a large peak value. The plot of the control input is shown below:

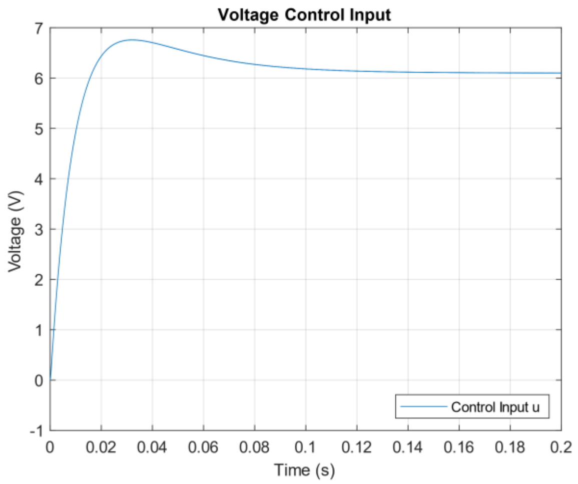

Fig.3 Voltage Control Input

2. Neglection of High Frequency Dynamics

The open loop plant is characterized by two LHP poles, but since the dominant one is the smaller in absolute value, we can neglect the faster one (that can be done neglecting the inductance term in the nominal plant while keeping the resistive component) and construct a controller on this plant.

The resulting controller will have one pole and one zero less than the controller builded on the nominal system, still guarantee stability and will be strictly proper.

Below are shown the poles and zeroes locations for the nominal cascade loop function and that one with neglected dynamics and the Bode plots of the two loop functions. As one can cleary see from Fig.5, the phase margin remain the same, as the behavior in the neighborhood of the crossover frequency, while the gain margin become infinite.

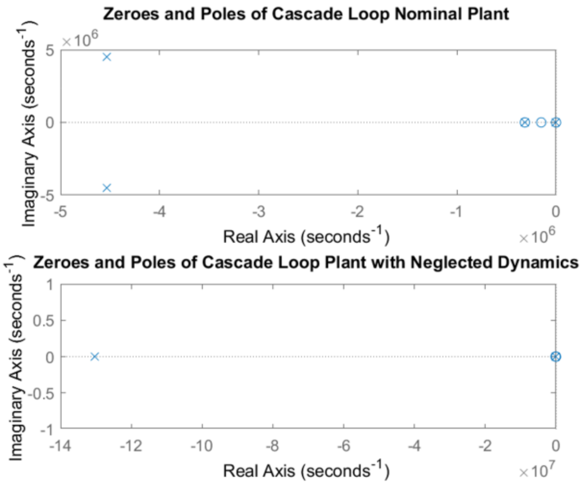

Fig.4 Pole Zero Map of the Plants

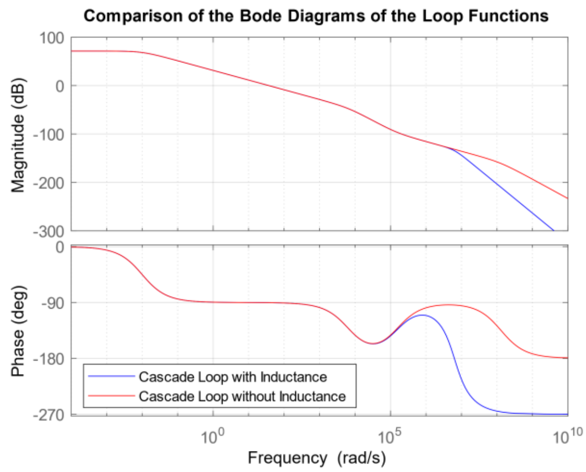

Fig.5 Bode Plots of Loop Functions

We would like to to compare the steady state value of the step response of the plant with neglected dynamics and the nominal one, when we control the system with the same controller built for the plant with neglected dynamics:

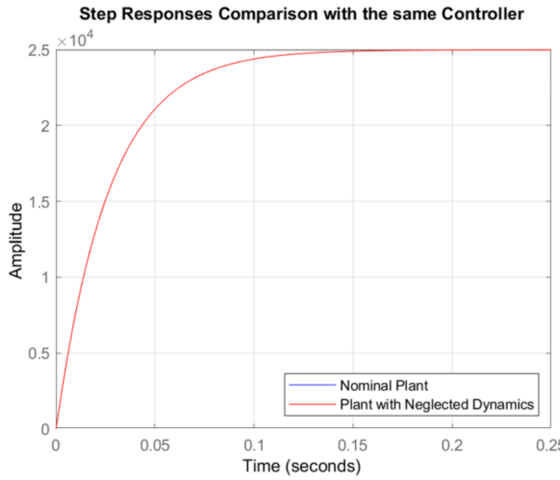

Fig.6 Step Responses Comparison

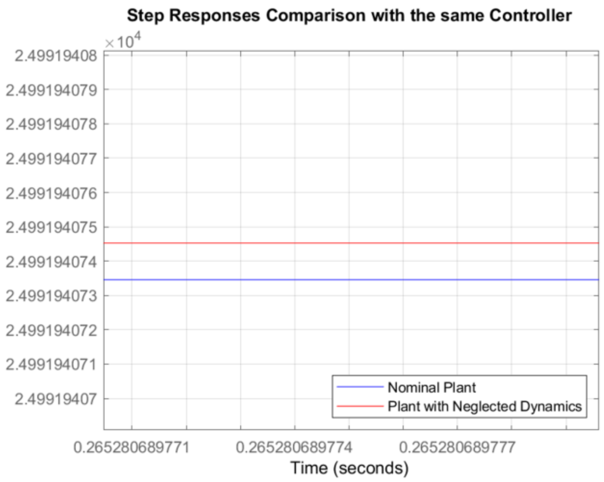

Fig.7 Step Responses Comparison at Steady State

In the end in the Matlab file I have investigated a weight to represent the neglected dynamic, by choosing that as an uncertain transfer function having a parameter varying between zero and the the time constant of the pole neglected, to mimic the behavior of this dynamic with an high pass filter. Below I showed the comparison between the nominal process, and the process with a neglected dynamics in cascade loop with a parametric weight that show the behavior of the system as the inductance approach to zero. As expected the shape of the bode plots are similar at low frequency and differ at high frequency because of the presence of the parameters.

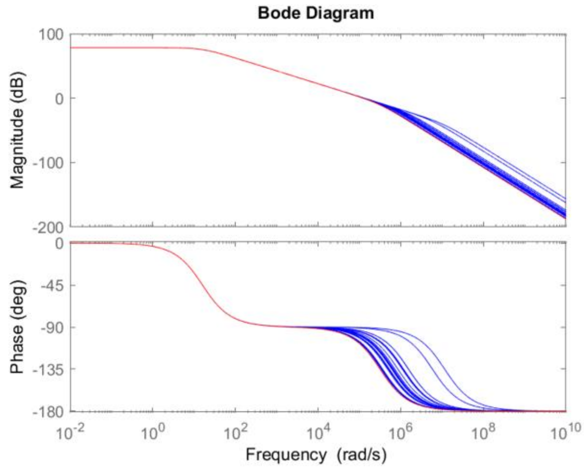

Fig.8 Bode Plots of Nominal Plant and Plant with a Weight on the Neglected Dynamic

3. Modelling Uncertainties

In the end we will analyze the effect of the perturbations acting on the parameters of the plant. All the uncertain parameters are defined using ureal Matlab command. Their nominal values are the same used for the nominal plant.

Below are shown the Bode plots of the in series with the controller open loop plant when it is affected by uncertainties.

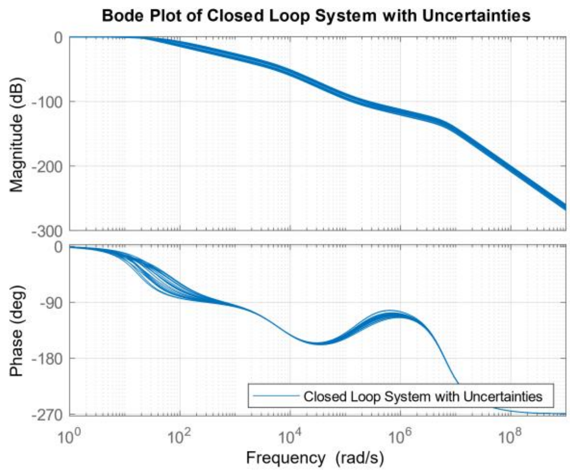

Fig.9 Bode Plots of Loop Function with Uncertainties

From this plot we can see that the bigger effects of the perturbations on the closed loop system are concentrated around the crossover frequency of the cascade loop, where the sensitivity and complementary sensitivity functions can't act simoultaneously.

The Nyquist Plot of the perturbed system is shown below.

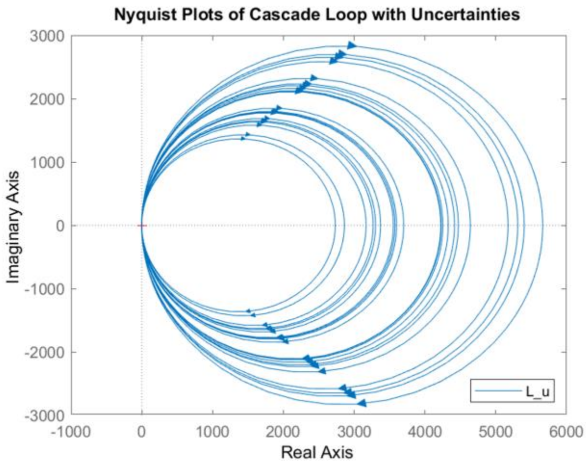

Fig.10 Nyquist Plot of Loop Function with Uncertainties

From the plot is clear that, since we have no RHP poles in the open loop plant, the closed loop system will be stable since we have no encirclementes of the point (-1,0) and we can see that the Nyquist plot does not approach this point neither.

This are the step and impulse responses of the closed loop system with unitary feedback.

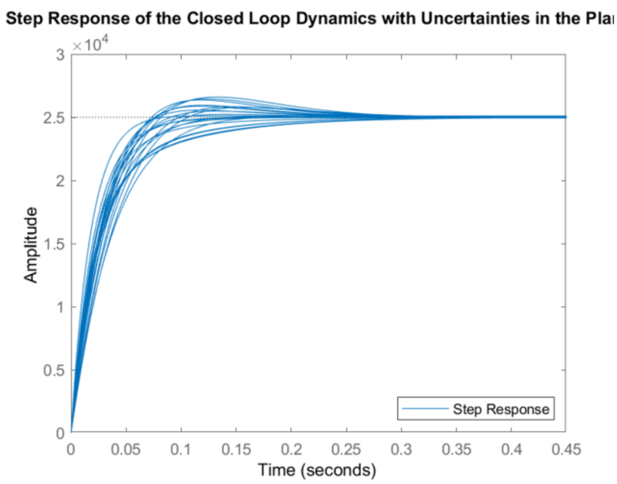

Fig.11 Step Response with Uncertainties

Hence the controller managed to track the desired angular speed when the parameters of the model are uncertain and can vary a given range.

What is new

I changed controller for point 1.

After having neglected the HF pole due to inductance, I have synthetized a new controller with new weights (changing closed loop specifications) and obtained better performance that are shown In my Simulink scheme "Sim1_Mot".

I've also founded a weight to represent neglected dynamics as an high pass filter . It may be useful to represent the frequency range in which this neglected dynamics affects the system. For example in my case this happen after 10^4. (as also seen from Fig. 8).

Of course with new controller also the plots of the uncertain plant will change, but we still have stability.

I added the robstab command in the end to have an idea of how much we could increase the parameters variations without losing stability.

Some plots are refereed to old systems : (1,2,3,4,9,10,11)

References

[1] https://www.faulhaber.com/fileadmin/Import/Media/EN_0620_B_FMM.pdf