

Using the Simulink Control Design in Speed Controller Tuning

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Abstract

Simulink® Control Design streamlines the design and analysis of control systems for nonlinear plant models built in Simulink. It offers possibility to automatically extract linear approximations of the model, perform frequency-domain analysis and tune the control system parameters directly in Simulink using a range of tools and techniques. The paper presents the application of the Simulink® Control Design in a PID controller tuning of a spark ignition engine with numerically optimize of the compensators with the purpose to meet time- and frequency-based design requirements.

Key words: control design, simulation, PID controller.

Introduction

The Simulink® Control Design software provides tools for linearization and compensator design for control systems and models [11]. Linearized models often simplify compensator design and system analysis. This is useful in many industries and applications, including:

- automotive: cruise control, emissions control, transmission;
- equipment manufacturing: motors, disk drives, servos;
- aerospace: flight control, guidance, navigation.

This software provides a graphical user interface (GUI) which can be used to:

- compute operating points of models using specifications or simulation;
- extract linear models from systems;
- tune compensator blocks in models with either single or multi-loop configurations.

Many common control system analysis and design methodologies require linear, time-invariant models. However, control systems and physical models created with Simulink® are often nonlinear and time-varying. Linearization is the approximation of a nonlinear system as a linear system, based on the assumption that the system is almost linear within a certain range of operation [2]. A linearized model can provide a good approximation to a nonlinear system when created and used carefully. With a linearized model it can [4]:

- express a model as a transfer function, state space model, or zero-pole-gain model;
- display and analyze the dynamic behavior of a model;
- use the compensator design tools to tune control systems;
- determine the response of a model to arbitrary input signals.

Compensator design process overview

Compensator design is the process of designing compensators for a control system so that the system behaves in a desired way. Compensators in Simulink® models are represented by blocks such as Transfer function, Zero-Pole-Gain and PID blocks. These blocks can act as feedback controllers, pre-filters, feedforward controllers, sensors etc [3]. Compensator design for Simulink models can be as simple as adjusting gains in a one of these blocks, or as complicated as adding, deleting, or moving poles and zeros in multiple compensators over multiple loops. Compensator design methodologies often make use of tools such as Bode diagrams, root-locus diagrams, or response plots. These tools require that the plant model is linear; however, most real-world systems are nonlinear [8, 12]. Simulink® Control Design simplifies the task of designing compensators for Simulink models by linearizing the model before creating a SISO Design Task in which it can edit and design the compensators using a variety of tools.

The Simulink scheme shown in figure 1, used to exemplify the application of Simulink® Control Design in controller tuning, contains, as Plant, a spark ignition engine model (adapted after `sldemo_engine.mdl` Simulink file), whose input signal is a controlled angle [11]. The scheme is provided with both Reference filter and PID controller in a single-loop feedback system.

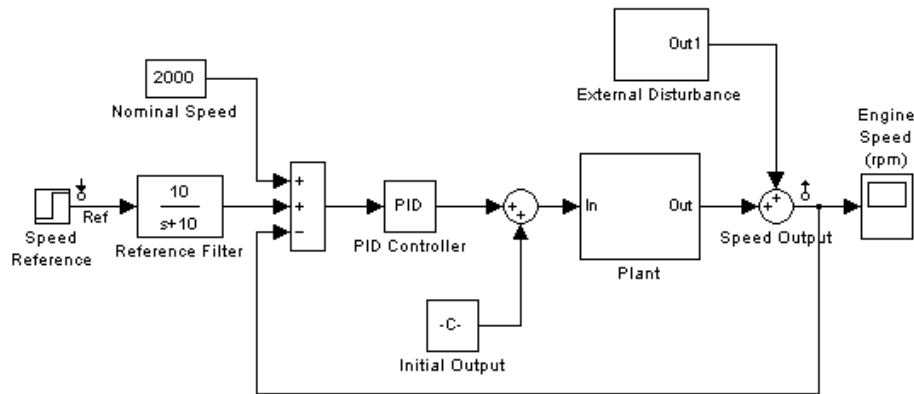


Fig. 1. The Simulink scheme for the speed control of an engine.

Compensator design in the Control and Estimation Tools Manager involves the following steps:

- picking blocks to tune;
- selecting closed-loop responses to design;
- selecting an operating point;
- creating a SISO Design Task;
- completing the design.

Computing a steady-state operating point

An important step in the compensator design process is the selection of the operating point about which the system is linearized. An operating point is a set of inputs, outputs and states that describe the operating conditions of a system. A steady-state operating point is an operating point in which all states remain constant over time [9, 10]. Many real-world systems are designed to operate at steady-state operating points. Computing a steady-state operating point is required for [6]:

- analyzing system dynamics at steady state using simulation;
- linearizing a model at a steady-state operating point;
- designing a compensator for use at a steady-state operating point.

Simulink® Control Design provides five methods for specifying the operating point [11]:

- from partial specifications about target values or constraints on a subset of the model's inputs, outputs and states;
- from Known Values when the values of states and inputs at the point of interest are known;
- by accepting the default operating point, defined by the initial values of the states, inputs and outputs, when these are very close to the operating point of interest;
- by simulating the system at the time of interest;
- by importing a previously saved operating point from another project.

Creating a SISO Design Task

At this stage in the considered example, in the Simulink® Compensator Design Task pane the following elements are selected:

- blocks to tune: Reference filter and PID controller;
- closed-loop responses: Step disturbance to Speed output and Speed reference to Speed output;
- operating point at which the model is linearized: the default point.

The software uses the specified information to perform the calculations necessary to create and configure the SISO Design Task. This includes several tools for tuning the response of SISO (Single Input Single Output) systems:

- a graphical editing environment that contains design plots such as root-locus and Bode diagrams;
- an LTI Viewer (LTI is an acronym for Linear Time-Invariant) window where we can view time and frequency analysis plots of the system;
- a compensator editor where we can directly edit the block mask parameters or the poles and zeros of compensators in our system;
- a tool that automatically generates compensators using PID, internal model control (IMC), or linear-quadratic-Gaussian (LQG) methods (uses the Control System Toolbox) [5];
- a response optimization tool that automatically tunes the system to satisfy design requirements with help of Simulink® Response Optimization.

The Design Configuration Wizard guides us through the selection of the open- and closed-loop systems we want to design and the configuration of the design and analysis plots we want to use in the SISO Design Task.

Tuning the controller

A preliminary PID controller design (with null derivative component), which was created using the compensator editor [1, 7], is used as a starting point to further refine the design using Response Optimization. At this stage the controller is tuned to satisfy the following performances:

- a maximum overshoot of 1% for the unit step response from Speed reference to Speed output to and a 3 second rise time to reach 95% of the setpoint value;
- a minimum loop gain of 10dB over the frequency range 1e-4 to 1 rad/sec to ensure good output disturbance rejection and reference tracking over this frequency range;

- a maximum loop gain of -10dB over the frequency range 10 to 1e4 rad/sec to ensure adequate high frequency noise rejection, and together with the low frequency requirement, to ensure a loop bandwidth of between 1 and 10 rad/sec.

Optimizing the system response. Simulation results

After selecting the compensator elements to tune (in example Gain and Real Zero of the PID controller) and adding design requirements for the response signals to satisfy (visible in graphs of figure 2), we are ready to approach the response optimization.

Within the Response Optimization node of the Control and Estimation Tools Manager, the optimization panel indicates the progress of the response optimization. The panel also contains options to present the types of progress information during the optimization and options to present the optimization algorithms [11]. The progress of the optimization is presented iteration by iteration, as shown in figure 3. Termination message from the optimization tell us that was found an optimal solution within the specified tolerances. We can check how well the optimized design meets the specified requirements by viewing the optimized responses from figure 4. We can also see the engine's output speed in figure 5, obtained after the PID controller tuning.

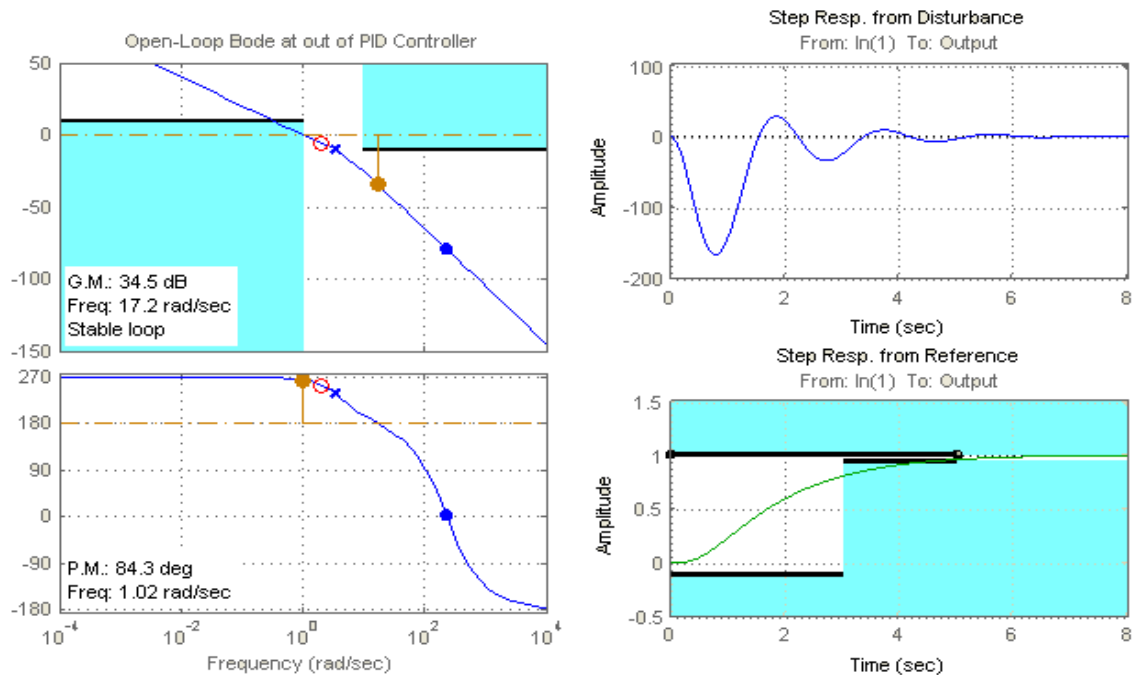


Fig. 2. Design and analysis plots before optimization.

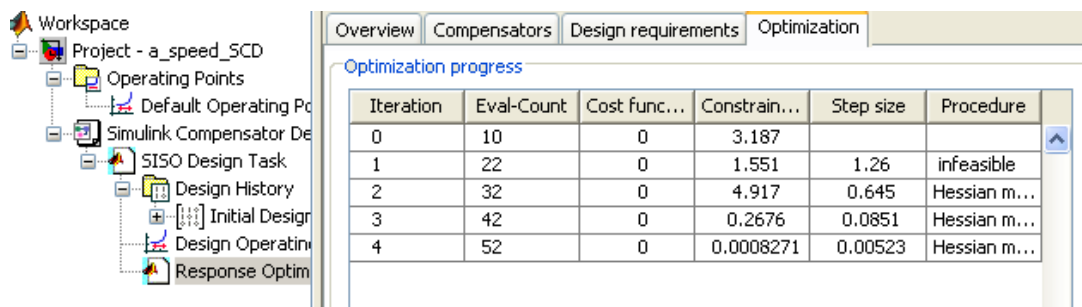


Fig. 3. The numerical progress data during optimization.

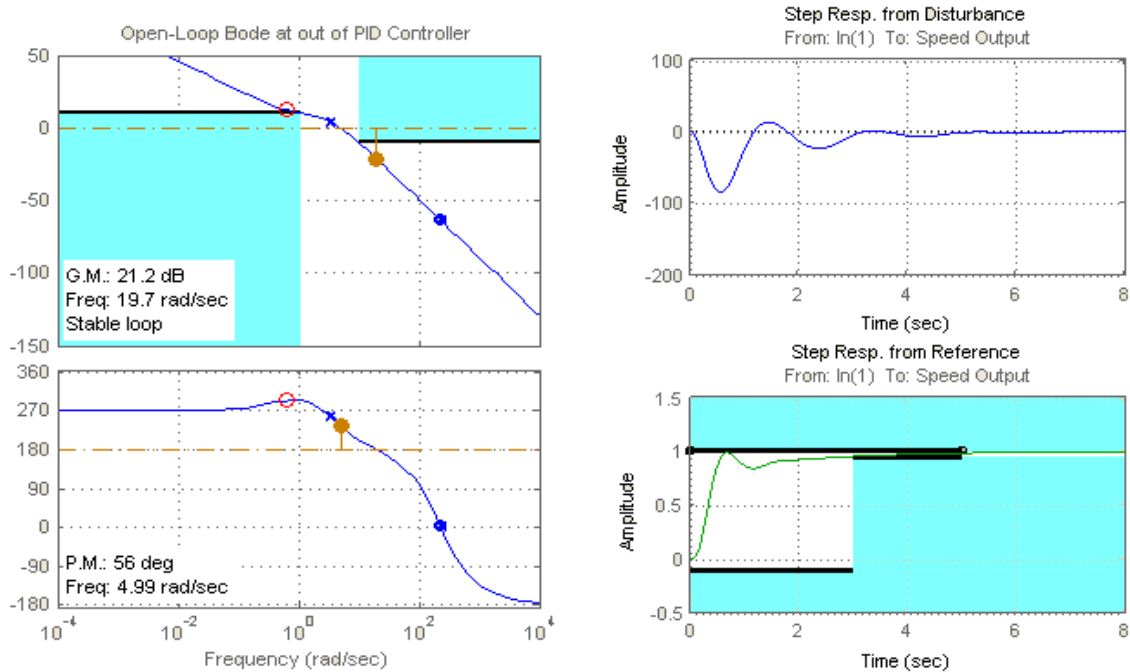


Fig. 4. Design and analysis plots after optimization.

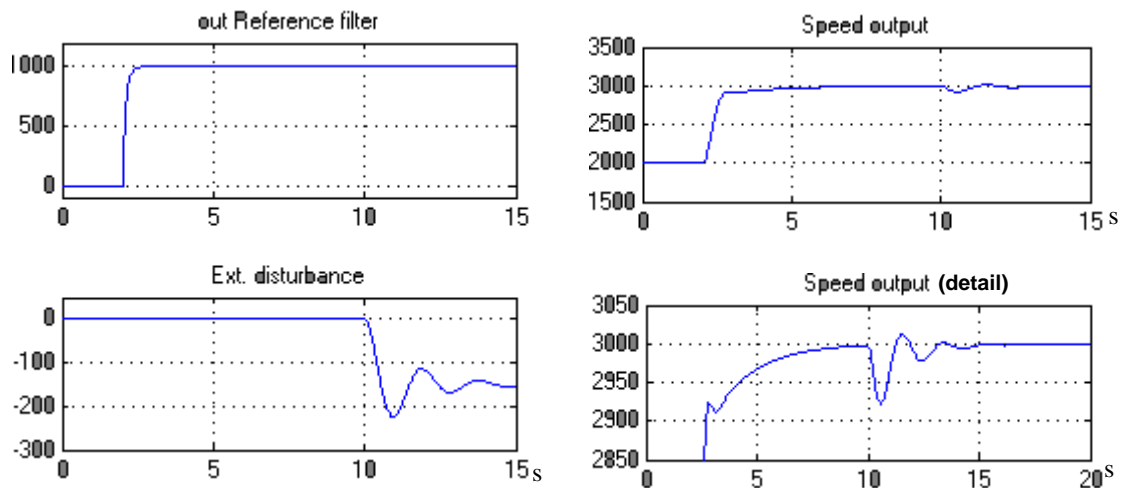


Fig. 5. The speed responses after optimization.

Conclusions

Simulink® Control Design streamlines the design and analysis of control systems for nonlinear plant models built in Simulink. It offers possibility to automatically linearization of the model, perform frequency-domain analysis and tune the control system parameters using a range of tools and techniques.

It was successfully applied in a PID controller tuning of a spark ignition engine with numerically optimize of the compensators with the purpose to meet time- and frequency-based design requirements.

Followed by a Matlab/Simulink simulation, it realized the following actions:

- displaying and analyzing the dynamic behavior of the model;
- using the compensator design tools to preliminary tune the control systems;
- numerically optimizing the compensators, applying Response Optimization, so that the response signals lie within the constraint bound segments;
- comparative presentation of Bode diagrams and step responses before and after optimization of the PID parameters;
- determining the response of the model after updating the optimum PID parameters to step variation of the speed reference and external disturbance.

References

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Utilizarea Simulink Control Design în acordarea reglatoarelor de viteză

Rezumat

Simulink Control Design facilitează proiectarea și analizarea sistemelor de control ale proceselor cu modele neliniare construite în Simulink. Cu ajutorul său se obține liniarizarea automată a modelului, optimizarea analizei în domeniul de frecvență și acordarea parametrilor sistemelor de control printr-o gamă variată de metode. Articolul prezintă aplicarea Simulink Control Design în acordarea unui regulator PID pentru reglarea vitezei unui motor termic cu optimizarea automată a parametrilor în scopul îndeplinirii condițiilor de analiză în timp și frecvență.