Chapter 6
Control Analysis and Simulation

INTRODUCTION

So far, we have talked about control requirement derivation, control structure design and control algorithm design steps in the model-based control development process. After the initial control algorithm design is completed, the resulted control system needs to be carefully examined to make sure that the control system behaviors and performances meet the initial control requirements.

In the control architecture and algorithm design stage, a linearized plant model around an operating point or a set of linearized plant models at different operating points within the operation range are first obtained and usually used for design and analysis such as for PID controller tuning, open and closed-loop analysis instead of the nonlinear, full order plant model developed based on physical principles. Once the control law designed based on the linear plant model(s) is considered adequate by meeting predefined control performance criteria, the evaluation of the control performance on the nonlinear, full order plant model is started. In this detailed system analysis, compared to conceptual control design and analysis, control implementation details are included in the controller model including actuator saturation (magnitude, rate or both), sensor noise and delay, bumpless transfer (controller switching or parameter change), control modes and mode change, etc. to fully characterize the actual control system.

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Control performances are evaluated in terms of four areas: set point tracking, disturbance rejection, noise reduction, and robustness against process variation and model uncertainty. The four aspects can be investigated both in the time domain and the frequency domain. In the time domain, step responses for set point change and disturbance change are generated, indexes relating to a step response such as the rise time, the settling time, the percentage overshoot, and the steady state error are used to compare against control performance requirements. In the frequency domain, the open/closed loop bandwidth, the gain margin and phase margin, the sensitivity function peak, and the complementary sensitivity function peak are used to compare against predefined control requirements. Pole and zero positions, the resonance frequency and damping ratio of complex pole pairs, singular values of multivariable system are also used to evaluate the system performance. Bode plots of open and closed-loop transfer functions are very useful for the frequency domain control performance evaluation. Similarly, for multi-input-multi-output control systems, singular value plots of open and closed-loop transfer function matrices are very helpful. Commercial control design software available is now very mature and has made the types of control analyses just mentioned earlier simple and easy, for example MATLAB control toolbox and MATLAB robust control toolbox. Using software control design tools, you can easily create plots such as Bode plot, Nyquist plot, Nicole's chart, and step response plot for visual examination, or you can also compute and plot poles and zeros, the gain margin and phase margin, the natural frequency and damping ratio of complex poles, etc. for stability and performance assessment. Powerful control analysis capabilities are built into the available modeling and simulation environments such as MATLAB/Simulink through both command line interface and graphical user interface (GUI), which is very efficient and user friendly for performing control system analysis in a modeling and simulation environment.

MIMO Control System Analysis Example

In chapter 4, we introduced a two-inputs-two-outputs plant control design example. In that example, the plant transfer functions were first identified from step responses generated from the detailed physical model of the plant using simulation by introducing step changes in the plant inputs one at a time. The plant model is given by