Advanced
PID Control

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Feedforward Design

5.1 Introduction

Feedforward is a simple and powerful technique that complements feedback. Feedforward can be used both to improve the set-point responses and to reduce the effect of measurable disturbances. Use of feedforward to improve set-point response has already been discussed in connection with set-point weighting in Section 3.4. We will now give a systematic treatment of design of feedforward control and also discuss design of model-following systems. The special case of set-point weighting will be discussed in detail, and we will present methods for determining the set-point weights. We will also show how feedforward can be used to reduce the effect of disturbances that can be measured.

5.2 Improved Set-Point Response

Feedforward can be used very effectively to improve the set-point response of the system. By using feedforward it is also possible to separate the design problem into two parts. The feedback controller is first designed to give robustness and good disturbance rejection and the feedforward is then designed to give a good response to set-point changes.

Effective use of feedforward requires a system structure that has two degrees of freedom. An example of such a system is shown in Figure 3.10. It is first assumed that the system has the structure shown in Figure 5.1. Let the process have the transfer function $P(s)$. We assume that a feedback controller $C(s)$, which gives good rejection of disturbances and good robustness, has been designed, and we will consider the problem of designing a feedforward compensator that gives a good response to set-point changes.

The feedforward compensator is characterized by the transfer functions $M_u(s)$ and $M_y(s)$, where $M_y(s)$ gives the desired set-point response. The system works as follows. When the set point is changed the transfer function $M_u(s)$ generates the signal u_{ff}, which gives the desired output when applied as input to the process. The desired output y_m is generated by $M_y(s)$. Under ideal conditions this signal is equal to the process output y. The control error e

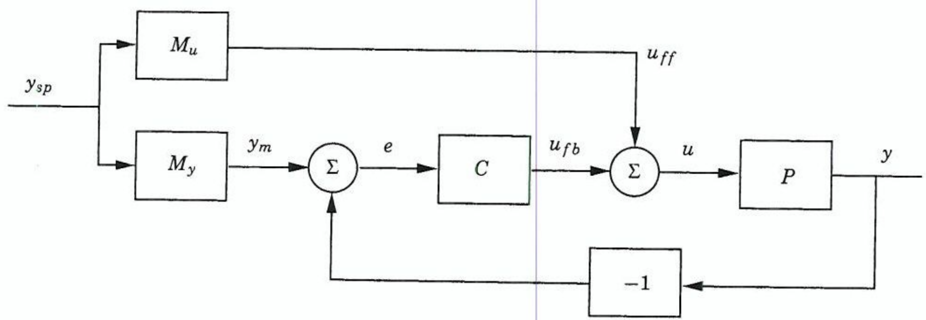

Figure 5.1 Block diagram of a system with two degrees of freedom.

is zero, and the feedback signal u_{fb} remains constant. If there are disturbances or modeling errors the signal y_m and y will differ. The feedback then attempts to bring the error to zero. The transfer function from set point to process output is

$$G_{yy_{sp}}(s) = \frac{P(CM_y + M_u)}{1 + PC} = M_y + \frac{PM_u - M_y}{1 + PC}. \tag{5.1}$$

The first term represents the desired transfer function. The second term can be made small in two ways. Feedforward compensation can be used to make $PM_u - M_y$ small, or feedback compensation can be used to make the error small by making the loop gain PC large. The condition for ideal feedforward is

$$M_y = PM_u. \tag{5.2}$$

Notice the different character of feedback and feedforward. With feedforward it is attempted to match two transfer functions, and with feedback it is attempted to make the error small by dividing it by a large number. With a controller having integral action the loop gain is very large for small frequencies. It is thus sufficient to make sure that the condition for ideal feedforward holds at higher frequencies. This is easier than to satisfy the condition (5.2) for all frequencies.

System Inverses

From (5.2) the feedforward compensator M_u is

$$M_u = P^{-1}M_y, \tag{5.3}$$

which means that it contains an inverse of the process model P. A key issue in design of feedforward compensators is thus to find inverse dynamics. It is easy to compute the inverse formally. There are, however, severe fundamental problems in system inversion, which are illustrated by the following examples.