ELEC ENG 4CL4:

Control System Design

Notes for Lecture #32

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Dr. Ian C. Bruce
Room: CRL-229
Phone ext.: 26984
Email: ibruce@mail.ece.mcmaster.ca

Chapter 10

Architectural Issues in SISO Control

Disturbance Feedforward

We show how feedforward ideas can be applied to disturbance rejection.

A structure for feedforward from a measurable disturbance is shown in Figure 10.2.

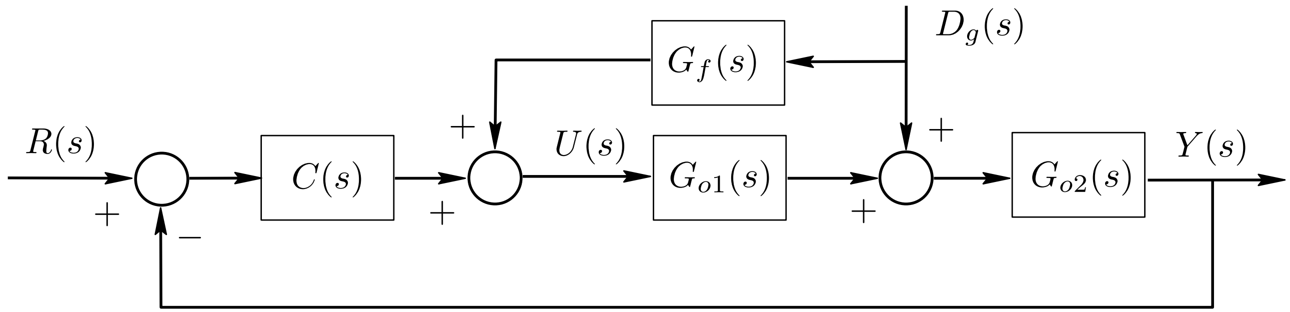


Figure 10.2: *Disturbance feedforward scheme.*

The proposed architecture has the following features

(i) The feedforward block transfer function $G_f(s)$ must be stable and proper, since it acts in open loop.

(ii) Ideally, the feedforward block should invert part of the nominal model, i.e.

$$G_f(s) \cong -[G_{01}(s)]^{-1}$$

(iii) Since usually $G_{01}(s)$ will have a low pass characteristic, we should expect $G_f(s)$ to have a high pass characteristic.

Example of Disturbance Feedforward

Consider a plant having a nominal model given by

$$G_o(s) = \frac{e^{-s}}{2s^2 + 3s + 1} \qquad G_{o1}(s) = \frac{1}{s+1} \qquad G_{o2}(s) = \frac{e^{-s}}{2s+1}$$

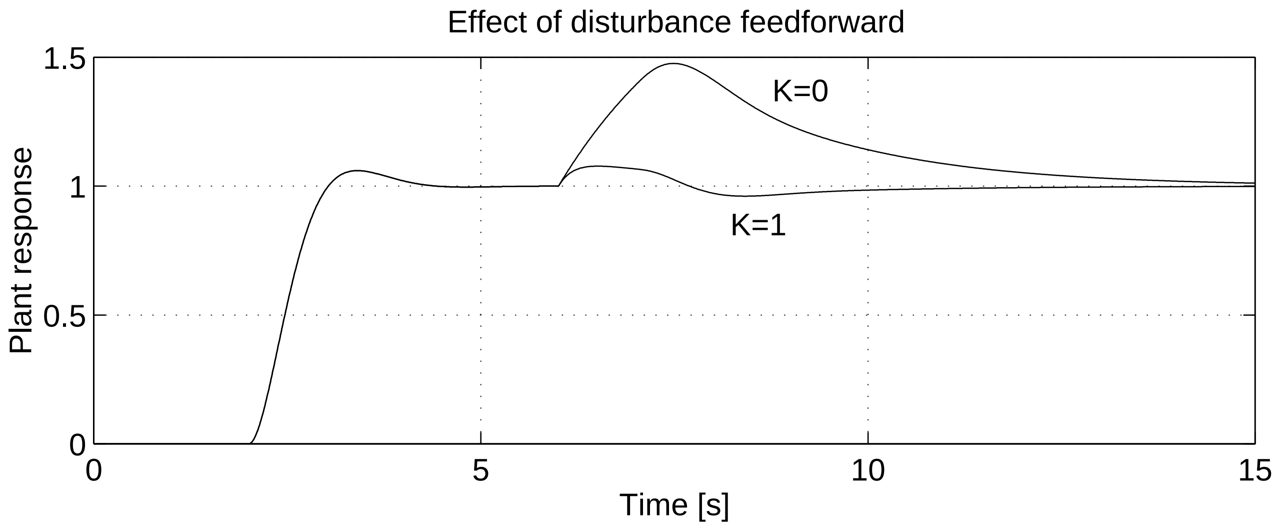
We assume that the disturbance $d_g(t)$ consists of infrequently occurring step changes. A feedback only solution to this problem would be hindered by the fact that the achievable loop bandwidth would be constrained by the presence of the delay in G_0. We therefore investigate the use of feedforward control. We choose the architecture shown earlier in Figure 10.2 and choose $-G_f(s)$ as an approximation to the inverse of $G_{01}(s)$, i.e.

$$G_f(s) = -K \frac{s+1}{\beta s + 1}$$

Where β allows a trade off to be made between the effectiveness of the feedforward versus the size of the control effort. Note that K takes the nominal value 1.

The next figure shows the effect of varying K from 0 (no disturbance feedforward) to $K = 1$ (full disturbance feedforward). [A unit step reference is applied at $t = 1$ followed by a unit step disturbance at $t = 5$].

Figure 10.3: *Control loop with (K = 1) and without (K = 0) disturbance feedforward*



We thus see that the use of disturbance feedforward can anticipate the disturbance and lead to significantly improved transient response.

Industrial Application of Feedforward Control

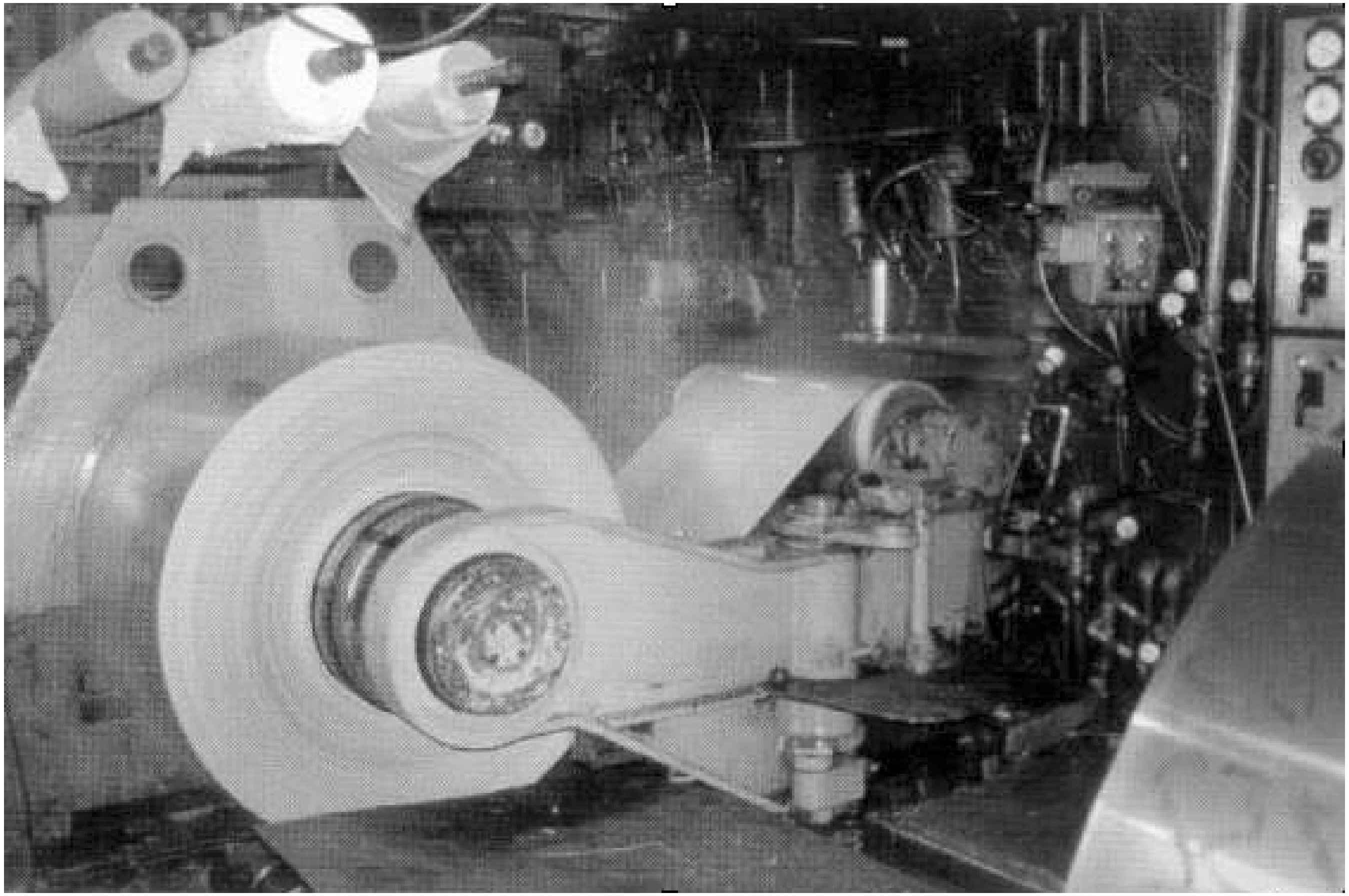
Feedforward control is generally agreed to be one of the most useful concepts in practical control system design beyond the use of elementary feedback ideas.

We will illustrate the idea by revisiting the hold up effect in Rolling Mills which was discussed in Chapter 8.

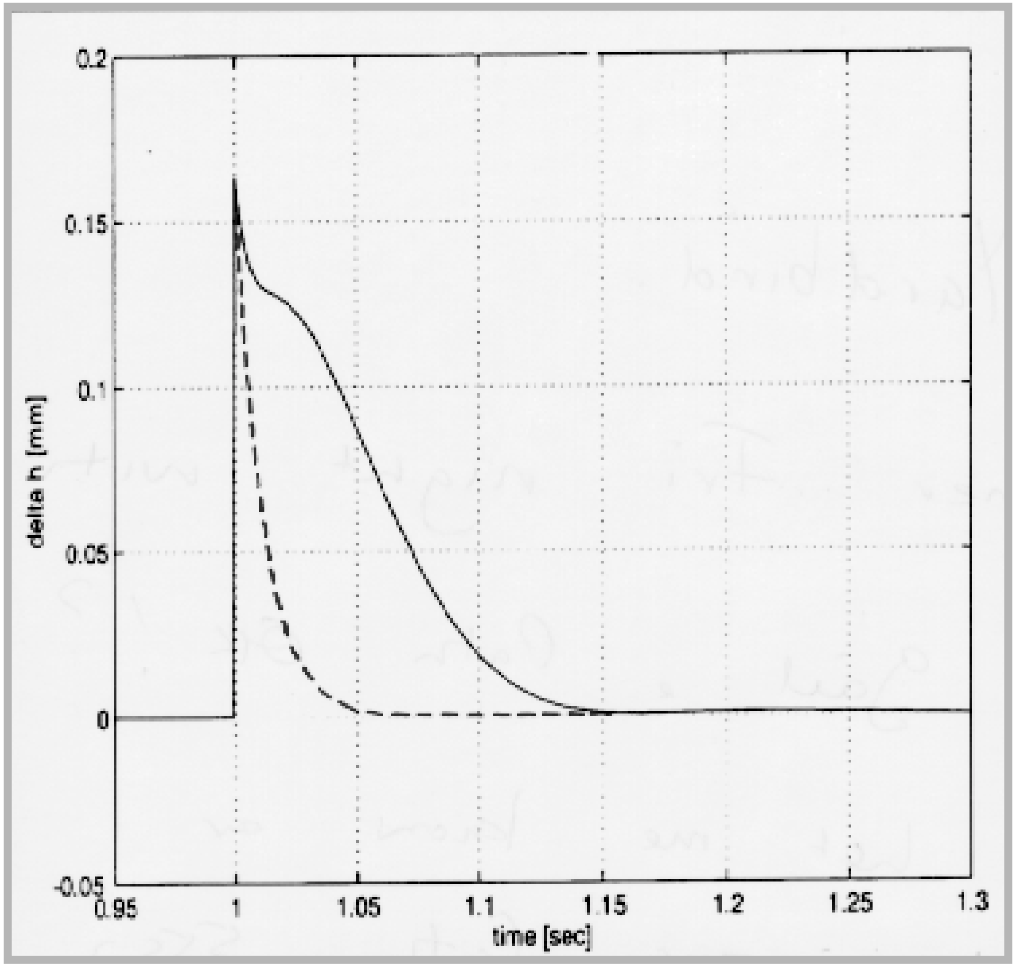
Hold-Up Effect in Reversing Mill Revisited

Consider again the Rolling Mill problem discussed earlier. There we saw that the presence of imaginary axis zeros were a fundamental limitation impeding the achievement of a rapid response between unloaded roll gap position and exit thickness. We called this the *hold-up* effect. The physical origin of the problem is tension interactions.

Reversing Mill



Hold Up Effect



The dotted line represents the expected disturbance response whereas what is actually achieved is the solid line.

Consider the schematic diagram shown on the next slide. We recall that the physical explanation for the hold-up effect is as follows:

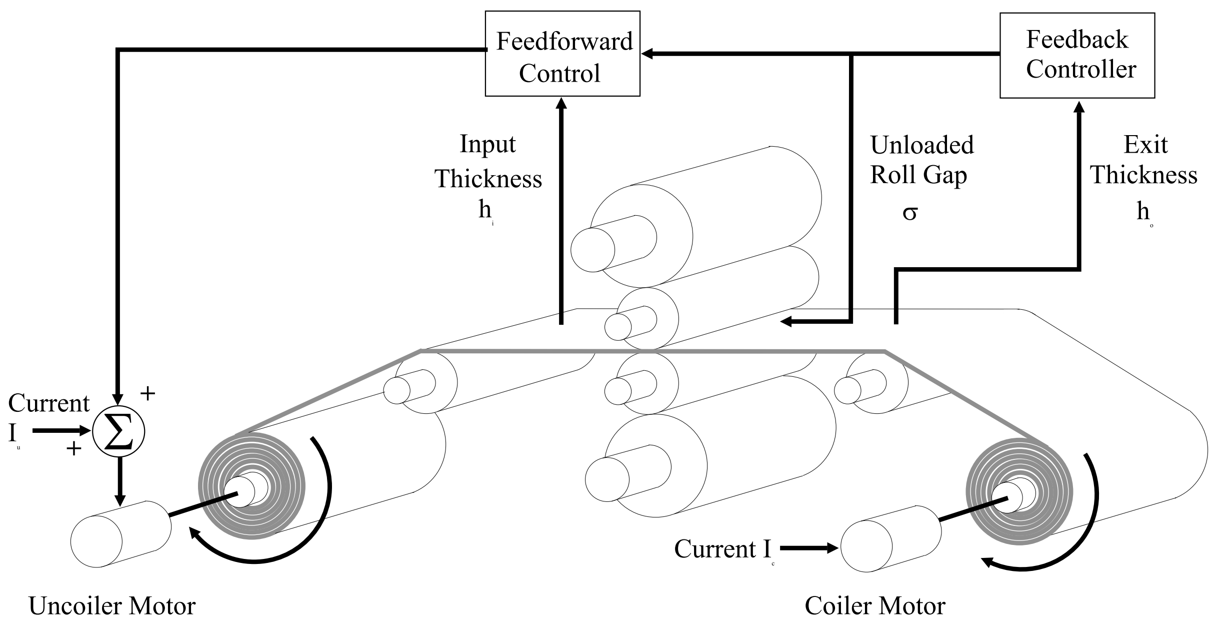
- Say the roll gap is opened;
- Initially this causes the exit thickness to increase;
- However, the exit speed is roughly constant (due to the action of another control loop), hence more mass comes out the end of the mill;
- Hence the incoming strip velocity must increase to supply this extra mass flow;

- However, due to the inertia of the uncoiler, this means that the input tension will increase;
- In turn, increased input tension implies a drop in exit thickness.

The exit thickness increase is thus *held up* until the uncoiler current controller can respond and restore the tension to its original value.

This phenomena manifests itself in the imaginary axis zero noted in Chapter 8 in the model linking roll gap to exit thickness.

Figure 10.6: *Feedforward controller for reversing mill*



The above explanation suggests that a remedy might be to send a pulse of current to the uncoiler motor as soon as we adjust the roll gap, i.e. to use **FEEDFORWARD**.

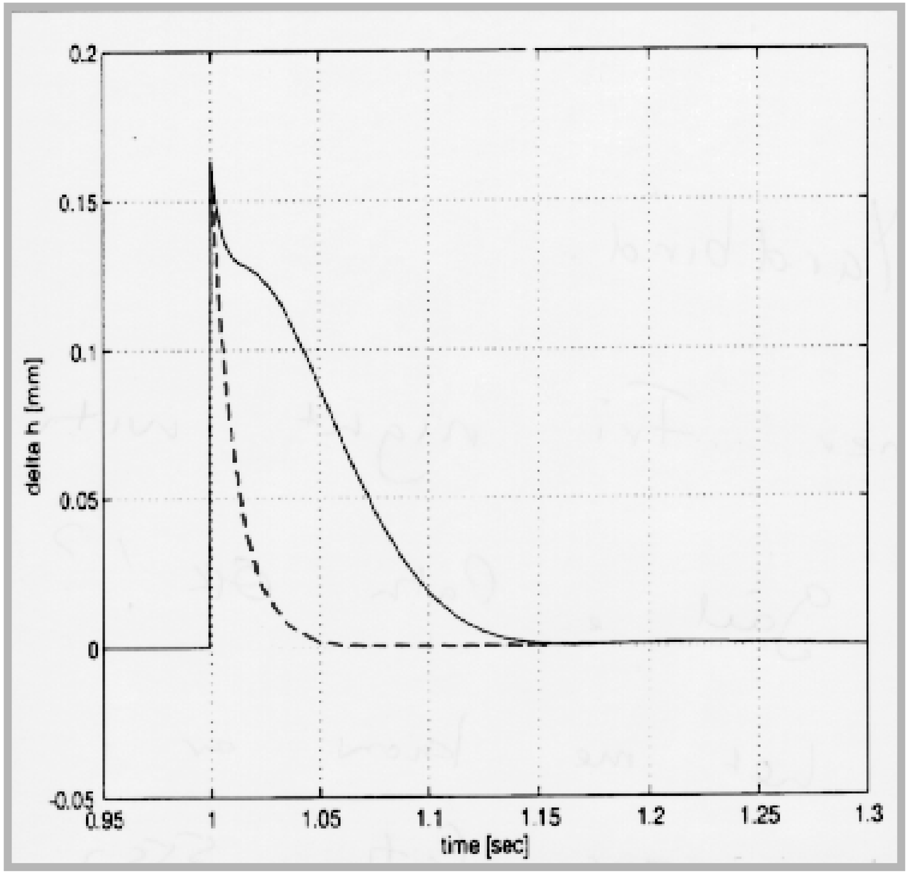
Indeed, one can show using the physics of the problem that tension fluctuations would be avoided by choosing the uncoiler current as

$$i_u(t) = \frac{J_u \omega_u^o}{v_i^o h_i^o K_m} \left[c_1 v_0^o \frac{d\sigma(t)}{dt} + c_2 v_0^o \frac{dh_i(t)}{dt} - v_i^o \frac{dh_i(t)}{dt} \right]$$

The above equation is seen to be a *feedforward* signal linking (*the derivatives of*) the unloaded roll gap position, $\sigma(t)$, and the input thickness, $h_i(t)$, to the uncoiler current.

Use of feedforward control in this example removes the fundamental limitation arising from the imaginary axis zero. This is not a contradiction in terms because the limitation was only fundamental within the single input (*roll gap*) single output (*exit thickness*) architecture. Changing the **architecture** by use of feedforward control to the uncoiler currents alters the fundamental nature of the problem and removes the limitation.

Result with Feedforward Control



Recall that the solid line was the best that could be achieved with a single degree of freedom control whereas using feedforward we can achieve the dotted line.

The above example delivers an important message in solving tough control problems. Specifically, one should look out for architectural changes which may dramatically change a difficult (*or maybe impossible*) problem into an easy one.