ELEC ENG 4CL4:

Control System Design

Notes for Lecture #23

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An Industrial Application (*Hold-Up Effect in Reversing Mill*)

Here we study a reversing rolling mill. In this form of rolling mill the strip is successively passed from side to side so that the thickness is successfully reduced on each pass.

For a photo of a reversing mill see the next slide. For a schematic diagram of a single stand reversing rolling mill, see Figure 8.6.

Single Stand Reversing Mill

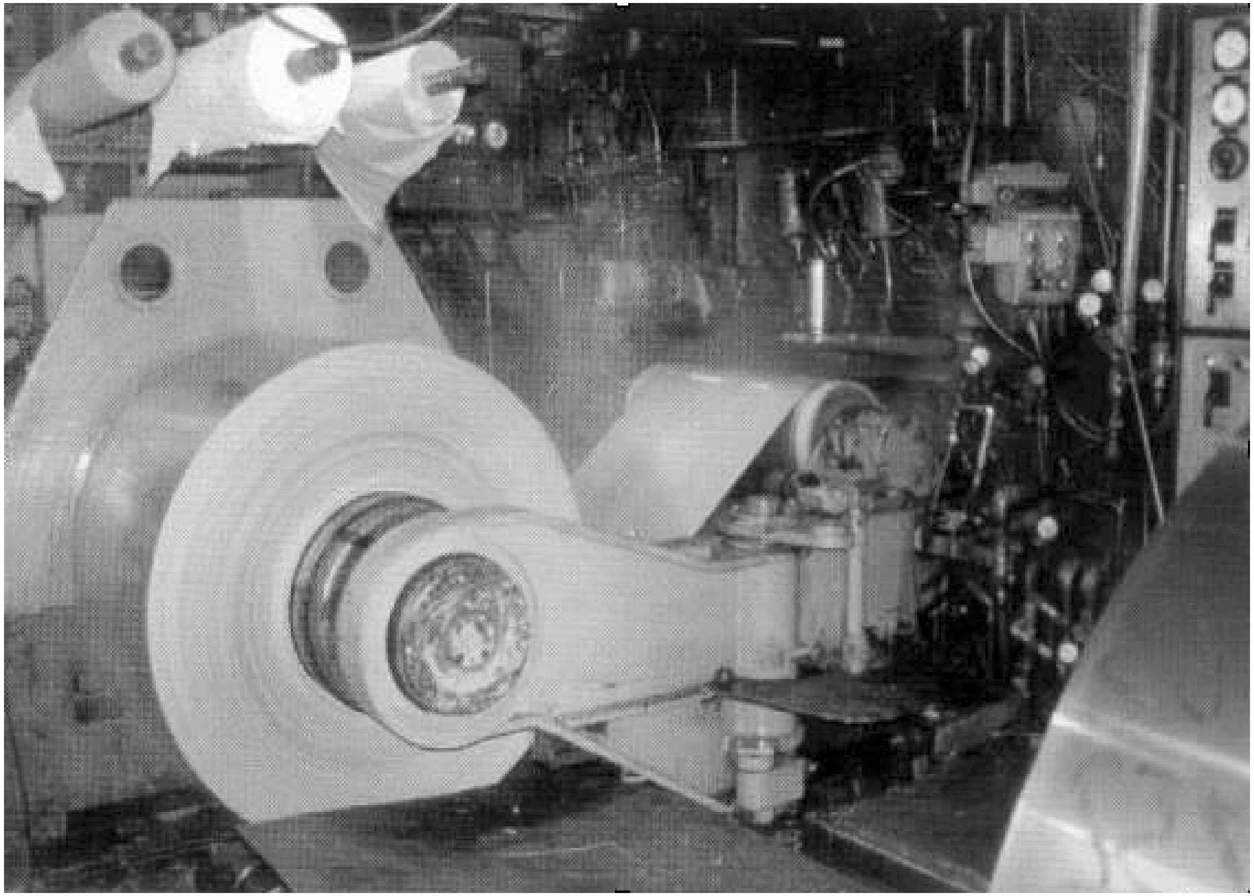
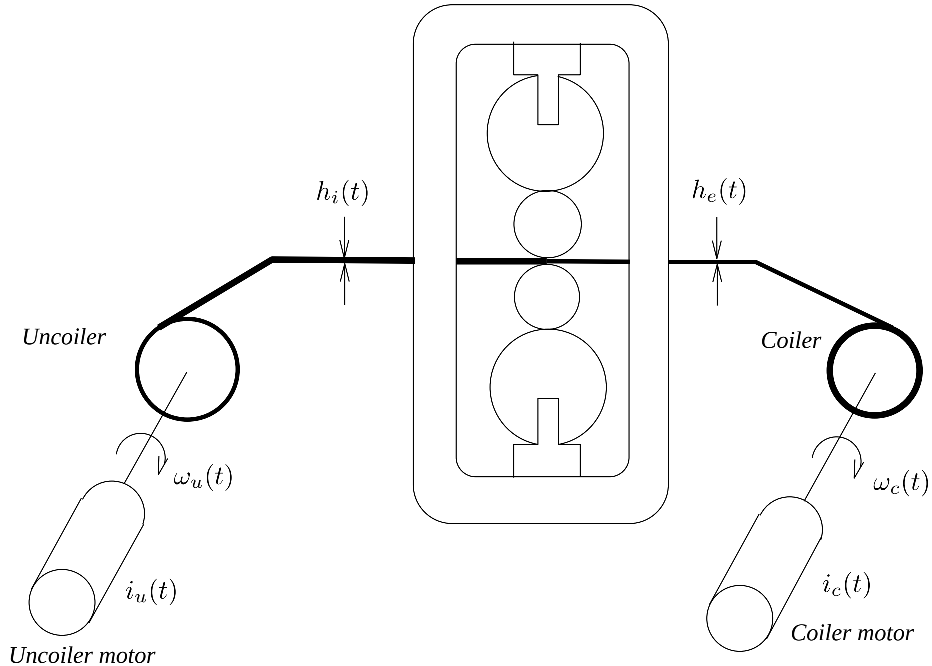
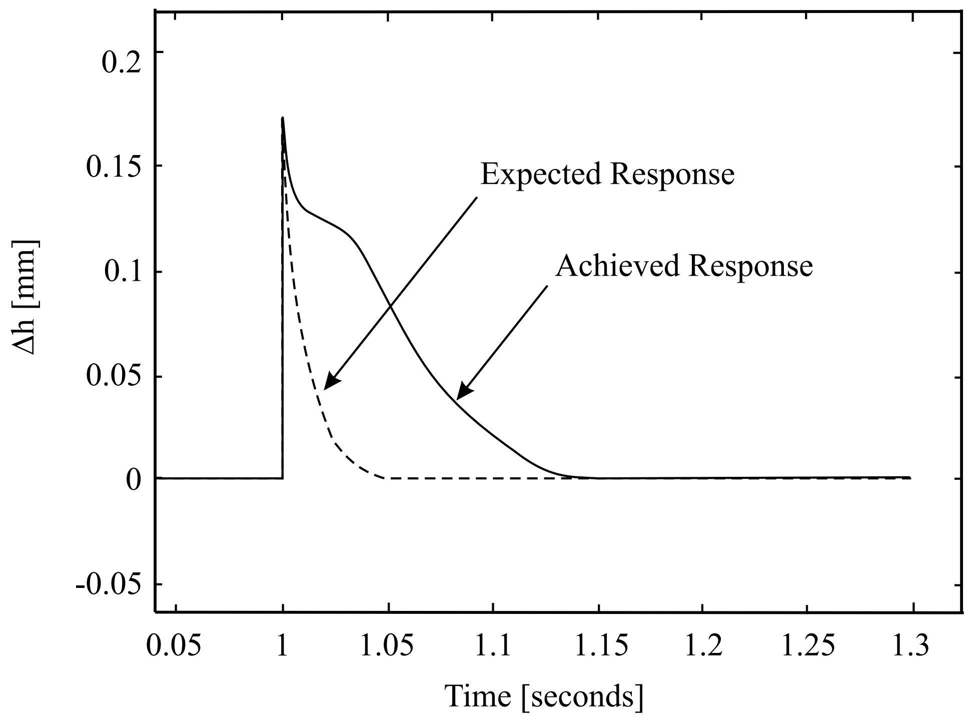


Figure 8.6: *Schematic of Reversing Mill*

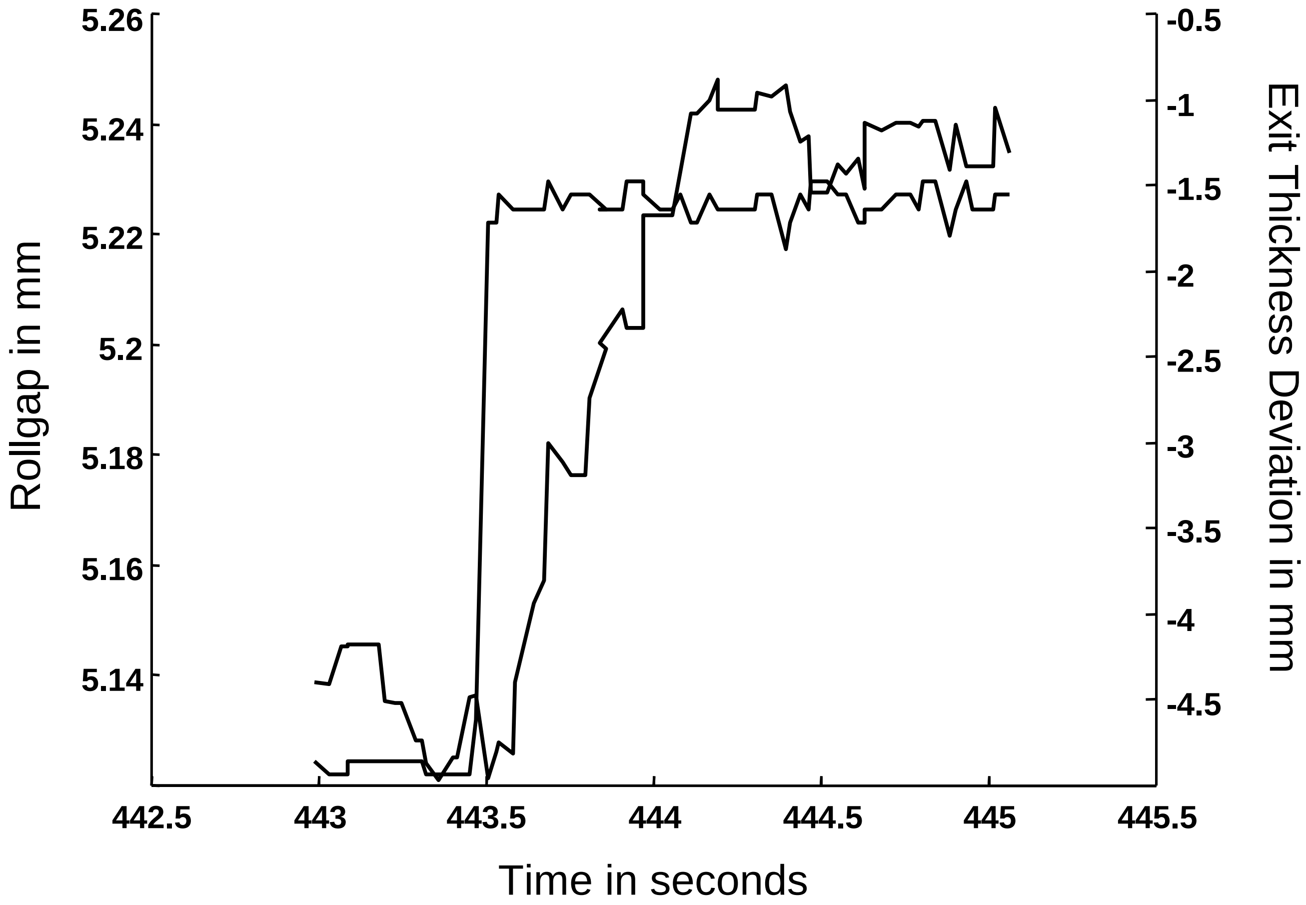


Despite great efforts to come up with a suitable design, the closed loop response of these systems tends to start out fast but then tends to hold-up. A typical response to a step input disturbance is shown schematically in Figure 8.7.

Figure 8.7: *Hold-up effect*



Industrial Results Showing the Hold-Up Effect

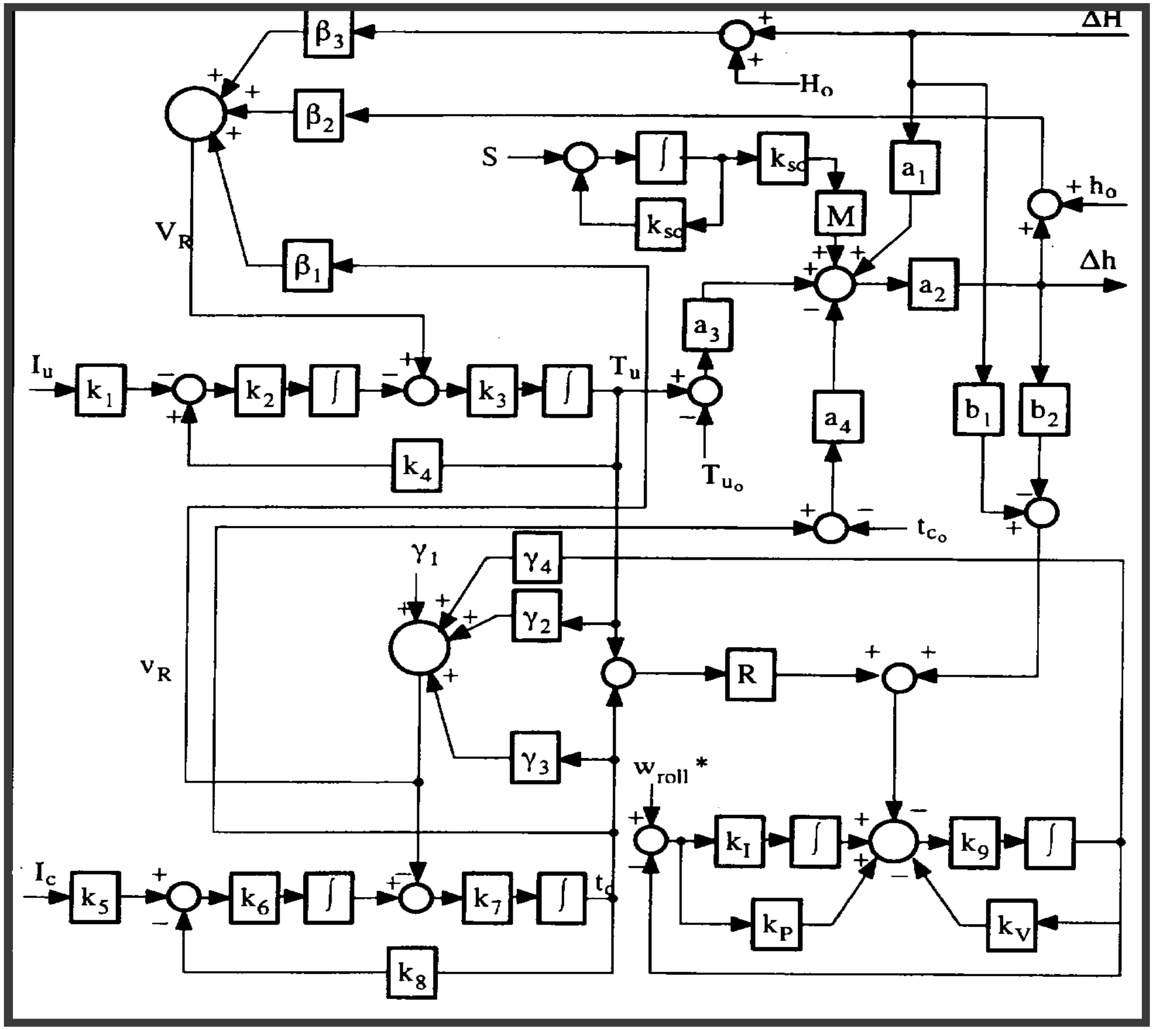


The reader may wonder:

1. *How the above result occurs*, and
2. *How it can be remedied.*

To answer this question, we build a model for the system. The associated Simulink diagram is shown on the next slide.

Block diagram of linearized model



Discussion

The transfer function from roll gap (σ) to exit thickness (h) turns out to be of the following form (where we have taken a specific real case):

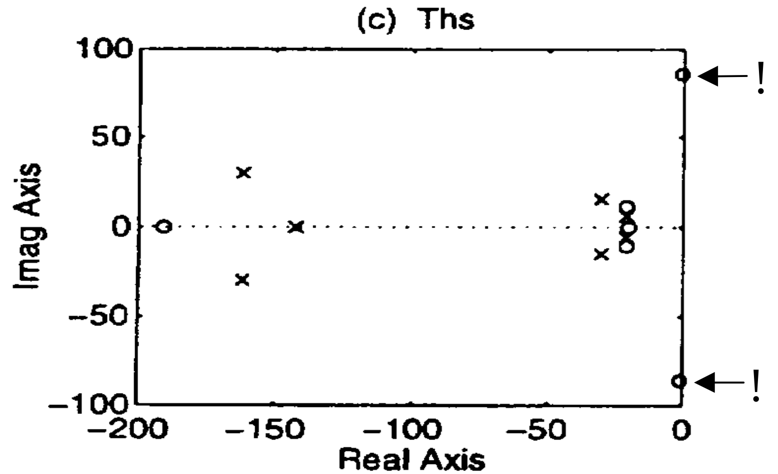
$$G_{h\sigma}(s) = \frac{26.24(s+190)(s+21\pm j11)(s+20)(s+0.5\pm j86)}{(s+143)(s+162\pm j30)(s+30\pm j15)(s+21\pm j6)}$$

We see (*perhaps unexpectedly*) that this transfer function has two zeros located at $s = -0.5 \pm j86$ which are (*almost*) on the imaginary axis.

These zeros are shown on the pole-zero plot on the next slide.

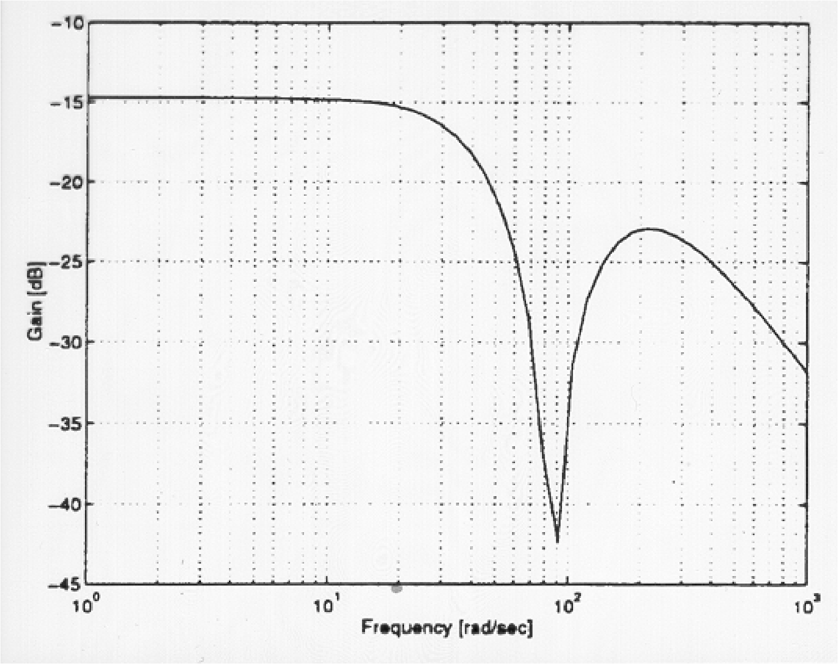
Poles and zeros configuration of linear model

(*Note the two imaginary axis zeros marked* !)

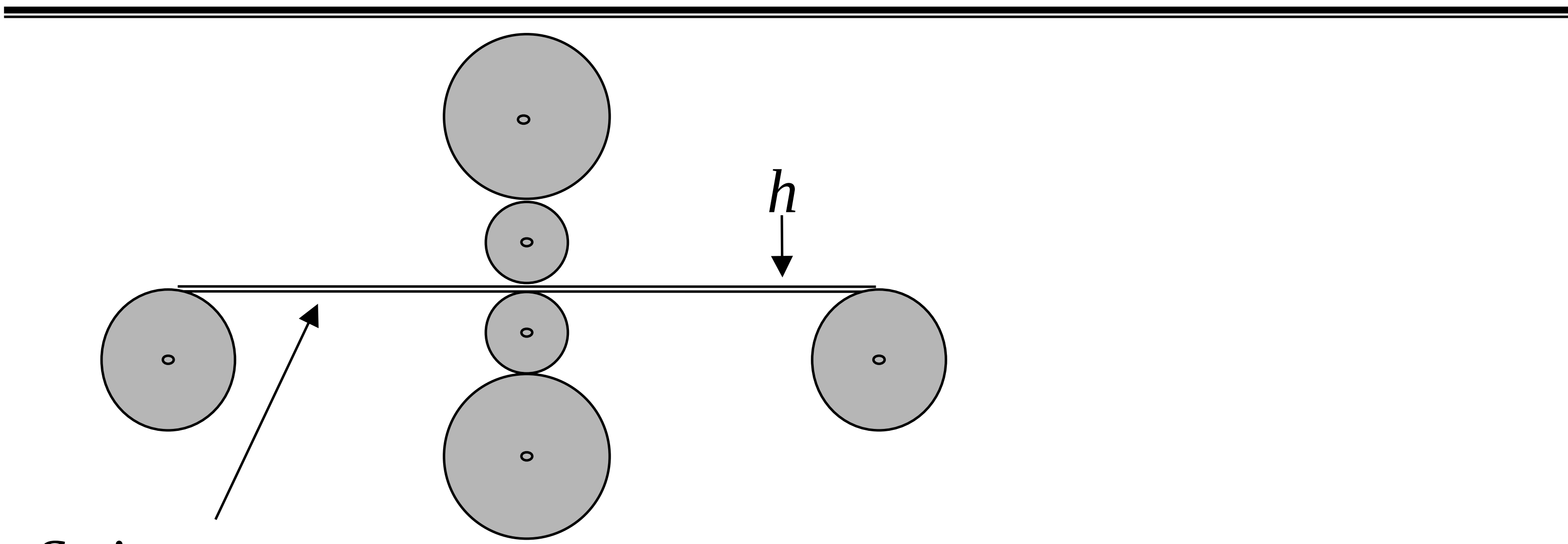


The corresponding frequency response shows a dip at the frequency of the imaginary axis zeros (*see next slide*).

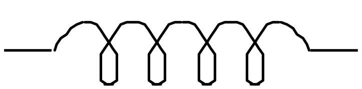
Frequency response of T_{hS}



A physical explanation for the zeros is provided by thickness-tension interactions. This is described on the next slide.



Strip acts
as
a spring



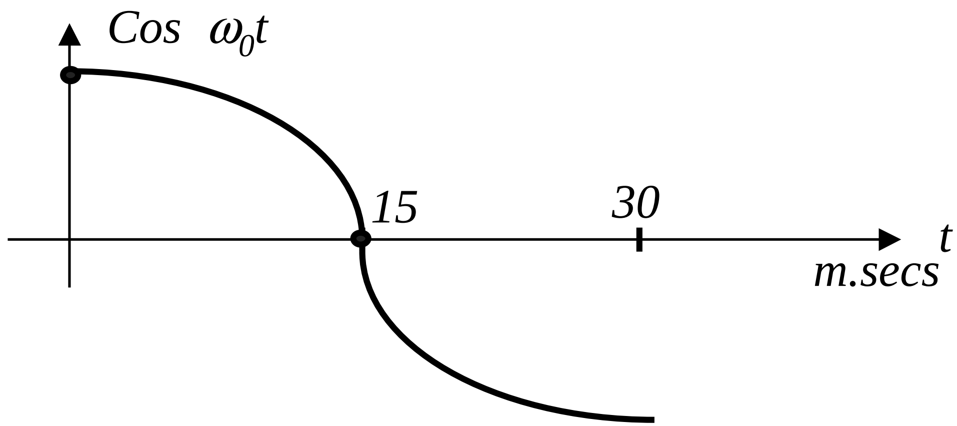
Rough calculation: Resonant Frequency
90 Rad Sec^{-1}

Slip turns these resonant poles into imaginary axis zeros.

Next, recall the fundamental limitations arising from imaginary axis zeros. These are summarized on the next slide.

$$\int_0^{\infty} (Cos\ \omega_0 t)e(t)dt = 0$$

In our case $\omega_0 = 90$ rad sec^{-1}



Only 2 Possibilities

- ❖ $e(t)$ changes sign quickly with large -ve values

  or

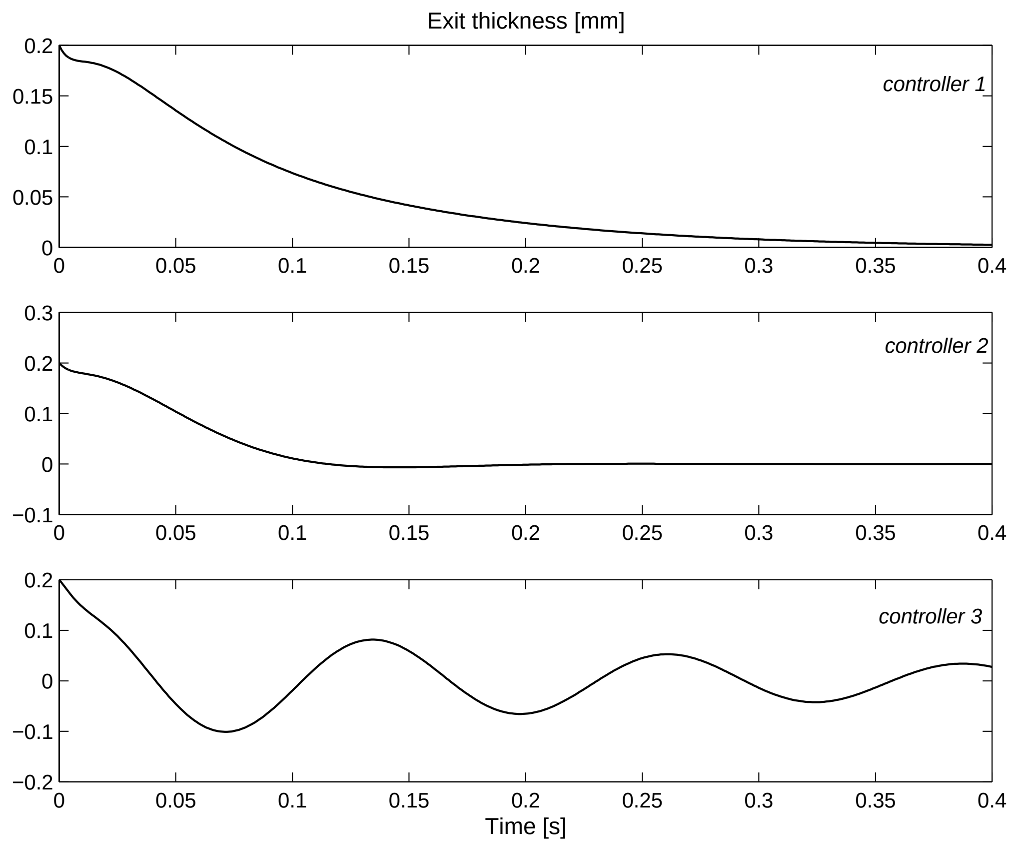
- ❖ $e(t)$ remains large in the period 15-30 msec.

Our previous analysis therefore suggests that the 2 (*near*) imaginary axis zeros will place fundamental limitations on the closed loop response time if significantly bad transients are to be avoided. Also, these limitations are fundamental, i.e. no fancy control system design can remedy the problem.

Simulations were carried out with the following three PI controllers. (These were somewhat arbitrarily chosen but the key point here is that the issue of the hold-up effect is fundamental. In particular, *no* controller can improve the situation at least without some radical change !).

$$C_1(s) = \frac{s+50}{s} \qquad C_2(s) = \frac{s+100}{s} \qquad C_3(s) = \frac{s+500}{s}$$

Figure 8.8: *Response to a step change in the strip input thickness*



Observations

We see that, as we attempt to increase the closed loop bandwidth (*i.e. reduce the closed loop transient time*) so the response deteriorates. This is in line with our previous predictions.