ELEC ENG 4CL4:

Control System Design

Notes for Lecture #20

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Chapter 8

Fundamental Design Limitations in SISO Control

This chapter examines those issues that limit the achievable performance in control systems. The limitations that we examine here include

- Sensors
- Actuators
  - maximal movements
  - minimal movements
- Model deficiencies
- Structural issues, including
  - poles in the ORHP
  - zeros in the ORHP
  - zeros that are stable but close to the origin
  - poles on the imaginary axis
  - zeros on the imaginary axis.

An understanding of these limitations is central to understanding control system design. Indeed, it is often more important to know what cannot be achieved (and why) than it is to generate a particular solution to a given problem.

Sensors

Sensors are a crucial part of any control system design, since they provide the necessary information upon which the controller action is based. They are the *eyes* of the controller. Hence, any error, or significant defect, in the measurement system will have a significant impact on performance.

Noise

The effect of measurement noise in the nominal loop is given by

$$
\begin{aligned}
Y_m(s) &= -T_o(s)D_m(s)\\
U_m(s) &= -S_{uo}(s)D_m(s)
\end{aligned}
$$

Also, we recall that $T_0(s)$ is typically near 1 over the bandwidth of the system. Thus, given the fact that noise is typically dominated by high frequencies, measurement noise usually sets an upper limit on the bandwidth of the loop.

Actuators

If sensors provide the *eyes* of control, then actuators provide the muscle. However, actuators are also a source of limitations in control performance. We will examine two aspects of actuator limitations. These are maximal movement, and minimal movement.

Maximal Actuator Movement

Recall that in a one d.o.f. loop, the controller output is given by

$$U(s) = S_{uo}(s)(R(s) - D_o(s)) \qquad \text{where} \qquad S_{uo}(s) \triangleq \frac{T_o(s)}{G_o(s)}$$

If the loop bandwidth is much larger than that of the open loop model $G_0(s)$, then the transfer function $S_{u0}(s)$ will significantly enhance the high frequency components in $R(s)$ and $D_0(s)$.

Example:

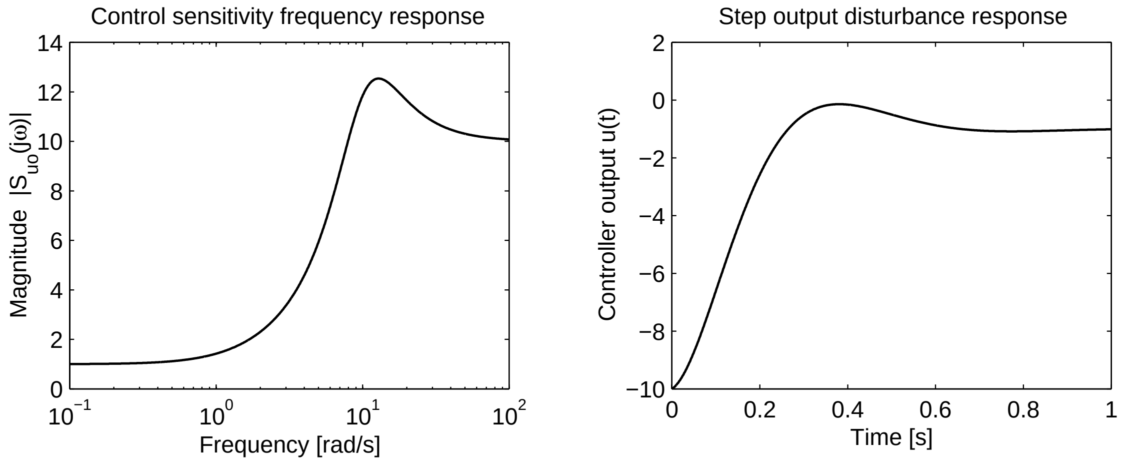
Consider a plant and associated closed loop given by

$$G_o(s) = \frac{10}{(s+10)(s+1)} \qquad \text{and} \qquad T_o(s) = \frac{100}{s^2 + 12s + 100}$$

Note that the plant and the closed loop bandwidths have a ratio of approximately 10:1. This will be reflected in large control sensitivity, $|S_{u0}(jw)|$, at high frequencies, which, in turn, will yield large initial control response in the presence of high frequency reference signals or disturbances.

This is illustrated on the next slide.

Figure 8.1: *Effects of a large ratio closed loop bandwidth to plant bandwidth*



The left hand plot shows that the control sensitivity grows significantly at high frequencies. The input signal resulting from a unit step disturbance is shown on the right hand plot. Note that the initial value of the input is approximately ten times the size of the steady state input needed to cancel the input.

Conclusion:

To avoid actuator saturation or slew rate problems, it will generally be necessary to place an upper limit on the closed loop bandwidth.

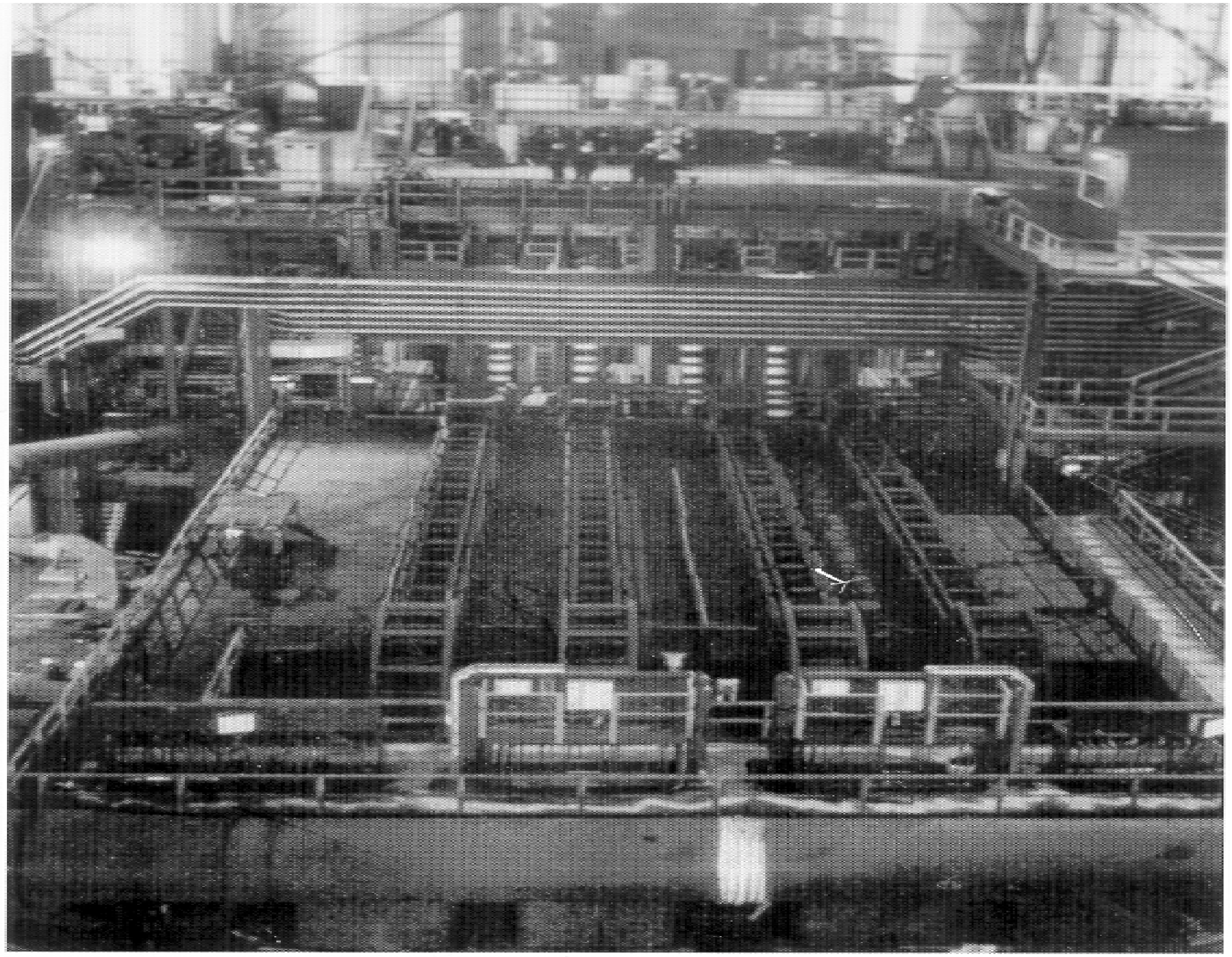
Minimal Actuator Movement

We learned above that control loop performance is limited by the maximal available movement available from actuators. This is heuristically responsible. What is perhaps less obvious is that control systems are often also limited by minimal actuator movements.

Example: Continuous Casting

Consider again the mould level controller illustrated in the following slides. It is known that many mould level controllers in industry exhibit poor performances in the form of self-sustaining oscillations. See for example the real data shown in Figure 8.2. Many explanations have been proposed for this problem. However, at least on the system with which the authors are familiar, the difficulty was directly traceable to minimal movement issues associated with the actuator. (*The slide gate valve*)

Continuous Casting Machine



Schematic diagram

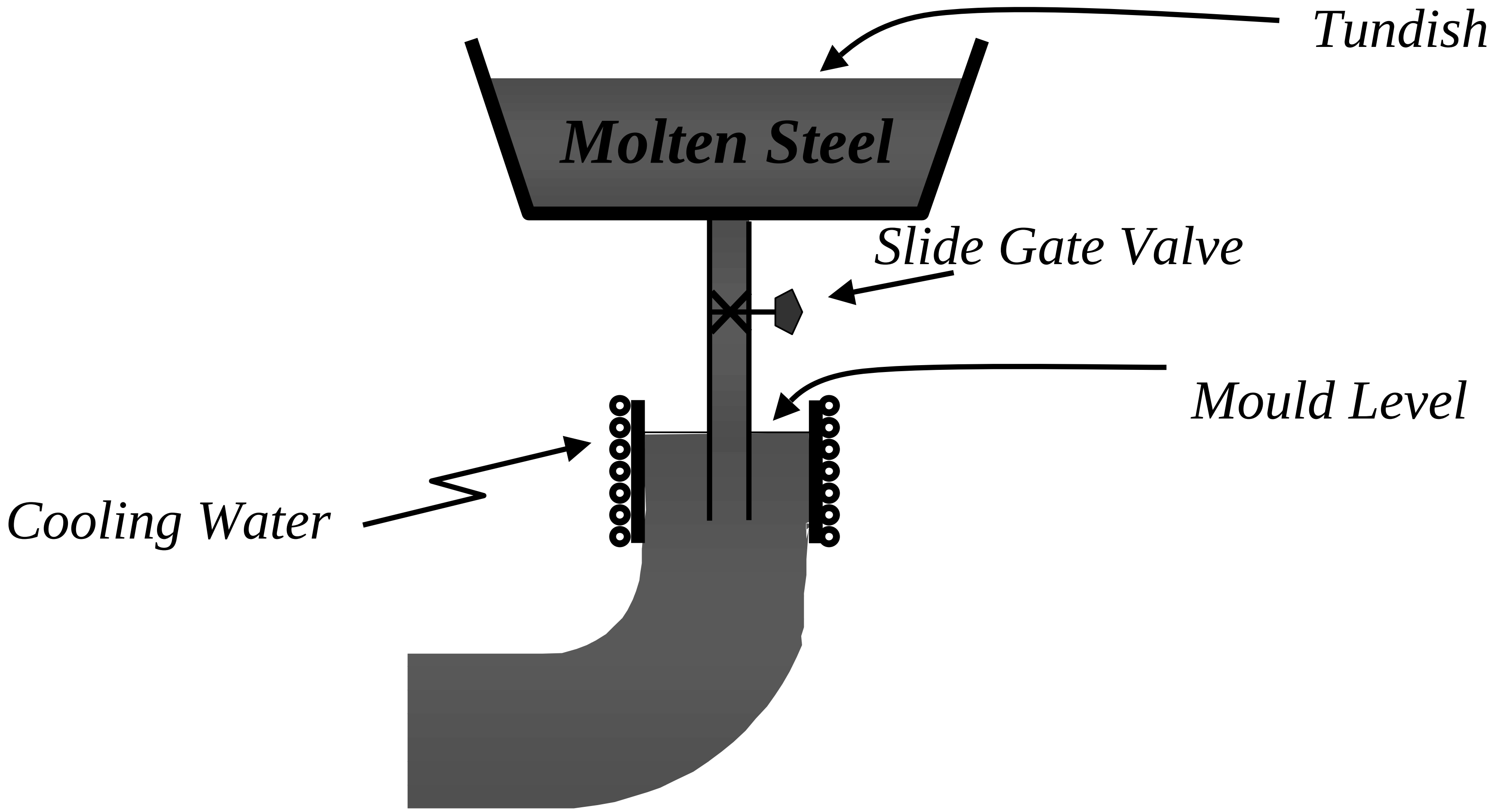
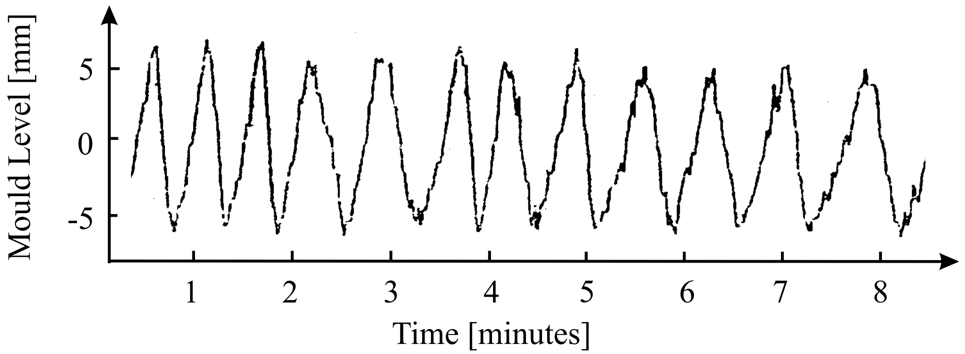


Figure 8.2: *Chart recording showing oscillations in conventional mould level control system*



The above oscillations result from the slide gate valve sticking until the level reaches some level, then the valve moves and the level ramps in the alternative direction until the error is again sufficient to move the valve. (*Remedies for this problem will be discussed later*).

Disturbances

Another source of performance limitation in real control systems is that arising from disturbances. This effect too can be evaluated using the appropriate loop sensitivity functions.

$$Y(s) = S_{io}(s)D_i(s) + S_o(s)D_o(s)$$

We observe that, to achieve acceptable performance in the presence of disturbances, it will generally be necessary to place a lower bound on the closed loop bandwidth.

Model Error Limitations

Another key source of performance limitation is due to inadequate fidelity in the model used as the basis of control system design. This was discussed in Chapter 5. A key function used to quantify these differences is the error sensitivity $S_\Delta(s)$, given by

$$S_\Delta(s) = \frac{1}{1 + T_o(s)G_\Delta(s)}$$

where $G_\Delta(s)$ is the multiplicative (*or relative*) model error. We conclude that:

To achieve acceptable performance in the presence of model errors, it will generally be desirable to place an upper limit on the closed loop bandwidth.