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## What is control?

Vaguely, it means manipulating some quantities of interest to some desired value.

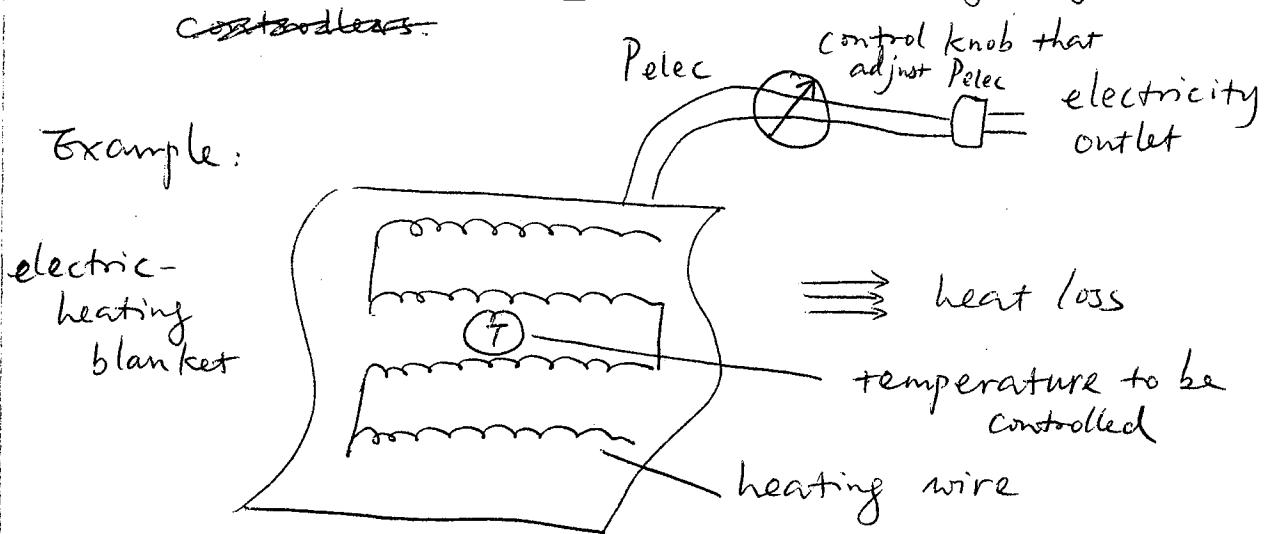
## Examples

1. Control human body
  - eye
  - arm, leg, hand
2. Human controls machines
  - control speed of driving
3. Automatic control of machines
  - cruise control
  - control the rotation speed of motor in CD-ROM Drive

Focus of this course: How to design "good" controller

~~cost-effective~~

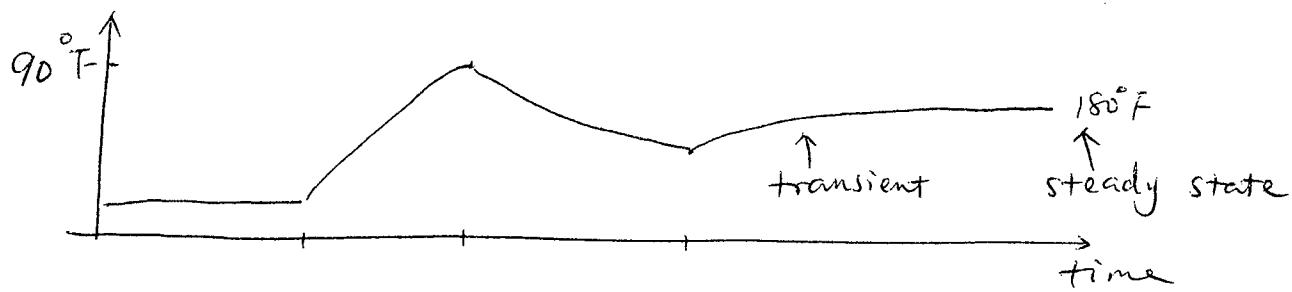
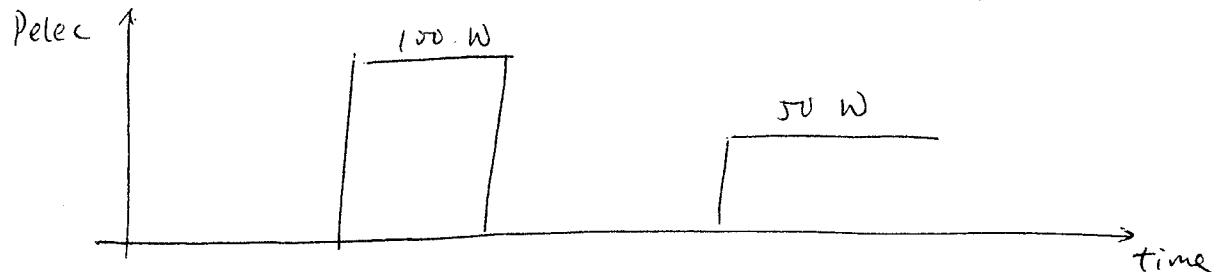
Example:



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This is a dynamic system with "memory"

- present value of  $T$  depends on past  $P_{elec}$

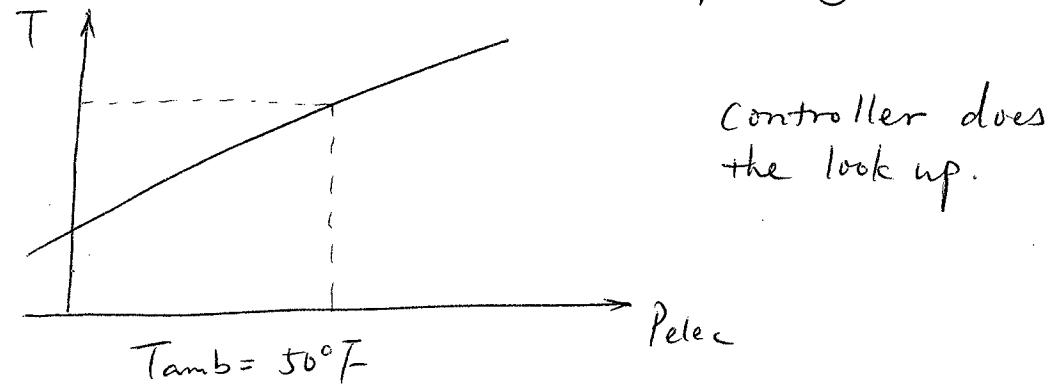


### A simple "open-loop" controller

"open-loop" means no feedback. The controller does not know or use the actual temperature  $T$ .

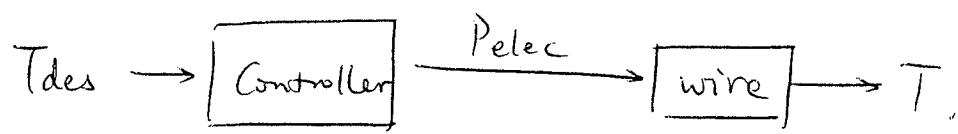
Idea: At a fixed ambient temperature  $T_{amb}$ , for every  $P_{elec}$ , we can measure the steady-state temperature  $T$ .

Conversely - given the desired temperature  $T_{des}$ , just set  $P_{elec}$  to the corresponding value.



(3)

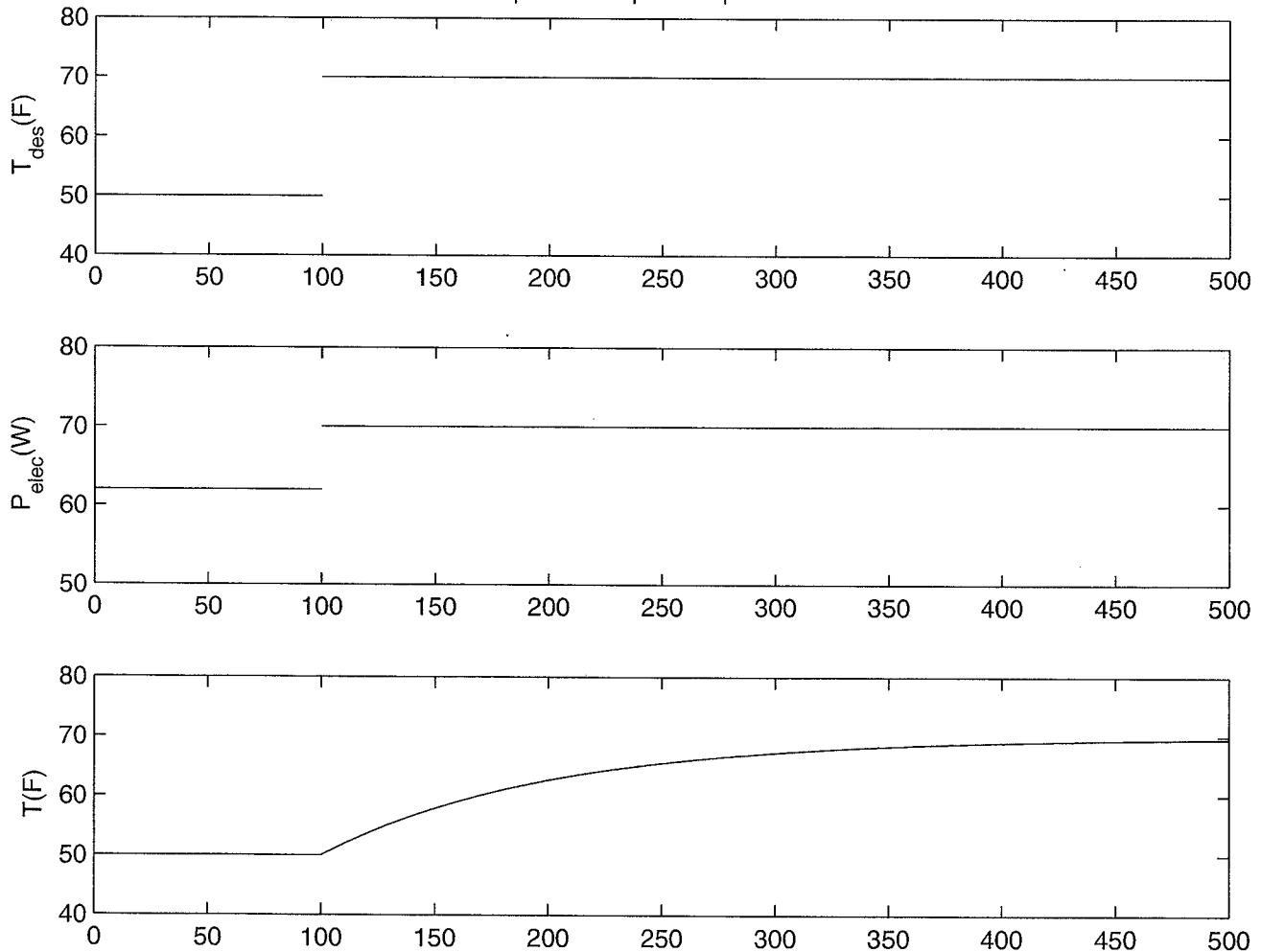
Diagram of open-loop controller



How well does this controller work?

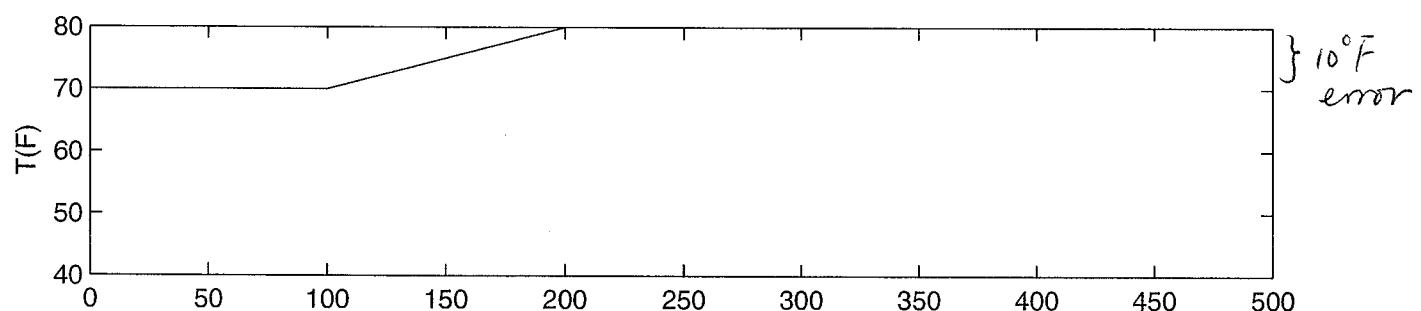
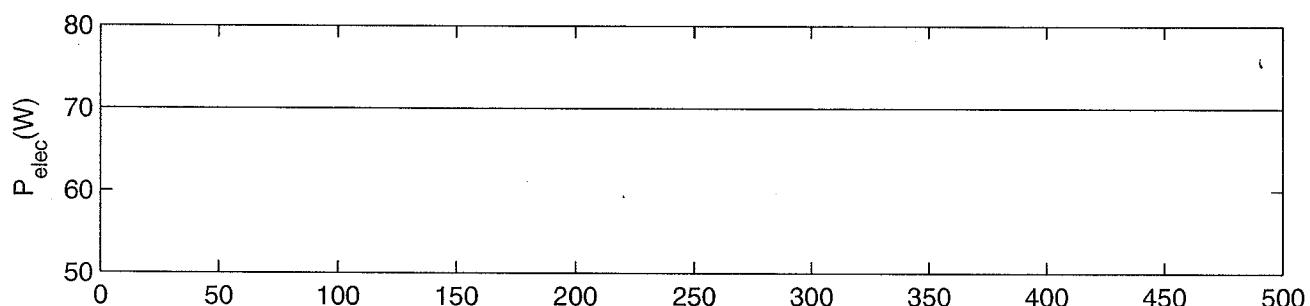
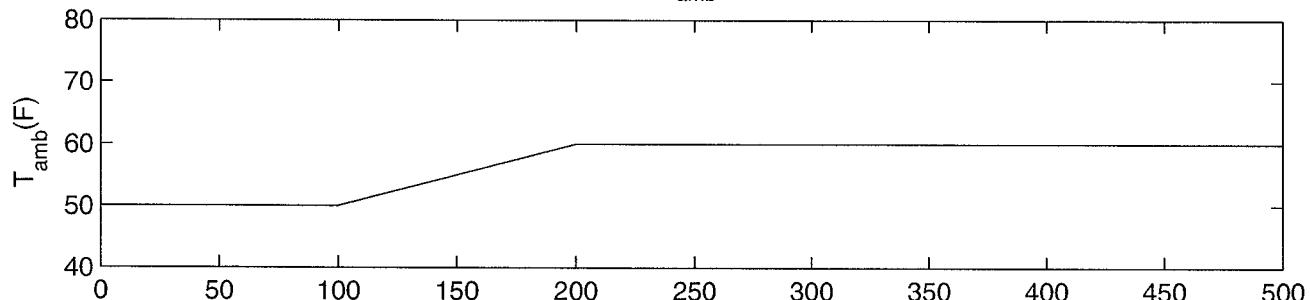
(4)

response of open-loop controller



$$T_{amb} = 50^{\circ}F$$

(5)

response to varying  $T_{amb}$  by open-loop control

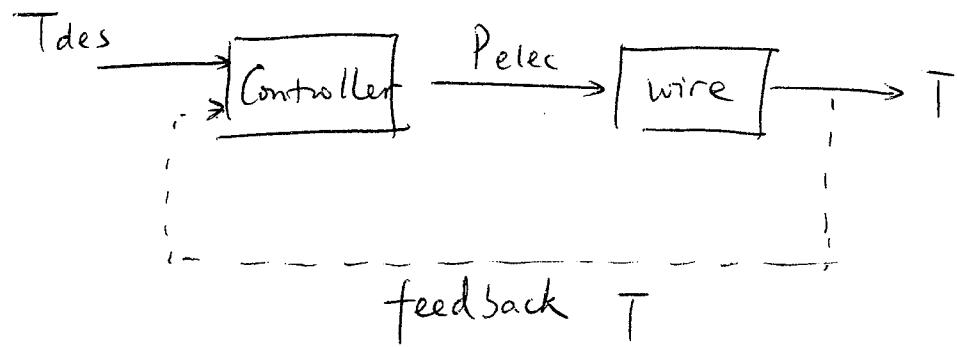
$$T_{des} = 70^{\circ}\text{F}$$

(6)

One of the biggest disadvantage of open-loop control is that it relies ~~on~~ too heavily on our model and assumption

For example, if the ambient temperature is not the same as in calibration, it will result into a steady error (see figure in previous page.)

### Feedback control



By adding a feedback loop, now the control action also depends on the actual temperature.

Intuitively, if error  $\equiv T_{des} - T > 0$ , Pelec is too low, otherwise, Pelec is too high.

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We will use the following simple feedback law.

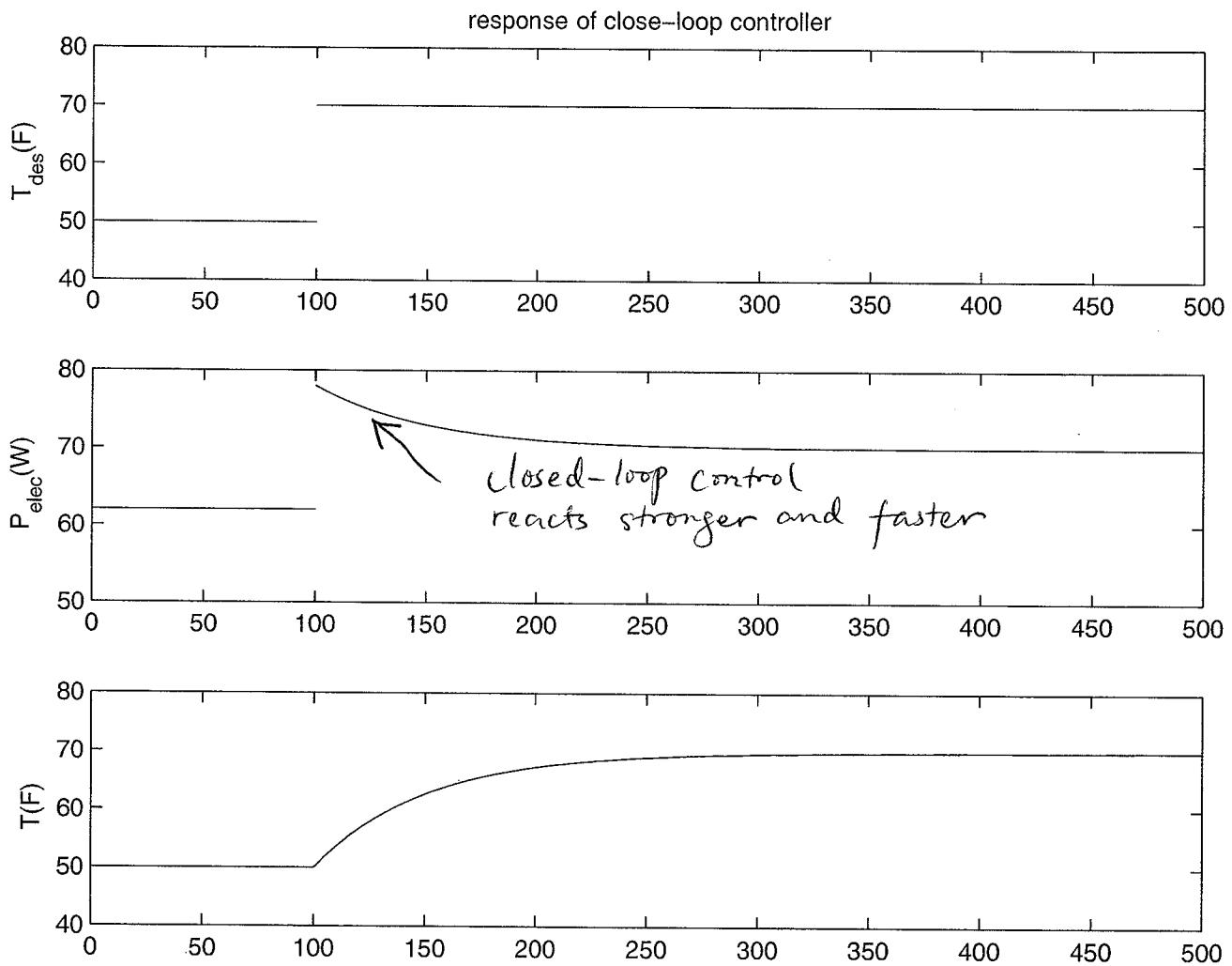
① Calculate error =  $T_{des} - T$

② Set

$$P_{elec} = P_{elec \text{ for OL controller}} + K \times \text{error}$$

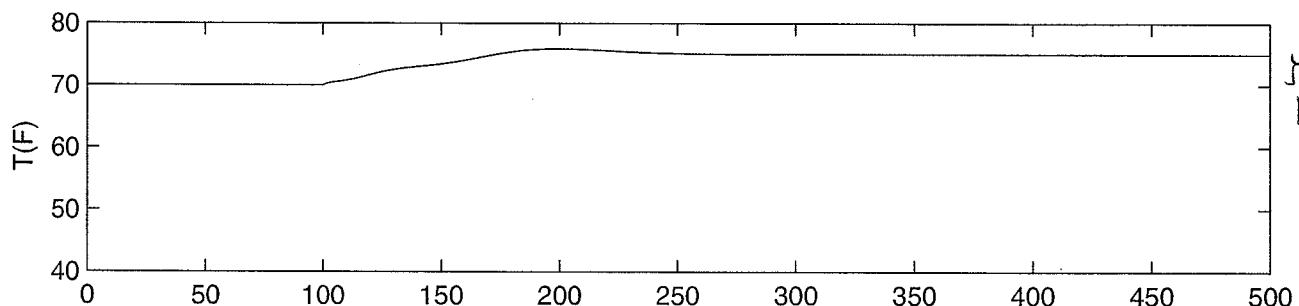
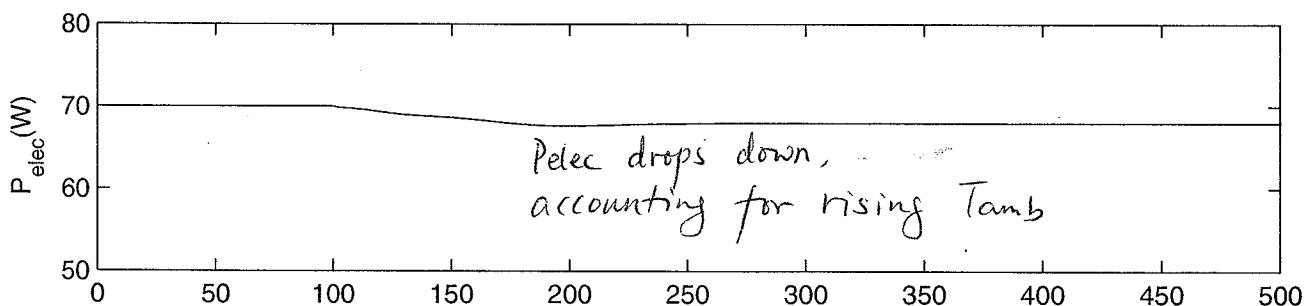
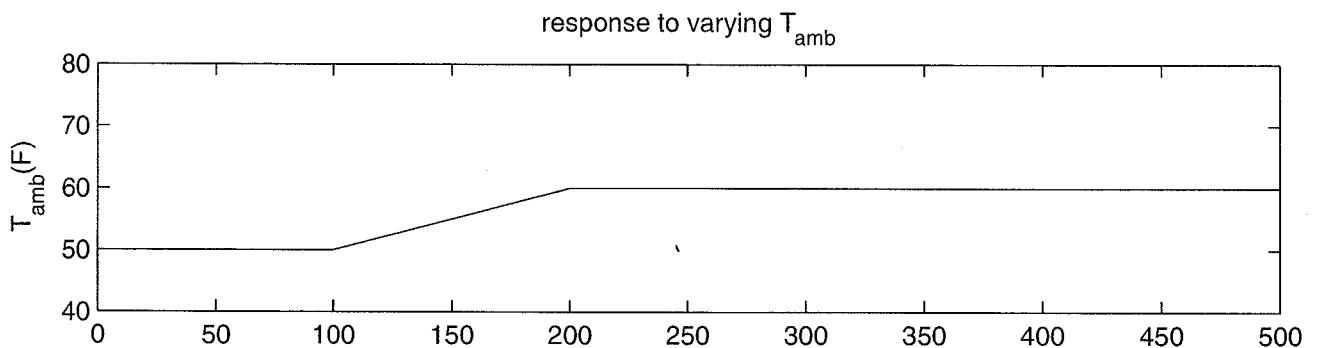
How well does this controller work?

(8)



$$T_{amb} = 50^{\circ}F, K=1$$

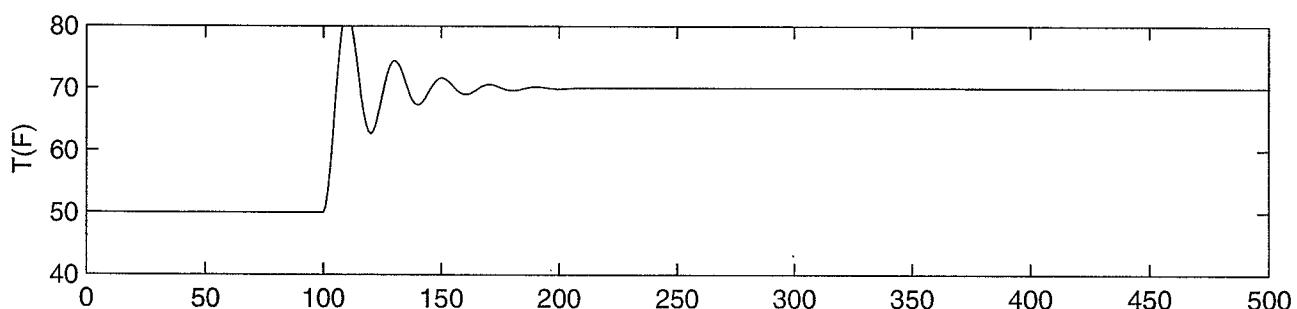
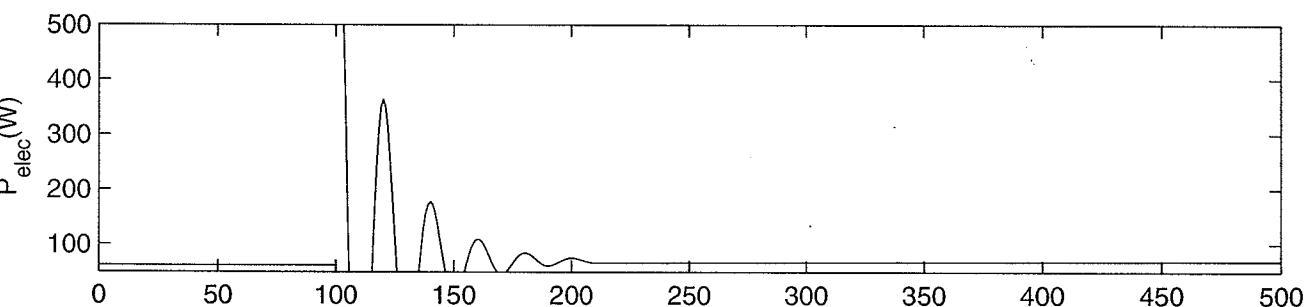
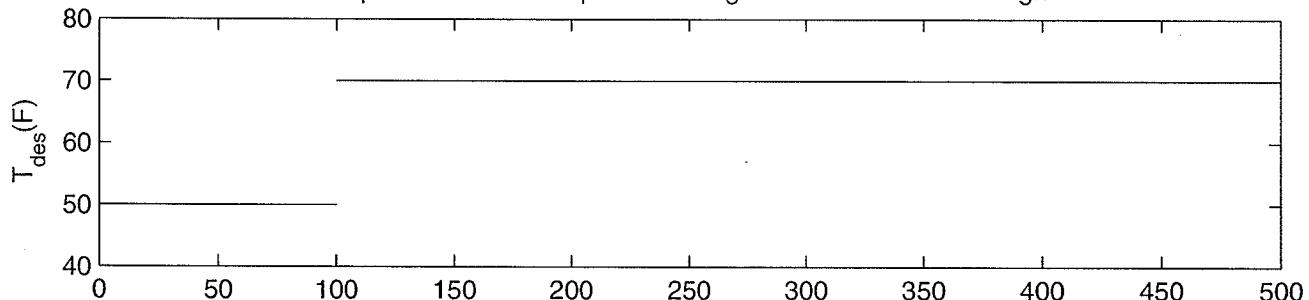
(9)



$$T_{des} = 70^{\circ}\text{F}, \quad K=1$$

(10)

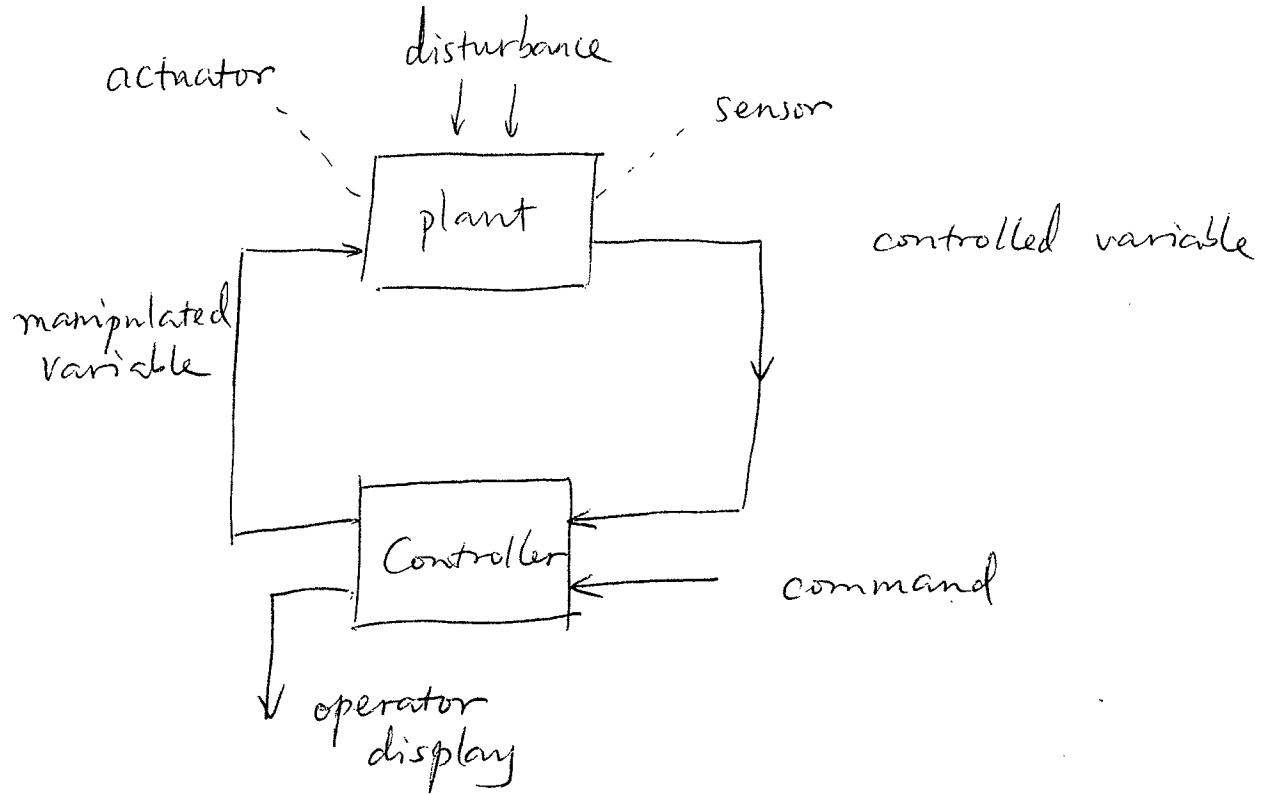
response of close-loop controller: gain of controller is too high!



$$T_{amb} = 50^{\circ}\text{F}, \quad K = 100$$

When  $K$  is too large, while the steady-state error is small, the system may become oscillatory or even unstable.

Schematic diagram of a general control system



Basic components of a control system

- plant (or process) is the system to be controlled
  - aircraft
  - missiles
  - traffic pattern
  - CD player
  - car
  - stock market

- controlled variable: the quantity or condition that is measured or controlled
  - temperature
  - speed
  - angle

Sensors measure the controlled variables

- speedometer
- thermometer

- manipulated variable: the quantity or condition that is varied by the controller so as to affect the value of the controlled variable
  - voltage
  - power
  - steam pressure

Actuators apply the manipulated variable to the plant

- motors
- heating elements
- pump

- Controller: processes information of controlled variables to yield the manipulated variables.  
Also produces operator diagnosis & warnings.  
Analog, electronic  
Digital  
Human
- Disturbances: signals that affect the system but are beyond our control, usually unknown  
wind gusts  
transistor noise  
fluctuations in operating conditions.

### Basic Steps in Control Engineering

#### 1. Modeling / Identification

To obtain a suitable mathematical model

① Decide on type of model

Examples: \* linear model of known parameters  
unknown parameters

\* nonlinear model

Factors to consider:

- \* Accuracy vs. complexity (10 components? 100?)
- \* Ease of mathematical analysis  
(linear models much easier)
- \* Economic considerations  
(more complicated model typically more expensive)

(b) Identify model parameters

once a model is decided upon, the numerical values of the parameters determining the model have to be obtained.

Involves running tests on the real system.

Factors to consider:

- \* Ease of running tests

(some systems are very hard to experiment with)

- \* Expense of running tests

- \* Time considerations

(some models might involve geological time scales)

(c) Validate model

Test how good the identified model is

## 2. System analysis

See how the system (model) behaves?

Some questions:

- \* how well does the system track?

- \* are there any steady-state errors?

- \* Is the system insensitive to ambient conditions?

- \* Is the system stable (do not oscillate excessively)?

Answered by theory and/or simulations. A set of specifications ("specs") can be laid down

(15)

as the desired improvement to be made (via control).

### 3. Design controllers

Once we have the mathematical model of the plant & the design specs, the problem reduces to determining the control law (what feedback processing do we need?) and implementing the law (what controller architecture is to be used?)

Determining the control law is a vast research area (mainly theoretical, with simulations)

Implementing the law is mostly an engineering problem (cost, ease of implementation)

### 4. Test performance of closed loop system

Implement the controller on the real system (not the model), see if it performs satisfactorily.

Often, it won't, so reiterate Steps 1-3

This course:

- 1: some modeling - simple mechanical & electrical models
- 2: some analysis - only single-input, single output, linear time-invariant lumped systems
3. some design - mostly frequency-domain methods (none of the modern optimal control based on state-space models)