EE 4323 – Industrial Control Systems
Module 4a: Actuators for Industrial Controls

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Actuators for Industrial Controls – Overview

- Motivation
- Basic concepts
- Solenoids
- DC servomotors, stepper motors
- Hydraulic actuators
- Pneumatic actuators
- Direct electrical actuation
- Summary of considerations

References:

- C. D. Johnson, *Process Control Instrumentation Technology*, Prentice Hall, Fifth Edition, 1997 (very good, emphasis on process control; **I have a copy here if you're iterested**)
- C. L. Nachtigal, *Instrumentation & Control - Fundamentals and Applications*, John Wiley & Sons, 1990 (practical / encyclodedic)

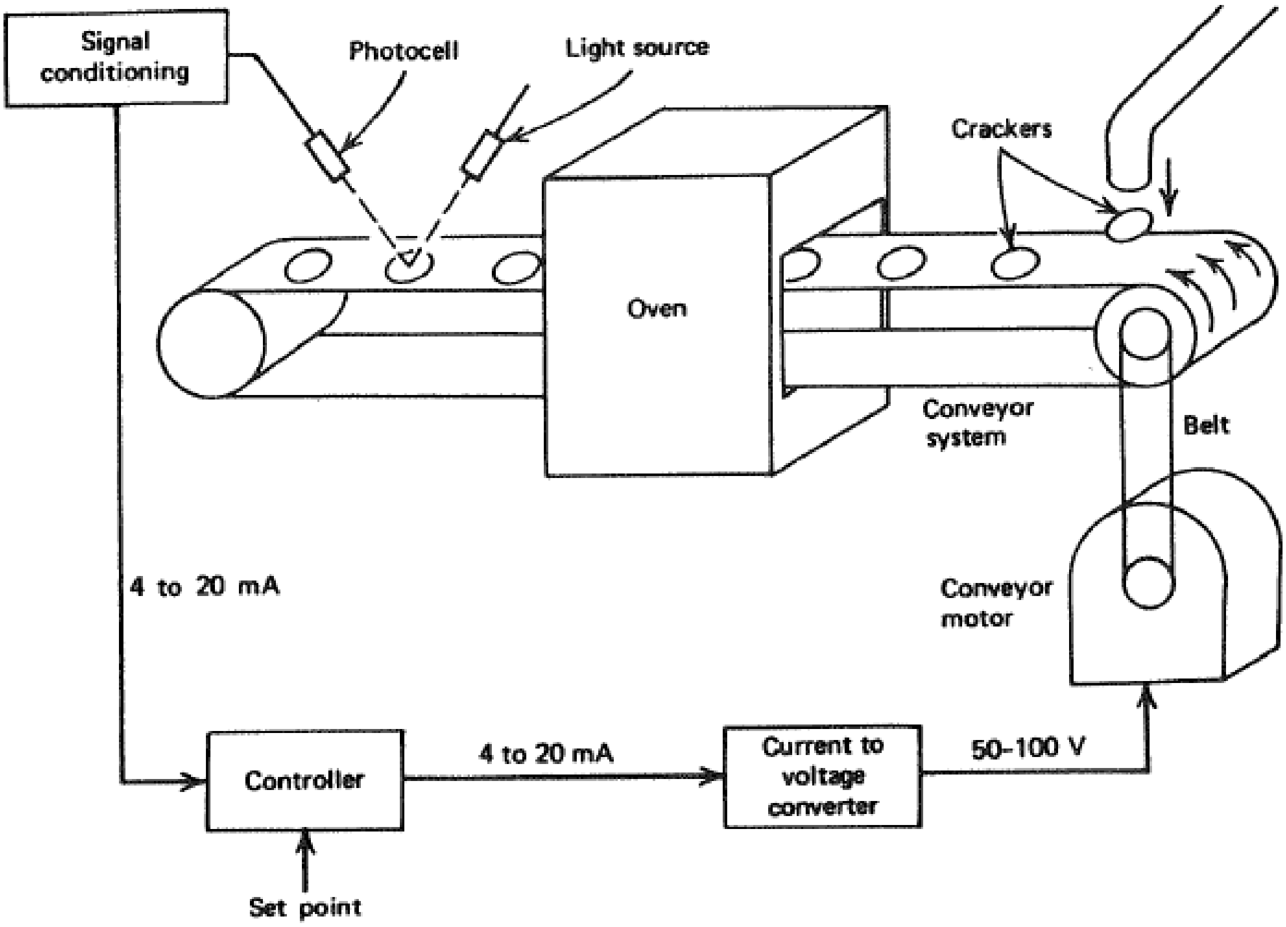
Motivation

- Deciding **what** to actuate and **how** to actuate it may be a major part of designing an industrial control system
- Actuator characteristics (static, dynamic) may be a **major factor** in determining (and limiting) a control system's performance
- Assuming an actuator is simply modelled as K_{act} may be **totally unrealistic**
- Determining a realistic actuator model (the best way to deal with limitations imposed by the actuator) is not trivial – it takes engineering judgement plus mathematical modelling techniques (physical modelling, model identification)
- **This module is not a presentation of the state-of-the-art in actuation; rather, this material is meant as a basis for discussing the issues**

Basic Considerations

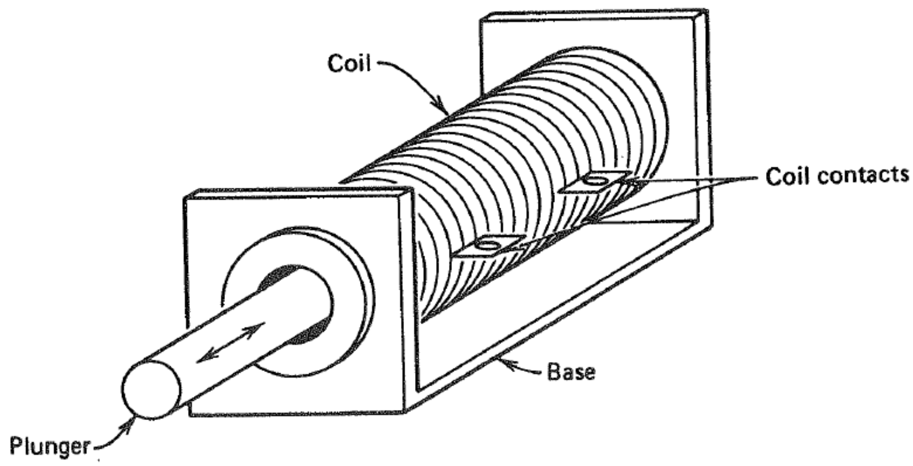
- Most fundamentally: **what variable do you need to actuate, over what range**; then factor in **imperfections** such as nonlinearity, loading, dynamic effects (lag), frequency response (related to lag), environmental effects, cost, ruggedness, reliability, ...
- The most basic limitations (imperfections) are **nonlinearity** and **dynamic response**; we will focus more closely on those issues and on using the Least Squares technique (Module 5) for modelling them. In this context, the most important considerations are:
  - What type of model to use – **nonlinear:** polynomial, piece-wise linear, exponential, log, ...; **dynamic:** usually continuous-time ($G(j\omega)$) – the question is **what order?**
  - In either case **overfitting** is a major concern (high-order polynomials, high-order $G(j\omega)$ model); in the case of static nonlinearity there is also the issue of model "safety" (e.g., high-order polynomials become dangerous outside the fitting range and may also be in error between fitted points, while piece-wise linear models don't suffer from these problems)
  - The above points should be carefully considered **before** doing Least Squares modelling

Down-to-Earth Example



- Goal: bake the crackers to a rich golden brown
- Use a simple "vision system" to judge; if they are too dark decrease the baking time (speed up the conveyor belt); if they are too light increase the baking time
- Note the "4 to 20 milliamp" signals; that is industry standard for interconnecting components

Translational Activation



- Iron plunger: pull only; magnetic plunger: push and pull
- Plunger position is quite nonlinear: push / pull force decreases with extension; range of motion limited (saturation)
- Dynamic lag is unlikely to matter unless the solenoid is large relative to the object being moved

Industrial Example:

ECO-WORTHY 16 Inch 12V Linear Motor Actuator Heavy - Duty Solar Tracker

Solenoid Application – Gear Shifter

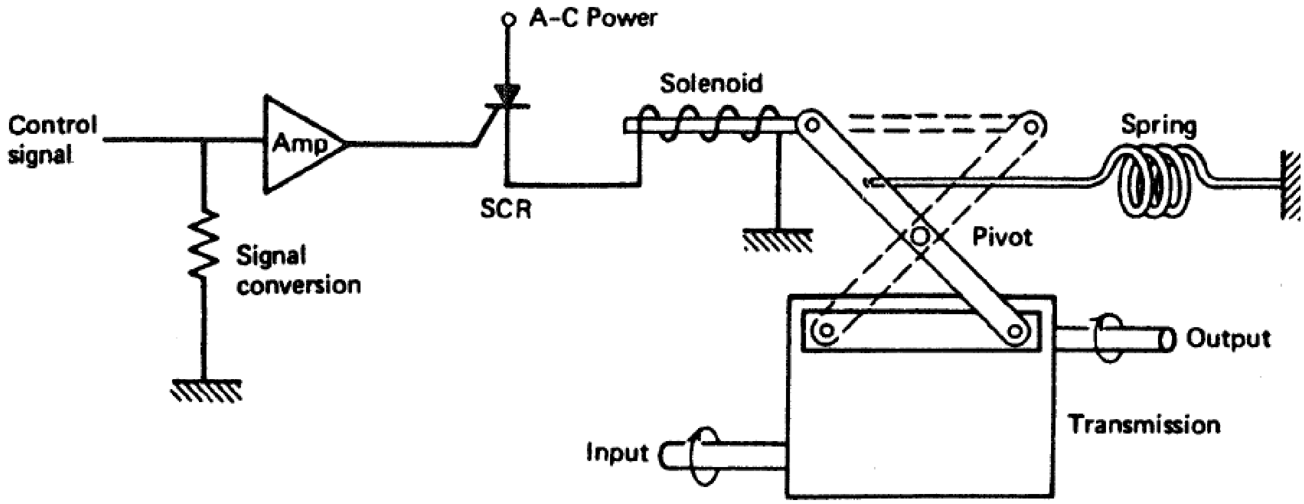
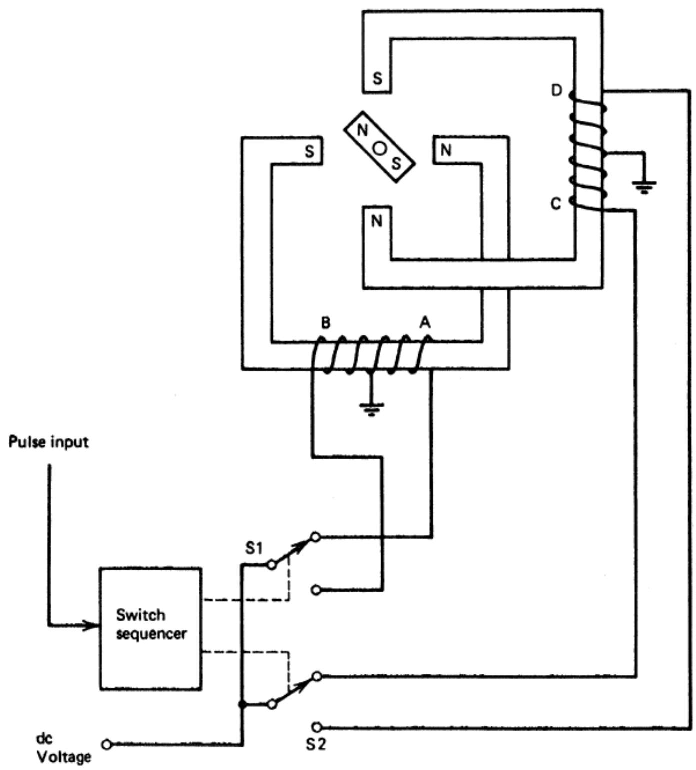


FIGURE 7.19
A solenoid used to change gears.

- Solenoid in pull mode (iron core) working against a spring
- Two-position operation ⇒ nonlinearity is unimportant as long as the solenoid is strong enough to perform its task crisply
- Dynamic lag is unlikely to matter in this application
- Notice that the solenoid is actuating an actuator – this is quite common

Rotary Actuation



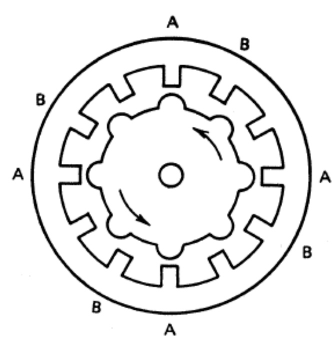
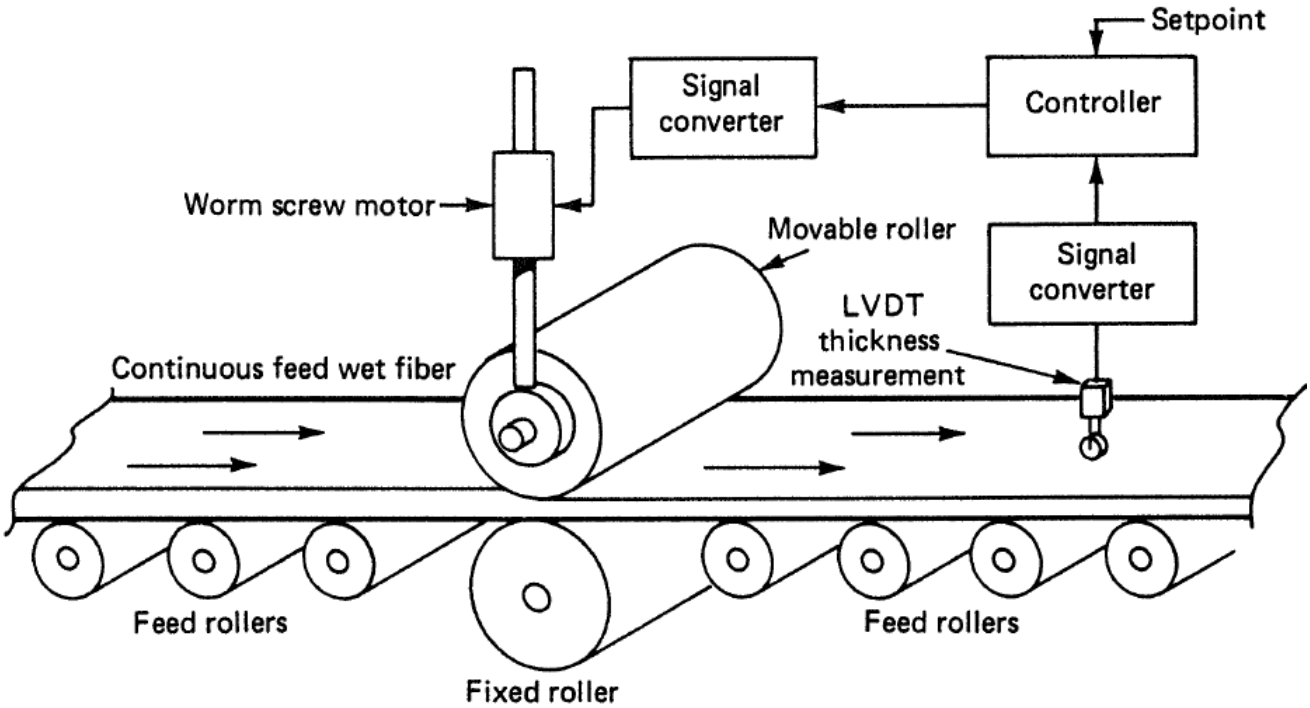


FIGURE 7.26
Cross section of a stepper with 8 rotor teeth and 12 stator poles. Note that the rotor lines up with the A poles. With the next step, the rotor will line up with the B poles.

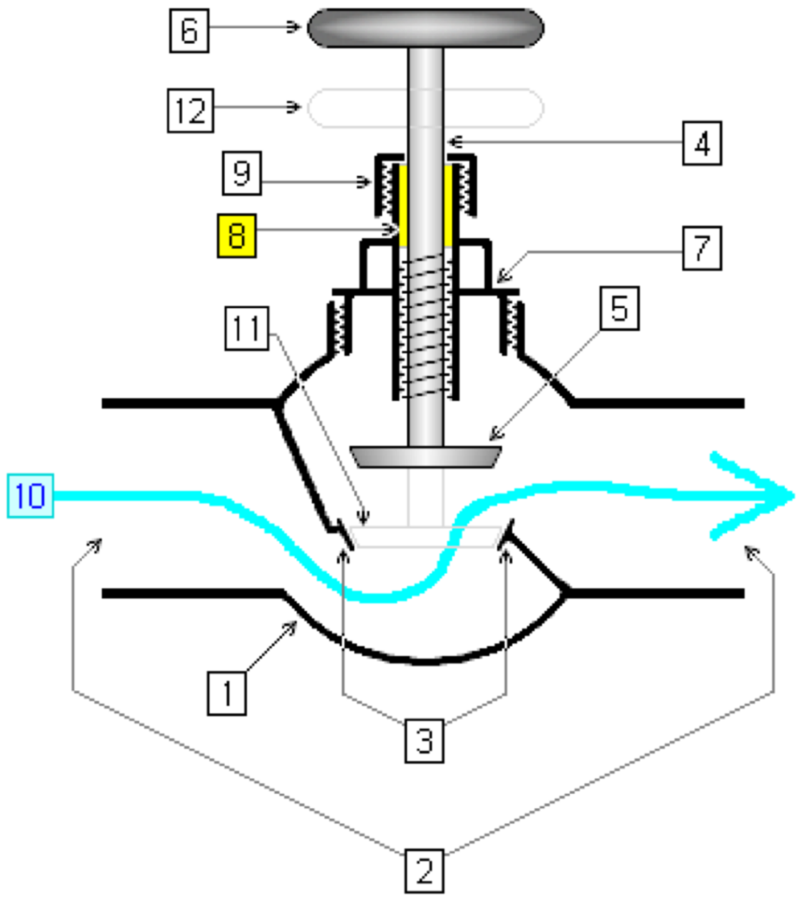
- Rotation is achieved by activating the stator electromagnets sequentially
- Discrete angular rotation only: 45°, 135°, 225°, ... (very crude but it may do your job); use 12 stator poles for better precision, ±30° in the lower figure; ±2° is possible
- The rate of stepping is governed by input pulse rate which controls the switching of the stator electromagnets; the rate is limited by the mechanical properties of the rotor (moment of inertia, friction)
- Unlimited range of operation (no angular saturation)

Stepper Motor Application

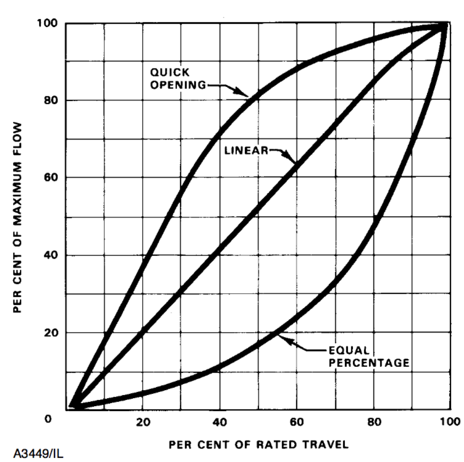


- A stepper motor is ideal for use in the worm-screw actuator – precise worm-screw angular position is desired for precise thickness control
- The discrete angular steps of the motor combined with the screw threads must allow sufficiently fine adjustments
- The sensor is an LVDT (linear variable displacement transformer), a very accurate position sensor for small displacements
- The LVDT should be close to the roller, to minimiza time delay

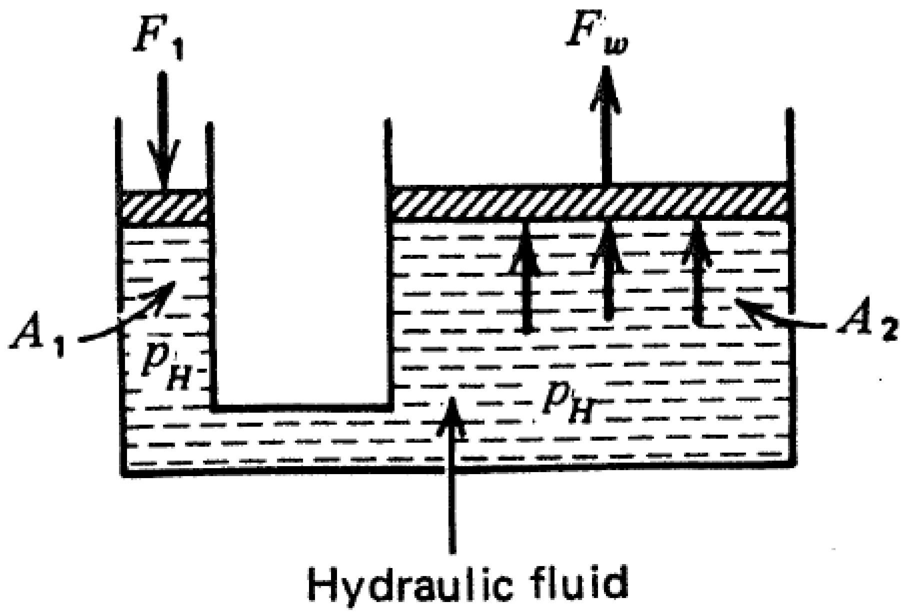
Solenoid or Motor Application



- Valve stem (4) position may be moved by a magnetic plunger solenoid or pneumatic actuator (if not threaded), or by a stepper motor
- A solenoid would increase the nonlinearity of the valve actuation and rate of flow
- The rate of flow may be linearly related to the valve stem travel, or "quick opening" or logarithic, depending on the geometry of the "stopper" (5, 11) and valve seat (3)

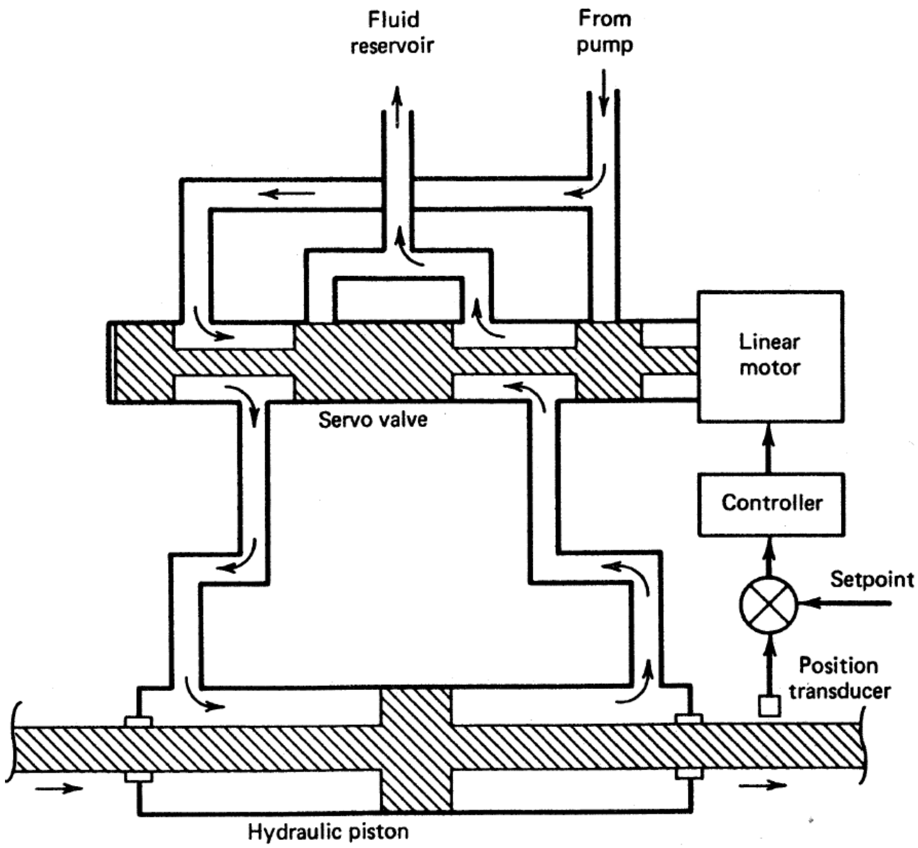


Simple Hydraulic Actuation



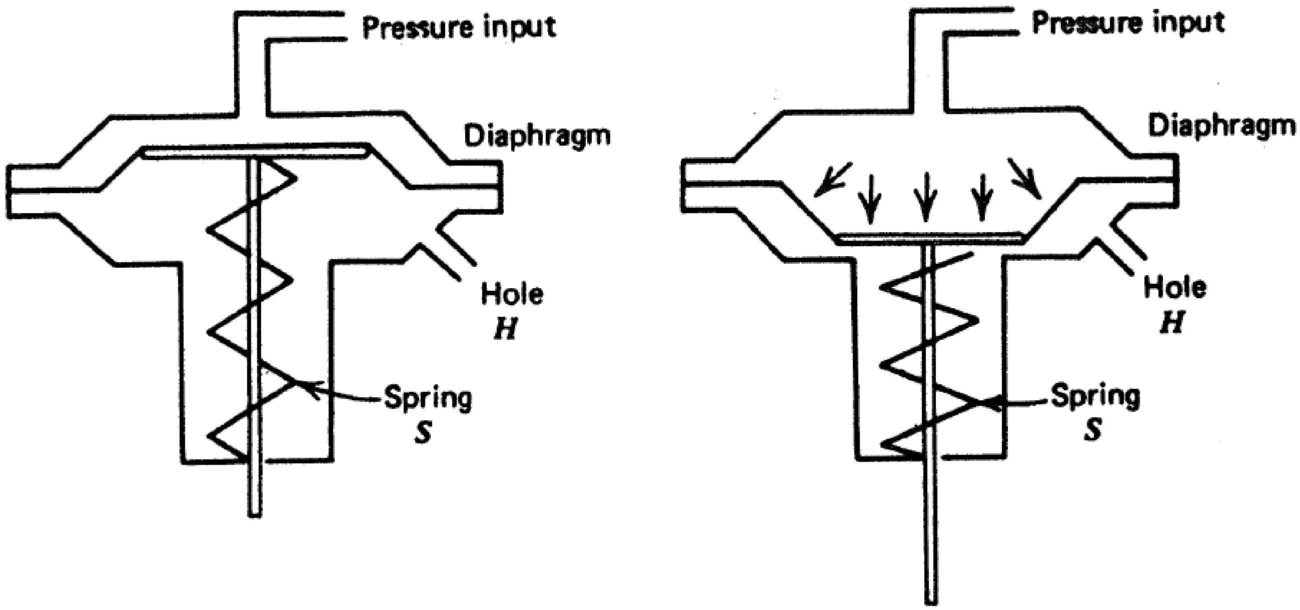
- Linear force multiplier: $F_w = \frac{A_2}{A_1} F_1$
- Vertical displacement is also linear: $\Delta y_2 = \frac{A_1}{A_2} \Delta y_1$
- Hydraulic fluid is virtually incompressible, so there is little dynamic lag (unless there are gas bubbles in the fluid, as occurs in bad brakes in your car)

Industrial Hydraulic Actuator



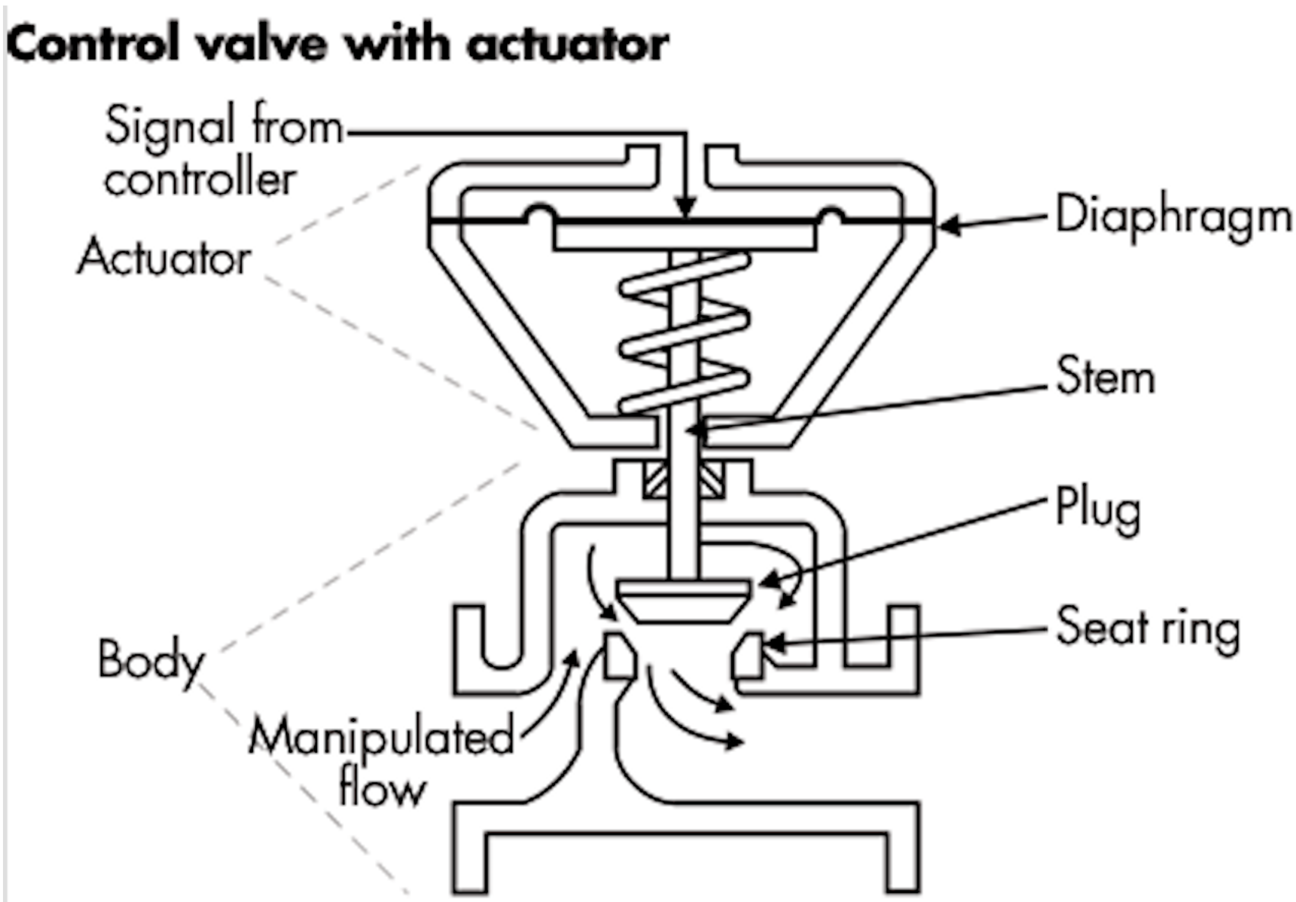
- The force applied by the linear motor is substantially multiplied in the actuation force of the hydraulic piston
- If the servo valve is moved half way to the right the fluid flow and motion are reversed
- If the servo valve is moved fully to the right the fluid flow and motion cease
- Note: the chambers of the servo valve are misdrawn
- Again, this is a linear force multiplier with a limited range of motion

Simple Pneumatic Actuation



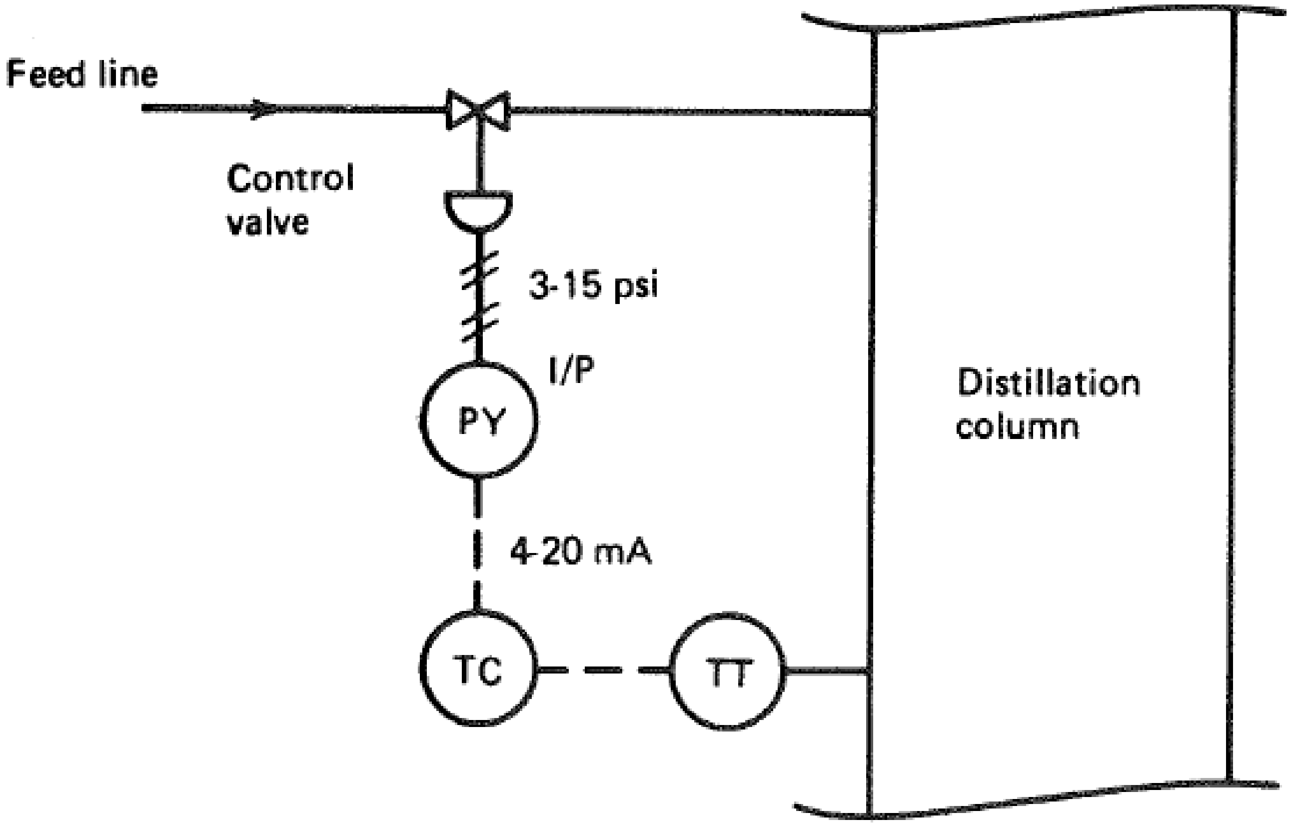
- Often used as a secondary actuator for a valve (next slide)
- A pneumatic actuator acts much like a solenoid, iron core if the air pressure supply is positive only, magnetic core if the air pressure supply can provide negative pressure (and if the diaphram geometry supports it)
- Another pneumatic actuator design uses a piston rather than a diaphram; the diaphram type may be nonlinear, depending on the diaphram's geometry; the piston type is linear until limits are reached
- Air is compressible, so the dynamic response may be important, providing lag and perhaps a response with overshoot if the losses are low

Compound Pneumatic Actuation



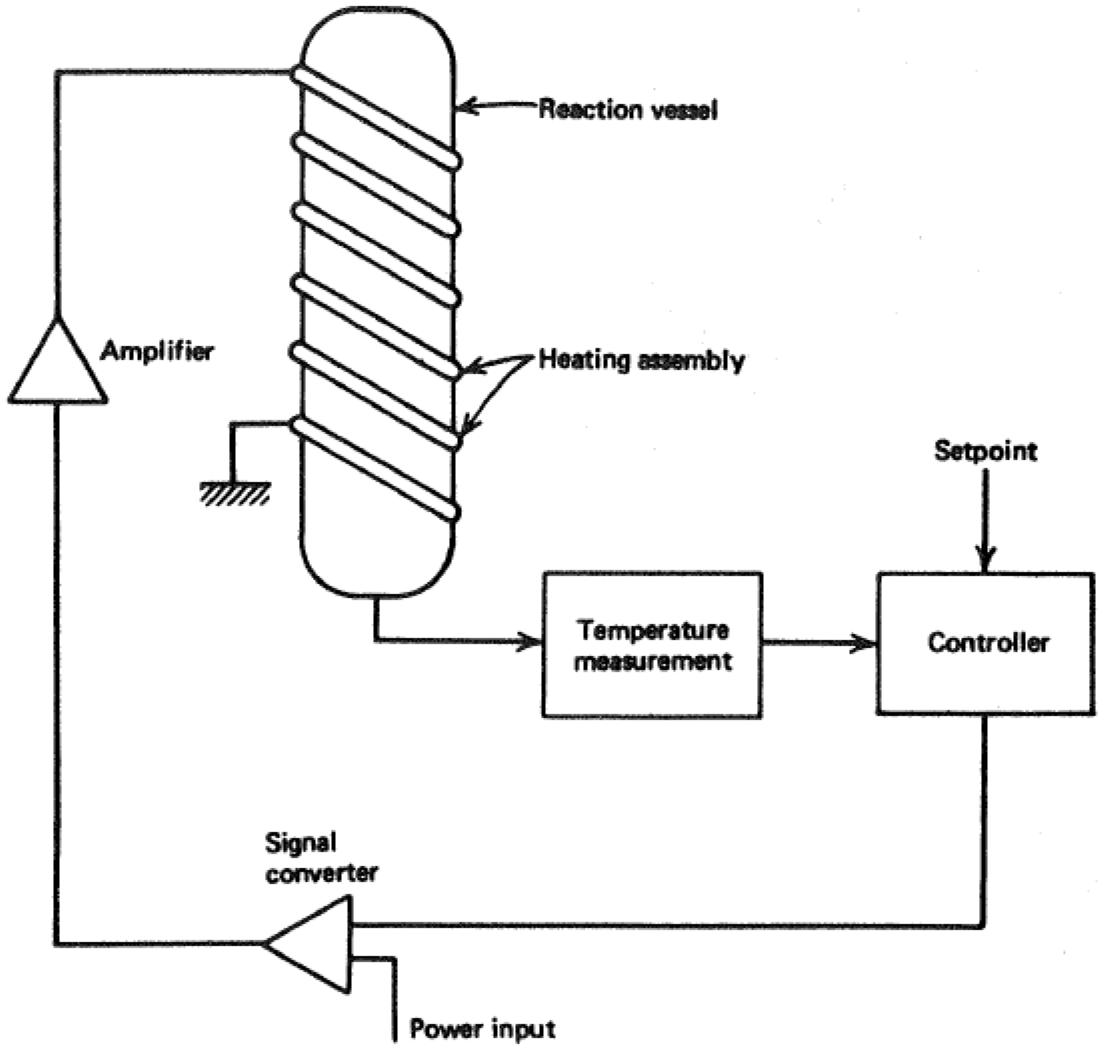
- The diaphram geometry shown will have a limited range of linearity; depending on the valve plug and seat (which may also provide nonlinear flow control) that may be important (for approximately linear flow contol) or not (for quick opening valve design)
- Availability of a compressed air supply is required, for practicality; some process control facilities may use pneumatic actuation throughout the operation, but as a single instance it's not feasible

Compound Flow Control (Cont'd)



- A valve actuation system may be used to regulate flow to a desired set point, or to implement volume control in a tank
- Here we see an electrical sensor and signal conditioning unit that yields a 4-20 mA signal which in turn is converted to 3-15 psi for valve actuation

Direct Electrical Actuation



- Temperature in a vessel may be controlled electrically, as shown, or by adding a "jacket" around the tank through which a hot liquid or steam may be circulated (e.g., a jacketed stirred tank reactor)
- Either is effective; the overarching issue is the facility infrastructure (availability of a source of hot liquid or steam)

Summary of Actuation Considerations

- First, **does the facility have pneumatic or hydraulic power available** for system implementation? Choose your approach and components accordingly.
- Does your application require **continuous/smooth actuation** (a servo motor) or will discrete actuation suffice (e.g., a stepper motor)?
- **Sizing** an actuator is very important – for example, a valve that is too small cannot provide adequate flow, one that is too large will make accurate flow control difficult; a solenoid that cannot provide sufficient force cannot do the job, if it's too strong you may be wasting money.
- As discussed, linearity / nonlinearity may or not be important; choose your actuators accordingly. Don't insist on linearity if it's not necessary; that would ordinarily add to the cost. Again, remember that **all actuators have limited range** which must not be neglected.
- **Remember: keep it simple, minimize cost, make it sufficiently rugged (with respect to both the component itself and the environment in which it will operate), make it reliable, . . .**