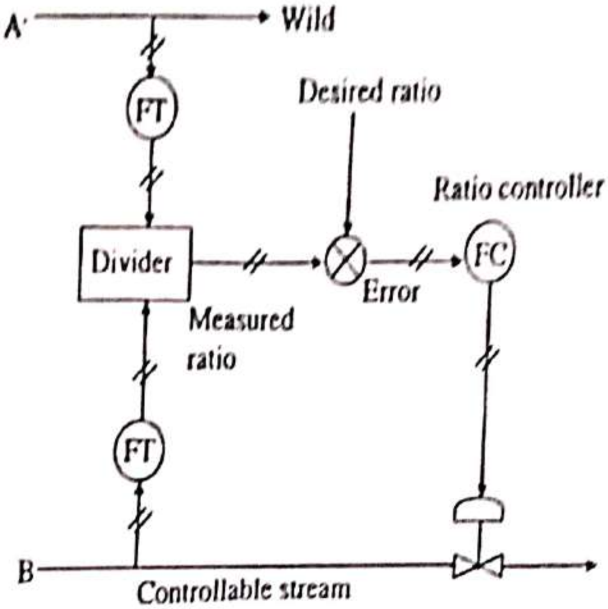
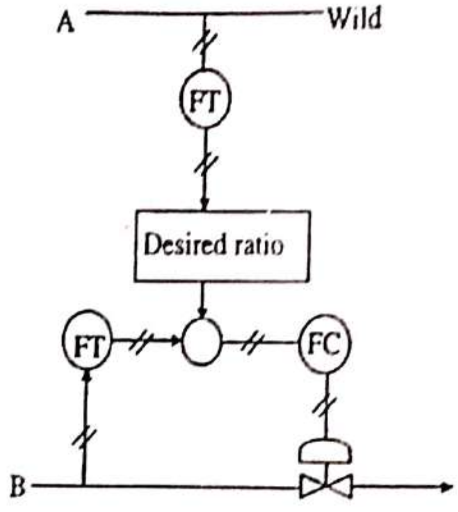
Control Configurations

...guration 1:

...control configuration, we measure both the flow rates, and take their ratio. This ratio is compared with ...ired ratio, and the deviation between the two is used to generate the actuating signal for the ratio ...oller.



...figuration 2:



...this configuration, flow measurement of the wild stream, A, provides set point for the controllable flow ...eam, B.

14 MATHEMATICAL MODELING & TUNING METHOD

oduction

hematical modeling of fluid systems and. thermal systems. As the most versatile medium for transmitting als and power, fluids–liquids and gases–have wide usage in industry. Liquids and gases can be nguished basically by their relative incompressibilities and the fact that a liquid may have a free surface, reas a gas expands to fill its vessel. In the engineering field the term pneumatic describes fluid systems that air orgases and hydraulic applies to those using oil.

istance and Capacitance of Liquid-Level Systems

sider the flow through a short pipe connecting two tanks. The resistance R for liquid flow in such a pipe or riction is defined as the change in the level difference (the difference of the liquid levels of the two tanks) essary to cause a unit change in flow rate; that is,

$$R = \frac{\text{change in level difference, m}}{\text{change in flow rate, m}^3\text{/sec}}$$

the relationship between the flow rate and level difference differs for the laminar flow and turbulent flow, ce the relationship between the flow rate and level difference differs for the laminar flow and turbulent flow, shall consider both cases in the following.

sider the liquid-level system shown in Figure (a). In this system the liquid spouts through the load valve in side of the tank. If the flow through this restriction is laminar, the relationship between the steady-state flow e and steady-state head at the level of the restriction is given by

$$Q = KH$$

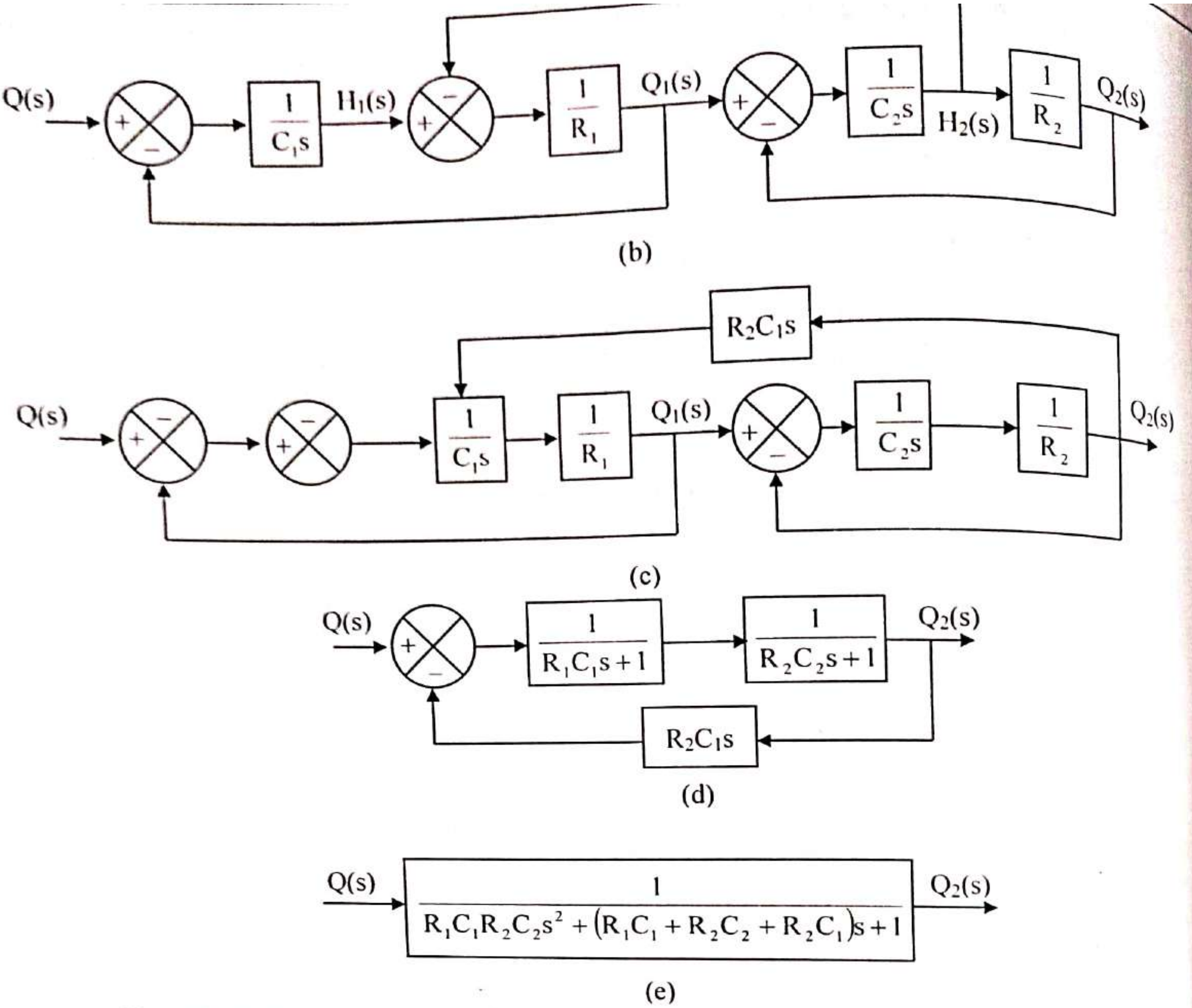


Figure: (a) Elements of the block diagram of the System shown in Figure; (b) block diagram of the system; (c)–(e) successive reductions of the block diagram.

Notice the similarity and difference between the transfer function given by Equation and that given Equation. The term R_2C_1S that appears in the denominator of Equation exemplifies the interaction between two tanks. Similarly, the term $R_1 C_2s$ in the denominator of Equation represents the interaction between the RC circuits shown in Figure.

PNEUMATIC SYSTEMS

In industrial applications pneumatic systems and hydraulic systems are frequently compared. Therefore, bef we discuss pneumatic systems in detail, we shall give a brief comparison of these two kinds of systems.

...parison Between Pneumatic Systems and Hydraulic Systems.

...fluid generally found in pneumatic systems is air; in hydraulic systems it is oil. And it is primarily the ...ent properties of the fluids involved that characterize the differences between the two systems. These ...ences can be listed as follows:

Air and gases are compressible, whereas oil is incompressible (except at high pressure).

Air lacks lubricating property and always contains water vapor. Oil functions as a hydraulic fluid as well as a lubricator.

The normal operating pressure of pneumatic systems is very much lower than that of hydraulic systems.

Output powers of pneumatic systems are considerably less than those of hydraulic systems.

Accuracy of pneumatic actuators is poor at low velocities, whereas accuracy of hydraulic actuators may be made satisfactory at all velocities.

In pneumatic systems, external leakage is permissible to a certain extent, but internal leakage must be avoided because the effective pressure difference is rather small. In hydraulic systems internal leakage is permissible to a certain extent, but external leakage must be avoided.

No return pipes are required in pneumatic systems when air is used, whereas they are always needed in hydraulic systems.

Normal operating temperature for pneumatic systems is 5° to 60°C (41° to 140°F). The pneumatic system, however, can be operated in the 0° to 200°C (32° to 392°F) range. Pneumatic systems are insensitive to temperature changes, in contrast to hydraulic systems, in which fluid friction due to viscosity depends greatly on temperature. Normal operating temperature for hydraulic systems is 20° to 70°C (680 to 158°F).

Pneumatic systems are fire- and explosion-proof, whereas hydraulic systems are not, unless nonflammable liquid is used.

...what follows we begin with a mathematical modeling of pneumatic systems. Then we shall present ...umatic proportional controllers.

...shall first give detailed discussions of the principle by which proportional controllers operate. Then we shall ...methods for obtaining derivative and integral control actions. Throughout the discussions, we shall place ...hasis on fundamental principles, rather than on the details of the operation of the actual mechanisms.

...eumatic Systems

...past decades have seen a great development in low-pressure pneumatic controllers for industrial control ...tems, and today they are used extensively in industrial processes. Reasons for their b ad appeal include an ...plosion-proof character, simplicity, and ease of maintenance.

Resistance and Capacitance of Pressure Systems

Many industrial processes an pneumatic controllers involve the flow of a gas or air through connected pi and pressure vessels.

Consider the pressure system shown in Figure (a). The gas flow through the restriction is a function of t pressure difference p_i - p_0. Such a pressure system may be characterized in terms of a resistance capacitance.

The gas flow resistance R may be defined as follows:

$$\frac{\text{change in gas pressure difference, } lb_f/ft^2}{\text{change in gas flow rate, lb/sec}}$$

or

$$R = \frac{d(\Delta P)}{dq}$$

where d(Δ P) is a small change in the gas pressure difference and dq is a small change in the gas flo Computation of the value of the gas flow resistance R may be quite time consuming. Experimentally, ho it can be easily determined from a plot of the pressure difference versus flow rate by calculating the slope curve at a given operating condition, as shown in Figure (b).

The capacitance of the pressure vessel may be defined by

$$\frac{\text{change in gas stored, lb}}{\text{change in gas pressure, } lb_f/ft^2}$$

or

$$C = \frac{dm}{dp} = V\frac{d\rho}{dp}$$

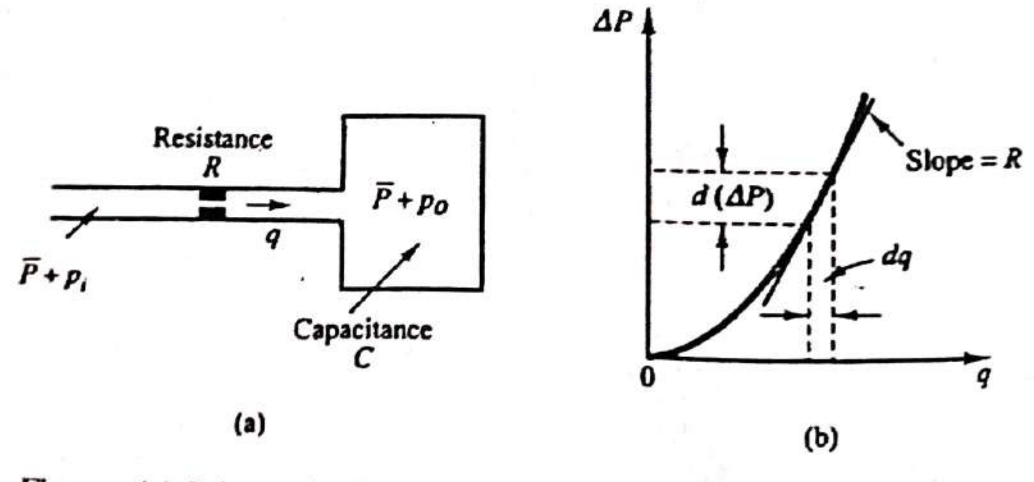


Figure (a) Schematic diagram of a pressure system;
(b) pressure-difference-versus-flow-rate curve.

C = capacitance, $lb\text{-}ft^2/lb_f$

m = mass of gas in vessel, lb

p = as pressure, lb_f/ft^2

V = volume of vessel, ft^3

ρ = density, lb/ft^3

...acitance of the pressure system depends on the type of expansion process involved. The capacitance can ...culated by use of the ideal gas law. If the gas expansion process is polytropic and the change of state of ...s is between isothermal and adiabatic, then

$$p\left(\frac{V}{m}\right)^n = \frac{p}{\rho^n} = \text{constant} = K$$

...e n = polytropic exponent.

...leal gases.

$$p\bar{v} = \bar{R}T \quad \text{or} \quad pv = \frac{\bar{R}}{M}T$$

...e p = absolute pressure, lb_f/ft^2

$\bar{v}$ = volume occupied by 1 mole of a gas, ft^3/lb-mole

$\bar{R}$ = universal gas constant, ft-lb_f/lb-mole °R

T = absolute temperature, °R

v = specific volume of gas, ft^3/lb

M = molecular weight of gas per mole, lb/lb-mole

$$pv = \frac{p}{\rho} = \frac{\bar{R}}{M}T = R_{gas}T$$

...re R_{gas} = gas constant, ft-lb,/lb °R.

...polytropic exponent n is unity for isothermal expansion. For adiabatic expansion, n is equal to the ratio of ...cific heats c_p/c_l where cp is the specific heat at constant pressure and c_L is the specific heat at constant ...ume. In many practical cases, the value of n is approximately constant, and thus the capacitance may be ...sidered constant.

...e value of dρ/dp is obtained from Equations we have

$$dp = Kn\rho^{n-1}\,d\rho$$

$$\frac{d\rho}{dp} = \frac{1}{Kn\rho^{n-1}} = \frac{\rho^n}{pn\rho^{n-1}} = \frac{\rho}{pn}$$