Examples of Application for
KRi Dual Process Simulator
Model KI-100 & KI-101

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KRi Dual Process Simulator

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Acknowledgements

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OVERVIEW

The following examples have been prepared to illustrate and to guide the user on how to set up the Dual Process Simulator. Examples vary from a common SISO system to a more complicated cascade control system.

The examples are organized as follows:

1. a description of the control problem with diagram(s) and equation(s);
2. a table which summarized the switch settings on front panel of the DUAL PROCESS SIMULATOR for the described process(es); and
3. a mimic diagram to show the connections between the DUAL PROCESS SIMULATOR and the controller(s).

Four examples of application are given to illustrate the use of the Dual Process Simulator:

1. **DC servo motor,**
2. **drum boiler,**
3. **pneumatic valve, and**
4. **heat exchanger.**

EXAMPLE 1 DC SERVO MOTOR

A DC servo motor (see Figure 1) can be described by a second-order model with one integrator and one time constant. A normalized model of the process is given by

$$V_m = \frac{V_s}{s\,(1+\tau\, s)} \qquad (1)$$

The time constant is only due to the mechanical parts of the system since the dynamics due to the electrical parts can be neglected. The input Vm is the voltage applied to the motor and the output Vs is the shaft position.

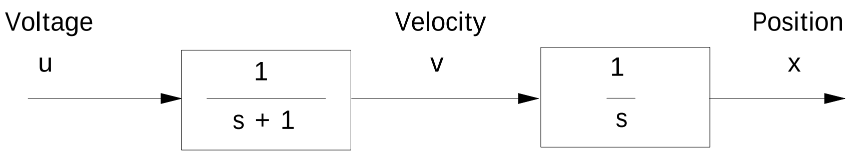

Figure 1 Normalized model of a DC servo motor

A current-controlled DC servo motor with shaft velocity as output can be also described by the above normalized model. Still another example that can be characterized by an integrator and a single pole is a ship where the input is the rudder angle and the output is the heading.

To simulate the DC servo motor, the Dual Process Simulator is set up as follows:

MODE	LOCAL
PROCESS A	SPEED : FAST DELAY : 0 GAIN : 1 LAG : 1 COMPLEX POLE : OFF UNSTABLE ZERO/POLE : III LAG (COUPLE) : OFF LOAD : NONE NOISE : OFF
PROCESS B	- not used -

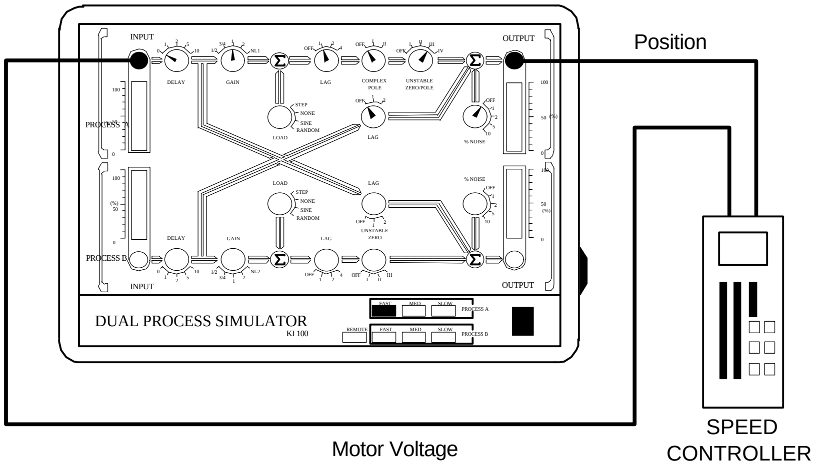

Figure 2 Connection Diagram for DC servo motor system

EXAMPLE 2 DRUM BOILER

A simplified representation of drum boiler is shown in Figure 3. Feed water enters the boiler with a flow rate q1(t) and temperature T(t) and it is heated by burning fuel. The generated steam flows out from the top of the boiler with flow rate q2(t) and a pressure p(t). A simple feedback control system has been installed to keep the level of water y(t) in the drum boiler constant by manipulating the flow rate of the feed water stream.

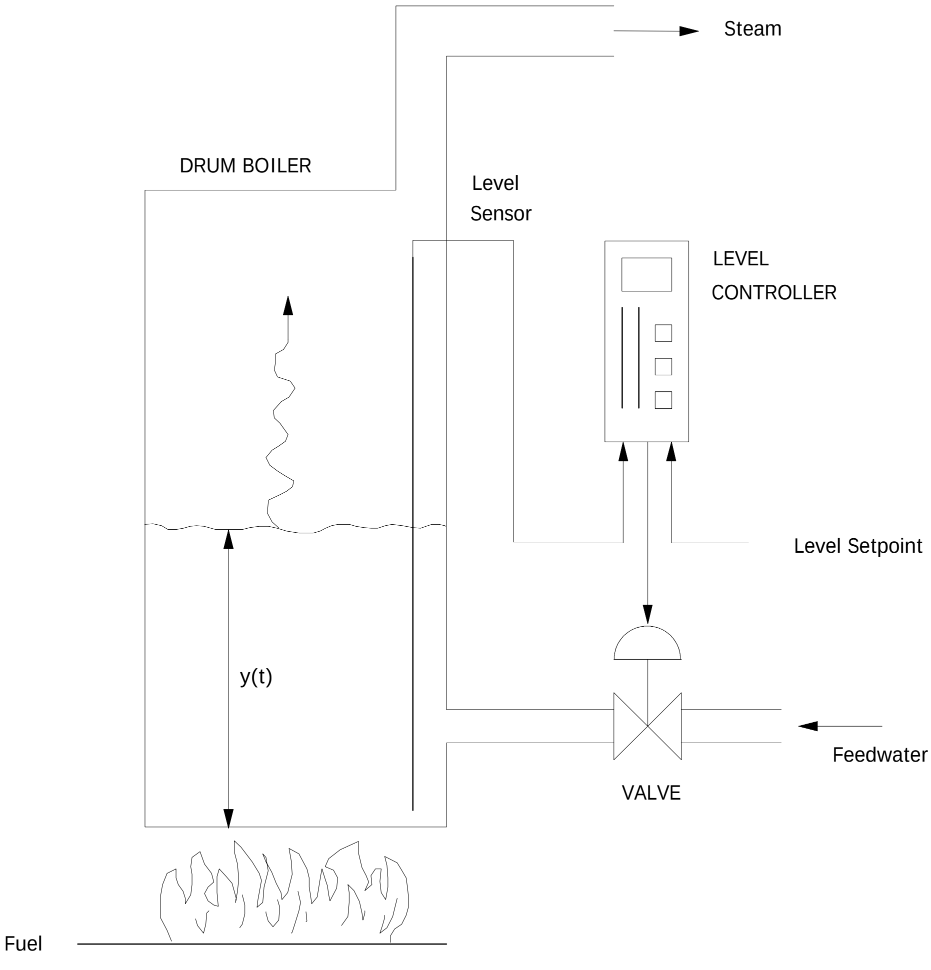

Figure 3 Simplified diagram of a drum boiler

The transfer function of the drum boiler system is the net result of two opposing effects:

$$\frac{Y(s)}{Q_1(s)} = \frac{K_1}{s} - \frac{K_2}{\tau s + 1} = \frac{(K_1\tau - K_2)s + K_1}{s(1 + \tau s)} \quad .....(2)$$

The two opposing effects can be explained as follows:

1. With constant heat supply, the steam production remains constant regardless of the flow rate of steam or feed water. Therefore, an increase

in cold feed water will cause the liquid level of the boiling water to increase in an integral form, K_1 / s.

2. An increase in cold feed water will cause the temperature to drop which will decrease the volume of the entrained vapor bubbles. This leads to a decrease of the liquid level of the boiling water, following a first order behaviour, that is, $-K_2 / (1 + \tau s)$.

For $K_1\tau < K_2$, the second term dominates and the transfer function has a positive zero at $s = -K_1 / (K_1\tau - K_2) > 0$. In other words, the process is non-minimum phase or it exhibits an inverse response.

A normalized model of the drum boiler with inverse behaviour is given by

$$H(s) = \frac{1 - a s}{s(1 + s)} \qquad \text{..(3)}$$

The Dual Process Simulator is set up as follows to simulate the non-minimum phase process:

MODE	LOCAL
PROCESS A	SPEED : FAST DELAY : 0 GAIN : 1 LAG : OFF COMPLEX POLE : OFF UNSTABLE ZERO/POLE : III LAG (COUPLE) : OFF LOAD : NONE NOISE : OFF
PROCESS B	SPEED : FAST DELAY : 0 GAIN : 1 LAG : 1 UNSTABLE ZERO[1] : I LAG (COUPLE) : OFF LOAD : NONE NOISE : OFF

Note:

1. UNSTABLE ZERO can be set to TYPE I, II or III.

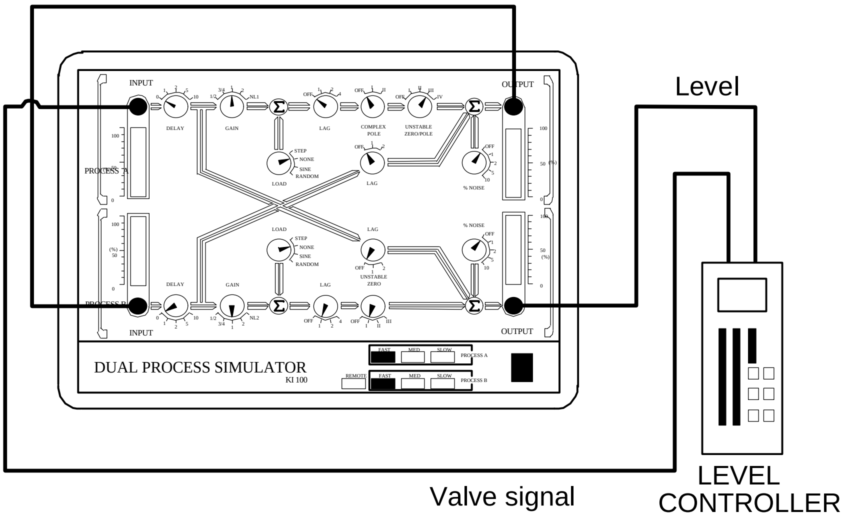

Figure 4 Connection diagram for drum boiler system

EXAMPLE 3 PNEUMATIC VALVE

The pneumatic valve (see Figure 5) is the most commonly used final control element. The transfer function of this valve is

$$\frac{x(s)}{p(s)} = \frac{A/K}{(M/kg)s^2 + C/Ks + 1} \quad \text{.........................(4)}$$

where x = displacement of valve,
p = pressure applied to open or close valve,
K = Hooke's constant for the spring,
A = area of diaphragm,
C = friction coefficient between stem and body, and
g = acceleration gravity.

If $M << Kg$, the dynamics of the pneumatic valve can be approximated by that of a first-order system.

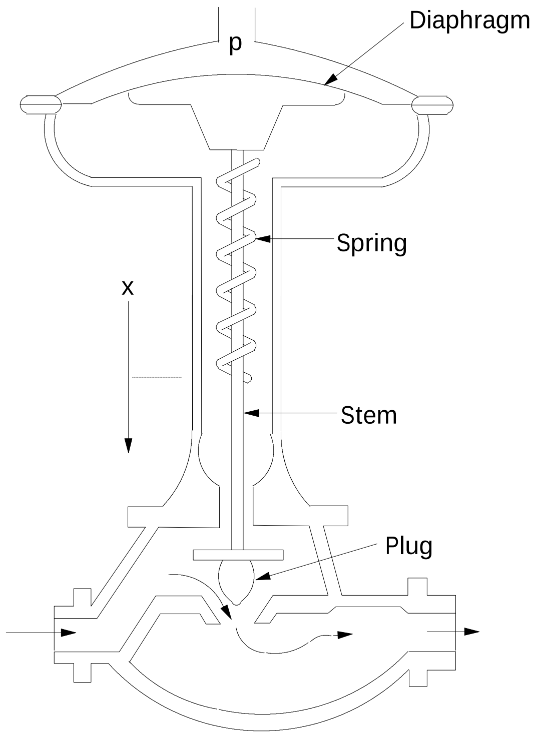

Figure 5 Pneumatic valve

Consider a tank system shown in Figure 6 where a pneumatic valve is used to regulate the outflow. A normalized model of the tank dynamics is given by

$$H_t(s) = \frac{K}{1 + 5s} \quad \text{..(5)}$$

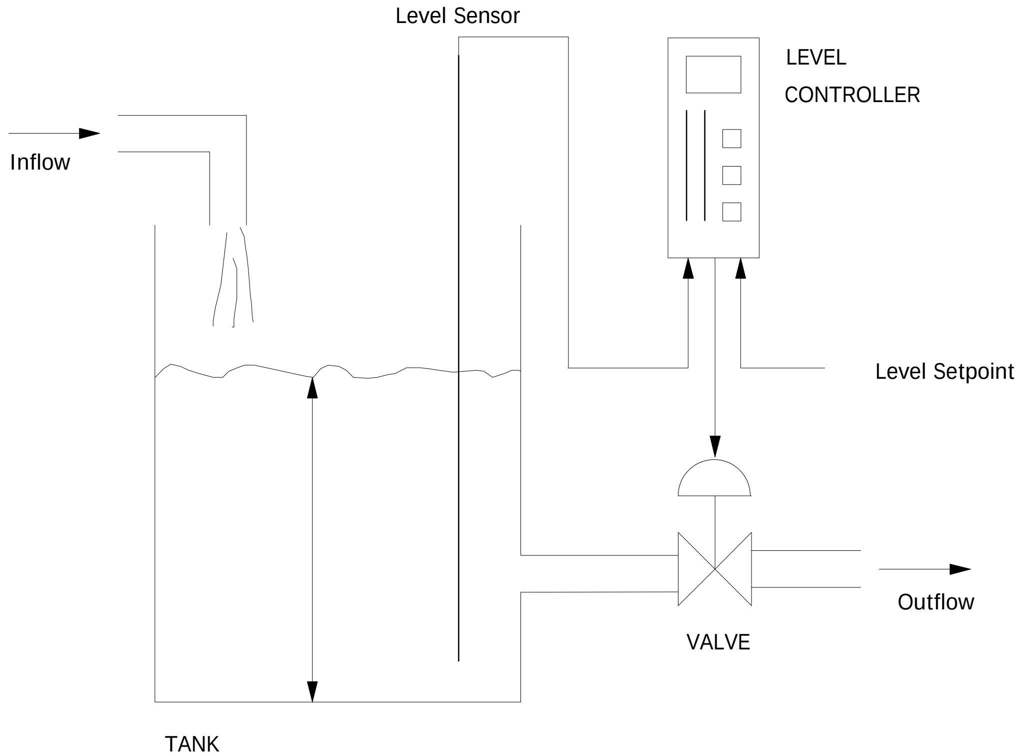

Figure 6 Tank system with regulated outflow

The pneumatic valve may be described by the following normalized model:

$$H_v(s) = \frac{1}{s^2 + \zeta s + 1} \quad \text{......................................(6)}$$

To simulate the tank with the pneumatic valve, the Dual Process Simulator is set up as follows:

MODE	LOCAL
PROCESS A (simulate pneumatic valve)	SPEED : FAST DELAY : 0 GAIN : 1 LAG : OFF COMPLEX POLE[1] : I UNSTABLE ZERO/POLE : OFF LAG (COUPLE) : OFF LOAD : NONE NOISE : OFF
PROCESS B (simulate tank)	SPEED : SLOW DELAY : 0 GAIN[2] : 3/4 LAG : 1 UNSTABLE ZERO : OFF LAG (COUPLE) : OFF LOAD : NONE NOISE : OFF

Notes:

1. COMPLEX POLE can be set to TYPE I or II.
2. K has been arbitrarily chosen to be 3/4.

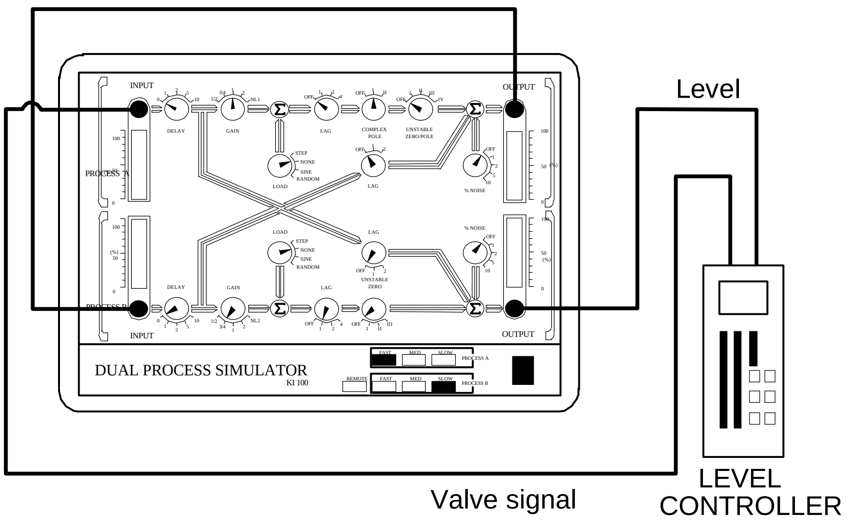

Figure 7 Connection diagram for tank system with pneumatic valve

EXAMPLE 4 HEAT EXCHANGER

In a cascade control system, there are one manipulated variable and more than one than one measurement. An example of a cascade control system is shown in Figure 8. The control objective is to keep the exit temperature of the product at a desired value.

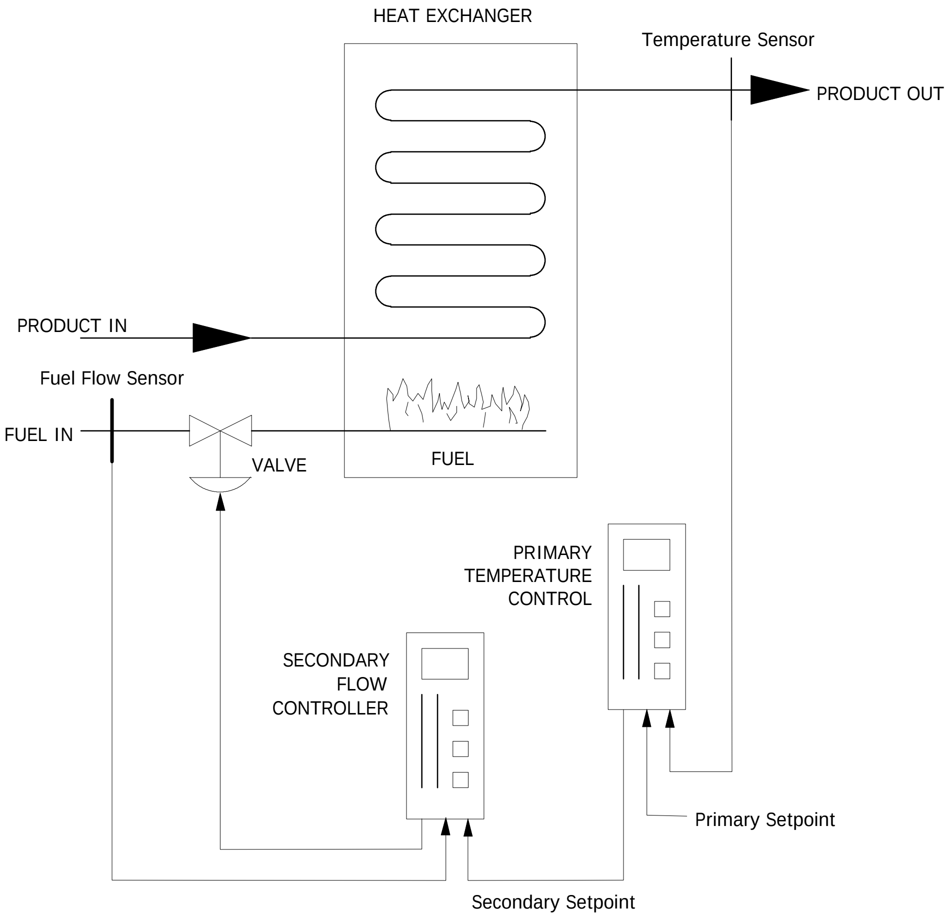

Figure 8 Cascade control of heat exchanger

The primary controller sets the demand for fuel to maintain the product temperature while the secondary controller monitors the fuel flow and maintains the fuel flow set by the primary controller regardless of changes in the fuel pressure. The major advantage of this configuration is that disturbances in the fuel pressure are corrected by the secondary controller before they can affect the product temperature as the dynamics of the secondary loop are much faster than those of the primary loop.

The two controllers of the cascade control system are standard feedback controllers (i.e. P, PI, PID). In practice, a proportional controller is used for the secondary loop since offsets in the secondary loop is not important.

Consider a process with the following transfer function for its primary and secondary elements:

$$H_p = \frac{e^{-2.5s}}{(1 + 5s)^2}$$
$$H_s = \frac{1}{(1 + s)} \quad \ldots\ldots\ldots (7)$$

The Dual Process Simulator is set up as follows to simulate this process:

MODE	LOCAL
PROCESS A (primary process)	SPEED : SLOW DELAY : 2 GAIN : 1 LAG : 2 COMPLEX POLE : OFF UNSTABLE ZERO/POLE : OFF LAG (COUPLE) : OFF LOAD : NONE NOISE : OFF
PROCESS B (secondary process)	SPEED : FAST DELAY : 0 GAIN : 1 LAG : 1 UNSTABLE ZERO : OFF LAG (COUPLE) : OFF LOAD : NONE NOISE : OFF

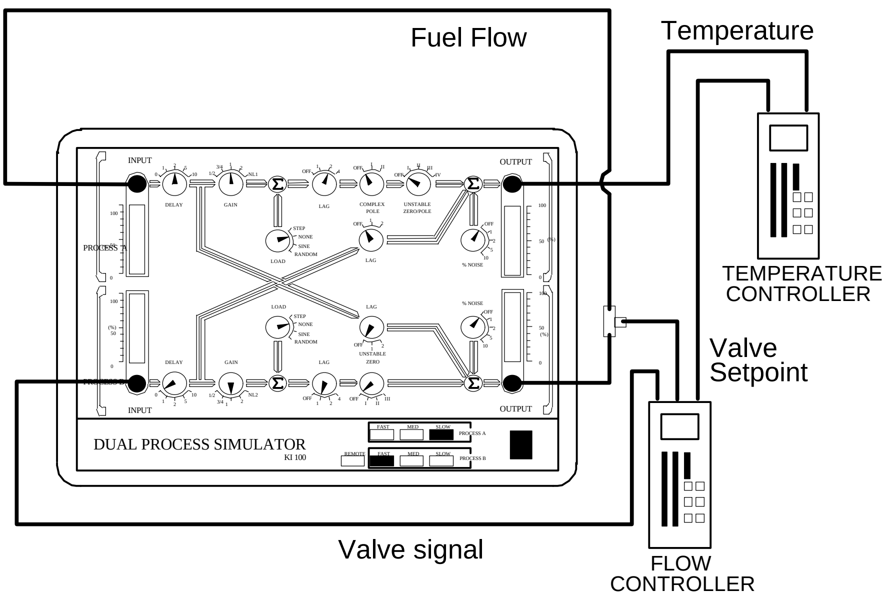

Figure 9 Connection diagram for heat exchanger system

Related References

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5. *DPS Trend User Guide for Dual Process Simulator* KentRidge Instruments, 1st Ed, 1994.

Other *KRi* Products

KentRidge Instruments Pte Ltd offers a family of control apparatus or equipment for teaching and research in control engineering:

- Coupled-Tank Control Apparatus PP-100
- Fan & Plate Control Apparatus PP-200
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- FlexiDrive PP-400
- Mixed Signal Test Unit TU-100
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