# APPLICATION EXAMPLES OF THE
# *KRi* Coupled-Tank Apparatus PP-100

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# Application Examples of the

## *KRi* Coupled-Tank Apparatus PP-100

**Acknowledgements**

**The Coupled-Tank Apparatus PP-100 is designed and manufactured by KentRidge Instruments Pte. Ltd. in collaboration with HYATECH, Australia.**

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**APPLICATION NOTE CT-101**

# APPLICATION EXAMPLES FOR THE *KRi* COUPLED-TANK CONTROL APPARATUS PP-100

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## OVERVIEW

This note has been prepared to guide the user on applications of the *KRi* Coupled-Tank Control Apparatus PP-100. This apparatus can be configured to model plants from a simple single input single output (SISO) system to a complicated two input two output (MIMO) system.

The description of each configuration contains:

1. a block diagram and equation of the nominal plant;
2. a mimic diagram to show the connections between the Coupled-Tank Control Apparatus PP-100 and the controller[i](s).

Four configurations are described:

1. **A first order single input single output plant (2 off)**
2. **One second-order single input single output plant,**
3. **A plant for cascade control**
4. **A two input two output (MIMO) plant.**

## DESCRIPTION OF APPARATUS

The *KRi* Coupled-Tank Control Apparatus PP-100 is a low-cost pilot plant designed for laboratory teaching of both introductory and advanced control systems theory. This apparatus can be used for teaching system modeling using static and transient measurements; steady state error analysis; transient response studies; and for evaluating the design, operation and application of common controllers as well as controller tuning methods. This apparatus also demonstrates fluid transportation and level controls; dynamic problems typical in the process control industry.

The equipment consists of two small tower-type tanks mounted above a reservoir which functions as storage for the water (see Figure 1). Water is pumped into the top of each tank by two *independent* pumps. The head of water in each tank is clearly visible on the attached scale at the front of the tanks. Each tank is fitted with an outlet, at the side near the base. The amount of water which returns to the reservoir is approximately proportional to the head of water in the tank since the return tube at the base of the tank functions as a pseudo-linear hydraulic resistance. The return tube is constructed of flexible tubing so that resistance may be increased by the use of a screw-type clamp[ii].

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[i] This may be commercial controllers, a PC equipped with the appropriate software and data acquisition system or *FlexUC* by the Kent Ridge Instruments Pte Ltd

[ii] not supplied

Figure 1 Coupled-tank control apparatus Model PP-100

The level of water in each tank is monitored by a capacitive-type probe. Signal conditioning circuits (at the rear of the unit) convert the measured capacitance (a function of the water level) to electrical signals in the range 0 to +5 volts dc. The zero level has been calibrated to represent the rest point of the water level, that is, when the tank is nearly empty (approximately 20mm on the scale), while the full state (+5volts) is calibrated at the level of the opening to the rear overflow stand-pipes. This occurs at approximately 300mm on the scale.

An internal baffle controls leakage between the two tanks to simulate complex tank arrangements. By turning the wing-nut on the top of the tank assembly, the baffle will be raised a small amount sufficient to provide a useful range of inter-tank resistance. A spring returns the baffle to the closed position when the wing-nut is released.

The two pumps at the rear of the unit are controlled by PWM (Pulse-Width Modulation) circuits using power MOSFET devices. The input signal to each pump circuit may be a PWM waveform generated by a microcontroller or other external device, or an external DC voltage in the range 0 to +5 volts.

## EXAMPLE 1 TWO SINGLE INPUT SINGLE OUTPUT (SISO) PLANTS

The two tanks of the Coupled-Tank Apparatus PP-100 can be configured to operate independently by lowering the baffle completely. As each tank has an independent pump and level probe, the apparatus is then effectively two single input single output plants. For each plant, the manipulated variable or plant input is the voltage (or PWM signal) applied to the pump and the plant or process variable is the water level in the tank. The nominal transfer function for each plant has the form:

$$H(s) = \frac{V_{level}}{V_{pump}} = \frac{Ke^{-ds}}{(1+\tau s)} \quad \text{(1)}$$

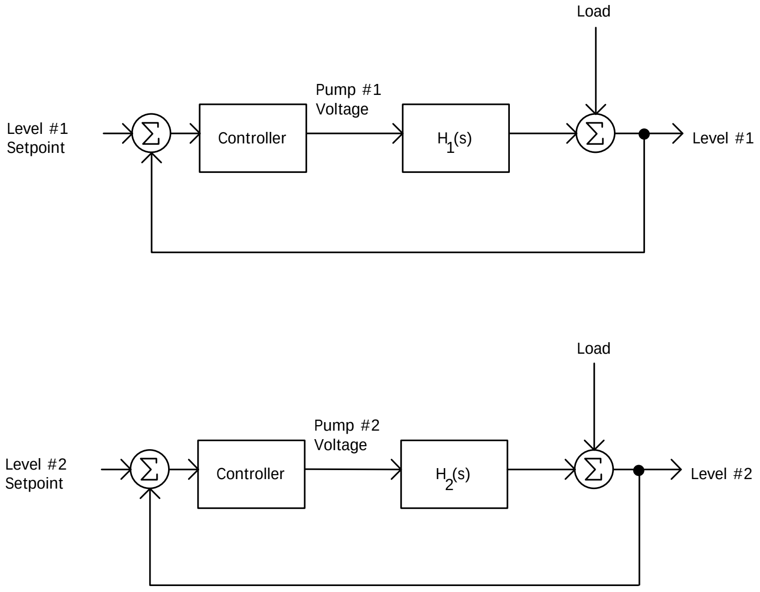

**Figure 2 Block diagram of the coupled-tank control apparatus configured as two SISO plants**

The baffle can also be used to deliberately introduce a little leakage between the two tanks. If both tanks are in use simultaneously, this is equivalent to a variable load disturbance on each plant, depending on the relative levels of water. A simple way to introduce a pulse disturbance into each process is to apply pressure on the return tubing, thus increasing the hydraulic resistance at the outlet.

To configure the Coupled-Tank Control Apparatus as two SISO plant(s), connect it up as follows:

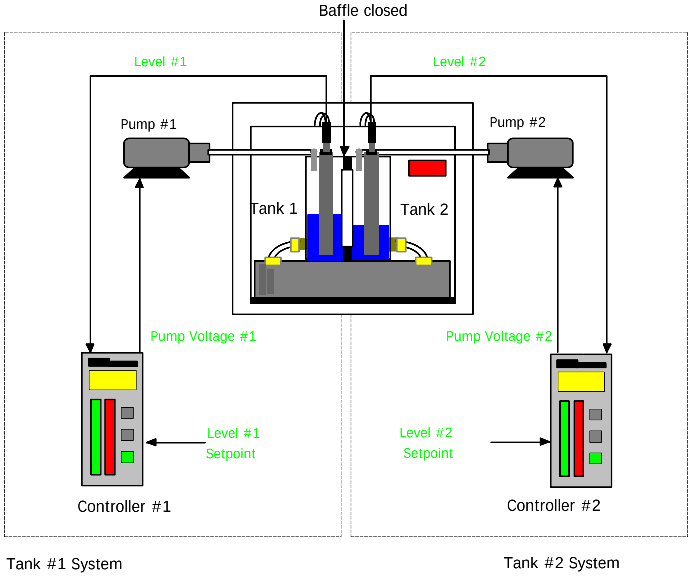

**Figure 3 Connecting the coupled-tank control apparatus as two SISO plants**

## EXAMPLE 2 A SECOND ORDER SISO PLANT

The apparatus can be configured to constitute a second-order single input single output (SISO) plant. In this case, the objective is to control the water level in the second tank by manipulating the voltage to the pump of the first tank. Raising the baffle allows water to flow between the two tanks. The transfer function of the second-order plant can be described as follows:

$$H(s) = \frac{V_{level(2)}}{V_{pump(1)}} = \frac{Ke^{-ds}}{(1 + 2\zeta\omega s + \omega^2 s^2)} \quad \text{..........................} (2)$$

In this setup, the water flow into tank 2, manipulated by a voltage signal to pump 2, constitutes an adjustable load disturbance. The characteristics of the dynamic response will depend on the steady state operating level as well as the degree of interaction determined by the baffle opening.

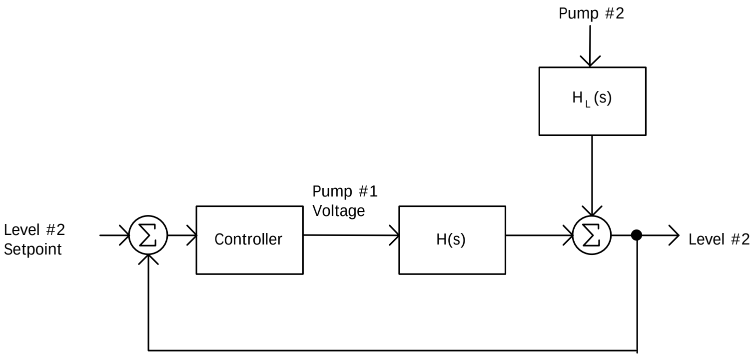

**Figure 4 Block diagram of the coupled-tank control apparatus used as a 2nd-order SISO plant**

## EXAMPLE 3 ONE CASCADE-CONTROL PLANT

In a cascade control system, there is one manipulated variable and more than one measurement. The two tanks in the Coupled-Tank Control Apparatus can be set up for cascade control as in Figure 6.

Here the control objective is to maintain the water level in the second tank at a desired level. The manipulated variable is the pump flow to the first tank. The secondary (slave) controller reads the level of water in tank 1 and manipulates pump 1 flow to regulate it to a setpoint determined by the output from the primary controller. The primary controller thus determines the setpoint of the secondary controller. The primary controller uses the level in tank 2 as its process variable. In effect it is attempting to control the tank 2 level by manipulating the tank 1 level.

Water flows from the first tank to the second tank at a rate determined by the baffle opening and the relative heads in the two tanks. With a suitable baffle opening, there is a significant time scale separation seen by the primary and secondary controllers. With this time scale separation, the advantage of cascade control is that the effect of a disturbance in the water level of the first tank on the water level of the second tank can be minimized.

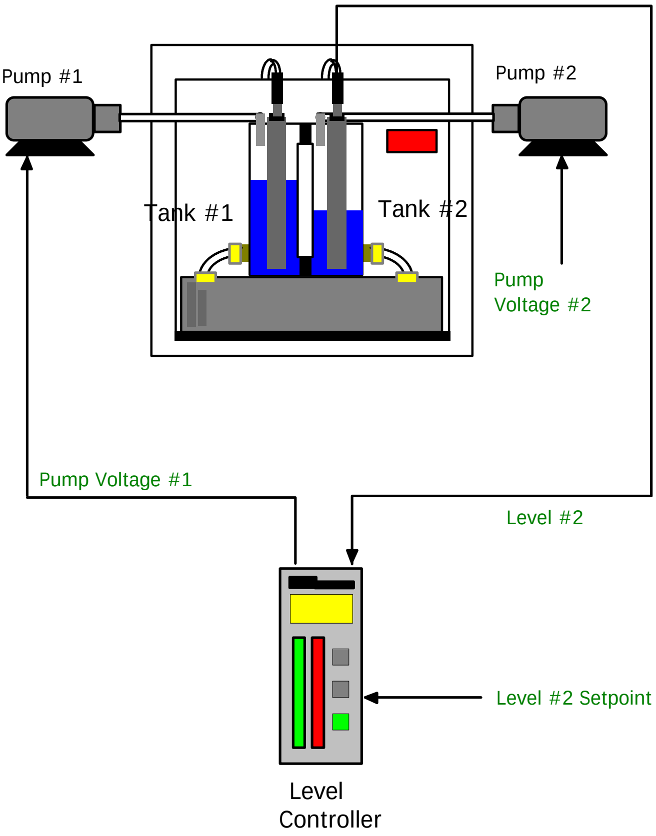

**Figure 5  Connecting the coupled-tank control apparatus as a 2nd-order SISO plant**

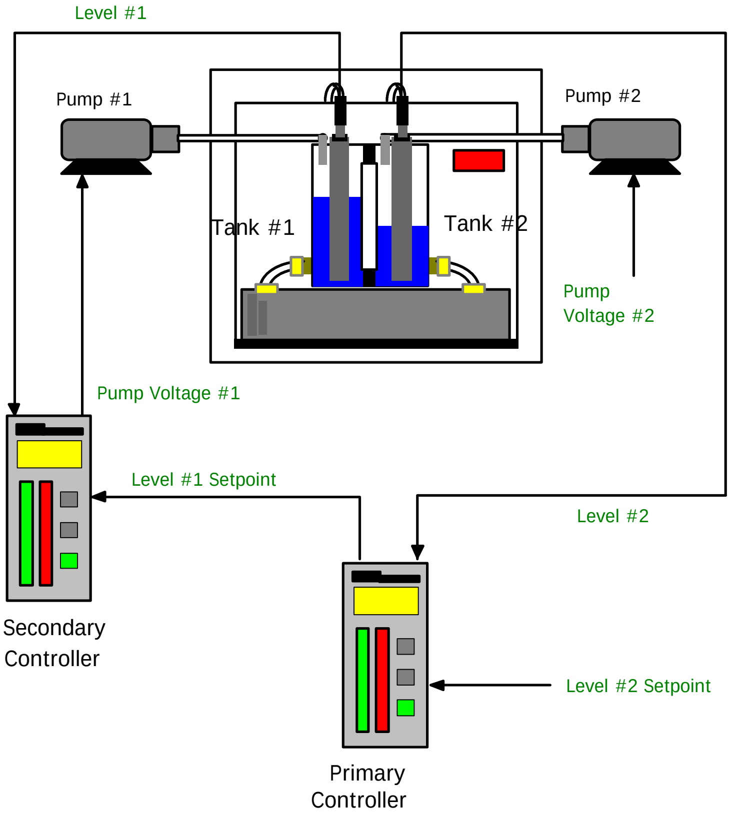

**Figure 6 Connecting the coupled-tank control apparatus for cascade control**

The pump flow into the second tank can be used as an adjustable load disturbance to perturb the plant and hence demonstrate the quality of the cascade control. This has two load effects: (1) a load disturbance directly on the water level of tank 2, and (2) a load disturbance coupled to tank 1 via the baffle opening.

The two controllers of the cascade control system are usually 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 are not important.

The nominal transfer functions for the primary and secondary elements are:

$$H_p = \frac{K_p e^{-d_p s}}{(1 + \tau_p s)} \qquad H_s = \frac{K_s e^{-d_s s}}{(1 + \tau_s s)} \quad \text{.........} (3)$$

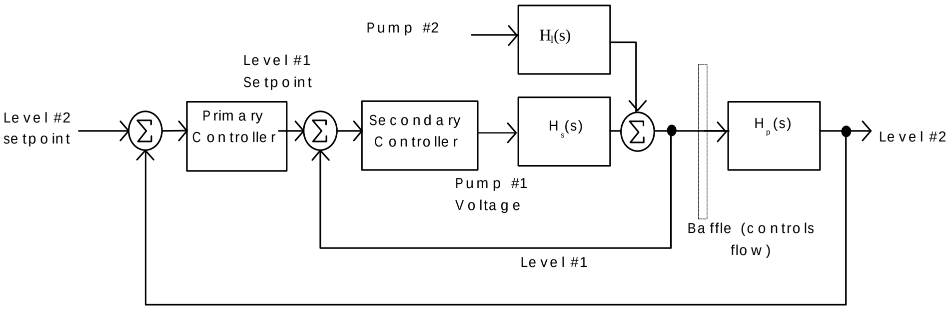

Figure 7 Block diagram of the cascaded-control plant

## EXAMPLE 4 A MULTIVARIABLE (MIMO) PLANT

Another example application using the Coupled-Tank Control Apparatus PP-100 is in multivariable control [2]. The apparatus consists of two tanks with two pumps, two level probes and a baffle which permits interaction. In other words, it is a two input two output plant (2x2 MIMO). Figure 8 shows a mimic diagram. The baffle plate opening serves to vary the degree of interaction. Load disturbances can be simulated by compressing the return tubing.

The MIMO plant can be described by the following nominal block transfer function.

$$\begin{bmatrix} y_1 \\ y_2 \end{bmatrix} = \begin{bmatrix} G_{11}(s) & G_{12}(s) \\ G_{21}(s) & G_{22}(s) \end{bmatrix} \begin{bmatrix} R_1 \\ R_2 \end{bmatrix} \quad \text{.........} (4)$$

Each of the terms $G_{ij}(s)$ would be a nominal transfer function of the form $\frac{K_{ij} e^{-d_{ij} s}}{(1 + t_{ij} s)}$. The block diagram in Figure 9 suggests a possible control structure [1]. This consists of a set of decouplers and a pair of controllers for the decoupled loops.

Reference 1, amongst others, discusses the control of such MIMO plants. There is ample opportunity here to demonstrate to students ideas such as decoupling control, relative gain array, dynamic measures of interaction, stability of multivariable systems and the tuning of multivariable controllers.

The apparatus in this configuration also serves as a convenient test bed for demonstrating process system identification for multi loop plants

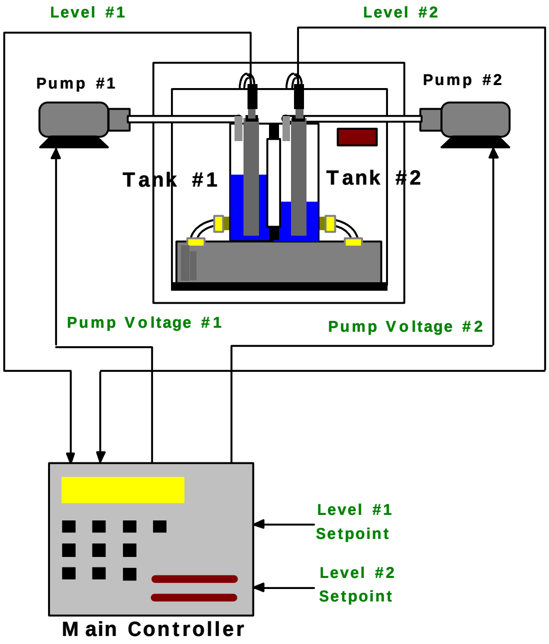

**Figure 8 Connecting the coupled-tank control apparatus as a 2x2 MIMO plant**

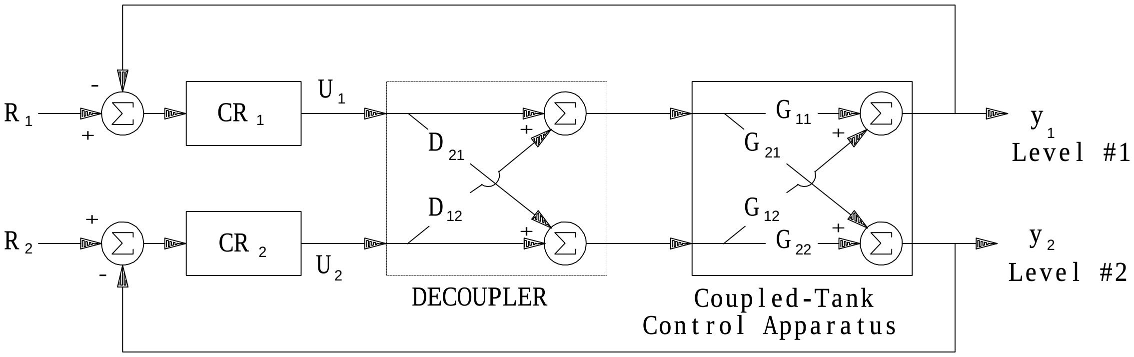

**Figure 9 Block diagram of the 2x2 MIMO plant**

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3. Astrom, K.J. and B. Wittenmark. *Computer Controlled Systems - Theory and Design*, 1990, Prentice-Hall.

## RELATED REFERENCES

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5. *Teaching with the KRi Coupled-Tank Control Apparatus Model PP-100*, Application Note: CT-104, KentRidge Instruments, 1995.

## OTHER *KRi* PRODUCTS

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

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