Cascade Control

Handle Processes that Challenge Regular PID Control

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In previous columns we have named **lags** in a process as major obstacles to good temperature control. When they are inconveniently long and come in multiple stages, first try to determine where changes to process design can avoid or reduce lags. Then do your best with PID control and if you fail to obtain the response you hoped for you can turn to **cascade control.**

Let's look at two kinds of lags that you encounter in the process heating industry.

Dead time

This is when an input occurs and you see no output until a time called the **dead time** has elapsed, after which the output appears, unchanged except for the delay. This is often associated with transport of material from one place to another.

An example is heating an air stream and sensing the temperature some distance downstream. This is sometimes called **transport lag** or **distance-velocity lag.** Before you consider an advanced control solution see if you can place the sensor close to the heater to give the controller the earliest possible opportunity to respond.

First order lag.

This is also called an **exponential lag.** One example is how a temperature sensor responds to a temperature change. First in a linear manner, then at an ever-decreasing speed approaching the final value. Here again, you can ease the controller's job by using the smallest mass sensor that is practical.

Adding an RC (resistance capacitance) or equivalent filter to reduce noise on a thermocouple output also introduces an exponential lag into the loop. Use a filter only when you have to and make sure that its response time is no more that about one tenth that of the dominant lag of the process.

The most common and usually the dominant exponential lag is associated with transfer of process heat through thermal resistance into a thermal capacity. An example is, heating the contents of a tank through the combined thermal resistance of an electrical heater's insulation and the tank wall. The thermal capacity is the tank and contents.

Some solutions, though they come at some cost, include induction, microwave or direct resistance heating. Here the material itself becomes the heater.

A practical process usually has multiple order lags e.g. thermal resistance followed by capacity. This is analogous to a string of resistance/capacitance low-pass filters.

Cascade control.

Cascade control is used to enable a process having multiple lags to be controlled with the fastest possible response to process disturbances including set point changes. Here you control a secondary, more responsive process that lies within the overall loop and influences the main process.

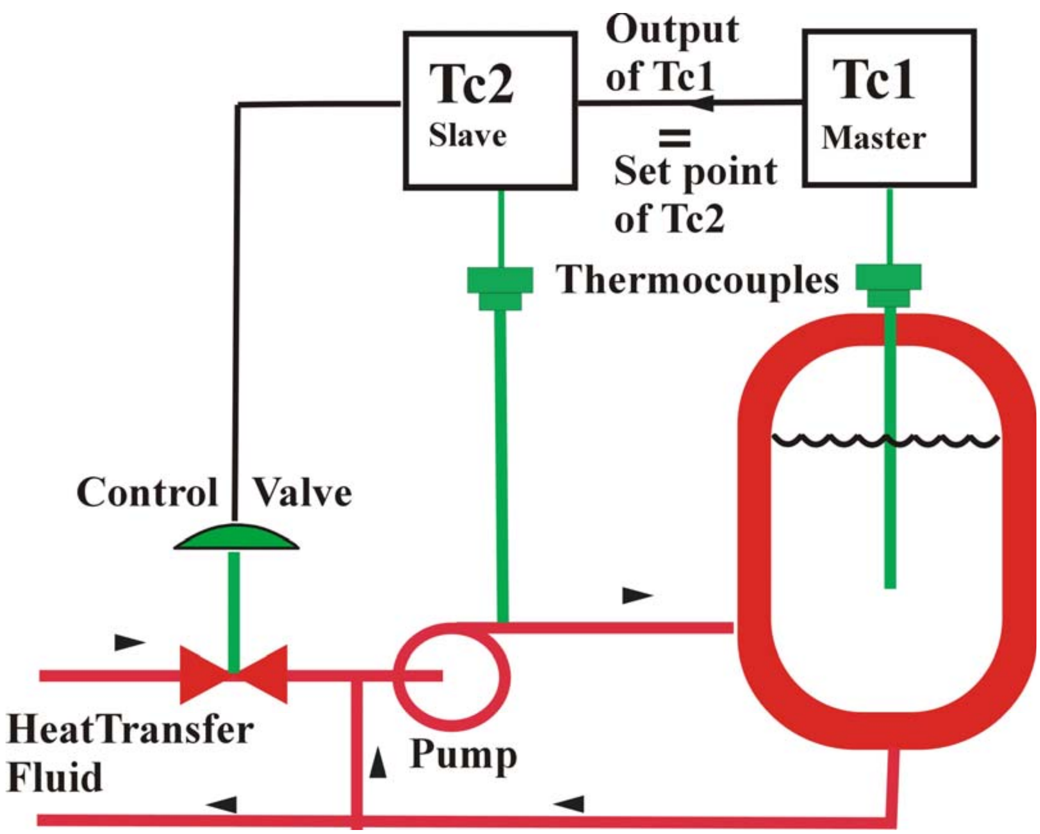

Fig 1 Cascade Control

Example of a cascade system.
Fig 1 shows a jacketed vessel whose temperature is controlled by a cascade controller. It is shown here for clarity as two separate controllers TC1 and TC2 although in practice the two share the same box or module.

TC1, the **master** PID controller, senses the vessel temperature but does not pass its output to the control valve at the primary heat source (incoming heat transfer fluid). That approach would make a single, sluggish and probably unmanageable control loop.

The output of TC1 becomes the set point input of TC2 the **slave** controller so it has to be expressed in degrees and ranged to match the sensor of TC2.
TC2, via the control valve, controls the heat transfer fluid temperature in the pump and vessel circuit. TC2 has to cope with disturbances in the upstream temperature and pressure due to demands from other processes sharing the source.

The output of TC1 being the set point of TC2 determines this fluid's temperature. So here we have two control loops, each one tighter and more responsive than the combined loop would be.

With this cascade arrangement upstream disturbances will be recognised and acted upon sooner by TC2 than by TC1 acting alone. This heads off disturbances that would affect the vessel temperature. With single loop control no knowledge of an upstream disturbance would be available until it had finally affected the vessel temperature.

TC1's output calls for a temperature at the fluid circuit not a valve position or flow - and the TC2 loop provides it. This linearises the fluid circuit temperature with respect to changes in set point coming from the output of TC1 in the face of control valve non-linearity and friction. Linearity of control action allows tighter controller performance of the slave loop.

You have to use your judgement regarding where you locate the slave controller sensor and valve (or final control device) in the overall loop. The speed (natural frequency) of the slave loop TC2 should preferably be upwards of 5 times faster that of the master, TC1.

Tuning.

Tune the slave loop first. Set TC1 to manual. Remove integral and derivative action from TC2 and tune it aiming for tight control. Absence of derivative avoids excessive activity of the slave loop. Overall integral action to remove offset in the vessel temperature is already provided by the master controller.

When tuning the master loop, return to cascade control, remove derivative action and tune in the normal way. Note that the slave loop now becomes part of the master loop that you are tuning at TC1. **Bumpless transfer** between auto, manual and cascade will be a standard feature of TC1.

Set point limits on the slave loop. If you know the range of TC2 (fluid) temperatures needed to hold the vessel temperature under all expected conditions, put those values as limits on the set point of TC2.

Configuration and settings on modern cascade controllers can be difficult and time consuming. Use a control equipment supplier who is familiar with process control and who knows his product.