U-Tune Tuning Calculator

U-Tune calculates proportional-integral tuning parameters for process controllers using the results of an open-loop step response. The calculation is based on the Kappa-Tau method [1].

Derivative action has not been included because low frequency noise and disturbances tend to dominant many industrial processes and derivative action provides little if any benefit in such conditions (the full version of U-Tune provides options for both PI and PID controller tuning).

This document describes the procedure for identifying the dominant characteristics of the step response giving examples of ideal and actual processes. A later section defines the common controller algorithms supported by U-Tune.

Contek Systems Ltd

U-Tune is designed and distributed by Contek Systems Ltd.

Contek is located in Aberdeen, UK and has extensive experience in analysing process control problems and optimising the performance of controllers in the onshore and offshore oil & gas industries.

Based on a broad practical and theoretical control engineering background, Contek is also the developer of control and mathematical applications for use on Microsoft® Windows.

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Procedure

The 'micro-lite' version of U-Tune is designed for processes with an open loop step response of the form shown in Figure 1. That is, when the controller is operated in manual mode and its output is stepped to a new value, the process variable (PV) does not respond initially but then rises to settle onto a new value. Some processes react rather differently to this: the process variable continues to rise until the controller output is stepped back again. Tuning of these integrating processes is supported by the full version of U-Tune.

The critical parameters defining the step response are:

- o The step size of the controller output (CO).

- The change in value of the PV.
- The time delay between the output step and commencement of the PV response.
- The time lag of the PV response i.e. the time from the end of the delay until the PV reaches 63% of its total change in value.

The easiest way to make these measurements is to read them from a DCS trend display or pen recording of the process variable and the controller output. If these are not available, try recording the data every few seconds and sketching the response curve.

When ready to start the test, put the controller into manual mode and ensure that the PV is steady, adjusting the controller output if necessary.

Record the initial values of the CO and the PV. If the PV is noisy, try to estimate the average value.

Step the CO upwards or downwards with as large a step size as possible. If the process response characteristics are unknown, it is advisable to commence with small steps and to repeat the test until suitable results are achieved.

When the PV has settled down again, record the new CO and PV.

Convert the PV change into percentage of the PV range. For example, if the PV is scaled from 20 to 100 psig, then a response starting at 28 psig and settling on 68 psig is a change of 50% of the 80 psi range. The controller output is usually already scaled in percentage, but this should also be converted if necessary.

Record the time in seconds between applying the step change and the PV beginning to change (although see later for further details). This is the time delay of the process.

Measure the time from the end of the delay to the point at which the PV reaches 63%, 86% and 95% of its change. The lag time is calculated as follows:

Lag 1 = Time to reach 63%
Lag 2 = Time to reach 86% / 2
Lag 3 = Time to reach 95% / 3

Take the average of the three results. This is the lag time.

Run U-Tune and enter the results in the Step Size, PV Change, Delay and Lag windows. Select the type of controller, ideal or parallel. Select either gain or proportional band, and the type of integral. Two sets of tuning parameters are provided, one giving a slow response and the other a fast response.

It is recommended that the test is repeated three or four times. Take the average of the measurements. If the measurements are very different, consider whether

the measurements have been taken correctly or if a process disturbance has occurred while performing the test. Discard any incorrect results.

Examples

Figure 1 shows the response of the process variable to a step change of the controller output applied at t = 0 seconds. The output is not shown but has changed from 20% to 65% i.e. the step size is 45%.

The process variable has started with a value of 25% of its range and begins responding to the step change after 1.2 seconds and settles down again at 85%. So the time delay is 1.2 seconds and the PV change is 85% − 25% = 60%.

The PV reaches 63% of its final change at 3 seconds after the step or 3.0 − 1.2 = 1.8 seconds after the end of the time delay.

Similarly, the time to reach 86% of the change is 4.8 seconds or 3.6 seconds after the time delay. Divide this by 2 giving 1.8 seconds.

Again, the time to reach 95% of the change is 6.6 seconds or 5.4 seconds after the time delay. Divide this by 3 giving 1.8 seconds.

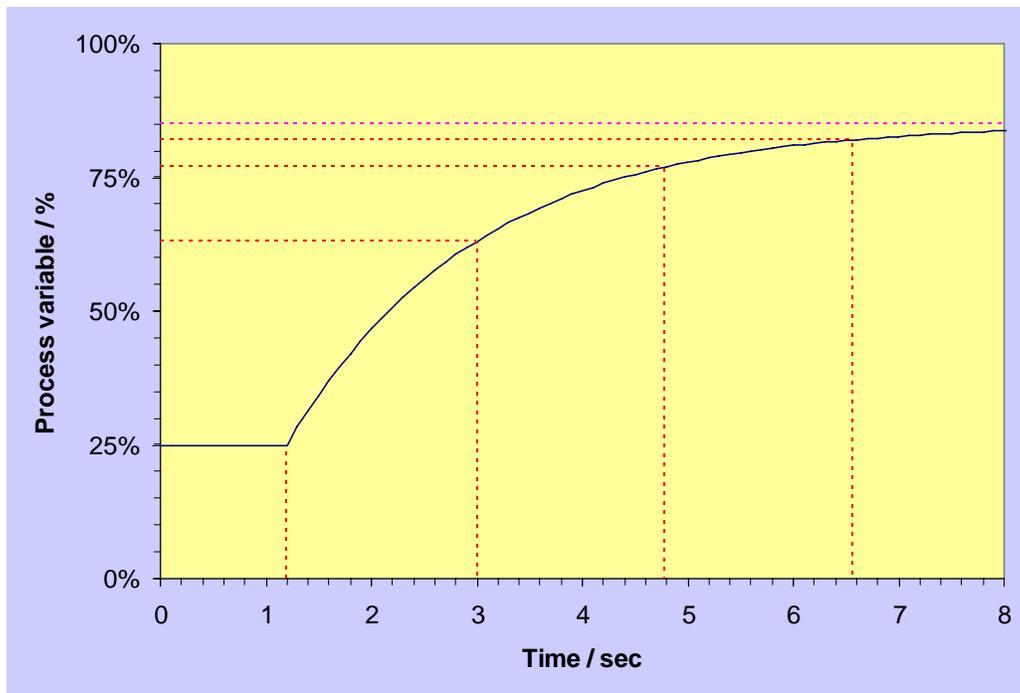The average of the three lag calculations gives the time lag of 1.8 seconds.

Figure 1: PV response to step change

Enter the step size, PV change, time delay and time lag into U-Tune as shown in Figure 2.

Figure 2: Values entered into U-Tune

For a ideal controller, U-Tune gives a gain of 0.2 and integral of 48.7 repeats/minute for a slow acting controller and 0.424 and the same integral for a fast acting controller. Derivative action should be switched off e.g. set to 0 seconds.

Further Examples

Figure 1 gave the step response of an ideal process. In practice, the responses are generally more S-shaped like in Figure 3 where the PV begins to rise slowly at first and then faster before slowing down again. Assume that the CO has changed at t = 0 seconds.

The time delay is now not quite as easy to measure. The best way is to mark the points for which the PV reaches 63%, 86% and 95% of its change. The difference in time between reaching 63% and 86% is the time lag and similarly between 86% and 95%. Subtract the time lag from the time to reach 63% and this gives the end of the time delay. For example, in Figure 3:

Time to 63%	68 seconds
Time to 86%	111 seconds
Time to 95%	152 seconds

This gives lags of 111 − 68 = 43 seconds and 152 − 111 = 41 seconds. Taking the average gives a time lag of 42 seconds. The end of the time delay will be 42 seconds before the PV reached 63% or 68 − 42 = 26 seconds.
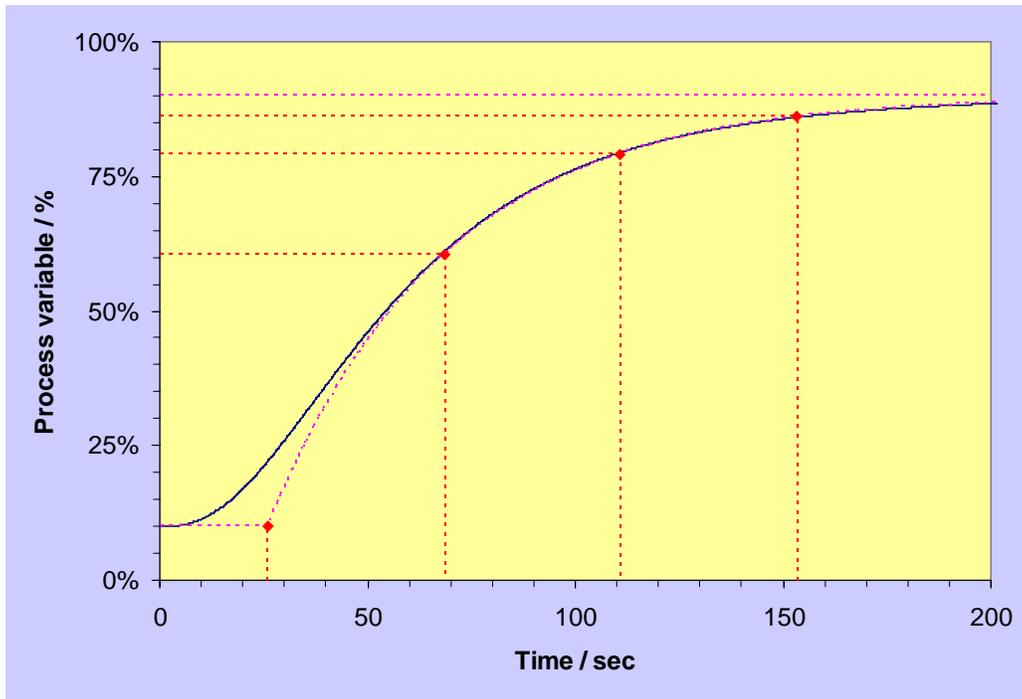
Figure 3: More normal step response

Figure 4 shows the response of a compressor anti-surge controller to a small step change of the recycle valve. The red vertical line shows the time at which the step change was applied. The PV is based on a computation of several compressor measurements including suction flow, which is typically a noisy signal. Hence, the PV is also displaying 1-2% noise. The recycle valve was also sticking slightly as can be seen from the larger 'jumps' at 85 seconds, 94 seconds and 104 seconds. Although hidden beneath the noise and disturbances, the general form of the response is apparent and it is still possible to make a reasonable estimate of the process characteristics. In fact, the full version of U-Tune was used to assist with identification. The eventual tuning was very successful.

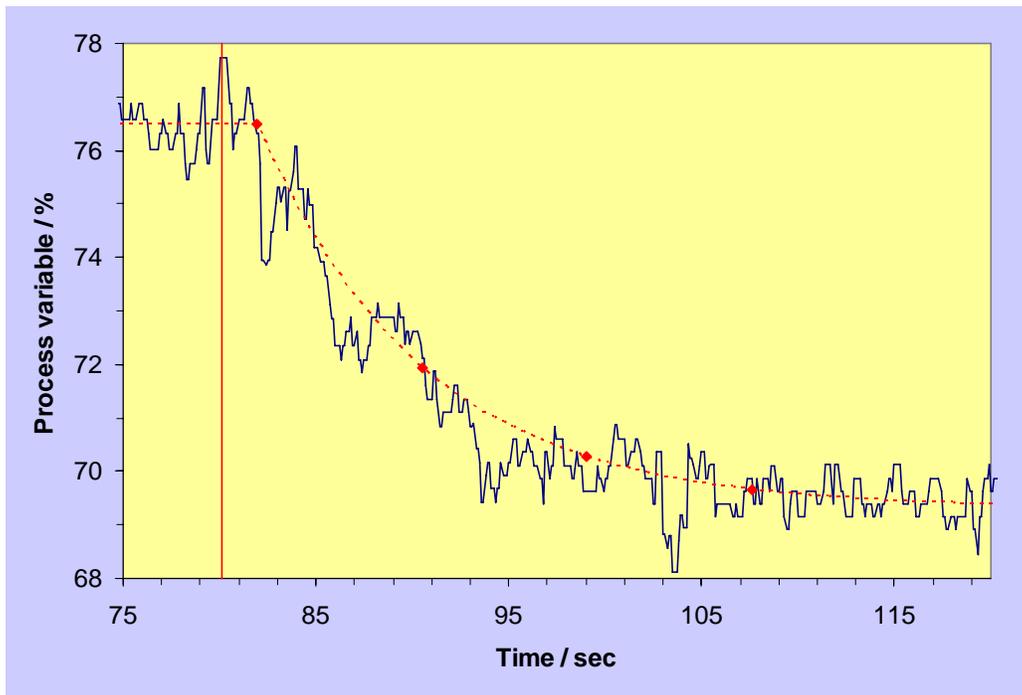|	
Step change	43.5 – 40.4 = 3.1% (not shown in Figure 4)
PV change	76.5 - 69.3 = 7.2%
Time delay	1.85 sec
Time lag	8.55 sec
Fast acting	Proportional band of 112% and integral 10.72 rep/min on a ideal controller

Figure 4: Noisy process variable

Types of Gain and Integral

The proportional term is usually specified either as gain K_p or proportional band *PB* where:

$$PB = \frac{100}{K_p} \text{ and } K_p = \frac{100}{PB}$$

The integral term is specified either in seconds/repeat, minutes/repeat, repeats/second or repeats/minute. Seconds/repeat T_i and repeats/second K_i are related by:

$$K_i = \frac{1}{T_i} \text{ and } T_i = \frac{1}{K_i}$$

Minutes/repeat is seconds/repeat divided by 60.

Repeats/minute is repeats/second multiplied by 60.

Types of Controller

Check the literature for your controller to see which controller algorithm is applicable:

Ideal:
$$Output = K_p.\left(1+\frac{1}{T_i.s}\right).e$$

Parallel:
$$Output = K_p.e + \frac{K_i}{s}.e$$

where K_p is the gain, T_i is the integral term in seconds/repeat (or minutes/repeat), K_i is the integral term in repeats/second (or repeats/minute) and e is the error (i.e. the difference between the PV and the setpoint).

The algorithms will be found with various combinations of proportional and integral terms e.g. the following is a ideal controller written in terms of proportional band and repeats/second:

$$Output = \frac{100}{PB}.\left(1+\frac{K_i}{.s}\right).e$$

Note that other types of controller are frequently encountered such as I-PD. These will not be covered here.

U-Tune (full version)

U-Tune 'micro-lite' provides only very limited functionality to assist with tuning of PI controllers on stable processes. The full version gives much more:

- View trend displays of the PV and CO.

- Use slider controls to identify the main features of the step response.

- Calculate PI or PID parameters for stable or integrating processes.

- Compare the results of a range of step tests and select the best.

Details and screenshots are available on the Contek website.

References

1. 'PID Controllers, Theory, Design and Tuning' Astrom and Hagglund