Relay-based PID Tuning

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ABSTRACT
Relay-based auto tuning is a simple way to tune PID controllers that avoids trial and error, and minimises the possibility of operating the plant close to the stability limit.

Difficulties of loop tuning

When you discuss loop tuning with instrument and control engineers, conversation soon turns to the Zeigler-Nichols (ZN) ultimate oscillation method. Invariably the plant engineer soon responds with 'Oh yes, I remember the ZN tuning scheme, we tried that and the plant oscillated itself into oblivion — bad strategy. Moreover when it did work, the responses are overly oscillatory'

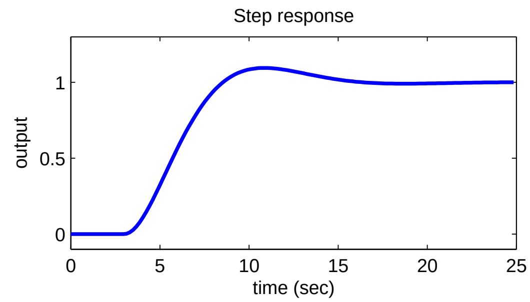
So given the tedious and possibly dangerous plant trials that result in poorly damped responses, it behoves one to speculate why it is often the only tuning scheme many instrument engineers are familiar with, or indeed ask if it has any concrete redeeming features at all.

In fact the ZN tuning scheme, where the controller gain is experimentally determined to just bring the plant to the brink of instability is a form of model identification. All tuning schemes contain a model identification component, but the more popular ones just streamline and disguise that part better. The entire tedious procedure of trial and error is simply to establish the value of the gain that introduces half a cycle delay when operating under feedback. This is known as the ultimate gain K_u and is related to the point where the Nyquist curve of the plant in Fig. 1(b) first cuts the real axis.

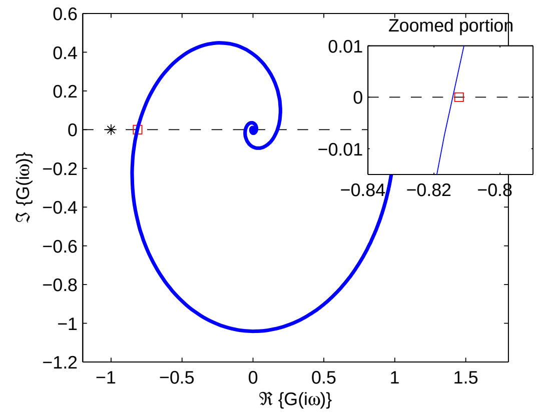
The problem is of course, is that we rarely have the luxury of the Nyquist curve on the factory floor, hence the experimentation required.

Need we stress the plant?

After experimenting with the ZN scheme a few times, one probably wonders if we can establish the ultimate gain without going 'critical'? The answer is a qualified yes, where the key is to temporarily swap a simple relay for



(a) An open-loop step response from the plant under test.



(b) An open-loop Nyquist diagram of a stable plant with some deadtime.

Figure 1. Characteristics of a plant to be controlled.

the PID controller in the feedback loop. This was first proposed in the early 1990s, and a very readable summary of PID control in general, and relay based tuning in specific, is given in [1].

As it turns out, under relay feedback, most plants oscillate with a modest amplitude fortuitously at the critical frequency. The procedure is now the following:

1. Substitute a relay with amplitude d for the PID controller as shown in Fig. 2.
2. Kick into action, and record the plant output amplitude a and period P.
3. The ultimate period is the observed period, $P_u = P$, while the ultimate gain is inversely proportional to the

observed amplitude,

$$K_u = \frac{4d}{\pi a} \quad (1)$$

Having established the ultimate gain and period with a single succinct experiment, we can use the ZN tuning rules (or equivalent) to establish the PID tuning constants. Incidentally, the modified values given in Table 1 are improved versions of the original constants given in most textbooks which have been found to be excessively oscillatory.

Table 1. Modified PID ZN tuning constants as a function of ultimate gain and period.

Specification	K_c	τ_i	τ_d
Original	$0.6K_u$	$P_u/2$	$P_u/8$
Little overshoot	$0.33K_u$	$P_u/2$	$P_u/3$
No overshoot	$0.2K_u$	$P_u/2$	$P_u/3$

The entire procedure of inserting the relay, providing a slight incentive for the system to oscillate, the amplitude and period measurement, and the subsequent computation of controller tuning constants can be reliably automated. Indeed commercial PID controllers such as the ECA series from ABB offer relay based auto-tuning as an option.

An practical tuning example

Suppose we wish to tune a plant whose step response is given in Fig. 1(a). One can immediately see that the plant response is mildly oscillatory with significant deadtime.

Under relay feedback with an amplitude of $d = 2$, we observe the limit cycle oscillations in Fig. 3 from which we can measure a period of $P = P_u \approx 12$ seconds with an amplitude of $a \approx 2$. Using Eqn. 1, we can compute the ultimate gain (or equivalently the gain margin) as $K_u = 4 \times 2/(\pi \times 2) = 1.2$.

For comparison the □ superimposed in the zoomed portion of Fig. 1(b) indicates that our experimentally calculated gain margin, $1/K_u$, is only very slightly off the actual gain margin. This should give us confidence.

Selecting the 'Little overshoot' option from Table 1 gives PID constants as $K_c = 0.4$, $\tau_i = 6$s, and $\tau_d = 4$s. Inserting these tuning constants in a PID controller gives the closed loop response shown in Fig. 4.

No one size fits all

Of course no one tuning method has been found to be infallible. The closed loop response in Fig. 4 is slightly slower

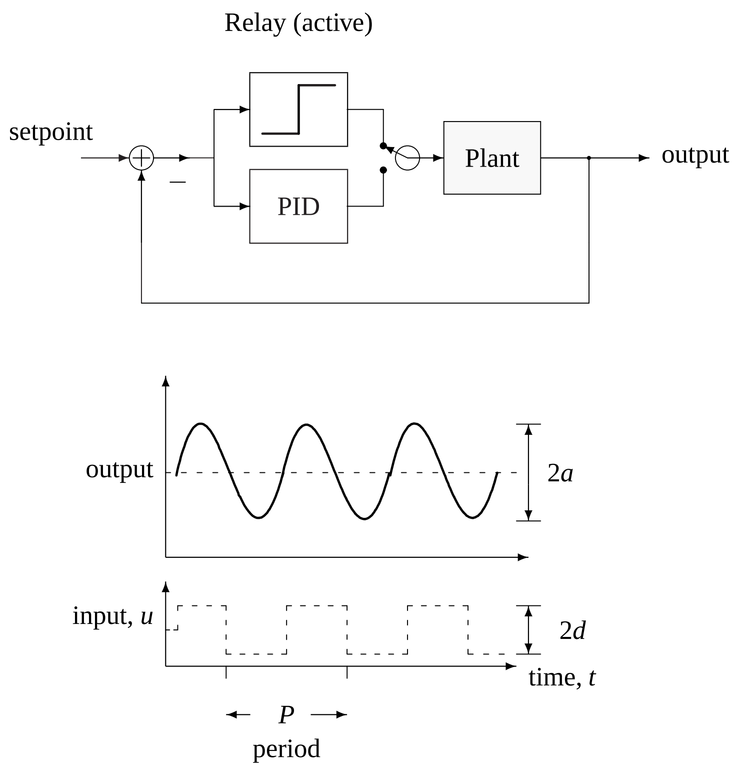


Figure 2. A plant oscillating under relay feedback with the PID regulator temporarily disabled.

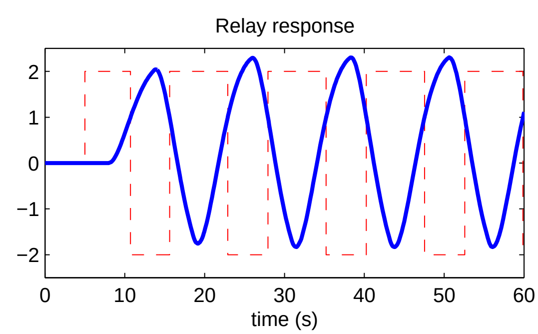


Figure 3. The plant from Fig. 1 operating under relay feedback.

than I would like, and exhibits a nasty spike in the manipulated variable. These attributes however are due to the simplistic way I have implemented the derivative component of the PID controller, and not due to the tuning procedure. In fact it is surprising just how good the ZN tuning scheme performs in general given that it relies on only a single point in the Nyquist diagram.

Since the development of relay-based autotuners in the 1990s, there have been many proposed extensions. One of the more fruitful was the realisation that by varying the hysteresis in the relay, it is possible to generate more points on the Nyquist curve. With more points, better tuning for the more pathological plants is possible.

Reflect on this

Good tuning methods are simple tuning methods. Loop tuning using relay feedback has three big advantages, namely:

1. We avoid a tedious trial and error search for the ultimate gain.
2. We avoid operating near the instability limit.
3. The procedure is easy to automate.

Next time you need to re-tune a control loop, try the relay-based scheme, you need only a stopwatch, a ruler, a calculator, and of course a relay.

References

[1] Karl-Johan Åström and Tore Hägglund. *PID Controllers: Theory, Design and Tuning*. Instrument Society of America, 2 edition, 1995.

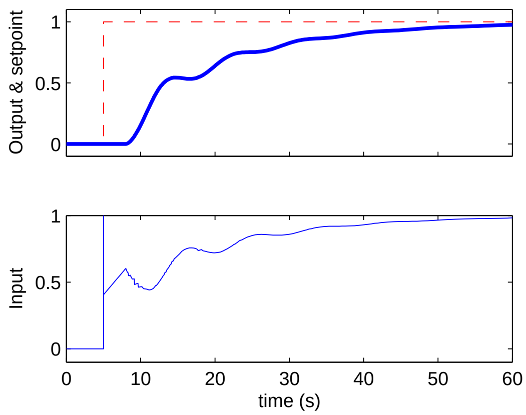


Figure 4. Response of the tuned PID controller to a setpoint step change.