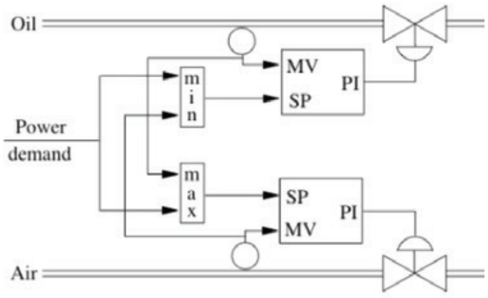
Auto-tuners for PID Controllers

Despite all the progress in advanced control, the PID remains the most popular controller. Any stable system can be controlled with an integrating controller; performance can be increased by adding proportional and derivative action. There is ample evidence that many manually tuned PID controllers do not work well. Automatic tuning has improved performance and simplified use.

PID controllers come in different varieties: as stand-alone components, as elements of distributed control systems, or embedded in instruments and systems.

PID control is used everywhere—in cellular phones, vehicles, process control, heating, ventilation, air conditioning, machine tools, and motor drives. Many PID controllers are found in cars, for example, in engine, cruise, and traction control. PID control is also embedded in instruments such as atomic force microscopes and adaptive optics. Because of their widespread use, it is difficult to precisely estimate the number of control loops installed each year, but an educated guess is that it is in the billions.



The PID controller is based on very simple ideas. As illustrated in the idealized formula below, the controller output is a combination of three terms:

- The proportional term reacts to current errors.
- Past errors are accounted for by the integral term.
- The derivative term anticipates future errors by linear extrapolation of the error.

$$u_{PID}(t) = k_p e(t) + k_i \int^t e(\tau)d\tau + k_d \frac{de(t)}{dt}$$

A remarkable property of a controller with integral action is that it gives the correct steady state, if a steady state exists, even for nonlinear processes.

Predicting a noisy signal by linear extrapolation is difficult; it is also difficult to find values of derivative gain k_d that give a robust system (tuning the derivative gain is more difficult than tuning the proportional and integral gains). Most PID controllers are in fact used as PI controllers.

A Real PID Controller

PID control is much more than what is captured by the simple idealized formula. To get a functioning controller, one must consider set-point weighting, filtering of the measured signal, protection for integral windup, as well as bumpless mode and parameter changes.

Complex System

The PID controller is a simple system. Well-developed architectures exist for building complex systems from the bottom up by combining PID controllers with linear and nonlinear elements such as cascade, mid-range, selector control, and gain scheduling. The figure on the left shows a system with PI controllers and selectors for controlling a burner that guarantees there will always be excess air.

Automatic Tuning

Traditionally, PID controllers were tuned manually using simple rules that date back to Ziegler and Nichols in the 1940s. The rules were based on process experiments. The step response method is based on measurement of the open-loop step response. The frequency response method is based on a closed-loop experiment where the system is brought to the stability boundary under proportional control. Unfortunately, the traditional rules resulted in systems with poor performance.

Automatic tuning has increased the use of derivative action. It has even been said: "This controller must have automatic tuning because it uses derivative action."

Automatic tuning can be done in many ways. In rule-based methods that mimic an experienced instrument engineer, features of the closed-loop response are calculated and controller parameters are adjusted based on empirical rules. Other methods are based on estimation of low-order process models, typically first-order dynamics with time delays. The controller parameters are then determined by a variety of control design methods.

Relay auto-tuning is another widely used approach that has proven to be robust and that brings attractive theoretical properties as well.

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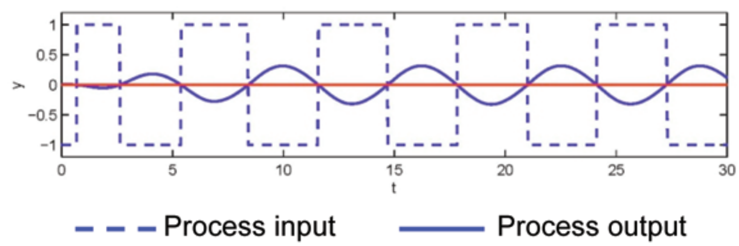
PID auto-tuners are in widespread use, especially in the process and manufacturing industries. All major instrumentation and control suppliers offer auto-tuning as a feature in their products. Auto-tuning software is also commercially available for PC, SCADA, and DCS platforms and in the simulation programs Simulink and LabView.

PID auto-tuners

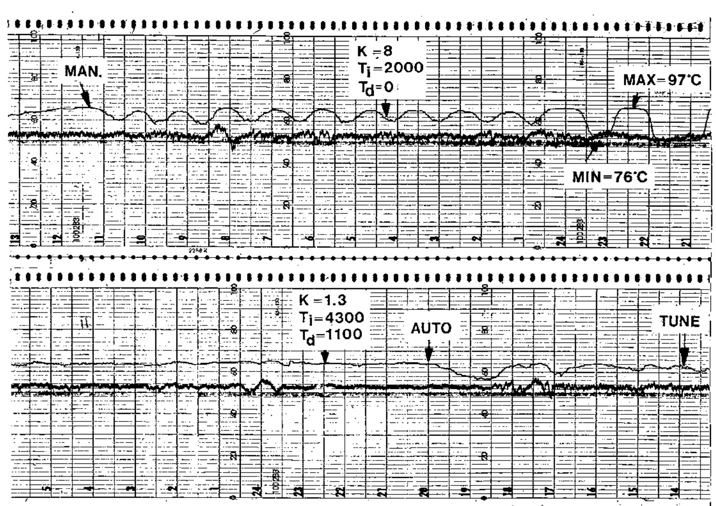
Relay Auto-tuning

In relay auto-tuning, the process is first brought to oscillation by replacing the PID controller with a relay function (see figure below). The controller parameters are then determined from the period and the amplitude of the oscillation. An interesting feature of relay auto-tuning is that it automatically generates signals that are customized for modeling critical aspects of the process. The relay can also be applied to a closed-loop system.

For typical process control applications, the relay auto-tuners can be designed so that tuning can be executed simply by pushing a button; there is no need to set any parameters. The auto-tuner can also be used to generate gain schedules automatically.



The data are from a recorder where time runs from right to left. A PI controller produced oscillations as seen in the top plot. The PI controller was switched to manual at time 11:15. The oscillation stops but the process drifts. An auto-tuner was installed and tuning was initiated at time 14:00 by pushing the tuning button; no further manual interaction was involved. Tuning is completed at time 20:00 and the controller switches to automatic with good control performance. The auto-tuner reduced the proportional gain, increased the integral time, and introduced derivative action with prediction time 1100 sec.



Relay auto-tuning of a temperature control loop on a distillation column

For more information: K.J. Åström and T. Hägglund, Advanced PID Control, ISA, Research Triangle Park, NC, 2004; T.L. Blevins et al., Advanced Control Unleashed: Plant Performance Management for Optimum Benefit, ISA, Research Triangle Park, NC, 2003.