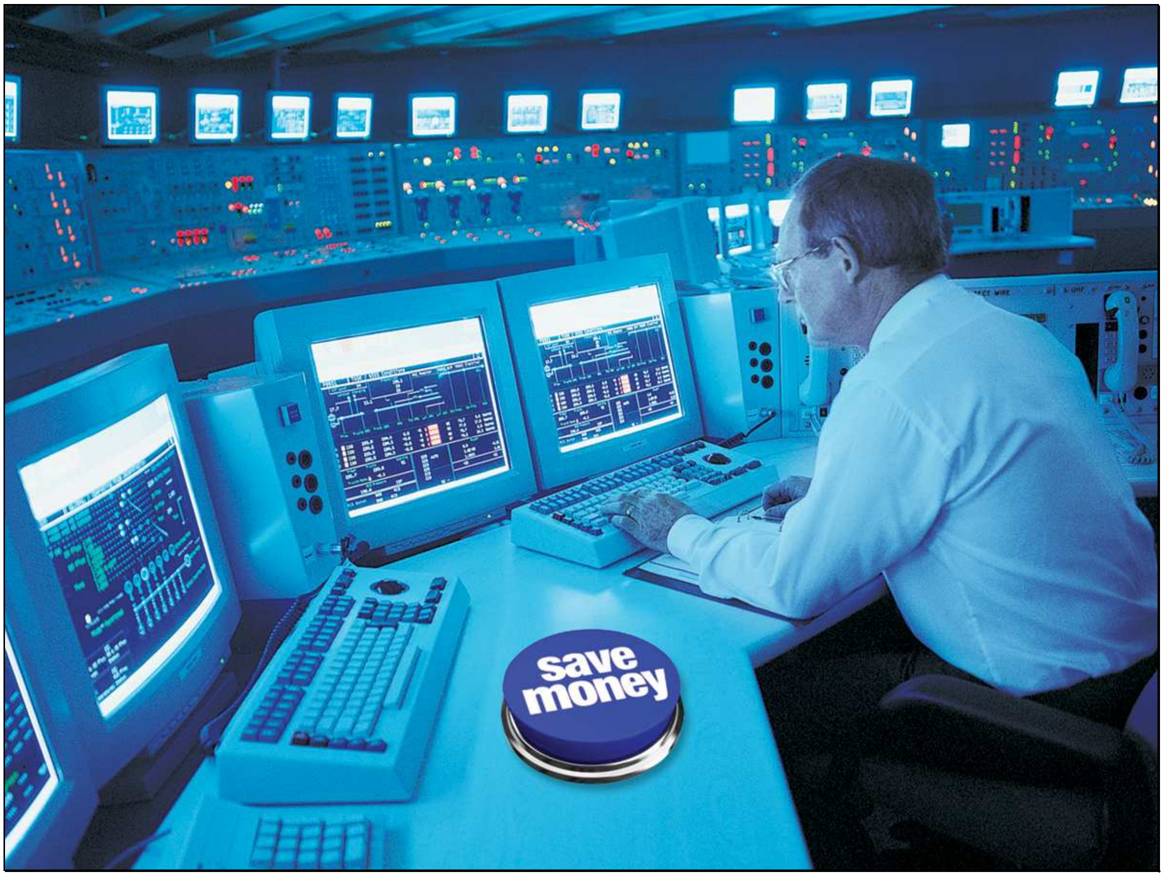

Control Systems
Investment and Return
Part 1 of 3

By F.G. Shinskey

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CONTROL SYSTEMS: INVESTMENT AND RETURN
with Examples from Industry

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Part 1 of a 3-part series

Part 1 covers Control System Objectives, as well as sharing case studies that demonstrate how control systems can deliver improved efficiency, reduced capital equipment costs, and improved product recovery. The remaining 2 parts of the series address even more ways to deliver business results with control systems.

Objective

The objective of a control system is to regulate process variables in such a way as to operate the plant at the safest, most productive and profitable conditions possible consistent with the existing market, available feedstock, and equipment limitations—*automatically*—that is, with minimal human assistance. There are two basic obstacles to reaching this goal in any given process: Instability and Ineffectiveness.

Instability is the result of control overreaction to a variation in the controlled variable, inducing a later and opposite variation of similar magnitude. It appears as cycling in one or more controlled variables, whose amplitude may be constant or not. A constant-amplitude cycle, known as a "limit cycle," is caused by a nonlinear element in the control loop. Limit cycles tend to be non-sinusoidal, and are not correctible by controller tuning or replacement—the nonlinear element (such as valve deadband) must be overcome. If the loop is linear, its sinusoidal cycle may either expand or contract, but an expanding cycle will eventually be limited by some physical stop, such as valve travel. Instability is costly in terms of wear on components, reduced production capacity, and inefficient utilization of resources such as energy.

Ineffectiveness is the inability to maintain the controlled variable at set point in the presence of variations in ambient conditions, feed rate and composition, and upsets caused by the actions of other controllers. The worst case is no control at all; next is Manual control that receives occasional operator attention; other cases include poorly tuned controllers, mismatched valve characteristics, and incorrectly configured loops. Control ineffectiveness also wastes resources, limits production capacity, and gives away valuable product. Examples follow with corrections that saved dollars—lots of dollars.

Case 1: Maximize Power-plant Efficiency

One of the key variables in determining the efficiency of converting fuel into electric power is the **temperature of superheated steam** from the boiler to the turbine-generator. Its maximum value of 1100°F must not be exceeded to protect the metallurgy of the steel tubing—higher values will weaken it, but lower values reduce plant efficiency. Variability also stresses the tubes. So variability must be minimized in the presence of changes in steam demand and fuel upsets. The smaller the variation allowed by the controls, the closer to 1100°F the temperature set point can be positioned.

Figure 1 compares the optimum step-load response curves for three different feedback controllers and a feedforward system that might be applied to steam-temperature control. (Optimum here is defined as having a minimum integrated absolute error IAE.) The least effective is proportional-integral (PI) control, giving the highest peak deviation from set point and the longest recovery time—also the highest integrated error (the area under the response curve). Adding derivative action gives PID control, which reduces both peak deviation and recovery time considerably. The PID controller's proportional band is lower by ¼, integral time reduced by more than ½, and integrated error lower than PI control by a factor of three. As a result, most steam-temperature controllers are PID.

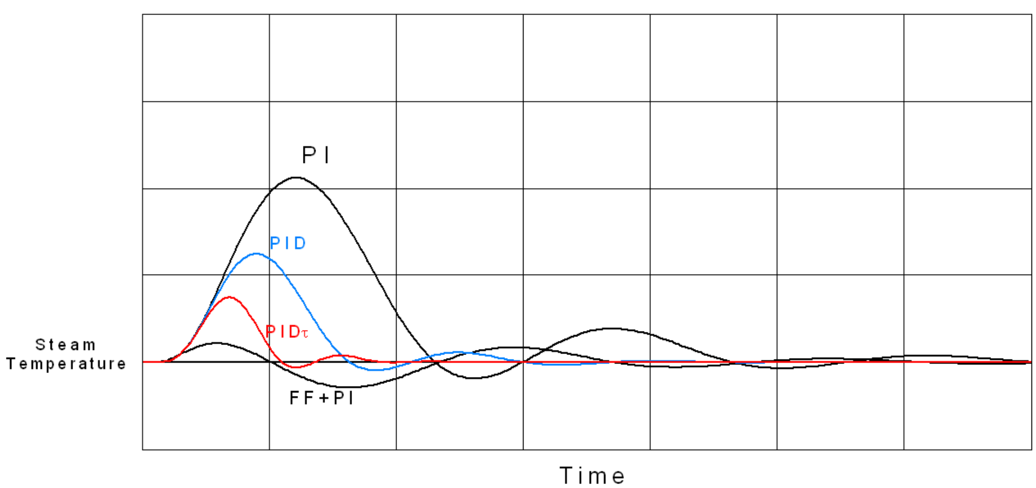

Fig.1. Choices for steam temperature control

Adding a dead-time compensator to the PID controller allows a further tightening of the response. Its optimum proportional band is lower than the PI controller by a factor of three, and integrated error lower by a factor of over seven. This is essentially the highest-performance feedback controller available. Its performance comes with a price, however—it is not particularly robust. The loop could go unstable when the steam flow falls by 21% or rises by as little as 12%. The system was applied to a **500-MW power boiler** as described in Ref.1. To protect against instability, optimum controller settings were determined at several levels of steam flow and all four parameters were gain-scheduled according to this program.

The last curve in Fig. 1 describes the response to dynamically compensated feedforward control (FF), where the manipulated flow of feedwater in a **2450-psi once-through boiler** is set in ratio to fuel flow, the ratio trimmed by a feedback controller. This minimizes peak deviation and reduces the integrated error to zero. This system resulted in the U. S. patent of Ref. 2.

Case 2: Capital Equipment Savings

At the Deer Island Treatment Plant in Boston, off-gas from sewage digestion is compressed and used to fuel boilers. Four 200-HP stainless-steel constant-speed **reciprocating compressors** were available to provide gas pressure at variable flow demand. Pressure was controlled by recirculating compressed gas back to the suction; each of the double-acting cylinders also had unloaders, and a clearance pocket. These devices allowed changing capacity in five unequal steps from 0 to 100 percent. As the pressure controller (PC) fully closed the recirculation valve to increase flow, logic then raised the capacity of the compressor by the next step. Two compressors were required to carry the full boiler load, with the third a standby and the fourth serving other users.

The compressors were being dismantled when I arrived because they “could not be controlled.” Each stepwise increase in capacity caused a pressure spike that overfired the boilers and caused black smoke and rumbling. The steps varied in size from 14 to 34%, with the largest causing the most trouble. The compressors were to be replaced by centrifugals of similar capacity at a cost of $1.2 million.

I persuaded management to let me try to control the recips, and guaranteed performance. First, the recirc valve characteristics had to be changed from equal-percentage to linear, and fitted with a digital positioner for accuracy and speed. Then a feedforward control program was created, which converted the (unequal) step sizes into equivalent motion of the recirc valve, implemented in a PLC. Finally, a one-second delay was added to the pockets and unloaders to give the control valve a head start when capacity needed to change. A second compressor was coordinated with the first one for higher loads.

When work was complete, the compressors could be exercised through the entire plant load range without a noticeable pressure pulse. (The same control system was then implemented on the other two compressors.) The order for replacement compressors was then canceled. All the details of the project and the effort required to achieve this objective are found in Ref. 3.

Case 3: Maximize Recovery of Distilled Products

Distilled products represent the most valuable commodities leaving a refinery or chemical plant, and have to meet rigid specifications. Their quality is also difficult to control, and subject to disturbances from all upstream variables, along with the weather. A typical example is a column separating polymer-grade **propylene** from propane in an olefins unit. The propylene, distilled overhead, is much more valuable than propane, but must contain only very small amounts of impurities to meet specifications.

One such unit required 200 trays, in two 100-tray columns, connected by vapor and reflux lines. Overhead vapor flow varied by 2½% diurnally, which doesn't sound like much, but when multiplied by the reflux/distillate ratio of 16, affected the overall material balance by 40%. With boilup and reflux flows both controlled, their difference, distillate flow, was the dependant variable. At night, it would decrease by as much as 40%, resulting in an average recovery of propylene distillate of only 80%.

The column was placed under feedforward material-balance control—distillate flow was used to control its composition—to eliminate interaction with the heat balance. Then differential pressure across the upper column was controlled by heat input, to maintain maximum vapor flow at night. The column was slow, with a time constant of about 24 hours, but once on-spec product was made, it stayed on-spec, and propylene recovery increased to 95%. The control system is described in Ref. 4.

In another refinery, **xylene** was being separated overhead for sale as a petrochemical feedstock from heavier hydrocarbons, which went to the gasoline pool. At $13/bbl more valuable than gasoline, its flow should be maximized, but much was being lost out the bottom by overpurifying the top product. The column was placed under feedforward material-balance control as described above, but another problem appeared in the composition feedback loop. The gain of a separation process encountered by its composition controller varies directly with the value of the controlled impurity. When the impurity level falls to zero, so does the gain, and the column becomes very steady—but unprofitable. As the set point is moved upward toward the specification limit—here 3 percent—the gain rises proportionately and cycling begins. The oscillation is often not sinusoidal, however, but shows sharp peaks and flat valleys, as described in Ref. 5.

This was a real problem with the xylene column, because the period of the cycle was about 3 hours. To linearize the loop, the analyzer controller (AC) was gain-scheduled, whereby its proportional band was made to vary directly with the measured value of the key impurity. The cycle then became more sinusoidal, and the AC could be tuned to stabilize the loop. After its set point was raised close to the specification limit, xylene recovery became essentially complete—none lost out the bottom. Less energy was even used than before, with total savings amounting to about $1 million a year.

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