9 Application of Protective Controls to Distillation Columns

9.1 INTRODUCTION

As mentioned earlier, most existing plant instrument systems consist of a large number of single-loop controls: one transmitter, one controller (usually proportional-reset), one manual/automatic station, and one valve. In real life, however, many a valve must be adjusted in accordance with changes in more than one process variable. For example, the steam valve to a distillation column reboiler may have to be adjusted in response to as many as half a dozen variables. With existing systems the operator usually must put the control loop into the "manual" mode and adjust the control valve position as all but one of the pertinent variables change. To put it another way, conventional "automatic" controls are automatic only in a limited sense over a limited range of conditions. One must superimpose upon them a kind of logic that spells out various courses of action to take as certain constraints, such as high column $\Delta P$, low tank level, or high temperature, are approached or reached. For conventionally instrumented plants, this logic is a major part of the formal instructions for operating personnel. In the case of highly integrated ("bootstrap") plants, the required logic, although it may be deduced and written down in advance, may be too detailed and complex to be absorbed readily by human operators.

In addition, the required reaction times in certain circumstances may be too short for typical human physiology. Automatic controls, on the other hand, provide continuous (or almost so for digital controls), simultaneous surveillance and recognition of operating conditions and continuous, quantitative response to them. They are also much more reliable than human beings.

To make a given control valve respond to more than one controller, we must have a means of telling the valve which controller to obey. To put it in
process control language, we want a multivariable control system instead of multiple, single-variable control loops. In the remainder of this section, we illustrate a number of techniques for accomplishing this with specific applications to distillation columns. The usual objective is to provide protective controls that permit the column to operate close to constraints without exceeding them. In so doing, we greatly improve our ability to achieve certain other control objectives:

—Automatic, or at least easy, startup and shutdown
—Automatic total reflux operation under specified circumstances
—Maximum-capacity operation
—Ability to make desired transitions in column terminal product compositions with minimum production of off-specification products
—Minimum interlock shutdowns, that is, ability to stay on the line a higher percentage of the time
—Minimum turndown requirements for both process streams and utilities

The fourth item is particularly important when feed-stock composition varies widely and it is desired to optimize column or train operation as, for example, with a computer.

We use the term override for the most part to refer to the use of two or more controllers connected to a control valve through high or low signal selectors. Logic is built in to enable one controller to “override” (i.e., take over from) the other controller or controllers.

9.2 OVERRIDES AND INTERLOCKS

In the chemical and petroleum industries, the most common types of protective controls are interlocks and overrides. Interlocks normally function in an abrupt manner to shut down a piece of equipment or one or more steps in a process. For example, if a column feed pump fails, a low feed flow interlock may be used to shut the column drawoff valves, and perhaps also to shut off steam. High column base temperature and high column differential pressure are sometimes interlocked to shut off steam to the reboiler. Usually interlocks must be reset manually by the operator.

By contrast, overrides can be designed to provide gradual, rather than abrupt, corrective action and function in both directions, that is, they do not have to be reset manually. As a generalization, interlocks are most useful in cases of equipment malfunction or failure; overrides are most useful in protecting the process and keeping it running as certain maximum or minimum permissible operating conditions are approached.
9.3 IMPLEMENTATION OF OVERRIDES

Many ways of implementing overrides are possible, but a particular one that is inexpensive and works well involves the use of combinations of devices such as described in the following.

**High Selectors (HS) or Low Selectors (LS)**

These devices select either the higher or the lower of two input signals. As many input signals as desired may be accommodated by arranging selectors in series. Multiple-input low-signal selectors are now available from vendors. In practice one or more selectors are inserted between the output of a “normal” controller and its final control element, usually a valve. The outputs of the “override” controllers are also connected to these selectors. As process constraints are approached, one of the override controllers will “take over” or “override” the normal controller and drive the final control element in the proper direction—either to force the process away from a constraint, or to hold it a safe distance from a constraint.

One may also construct a median selector with two high selectors and two low selectors as shown in Figure 9.1. The major application has been for auditing multiple flow measurements to a chemical reactor. If either the high or low measurement deviates too far from the median value, an alarm or interlock is activated. So far we have found no applications to distillation, but it is a technique that is worth keeping in mind.

**High Limiters (HL) or Low Limiters (LL)**

High and low limiters are devices that reproduce the input signal 1:1 up to a predetermined maximum value (HL) as shown by Figure 9.2, or down to a predetermined minimum value (LL) as shown by Figure 9.3. In either case the cutoff or limiting value is readily adjustable.

Functionally, a high limiter is a low selector plus a signal source such as a supply regulator (Figure 9.4). It thus can be constructed with two separate devices or assembled into one housing. Correspondingly, a low limiter is a signal source plus a high selector (Figure 9.5); it also may be assembled with two devices or purchased as a combined device.

**Summers**

Summers are devices that add or subtract. If pneumatic versions with adjustable gain are required, one should avoid those with pressure-dividing networks. Their accuracy is poor.
FIGURE 9.1
Median selector (J. P. Shunta design)
9.3 Implementation of Overrides

FIGURE 9.3
Low limiter

FIGURE 9.2
High limiter
FIGURE 9.4
High limiter schematic

FIGURE 9.5
Low limiter schematic
Three types of controllers have been used in override circuits; two of them widely, and the third less frequently.

**Proportional-Reset (PI) or Proportional-Reset-Derivative (PID) Controllers**

Both of these are commonly used as normal controllers, although the PI type is occasionally used as an override controller. PID controllers, if used, should be so designed that the derivative acts only on the measurement signal, not on the controller output. Both PI and PID controllers must contend with the problem of reset windup, discussed below.

**Proportional-Only Controllers**

The fixed-gain proportional-only relay, either direct acting or reverse acting, with adjustable bias has become one of the most widely used devices in override circuits. Common values of gain are 2, 3, 4, 6, and 25. Use of the minus sign (−) with these figures implies reverse action, or negative gains.

A proportional-only controller or relay follows a straight-line equation.

\[ \theta_o = K\theta_i + B \]  

where

- \( \theta_o \) = output signal
- \( \theta_i \) = input signal
- \( B \) = bias
- \( K \) = proportional gain

We have found it convenient to calibrate pneumatic, fixed-gain relays in terms of the input signal, \( [\theta_i]_9 \), required to produce 9.0-psig output. Then

\[ 9.0 = K[\theta_i]_9 + B \]  

or

\[ B = 9.0 - K[\theta_i]_9 \]  

On substituting equation (9.3) into equation (9.1) we obtain:

\[ \theta_o = K (\theta_i - [\theta_i]_9) + 9 \]  

The instrument may now be calibrated by putting \( [\theta_i]_9 \) into the input and adjusting the bias for 9.0-psig output.

For override purposes we use proportional-only controllers if possible, largely to avoid some problems associated with PI controllers. If the latter are used for override purposes, no fixed relationship will exist between controller output
and process variable. A sudden disturbance can cause an overshoot above the set point, with the amount depending on the magnitude and rapidity of the upset and the reset time and proportional band of the controller. Further, for a given upset, the output of a proportional-reset controller usually swings through wider limits than the output of a proportional-only controller. These features make this type of override highly undesirable in those applications where, for safety's sake, certain limits must not be exceeded. Maximum temperature in some chemical reactors is a good example of this. We thus use proportional-reset override controllers only in those cases where good control could not be obtained with gain 2 or higher proportional-only overrides because of closed-loop stability problems. Examples include column \( \Delta P \) or base pressure.

For predetermined maximum and minimum limits, we select a proportional-only controller with a gain that will drive the valve from 3 to 15 psig (or vice versa). Thus:

\[
\text{Proportional gain} = \frac{15 - 3}{\text{max} - \text{min}}
\]

where "max" and "min" are in terms of the process transmitter output.

Consider a system where a low base level override is to be used to close the steam valve. Its output is compared with that of the normal controller through a low selector. Let us say that we want full override action to occur between zero level (3 psig) and the 25% level (6 psig). Then the required proportional gain is:

\[
\text{Proportional gain} = \frac{15 - 3}{6 - 3} = \frac{12}{3} = 4
\]

Since the gain 4 relay is to put out 15 psig at the 25 percent level, and its output goes to a low signal selector, it clearly will exercise no control action at a level of 25 percent. On the other hand, if level is dropping, the output of the gain 4 relay will drop below that of other controllers at some value of level above zero. We are never sure, therefore, at what point the low-level override will take over, but we know positively that it will be between the zero and 25 percent levels.

**Floating or Integral Controller**

This type sometimes is used as a normal controller instead of a PI controller when required proportional gain would be very low or where it would need to be changed frequently as process conditions change.

### 9.5 ANTI RESET-WINDUP

**Single-Loop Controls**

When control of a valve is transferred from one controller to another through a selector, we would like this to happen without a bump. Since the
selectors will switch on very small differential signals, they will in themselves introduce no significant jolt. The major potential source of bump is reset windup in overridden controllers.

In all commercial pneumatic controllers, reset action is obtained by a positive-feedback, unity-gain circuit that feeds the controller output signal back through a needle valve into a reset chamber. This feedback is normally internal, but in some commercial controllers it may be taken from an external connection by proper orientation of a switchplate on the body of the controller. If, now, we use the valve-loading signal as the reset-feedback signal, we will get normal reset action when the controller is controlling. When, however, another controller takes over, reset action in the first controller ceases, but its output goes up and down with the valve-loading signal. This tracking action is delayed by the reset time constant, which for many controls (such as liquid flow control) is small. The output of the overridden controller will differ from the external reset feedback signal by the product of its gain, $K_r$, and the error signal, $e$.

The anti reset-windup technique discussed above is known as “external reset feedback.” For most applications either it, or the modification mentioned below, is our preferred scheme. It has the disadvantage that the controller output signal, commonly labeled “valve position,” is really different from the actual position. It differs by the product of the error signal times the proportional gain. Lag in the reset circuit may cause further error. A modification therefore is introduced by some vendors, particularly in the newer microprocessor controls. This consists of setting the reset time equal to zero when the controller is overridden. This technique is sometimes called “integral tracking.” It should not be used with auto overrides.

Another technique is called “output tracking”; the overridden controller output is driven to almost the same value as that of the overriding signal. This does have the advantage that the controller output signal is nearly equal to the valve-loading signal. However, according to Giles and Gaines, this technique does not work as well, at least under some circumstances, as does integral tracking. Various other techniques have been described by Khanderia and Luyben. As an example consider the simple system of Figure 9.6. It shows a distillation column with a base temperature controller and a column $\Delta P$ controller, both connected through a low selector to the steam valve, which has air-to-open (AO) action. Let us assume that at startup time the base of the column has enough low boilers that it will boil at a temperature lower than the normal temperature controller set point. If we do not lower the set point, the temperature controller will open the steam valve wide, the column-base contents will boil very rapidly, and column pressure drop will shoot up. As it goes above the $\Delta P$ controller set point, this controller output starts to decrease, and when it becomes lower than the output of the temperature controller, it takes over the steam valve through the low selector. The steam valve is now held open just far enough to keep column $\Delta P$ at the set-point value (chosen to be the maximum acceptable). Eventually the low boilers are taken overhead and base temperature rises to the point where the temperature controller takes over. Since the operator
does not need to change the $\Delta P$ controller set point, it can be located away from the panel in an override cabinet.

Several points should be noted about this system:

—Since the override controller is of the proportional-reset type, there will not exist a fixed, known relationship between the controller output and process transmitter output.
—The overriding controller—in this case differential pressure—must have a smaller reset time than the normal controller or it will sometimes take over at values of column $\Delta P$ different from the override controller set point.
—Manual–automatic switching is not necessary since both controllers have anti reset-windup.
—If the system of Figure 9.6 is started up in the automatic mode, the control valve will open and the controlled variable will rise toward the set point at a rate determined by the reset time constant.

The first two points lead us to use proportional-only overrides where possible, while the third suggests that automatic startup and shutdown can be obtained with an air switch and several three-way pneumatic valves.

It should be noted that only a few of the electronic analog controllers on the market have external reset feedback or some other satisfactory anti reset-windup scheme. But newer digital and microprocessor-based controls (as of late 1983) use a variety of techniques, most of which appear to be satisfactory.

**Cascade Controls**

The preceding technique works well for conventional single-loop controls and for secondary or slave loops in a cascade system. But for primary or master controllers, we do something different since the valve-loading signal is no longer meaningful for reset feedback.

To eliminate reset windup, we break the master controller internal feedback as before, but now we use the secondary measurement for feedback as shown by Figure 9.7. If, for example, we have temperature cascaded to flow, we feed the output from the flow transmitter back into the master controller reset circuit. This means that during normal control the lags in the secondary control loop appear in the reset feedback circuit of the primary controller. If, as usual, the slave loop is much faster than the master loop, this technique will not appreciably increase the master controller reset time.

**9.6 FEEDFORWARD COMPENSATION WITH OVERRIDES**

A convenient method for providing feedforward compensation that does not interfere with either normal reset or antireset windup involves the use of an “impulse” relay and a summer as shown in Figure 9.8. In pneumatics these functions are sometimes combined into a single device. The impulse function
FIGURE 9.6
Column base temperature control with ΔP override
FIGURE 9.7
Antireset windup for cascade loops
passes only the transient part of the feedforward signal. This eliminates or avoids scaling problems with the summer since the steady-state or dc component of the feedforward signal is blocked. It can be shown that best results are usually achieved if the impulse relay time constant is set equal to the PI controller’s reset time.¹ The theory is discussed briefly in Chapter 12.

### 9.7 OVERRIDES FOR COLUMN OVERHEAD SYSTEM

Let us assume we have a conventional column with the following normal controls:

- Condensate receiver level controls top-product drawoff.
- Base level controls bottom-product drawoff.
- Reflux is ratioed to feed.
- Steam is ratioed to feed.

As indicated by Figure 9.9, this column has a horizontal condenser and vertical, cylindrical condensate receiver or reflux drum. We will assume that the level controller is of the PI type with set point at midscale of the level transmitter span and that gain 2 auto overrides are employed. The level overrides then function as described in the following.

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¹ The theory is discussed briefly in Chapter 12.

**FIGURE 9.8**

Impulse feed forward with PI controller and overrides
FIGURE 9.9
Overrides for column overhead system
9.7 Overrides for Column Overhead System

Low Condensate Receiver Level Override on Reflux

As liquid level rises to the lowest position (3 psig), the output of reverse-acting override A1 with gain 4 starts to decrease from 15 psig; when the level reaches 25 percent (6 psig), the output of A1 is 3 psig. This permits the reflux valve to open and the reflux controller to take over somewhere in the lower 25 percent of level. If the level drops again, this override starts to close the reflux valve.

This design should be compared with that of Figure 3.26 where a PI level controller was used with auto overrides, and high and low level overrides acted on the reflux flow controller set point. This permits accurate calculation and prediction of override behavior, and overall is probably preferable. We are using this scheme increasingly. It has been a more common practice in the past, however, to have overrides act directly on the valve as in Figure 9.9.

High Condensate Receiver Level Override on Reflux

If liquid level rises above 75 percent, the output of reverse-acting override A2 with gain 4 starts to decrease from 15 psig and reaches 3 psig at 100 percent level. This drives the reflux valve open. These two overrides are particularly helpful for a column with a high reflux-to-distillate ratio. Without such protection moderate changes in reflux flow could either flood the receiver or run it dry.

Low-Low Condensate Receiver Level Override on Cooling Water

To guarantee condenser cooling-water flow during startup, override A10 holds the cooling-water valve open as long as the condensate receiver level is low. A10 usually has a gain of –25 and is so calibrated that it has an output of 9 psig when its input is about 3.5 psig. The normal controller for this valve may be the cooling-water exit-temperature controller, or in the case of vacuum or pressurized columns, it may be the pressure controller.

Overrides on Distillate Valve

The distillate valve may be held closed by override A3 until overhead composition or temperature reaches a satisfactory value; it may also be closed by high liquid level in the next process step. Reflux pump operation is made automatic by switch S1. As the condensate receiver level transmitter output increases above 3 psig, S1 starts the pump. Similarly, if the reflux drum loses its level, the pump shuts down.

For some columns it is desirable to maintain a minimum reflux flow rate. This would require an additional override on the reflux valve.

Condenser-Cooling-Water Overrides

As mentioned in Chapter 3, some plants like to control condensate temperature by throttling cooling water as shown in Figure 3.2. This seldom works well,
if at all, so it is increasingly common to provide an override from cooling-water exit temperature as shown by Figure 9.10. If the condensate temperature becomes too low, causing the condensate temperature controller to cut back on cooling water, the cooling-water exit temperature rises. To minimize fouling and corrosion, it is usually desirable to limit exit cooling-water temperature to a maximum of 50–60°C, particularly if 316 SS is used. The override scheme of Figure 9.10 will accomplish this.

### 9.8 OVERRIDES FOR COLUMN-BASE SYSTEM

The column-base system shown by Figure 9.11 features a thermosyphon, vertical-tube reboiler. The base liquid level transmitter is installed and calibrated...
FIGURE 9.11
Overrides for column base system
as recommended in Chapter 4. The PI controller has gain 2 auto overrides, and the set point is at midscale. The level overrides then function as in the following.

**High-Base-Level Override on Feed**

As liquid level in the base rises from 75 to 100 percent, the output of gain \(-4\) override \(A5\) goes from 15 to 3 psig; this closes the feed valve through a low selector.

**Low-Level Override on Steam**

As liquid level rises from zero to 25 percent, override \(A9\) output increases from 3 to 15 psig. This permits the steam valve to open and the steam controller to take over somewhere in the lower 25 percent of level. If the level drops below 25 percent, the override starts to close the steam valve. This prevents “baking” the reboiler tubes (which fouls them) when there is too little liquid to keep the tubes wet.

**High-Base-Pressure or High-Column \(\Delta P\) Override on Steam**

As increasing boilup increases column \(\Delta P\) or column-base pressure (especially during startup), override \(A7A\) or \(A7B\), acting through a proportional-reset controller, will limit maximum steam flow. This is accomplished by setting a 9-psig set point on the controller and biasing gain 1 relays \(A7A\) and \(A7B\) such that their outputs are each 9 psig when the maximum permissible column \(\Delta P\) and base pressure are reached. Whichever is reached first will then initiate override action.

A convenient way of determining maximum column \(\Delta P\) is from the equation:

\[
\Delta P_{\text{max}} = 1.2 \Delta P_{FS} \tag{9.5}
\]

where \(\Delta P_{FS}\) is the flowsheet value of \(\Delta P\). This is based on the common practice of designing columns such that the flowsheet value of boilup is about 80 percent of the boilup that would cause flooding. The factor of 1.2 gives a \(\Delta P_{\text{max}}\) just short of flooding. For determining maximum permissible pressures for overrides and interlocks, consider four pressures:

- Relief valve set pressure, \(P_{RV}\)
- Interlock set pressure, \(P_{IN}\)
- Override set pressure, \(P_{OR}\)
- Normal operating pressure, \(P_N\)

A convenient way of setting \(P_{IN}\) and \(P_{OR}\) is to let

\[
P_{IN} = P_N + 1/2 (P_{RV} - P_N) \tag{9.6}
\]

and

\[
P_{OR} = P_N + 1/4 (P_{RV} - P_N) \tag{9.7}
\]
Minimum Steam Flow Controller

As liquid level rises from 75 to 100 percent, override A5 closes the feed valve. At a level transmitter output of 15 psig, A5 has an output of 3 psig. With steam/feed ratio control, this would also cut off steam. But it is desirable to maintain enough boilup that the trays (sieve or valve) do not dump or weep. For this we provide an override (not shown) that is a minimum steam flow controller. In most cases we have found it advisable to adjust override biases so that a high level pinches feed before steam.

Miscellaneous Column-Base Overrides

The base system contains two more overrides. During startup A4 holds the tails valve closed until base composition reaches a desired value. A6 closes the steam valve if base temperature becomes too high.

It should also be noted that the bottom-product valve may be closed by an override from the next process step. The bottom-product pump is operated automatically by switch S2, which turns the pump on whenever the base level transmitter increases above 6 psig.

9.9 Automatic Startup and Shutdown

Two kinds of startup and shutdown are commonly encountered, depending on whether the column base is full ("wet") or empty ("dry") when the column is shut down. As will be seen, wet column startups and shutdowns are much faster. The same basic override system permits automatic startups regardless of whether they are wet or dry. It should be noted that no formal program or sequence control is necessary. Instead, as soon as steam and feed are available, the column comes on line at the maximum speed permitted by the constraints. Depending on circumstances, a column may or may not follow the same sequence of constraints from startup to startup.

Wet Column Startup

If a column is shut down by closing the steam and drawoff valves, the entire column contents accumulate in the lower section of the column. Typically the liquid level rises well above the vapor inlet from the reboiler and up over some of the lower trays. (Some column designers prefer to provide enough space below the first tray that it can never be flooded.) Such a shutdown may be made to accommodate production scheduling or may have been forced by process interruptions elsewhere. The column may be started up again simply by turning on the steam.

As shown in Figure 9.6, an automatic startup may be accomplished with an air switch connected to a three-way, air-operated valve in the air line between the steam valve and its overrides. The "on" position corresponds to a through
connection; in the "off" position, the output of the overrides is dead-ended and the signal connection to the valve is vented to the atmosphere. It is probably preferable for each column to have its own switch, but a master switch can be used to start a complete train.

The adjustable lag box (commonly an inverse derivative unit, or, in electronics a first-order lag or integrator) is so hooked up that when the switch is positioned to "operate," the steam valve opens slowly. When the switch is moved to "shutdown," the steam valve is closed immediately.

With all controls on automatic, including condenser cooling-water controls not shown in Figure 9.6, the operator pushes the switch to "on." The steam valve immediately begins to open slowly, and continues opening until the column ΔP override pinches it a little. It stays at a partly open position until dropping base level closes it further. The column feed valve stays closed until falling base level permits it to open. Eventually decreasing low boiler concentration in the base permits the bottom-product valve to open and be controlled by base level. Column-base composition is then controlled by throttling the steam valve.

In the meantime inventory is starting to build up in the reflux drum. The column stays on total reflux until overhead composition is satisfactory and reflux drum level has risen high enough for the overhead composition controller to take over the reflux valve. Since this procedure permits maximum possible steam flow with only one or two constraints, it is the fastest possible procedure for getting a column on line. In addition, since each column in the train starts with adequate initial inventory, it is not necessary for downstream columns to wait for upstream columns to get started. This procedure, therefore, puts a train on stream much faster than does a dry column startup.

To shut down a column or train, it is only necessary to switch the master switch to "shutdown"; this shuts off the steam, feed, and drawoff valves. Liquid then drains down into each column base. This procedure has worked well for small columns, say, 6 feet or less in diameter. For larger columns there have been some cases where the lower trays were damaged. It is probably safer, therefore, before startup to pump column-base contents down to a level well below that of the bottom tray. In doing this one should also allow for displacement of liquid from a thermosyphon reboiler; once boilup has been established, most of its tube volume will be vapor.

Some plants have spare or utility tanks that can be used as temporary reservoirs for excess column-base contents.

**Dry Column Startup**

In this case, the columns have little or no inventory, top or bottom. Startup of the train is accomplished by turning the master switch to the "operate" position. As before all controls are initially on "automatic." The steam valve starts to open as soon as base inventory builds up. All controls then operate as indicated previously. Since, however, the second column cannot start until
it begins to get feed from the first, it may take a long time to get the whole train going.

Shutdown is accomplished by shutting off feed to the first column. Each column then automatically works its overhead and base inventories down to the lower 25 percent zone. At this point the operator must exercise manual control of the bottom product and steam valves to work column inventories down to very low levels. When this has been done, the columns may be shut down by switching the master switch to "shutdown."

To get everything out of the columns, as might be required for maintenance work, manual drain valves must be opened and residual column contents taken off in drums or other containers.

9.10 "IDLE" OR TOTAL REFLUX

The controls discussed are capable of operating the columns in an "idling" or total reflux condition with either a high or a low column inventory.

High Column Inventory

If, during normal operation, the bottom- and top-product valves of a column are closed manually or are held closed by a total reflux switch, the overhead and base inventories build up until the feed valve is shut off. The column is then on total reflux with the steam valve controlled by \( \Delta P \) and reflux flow set by condensate receiver level.

The column can be put back on normal control by switching the two level controls to automatic, or by the total reflux switch.

Low Column Inventory

If, during normal operation, the feed valve to a column is closed manually or closed by some upstream override, the column will work its overhead and base inventories down to the 25 percent levels and then put itself on total reflux. Normal operation is restored by putting the feed valve back on automatic, or by coming out of the override condition. Note that feed pump failure will put the column on total reflux by this method.

For total reflux a separate switch may be provided that actuates air-operated, three-way valves in the air lines to the drawoff valves. The startup/shutdown switch then controls only the feed and steam valves. This design permits the operator to put the column into total reflux, when desired, or to take it out of total reflux during startup upon ascertaining that it is proper and safe to do so.

Product Recycle to Feed Tank

To minimize the transition from total reflux to normal operation, it has been proposed to switch first from total reflux to recycling product streams
back to the feed tank. Then when the column is lined out—that is, making the desired separation—one may close the lines back to the feed and open the normal product lines to storage or the next process step. This eliminates the upset that sometimes occurs when switching from total reflux to normal operation. We are not aware, however, of any industrial applications.

9.11 MISCELLANEOUS OVERRIDES

Centrifugal Pump Bypass

At startup and shutdown, it is sometimes necessary to have a centrifugal pump running for a period of time while no product is being taken. It is undesirable, however, to "dead head" a centrifugal pump very long. Various expedients have been devised to take care of this. One popular method is to provide a bypass line with a restricting orifice. This is a low-investment design but it wastes horsepower.

Another approach, shown in Figure 9.12, uses a small valve in a bypass line. The controls are so arranged that as the flow approaches the specified

![Diagram](image)

**FIGURE 9.12**
Scheme for protecting centrifugal pump against dead heading
minimum value, a high-gain relay opens the normally closed bypass valve. This
is not an override in the normal sense since no signal selectors are needed. The
high-gain relay should have hysteresis or detent to prevent chatter.

If the bypass line cannot be connected back to a tank or receiver as indicated,
but must be connected to pump suction, a cooler should be installed in it to
prevent overheating. If a flow measurement is not available, the high-gain relay
can be set to open the bypass valve as the normal valve approaches the closed
position.

**Overrides for Maximum Capacity**

Where it is desired to be able to run a column or train at maximum capacity,
certain additional overrides may be needed.

A. **Entrainment Override**

With the previously discussed system, the limitation on any one column is
the maximum permissible column $\Delta P$ that was taken to be a known, fixed
value. For some columns, however, as one increases feed rate slowly and before
flooding starts, a plot of top composition, $x_D$, versus reflux flow, $w_R$, shows a
maximum value of $x_D$ at a particular reflux rate as shown by Figure 9.13. To
put it another way, at some high feed rate, an increase in reflux flow will cause
a decrease in overhead purity, $x_D$. This is so because the increase in entrainment
offsets the effect of increased reflux. This usually occurs at a column $\Delta P$ considerably
higher than the nominal maximum permissible $\Delta P$. It should be noted, however,
that the peak of the $x_D$ versus $w_R$ curve does not occur at fixed, reproducible
values of $x_D$, $w_R$, and $\Delta P$. By measuring $x_D$ and $w_R$ and computing $dx_D/dw_R$,
one can devise an override control system that maintains a positive value of
$dx_D/dw_R$ by pinching the steam or feed valve. This would replace the $\Delta P$
override. Implementation is shown in Figure 9.14.

B. **Limited Utility Override**

If the condenser or reboiler limits before the column proper does, one may
use either the cooling-water valve position or steam-valve position for override
purposes. Generally, for good control, it is not desirable for valves to go more
than 95 percent open or less than 10 percent open, except on a momentary
basis. Overrides may be provided such that if either valve goes beyond this
value, the feed valve is pinched slowly until the utility control valve’s position
is back to a reasonable value. This requires a slow-acting override incorporating
a proportional-reset or floating controller. A particular arrangement is shown
in Figure 9.15.

For highly integrated plants, it may be necessary to protect the utility supply
during startups. In “bootstrap” plants, for example, it may be necessary during
wet startups to avoid putting such a demand on the steam header as to reduce
header pressure seriously. One automatic approach is to connect header pressure
to overrides on the reboiler steam valves to close them partially as header
pressure drops. A possible hookup is shown on Figure 9.16.
FIGURE 9.13
Effect of entrainment on overhead composition

FIGURE 9.14
Entrainment override
C. Automatic Balancing of Condenser and Reboiler Heat Loads

If the condenser and reboiler do not have balanced heat-transfer capability, one of them will limit before the other does as feed rate increases, provided the column itself does not limit first. One way of balancing these two heat exchangers on pressurized or vacuum columns, thereby permitting maximum column capacity, is to feed the steam valve and cooling-water valve positions into a summer with gain whose output becomes the "set point" of the column pressure controller as shown in Figure 9.17. Note that a high limiter holds signal $A$ constant for cooling-water-valve loading signals greater than 4.2 psig and a low limiter holds $B$ constant for steam-valve loading signals less than 13.8 psig. The summer bias, $C$, then becomes the pressure controller normal set point.

If, for example, the condenser cooling-water valve opens wider than the steam valve, and if its loading signal is less than 4.2 psig, the summer or "balance" controller calls for a slightly higher column pressure to increase condenser heat transfer.

The column and auxiliaries, of course, must have adequate static pressure ratings, and the required range in pressure must not be so large as to cause adverse changes in relative volatility.

9.12 DESIGN CONSIDERATIONS

It is probably apparent that most overrides are really feedback control loops. They therefore are subject to stability considerations. In many cases they are also subject to truly hard constraints, as, for example, maximum column-base pressure. Since any feedback control system must have some room within which to work, the overrides must be so designed that the process does not normally approach the hard constraints too closely.

In the case of overrides with proportional-only action, we can visualize, as shown in Figure 9.18, a zone between hard and soft constraints. The width* of this zone is determined by the override loop gain, which is limited by stability considerations. With a proportional control loop designed for dead-beat response, there is a unique relationship between the value of the manipulated variable and the distance between the process variable and its hard constraint. The manipulated variable always reaches its maximum (or minimum) value before the process variable exceeds its hard constraint. The soft constraint will correspond to the minimum (or maximum) value of the override output. The takeover point between normal and override controls will be at a variable position (depending on operating conditions) somewhere between the hard and soft constraints.

* It is very helpful to think of this zone as a fraction of the measured variable transmitter span.
FIGURE 9.15
Limited utility override on feed
FIGURE 9.16
Steam header pressure protective override

FIGURE 9.17
Control scheme for balancing condenser and reboiler heat loads
9.13 OVERIDES FOR SIDE-DRAW COLUMNS

We will conclude this chapter with a brief discussion of some of the overrides that may be encountered on side-draw columns. We will choose, as an example, the column of Figure 9.19. This is a purification column in a solvent-recovery system. A small amount of low boilers must be removed overhead, and a small amount of high boilers must be removed as bottom product. Most of the feed is taken off as sidestream. Following are the most important overrides.4

1. High and low feed-flow limiters are set according to the required column turndown (ratio of maximum specified feed flow to minimum specified feed flow); see Figure 9.20. Increasingly we are putting the limiters in the set-point channel instead of as shown.

2. Low base temperature or low top temperature holds all drawoff valves closed (Figure 9.21). Usually a gain 6 override is adequate, but this really depends on column composition dynamics. The function here is to hold the column on total reflux until overhead and base compositions are nearly correct. On-stream analyzers would permit a better job here.

3. High column ΔP or high base pressure closes the steam valve. A proportional-reset controller is usually necessary here. Typical gain is 0.5 and reset time is usually 20–40 seconds. Since column dynamics are about the same for either variable, only one controller is necessary if the two transmitters are scaled to have the same gain. A high selector chooses between them. All overrides for the steam valve are shown in Figure 9.22.
FIGURE 9.19
Flow rate controls for composition control
4. For columns with a sidestream vapor drawoff, it is necessary to maintain a minimum vapor flow up the column above the drawoff point. As shown by Figure 9.23, this is accomplished by calculating the total vapor flow from the reboiler from the steam flow, and subtracting the sidestream vapor flow to get net vapor flow up the column. This signal becomes the measured variable to a proportional-reset controller whose set point is the minimum vapor flow called for by the column designer. The output from this controller goes to a low selector in the path between the base level controller and the sidestream drawoff valve. If, then, calculated vapor flow up the column becomes less than required, the override controller closes the sidestream drawoff valve just enough to force the required additional vapor up the column.

5. For columns with a sidestream liquid drawoff, it is necessary to maintain a minimum liquid flow down the column below the drawoff point. As shown by Figure 9.24, this is accomplished by subtracting the sidestream drawoff flow from the estimated internal reflux to calculate the net liquid flow down the column. If this flow is insufficient, the override controller pinches back on the drawoff valve until the downflow becomes adequate.

**FIGURE 9.20**
Feed flow system
FIGURE 9.21
Low temperature overrides for drawoff valves
Steam valve overrides

**FIGURE 9.22**

Application of Protective Controls to Distillation Columns
FIGURE 9.23
Override for minimum vapor flow up column
FIGURE 9.24
Override for minimum liquid flow down column