Central Lines

For $\bar{X}$: $\bar{X}' = 35.00.$

$n = 5$:

For R: $d_2\sigma' = 2.326\ (4.20) = 9.8.$

Control Limits

$n = 5$:

For $\bar{X}$: $\bar{X}' \pm A\sigma' = 35.00 \pm (1.342)\ (4.20),$ 40.6 and 29.4.

For R: $D_2\sigma'$ and $D_1\sigma'$ = (4.918) (4.20) and (0) (4.20), 20.7 and 0.

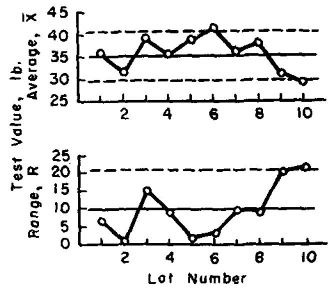


FIG. 11.—Control Charts for $\bar{X}$ and R. Small samples of equal size, $n = 5$; X', σ' given

RESULTS.—Lack of control is indicated by results for lots Nos. 6 and 10. Corrective action is required both with respect to averages and with respect to variability within a lot.

not that the range is so good, it is that the standard deviation is so poor for small samples.

The Control Chart method of Quality Control is a method of keeping track of the variations in the mean value and the degree of scatter from the mean. The procedure is to take samples of relatively small size—from 4 to 10 usually—and determine the mean and the range on each sample. The samples should be of the same size, and since the size is small, the range is a good measure of scatter. Values for a group of such samples are given in Figure 10.

In setting up the graphs upon which such values are plotted, it is very helpful if the scatter about the mean value has been determined previously. One can then enter the tables provided in the manual and draw charts as shown in Figure 11.

By observing the location of the points on such charts, one can determine whether the operation is aimed at the right mean value and whether the deviations from this value are under control. Since the limits are 3σ limits, the chances of a properly handled sample being out of limits by sheer chance are only 3 in 1,000. For this reason the out-of-limit values are an indication of lack of control.

Basic Theory of Automatic Control

C. W. BOWDEN JR., Minneapolis-Honeywell Regulator Company, Industrial Division, Philadelphia, Pennsylvania

DURING the past half century the chemical industry in the United States has been one of the nation's prime examples of the continuing evolution of industrial technology. New processes have been introduced, new products have been produced, and, perhaps even more significant, ever greater manufacturing efficiencies have been attained. Sometimes when we look back that far, statistics get a little fuzzy. In the case of the chemical industry the changes and developments since the turn of the century have been so revolutionary that statistics back that far would be virtually meaningless. Let's look at just the last 15 years. This period in itself presents a revealing picture.

C. W. Bowden Jr.

The volume of production in the chemical industry in the year ending April 1953 totaled more than $19 billion, as contrasted with less than $4 billion in 1939. This is a 190% increase in volume. If we adjust for price changes, etc., it means that today's physical volume is three times what it was 15 years ago.

Obviously this hasn't been accomplished simply by the influx of hordes of additional workers. Actually, if we go back to our statistics, we see that employment is less than twice that of 1939.

The chemical industry has reached this volume by encouraging and accepting technological advances, by introducing new continuous methods of production, and by the continued application of more and more automatic instruments to help control these operations. With the new technology today's chemical plant worker turns out some $26,000 worth of material while his 1939 counterpart could produce only $15,000 worth. This is a pretty impressive growth picture, is it not—to have happened in only 15 years?

The oil and fat industry can take a bow also for its segment of the chemical industry has had parallel progress. Not to go into another statistical study, there is one basic comparison which fully illustrates the growth of the soaps, fats, and oils industry. In prewar days the United States annually imported some 1.3 billion pounds of fats and oils. Today the industry's progress is reflected in the fact that the United States is a net *exporter* of 1.1 billion pounds.

This change has resulted from a number of factors. There has been the increase in production of domestic oil-bearing materials and the effect of wartime dislocations. But one of the major factors has been the continuing development of solvent extraction methods. Today's techniques harness a multiplicity of industrial instruments to control these processes.

For example, at the Glidden plant in Indianapolis the processing of soybeans is accomplished by matching improvements in equipment with the application of new control techniques. These recording and recording-controlling instruments made by Honeywell maintain close watch over the process variables. The instruments thus contribute efficient operation of the continuous extractor, eliminating the hazards and expense of solvent loss while increasing the yield of high-quality, reproducible end-products.

We all realize that this rapid change-over to continuous operation has not been confined to any particular branch of the chemical industry. It has been industry-wide and is being further accelerated by economic conditions. The large growth of markets, the scarcity of qualified operators, and the rising labor costs have compelled all producers to seek maximum efficiency. Usually highest efficiency is found in continuous processing, and it is nearly always possible to produce a superior product at lower costs in a continuous plant.

The change from batch to continuous method causes some very significant changes in operational procedure. In a batch plant changes are relatively slow. A good operator can often handle a batch with a minimum of instruments. Because of the slow rate of reaction, minor errors in temperature or pressure tend to average out and may not have too serious an effect on product quality.

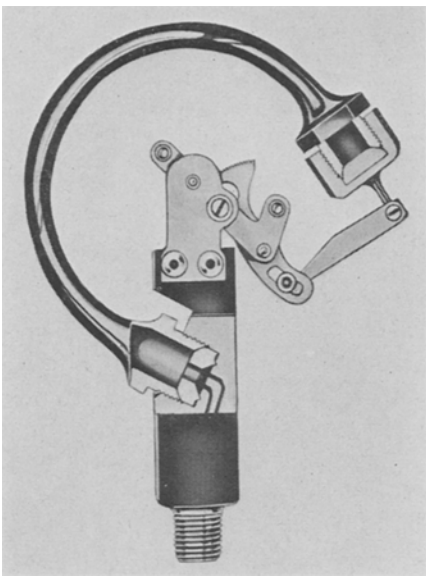


FIG. 1. Bourdon tube for measurement of high pressure.

Continuous processing is vastly different. Reaction time is short! All the components of the final product move rapidly through the process equipment. Any material which passes through the plant when all of the variables are not at correct values is sub-standard and may spoil a large quantity of product. There is no time for averaging out! Every important variable must be held constantly within the permissible limits. Such control tolerances could not be held without very precise measurement, and it is doubtful whether the most highly trained technician could operate the process manually, even with the best of measurement. Accordingly automatic control is essential and is widely utilized. As a result, side reactions are inhibited, separations are more complete, and product quality is higher and more uniform.

Proof of these facts is readily available. Statistically speaking, the percentage of total plant investment devoted to instrument purchases since 1930 has increased nine times. This is in spite of the fact that instrument prices have risen much more slowly than those of most other process equipment. Evidence that the process industries (chemical and petroleum) have contributed heavily to the increased use of automatic control can be seen from current sales to these industries. Of all the instruments sold, more than 40% are bought by chemical producers and oil refiners.

Because industrial instruments and automatic controllers have assumed such an important place in the oil and fat industry, the basic principles regarding their correct usage should be a part of the operating knowledge of every technical man.

Instrument Measuring Systems

A study of instruments should, of course, start with measuring systems. I shall briefly describe the various systems most widely used.

Although the types of measurements made in modern industrial plants add up to a very sizable number, industrial instrumentation is based upon a small group of the most commonly required quantities. Included are temperature, pressure, flow, and liquid level. Each of these variables can be measured in several ways. I shall describe only the most conventional means.

Depending upon the instrument range, pressures are measured by a Bourdon tube, a spiral, or a spring loaded bellows. In higher ranges, above about 4,000 p.s.i.g., the Bourdon tube, as shown in Figure 1, is most frequently used. Below 4,000 p.s.i.g., down to about 15 p.s.i.g., the spiral, as shown in Figure 2, is the most satisfactory element. Because the spiral is, in effect, a series of Bourdon tubes connected end to end, it is more sensitive than a single Bourdon.

For ranges of 15 psig and less, neither the Bourdon tube nor the spiral provides enough power to operate all the functions of a recording automatic controller. To obtain sufficient torque a bellows is used. In general, the lower the instrument range, the larger the bellows. The bellows is also easily adaptable to compensation for ambient pressure, where absolute pressure measurements are necessary. Compensation is obtained by an additional evacuated bellows operating in conjunction with the measuring bellows as shown in Figure 3.

The simplest temperature measuring device is the pressure type of thermometer (Figure 4). This instrument utilizes a metal bulb connected by a capillary tube to a pressure-measuring element in the instrument case. The fill expands or contracts as bulb temperature varies, this changes the internal system pressure in proportion to temperature change. The

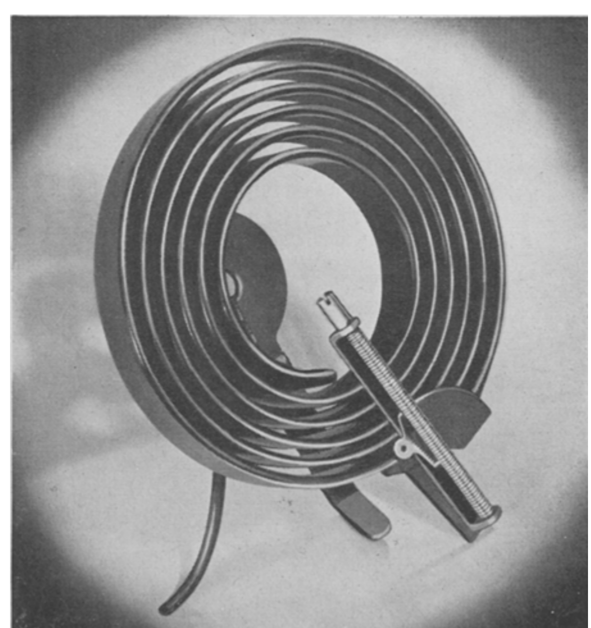


FIG. 2. Spiral for pressure measurement.

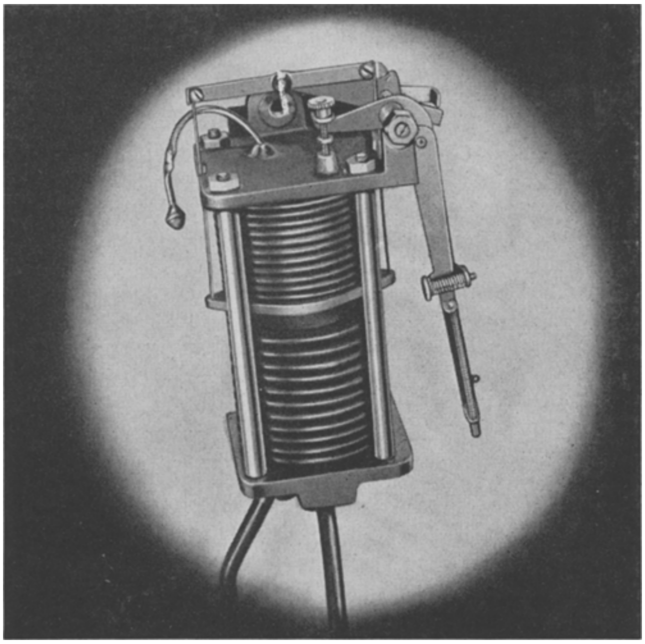


FIG. 3. Absolute pressure measuring unit.

pressure is calibrated in terms of temperature. Thermometers are filled with an inert gas, mercury, or some other liquid. One variety of thermometer, called the vapor-fill type, is partially filled with a volatile liquid. The vapor pressure of the vaporized fluid over the liquid increases as temperature increases. Because vapor pressure increases in proportion to the square of the temperature, this instrument utilizes a square root or non-linear scale. The wide graduations of the upper portions of the range give increased readability and often improve automatic control.

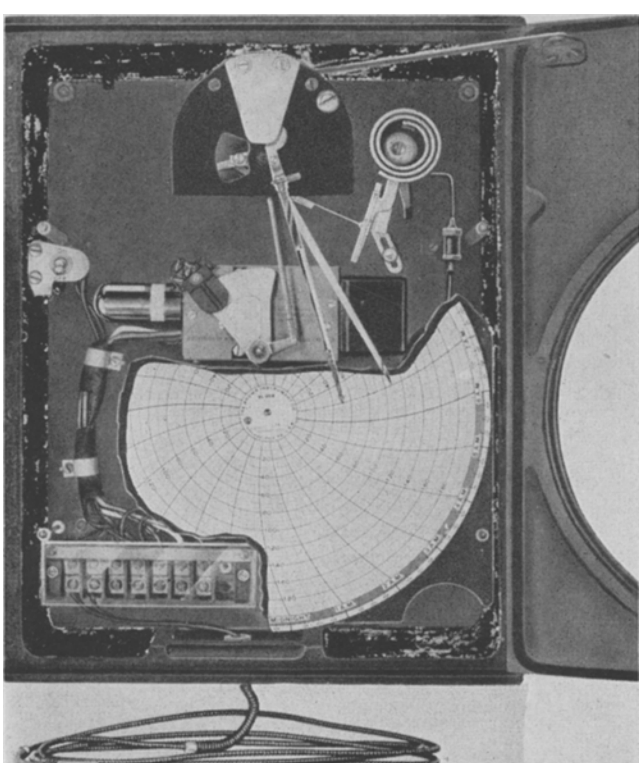


FIG. 4. Pressure type thermometer including electric control unit.

Some users however object to the non-linear calibration and the fact that inversion causes instability when the measured temperature reaches ambient.

Thermometers are supplied with ranges up to 1,200°F. but are most frequently used for measurement of temperatures below 600°F. Usually for temperatures above 600°F. a thermocouple is employed. The thermocouple can be connected to a millivoltmeter, or calibrated galvanometer, if about 1% accuracy is sufficient and if narrow ranges are not needed.

For higher accuracy and narrower ranges, the thermocouple is used with a potentiometer, as shown in Figure 5. The majority of potentiometers in use

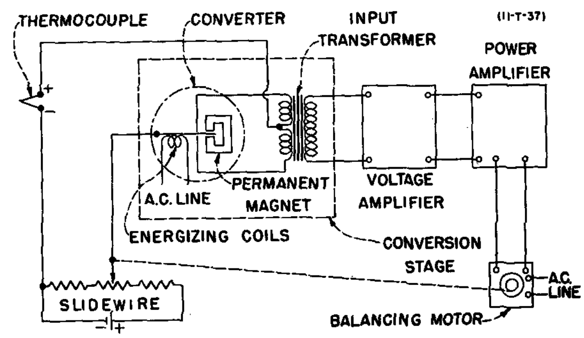


FIG. 5. Schematic diagram of ElectroniK Potentiometer Circuit.

today are of the electronic self-balancing type. Because of the accuracy, versatility, and dependability of these instruments, they have become very widely used for temperature measurement in all ranges. Thermocouples are low in cost and are easy to install. The extension leadwires to the instrument are not so subject to damage as thermometer capillaries, and, if damaged, the wires can be easily spliced.

Where very narrow temperature spans must be measured, the resistance thermometer is the most practical answer. The bulb, or temperature sensitive element of this kind of thermometer, is a coil of wire which changes its electrical resistance as temperature changes. The instrument is usually a self-balancing wheatstone bridge.

The electronic self-balancing potentiometer, or wheatstone bridge, is today one of the most widely used instrument types. Any measurement which can be transduced into an emf or a resistance can be recorded or controlled by these devices. Among the variables which are measured by such systems are pH, conductivity, pressure, load, speed, electrical power, and a great many more.

Flow is most often measured by means of a differential head meter. Some means of introducing a temporary pressure differential in the flowing medium, such as a venturi tube or thin plate orifice, is placed in the flow line. Pressure taps located to sense the differential are connected to a manometer which is calibrated in terms of flow (see Figure 6). Both mercury manometers and diaphragm differential pressure measuring devices are commonly employed.

Flow may also be measured by differential area meters such as the Rotameter. A few other highly specialized devices are used for measuring flows where unusual conditions exist.

Liquid level measurements differ, depending upon whether the vessel to be measured is under pressure or exposed to atmosphere. In open tanks the pressure

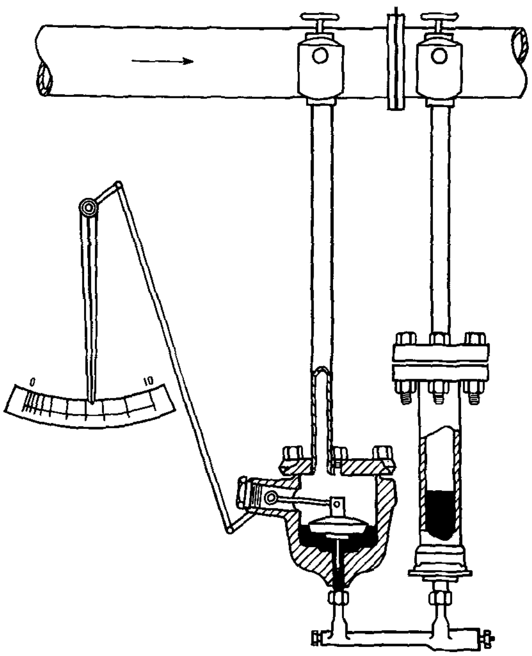


FIG. 6. Schematic representation of Mercury Manometer Flow Meter.

head of liquid gives a direct indication of level. Where it is convenient, the pressure gauge is connected to the base of the tank. If this is not practical, a tube is immersed into the tank to a point below minimum level. Air is passed slowly into the tube and bubbles up through the liquid. The back pressure of air in the tube is a measure of liquid head (see Figure 7). Where positive or negative pressure exists in a closed tank, some correction must be made to compensate for its effect on liquid head. A manometer connected to measure the differential pressure at the bottom and the top of the vessel gives the necessary compensation and produces a direct measurement of level, as shown in Figure 8.

Automatic Control

Except for the self-balancing potentiometer and wheatstone bridge, the power available in industrial instruments is somewhat limited. To operate the automatic control components therefore, it is necessary to use a minimum amount of force. The control units, both electric and pneumatic, are designed to operate with a very little drag on the measuring system.

Automatic controls are available with several different kinds of action. This is necessary in order to select the form or mode of control best suited to each individual problem. While it would easily be possible to design a universal controller, such an instrument would be far too expensive and complicated for most installations. It is far better to have the different types of controllers always available so that the simplest unit which will give adequate performance in any given application can be selected.

The great majority of modern controllers are operated either by pneumatic or by electric power. In the process industries pneumatic control is by far the most widely used. It is preferred because of its simplicity, easy maintenance, flexibility, high performance, and inherently non-hazardous means of operation.

Air Control

The output of an air controller is an air pressure rather than a quantity of air. Under balanced conditions there is no flow of air through the lines, only a pressure in the system, large enough to hold the valve at the required position against the force of the spring. As a result, a well-designed air controller should use very little air and should be very rapid in response. The response of air control actually is very

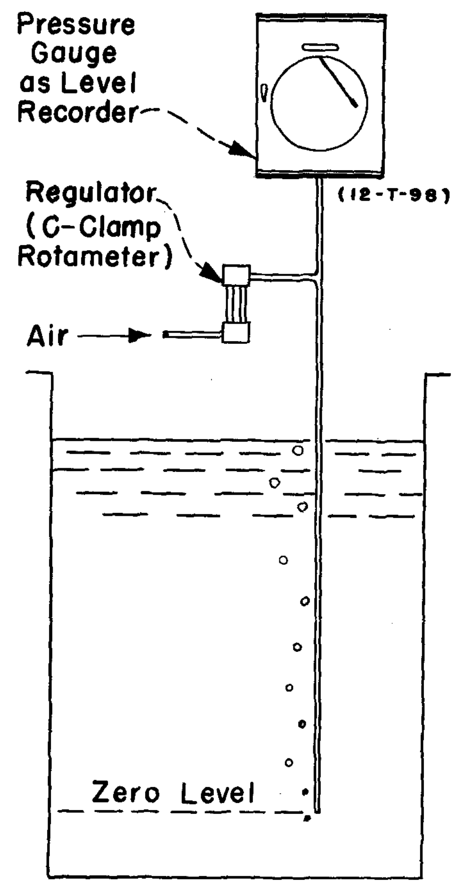


FIG. 7. Bubbler type liquid level measuring system for open tanks.

fast except where long transmission lines are used. A long line holds a fair quantity of air which is a compressible fluid. Any change in pressure produces a change in volume, and flow of air results. Because of line resistance to flow, appreciable time elapses before the system balances. Where transmission distances are less than 400 feet, the lags are insignificant. Transmission distances between 400 and 1,000 feet

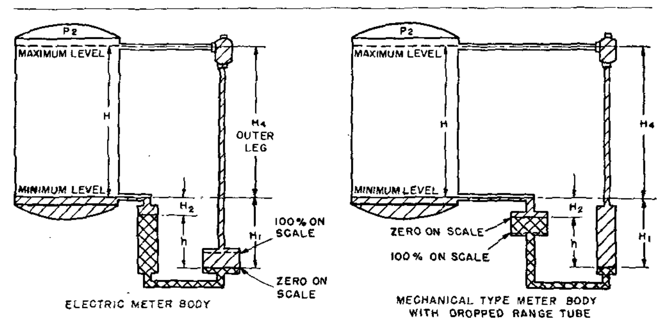


FIG. 8. Manometer type liquid level measuring system for closed tanks.

can be used if maximum speed of response is not required, but air transmission beyond 1,000 feet is generally considered impractical.

Because air controllers transmit pressure instead of quantity, they are theoretically immune to the effects of leaks in transmission lines. Actually, they can overcome the effects of small leaks in output lines, provided that the controller can deliver a greater quantity of air at the required pressure than is necessary to operate the valve and compensate for the leak. As soon as a leak occurs however, flow of air again becomes a problem. It is evident that regardless of controller capacity, if a leak is large enough so that the pressure drop introduced by flow becomes significant, the leak will seriously interfere with controller operation.

The Valve

A complete control system must include some device capable of accepting the signal from the controller and translating it into corrective action. The device usually employed for this purpose in air control systems is the diaphragm motor valve, shown in Figure 9. The valve body is essentially a globe valve with a sliding stem instead of the customary screwed stem. If the valve is a throttling type for proportional control, the disc, or valve closure, is characterized to give the required flow rate for each increment of lift.

The actuator or diaphragm motor for the valve is a spring-loaded diaphragm, which operates a push rod connected to the valve stem. The spring and diaphragm area are matched so that a change in pressure from 3 to 15 p.s.i. will cause the motor to move over its full range of travel. Thus the motor must take a definite position for each value of transmitted air pressure.

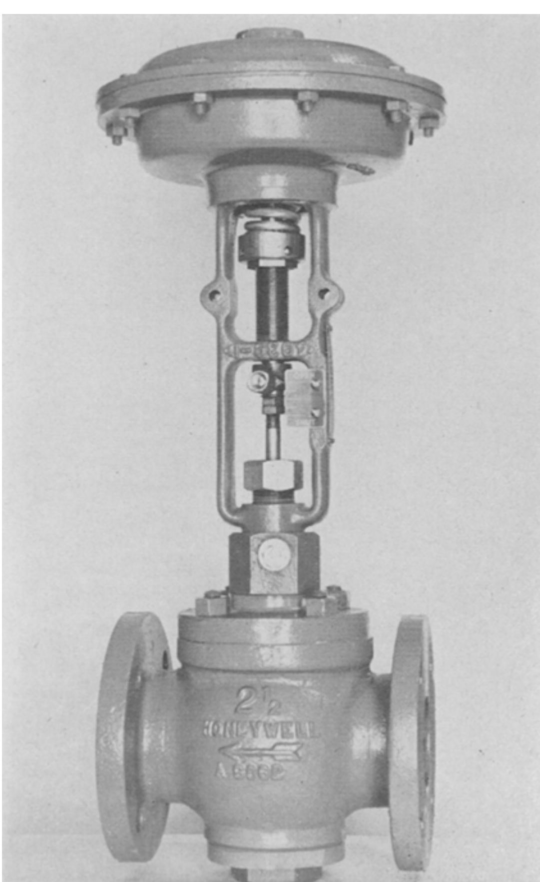


FIG. 9. A typical diaphragm motor valve.

Operation of Air Controllers

In order to utilize the various modes of automatic control most effectively, some knowledge of their operation is desirable. Because the basic principle of operation is similar in all currently available units regardless of the manufacturer, I shall describe the operation of the make I know best, namely Brown Instrument air control.

The basic idea of air control is quite simple, as shown in Figures 10 and 11. If a restriction is placed in an air line, the pressure downstream from the restriction can easily be varied by regulating the flow of air from the end of the line. The device used to regulate flow is a nozzle and flapper. The nozzle, of course, must offer less restriction to flow than the fixed restriction. If the flapper is moved away from the nozzle, the pressure downstream from the restriction drops almost to zero; when the flapper is against the nozzle, the pressure rises very nearly to supply pressure. A "T" connection between the restriction and the nozzle is the controller output connection. In most cases the controlled pressure is used to operate a diaphragm motor valve.

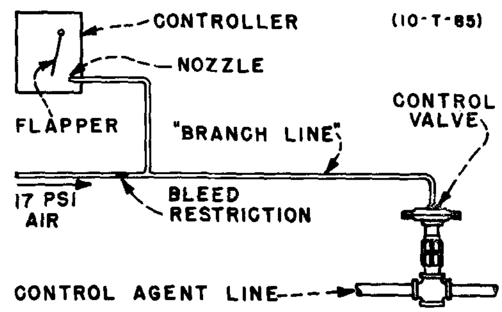


FIG. 10. A simple nozzle pressure air control system.

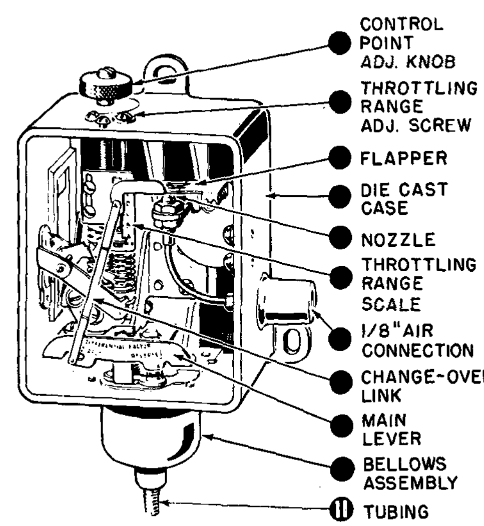


FIG. 11. Controller utilizing nozzle pressure system.

This simple type of nozzle pressure transmitter is quite widely used, particularly for non-critical applications. It is offered in on-off and narrow band proportional control, described in Figures 12 and 13.

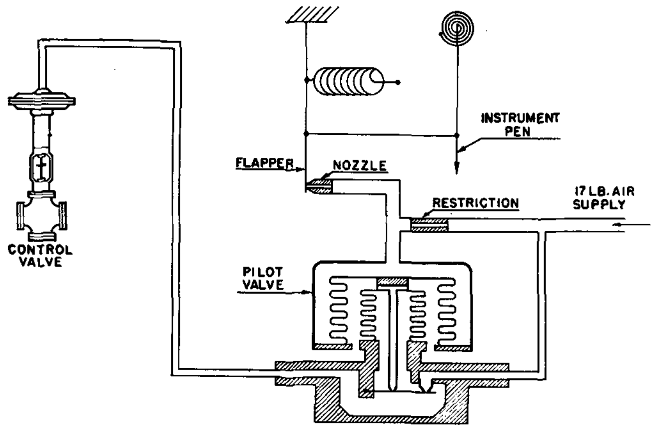


FIG. 12. Two-position pilot type controller.

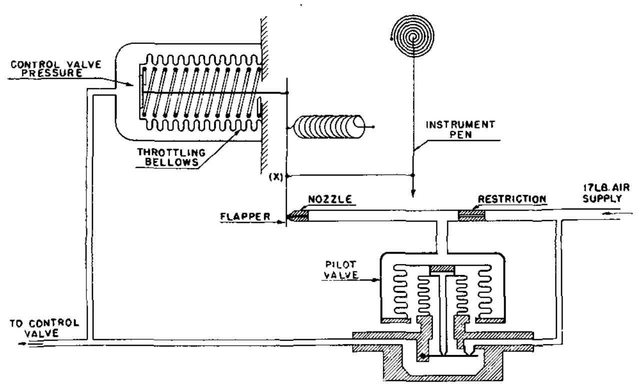


FIG. 13. Proportional air controller.

The advantages are simplicity and low cost. The disadvantages are relatively high air consumption, slow response, only fair reproducibility, and susceptibility to air line leaks because of the limited output capacity. The disadvantages are serious enough to prevent use of these controllers in most heavy-duty industrial applications.

The quality of performance needed for the majority of industrial uses is obtainable from a pilot type of controller. In this kind of controller the flapper nozzle combination operates at low pressure, from about 0.5 to 3.5 p.s.i.g. This low pressure controls a much higher pressure output, which is the same as for the nozzle pressure system, namely 3 to 15 lbs. The nozzle pressure operates the pilot. The pilot is a simple multiplying relay where two bellows of different sizes are opposed so that the force exerted by the low pressure against a large area equals the force exerted by the higher pressure over a smaller area.

The quantity of air in the nozzle system is small, the ports of the pilot are large since they need to be open only when pressure is changing. Accordingly air consumption is low, but output capacity is high and response is fast.

The Control Modes

The most important control modes in order of increasing complexity are:

Two position, or on-off
Floating
Proportional plus manual reset
Proportional plus automatic reset
Rate action which may be added to proportional control.

Floating control is seldom used in the process industries, but it is quite important for reasons which I will explain later.

Two-position control is adequate for many applications. Where measuring and control lags are small and process capacity is large, this control mode will frequently maintain the process variable within very narrow limits. Even under less favorable conditions, but where some deviation from the desired value or set-point is permissible, on-off control still may be used. Two-position, or on-off control is only occasionally employed in continuous processing, but it often does a very satisfactory job in large batch processes such as the Twitchell Process.

Two-position control produces a characteristic sine wave record. As process capacity decreases, the amplitude of the wave form increases rapidly and frequently also tends to increase somewhat. When the amplitude of the wave reaches an intolerable value, it is necessary to utilize some form of proportional control.

Perhaps the simplest method for gaining proportional action is single speed floating control. I do not know of any pneumatic floating control equipment, but electrically operated floating control is fairly widely used. It is achieved by use of a reversible motor to drive the valve. Two electric switches are used in the control instrument. One is placed just below the set point and the other just above it. The switch below the set point drives the motor in a direction to open the valve, and the other operates the motor in a reverse direction. At the set point both switches are open, and the motor remains at rest.

The principal fault of floating control is that the motor speed must be quite low to prevent driving past the set point. Any considerable process upset therefore results in a deviation of long duration. Faster speed motors cannot be employed to correct this fault because they cause the controller to cycle rather badly. The advantage of floating control is that it is not affected by "offset," and hence no form of reset is required.

Occasionally proportional speed floating control is employed. This type of control differs from single speed floating control in that the speed at which the motor turns is proportional to the amount of displacement between the pen and the set point index. Proportional speed floating control is not too widely used because the circuitry is fairly complex and because proportional plus reset control will usually produce superior results at little or no increase in original cost.

In true proportional control the position of the final control element or valve is adjusted by the controller to deliver the amount of corrective agent necessary to maintain the variable at the set point. The portion of the instrument span over which proportional control will cause the valve to move from fully closed to fully open is known as the proportional band. Usually the band width is adjustable. As an example, suppose we have an instrument with a range of zero to 100. If set point were at 50 and proportional band at 10%, we would expect the valve to be wide open at 45 on instrument scale and fully closed at 55. At set point or 50 we would expect the valve to be half open. If the proportional band were at 100%, the valve would be fully open at zero on the scale and fully closed at 100. Frequently in low capacity processes the proportional band is set even wider than 100%. When the proportional band is beyond 100%, full scale of movement of the instrument pen will not cause the valve to move from fully open to fully closed.

Another convenient term for proportional band is "gain." Gain actually is the reciprocal of proportional band. It can be defined as the ratio of amount of correction to the amount of deviation.

Where on-off, or two position control is used, the flapper takes only two positions, against the nozzle or well away from it. To obtain proportional action, the flapper must take practically an infinite number of intermediate positions. The wider the proportional band is, the more precisely must the flapper be positioned. Furthermore the total travel of the flapper to change output pressure from 3 to 15 p.s.i. is only about three-thousandths of an inch.

If it were necessary to adjust the flapper from only a single point, any lost motion in linkage would be completely intolerable. Even if we could manufacture parts with zero tolerances, costs would be entirely prohibitive so some alternate expedient must be utilized to set the flapper position. The method actually employed is a "feed back" arrangement, which has several distinct advantages.

In the first place, by adjusting a relatively long flapper from two positions, each adjustment can be large enough so that the small amount of lost motion in the linkage becomes inconsequential. Secondly, adjustments are made from two sources which tend to cancel out all lost motion. The third advantage is probably most important; the feed back bellows actually measures controller output. Any errors in output are measured and quickly corrected.

In the proportional controller the feed back unit has a calibrated spring and bellows unit which is practically identical to a pressure-measuring element. The output air from the pilot valve (the same pilot as in the on-off controller) is measured by this spring and bellows unit, which then positions the flapper fulcrum in accordance with output pressure.

The differential linkage, which mechanically detects the difference between the pen and set point index, positions the flapper from its free end. Highly accurate operation is assured by this arrangement. Actually two forms of the proportional controller are available. The simpler of the two permits adjustment of the band from about 1 to 10% of instrument span. A more complex unit is precise enough to permit setting the proportional band as wide as 150%.

From the preceding discussion it should be evident that for every position of the instrument pen within the proportional band, there will be a distinct position of the control valve. If reset were not provided in proportional controllers, the valve would always be half open when the instrument pen was at the set point. This would be a very inconvenient arrangement. For example, if we had a temperature controller set at 150° and for some reason had to raise the set point to 250°, it is obvious that the same valve at the same percentage opening could not supply the additional heat necessary to maintain the higher temperature. The result would be that the controller would finally line out at some value below the set point. The difference between the set point and the actual controlled value is called "offset" or "droop."

Reset is the adjustment which permits the proportional band to be shifted with respect to the set point. Adjustment of the reset therefore changes the position taken by the valve when the instrument pen is at the set point and consequently eliminates offset.

Automatic Reset

Offset or droop results when set point changes are made. Other conditions also result in offset. These are known as load changes. In temperature control problems, changes in ambient temperature, drafts of air blowing against the vessel, changes in the quantity of the material being heated, or in the specific heat of the material, changes in the heat content of the corrective agent, such as steam pressure or BTU value of fuel, are all examples of load changes. Particularly in continuous processes such load changes occur frequently or even constantly.

Where the load changes tend to be small and process characteristics are such that a narrow proportional band can be used, the offset may be small enough to be negligible. With wide proportional bands, load changes are much more serious. Because they occur so frequently, manual reset adjustments are unsatisfactory. Automatic reset is required.

Automatic reset is actually proportional speed floating control superimposed onto proportional control. Proportional speed floating control tends to drive the valve in a direction to return the instrument pen to the set point. The speed of the action is proportional to the amount of deviation. In automatic reset control the action is to move the proportional band rather than the valve, but the net result is the same. To describe the action of these controllers, we can say that a proportional controller corrects according to the size of the deviation. Automatic reset corrects according to the duration of the deviation.

Reset is calibrated in repeats per minute, or the number of times the proportional action is repeated in either direction, in one minute by reset action. In other words, the effect of proportional action is duplicated by reset, and the number of duplications per minute is the number of repeats per minute.

The operation of an automatic reset controller is somewhat more complex than that of a simple proportional controller and is perhaps a little more difficult to understand. In the Brown Air-O-Line unit reset is obtained by liquid action. Whenever a deviation occurs, proportional action immediately starts to correct for it. As a result of the changed output pressure, the follow-up bellows assumes a new position. The inner spring then exerts a pressure difference

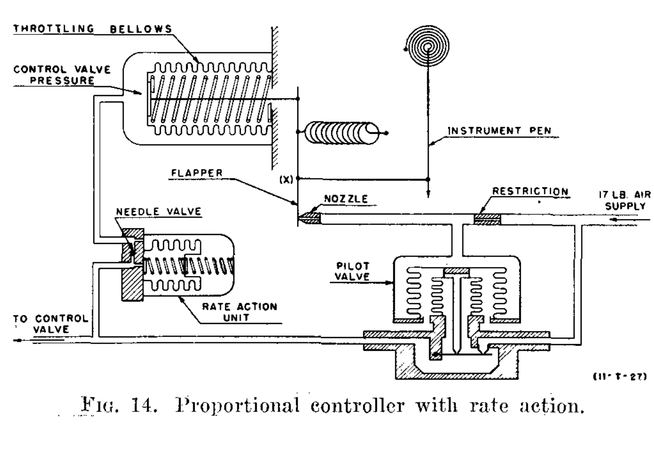


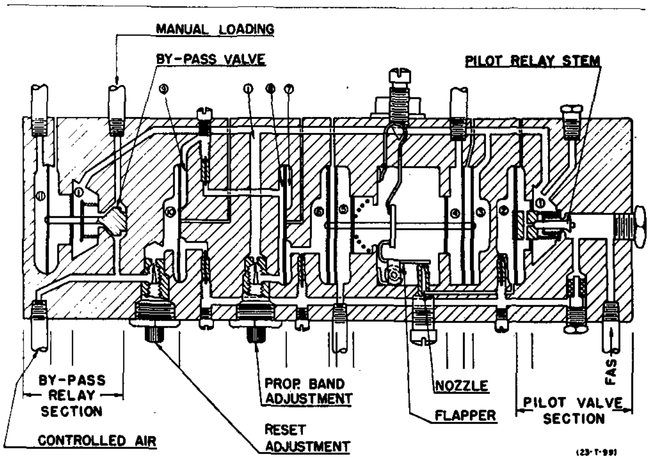
FIG. 14. Proportional controller with rate action.

upon the liquid fill in the two sections of the unit, causing the liquid to flow through the connecting passage until pressures are again equalized. The flow of liquid tends to return the flapper fulcrum to a central or balanced position. This changes the relationship of the position of the follow-up bellows to that of the flapper position so that the controller is able to balance out at any output pressure which will maintain the pen at the set point. The key to understanding this kind of control is fairly simple. The two separate actions, proportional and reset, continue to change the output pressure separately and independently until the instrument pen returns to the set point. Balance can be restored only when the controller is "lined out." If the pen is not at the set point, the output pressure cannot remain at any particular value.

Reset rate is set by adjusting the needle valve in the connecting passage until the liquid flows at the necessary rate to give the desired number of repeats per minute.

Heat exchangers usually require proportional plus reset control. Although they often seem to present a simple control problem, they are actually somewhat difficult to handle because of their small capacity.

Proportional plus reset control (Figure 15) is ideally adapted to continuous operations, but it has a serious weakness in batch operation. If in a temperature control problem we start to heat a kettle from room temperature to some higher value, the valve, of course, will open to admit the heating agent. Some time will necessarily elapse as the kettle is heating to the set point. Meanwhile, because the instrument pen is not at the set point, automatic reset will shift the proportional band in a direction to hold the valve open. The reset action will continue to shift the band so long as the pen remains below the index. Often the band will be moved to the end of its travel where the valve will be wide open even though the pen is at the set point.



SCHEMATIC DIAGRAM OF PNEUMATIC BALANCE PROP. PLUS RESET CONTROLLER

FIG. 15. Tel-O-Set controller.

When the temperature finally reaches the desired value, the controller is unable to begin adjusting valve position because of the proportional band shift. The pen must therefore continue to rise well above the set point and remain above until the reset action swings the band back to its correct position. Often this takes a considerable amount of time, and product quality suffers.

Because of this action it is well to avoid proportional plus reset control on batch operations and on units where startup characteristics are important unless reset is known to be required. Frequently batch reactors are large enough so that satisfactory control can be obtained with two-position or narrow proportional band controllers. Where reset is required in batch or semi-continuous plants, it is possible to counteract the undesirable features by the addition of rate action to the controller. How this is done will be described later.

Rate Action

Occasionally control problems are encountered where measuring or control lags are so serious that proportional control will not hold the variable within permissible limits. Another mode of control called "rate action" will usually produce satisfactory results. Rate action, when used, is superimposed onto either proportional or proportional plus reset control. As can be inferred from the name, rate action or derivative control corrects in accordance with the rate of deviation. This is accomplished by a temporary over-correction. The amount of over-correction, which is called the amplitude, is a fixed quantity. The duration of the over-correction, called the rate time, is adjustable. The effect of rate action is to shorten briefly the proportional band or increase the gain of the controller.

The rate action unit is a double spring-loaded bellows, which is located in the feed back line between pilot output pressure and the follow-up bellows. The output pressure is delivered to the interior of the bellows. The confined area outside of the bellows is connected to the follow-up bellows. There is a by-pass with a needle valve connected between the two lines.

Any deviation of the instrument pen, of course, will change the flapper position which will immediately change the pilot valve output. However the rate action unit prevents the follow-up action from re-positioning the flapper fulcrum. Actually the bellows of the rate unit cause it to transmit one-tenth of the change in output to the follow-up unit immediately, and the full pressure is gradually transmitted as air leaks through the needle valve. The effect is a temporary correction about 10 times as large as would be obtained without rate action. The amplitude of the rate action therefore is 10. The rate time may be varied over a fairly wide range by adjustment of the needle valve.

The bellows in the rate unit serves the very useful purpose of regulating rate amplitude. Without it the controller output would tend to shift between 3 and 15 p.s.i. and would swing the process variable too widely.

This rate action unit produces its action after that of the proportional or proportional plus reset action. For continuous processes on stream, rate action of this variety does a very adequate job. For startup characteristics or batch operation, rate action should precede proportional plus reset action.

Rate action is sometimes called anticipatory control. This, of course, is incorrect. No control action can occur until a deviation occurs. True anticipation is impossible. Rate action does tend to anticipate the extent of the deviation however because the extent is somewhat dependent upon the speed of departure from the set point.

All of the Brown air control units operate with the identical pilot valve, use the same connecting linkage, and are easily changed by the user. Changing is further simplified because the mounting screws are the same for all units. Thus the air control system is composed of interchangeable building blocks for the convenience of the user and his maintenance department.

Miniature Instruments

All of the air control units which have been discussed are of the type mounted within the instrument case. They are operated by mechanical linkage with the instrument pen and set point pointer. The advent of miniature instruments a few years ago has resulted in the development of a new type of air controller.

The new miniature instruments are so small that it has been impractical to mount conventional air control units within the instrument case. Furthermore it has been found desirable in some cases to locate the controller as close to the valve as possible. In order to meet these conditions, new separate mounting controllers have been developed.

Obviously some new means was necessary to relay a deviation signal to a separately mounted controller. Pneumatic transmission of the value of the process variable and the set point in terms of an air pressure between 3 and 15 p.s.i. is employed for this purpose.

The Tel-O-Set controller is the Brown unit of this type. It is available in three models. The simplest variety has a fixed proportional band with adjustable automatic reset, another has an adjustable proportional band and adjustable automatic reset, and the third has an adjustable band and reset with rate action.

The most widely used model is the one with adjustable band and reset. At first glance it looks quite complex. Actually it is no more complicated than the Air-O-Line. The pilot and nozzle system in this controller are quite similar to the one used with the Air-O-Line. The next portion of the controller is known as the deviation section. It takes the place of the differential linkage and follow-up bellows of the Air-O-Line.

The deviation section is constructed so that the air pressures representing set point and process variable oppose and balance each other. Any deviation will upset the balance and cause the flapper to change its position. This, of course, will immediately result in a change in the output pressure from the pilot. All of the output pressure is fed back to the negative balancing section, but except at balance only a part of it reaches the positive or rebalancing chamber. The pressure in the positive chamber depends upon a fixed and an adjustable restriction. The difference between the positive and negative feed back establishes the amount of true proportional correction which the controller immediately delivers. This type of action permits the controller to balance out so that the set point pressure and the process variable signal are at different values.

Meanwhile the output pressure bleeds into the reset chamber, causing the pressure in the positive chamber to rise to that in the negative chamber. This, of course, keeps the output pressure changing until finally the controller returns to a balanced condition where the process variable pressure must equal the set point pressure. Only when balanced conditions exist can the controller output stabilize, but the output pressure can stabilize at any value between 3 and 15 p.s.i. so long as the set point and variable are equal.

The Tel-O-Set controller accepts a separate signal equivalent to process variable rather than a deviation signal as does the Air-O-Line. Because of this it is a relatively simple matter to introduce rate action into the process signal to the Tel-O-Set. This is actually done in the three-mode controller. The effect of rate action in this position is essentially the same as it is with the Air-O-Line. There is one important difference however.

Where rate is added to the process variable, the effect is to transmit a false signal to the proportional and reset sections of the controller whenever the variable is changing. The rate action exaggerates the amount of change. In other words, it transmits to the controller information that the deviation which has occurred is much larger than it actually is. Therefore the controller overcorrects and tends to return the pen to the set point more rapidly. Obviously rate must be very carefully adjusted to prevent throwing the process into a cycle.

This exaggerated signal is very valuable in control of batch reactions or on startup service where automatic reset is employed because the signal to the controller indicates that the variable has reached and passed the set point before it actually arrives there. This causes the automatic reset action to start shifting the proportional band in the direction necessary to avoid overshoot before the set point is reached. When a three-mode controller of this kind is correctly adjusted, overshoot is completely eliminated. The variable rises to the set point and "lines out" without over-travel. Rate action, because it is proportional to the rate of deviation, has no effect when the variable has stabilized so the controller maintains the process at the true set point.

Electric Control

Every mode of control which is available in pneumatically operated units is also available in electrically operated units although pneumatic controllers usually are available with much wider proportional bands than electric control. There are other modes commonly offered in electric forms which are not available in pneumatic. Among these are single speed floating control, which we have discussed, and timed proportional control.

Timed proportional control operates with an on-off valve. It differs from on-off action in that the relation of "on time" to "off time" is dependent upon the position of the instrument pen with respect to the set point within the proportional band. In other words, the two-position controller turns the power off when the pen is above the set point and turns it on when the pen is below the set point. The relative position of the pen and the index determines the percentage of on and off time during the preset control cycle. The cycle during which the on and off time is varied with respect to process requirements is adjustable. The proportional band is also adjustable. Time-proportional or pulse type of controllers are available with and without automatic reset.

Timed proportional control is ideally adapted to electrically heated and fuel fired processes where the heater or burner does not operate efficiently at reduced rates. This type of control is quite flexible and produces excellent results in many cases where no other mode of control is adaptable.

I shall not describe the operation of electric controls in detail. They are not too widely used in the process industries.

Selection of Controllers

Now that I have described the principles and the method of operation of the various modes of control, I would like very much to give some mathematical rules covering the selection of the best controller for every application. Such equations do exist. It is too bad we cannot use them. Unfortunately some of the terms in each equation are impossible to define.

To date, the application of automatic control to chemical processing is largely an art rather than a science. Experienced instrument men can usually select a controller which will perform adequately in most applications. The selections however are more often based upon comparison of the problem with one previously solved than on a scientific analysis of the problem at hand. The correct selection is made surprisingly often, but wrong guesses are frequent enough that a new process is seldom started without some change in controllers.

The need for developing a scientific approach to the application of automatic control is well recognized by the instrument industry. Much of our best brain power has been devoted to it for a good many years. Until recently however most of the work has been somewhat disappointing.

Previously the approach has been to make step changes in the process of the controller and to observe the characteristics of the recovery curve. It was called the transient response method. The method was fairly good for evaluating a single component of a control system but not very satisfactory for evaluating the system as a whole.

Servo Techniques

Shortly after the last war it became evident that an automatic control loop is a feed back system not too dissimilar to an anti-aircraft gut pointer or an aircraft autopilot. The systems developed for the analysis of these servomechanisms should therefore be useful for analysis of automatic controllers. A test program proved that servo theory was applicable to controllers, and today there is a great deal of interest and activity in servo analysis.

Servo techniques can become quite complex, but much of the theory is relatively simple. The basis of the method is frequency response rather than step change or transient response of earlier analytical work. Frequency response is essentially a dynamic method of analysis, which is applicable to dynamic processes.

Frequency response analyses are made by introducing a sinusoidal disturbance into a system and observing the output signal. The input disturbance is continually changing, and the output follows the same pattern. However the sine wave of the output lags the input by some increment of time, and the output signal is very likely of a different order of magnitude from that of the input. The output signal therefore shows the phase shift and amplitude difference. Studies are made at various frequencies, and the results can be reported in graphical or mathematical terms. The results are known as transfer functions.

The basic theory of the servo approach is that although each component of a control loop will have some deficiencies, the system can be designed so that the deficiencies of one unit are compensated for in other units. Knowing the transfer function of a process and those of various available controllers, it is possible to select the components to accomplish the necessary precision of control.

The fact that the servo approach is a practical method for evaluating control problems has been proved during the last few years. Our group of servo engineers at the Brown Division of Minneapolis-Honeywell have had the opportunity to evaluate several extremely difficult control problems in customers' plants. As a result of their findings, they have been able to recommend the necessary controllers for the applications studied. After installation of the instruments recommended, operating experience over considerable time has proved the value of the work. Controller performance has been completely satisfactory.

Because test results have so well justified servo analysis, we are using this technique to design the necessary performance into all of our newer instruments and automatic controls. Those instruments which have been designed on the basis of servo analysis are also proving their performance in a great many industrial applications.

Of course, at this early date the servo approach is not a cure-all. Before any instruments can be selected by this method, a thorough study must be made of the process. This is a time-consuming and expensive procedure and in some cases may be impossible because it is inadvisable to disturb some processes. Certainly however as studies are made and data collected, not only will instruments be improved, but manufacturers will produce more controllable process equipment. The rewards will be tremendous.

Even today plant designers are using automatic control quite effectively. Plants are becoming more compact as surge capacity is reduced or eliminated, safety factors are being lowered, and the plants are being operated more nearly at their ultimate capacity. It is quite difficult to estimate the savings in plant cost resulting from maximum utilization of instruments, but large savings have resulted. For example, a few years ago Procter and Gamble cited a case where $15,000 was spent for instruments which resulted in a saving of $40,000 in process equipment. There are many more similar cases, but relatively few have been publicized. The mere fact that instrument purchases have been expanding so rapidly is in itself proof of their value.

WHAT the future holds for the chemical industry is hard to predict. As I look back over the accomplishments of the last half century, there is one thing in particular that stands out in my mind. More and more I realize that the technological advancement of the industry has not been a by-product of scientific and engineering research alone—as important as this work has been. Rather, it seems to me, this tremendous growth has been the result of progressive management thinking.

True, there were strong stimulants to encourage the adoption of new techniques and the acceptance of automatic controls. There was also the high value of annual production compared to capital investment that really necessitated waste reduction and quality improvements. There was also the availability of specialists in engineering and the sciences to help translate such new concepts as automatic control. But, above and beyond all of this, there was a management philosophy that grasped the importance of these new ideas and re-directed its thinking from traditional channels to encourage the adoption of these ideas. Despite all of the other stimuli, the scientific and technological developments, the fact remains that it was not until top management was able to raise its own thinking that the old-fashioned approaches to design, to processes and process control, were made obsolete.

It is this early recognition and understanding of the basic concepts of automation by the chemical industry management that excites me about the industry's future in today's technological race. I have pointed out previously that the obstacles on the road to the ultimate in automation are not necessarily technological limitations. These obstacles involve the thinking, the attitudes of businessmen. A philosophy of industrial management must be evolved that will correlate the work of the servo engineer, the research engineer, and top management. By its past record the chemical industry's attitude is one that has established a healthy environment for the growth of the contemporary trend toward more automation.

Because and as the result of this, I believe I can envision the chemical plant of the future. It will be a structure more modern, more self-sufficient, and more efficient than we know today. It will not, for example, have two-thirds of its inventory tied up in storage tanks. I believe the application of servo mechanism techniques will eliminate the necessity for maintaining goods-in-process inventories at each stage of the production process. The servo techniques will instead maintain the proper relationships between the various production phases and will permit the system to correct the errors without disrupting the production operations. Obviously under such conditions a reservoir of goods-in-process inventories, standing idle, will not be needed to smooth over the production disruptions. I am sure that the costs of the controls will be offset by this contraction of inventories.

When will this come about? Perhaps not for 10 years, possibly even 50 or 100. The industry knows more about its coming requirements than I do. But the fact remains that newer and more critical processes will need more sensitive control equipment and more advanced concepts of automation. We are confident that we shall be ready for the problems that may arise.

Economics of Cottonseed Extraction

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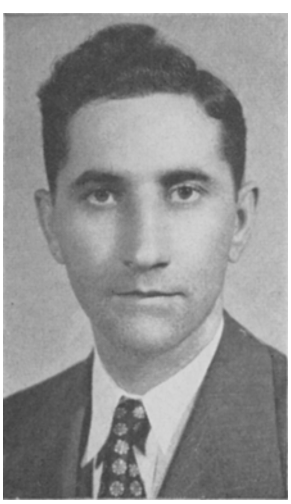
SINCE the products of the cottonseed industry are so varied and compete in fluctuating markets, any economic analysis is difficult. Furthermore a cottonseed processor is presented with several competing processes to replace hydraulic pressing. Products from each of these processes differ in appearance and other properties from present trade standards. In choosing among these processes, no processor can be guided by generalizations about economics but must take into account the nature of the seed available to him, utility and labor costs in his area, and the acceptance of products in his market. It will appear from this economic analysis that no one process has clear superiority in every situation.



Keator McCubbin

Why Solvent Extraction?

To provide a comparative background on solvent extraction, a brief discussion on economics of soybean extraction is included. For soybeans the case for solvent extraction is easily demonstrated. Solvent extraction can produce by well-established methods 351 pounds of oil per ton of beans, compared with 286 by screw pressing, and at every historical price for oil and meal there is some plant capacity above which investment in a solvent plant can be justified. Since in the soybean industry it is not customary to adjust the meal to constant protein content, the increased value of the product of solvent extraction is calculated as pounds of oil times the difference between oil and meal prices. For example, when meal is 3c a pound and oil is 12c a pound, the increased product value is 65 pounds of oil × 9c, or $5.85 per ton. This is an increase of 6.9% from an original total product value of $84.54.

For cottonseed, solvent extraction to ½% residual oil can produce 364 pounds of oil from a ton of seed, compared with 320 for hydraulic pressing and 330 for screw pressing. Since cottonseed meal is adjusted to a constant protein content with hulls, the increased value of the product is calculated as pounds of oil times the difference between oil and hull prices. With meal at $60 per ton, oil at 12½c per pound, hulls at $20 per ton, and linters averaging 7½c per pound, the gross product value per ton of seed from hydraulic pressing is $85.61, from screw pressing $86.76, and from solvent extraction $90.67. Percentagewise the increase from hydraulic pressing to solvent extraction is 5.9%, and from screw pressing to solvent extraction 4.5%.

When compared in this way, the soybean and cottonseed pictures are not much different, and the same basic incentive exists which has led to almost complete adoption of solvent extraction of soybeans. There is no need to demonstrate to this audience that the major variable in this picture is the price of oil, or, more accurately, oil less meal in the case of soybeans and oil less hulls in the case of cottonseed. For cottonseed, the meal generally leaves solvent plants with 10 to 12% moisture as compared with 7 to 10% moisture in meal from hydraulic or screw press plants. The moisture in raw cottonseed usually averages about 7½%. Therefore a cottonseed solvent plant