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AGRICULTURAL MATERIALS HANDLING MANUAL

PART 5 CONTROL

SECTION 5.1

CONTROLS AND INSTRUMENTATION

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AGRICULTURAL MATERIALS HANDLING MANUAL

PART 5 CONTROL

SECTION 5.1

CONTROLS AND INSTRUMENTATION

The Agricultural Materials Handling Manual is produced in several parts as a guide to designers of materials handling systems for farms and associated industries. Sections deal with selection and design of specific types of equipment for materials handling and processing. Items may be required to function independently or as components of a system. The design of a complete system may require information from several sections of the manual.

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FOREWORD

There is often no clear distinction between devices which are used for control and those used for instrumentation. This section of the *Materials Handling Manual* covers both instrumentation and control. Instrumentation and control are dealt with separately, except at the point where the information on both appears relevant to the development of the control system.

There are many ways to control the various operations found in materials handling systems. Some control methods may perform the function better under a particular set of circumstances than alternate methods. Most control alternatives should appear at one point or other in the following material. It is then the task of the system designer to put together the control system needed.

Where possible, the descriptions are written in the language of switching circuits.

Additional information is included in an appendix.

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SECTION 5.1 CONTROLS AND INSTRUMENTATION

5.1.1 INTRODUCTION

Controls and instrumentation are the key to successful operation of a materials handling system. The controls and instrumentation may be simple or complex, ranging from a single on-off switch to a sophisticated computer.

Instrumentation provides information to be used to control the process. This information may be provided to the operator or to the control system or to both. Instrumentation might be used to show motor current or voltage, the level of material in bins, or the throughput of the system.

The control system does just what its name implies — controls the operation of the materials handling system. If the control system requires complete surveillance while it functions, it is termed manual. However, if, except for initiating the control sequence, the system will function by itself, repeating the control sequence as needed, the system is termed automatic. If part of the control sequence requires surveillance but the rest does not, the system is termed semi-automatic. The control sequence is that chain of events that occurs between initiation and completion of control.

5.1.1.1 Language of Control Systems

Each science has a set of words or terms which have a different than normal meaning when applied to that science. The science of switching circuits is no exception. In addition, this science uses a mathematics which helps with the understanding and the design of switching circuits. Some knowledge of the terms and the mathematics is particularly helpful since some of the hardware names are borrowed from the language. The language is more descriptive of circuit operation.

5.1.1.1.1 Circuit Names

Suppose you have a series circuit controlling an auger motor comprised of the motor starting switch and the grain sensor. Diagramatically, it would appear as shown in Figure 5.1.1.1.

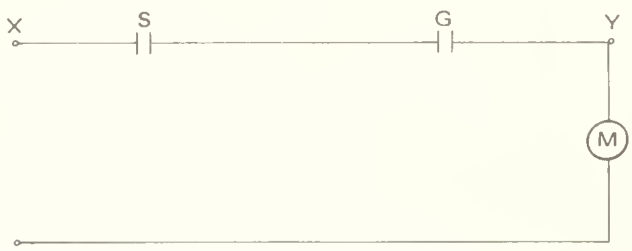


Figure 5.1.1.1 Series circuit

What happens in the path between X and Y determines the circuit operation.

Both the starting switch S and the grain sensor switch G must close before the motor will start. In other words, both S and G must be closed.

In another system, a parallel circuit (Figure 5.1.1.2), either the starting switch S or the thermostat T must be closed before the fan motor will run.

The key to the first circuit, the series circuit, is the fact that switches A AND G must be closed. The key to the second is that either switch S OR T must be closed (or both). Thus, in this language of switching circuits, a series circuit is called an AND circuit and a parallel circuit an OR circuit.

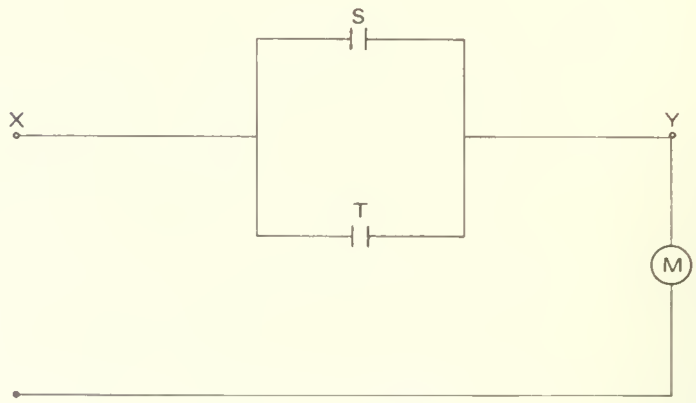


Figure 5.1.1.2 Parallel circuit

5.1.1.1.2 Truth Tables

The truth table is useful in working with switching circuits. The table gives the conditions required to complete the circuit to the action devices. In the truth table for the AND circuit the column S designates the positions for switch S, column G the positions of switch G, and, the column marked True shows when a true or through circuit exists between the points X and Y.

Truth Table for the AND Circuit

S	G	True
F	F	F
F	T	F
T	F	F
T	T	T

F = False (switch in off position)
T = True (switch in on condition)

Truth Table for the OR Circuit

S	T	True
F	F	F
F	T	T
T	F	T
T	T	T

Switches have either of two conditions; they are either off or on. Instead of F or T, the symbolic figures of 0 and 1 are often used to denote an off or on condition. The 1's and 0's do not have any numerical significance.

It should be noted that there are two types of OR circuits. In the previous example the circuit will be true if either switch S or T is closed and it will certainly be true if both are closed. This is called an inclusive OR since a true condition is possible when both are closed and is included in the truth table. The switches used have only one on position and are single pole single throw switches.

There is another single pole switch which, depending on its position, provides two on positions. Switch R is an example (Figure 5.1.1.3).

There exists an on condition either between points 1 and 2 or 1 and 3. Again the key word is OR but this time it is an exclusive OR since the possibility of both conditions being true at the same time is excluded. An exclusive OR condition exists in the statement, "The car is black or white". The inference is that it cannot be both at the same time.

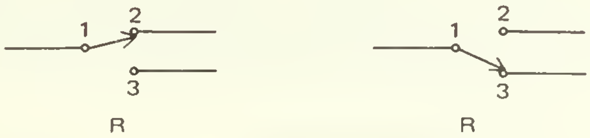


Figure 5.1.1.3 Exclusive OR

5.1.1.1.3 **Switch Designations**

A single letter is usually used to designate a switch. An example is the letter S used in a previous example. There are two variations used with this system of single letter identification.

1. If the switch is a single pole single throw or its equivalent (has either an on or off condition) the S indicates the on or 1 condition and S′ indicates the off or 0. S′ is said either as "S prime" or "NOT S".
2. If the switch is a double throw type then S indicates one on position and S′ indicates the other. Switches may be manually or electro-magnetically operated (relays). If the switch (SPDT) is part of a relay, S represents the current path that is closed when the relay is deenergized and S′ the path that is closed when the relay is energized (Figure 5.1.1.4).

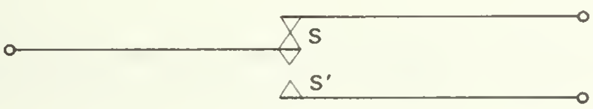


Figure 5.1.1.4 Relay contact designations

A further modification occurs with a relay (Figure 5.1.1.5). The capital letter designates the coil and the small letter the condition of the double throw contacts. T = 0 states that the relay coil is turned off; T = 1 that the coil is energized; T, the condition of the normally closed points and T′ the condition of the normally open section. Both T and T′ may equal 0 or 1.

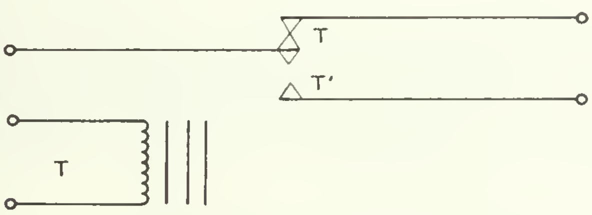


Figure 5.1.1.5 Relay designations

5.1.1.2 **Mathematical Expression**

The foregoing circuits can be expressed mathematically. The AND circuit is given as S.G or simple SG (expressing multiplication). The OR circuit is S + T (addition). The mathematics can often be used to simplify the transmission function T. The transmission function states all the control circuit paths, i.e. all the paths between X and Y.

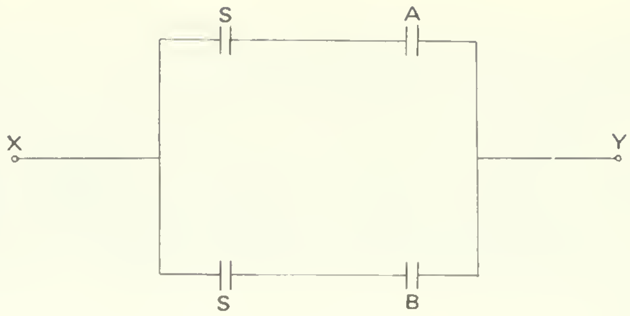


Figure 5.1.1.6

In Fig. 5.1.1.6 the path between X and Y is then: T = SA + SB (Note that the two sections marked S both operate together.)

Normal algebra would suggest that T could be simplified to: T = S(A + B). The new circuit would be as shown in Figure 5.1.1.7.

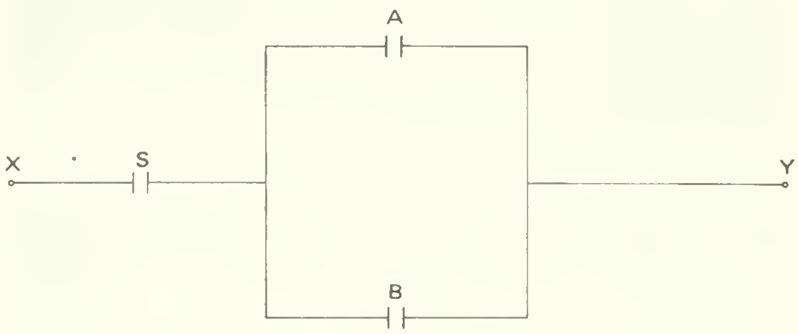


Figure 5.1.1.7

This second circuit performs the same function as the other but requires one less switch. One more example will show further mathematical simplification. Suppose the circuit in Figure 5.1.1.8 was analyzed.

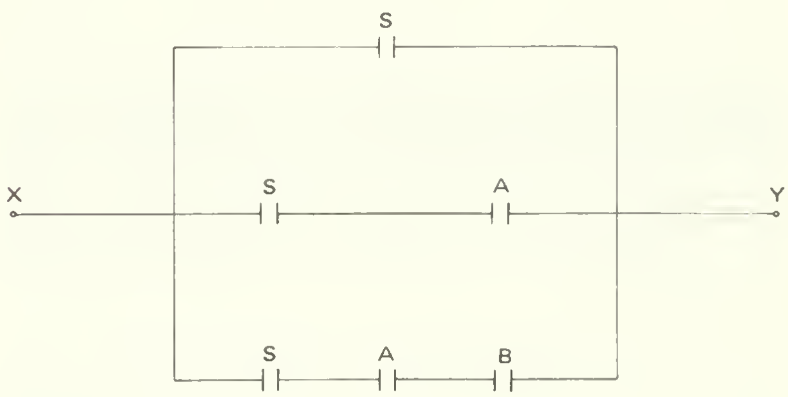


Figure 5.1.1.8

T = S + SA + SAB.

Simplified mathematically

$$T = S(1 + A + AB)$$
$$T = S(1 + A(1 + B))$$
$$T = S(1 + A)$$
$$T = S$$

This is not as obvious from the algebra as is the first case. However, when 1 appears in the expression as it does in this case within the brackets it indicates a continuous on condition regardless of the state of the remaining switches A and AB. When that happens, all the expressions within the brackets equal 1, i.e. $1 + A + AB = 1$ and the expression disappears.

The 1 from the expression $(1 + A + AB)$ or from the truth tables is referred to as logical 1; the zero as logical 0. Some rules for adding the logical 1's and 0's are: $0 + 0 = 0$, $1 + 0 = 1$, $0 + 1 = 1$ but $1 + 1 = 0$ with a 1 to carry. As an example, if 0110 is added to 0100 the result is 1010.

$$\begin{array}{r} 0110 \\ 0100 \\ \hline 1010 \end{array}$$

It is again emphasized that these are not numerical 1's and 0's. The logical 1 may actually be several volts or pascals (pounds per square inch) or any other signal value. Logical 0 may likewise be several volts or pounds but less than the value denoted as logical 1. Logical 0 could also be zero volts or negative volts. The rule is that it be less than the value used for 1.

Some mathematical rules that are used with switching circuits and that are different from standard algebra are shown in Figures 5.1.1.9 and 5.1.1.10. If a circuit occurs where two switches perform the same function, the rule shown in Figure 5.1.1.9 holds.

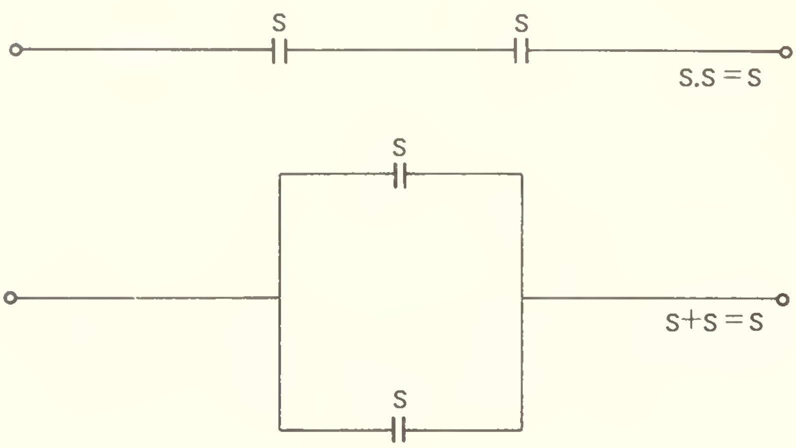


Figure 5.1.1.9

However, if the sections are part of a double throw switch, then the rules shown in Figure 5.1.1.10 hold.

Observations will show that the AND circuit in Figure 5.1.1.10 can never be turned on and the OR circuit cannot be turned off.

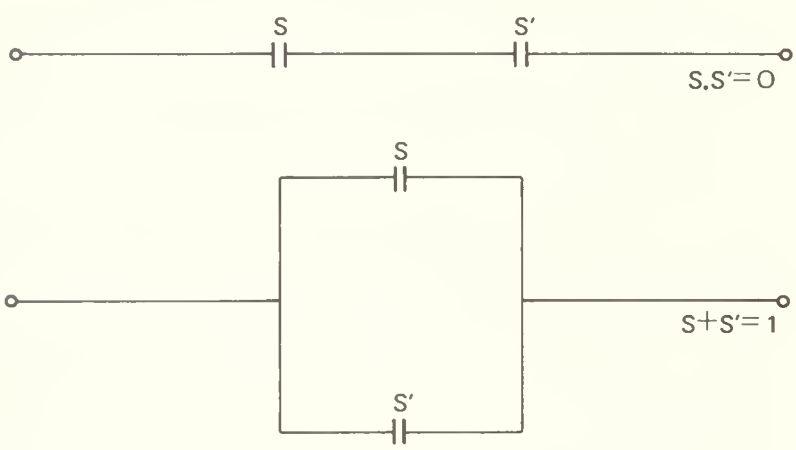


Figure 5.1.1.10

Some switching circuits can become very involved and the resulting transmission statements (functions) complex. These are simplified as much as possible through the use of boolean algebra. Graphical and/or other mathematical procedures may be used to reduce the circuits. One of these graphical methods uses Karnaugh mapping. Further rules of boolean algebra and an example of Karnaugh mapping are included in the appendix.

5.1.1.3 Solid State Devices

5.1.1.3.1 Gates

Other devices (solid state) are available that perform exactly the same functions as single pole single throw switches. These devices operate similarly to relays. A signal activates the device to turn it on. However, most units have several inputs. The unit may turn on if any one input is activated; others require that all inputs be activated before an on condition exists. Such devices are called gates. If one input activates the gate, it is called an OR gate. If all inputs are required, the gate is an AND gate. Gates replace parallel and series circuits.

Figures 5.1.1.11 and 5.1.1.12 illustrate symbols for the gates.

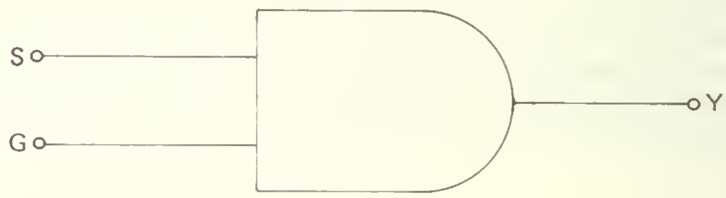


Figure 5.1.1.11 AND gate. A signal must exist at both S AND G to provide an on condition at Y.

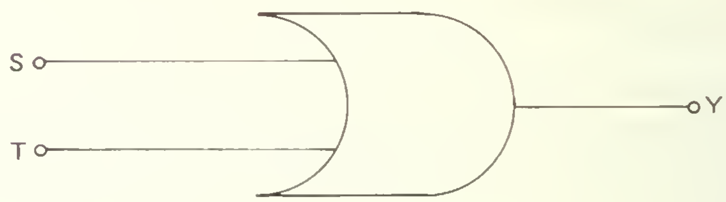


Figure 5.1.1.12 OR gate. A signal must exist at either S OR T (or both) to create an on condition at Y.

Negative gates are often used. The negative gate simply inverts the incoming signal so that logical 1 becomes logical 0 or vice versa. Negative gates are often used with other solid state devices such as AND and OR gates. This results in Not AND and Not OR circuits commonly called NAND and NOR respectively. These gates are created by incorporating an inverter or NOT circuit into the output of the gate (Figures 5.1.1.13 and 5.1.1.14).

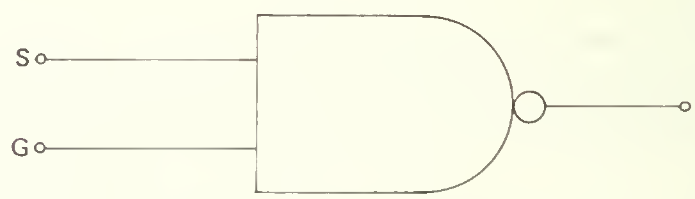


Figure 5.1.1.13 NAND gate

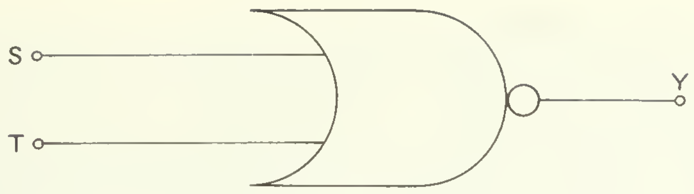


Figure 5.1.1.14 NOR gates

Truth Tables

NAND				NOR		
S	G	T		S	T	T
0	0	1		0	0	1
0	1	1		0	1	0
1	0	1		1	0	0
1	1	0		1	1	0

A control system can be built using logic devices instead of the older mechanical type of hardware. It will be an assembly of AND, OR, NAND, NOR and NOT devices as required.

The most common types of gate used are the negative gates. By using these and employing rules of boolean algebra AND, OR and NOT circuits can be produced as well as the negative NAND and NOR.

5.1.1.3.2 Flip Flops

There are other logic circuits. One often used is the flip flop circuit. This is a sort of double circuit which will turn on with a signal input but will not turn off until a second input signal arrives, hence the name flip flop. Because of this flip flop action, flip flops are often used as counters providing a division by two to incoming signals. If several flip flops were arranged in series, any division by two or multiples of two is possible. In fact, by feeding back counts from some of the later stages to earlier stages, division by any number, even or odd, is possible.

5.1.1.3.3 Integrated Circuits

Solid state devices may be combined to create a specialized unit. This combination or integrating of circuits creates the so-called integrated circuit (IC). Some combinations are more commonly used than others.

Some integrated circuits themselves have been integrated into larger combinations. These are called medium scale integrated circuits (MSI) or for some still more complex integrations large scale integrated circuits (LSI). These latter become the heart of calculators and computers. Integrated circuits are often referred to as chips.

In spite of the seemingly endless variety of logic circuits, there is much in common about them. For one thing, logic circuits are divided into families. Members of the same family are compatible with each other. No interface is needed to inter-connect units to form a specialized control system. Terms like TTL are used as family names. All TTL logic circuits would be compatible with each other - TTL means transistor transistor logic. Another is I^2L logic (from integrated injected logic).

However, there is other compatibility between various families. Most families operate on 5 volts. All come in one of several standard packages. Standard sockets are available for these packages.

5.1.1.3.4 Clock Pulses

Because of manufacturing tolerances, the speed of switching (or changes of state) is variable between units. To counteract this indefinite speed, control pulses are used to control the time of changes in state. The control pulses occur at preset intervals and are called clock pulses. All changes in state occur in response to the clock pulse and not at random as they otherwise would.

The basic control system reacts to an input signal and starts the control sequence in response to the input. The system also provides an output signal to the device being controlled - the motor for example.

5.1.1.4 Types of Control Signals

Signals may be of two general types - a ramp or a step signal. Both are illustrated in Figure 5.1.1.15.

Turning on a switch to supply power to a device would create a step signal since up until time $t = 0$, no voltage is present. At time $t = t_1$, all the voltage is suddenly present creating the step.

Some systems react to a steadily increasing signal input called a ramp input because of its shape. At some preset level, the control sequence begins. In this case, the ramp input has been converted to a step signal by the control system. In a water system, the pressure switch is subjected to the steadily increasing water pressure. At a preset value, the pressure switch suddenly acts to cut power to the motor. Later, as the ramp reverses and decreases in value, the switch acts at some point in response to the steadily decreasing signal (pressure) to create the on signal to the pump motor. With both types of signal, the reaction to the inputs can be reversed, i.e. turn off when the signal is present or when, in the case of the ramp, the ramp reaches a preset value.

The presence of a signal is often designated by a 1 (one) and the absence of a signal by a 0 (zero). The 1's and 0's in no way designate a numerical value. Sometimes when a signal is present at the input, the input is said to be high. When no signal is present, the terminology used is that the input is low.

For simplification, the change from one state to the other (the on to off transition) is assumed to be instantaneous. The only time that a control system designer would be concerned with the transition state (the in between state) is when the outcome of the transition might be different from time to time if one component acted faster some times than at another. The actual outcome would then depend on which closed (or opened) first. Such a situation is a race condition. A race condition occurs with relays. It is not usually a problem with solid state devices if clock pulses are used. Unless one is deliberately designing some sort of roulette game such a race situation must be guarded against.

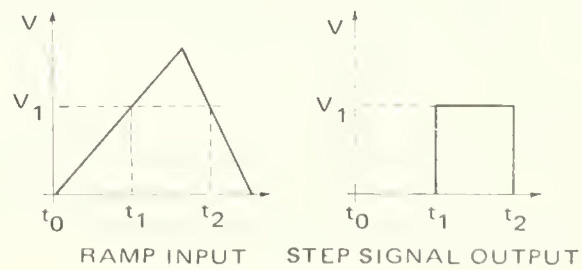


Figure 5.1.1.15 Control signals

Like the input, the output signal may be digital (step) or proportional (ramp). The more common output is digital. The output is either all present or is not present without an in between state.

Some control systems produce a proportional signal wherein the amount of output changes proportionately with a change in input. The change may be either directly proportional or inversely proportional.

The control system may modify the output signal with respect to the input. The modification may be: amplification; inversion; time-delay. The output may be single ended, i.e. be directed to a single controlled device, or it may be multi-ended and supply control to several devices. Control is then sequential.

However, in some systems, the output signal may be different at different times in response to a change in input signal, i.e. one type of input will produce a particular output but a little later in the control sequence the type of output may change.

5.1.1.5 Control System Sections

All control systems are comprised of three sections or sub-systems:

1. the pilot device;
2. the decision device;
3. the action device.

The pilot device initiates the control sequence.

The decision device decides if the control sequence can proceed.

The action device causes the controlled action to commence.

As an example, suppose the control system controlled the motor of a grain auger intended to fill a grain bin. The pilot device would be the starting button that actuates the magnetic motor control. The decision device would be the sensor that detects the presence of grain to be elevated. It would 'decide' if the control sequence could proceed. If grain were present, the magnetic controller - the action device - would close supplying current to the motor.

In a simpler system, all three devices, pilot, decision and action, would be one and the same unit as for example, a manually operated on-off motor switch. Here the pilot and action device are the same device; the decision device would be the overload detection units and the human operator. However, in complex systems, there may be more than one single section to the pilot, decision or action devices.

5.1.2 CONTROL COMPONENTS

5.1.2.1 Control Switches

Most control systems use magnetically operated switches (relays) to make and break current. Control switches are then used to make or break the current to the relays which are themselves the action devices.

Depending on their location in the circuit, control switches are the pilot or decision devices. Pilot devices are in OR circuits. Decision devices are in AND circuits. Some devices which may be pilot devices in one circuit become decision devices when used in another.

5.1.2.1.1 Push Buttons

Push buttons are used to control magnetic contactors. The push buttons (there are normally two to a set - start and stop) may be located on the enclosure containing the motor starter or may be mounted in a separate enclosure. When mounted separately the assembly of push buttons and enclosure is referred to as a push button station. There may be more than one station for control from separate points if required. Indicator lights are often used with push buttons.

Requirements for Push Button Stations

Local wiring ordinances will state the location of the station with respect to the unit being started. It (the station) must, for example, be within sight of the unit and there may also be further limits with respect to distance. Additional stations or special stations may also be required by wiring ordinances. As an example, a key operated stop button may be required for a silo unloader. The key is removed from the stop button when the unit is being moved or serviced in the silo. With the stop button locked open, the unloader cannot be accidentally started.

Types of push buttons are given in Table 5.1.2.1.

5.1.2.1.2 Snap Action

These are switches, the switching mechanism of which operates with a very small travel distance and hence the name snap action. As soon as pressure is released from the actuating mechanism the switch returns to its original contact position. The switch bodies are compact and the switch operating mechanism may be of a variety of types.

These switches are generally part of the decision section of the control system, often being used directly as limit switches, level controls and in other positions. They may be wired normally-on or normally-off. Normally-on means that when the switch is quiescent, i.e. with no pressure on the operating part, the switch is on. These switches usually control the action device which supplies current to the motor or solenoid.

Button operated snap action switches often are the operating part of the switches designed to perform special functions such as: limit switches; pressure switches; bin fill switches; level switches.

Solid state replacements are available for snap action switches. These have the same mechanical appearance as to size, mounting and actuation. The circuit is operated by a plunger driven magnet. There are no contacts. Limits of operating voltage and current depend on the device.

5.1.2.1.3 Limit Switches

These are special snap action switches used to limit something, be it travel of a feed bunk mechanism or other similar devices. The snap action switch is mounted in a weatherproof enclosure and operated by an external mechanism such as a plunger or a lever arm.

5.1.2.1.4 Pressure Actuated Switches

Pressure or lack of pressure from some medium is used to actuate the pressure switch. When pressure reaches a predetermined level, the switch is actuated. Unless designed for a specified purpose, the switch contacts will

TABLE 5.1.2.1 Types of Motor Starter Push Buttons

Function		Indicators		Types of Buttons		Enclosures
Start-Stop Start-Stop-Reverse Start-Stop-Reverse-Jog Stop	→	With or Without Indicator Lights	→	Flush & Extend Knob Operated Wing Lever Mushroom Head Lock Push Buttons Selector Push Buttons Rocker Arm Operated	→	NEMA Type 1 Type 4 Type 7-9

TABLE 5.1.2.2 Snap Action Switches

Contact Arrangements	*Current Ratings at 125/250 VAC	**Nominal Sizes in mm (Inches)	Operating Mechanism
SPST	3 amps 125 VAC only	19.8 x 9.1 x 6.35 (.78 x .36 x .25)	Button
DPST	5 amps	10.4 x 15.8 x 10.4 (.41 x .625 x .41)	Push Button
	10 amps	45.7 x 16.3 x 16.3 (1.8 x .64 x .64)	Lever Arm
	15 amps 20 amps		Lever Arm with Roller

*Not all contact arrangement available in all ratings
**Size varies with current rating

be of the exclusive OR type and thus can be connected normally-open or normally-closed as desired. Double contacts are available.

Some pressure switches deactuate as soon as the pressure changes in the opposite direction. Other pressure switches have an adjustable hysteresis effect closing at one pressure and opening at a different pressure. This is typical of the pressure switch of an automatic water system.

Solid state pressure switches are available.

5.1.2.1.5 Proximity Switches

This type of switch is actuated when an object comes within a preset distance of the sensor. One use in a materials handling system would be to sense the presence (or lack of presence) of material in order to begin or discontinue the materials handling process.

5.1.2.1.6 Reed Switches

As the name implies, these switches are small reeds usually enclosed in a sealed tube. Switch configuration is either normally on, normally off or exclusive OR. Actuation of the switch is by magnetism. These switches have low current handling capabilities.

5.1.2.1.7 Selector Switches

These are rotary switches of one or more poles and several positions. A selector switch switches a particular function to one of several circuits or conversely, selects one of several functions for one circuit. An example is a hand-off-automatic selector switch which might be used for a ventilation system. In the off position, the fan is turned off. In the hand position, the fan runs manually, i.e. continuously. In the automatic position, the fan operation is controlled by a thermostat. (Figure 5.1.5.1)

5.1.2.1.8 Thumbwheel Switches

Thumbwheel switches are special rotary switches with the actuator turned 90° from the standard position. These may appear as single or multiple side by side units. Each switch may have several positions but 10 is the usual number. The switch mechanism is moved by the thumb and as the switch is moved, a visible number changes to indicate the position. Thumbwheel switches are often used to call up specific items. For example, a single thumbwheel switch moved to position 6 might cause the bin filler to move to bin 6. Two switches, side by side, set to 1 and 4 to indicate the number 14, might be calling for 14 units of a particular material to be added to a mixture.

5.1.2.1.9 Electro-chemical Switches

These switches are actuated by the presence of a liquid. Generally two contacts are placed so that they can come in contact with the liquid. If the liquid level is high enough to submerge the contacts, the switch is actuated. Internal switch contacts will be of the exclusive OR type to allow connection as normally-on or normally-off.

5.1.2.1.10 Level Switches

1. Liquid Level

Float Switches: These sense liquid levels. Contacts will be of the exclusive OR type. Float switches may or may not have a hysteresis effect. Hysteresis is required if the switch is required to start the refilling process when a minimum liquid level is reached and to stop the process at the higher level. Ordinarily, the amount of hysteresis would be adjustable to allow different liquid levels to be set.

Electrical: A pair of contacts is exposed to a liquid. When the liquid level reaches the contacts a circuit is completed. As a result, either a relay may operate or a circuit be completed to a logic device. If a second contact, or pair of contacts, is placed at another elevation, the two sets of contacts can be used to control a liquid level in the container. The amount of hysteresis is controlled by the difference in elevation between the two sets of contacts. This hysteresis may be adjustable or may be fixed. This depends on the mounting method used for the contact assemblies.

2. Material Level
Sometimes it is necessary to know the level of materials in a bin. Pressure switches or proximity switches located on the bin wall at the appropriate heights detect the presence of the material at that level. The output signal from the switch(es) enters the control system to provide the required control.

5.1.2.2 Electro-mechanical-relays

5.1.2.2.1 Contactors

There are relays intended to make and break circuits with high currents. Their contacts are usually of the type found in Figure 5.1.3.1. Motor starters are contactors to which overload sensors have been added. Sizes are given in Table 4.1.1.16. There may be contacts for up to four poles.

5.1.2.2.2 Stepping Relays

In this type of relay, each time a signal is inputted the relay moves (steps) to a new position as part of a cycle of steps. This cycle begins repeating after the last step. If this were a 10-step relay stopped at step 5, it would take 9 steps to reach step 4.

5.1.2.2.3 Time Delay Relays

See time delay switches 5.1.4.3.

5.1.2.2.4 Solid State Relays (SSR)

The word relay is a misnomer since no moving parts are used. The device performs the same function as a relay. Instead of mechanical components solid state devices controlled from a separate power source are used to switch currents on and off to the unit being controlled. Voltages and currents to the controlled unit may be up to 480 VAC and 20 amperes.

Solid state relays may have a virtually unlimited lifetime if operated within their ratings. Current switching should be done at the instant the current sine wave crosses zero current (zero crossover). The relay must be mounted on a heat sink to dissipate heat. The relay being solid state is encapsulated which protects it but also makes it impossible to inspect as would be true for a magnetic relay. Most solid state relays are TTL compatible to allow use with that type of integrated circuit.

One other disadvantage of the SSR is that if the load currents drops to a few milliamperes the device may turn off unlike the mechanical relay which stays turned on.

Surge current is generally limited to 8 to 10 times full load current for one cycle. Solid state relays tend to cost much more than mechanical relays but prices are being reduced.

5.1.3 MOTOR STARTERS

The most widely used circuit in materials handling systems is the motor starter circuit. Although these are called motor starters, the units can be used to control and supply current, within their capabilities, to devices other than motors. Some examples are solenoids, lights, and heaters. Basic circuits are described in the following sections.

The basic motor starter is a complete control system in itself and is comprised of three subsystems of pilot, decision and action devices. The pilot system is the part, electrical or mechanical, which starts the control process. The decision device is the overload sensor. The action device is the set of contacts which close to supply the motor current.

There are two types of motor starters, namely manual and magnetic. The difference is in the method by which the motor current contacts are closed. Manual starters are the simplest but are available for smaller size motors. They are complete in one enclosure and control the motor from one location only. Magnetic starters are more complex and are available for all motor sizes. They may occupy several enclosures and provide control from several locations.

5.1.3.1 Manual Motor Starters

Current to the various components of the materials handling system is controlled by a manually operated switch. An arc occurs across contacts as an inductive circuit is opened. To reduce the effects of the arc, the contacts must be opened as quickly as possible. The speed of opening is increased by the use of springs and by using double contacts as shown in Figure 5.1.3.1.

Figure 5.1.3.1 Typical double contact arrangement for starters

In alternating current systems, the reversing of current direction in each cycle assists in breaking the arc. This does not occur with DC and thus switches have a lower current rating when used on DC.

Manual switches are available up to 7½ hp sizes at 440 to 600 volts in a variety of CEMA enclosures (see Table 4.1.18, Section 4.1). Included in the motor starting switch is the motor overload protection which will interrupt the current if the motor overloads.

Manual switches, besides those for starting and stopping single speed motors, can also be obtained for two speed control and for reversing motors.

5.1.3.2 Magnetic Motor Starter

In this type of starter the motor current contacts are closed and held closed by magnetic force. Double current carrying contacts as used in the manual starters are utilized in the magnetic motor starter.

5.1.3.2.1 Operation

From Figure 5.1.3.3, M is the magnet coil of the contactor which operates the normally open switches W, X, Y and Z.

1. The magnet coil will be energized if the normally open start button is pressed AND the normally closed stop

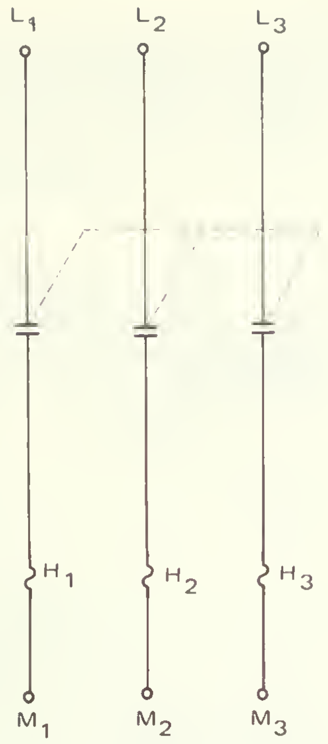


Figure 5.1.3.2 Manual motor starter circuit

button is closed AND overload 1 AND overload 2 AND overload 3 are closed.

2. The magnet will stay energized if the stop button AND either the start button OR the hold-in switch W is closed AND overload 1 AND overload 2 AND overload 3 are ALL CLOSED.

When the magnet coil operates the contactor, all four contactor switches W, X, Y and Z close. W now being closed acts as a hold-in to hold the contactor in operation (closed) provided the other conditions listed above under 2 are met.

The contactor will remain closed until one of the AND sections of the circuit is opened at which time current to the magnet coil will stop and the contactor will open.

The use of the switching language to describe the operation rather than the use of the words series and/or parallel should help the understanding of further circuit changes.

The transmission function T for the motor starter is as follows:

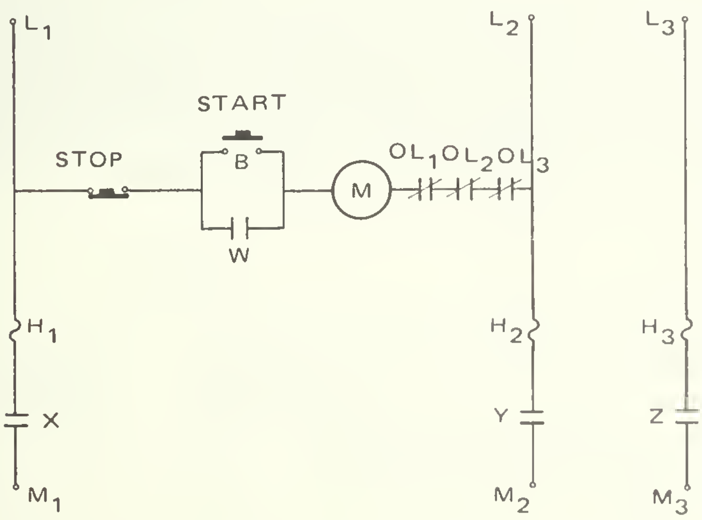


Figure 5.1.3.3 Magnetic starter circuit

$$T = A(B+W)C.D.E. \text{ or } T = A.C.D.E(B+W)$$

Since X,Y,Z. must all be true in order to supply current to the motor and are true if the magnet coil M is energized, this section of the function is omitted from the total transmission function. Only those parts of the function which affect the operation of the magnet coil M are used.

If T is true, the contactor closes and the motor runs. The truth table becomes:

A	C	D	E	B	W	T
1	1	1	1	0	0	0
1	1	1	1	1	0	1
1	1	1	1	0	1	1
1	1	1	1	1	1	1

This is not the complete table. The complete table would be much longer. However, if a 0 appears anywhere in any of the columns under A, C, D, E, the table will be false no matter what other values appear and the contactor will be open.

If the circuit is examined, it will be seen that any other switch installed in the AND part of the circuit will stop the circuit if opened during operation or will prevent the circuit from operating if open. Likewise, any switch installed in the OR part of the circuit and closed will cause the circuit to operate provided all AND sections are true. (It is assumed that the switches are switches with off and on positions.)

5.1.3.2.2 Magnetic Coil Voltages

Magnet coils are available for a variety of voltages. Coil voltages match the voltages of the circuit to be contolled except that at higher motor voltages (above 230 volts) it is more common to use a coil operating at a lower voltage, usually 115 volts. The control voltage, if lower than the controlled circuit voltage, is supplied by a transformer. High control voltages require that all components have high voltage ratings increasing installation costs. There may be additional hazards with higher voltages. Thus lower control voltages are used.

5.1.3.2.3 Push Buttons

Push buttons are required by magnetic starters. Push buttons may be mounted on the starter cover or may be separate. Indicator lights are often used. See Section 5.1.2.1.1 for push button details.

5.1.3.3 Starter Sizes

Starters are available in a variety of sizes, the size to be used being dependent on the current to be handled by the contactor. These are listed in Section 4.1, Electric Power Units, Tables 4.1.1, 4.1.16, and 4.1.17.

5.1.3.4 Starter Enclosures

The type of enclosure required is dependent on the location of starter and the type of environment. Enclosure standards and types are listed in Section 4.1, Table 4.1.18.

5.1.3.5 Overloads

Suitable sized overloads are obtained at the time the motor switch is purchased. One physical size of switch will work for a variety of motor sizes up to the maximum rating of the switch. All that is necessary is to obtain the correct overload size for the specific motor to be used. The overload is usually rated at 125% of the full load motor current.

5.1.3.5.1 **Overload Sensors**

Most overload sensors are heat sensitive devices. A bimetal strip is heated by a heater through which the motor current passes. As long as the motor current remains below 125% of its rated value, the overloads do not act. If the current exceeds 125% the overloads will act, the time required depending on the value of excess current.

Under overload current, the bimetallic strip becomes heated sufficiently to bend far enough to operate the overload(s).

Some overloads are magnetically operated. If the motor current becomes sufficiently great, the magnetic force developed will operate the overload.

5.1.3.5.2 **Overload Resets**

There are two kinds of overload resets: manual and automatic. With a manual reset, the overloads are reset manually usually by pressing a button on the cover of the starter enclosure. In the automatic reset, current is restored to the motor automatically after a timed period.

Manually reset overloads are used where a hazardous situation might be created if the device controlled by the starter were to restart unexpectedly (Table saw for example.)

Automatic resets are used where a hazard would exist if the controlled device did not restart automatically, for example, a ventilation sytem or a product cooling system.

5.1.3.6 **Wiring Description**

In Figures 5.1.3.2 and 5.1.3.3, L_1, L_2 and L_3 are the input lines from the supply. M_1, M_2 and M_3 are the connections to the motor. In this case, the motor is a three phase type necessitating the three lines.

For single phase, 230 volt operation, the circuit from L_3 to M_3, including contactor switch section Z and overload sensor H_3, would not be used. H_2 and OL_2 are not used for 230 volt single phase operation.

For single phase 115 volt operation L_2 - M_2 will be the neutral connection. Contactor switch section Y will not be used.

In some instances, single phase 230 volt and 115 volt starters can be purchased. However, three phase starters can be used for all installations although there will be a redundancy of components if used on single phase.

5.1.3.7 **Circuit Modifications**

The basic control system has to be modified to provide other than the basic function or to respond to other than a standard input.

Some of the desired functions that the control system has to respond to or to provide outputs for are listed in the following subsections.

5.1.3.7.1 **Reversing**

In control systems, it is sometimes necessary to be able to reverse motors on command. Most motors can be reversed (See Section 4.1 Part 4.1.9.2).

Polyphase Motors

Figure 5.1.3.4 shows a diagram for a reversing magnet controller for three phase motors.

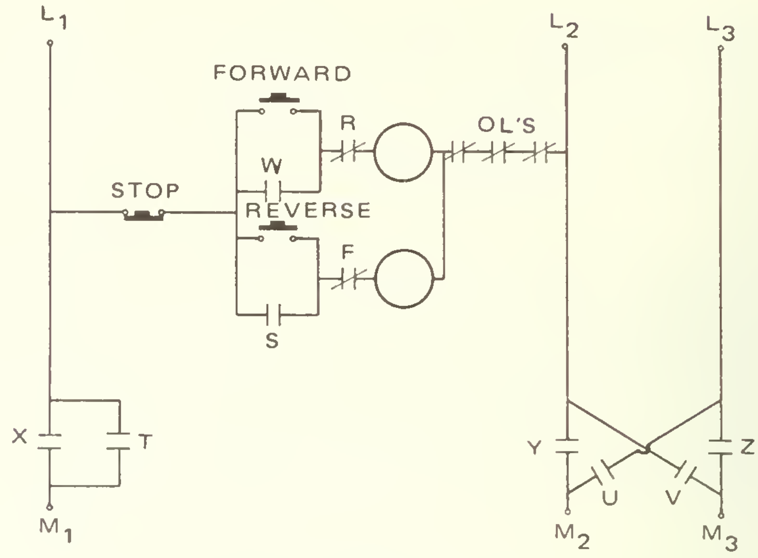


Figure 5.1.3.4 Magnetic reversing switch

When the forward start button is pressed, the forward magnetic coil is magnetized closing contacts, X, Y, Z and the hold-in W. Switch F in the AND circuit for the reverse circuit is opened. This prevents the reverse magnetic coil from being accidentally energized. As well, there is a mechanical interlock fitted which prevents the other magnetic coil from closing its contacts when the first is energized.

To reverse, first the stop button is pressed, then the reverse button. The reverse magnetic coil when energized closes contact T, U, V and S, and the hold-in, opening R in the forward AND circuit. lines 1, 2 and 3 are connected to M_1, M_3 and M_2 respectively instead of to M_1, M_2 and M_3.

Manual reversing switches are available. These have a center off position, forward and reverse. These mechanically make the connection of L_1, L_2, L_3 to M_1, M_2, M_3 for forward or to M_1, M_3, M_2 for reverse.

Single Phase

Some single phase motors such as the shaded pole type cannot be reversed. Other single phase brushless motors reverse by intechanging the starting winding connectors with respect to the running winding connections. For these motors, a double pole double throw switch of sufficient current rating is used as given in Figure 5.1.3.5.

Reversing can be effected only when the motor has completely stopped. If the switch is operated while the motor is running, it continues to run in the same direction until it is stopped. Then, it will start in the opposite direction when current is restored.

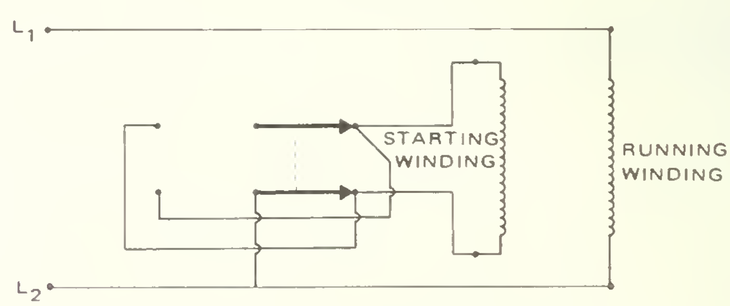


Figure 5.1.3.5 Manual single phase reversing switch

Single phase motors utilizing brushes such as repulsion induction motors can only be reversed by mechanical means. The brush assembly must be moved mechanically or electro magnetically to the opposite side of hard neutral. The change is usually to a point ±15° from hard neutral (Section 4.1.9.2).

5.1.3.7.2 Jogging

Sometimes it is necessary to cause a motor to move only a fraction of a turn. This type of operation is referred to as jogging. A control circuit is given in Figure 5.1.3.6.

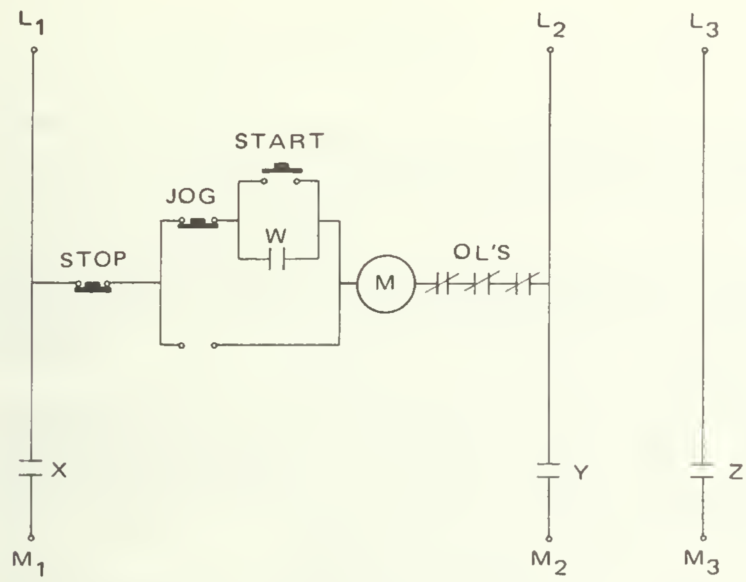


Figure 5.1.3.6 Jogging control circuit

When the start button is pressed, the magnetic coil M is magnetized and closes the motor contacts X, Y and Z as well as the hold-in W.

If the jog button is pressed, the magnetic coil circuit is broken and contacts W, X, Y and Z open (if closed). When the jog button is pushed further to the bottom of its travel, the magnetic coil circuit is again closed and the motor moves. Movement continues only while the jog button is held fully pressed. When it is released, the motor stops.

5.1.4 CONTROL CIRCUITS - GENERAL

5.1.4.1 Counting

Often in a materials handling system, a count is required. An example might be in the proportioning of a feed mix: 8 units of ground grain, 2 units of concentrate and 1 unit of another material might be required.

5.1.4.1.1 Mechanical Event Counters

5.1.4.1.1.1 Digital

A number of types of mechanical counters are available. In some, a tab on a rotating member strikes a finger on the counter during each revolution indexing the counter to a new position. In others, a connection is made by means of a flexible cable which rotates. A system of gears changes the number of rotations of the cable to a new value which actuates the counter. Actuation is usually achieved by rotating a drum on the periphery of which are the numbers. When the drum has turned one revolution, i.e. counted to 9, it indexes the next drum to the left, one increment. This is typical of odomoters or revolution counters used in vehicles. Some other simpler ones rotate a single dial once in response to many input turns. The turns or fraction of turns must be visually recorded.

5.1.4.1.1.2 Electro-Mechanical-Digital

Another type is actuated by electrical impulses generated by a transducer of some description. Each impulse causes the unit to add 1 unit to the accumulated count. Input to the transducer may be a mechanical, a magnetic, or an optical occurrence which the transducer converts to an electrical output. The count can be mechanically reset to zero to start over.

5.1.4.1.1.3 Stepping Relays

Stepping relays may be used as counters. A stepping relay is one which moves one increment for each input pulse. After a certain number of pulses, it will be around to the beginning again. The relay opens and/or closes circuits with each increment.

Suppose a count of 5 is desired and the relay has 10 positions, then connections would be made to the first and sixth positions. Every fifth input pulse would energize the second circuit. If a higher count is required, a second relay would be energized from the first. Every 10th pulse would be fed to the second causing it to increment one step. If this second relay also had 10 positions, the circuit could provide a count to 100 or any number between 1 and 100.

One limiting factor with mechanical counters which operate (count) in response to an input pulse is the time required to effect the change in count. Counting speed is then relatively slow, being, at most, a maximum of a very few per second. Counters of the odometer-type will count at much higher speed.

Electronic counters will count at speeds beyond the capabilities of mechanical counters.

Mechanical counters may show counts which continuously increment with the passage of time. Others show instantaneous values, i.e. the number of turns per minute (revolutions per minute). These latter are tachometers.

5.1.4.1.2 Electronic Counters

5.1.4.1.2.1 Binary Counters

A switch has only two conditions, it is either on or off. There is not any condition when the switch is partly on or off. Because of these two positions, switches can be used to represent a binary number and a binary counting system can be developed using switches. Since most people work in a numbering system based on 10's and not 2's, a conversion between the 10's system (decimal) and the 2's (binary) is required. In a binary system, 2's to various powers are displayed. Any decimal number (from 0 to 15) can be represented in binary by four switches each controlling a light. Each light represents a power of 2.

The right hand switch in Figure 5.1.4.1 represents 2 to the 0 power, the second from the right 2^1, next 2^2 and the left one 2^3.

If all lights were lit indicating each binary position to be true, i.e. equal to logical 1, the 4 lights would indicate:

$$2^3 + 2^2 + 2^1 + 2^0 = 8 + 4 + 2 + 1 = 15.$$

In binary form, the designation would be 1111. Similarly if lights two and four were lit, the number would be:

$$0 + 2^2 + 0 + 2^0 = 0 + 4 + 0 + 1 = 5.$$

In binary, it would be 0101. In this system of binary notation, the condition of all four must be given. None can be left out even though some are 0. As a further example, 0110 would be:

$$0 + 2^2 + 2^1 + 0 = 6.$$

In some situations, more than 4 binary bits (positions) are used per decade. Seven is a common number. Four of the seven are message bits. The other three, interspersed with the message bits in a particular order, are correction bits. The seven are checked when the message is read. Up to two errors can be determined and one error corrected. In some systems, if the message is correct, the seven bits will add to zero; in others the seven will add to one. This addition is to determine parity. The terms used respectively are even or odd parity for 0 or 1.

Although is it possible to show binary equivalents to decimal numbers as high as 15, it is not usual to go higher than 9*.

Each set of 4 binary positions used to represent a decimal number is called a decade. To represent higher decimal numbers than 9, two or more decades are used. (A number greater than 15 requires two decades in any case.)

The right hand decade represents the number of units, the next left the number of 10's, the next the 100's and so on.

Counters may form part of the control circuit or be part of the instrumentation or be in both.

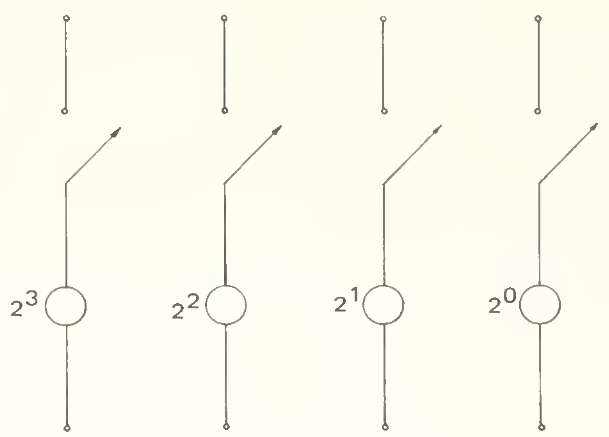


Figure 5.1.4.1 Binary number display using lights

5.1.4.1.2.2 Electronic Digital Counting Circuits

A circuit for an event counter which will display a count up to the number 9 is given in Figure 5.1.4.2. This can be expanded to count to any decimal number desired by adding more similar sections.

IC's 7490, a decade counter and 7448, a decoder-driver, are readily available. The 7490 contains flip flops interconnected so that it produces a binary output of the number of input signals. When the 10th input signal occurs, the device recycles and starts over again. The 7448 converts (decodes) the binary outputs of the 7490

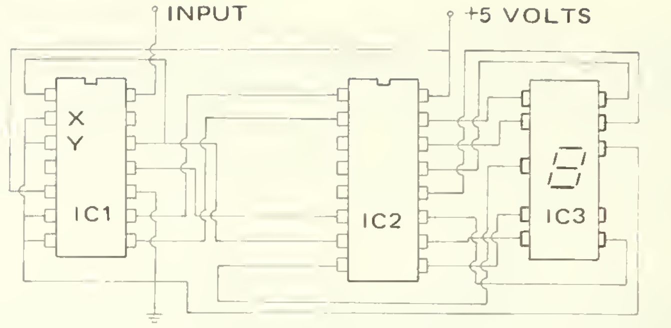


Figure 5.1.4.2 Circuit diagram for a digital counter

and supplies these to the right segments of the MAN 4 light emitting diode chip to display the decimal equivalent of the current binary output of the 7490.

As stated, the circuit can be duplicated to add a second or more digits to the display. At the 10th input pulse to the 7490, an output pulse appears at pin 11. This pin is connected to the input pin #14 of the 7490 of the second section.

The second decoder will cause the second LED readout to change to a 1 from 0. The count will advance by 1 for every 10 input pulses. Connecting pin 11 of the second 7490 to pin 14 of the third will actuate that LED readout to read after 100 input pulses to the first.

If a switch is connected between the input signal source and pin 14, the count can be turned off and on. If a second switch is connected between X, Y and ground, the entire display and counters can be reset to zero and the count started over again.

A latch can be inserted between the counters and the driver for the displays. The latch is an integrated circuit which is a memory device which when triggered remembers the count that was present at that instant in time. This count is fed to the driver(s) and displayed. When the next latch pulse comes along, the new count is retained (remembered) and displayed. The latching pulses may come from a timing device (see 5.1.1.3.4) or from some other source.

The counter can be used to actuate a signal, a control function or both at a certain count. Suppose the signal was desired at a count of 25 units. A three input AND gate would be required as shown in Figure 5.1.4.3.

An output will occur at Y only when a signal appears simultaneously at all 3 inputs. The first time that this will happen during a counting sequence is when a count of 25 is reached. The AND gate output could be connected: to a latching device to create a signal; to the OR circuit to start a sequence; or through a NOT gate to the AND circuit to stop a sequence. Interface equipment may be required with either of the latter two functions.

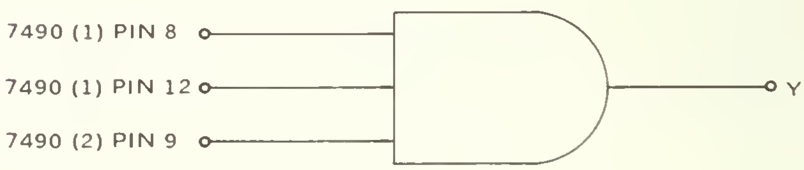


Figure 5.1.4.3 Three input AND gate

*An exception is the hexadecimal code.

To develop a control signal from another count may require a more complicated circuit. At the most, a four input AND gate plus NOT gates will be required for each decade counter being sampled.

IC's are available which contain the display, driver, latch, decoder and counter in one chip. The single chip greatly reduces the wiring and time required to make pulse counters. A chip will be required for each significant digit to be displayed. Chips are interconnected to provide ongoing counts to the decades ahead.

One disadvantage of the single chip is that the whole must be replaced if one section fails.

5.1.4.1.3 **Revolution Counters**

5.1.4.1.3.1 **Tachometers**

Some tachometers are mechanical, others are electric and still others electronic.

Mechanical Moving Pointer: A flexible shaft connects from the shaft whose speed is to be measured to the tachometer. Inside the tachometer, a permanent magnet is rotated. A disc, fastened to the indicator and spring loaded to return to zero, attempts to move in the direction and in response to the turning magnet. The amount that the disc can rotate away from zero is determined by the return spring pressure and the speed of the rotating magnet. The dial is calibrated in an appropriate fashion.

Electrical: A small generator is turned by the shaft whose speed is to be measured. Generator voltage is proportional to speed. The tachometer is a voltmeter which measures the generated voltage and hence speed. Its dial will be calibrated in units of speed per time element.

Digital Electronic: A special electronic counter is actuated by pulses generated by the rotating shaft. These pulses may be generated mechanically, magnetically, optically, or by other means. The counter is allowed to count for a predetermined time interval. At the end of the time interval, the count is displayed. At the end of the second time interval, the new count is displayed. The time interval and the number of pulses generated per revolution are selected so that the figure displayed is the speed per desired unit of time. For example, suppose a shaft rotated at a known speed of 3600 rpm. If 8 pulses were produced each revolution, 480 would occur per second. If the time interval chosen over which to accumulate the count was 0.75 seconds, a count of 360 would have accumulated and would be displayed as 360 (x 10) rpm. If the shaft slowed to 2400 rpm, the display would read 240 (x 10). Resolution would be to the closest 10 revolutions per minute. Operation of the actual electronic counter is described in Section 5.1.4.1.1.1.

5.1.4.1.3.2 **Hour Meters (Running Time Meters)**

Hour meters are counters which after a preset number of counts display hours, minutes and tenths of minutes. The amount displayed is based on the assumption that the device was operated at a recommended speed. The hour meter is a counter which at the end of the specified number of revolutions, shows a time increment based on a speed. Thus, it does not show clock time but rather time based on the number of revolutions or events which have occurred.

Another type of hour meter does display true machine running time. It is a special clock started when the machine is activated and stopped when it is deactivated. The display is true time independent of device operating speed.

5.1.4.2 **Memory**

A memory device is best described by an example. A latching relay is a relay which when actuated by a signal (input pulse) will turn on and stay latched on whether the input signal continues or disappears. It will not unlatch and turn off until a second signal appears. It will then stay off until another signal appears. The relay 'remembers' to stay turned on or turned off.

A set of switches, some of which are turned on or off, form a memory. The individual switches are tested to determine which switches represent logical 1 or logical 0. Elements which may be electronically on or off, i.e. represent a 1 or 0, may form memories. These elements may simply be magnetic particles which are read. A magnetized particle represents 1 and unmagnetized 0.

The memory is used to cause the control system to go through the control sequence in a specific fashion. This sequence then is a control program. A water pump is programmed to start and stop at discrete tank pressures. The program can be altered by changing the pressure setting. The main control of an automatic washer is preprogrammed to operate the washer through its cycle of fill, wash, empty, rinse and spin. Programs can be altered by changing the memory. This would be difficult to change for the automatic washer but some other program memories are made to be easily changed.

A program is defined as the total set of events which a control system follows in executing its operation.

5.1.4.3 **Time Delays**

5.1.4.3.1 **Types of Time Delays**

A time delay can be thought of as a special type of memory which, in this case, remembers to delay the start or finish of an event for a specified length of time.

Time delays are generally of four types.

5.1.4.3.1.1 **Heat**

A time delay can be effected by heating a bimetallic strip which, after a pre-determined time, bends sufficiently to open or close a set of contacts thus cutting off or supplying current to the device being controlled. The length of time delay will be influenced by changes in line voltage and ambient temperature.

5.1.4.3.1.2 **Fluid**

These depend on the time required for the leakage of some fluid, be it gas or liquid, into or out of a chamber. The chamber collapses (or expands) and at some point operates a set of contacts. This system is usually used for short time delays.

5.1.4.3.1.3 **Clock**

A clock mechanism starts and after a pre-determined time actuates a set of contacts. These are usually used for long time delays.

5.1.4.3.1.4 **Electronic**

Here the fluid is electricity and the chamber a capacitor. Electricity leaks from or into the capacitor. At a predetermined level of charge, a switch operates. The switch may be a transistor or a mechanical switch operated by a transistor. Some of these time delays may be used for time delay periods of up to an hour but shorter periods are more usual. A typical circuit appears in Figure 5.1.4.4.

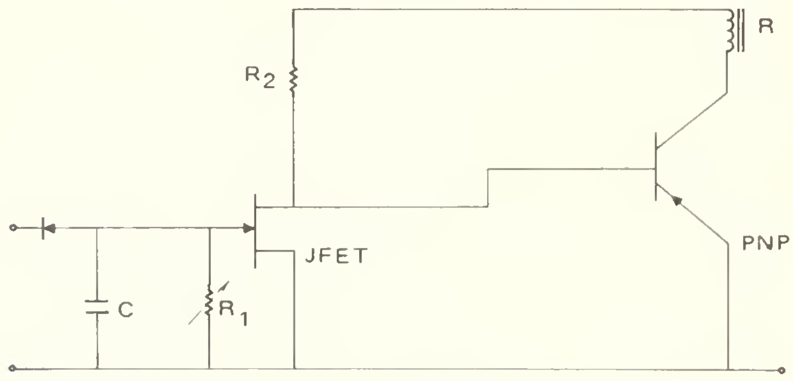


Figure 5.1.4.4 Electronic time delay

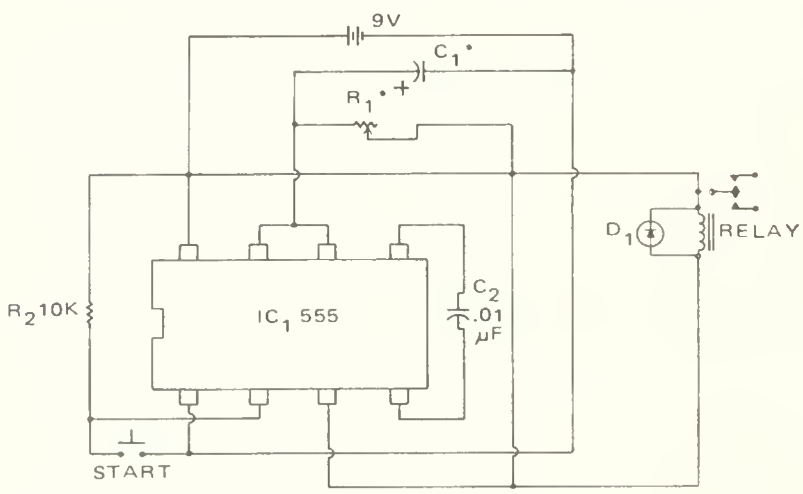
A pulse is applied to the input and R operates. It will not de-energize after the removal of the pulse until the voltage across C has reduced to a certain level. R_1 controls the time required to effect this voltage drop. The addition of a NOT gate would create the time delay on energization instead of de-energization.

Another timer can be built with an integrated circuit and a few discrete components. This timer will give precise control over times from a few milliseconds to 5 minutes depending on the components used. A circuit is given since timing devices are widely used in materials handling systems. The circuit will turn on or off devices depending on what contact arrangements are used on the relay.

The values of C_1 and R_1 determine the length of the time delay. Typical values are:

R_1	C_1	Approximate time
10 kilohms	100 μf	1 second
10 megohms	100 μf	50 seconds

Closing S momentarily will start the time delay. Output is taken from the normally closed or normally open contacts of the relay. A circuit diagram appears in Figure 5.1.4.5.



*SEE TEXT FOR SUGGESTED VALUES

Figure 5.1.4.5 Circuit diagram for integrated circuit time delay

5.1.4.4 **Sequencing and Timing**

Many control systems are comprised of several control subsystems each of which control a part of the total. The sequence in which the subsystems operate becomes important. For example, as a simple system starts up, a grain grinder is started and the grain is turned on. On shut-down, the grain is turned off and the grinder stopped after the grinder has emptied.

The time delay may occur on energization (TDOE) or on de-energization (TDODE). A set of instantaneously operated contacts may also be included. These latter may make or break the circuit or do both.

The same time delay may be capable of any of the functions. The installer decides at the time of installation whether the time delay will be on energization or de-energization and whether the instantaneous contacts (if fitted) will make or break. He can reverse the action if he wishes.

Electronic time delays are reversible by adding negating gates.

Because electromagnets are fitted to the mechanical time delays to start the timing sequence, time delays of this sort are called time delay relays.

Such a system is said to be sequential. The various events (four in the example) are programmed to occur in correct order and where necessary for the correct length of time.

5.1.4.4.1 **Timing Charts**

In a more complex system than the example, a timing chart may be useful. A timing chart (Figure 5.1.4.6) graphically displays the start and stop of each sub-event in relation to the other sub-events and the overall control.

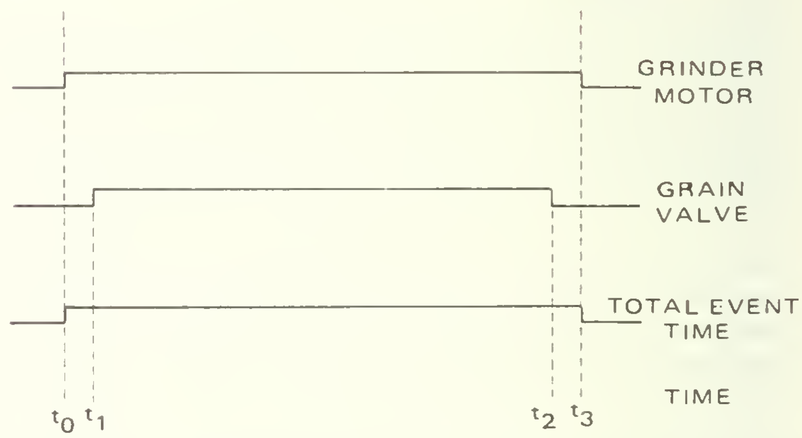


Figure 5.1.4.6 Timing chart for two events: grinder motor and grain valve

If a conveyor were used to convey the ground grain away from the grinder, it would have to start at the same time as the grinder and continue to run after the grinder shut off to convey all the ground grain out of the system. The timing chart would then be as shown in Figure 5.1.4.7.

5.1.4.4.2 **Sequencing**

In some control systems where more than one motor (or event) is involved, the sequence of starting and/or stopping the operation becomes important. For example, a processing unit is started and then the material to be processed is turned on. At shutdown the material is turned off and the processing unit stopped after it has

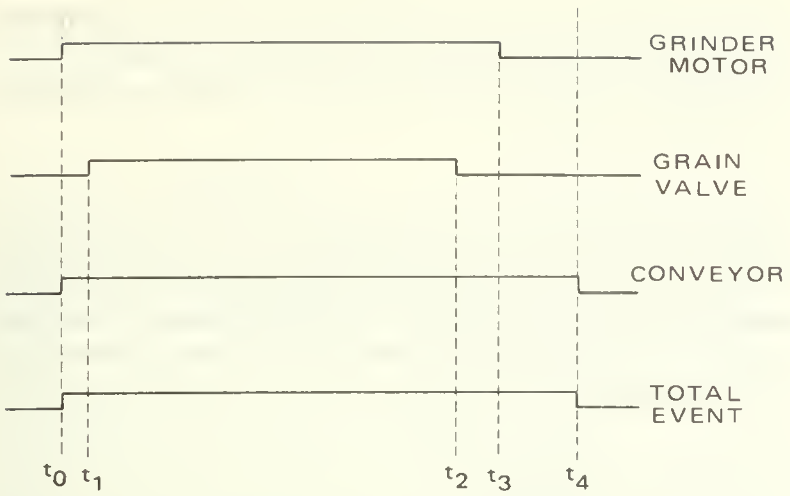


Figure 5.1.4.7 Timing chart for three events: grinder, grain valve and conveyor

cleared itself. The motor contactor closes; after some period the solenoid valve controlling the flow of material operates. The container into which the processed material goes becomes full and a container level switch operates to shut down the system. The solenoid valve closes and after a preset period the motor contactor opens. This example involves both sequencing and time delay.

Another example of sequencing would be the progressive starting of a series of conveyors to prevent a pile-up of material at one point. An added complication would be the requirement that the entire conveying system shut down if one section fails.

Suppose, in a process, a grinder is to run providing that there is a supply of material and that the conveyor system from the grinder is operating. The conveyor is also to run for a time period after the grinder has stopped.

The basic logical statement would be: If there is a supply of material AND the conveyor is running AND the overloads are closed, the grinder will run.

The supply sensor snap action switch and the conveyor will be part of the AND circuit. The circuit might be realized from conventional hardware, as shown in Figure 5.1.4.8.

Pushing Start 2 button energizes the TDODE (time delay on de-energization) relay. Its instantaneous contacts, X and Y, close along with the TDOE contact, Z, starting the conveyor. Then, and only then, can the grinder motor be started by pushing Start 1 button. The grinder motor will

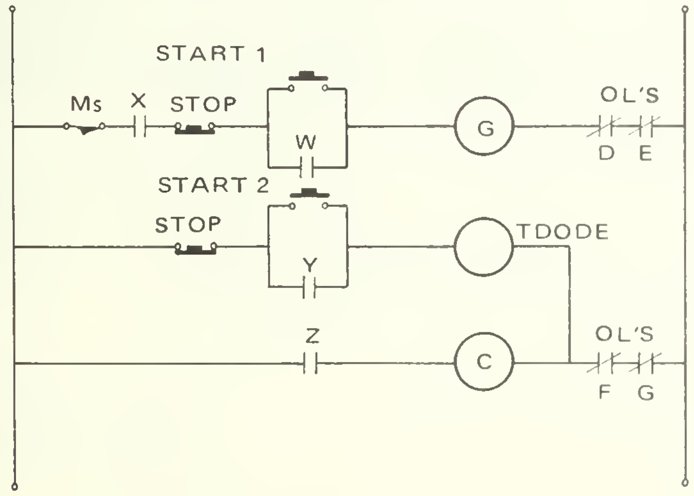


Figure 5.1.4.8 Preliminary sequential control circuit

start if the switch, M_s, is held closed by the presence of material to be ground.

One can refine the circuit. As it exists in Figure 5.1.4.8, the conveyor motor will continue to run whether or not anything occurs in the grinder motor circuit. If the overload relays of the grinder motor acted the conveyor would continue to run. If the circuit is rewired, as in Figure 5.1.4.9, the opening of any of the motor overload devices would cause both the grinder and the conveyor to shut down. If the supply to the grinder failed, the conveyor would stop after the time delay. This latter is shown in Figure 5.1.4.10.

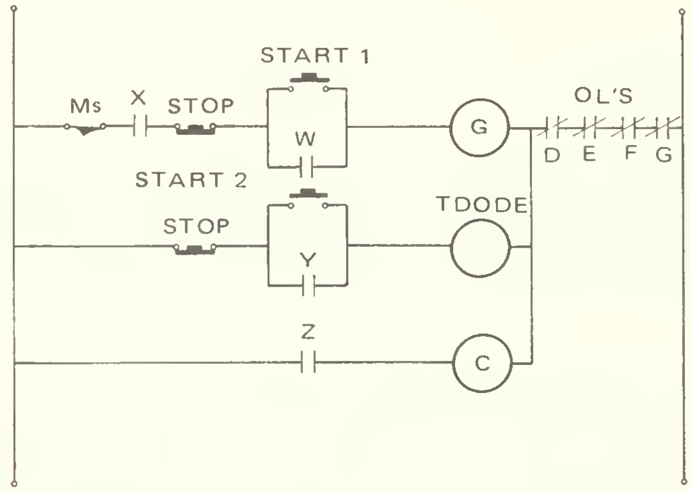


Figure 5.1.4.9 First modification to sequential control circuit

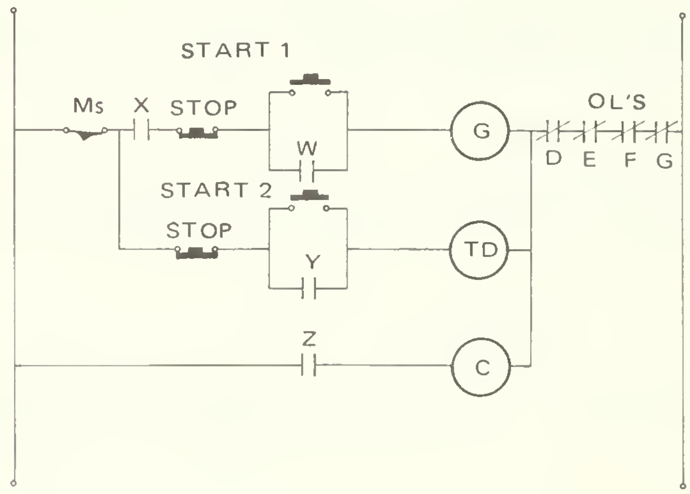


Figure 5.1.4.10 Second modification to sequential control circuit

If it is intended to reduce the number of circuit components further, changes can be made as in Figure 5.1.4.11.

Pushing the Start 2 button will energize the time delay relay, causing instantaneous contacts, X and Y, to start the grinder and hold in the time delay and the time delay contact, Z, to start the conveyor. If either the stop button is pushed or the supply switch opens, the instantaneous contacts open, the grinder stops and the time delay begins opening contact Z, after the time period, to stop the conveyor.

The transmission function, T, would be:

$$T = DEFG(AB(X + C + Y) + Z)$$

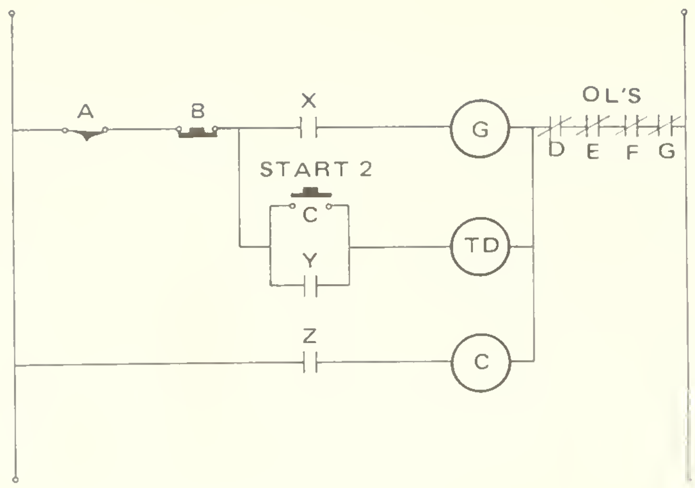


Figure 5.1.4.11 Final version of sequential control circuit

The above illustrates the progressive steps towards intuitively designing a sequential circuit. Sequential circuits may be designed mathematically. A sample of the method appears in the appendix.

5.1.5 SPECIAL FUNCTION CIRCUITS

The following are control circuits intended to provide control for special purposes. The section is in two subsections. The first outlines electro-mechanical controls and the second solid state controls to achieve the same functions. Not all possibilities are included. In some cases some of the circuits suggested may be realized in other ways using other components.

5.1.5.1 Temperature Control

5.1.5.1.1 Digital

A thermostat is inserted as part of the AND circuit to the contractor or, if the thermostat contacts have the proper current ratings, directly into the motor circuit.

5.1.5.1.2 Proportional

The output of some temperature controllers is proportional to the amount separating the sensed temperature from the preset temperature. The speed of the controlled unit is decreased as the temperature difference decreases.

A special controller and a variable speed motor are used in this control system.

5.1.5.2 Weighing

The usual method is to weigh in increments. The material is stored until sufficient is accumulated to reach the required weight. Material flow is halted until the accumulated amount is dumped, and after dumping, a new accumulation begun.

5.1.5.2.1 Mechanical

The actual sensing of weight can be achieved by using a set of scales whether the scales operate a beam or a pointer. The beam, as it rises when balance is obtained, may:

1. actuate a snap action switch;
2. break or make a beam of light.

The pointer may contact a switch or pass before a light sensitive device. The latter is more satisfactory since it cannot interfere with scale operation. However, dust, if allowed to accumulate on the sensor, can adversely affect operation.

When the scales actuate the sensing device, the other parts of the circuit must operate to:

1. interrupt the supply of materials;
2. dump the weighed amount;
3. return the hopper to the regular position;
4. restart the supply of material.

As the scale beam rises (Figure 5.1.5.2), it operates the snap action switch A, connected normally-open, closing it to cause the dump mechanism to operate. As soon as the dump mechanism begins to operate the switch B closes. It had been held open by the dump mechanism when in the correct position to receive material. The dump mechanism cycles in spite of the fact that the scale beam will drop away from the switch A. The cycle continues until the dump mechanism has returned to its receiving position and opened B breaking the dump circuit.

As soon as the dump cycle begins, the relay operates to break the circuit to the solenoid feed control valve which closes. This reopens when current is interrupted to the

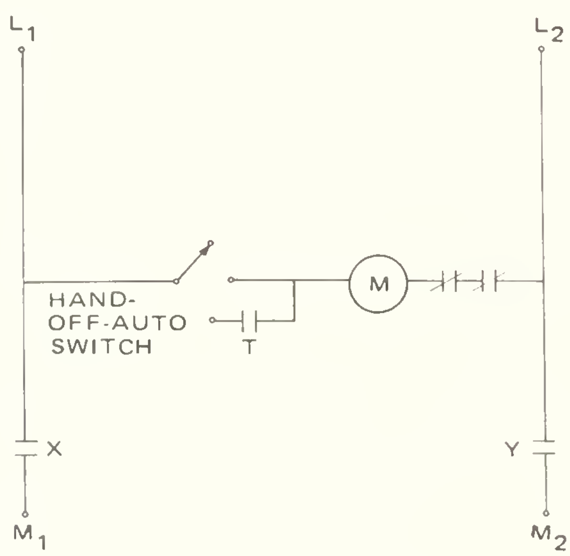


Figure 5.1.5.1 Hand-off-automatic control circuit

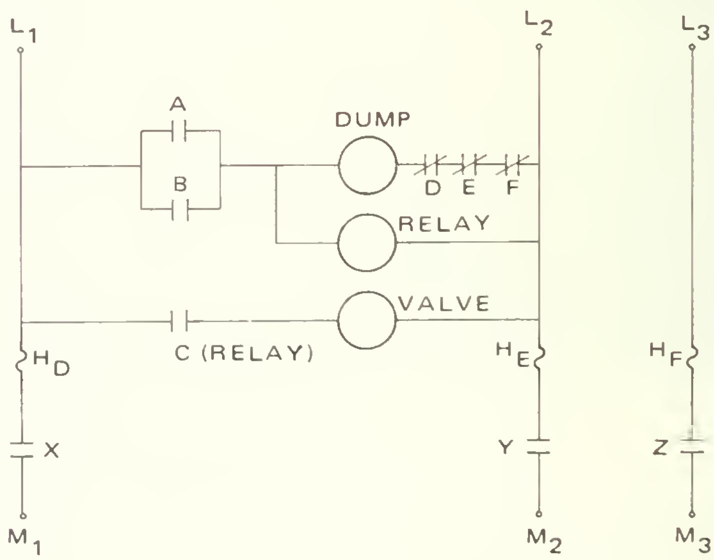


Figure 5.1.5.2 Circuit for weighing system

relay when the dump mechanism completes its cycle. If a photo-electric device were used, its relay contact would replace switch A.

5.1.5.2.2 Electronic

Weighing can be achieved without using scales. A weight will create a force which in turn will create tension or compression in the supporting structure. The change in tension (or compression) will be directly proportional to the weight (force) which created the change.

Strain gauges fixed to supporting members will detect the changes in strain by the changes in forces.

Strain gauges mounted on a support member are connected in a bridge circuit, much like the simplified circuit shown in Figure 5.1.5.3.

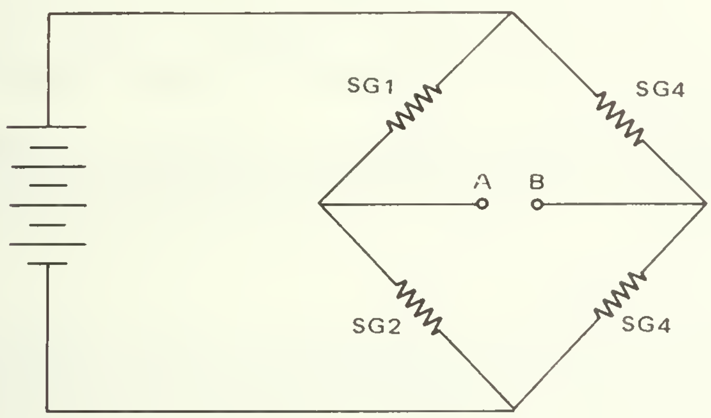


Figure 5.1.5.3 Simplified strain gauge bridge circuit

Since all gauges are identical, the potential across the points A and B will be 0. Strain will cause the resistance of each bridge member to change causing the meter to read something other than zero. As weight is added to the container, the bridge will become more unbalanced. When the correct weight is reached, the predetermined bridge unbalance will cause the dumping circuit to operate.

The circuit shown in Figure 5.1.5.3 will require a method of balancing and amplifying the extremely small unbalance created by strain. The bridge output is applied to a differential amplifier (Figure 5.1.5.4) where it is compared to a reference signal. As long as the bridge output signal is less than the reference signal, the output signal will be of the wrong polarity to operate the circuits which follow. As soon as the output from the bridge exceeds the reference voltage, the amplifier output will supply an output signal to the dumping circuit.

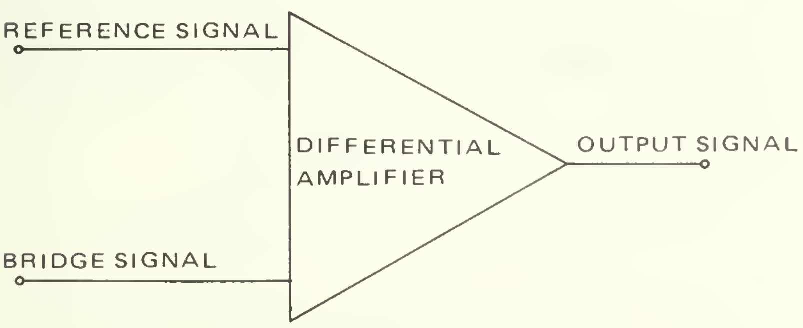


Figure 5.1.5.4 Comparator circuit for weighing circuit

5.1.5.3 Pressure Control

5.1.5.3.1 Digital

5.1.5.3.1.1 Spring-Loaded Paddles

Material depresses the paddle to operate the snap action switch (Figure 5.1.5.5).

The paddle must be constructed and mounted so that as the material level drops, the material drops away leaving none behind to inhibit proper operation.

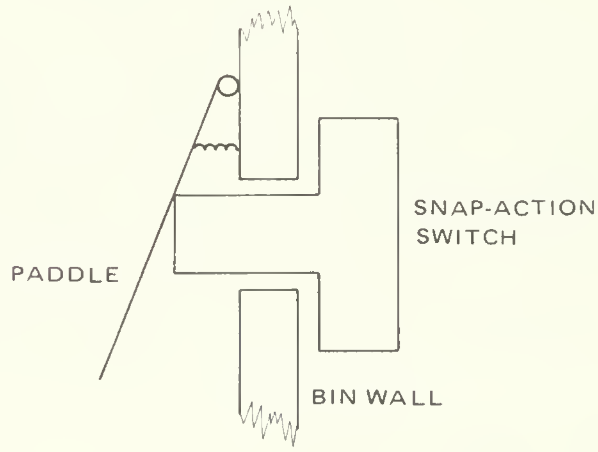


Figure 5.1.5.5 Spring loaded paddle switch

5.1.5.3.1.2 Diaphragm

Material pressure against the diaphragm causes the switch to operate (Figure 5.1.5.6). A diaphragm would be used where the material was semi-liquid or dusty.

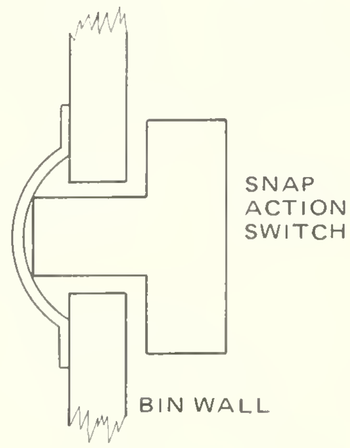


Figure 5.1.5.6 Diaphragm operated switch

5.1.5.4 Limit Control

Some materials handling operations must shut down when feeding operations are completed. A limit switch is used. This limit switch is usually a snap action switch operated by a pressure device. It is located in the AND circuit.

5.1.5.4.1 Switch Mounting

The limit switches must be mechanically protected against damage from improper vehicle handling. This is usually achieved by mounting the switch behind a solid framework with the operating mechanism extending through the mount to contact the vehicle. The switch could be mounted in a spring-loaded arm which deflects.

5.1.5.4.2 **Location**

Location must be such that proper operation is obtained, i.e. the bin is full enough when the operation is terminated by the limit switch and that operation can begin again when necessary.

Examples:
Termination of bin fill of several self-feeding bins - the common method of conveying materials to bins of this type is by auger. A downpipe extends from the auger as it crosses each bin. All material flow is directed into the first bin until it fills, then material is conveyed to the second and third until each is filled. A limit switch is mounted at the last bin to stop the operation. This limit switch (Figure 5.1.5.7) may be mounted at the end of the auger so that when the last bin is filled, material pressure depresses the limit switch. Care must be taken to make sure that the switch will reclose as soon as material level drops in order that the operation can be restarted when necessary. (Restart could be achieved through a second sensor mounted at the minimum allowable bin level.)

5.1.5.4.3 **Fail Safe Control**

Sometimes circuits of this type fail to operate and the filling operation will continue. To minimize that problem, a material sensor could be situated to detect that material is being supplied to the last bin. A time mechanism actuated by the sensor would shut down the supply system after a certain operating time. The time would be set somewhat longer than that period normally required to fill the bin.

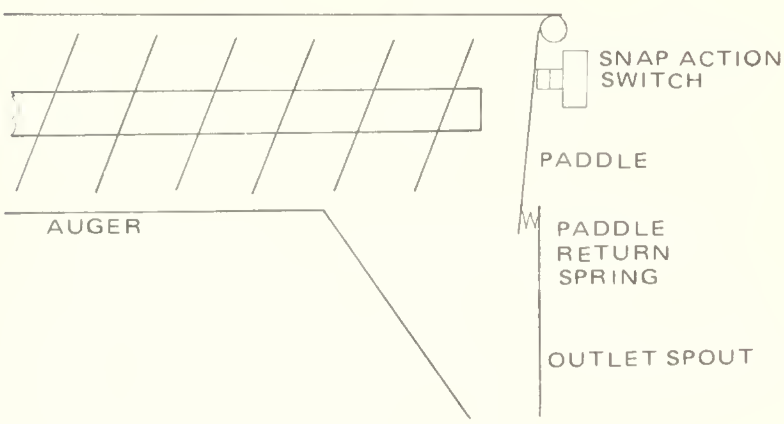


Figure 5.1.5.7 Diagram of termination control of bin filling

5.1.5.5 **Position**

Some materials handling operations require that a vehicle be properly positioned for filling or unloading to prevent material spillage.

Limit switches can be made to inhibit the operation unless the vehicle is in the right position.

Examples:
1. A wagon or truck is to be filled with material. In order to do this, it has to be backed under the delivery spout. When it has reached the proper location, it depresses a limit switch which closes the AND circuit of the delivery mechanism. The filling mechanism can then be actuated.
2. A wagon or truck when being unloaded must be aligned within narrow limits. In Figure 5.1.5.8 two

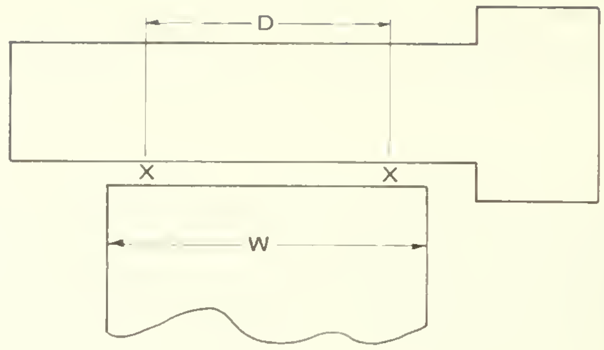


Figure 5.1.5.8 Position control for wagon unloading

sensors are used. If these are mounted at the positions marked X, they will inhibit the unload operation unless:
a. the vehicle is close enough to the receiving hopper;
b. the end gate is parallel to the receiving hopper;
c. the vehicle is properly located with respect to the length of the receiving hopper, i.e. not too near one end or the other.

Distance d is determined by the accuracy of alignment required. Accuracy increases as length d approaches length w.

5.1.5.6 **Index**

Often a delivery spout must be turned to deliver materials to a new location. This operation can be done by remote control. The process is that of indexing in the sense that a specified piece of equipment can be directed to one of a specified number of locations.

The normal method of indexing is to arrange sets of contacts (switches) that are operated by the mechanism under control as it turns. Each set of contacts operates at the precise moment the mechanism reaches one of its possible operating positions. The contacts are usually snap action switches operated by a cam rotating with the mechanism being controlled.

All the snap action switches are connected to the AND part of the circuit controlling the movement of the mechanism. Each snap action switch is opened when the mechanism is precisely aligned and the mechanism would stop in this position. However, each snap action switch is by-passed by the selector switch except the one located at the position desired.

Turning the selected switch to a new position by-passes the open snap action switch and the indexing mechanism starts and runs until it reaches the new location

Figure 5.1.5.9 shows the arrangement of snap action switches for index control and Figure 5.1.5.10 is a

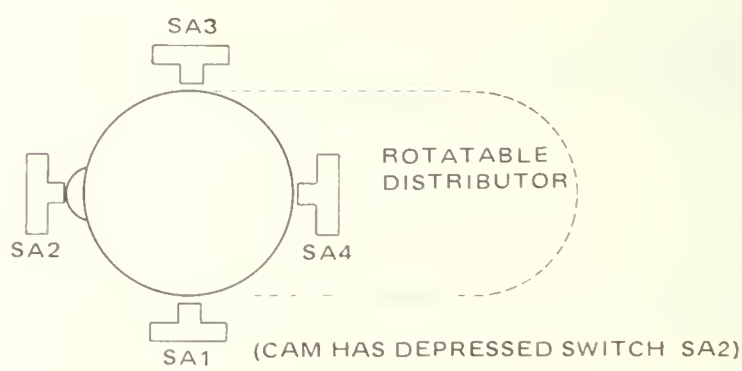


Figure 5.1.5.9 Snap action switch arrangement for index control

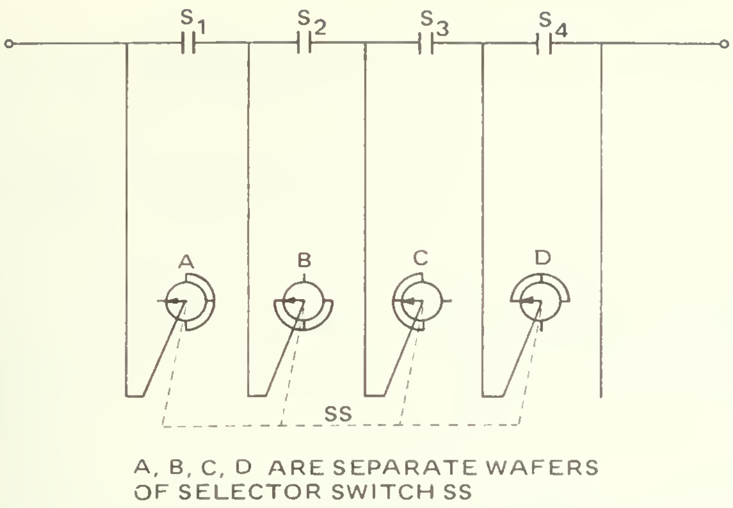


Figure 5.1.5.10 Schematic diagram of index control selector switch

schematic diagram of the index control selector switch.

Should the mechanism under control be the type where it turns one way as far as it can and then must be brought back to the opposite end then limit switches are installed at each end of travel. When the mechanism contacts the limit switch travel direction is reversed.

Lever-operated snap action switches are installed at each index position as outlined above. When the spout contacts the lever, the switch opens breaking the AND circuit and movement stops until a new position is selected.

5.1.6 SOLID STATE IMPLEMENTATION OF CONTROL CIRCUITS

5.1.6.1 AND, OR Circuits

In an AND circuit wired with conventional hardware, switches are simply connected in series; for an OR circuit the same applies except switches are connected in parallel.

If the solid state devices are used (gates) wiring is different even though the circuit output is the same. Conventional snap action switches are used but their supply voltage is that specified by the device manufacturer. An interface is used at the output of the gate circuits to control the standard magnetic switch.

It is not practical to replace the standard magnetic switch but if a complex control circuit is being built, then the gate circuits will have increasing value.

Possibilities are endless. Here is a sample circuit shown in conventional hardware and in gate circuits (Figures 5.1.6.1 and 5.1.6.2). If negative gates were used, simplification in terms of hardware would be possible (only one gate type is used throughout). Any gate is available with multiple inputs. If sufficient inputs in a single device are not available, then multiple gates can be used.

5.1.6.2 General Implementation of Solid State Control

Most control systems can be implemented in solid state devices. Some disadvantages are cost, the inability to inspect solid state devices, and the fact that solid state devices do not have the ability to carry currents in excess of 20 amperes and voltages greater than 440 volts. Advantages are compactness, versatility, long life, and low control voltages.

Some manufactures have solid state devices available. Some devices are plug-in to allow easy assembly and when necessary, replacement of units. Power supplies to provide the control voltages are part of the packages as well as mounting and interconnecting hardware.

Device functions are still controlled by regular pilot devices such as optical, magnetic and proximity sensors, and switches, among which are level sensors, snap action switches, and limit switches. But these, instead of operating at the more normal control voltage of 115 volt AC and up, operate at low voltage, low current DC. Five volts is the normal voltage but one manufacturer of static control systems uses 12 volts. One drawback of mechanical switches is that sometimes the contacts bounce. With fast acting low current devices, the bounce is a disadvantage and a bounce eliminator is used. This is a device which is triggered on when the contacts first close. It will not reopen for a short period of time. Thus, if the switch contact does bounce, the device being controlled does not see the bounce.

A sample problem implemented in solid state will serve as an example. Suppose a cattle feeding system is to be controlled wherein the system starts from a push button and continues until the feeder is full unless a malfunction occurs. The malfunction may occur in the silo unloader or grain unloaders. All conveyors must be cleared before shut down.

In Figure 5.1.6.1, a conventional circuit, closing switch F will produce an output at Y OR closing switches A AND B AND C AND either D OR E will produce an output. The Boolean expression is Y = (ABC(D+E)) +F

In Figure 5.1.6.2, if a voltage designated as logical 1 is

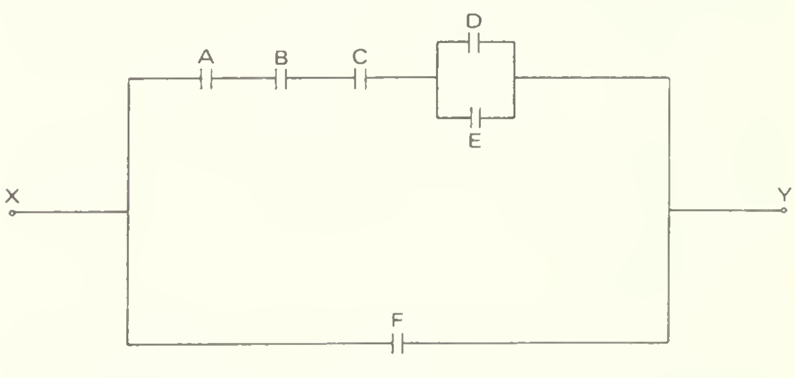


Figure 5.1.6.1 Sample conventional switch circuit

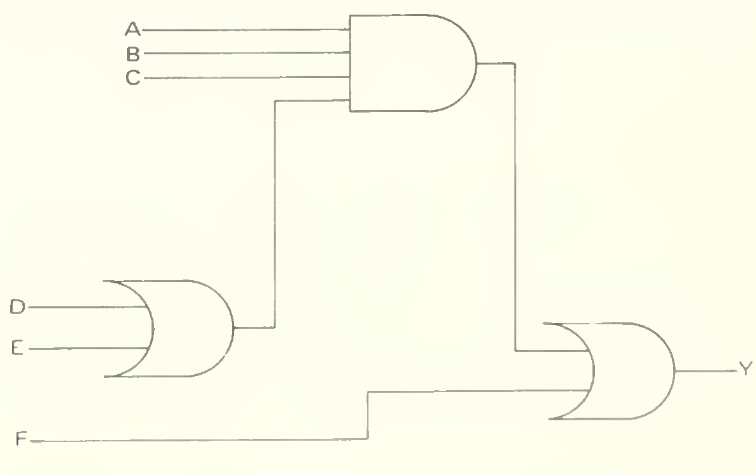


Figure 5.1.6.2 Circuit from Figure 5.1.6.1 implemented in solid state

applied to the inputs (as per the Boolean expression) it will produce an output at Y.

The chief advantages of the latter circuit are its small size and the low voltage required for the switches supplying the various inputs.

Figure 5.1.6.3 shows a circuit built of conventional hardware. When the start button is pushed SM, TD1 and TD2 are all energized providing sensors FC, GC and SC are closed. The circuit is held in by W which is part of the SM contactor. TD1 and TD2 instantly energize AM to the auger motor and FM to the main feed conveyor motor.

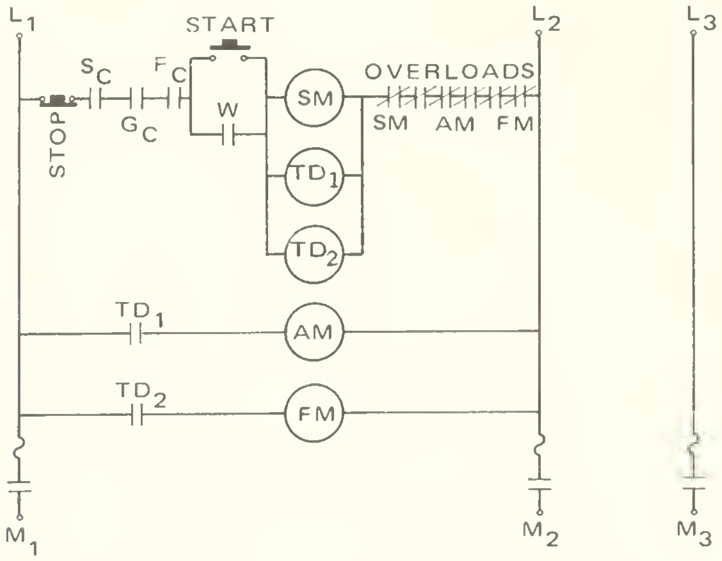


Figure 5.1.6.3 A circuit in conventional hardware

When feed operates FC, the feed sensor, the circuit to the time delays and to SM, the silo unloader contactor, is broken and the silo unloader stops. The auger motor and feed conveyor motors stop at the end of the time delays. If any of the overloads or GC or SC operate the circuit will close down.

The system will start with a push button but sensors, to sense material flow, must be located at:

1. silage conveyor SC
2. grain conveyor GC
3. end of feeder FC

Power will be supplied to silo unloader SM, grain auger AM and feeder FM. Time delays must be incorporated so that after the silo unloader stops, the silage and grain conveyor will empty just before the feeder completely fills. Location of FC, the feeder sensor, would be such that it would sense the presence of feed far enough from the end of the bunk to allow the conveyors to empty before the bin filled.

Timing Diagram

All devices in Figure 5.1.6.3 should start when the push button is depressed. When feed reaches the feed bunk sensor, FC, the silo unloader should stop, the grain conveyor continue for a time interval then stop and, finally, the main conveyor stop after another time interval. If there is an interruption in silage, the grain should be shut off and the conveyor stopped. The diagram is shown in Figure 5.1.6.4.

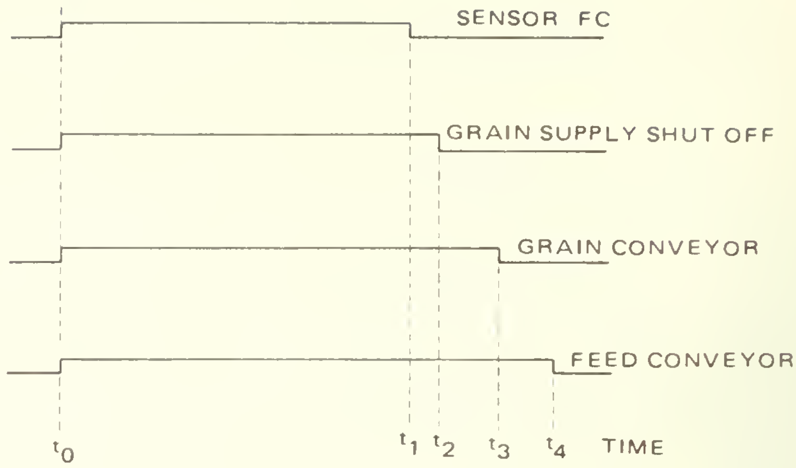


Figure 5.1.6.4 Timing chart for sequential circuit
Transmission Function

$T_1 = F_cG_cS_c(S + W)\,OL_1OL_2OL_3OL_4OL_5OL_6$

$T_2 = T_1TD_1$

$T_3 = T_1TD_2$

If there is an interruption in grain supply, the silo unloader, grain conveyor and main conveyors should stop. If any of the motors overload, the system should stop.

The same circuit, made of solid state hardware, is shown in Figure 5.1.6.5.

Circuits like these can be built from components such as gates and solid state relays which are available through electronic component manufacturers' outlets. However, some manufacturers of regular control hardware also manufacture what they term static control hardware. These components are special solid state elements comprising solid state relays, gates of all types, interface

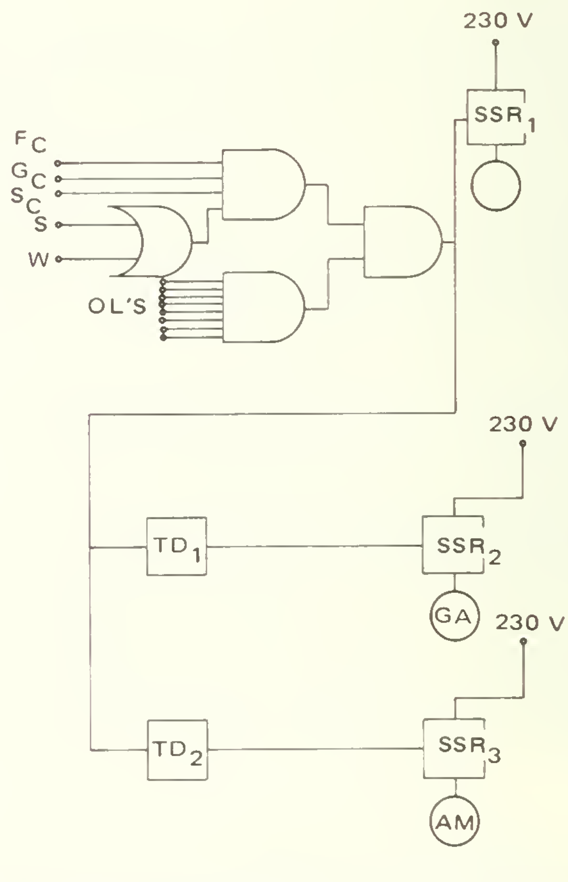


Figure 5.1.6.5 Circuit from Figure 5.1.6.3 implemented with solid state devices

units to standard control hardware such as contactors, power supplies and mounting hardware.

From these components, control circuits such as the foregoing can be realized in solid state hardware. Each company, however, has its own line of solid state hardware. It is unlikely to be too compatible with hardware manufactured by another company.

The designer must utilize manufacturers' literature such as component catalogues and manuals in order to develop his circuits. A check with a local sales outlet for wiring equipment supplies will give an up-to-date list of suppliers of such specialized control components.

So far, the control circuits described have been non-automatic. The basic control circuit has been modified to provide more sophisticated control. The additions have been to the pilot or decision subsystems. Further additions are needed to provide automatic control. Some knowledge of automatic control is needed.

5.1.7 AUTOMATIC CONTROL SYSTEMS

5.1.7.1 General

When a controller repetitively performs a series of events over a range of varying conditions without human guidance, the controller is termed automatic. There are two types of automatic control systems; open or closed loop. The difference between the two depends on whether or not the output is used to influence the input. Where the output does affect the input, the system is termed closed loop.

5.1.7.1.1 Feedback

Closed loop automatic control systems operate from information being fed back to the input of the system from the output. This is called feedback. As an example: in an automatic water system, information related to water pressure is fed to a decision device, the pressure switch, to control the stop-start cycle of the motor. In this system, the pilot device would be the on-off switch supplying power to the water system. The decision device is the pressure switch which decides when the action device supplies power to the pump motor.

In many systems, the feedback signal is used in its original form but in others, it must be modified to be usable, e.g. converted from a mechanical to an electrical signal or vice versa.

5.1.7.1.2 Stability

One important characteristic of an automatic feedback control system is its stability, i.e. its ability to repeat the same control sequence over and over again in exactly the same way over a range of operating conditions. Stability may also refer to the way in which it performs each complete control action. Suppose the control system was controlling an elevator. The elevator must stop smoothly and exactly at the floor selected. If, however, the elevator stopped above the floor level, then dropped a bit below and returned then to the exact location, the system could be said to be marginally stable. Instability could be defined as unpredictability.

5.1.7.1.3 Description of an Automatic Control System

An automatic feedback control system may be represented by the diagram in Figure 5.1.7.1.

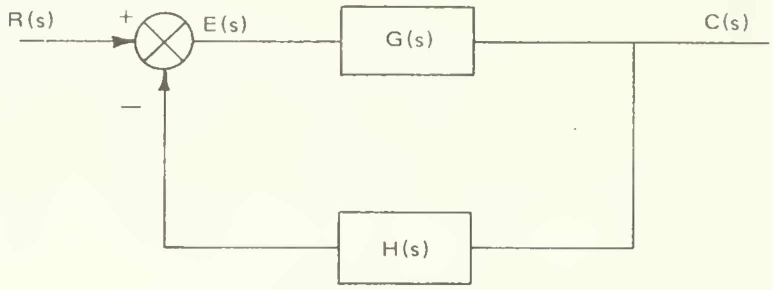


Figure 5.1.7.1 Diagram of typical automatic control system

Each of the following Laplace transforms represents the transfer function of part of the control system. A transfer function is an equation which mathematically describes the operation of that component. A Laplace transform is a special operational procedure used on the equation to simplify the solution.

G(S) represents the transfer function of the forward path of the control system, e.g. the pump and motor.

R(S) is the reference signal - the requirement that the pump start at the particular pressure and stop at another higher pressure.

C(S) is the output signal. C(S) is fed back to the summing point where it is summed with the reference signal R(S) to produce the error signal E(S). G(S) is influenced by the error signal. If C(S) requires modification, the modification is done by H(S) in the feedback path. If no modification is required, the term H(S) disappears. W(S) (the transfer function for the entire system) can be written as:

$$W(S) = \frac{C(S)}{R(S)} = \frac{G(S)}{1 + H(S)\,G\,(S)}$$

These elementary transfer functions can be replaced with the actual transfer functions of the various sections of the control. The complete system transfer function can then be subjected to various analysis to determine the complete system operation and the system stability.

However, most materials handling systems operate in cycles per hour rather than in cycles per minute or cycles per second. Stability is then not a problem in systems of this sort nor is it normally necessary to determine the transient response. Transient response is the reaction of the system to an input signal, i.e. what happens in the system between the time of application of an input signal and the time at which the system again operates in a stable manner.

5.1.7.2 Automation of Control Circuits

A clue can be taken from Figure 5.1.3.3 as to a method of making the circuit operate either semi-automatically or automatically. Suppose the circuit controlled an auger supplying a bin with grain. Press the start button and the contactor would close and the auger motor would run and elevate grain. Without regard to the control circuits, what conditions would be necessary in order that grain be elevated properly?

1. That there was a grain supply available;
2. That the bin did not overfill.

If a grain sensing device were installed at the auger input and the normally open switch controlled by the device was wired as part of the AND circuitry (Figure 5.1.7.2), the auger would stop if the grain supply failed. If a second normally closed switch operated by the presence of grain was installed at the top of the bin to be filled and if this switch was wired into the AND part of the motor control circuit, then the system would stop when the bin filled.

The addition of two snap action switches with grain pressure sensing devices added to them has converted a manual system to a semi-automatic system.

If another pressure operated normally closed switch was installed near the bottom of the grain bin and connected to the OR part of the motor control circuit, the system would be fully automatic. When the grain in the bin falls below a certain point and grain pressure is released from the lower grain sensing switch, that switch goes to the on position. Since it is in the OR part of the circuit, current is supplied to the contactor coil providing all the AND circuit sections are closed. The auger motor starts. Hold in switch W closes in the OR circuit.

The motor continues to run. Grain pressure opens the lower grain sensing switch but operation continues since hold in switch W provides a current path. As soon as grain reaches the upper grain pressure switch, that switch opens in the AND circuits and auger operation stops.

Operation would cease during the filling process if the grain supply failed, the motor overloaded or the stop button was depressed. Operation could not start again until either the grain fell below the lower bin sensor or the start button was pressed. (It would start under these conditions providing all AND sections were closed.)

To complete the control circuit, a positive type of off switch should be provided to lock the circuit off when operation was not needed. The complete circuit now looks like Figure 5.1.7.2.

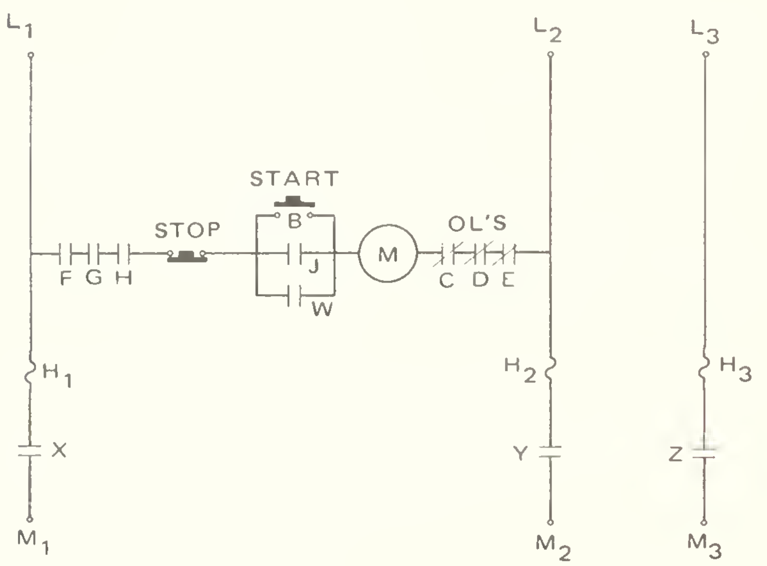


Figure 5.1.7.2 Control circuit which has been automated
F = lock-off switch
G = grain supply sensor
H = full bin sensor
J = empty bin sensor
T = (B + J + W)FGHACDE

The above circuit is not the only way that this type of automation can be achieved. A grain sensing switch may be installed inside a long tube (round or rectangular) or behind a shield extending from near the top of the bin to almost the bottom.

The switch, wired as normally-closed, is connected to the AND circuit; the OR sections are removed. Figure 5.1.7.3 illustrates the circuit.

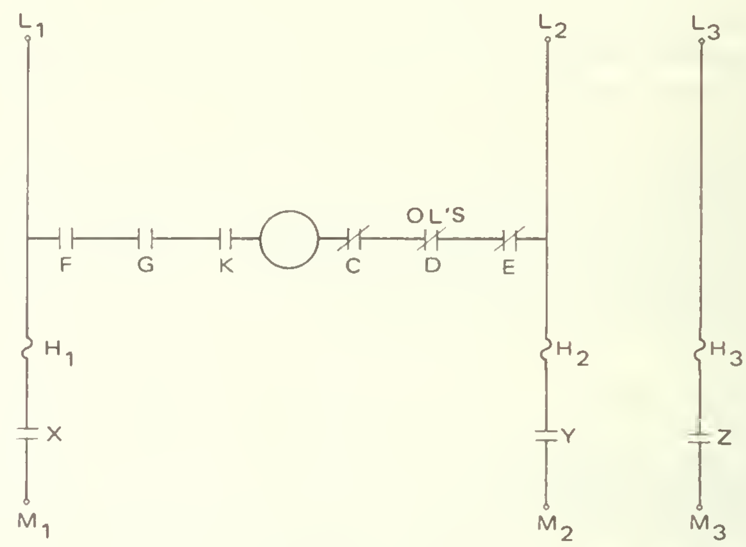


Figure 5.1.7.3 Alternate automatic control circuit
F = lock off switch
G = grain supply sensor
K = bin switch

In order that the contactor coil be energized:

T = F G K C D E

Grain is supplied to the bin. At some point in time, the bin becomes full enough that the grain runs over the top of the tube with the sensor in it and forces the sensor to move and operate the snap action switch. The contactor opens.

Grain pressure remains against the switch until the level of the grain drops below the bottom of the tube; grain then runs out of the tube releasing the pressure on the switch. The switch closes and the refilling process starts over.

This is an example of how circuits can sometimes be simplified. It is true too that in simplification versatility often suffers. With this particular simplified circuit, the auger cannot be restarted when the bin is partially emptied as it can with the more complex circuit.

Some materials handling system controls go beyond the ones so far mentioned in their degree of sophistication. More elaborate control systems are required. Control systems of greater sophistication appear in section 5.1.10.

So far, control systems have been digital, i.e. respond to signals which are either on or off. Sometimes control, the output of which varies in proportion to the strength of the input, is required. Proportional control follows in Section 5.1.8.

5.1.8 PROPORTIONAL CONTROL

5.1.8.1 General

Often, instead of applying a preset voltage or current, control of a device is effected by varying the amount of voltage or current applied to the system. Such control is called proportional control.

Proportional control is based on the formula:

$E = IZ$

where E is the voltage in volts;
I is the current in amperes;
Z is the impedance in ohms.

The term Z is complex, being of the form a + jb ohms. The first part of the complex term, a, is the real resistance; the second part, jb, is the imaginary resistance or reactance, which may be either positive or negative in value. Alternating current circuits can exhibit both real resistance and reactance but direct current circuits have only real resistance. In that case the imaginary term no longer exists and the formula becomes:

$V = IR$

where V is the DC voltage;
I is the current in amperes;
R is the resistance.

R is usually said to be constant for a given circuit with V and I being the variables.

Whether one used V or E to designate voltage is immaterial but often E is used for AC voltage and V for DC. Arrows are used to designate DC voltages, the arrow pointing to the positive terminal. A straight line designates an AC voltage (see Appendix).

The formula for the determination of power in a circuit is

$W = EI\cos\theta$

where W is number of watts;
E is number of volts;
I is number of amperes;
θ is the angle between the voltage and the current vectors.

In DC circuits the phase angle is always 0 with the result that $\cos\theta = 1$ and disappears from the formula. Ohm's law may be combined with the power formula to yield various derivatives such as $W=I^2R$.

Control of the various elements of electricity is determined from these two formulae. Voltage can only remain constant if the other two components are varied; one must increase while the other decreases proportionately. If these conditions are not met, the voltage will no longer be constant.

The following are various methods of control of voltage and current in direct and alternating current circuits.

5.1.8.2 Voltage Control

5.1.8.2.1 Direct Current Voltage Control

R in the formula V = IR is regarded as a constant. The circuit in Figure 5.1.8.1 will provide an output voltage lower than Vin. Vout = Vin - IR. However, Vout will change if I changes. The circuit may be changed to that shown in Figure 5.1.8.2. Again the output voltage, Vout, is lower than Vin. It is commonly called a voltage divider circuit.

$V_{out} = V_{in} - IR$, and
$I = I_1 + I_2$.

If I_2 changes value then Vout will change but the change will not be as great as in the previous circuit. If I_2 is made smaller with respect to I then the change will be smaller.

A constant voltage can be provided if it is necessary. Certain devices referred to as voltage regulators are

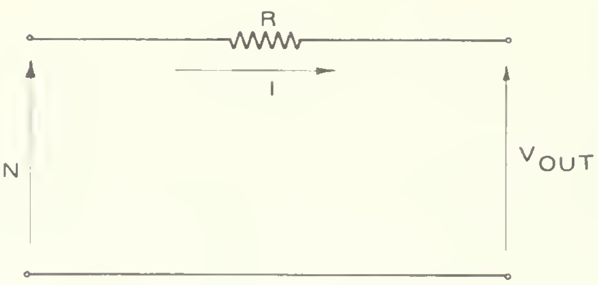


Figure 5.1.8.1 Direct current voltage control

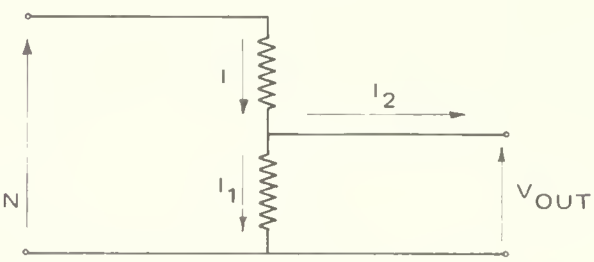


Figure 5.1.8.2 Voltage divider circuit

available to provide a constant voltage over a range of current. Such voltage regulators are a form of variable resistance and each will have a particular power rating which if exceeded will damage or destroy the device.

The fixed voltage regulators will maintain a voltage within specified limits. If a different fixed voltage is required another unit must be used.

However, units are not always available to provide the exact voltage required. If an exact voltage is required other than what could be provided by stock units, a variable constant voltage unit must be used.

5.1.8.2.1.1 Fixed Direct Current Voltage

A voltage regulating tube is a vacuum tube incorporating a conducting gas. The tube has a fixed resistance until conduction takes place, at which time the resistance varies (Figure 5.1.8.3).

The minimum value of R must be such as to limit the value

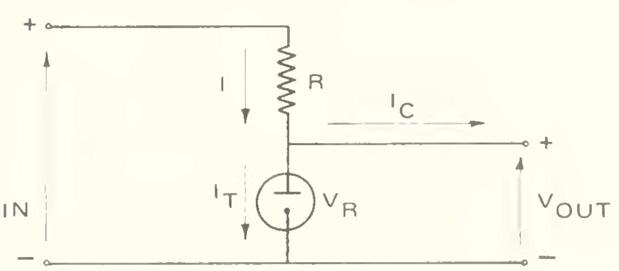


Figure 5.1.8.3 Fixed voltage control using VR tube

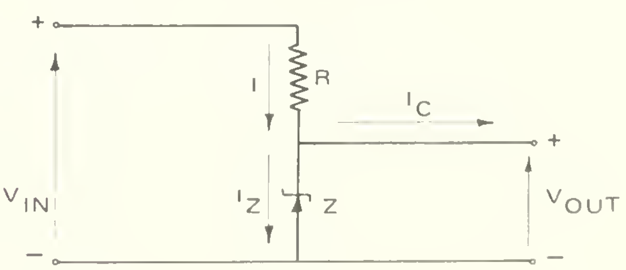


Figure 5.1.8.4 Fixed voltage control using Zener diode

of I_T to the maximum safe value for the tube when I_C is at its minimum expected value and Vin is maximum. The maximum value of R cannot exceed the number of ohms required to provide the minimum I_T with Vin minimum and I_C at its maximum value. Only a certain amount of flexibility with regard to input voltage and output current is available to the circuit designer. If Vin falls below a certain minimum then Vout will no longer be regulated but will vary. Voltage regulator tubes are used where Vout is equal to or greater than 75 volts. Tubes may be used in series to provide various voltages not available from a single tube.

Zener diodes are used for lower voltages and are available in a variety of voltages and power ratings. The circuit and circuit constraints are similar to those for VR tubes.

From Figure 5.1.8.4,

$$I_z \text{ max.} = \frac{P_z}{V_{out}}$$

where: Pz is the power rating of the zener diode and Vout equals the diode voltage

$$I = I_z + I_c$$

$$V_{in} = IR + V_{out}$$

From the above, the values of R and/or the maximum of Vin can be obtained. Vout will vary until Vin has some value greater than Vout.

5.1.8.2.1.2 Variable Direct Current Voltage

Many times it is desirable to vary the voltage supplied to a device. If the voltage does not need to remain exactly constant then a variable resistance (Figure 5.1.8.5) is used.

Vout depends on the value of I. The rheostat, R, must have a power rating in excess of the value of I^2R.

A change from the above to the circuit shown in Figure 5.1.8.6 will reduce the effect of a change in I, particularly as I_1 becomes less than I_2.

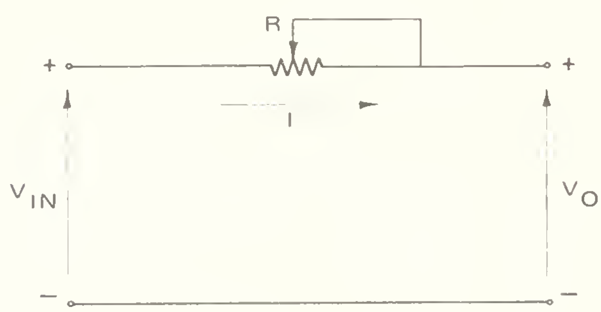


Figure 5.1.8.5 Variable voltage control, variable resistance

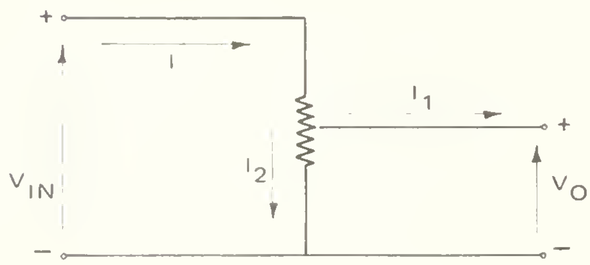


Figure 5.1.8.6 Variable voltage control - voltage divider type

The circuit shown in Figure 5.1.8.7 will be useful where the voltage must be varied between limits but once changed remain constant. R_3 is adjusted to set Vout to the desired level. Vout will remain constant over a wide change in I. Transistor Q_1 must have a current rating higher than the value of I. Breakdown voltage of Q_2 must be greater than the highest value of Vout minus the zener voltage. Such a unit may be built but good commercial units are available.

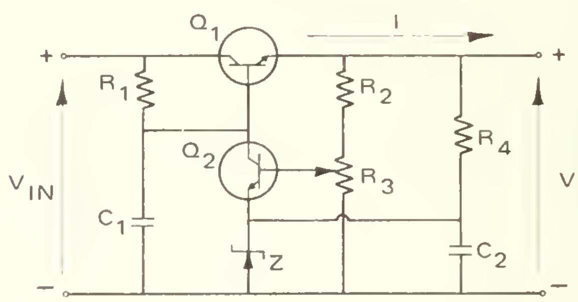


Figure 5.1.8.7 Solid state regulated variable voltage control

5.1.8.2.2 Alternating Current Voltage

Some circuits intended for control of DC voltages will work on AC - such circuits being those using resistances only. Resistances waste electricity. Since alternating current produces reactance in certain devices, reactance is used to create resistance to alternating current.

The amount of reactance is determined from the following:

$$X_L = \omega L$$

where X_L is the inductive reactance
ω is the angular frequency from $\omega = 2\pi f$, and
L is the inductance in henries

$$X_C = \frac{1}{\omega C}$$

where X_C is the capacitive reactance,
ω is the angular frequency, and
C is the capacitance in farads.

Since all circuits have some real resistance resulting from the resistance of wire, the complete resistance to alternating current is the impedance Z from:

$$Z = \sqrt{R^2 + X^2}$$

or, more completely:

$$Z = \sqrt{R^2 + (X_L + X_C)^2}$$

If the resulting phase angle is important then the equation becomes:

$$Z = \sqrt{R^2 + (X_L + X_C)^2} \ \mathrm{Tan}^{-1} \frac{X_L + X_C}{R}$$

where $\mathrm{Tan}^{-1} \frac{X_L + X_C}{R}$ is the phase angle.

Alternating Current Voltage Control

In Figure 5.1.8.8, the value of Eout for a specific X_L will depend on the value of I. If I varies then Eout will vary.

Eout (Figure 5.1.8.9) can be varied by changing the value of I_{DC}. The amount of direct current affects the

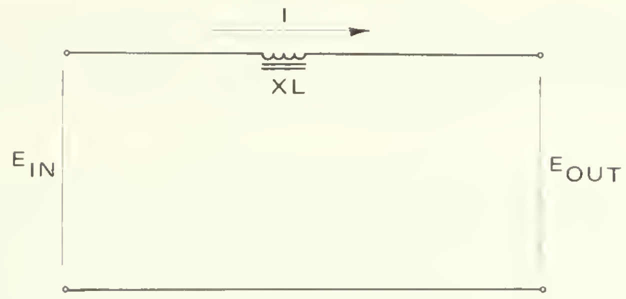


Figure 5.1.8.8 Alternating current voltage control - fixed

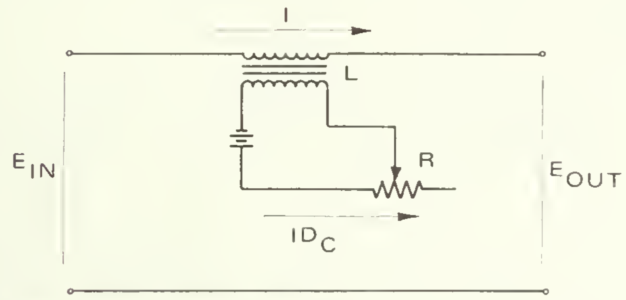


Figure 5.1.8.9 Alternating current voltage control - variable

impedance of L and the value of Eout and I. Current and voltage may be varied over a range of values.

One disadvantage of the above circuits is that the phase angle of the current vector will vary with respect to the voltage vector as the value of L is changed. Though this effect does not occur with pure resistive circuits, some applications exist where this effect could be important.

Often, in instrumentation, the AC input voltage to equipment must be kept constant. Automatic voltage control devices are available which will maintain a constant output voltage in spite of a varying input voltage.

5.1.8.3 Current Control

Usually, any device which will supply a variable voltage will also provide a variable current. Thus, many of the circuits shown in the previous section may be used to provide a variable current. However, special devices are available to provide a constant current. The current may be fixed or be variable within certain limits. These maintain a constant current once the value is selected. Commercial devices are available.

5.1.8.4 Power Control

Since the power of a circuit is a function of voltage and current, the effective power of an AC circuit can be varied by cutting off the electrical flow for part of a cycle. A complete AC cycle has the classic sine wave form. If the AC signal is cut off for part of the cycle then the effective power of that cycle is reduced. This procedure is used for speed control of the universal type of motor. Either triacs or silicon controlled rectifiers may be used.

5.1.8.5 Speed Control

5.1.8.5.1 SCR Controls

Many devices feature what is popularly described as a 'solid state' speed control. The device used is a silicon controlled rectifier (SCR). Its action is somewhat analogous to an intermittent syphon. Water builds up in the tank to a point where the syphon begins to operate and the tank is emptied. The process starts again when the water level is high enough.

The SCR is a three electrode semiconductor with four layers (a sort of double diode). Unlike a standard diode the SCR while it is quiescent has high resistance to current in both directions. Thus, if alternating current is applied to the SCR no current in either direction will result.

A SCR has an additional element called a gate. If the SCR is connected with a positive voltage on its anode, there will not be a current until a voltage is applied to its gate. This gate voltage must be positive with respect to the cathode. The SCR will immediately turn on (conduct) and a current results. This current will remain even though the voltage to the gate is removed. Should the voltage to the anode be removed or change polarity current through the device will stop. The SCR will then stay turned off regardless of what happens to its anode voltage. A new positive voltage must be applied to its gate to cause the SCR to conduct again.

The SCR is fast acting. Typical turn-on and turn-off times are 2μ sec (micro-seconds, 10^{-6} seconds) and 60μ sec, respectively.

If an SCR is connected to alternating current and its gate fed a reduced amount of alternating current from the same source, the SCR will turn on at some point during the positive half of the alternating current cycle and off when the cycle reverses (this occurs if the anode is connected to the incoming alternating current). The turn-on point is controlled by the amount of alternating current applied to the gate. This latter can be made variable and thus provide a variable direct current output from the SCR.

SCR's can be used in full wave or bridge rectifier configuration with single or three-phase alternating current systems.

Figure 5.1.8.10 shows a simple speed control circuit suitable for a series wound, direct current motor (a universal alternating current motor).

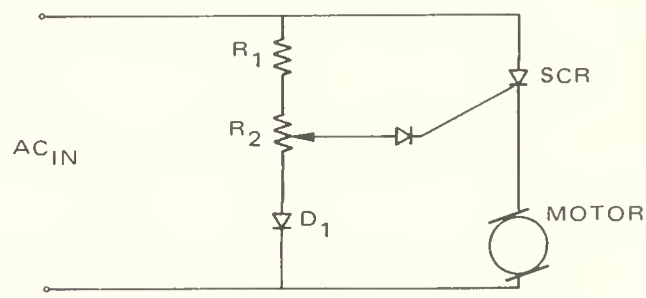


Figure 5.1.8.10 Basic speed control circuit

The SCR is turned on at a point during the positive half of the cycle determined by the setting of R_2. It turns off during the negative half cycle. Any motor generates a counter electromotive force as it rotates. When the motor driving current is cut off by the SCR, counter EMF is still produced by the armature because of residual magnetism in the field. The CEMF back biases the SCR which will not conduct until the gate voltage rises above the CEMF. This forms a type of regulator circuit which helps maintain a constant speed. Diode D_2 prevents damaging reverse voltage from being applied to the SCR gate.

The same circuit, using the additional parts shown in Figure 5.1.8.11, can be used with a shunt motor.

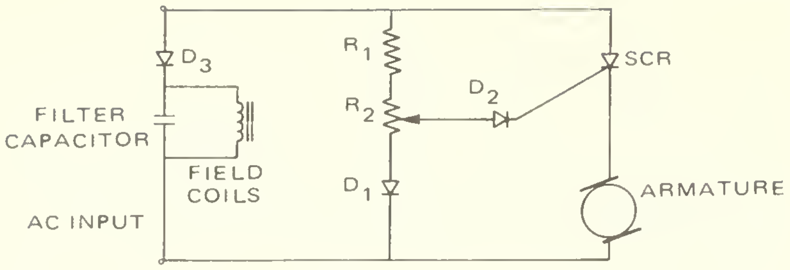


Figure 5.1.8.11 SCR Control for shunt wound motor

Diode D_3 is used to provide direct current voltage to the field coils.

Speed control circuits of this kind can be applied to any size direct current motor provided suitably rated components are used. The motor will develop up to about 75% of its rated power.

5.1.8.5.2 **Triac**

The triac can be loosely described as a sort of double silicon controlled rectifier. The name implies a TRIode (three electode) AC switch. The triac can conduct or block current in either or both directions and it can be triggered on in either direction by a positive or negative gate signal. When the current drops below a certain level it will stop conducting.

Advantages of a Triac. High power levels can be controlled by a low power control source. Unlike the SCR with control over a half wave and conduction in one direction, the triac has full wave control and conduction in both directions. The triac resets itself every half cycle.

Figure 5.1.8.12 illustrates a simple circuit wherein the triac controls the voltage applied to the load. A sample use for the circuit would be in motor speed control.

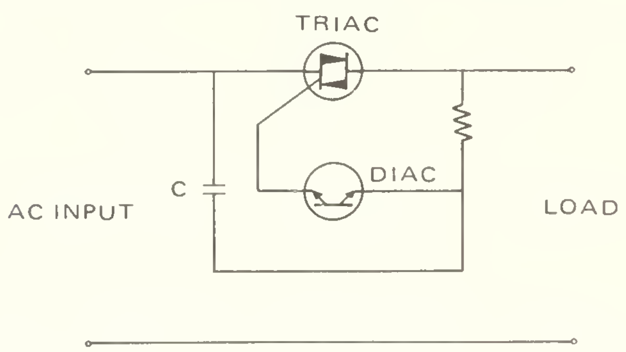


Figure 5.1.8.12 Basic Triac voltage control circuit

A triac could be used to replace a single-pole, single-throw relay wherein the application of a small signal voltage to the gate would cause the triac to conduct.

In the circuit shown in Figure 5.1.8.13, S_1 applies a small voltage, limited in value by R_1, to the gate of the triac turning it on.

One note of caution. Since triacs require only a very low power source for control, they are sometimes subject to interference on the power lines. When a device is started, particularly if it is a large size, a pulse appears on the power line. If that device is being controlled by another triac, pulses from that triac may appear on the power line. These pulses, which would not affect mechanical relays, can and do affect other solid state relays such as those utilizing triacs. The other triacs may partially turn on when they should not. Such interference is called cross talk. Reference to the bibliography will show sources of additional information.

5.1.8.6 **Alternating Current Frequency Control**

Some AC devices respond to the AC frequency. Some control of these devices may be effected by changing the frequency. This can be done by generating the desired frequency at a power level great enough to drive the device. The basic control unit is a very stable variable frequency oscillator whose output is amplified to a sufficient power level. These devices are commercially available.

Some devices which are affected are certain AC motors and timing devices. The amount of change in speed possible depends on the particular unit. Increasing the frequency increases the speed and the impedance and reduces the current. As a result, the power output of the unit will be reduced. Decreasing the frequency decreases the speed but it also decreases the impedance which in turn will increase current. Care must be taken that the current does not exceed the safe level for the device.

5.1.9 ELECTRICAL MEASUREMENTS IN CONTROL SYSTEMS

Some measurement devices have been discussed previously, such as those to measure speed, counting and running time. Particularly in manually controlled systems, the operator has a need to know the current, voltage and power being applied. Based on the meter information, the operator then regulates the systems.

5.1.9.1 **Moving Coil Instruments**

Most electrical meters are of the moving coil or d'arsonval movement. In this type, electricity flowing through a coil of wire creates a magnetic field. The coil is free to rotate and is located in a second strong magnet field. The coil attempts to rotate. Rotation is restrained by a hair spring. The amount of rotation depends on the strength of current and the hair spring tension. Meters of this type can be made which will give full scale deflection with currents as low as 10 micro amperes. Direct current only is measured. If the meter is to measure AC, the AC must first be converted to DC by a rectifier circuit.

5.1.9.1.1 **Ammeter**

The ammeter, if it is connected into the circuit, is in series. Current to the device then must pass through the meter. Often the actual meter used is capable of measuring only

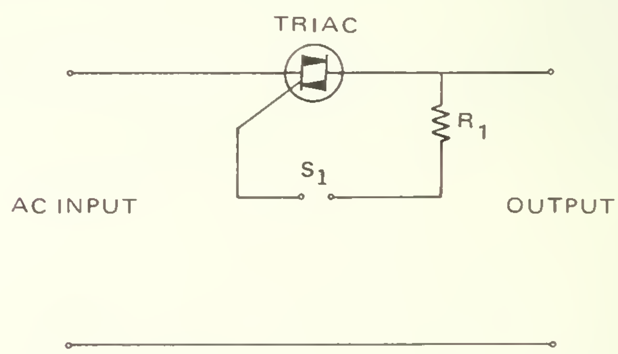


Figure 5.1.8.13 Triac switching circuit (solid state relay)

a relatively small current. The bulk of the current to be measured passes through a meter shunt and a small portion of current actually passes through the meter which has been calibrated accordingly.

It is not always necessary to use a meter connected into the circuit. Electricity flowing in a wire creates a magnetic field, the strength of which is dependent on the amount flowing. In some meters, the current carrying wire is looped through a pickup on the back of the meter which has a soft iron core. The core attempts to align itself with the magnetic field but is restrained by a spring.

If AC is being measured, a current transformer can be used. The alternating magnetic field about the wire generates a voltage on the secondary proportional to the current. A voltmeter reads this voltage but is calibrated in amperes. Current transformers are available for a wide range of AC currents.

5.1.9.1.2 **Volt Meter**

The same d'arsonval meter will measure voltage. The meter is an ammeter but by putting resistance in series to limit the meter current, it will read voltage. Suppose the meter requires 50 microamperes to read full scale and the voltage to be read is 250 volts.

Ohm's Law $V = IR$ becomes $R = \frac{V}{I}$

and $R = \frac{250}{50 \times 10^{-6}}$

$R = 5 \times 10^{6}$ ohms

This works out to be 20,000 ohms per volt and the meter is said to have a sensitivity of 20,000 ohms per volt. If AC is to be measured a bridge rectifier is inserted into the meter circuit to convert the AC to DC.

5.1.9.1.3 **Watt Meters**

In Section 4.1.7.2.7 of the Power Units Section, it is shown that many AC circuits have reactance and that the power in such a circuit is:

$W = WI \cos\theta$

where θ is the phase angle. A watt meter combines voltage and current and the phase angle to measure watts. However, since the number of volt amperes in a reactive circuit is greater than the number of watts, it is more common to measure the volt amperes.

5.1.9.2 **Digital Meters**

With moving indicator meters, the user must convert the position of the meter indicator to the number of volts or amperes or watts. He does this by comparing the position of the indicator to the scale. He may also mentally have to multiply the reading by a multiplier to obtain the final reading. Meters are available which read directly in digits. Current or voltage in the circuit is sampled and the value digitized. Digital meters are more expensive. Digital output from these meters can be used to effect control.

5.1.10 CONTROLS WITH INTELLIGENCE

Materials handling systems can become more sophisticated than those described up to the end of Section 5.1.8. Sophistication increases as machine directed control increases and the requirement for human control decreases. Systems described so far are termed hard-wired. Hard-wiring means that components are permanently connected together to do certain operations one after the other; in other words to follow a preset sequence or program. A hard-wired system has little flexibility. The program cannot be altered without a major rewiring of the components. Often additional or other components are required. The new program has little flexibility.

Very complex control systems can be built using relays and logic elements for AND, OR or NAND, NOR circuit elements. The latter may be mechanical or solid state logic elements. Part of the complexity comes from the interconnection of components needed to achieve the sophistication of control required. As stated, once completed, such a control system has little flexibility and must be rewired to change the control pattern or program.

5.1.10.1 **Microprocessor**

A microprocessor is a control unit which will provide certain outputs based on certain inputs. The output provided for a particular input depends on what the processor has been instructed to do when that particular input is present. So far, this type of control is no different than the more conventional control systems. The microprocessor differs in that it reads the instruction it is to follow from a memory and then it provides a certain output. It may make certain decisions of its own based on the inputs. It is thus said to be smart or intelligent. After the instruction has been completed, the microprocessor goes to the next step again recorded in a memory. The microprocessor literally reads the instruction from the memory for its next action much the same as the human operator would follow a list which gave directions for a particular operation. Give the operator a new list of directions and he performs a different set of tasks. Change the memory that lists the instructions to the microprocessor and it performs another set of control functions. The oprator knows how to perform many of the functions and requires only a minimal list of instructions. The microprocessor, however, must have a very detailed list of instructions since the number of functions that it can perform by itself are very limited.

Microprocessors may be used in many ways but are usually used for one of two main functions. These are: 1) as a logic processor for dedicated control, i.e. a controller, or 2) a data processor (micro-computer). As a logic processor, the microprocessor is dedicated or hard wired. However, the control process can be changed by changing the control memory, i.e. the list of instructions. If any rewiring is necessary the changes are relatively simple in comparison to the changes required with the

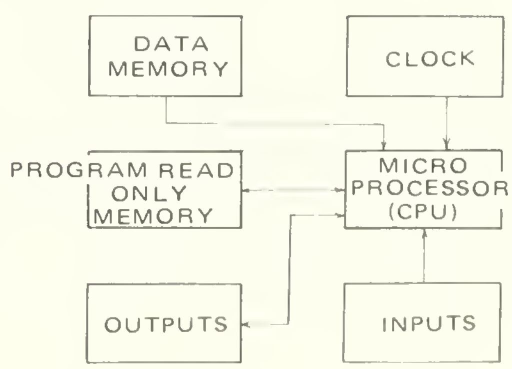


Figure 5.1.10.1 Block diagram of a logic processor

conventional control. Control flexibility can be increased by changing the memory. For example, suppose a time delay is to be incorporated where none existed before. In conventional control a time delay unit (a time delay relay or a solid state time delay) must be wired into the circuit and the time delay itself adjusted to the right delay. With the microprocessor, the memory is changed to not only incorporate a time delay as one step but to define the exact length of this delay. No components are added and no wiring changes are required.

The microprocessor is the central processing unit, the device which reads the instructions and follows them. The Programmable Read Only Memory (PROM) which is permanent, i.e. does not erase if power is turned off, carries the list of instructions or steps. The PROM can be reprogrammed or another PROM substituted to change the control sequence. The data memory is the place where the Central Processing Unit (CPU) temporarily stores the results of calculations or other events. Various sections or all of the data memory can be erased or changed by the CPU. (a power interuption will also erase this memory). Inputs are bits of information coming into the system that the CPU may sample as the program memory steps require as for example the level of a bin. The outputs are the control outputs going to various controlled components such as the signal to stop or start a motor or open or close a valve. Input and outputs of the microprocessor (CPU) are connected to the real world through interfaces.

Inputs and outputs are digital signals. However, proportional signals may be transformed to digital signals for use by the microprocessor and the outputs converted to proportional signals when required.

As stated, the microprocessor goes through the program memory one step at a time and provides outputs. All of this movement through its functions must be controlled timewise. The clock simply provides timed pulses to the CPU. The CPU moves to the next step at each clock pulse.

The microprocessor advances through its list of instructions completing the instruction and moving to the next instruction. The list may jump the control ahead or back several instruction steps depending on the condition of an input parameter when the particular instruction step is reached. The last instruction step of all may shut down control until the system is reset or the last step of all may send the control back to an earlier step or back to the beginning.

As an example of further flexibility at any point in the directions, the microprocessor can be made to do arithmetic calculations and based on the outcome do any of several other functions. It can also store results in a second memory for use at another point in time according to instructions. Because of these abilities the controller is said to be a smart control or a controller with intelligence.

5.1.10.1.1 Programmable Controllers

Ready to use off-the-shelf units utilizing a microprocessor are available from several companies. These are adaptations of the microprocessor controllers, the adaptation being that they have a built-in system for programming the controller and for changing or modifying it at any time.

A designer with some expertise in the use of microprocessors can design his own control system to match his requirements, selecting the proper components. This expertise is not needed to utilize a programmable controller. A programmable controller with sufficient capacity for the work intended is purchased. With it comes a set of instructions on how to program the controller through a keyboard which is part of the controller.

The capacity of most programmable controllers can be increased within limits by add-on units.

5.1.10.2 Computer Controller

This type of controller is controlled by a computer which may be small or large. The computer control goes on in sophistication from where the microprocessor and/or programmable controllers leave off. All the computation and decision making ability of the computer is available for the control.

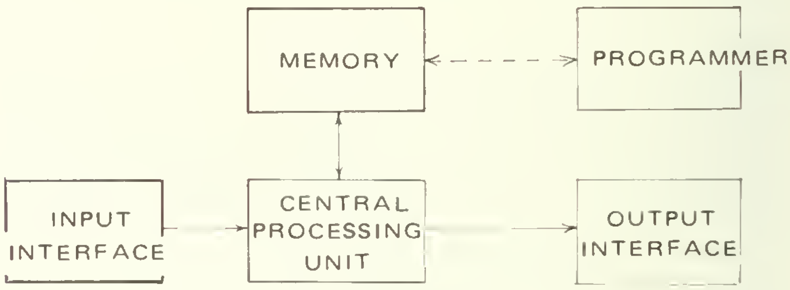


Figure 5.1.10.2 Block diagram of programmable controller

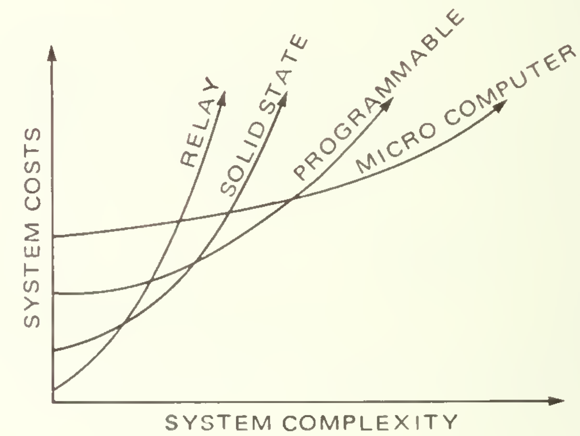


Figure 5.1.10.3 Relative control system costs as related to system complexity

Figure 5.1.10.3 shows the cost versus complexity relationship for various methods of control. A simple system using relays is much less expensive than the same system controlled by a micro computer. However if the system is complex the cost for a relay system would be greater than if the system were based on a micro computer.

5.1.11 MEASUREMENT AND CONTROL OF NON-ELECTRIC FACTORS*

The following sub-sections pertain to the measurement or control of other mediums than that of electricity as, for example, air flow, humidity, liquid, bulk and light.

Various methods of control and measurement are listed together with the hardware required to effect the control or measurement. The hardware is listed by method of

*Revision of former Materials Handling Manual 5 1 operation in the following order: mechanical, electrical, optical, and any combinations of these.

Note: Some of the following sub-sections are covered more fully in other sections of the materials handling manual. They appear here because of their relevance to control but in less detail.

5.1.11.1 Characteristics (Table Headings Common to all Tables)

Flow Quantity or Quantity Handled: This is a measure of the amount of material being handled. The key is:

- S = Small quantities only
- L = Large quantities only
- A = Any amounts of materials. Not necessarily with the same item of equipment, but this type of equipment could be used for any desired quantity.

Metering: The metering column indicates how well the method considered will measure and control the amount or weight of a material being handled. (Or in other cases the ability of the method to measure and control the variable in question).

Hand Portable: This indicates the ease of applying this measurement manually to one or more locations or pieces of equipment.

Automatic: This is a measure of the ability of a measurement method to perform automatically (without human supervision).

Local: This indicates how good an indication/control the method gives at the instrument itself.

Remote: If a method is capable of remote measurement and/or control it is rated in this column.

Continuous: This indicates how well the method will keep a continuous measure or control of the variable.

Power Required: This column uses the following key:

- E = means that external electrical power is required to operate the sensing element and/or perform the control function.
- P = means that mechanical power is required and control and/or measurements are obtained directly from this.
- EP = means that both electricity (for sensing), and mechanical power are required. (Mechanical power exceeding the usual small electrical control element power is required.)
- — = means that no external power is required.

Ease of Operation: The ease of operation column indicates the complexity of the measurement and/or control operation and is a measure of the ease with which an operator can obtain satisfactory results with the method in question.

Dependability: This considers the sensitivity of the measuring and control equipment to damage, wear, misuse and failure due to the failure of components such as electron tubes, relays, bearings, sensing elements and the like. This rating is based on the complexity of the equipment, its composition, its use, and its environmental hazards.

Relative Cost: A general estimate of the relative cost of the various methods. Depending upon individual applications and requirements, the actual costs could be much different. These ratings attempt to give an indication of the relative cost between different methods of doing the same job.

5.1.11.2 Gases - Measurement and Control

When handling air and other gases the common factors to be measured and controlled are:

1. Velocity
2. Volume
3. Temperature
4. Humidity
5. Pressure

These factors and some of the common methods to measure and control them are listed in Table 5.1.11.1. Some definitions applicable to Table 5.1.11.1 are as follows:

Air Movement:

- Unrestricted: Flow in the open, not enclosed, in a horizontal plane, with air flow from any direction.
- Pipe: The flow of air within a pipe or other confining enclosure. Usually forced flow.
- Pressure: Flow through a pipe or channel under a static pressure much different than atmospheric.

No Air Movement:

- Tank Measurement: The measurement of air characteristics within a tank assuming no forced air movement within the tank.

The methods and equipment listed in Table 5.1.11.1 are generally available and are briefly described below.

1. Swinging Vane: An Anemometer in which the air movement working against gravity, spring, or artificial pressure, forces a vane to change its position and therefore its indication. The position movement can control the velocity directly by means of switches or pickups.

2. Rotating Vane: An Anemometer in which the air movement turns a propeller mechanism whose rotational speed is measured and used to determine the air velocity.

3. Rotating Cup Anemometer: Cups on arms pivoted to rotate in a horizontal plane.

4. Pitot Tube Anemometer (Velometer): A differential pressure comparing the velocity pressure with the static pressure. The unit which senses the velocity and static pressure is called a pitot tube. The velocity pressure pickup is an open end tube pointing into the air stream. The static pickup is not exposed to the air stream.

5. Venturi and Orifice Anemometer: For pipe flow a restriction in the pipe causes a change in the static pressures at the throat as compared to the normal flow. A differential pressure meter measures the difference.

6. Manometer: A tube often in the shape of a u has one of its ends exposed to the point of pressure to be measured and the other to a static source. The measurement of the displacement of the liquid from the normal position determines the pressure.

7. Hot Wire Anemometer: A resistance bridge in which one arm is a heated wire exposed to the air flow. The change in resistance (or current) is related to the

TABLE 5.1.11.1 Selection Chart for Air Characteristics and Applications

Key 1 = Good
2 = Average
3 = Poor
D = Direct
ID = Indirect
E = Electronic
EP = Electric Power
P = Physical

No.	Applications					Flow*						Characteristics – Equipment – Measurement					Control			System					
	Velocity	Volume	Temperature	Humidity	Pressure	Flow Quantity	Unrestricted	Pipe	Pressure	Tank Measurement	Metering	Hand	Automatic	Local	Remote	Continuous	Local	Remote	Continuous	Power Required**	Ease of Operation	Dependability	Relative Cost	Notes	No.
1	D	ID				L	2	1	1	-	2	1	2	1	3	1	2	2	2	-	1	1	1	Simple - practical	1 Swinging vane
2	D	ID				A	2	1	1	-	1	1	1	1	1	1	1	1	1	E	2	2	3	Good but expensive	2 Rotating vane
3	D	ID				L	1	3	3	-	2	1	1	1	1	1	1	L	1	E	2	2	2	Good for wind measure	3 Rotating cup anemometer
4	D	ID				L	3	1	1	-	3	2	3	2	2	2	3	3	3	-	3	1	2	Differential pressure measurement	4 Pitot tube anemometer
5	D	ID				A	3	1	1	-	2	3	3	2	2	2	3	3	3	-	3	1	1	Differential pressure measurement	5 Venturi and orifice anemometer
6	D	ID			D	L	1	2	1	-	3	1	3	1	3	1	3	3	3	-	2	1	1	Good for low pressures	6 Manometer
7	D	ID				A	2	1	1	-	1	1	3	1	1	3	1	1	3	E	3	2	3	Often used to calibrate others	7 Hot wire anemometer
8	D	ID				A	2	1	1	-	1	1	3	1	1	3	1	1	3	E	3	2	3	Often used to calibrate others	8 Thermocouple anemometer
9			D			A	1	1	1	1	1	1	1	1	2	1	1	2	1	-	1	2	2		9 Expansion bulb thermostat
10			D			A	1	1	2	1	-	1	1	1	-	1	1	-	1	-	1	1	1	Simple, rugged	10 Bimetal thermostat
11			D			A	1	1	1	1	-	1	1	1	1	1	1	1	1	E	1	2	3	Several points can be	11 Thermocouple meters
12			D			A	1	2	2	1	-	1	1	1	1	1	1	1	1	E	1	2	3	connected to the same	12 Resistance thermometer
13			D			A	1	1	1	1	-	1	1	1	1	1	1	1	1	E	1	2	3	measuring instrument	13 Thermistor
14				D		L	1	3	3	3	-	1	-	1	-	-	-	-	-	P	3	2	2	Open air measurements	14 Sling psychrometer
15				D		A	2	1	3	3	-	2	2	1	1	1	1	1	1	E	2	2	3	Hand method same as 10	15 Wet-dry bulb (w/controller)
16				D		A	1	2	3	1	-	1	3	2	-	2	3	-	3	-	1	3	2	Very delicate	16 Hair hygrometer
17				D		A	1	2	3	1	-	1	3	2	-	2	2	-	2	-	1	2	2		17 Membrane hygrometer
18				D		A	1	1	1	1	-	1	1	1	1	1	1	1	1	E	2	2	3	RH range limited	18 Electrical conductivity hygrometer
19				D		L	3	3	-	2	-	1	1	2	2	3	2	2	3	E	2	2	3	Laboratory measurements	19 Dew point meters
20					D	A	-	3	1	1	-	1	1	1	-	1	1	-	1	-	1	2	2		20 Pressure gage w/control
21					D	A	-	2	1	1	3	3	3	3	-	3	1	-	1	-	1	1	2		21 Opposed diaphragm
22	ID	D				A	-	2	1	-	2	3	1	1	3	1	2	-	2	-	1	1	2		22 Orifice or nozzle
23	ID	D				S	-	1	3	-	1	2	1	1	3	1	1	3	2	P	1	2	2	Forced flow	23 Rotating gear or paddles
24	ID	D				S	-	1	3	-	1	1	2	1	2	2	1	3	2	P	2	2	3	Forced flow	24 Bellows
25	ID	D			ID	S	-	1	1	-	1	2	1	1	2	2	1	2	1	P	2	1	2	Forced flow	25 Piston

*See 5.1.11.1 for definitions
**Power Required, see 5.1.11.1

cooling effect of the air flow and is measured to give the indication.

8. Thermocouple Anemometer: Similar to the Hot Wire Anemometer except a thermocouple is used to indicate the cooling of the hot wire.

9. Expansion Bulb Thermostat: (5.1.11.3 - No. 13).

10. Bimetal Thermostat: (5.1.11.3 - No. 12).

11. Liquid in Glass Thermometer: (5.1.11.3 - No. 11).

12. Thermocouple Meters: (5.1.11.3 - No. 15).

13. Resistance Thermometer: (5.1.11.3 - No. 14).

14. Thermistor: (5.1.11.3 - No. 16).

15. Sling Psychrometer: Two thermometers are rotated through the air. One has a moist covering to give the wet bulb temperature. The other gives the dry bulb temperature.

16. Wet-dry Bulb (w/controller): Two resistance thermometers, thermistors, or thermocouples are connected in the air stream, one with a wet bulb arrangement, to read the wet bulb and dry bulb temperature. These operate the controllers. Require 274 m/min (900 ft/min) or more to operate.

17. Hair Hygrometer: Hair (usually human) is stretched to form the active element and is connected to operate an indicator.

18. Membrane Hygrometer: Animal membrane is used as the active element. This is stronger and produces more force than the hair hygrometer, but will not hold calibration as well. Nylon is also used.

19. Electrical Conductivity Hygrometer: An electrical grid separated by a semi-conductive material (humidity sensitive). These generally have a limited humidity range and must be held at a constant temperature.

20. Dew Point Meters: Air is cooled until it reaches its saturated state. This temperature and the original give the humidity.

21. Pressure gauge w/control: (5.1.11.3 - No. 4).

22. Opposed Diaphragm: (5.1.11.3 - No. 5).

23. Orifice or Nozzle: (5.1.11.3 - No. 17).

24. Rotating Gear or Paddles: (5.1.11.3 - No. 18).

25. Bellows: A diaphragm or bellows which fills and empties or which displaces a fixed quantity of air per stroke or movement. The number of strokes or movements will give a measure of the volume.

26. Piston: A piston pump will also supply a measure of the quantity being produced. These will also produce and control pressures.

5.1.11.3 **Liquid Measurements and Control**

The desired controllable factors in handling liquids are:

1. Level
2. Weight
3. Volume
4. Temperature
5. Color

Table 5.1.11.2 gives the most common methods of measuring and controlling these factors, with the

TABLE 5.1.11.2 Selection Chart for Liquids Applications and Characteristics

No.	Level	Weight	Volume	Temperature	Color	Quantity Handled	Open	Sealed	Free	Forced	Level	Inclined	Vertical	Gravity	Open Channel	Metering	Hand-Portable	Automatic	Local	Remote	Continuous	Local	Remote	Continuous	Power Required**	Ease of Operation	Dependability	Relative Cost	Method
	Applications													Characteristics Equipment											Characteristics System				
	Characteristics					Tanks*			Pipe Flow*					Flow*			Meas-sure't				Control								
1	D	ID	ID		ID	L	1	3	-	-	-	-	-	3	1	3	1	3	1	-	1	-	-	-	-	1	1	1	1 Ball Float and indicator
2	D	ID	ID			L	1	1	-	-	-	-	-	3	1	3	3	1	2	-	2	1	-	1	-	1	1	1	2 Float valve
3	D	ID	ID		ID	A	1	1	-	-	2	-	-	3	3	-	1	3	1	-	1	-	-	-	-	1	1	1	3 Gauge glass
4	ID	ID	ID			L	2	2	3	2	3	3	3	-	3	3	1	2	1	3	2	1	3	1	-	2	2	2	4 Pressure gauge w/control
5	ID	ID	ID			L	2	2	-	2	3	3	3	-	-	3	3	3	3	3	3	1	-	1	-	1	1	2	5 Opposed diaphragm
6	ID	ID	ID			L	1	1	-	-	-	-	-	2	2	-	2	1	1	1	1	2	2	2	E	3	2	3	6 Electrode probe
7	ID	D	ID			L	1	1	3	3	3	3	3	2	2	3	1	3	1	3	2	3	-	3	-	2	1	1	7 Counter balanced beam
8	ID	D	ID			L	1	1	3	3	3	3	3	2	2	3	1	2	1	3	1	2	-	3	-	1	2	1	8 Springs
9	ID	D	ID			L	1	1	2	2	2	3	3	2	2	2	2	2	1	1	1	1	3	1	-	1	2	2	9 Hydraulic load cell
10	ID	D	ID			L	1	1	2	2	2	2	2	2	2	2	3	1	1	1	1	1	1	1	E	1	2	3	10 Electric load cell
11				D		L	1	3	3	3	3	3	3	2	2	-	1	-	2	-	2	-	-	-	-	2	2	1	11 Glass Thermometer
12				D		L	1	2	2	3	2	2	2	2	2	-	1	1	1	3	1	1	-	1	-	1	1	1	12 Bimetal thermostat
13				D		L	1	1	2	2	1	1	1	1	1	-	3	1	1	1	1	1	1	1	-	2	2	2	13 Filled bulb thermostat
14				D		L	1	1	2	2	1	1	1	1	1	-	3	1	1	1	1	1	1	1	E	2	2	3	14 Resistance Thermometer
15				D		A	1	1	1	1	1	1	1	1	1	-	3	1	1	1	1	1	1	1	E	2	2	3	15 Thermocouple control
16				D		A	1	1	1	1	1	1	1	1	1	-	3	1	1	1	1	1	1	1	E	2	2	3	16 Thermistor control
17	ID	ID	D			A	2	2	2	1	1	1	1	1	-	1	2	-	3	-	3	2	-	2	E	2	1	1	17 Orifice or nozzler
18	ID	ID	D			S	-	-	1	1	1	1	1	2	2	-	2	2	2	2	3	1	1	1	P	1	1	2	18 Rotating gear or paddle wheel
19	ID	ID	D			L	-	-	-	-	-	-	-	1	1	1	3	-	3	-	3	2	-	2	E	2	1	1	19 Notch or weir
20					D	A	2	2	3	3	3	3	3	2	2	3	2	2	1	3	3	3	3	3	E	3	3	3	20 Photo cell and filters
21					D	A	2	2	3	3	3	3	3	2	2	3	2	2	1	1	1	2	2	2	E	3	3	3	21 Multiple selective photo cells

Key
1 = Good
2 = Average
3 = Poor
D = Direct
ID = Indirect
E = Electronic
EP = Electric Power
P = Physical

*See 5.1.11.1 for definitions
**Power Required, see 5.1.11.1

characteristics and applications of these methods.

Some definitions applicable to Table 5.1.11.2 are as follows:

Tanks

Open: A tank open at the top. Inlet and outlet can be at any point on the tank.

Sealed: A tank under pressure or with no exchange of air and no fluid leakage. Inlet and outlet can be located at any point on the tank.

Pipe Flow

Free: Non-forced flow through a pipe. The pipe can be partially or completely full.

Forced: The fluid is forced through the pipe under pressure.

Level: The flow can be either free or forced so long as the pipe is level.

Inclined: The pipe is inclined at an angle between level and vertical. (Evaluations are based on a 30° to 60° angle, if either limit is approached the ratings will usually approach those given for those conditions).

Vertical: The pipe is oriented vertically.

Flow

Gravity: The fluid flows due only to the force of gravity.

Open Channel. The flow is restricted on the bottom and sides but not on top. The channel can have any configuration.

The methods as indicated in Table 5.1.11.2 are briefly described and pictured following.

1. Ball Float and Indicator: This is a dial driven by a float to manually observe the fluid level in a tank or a trough. It is possible to use a complete enclosed unit in a tank and observe the reading through a window.

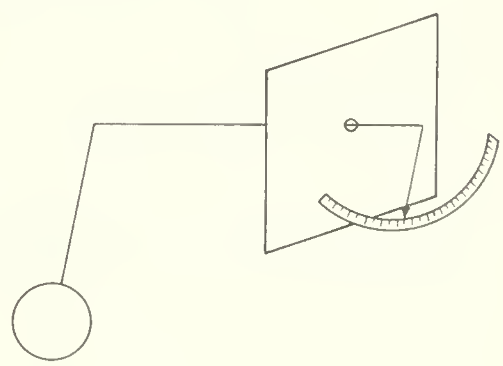


Figure 5.1.11.1 Ball float and indicator

2. Float Valve (limited range of measurements and control): Simple and dependable for use with open or atmospheric pressure tanks. Pressures greater or less than atmospheric will present problems. This unit must be located within the tank requiring access to the tank for inspections and repairs, also the valve must be located close to the float and mechanically connected to it. This unit does not perform well if excessively vibrated. This

unit can be combined with an indicator to show level. Electrical connections can be installed to give a remote indication, control, or feedback to a meter controller at an added expense.

3. Sight Gauge: This operates like a window in the tank to observe the level of the liquid. The external gauge usually has a limited range and must be kept clean to give a dependable reading. This type can be used under a variety of pressures and temperatures, but must be observed optically to obtain a measurement.

4. Pressure Gauge and Control: This method uses the pressure head developed by the liquid to operate a controller to regulate the level of the liquid, the weight of the liquid or the quality of the liquid, whichever is desired.

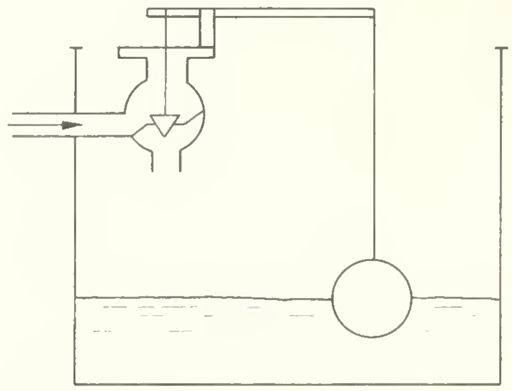


Figure 5.1.11.2 Float valve

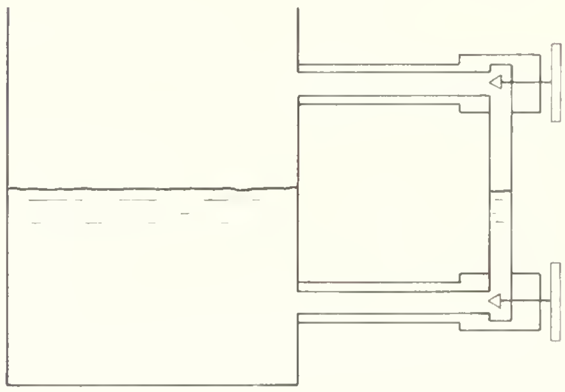


Figure 5.1.11.3 Gauge glass

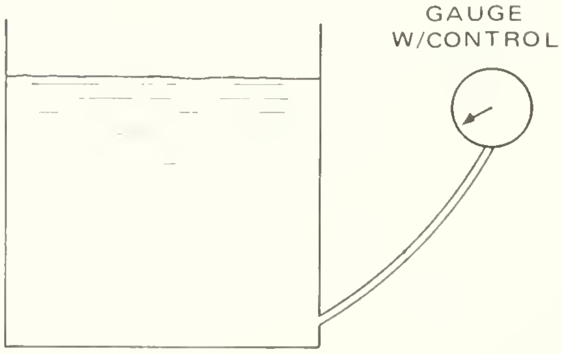


Figure 5.1.11.4 Pressure gauge and control

5. Opposed Diaphragm: The pressure of the liquid is fed to one side of a diaphragm and is balanced by a spring on the other side. If an imbalance occurs, the diaphragm moves, opening or closing the connected valve to obtain equilibrium.

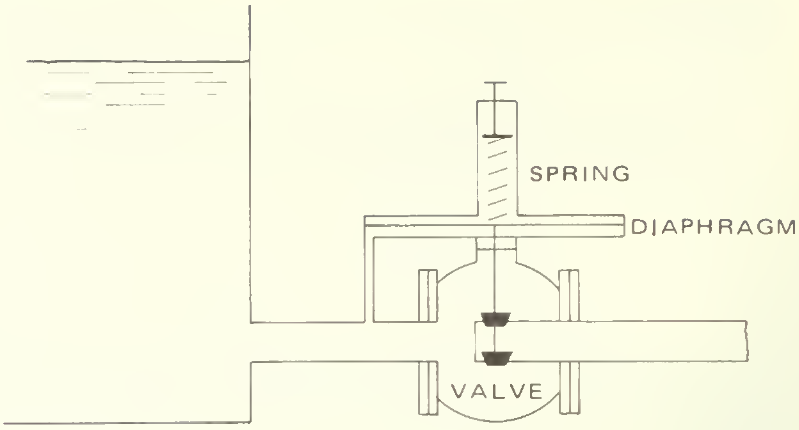


Figure 5.1.11.5 Opposed diaphragm control

6. Electrode Probe Method: The change in resistance or capacitance between two electrodes can be used to control the level of a liquid in a container. This can be used for liquids which will not be ignited by arcing. (See also 5.1.2.1.10)

7. Counterbalance Beam: A container or section of a conveyor being free to respond to weight changes is balanced by a weight on a beam. The end of the beam either operates a pointer and/or contacts a row of microswitches which signal and/or control the supply. See also 5.1.5.2, Weighing.

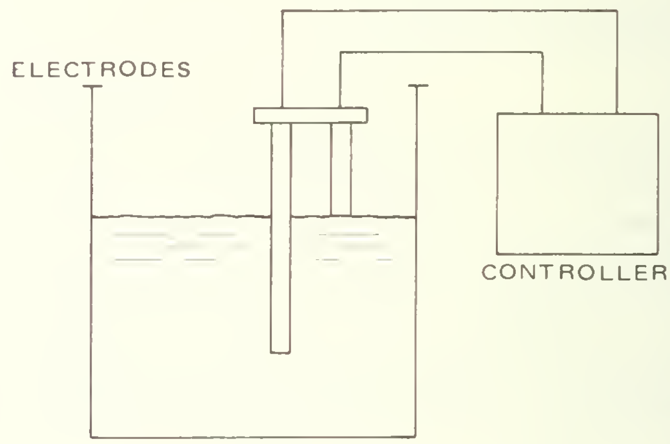


Figure 5.1.11.6 Electrode probe controller

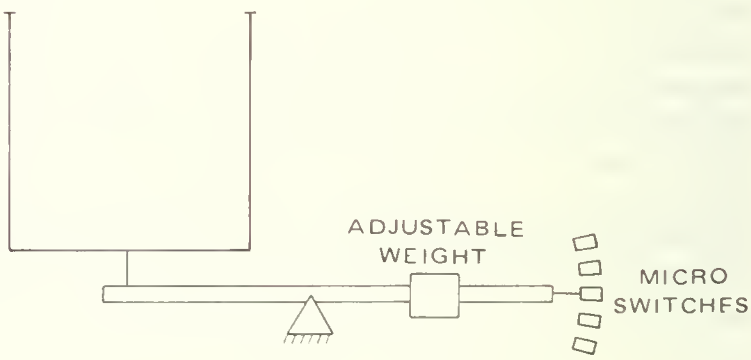


Figure 5.1.11.7 Counterbalanced beam

8. Springs: The section of conveyor or container containing the material is supported by springs. The deflection gives a measure of the weight of the material. Switches may be used as in the counterbalanced beam method to give signal and control characteristics.

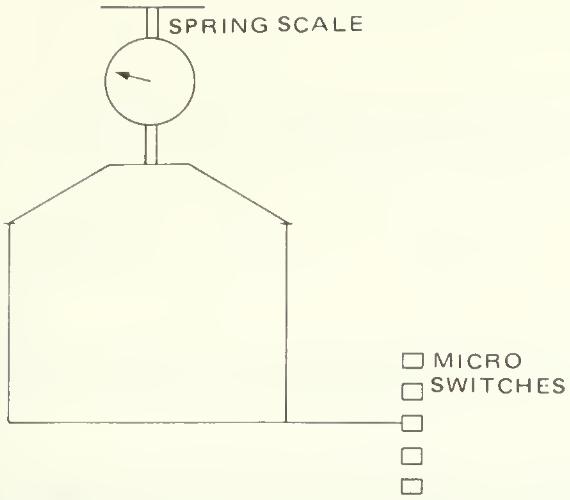


Figure 5.1.11.8 Spring weighing

9. Hydraulic Load Cell: A hydraulic load cell uses a fluid to transmit the weight from the load cell to the controller which controls the input to the system. These units are fairly sensitive and provide a good control.

10. Electric Load Cell: The change in weight changes the resistance in the electric load cell which is measured by the controller and used to initiate the control signals. This control is very sensitive and gives good control characteristics.

11. Thermometer: The common glass bulb, mercury filled thermometer is inexpensive and good for room temperature where a fairly accurate measure of the temperature is desired. These are delicate and cannot be exposed to rough treatment or extremes of heat without destructive damage. They can be immersed in static fluids or in moving fluids if they are shielded, but in solids the physical shielding problem would virtually eliminate their use.

12. Bimetal Control: These operate by the dissimilar expansion of metals using a composite bar to bend (or in some instruments to rotate) opening or closing electrical contacts and/or driving a pointer. This is the principle that is used in many circuit breakers and electrical overload devices.

13. Vapor-Gas-Liquid Filled Bulb Thermostat: The bulb may be filled with a gas, a liquid or with a liquid and vapor. The operating characteristics of each of these are basically similar and depend upon the transmission of pressure caused by the expansion of the material in the bulb (gas, liquid or vapor) to the controller. These are sensitive controls with a common accuracy range to about 0.3°C. The bulb and controller must be connected by tubing and except in special cases, this connection must remain attached. If a bulb or tube is broken or kinked, the whole control must be replaced. The tube connections are often sensitive to vibration.

14. Resistance Thermometer: The sensing bulb is similar in size to the gas or liquid bulb but contains a temperature sensitive resistance. This bulb can be connected to almost any bridge type controllers and a number of bulbs may be used with a single controller. The bulb may be removed from the controllers for ease in handling or insertion. These are fairly rugged and give excellent control characteristics. The accuracy range extends to 0.01°C.

15. Thermocouple Controls: The thermocouple temperature controller uses a simple wire junction which is very small, has no appreciable thermal lag, and can fit almost anywhere. It is mechanically rugged, electrically simple and gives accurate results. A number of thermocouples can be switched to the same controller to control or measure the temperature at a number of

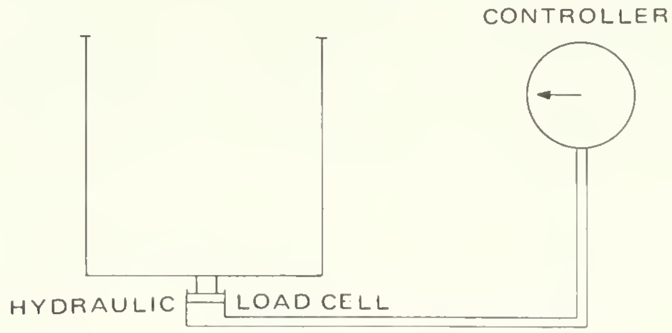


Figure 5.1.11.9 Hydraulic load cell controller

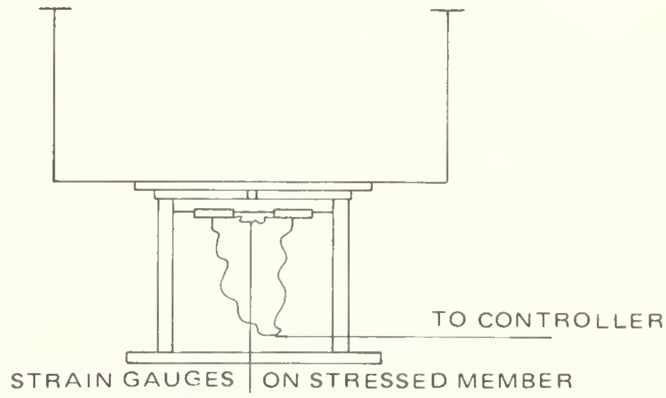


Figure 5.1.11.10 Electric load cell controller

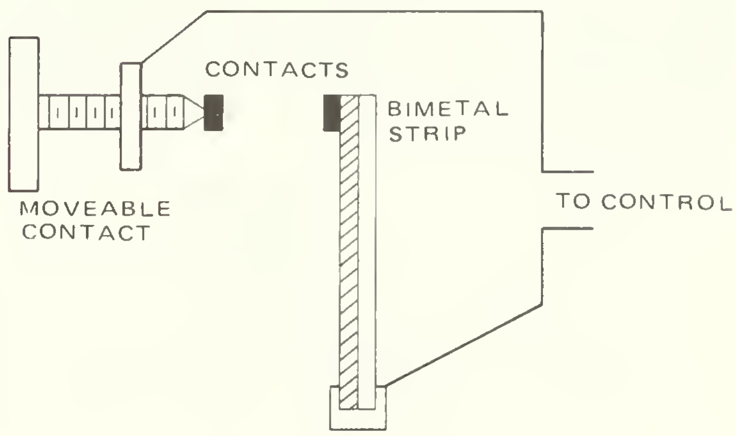


Figure 5.1.11.11 Principle of bimetal control

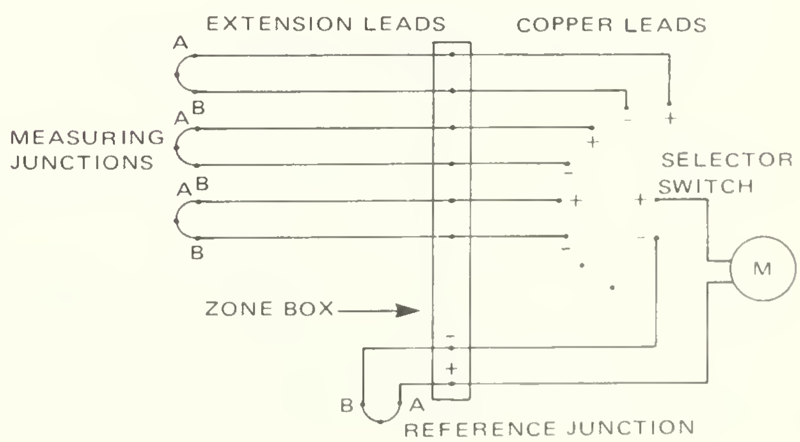


Figure 5.1.11.12 Multiple thermocouple circuit with three measuring thermocouples and one reference thermocouple

locations. These are sensitive to voltage or potentials around the sensing elements and wires.

16. Thermistor Control: The thermistor control is a cross between the resistance thermometer and the thermocouple control, using the size and flexibility of the thermocouple with the resistance measuring principles of the resistance thermostat. This gives a stable, accurate, flexible and sensitive control for temperature. It is not as strong or mechanically rugged as the thermocouple.

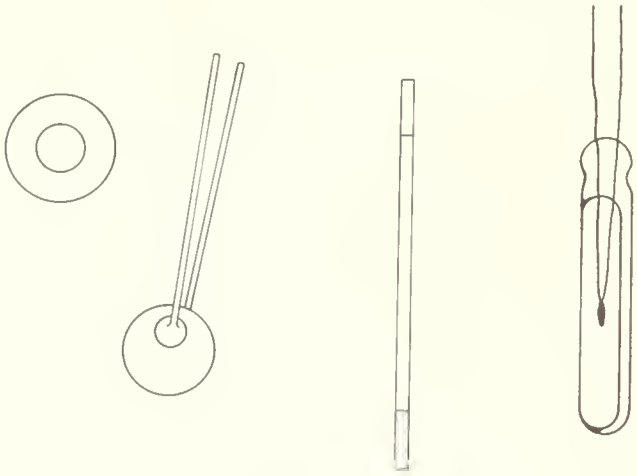


Figure 5.1.11.13 Thermistors

17. Orifice or Nozzle: The orifice or nozzle gives a fixed area for a liquid to flow through. The nozzle or orifice can be calibrated to give flow or quantity per unit time with a constant head (pressure), or, if the measurement must be made in a pipe, with a given pressure drop across the orifice. Orifice or nozzle meters are standard industrial instruments and can be found in various references. For control either a variable head (pressure) or a variable opening can be used.

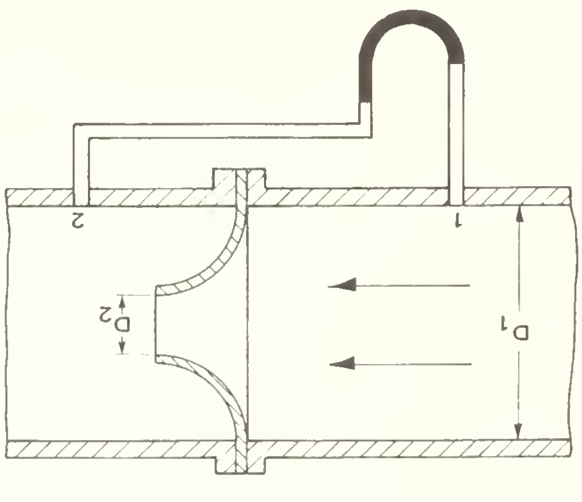


Figure 5.1.11.14 Nozzle pipe flow meter

18. Rotating Gear or Wheel: This method is a physical measurement of movement by having a gear, paddle or propellor pump force the fluid. With the capacity per rotation known, the volume moved is known and can be controlled. These can be used simply as driven elements to measure and to operate a controller, or can be driven to control the quantity flowing.

19. Weirs: Weirs are used to measure and control liquids in open channels. Flow is proportional to the height above the base of the notch and is related as shown in

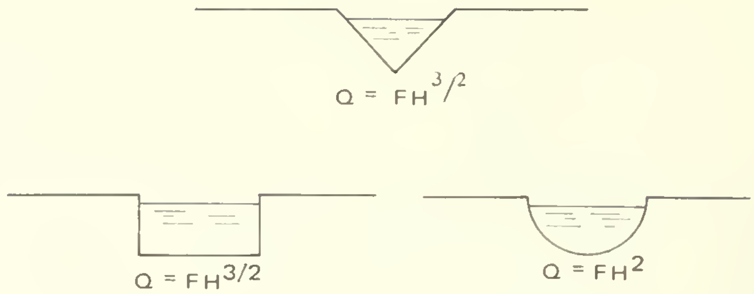


Figure 5.1.11.15 Three forms of weirs and their associated expressions for capacity

Figure 5.1.11 (where Q is flow rate, F is a proportionality factor and H is depth of flow). A variable height weir can provide control.

20. Photo Cell and Filters: The photo cell observes the material being examined through a filter. A signal can be either the maximum light reflected or the minimum light reflected, whichever is desired. With liquids the light can also shine through the fluid to the photo cell to measure the color and light transmission of the fluid. The photo cell output will be an indication of the color and composition of the material.

21. Several photo cells are used with filters of various color sensitivities built into them. When a photo cell sees the color it responds to, it sends its signal to the controller to initiate the desired action.

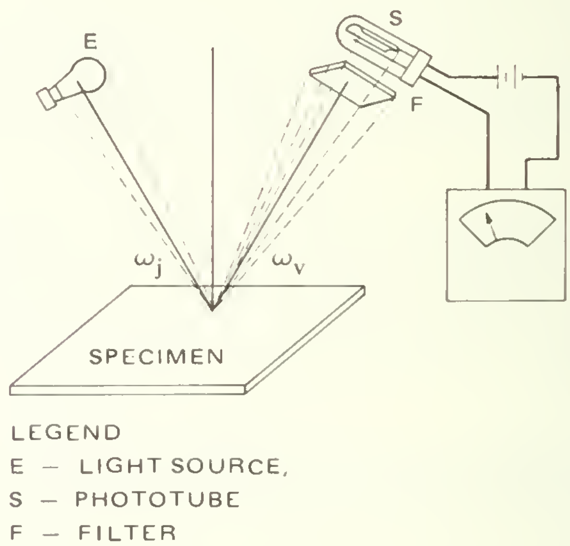


Figure 5.1.11.16 Photo cell and filter color selector

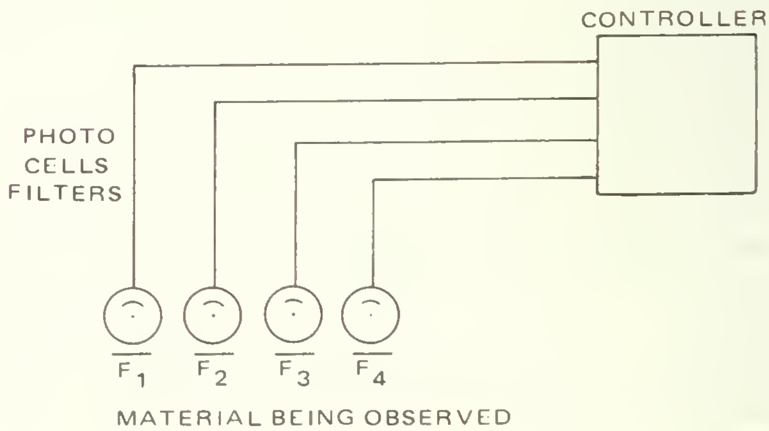


Figure 5.1.11.17 Multiple photo cell filter arrangement to detect and control color

5.1.11.4 Free Flowing Solids - Measurement and Control

Free flowing solids include farm materials which will flow and not stick, such as grains and ground feeds. The desired controllable factors in handling these materials are:

1. Flow,movement or velocity
2. Volume
3. Weight
4. Size
5. Temperature
6. Color

Table 5.1.11.3 is the selection chart covering some of the common methods of measuring and controlling these factors.

Some definitions applicable to flow conveyors, Table 5.1.11.3, are described as follows:

Bulk: Material flowing in a conveyor as a unit which can be separated from other similar units; such as buckets, scoops, bags or other units of handling.

Free: Free flow with each portion of the material blending into the next with no separate divisions or units of material transfer (continuous flow).

Level: The flow can be either bulk or free so long as the conveying is level.

Inclined: The conveyor is inclined between level and vertical. The evaluation is for some middle angle between 30° - 60°; as either the level or vertical limit is approached, the rating will change toward the corresponding value for that limit.

Vertical: The conveyor is lifting the material vertically.

Gravity Flow: A flow of material due to gravity alone, which can be any of the other types of flow, bulk, free, inclined or vertical.

The methods as shown in Table 5.1.11.3 are described previously under liquid measurements or described briefly below.

1. Rotation of a wheel or auger - By measuring the number of rotations of a conveyor drive wheel or an auger, the flow can be determined. A sensing unit is required to count each revolution or to develop a voltage proportional to the rotation which can then be calibrated and used to measure and control the flow of solid or semi-solid materials.

2. The number of strokes of a shuttle-type conveyor will give an indication of flow when it is handled in a manner similar to the rotation of a wheel or auger.

3. The linear movement of a conveyor belt can be determined by the rotation of the drive wheel or by using a riding wheel to indicate the distance the belt moves. Small trippers can be attached to the belts, or, if there are links or ridges these can be used to energize a small switch to form electric pulses, which when counted or integrated, will give a measurement of the belt movement. This movement can give a fairly precise measure of the material flow.

4. The number of buckets, compartments or conveyor bars passing a given point will indicate the flow and/or the quantity and/or position of the materials being handled. A simple counting device will give the flow and

TABLE 5.1.11.3 Selection Chart for Free Flowing Solids Applications and Characteristics

	Applications														Characteristics: Equipment								Characteristics: System				
	Desired Characteristics						Flow Conveyors*								Measure-ment					Control							
No.	Movement	Volume	Weight	Size	Temperature	Color	Quantity Handled	Bulk	Free	Level	Inclined	Vertical	Gravity Flow*	Metering	Hand	Automatic	Local	Remote	Continuous	Local	Remote	Continuous	Power Required**	Ease of Operation	Dependability	Relative Cost	Method
1	D	ID	ID				A	-	-	1	1	2	3	1	2	2	1	1	1	2	3	3	EP	1	2	2	1 Rotation of wheel or auger
2	D	ID	ID				A	2	-	2	2	3	-	2	2	2	1	1	2	2	3	3	EP	1	1	2	2 Number of strokes of shuttle
3	D	ID	ID				A	-	-	1	1	3	-	1	2	2	1	1	1	2	3	3	EP	1	1	2	3 Linear speed of conveyor belt
4	D	D	ID				A	1	-	2	2	2	-	2	1	1	1	2	1	3	3	3	E	1	1	2	4 Number of buckets or compartments
5	ID	D	D				L	1	1	2	-	-	2	2	1	1	1	3	-	1	2	-	EP	3	2	2	5 Batch measuring equipment (Automatic)
6	D	D	ID	D			L	-	1	1	1	1	1	1	1	1	1	2	1	2	2	2	EP	2	1	2	6 Paddle wheel
7	D	D	ID				L	-	-	1	1	1	-	1	2	2	3	3	3	1	2	2	P	1	1	1	7 Auger feed with variable inlet
8	D	D	ID				A	-	3	1	1	2	-	1	2	2	2	2	2	1	2	2	P	1	1	1	8 Belt conveyor with variable gate
9	ID	ID	D				A	1	1	1	2	3	2	2	1	3	1	3	3	2	-	3	-	3	1	1	9 Counter balanced beam
10	ID	ID	D				A	2	1	1	3	3	2	2	1	3	1	3	1	3	1	3	-	1	2	1	10 Springs
11	ID	ID	D				L	1	1	2	2	3	2	2	2	2	1	1	1	1	2	1	-	1	2	2	11 Hydraulic load cells
12	ID	ID	D				L	1	1	1	1	2	2	2	3	1	1	1	1	1	1	1	E	1	2	3	12 Electric load cells
13	ID	ID	D				L	2	1	2	2	2	2	2	3	1	1	1	1	1	1	1	E	1	2	3	13 Deflection or strain in supports
14				D			A	3	1	1	2	3	1	-	2	3	3	3	3	3	3	3	P	2	2	2	14 Screens and scraper
15				D			A	3	1	1	2	3	1	-	1	3	1	3	3	3	3	3	P	2	2	2	15 Shaker screens
16				D			A	1	2	3	2	2	1	-	2	2	2	3	2	2	3	2	P	2	2	3	16 Grinders mills crushers
17					D		L	2	3	2	2	2	3	-	2	-	2	-	2	-	-	-	-	2	2	1	17 Thermometer (glass)
18					D		L	1	2	1	1	1	2	-	2	1	1	2	1	1	-	1	-	1	1	1	18 Bimetal thermostat
19					D		L	1	2	1	1	1	2	-	2	1	1	1	1	1	1	1	-	1	2	2	19 Filled bulb thermostat (gas liquid)
20					D		L	1	2	1	1	1	2	-	3	1	1	1	1	1	1	1	E	1	2	3	20 Resistance thermometer
21					D		A	1	2	1	1	2	2	-	3	1	1	1	1	1	1	1	E	2	2	3	21 Thermocouple control
22					D		A	1	2	1	1	2	2	-	3	1	1	1	1	1	1	1	E	2	2	3	22 Thermistor control
23	ID	ID				D	L	2	2	1	2	3	3	3	2	2	1	3	3	3	3	3	E	3	3	3	23 Photo cell with filters
24	ID	ID				D	L	1	2	1	1	2	1	3	2	2	1	2	2	2	2	2	E	2	3	3	24 Multiple selective photo cells

Key
- 1 = Good
- 2 = Average
- 3 = Poor
- D = Direct
- ID = Indirect
- E = Electronic
- EP = Electric Power
- P = Physical

*See 5.1.11.4 for description

**Power Required, see 5.1.11.1

quantity measurements, while micro-switches or similar sensing elements at the points of interest will indicate the location of transported material.

5. Batch measuring equipment can be set up to automatically measure a desired amount of a material or a mixture of materials by weight or volume. Weight is the simplest. The inlet allows material to enter until the weight reaches a preset level, at which time it shuts off the supply. Then if some other material is to be added it can be started as the first turns off. The second then fills until the increased weight operates another switch to stop its flow. After all the desired elements are added the final switch can open an outlet and empty the container or it can be held for a signal from the master control. When the container has emptied and returned to its original position the filling can be commenced again automatically. For volume measurements this same operation can be done with a series of pressure or flapper switches along the side of the container and a spreader to evenly distribute the incoming material. This type of switching would operate in the same manner but make the measurements according to volume instead of weight. See also 5.1.5.2.1.

6. A paddle wheel can measure and/or control the flow and volume of a material taken from a bin or a conveyor by its positive action of picking up a volume and moving it to another location. Fitted with specified openings a paddle wheel can be used for separating or sizing the solid material passing around or over it.

7. An auger with a variable inlet, operating at a constant speed, will provide a variable flow or volume. The amount of material moved by the auger will depend on other factors than the inlet opening, such as the auger position and material uniformity. These other factors are fairly constant for any particular arrangement.

8. A conveyor with a variable gate will give control of the volume of material being handled. By calibrating the position of the gate and knowing the material and conveyor speed, the volume and flow can be determined and controlled.

9. Counterbalanced beam (5.1.11.3.7)

10. Springs (5.1.11.3.8)

11. Hydraulic load cells (5.1.11.3.9)

12. Electric load cells (5.1.11.3.10)

13. The deflection or strain in a supporting member can be measured to give an indication of the weight of material supported by it. Thus a support for a conveyor, a bin, or other loaded member can be equipped with strain gauges and used to measure the load on that member. This can be fed to a control to obtain the response required (see 5.1.5.2.2).

14. Screens and scrapers will give a measure of the size of a material but will do little to adjust the size other than separate it. A very strong screen and a roller could reduce the size of granular materials such as many fertilizers but generally screens with a scraper to move the material over the screens will have most application in sorting or separation according to size in continuous flow systems.

15. Shaker screens use control power to shake the screens and move the material relative to the surface of the screen, rather than move the material by direct contact. This principle is used in many applications, especially for testing a given sample for size distribution. They can be adopted for continuous flow, but are not good system components due to the lack of reliability of flow.

16. Grinders and mills are a very commonly used element of equipment in a materials handling system, and seldom have much measurement or control function in their operation. To use such equipment in automatic systems, the grinder must be driven by a source of power which can be started and stopped automatically. The grinder must have capacity matching or exceeding the rest of the system, and it must be equipped with overload and safety controls to turn it and/or its supply of material off in case of trouble (Clogging - overloading - power loss - mechanical failure).

17. Thermometer (5.1.11.3.11)

18. Bimetal thermostat (5.1.11.3.12)

19. Vapor-gas-liquid filled bulb thermostat (5.1.11.3.13)

20. Resistance thermostat (5.1.11.3.14)

21. Thermocouple controller (5.1.11.3.15)

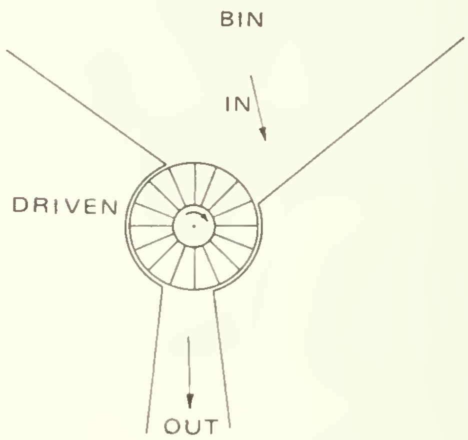


Figure 5.1.11.18 Paddle wheel meter

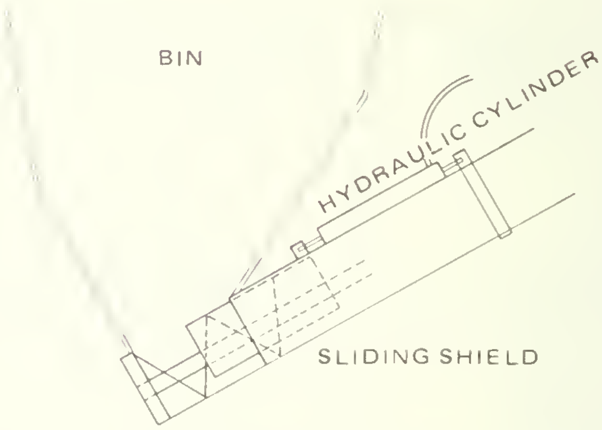


Figure 5.1.11.19 Auger with hydraulic inlet control

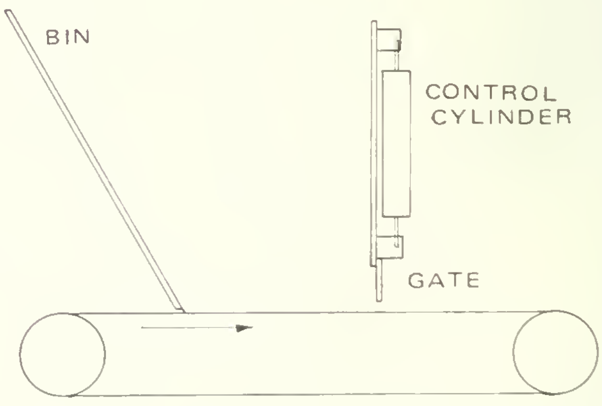


Figure 5.1.11.20 Belt conveyor with a variable gate

TABLE 5.1.11.4 Selection Chart for Non-Free-Flowing Solid Applications and Characteristics

Key
1 = Good
2 = Average
3 = Poor
D = Direct
ID = Indirect
E = Electronic
EP = Electric Power
P = Physical

No.	Applications: Characteristics: Movement	Weight	Position	Temperature	Color	Applications: Unit Loads	Bulk Handling	Continuous Flow	Counting (Units)	Characteristics: Equipment: Measurements: Hand	Automatic	Local	Remote	Continuous	Equipment: Control: Local	Remote	Continuous	System: Power Required*	Ease of Operation	Dependability	Relative Cost	Method
1	D	ID	D			-	-	1	-	3	2	2	2	2	2	2	2	EP	2	2	2	Linear speed of conveyor belt
2	D	ID	ID			2	2	2	2	2	2	1	1	1	1	2	2	EP	2	2	2	No. of buckets or compartments moving past
3	D	ID	ID			2	3	2	2	1	2	1	1	1	2	2	2	EP	1	2	2	Paddle wheel
4		D				3	1	3	3	1	3	1	3	3	1	3	3	-	2	1	1	Counter balanced beam
5		D				3	1	3	3	1	3	1	2	2	1	3	3	-	1	2	1	Springs
6		D	ID			2	1	2	3	1	1	1	2	1	1	2	1	-	1	2	2	Mechanical indicator
7		D	ID			2	1	2	3	1	1	1	1	1	1	1	1	E	2	2	3	Hydraulic load cell
8		D	ID			2	2	2	3	3	1	1	1	1	1	1	1	E	2	2	3	Electric load cell
9			D			1	1	2	1	1	1	1	1	1	1	1	1	E	1	1	1	Deflection of supports (strain)
10			D			1	1	2	2	1	2	1	3	1	1	3	1	-	1	1	1	Snap-action position indicator
11				D		2	2	-	-	1	-	1	-	3	-	-	-	-	2	2	1	Thermometer (glass)
12				D		1	1	3	-	1	1	1	-	1	1	-	1	-	1	1	1	Filled bulb thermostat (gas-liquid)
13				D		1	1	2	-	1	1	1	2	1	1	2	1	-	1	2	2	Bimetal thermostat
14				D		1	1	2	-	1	1	1	1	1	1	1	1	E	1	2	3	Resistance thermometer
15				D		1	1	1	-	1	1	1	1	1	1	1	1	E	2	2	3	Thermocouple control
16				D		1	1	1	-	1	1	1	1	1	1	1	1	E	2	2	3	Thermistor control
17	ID		ID		D	1	1	1	1	2	2	2	2	2	2	2	2	E	2	2	3	Photo cell with filters
18	ID		ID		D	1	1	1	1	2	1	2	2	2	1	1	1	E	2	2	3	Multiple selective photo cells

*Power Required, see 5.1.11.1

22. Thermistor controller (5.1.11.3.16)
23. Photo cell and filters (5.1.11.3.20)
24. Multiple selective photo cells (5.1.11.3.21)

5.1.11.5 Non-Free-Flowing Solids - Measurement Control

Non-free-flowing solids include the farm products which are handled in sacks, bales, or in other unit loads having characteristics such as that they will not flow freely and must be physically moved whenever movement is desired. The factors that must be controlled for these materials are:

1. Movement
2. Weight
3. Position
4. Temperature
5. Color

These factors are considered in Table 5.1.11.4 along with other applications and characteristics of the common methods of measurement and control of non-free-flowing solids. All methods indicated on this table except 9 and 10 are described briefly under 5.1.11.3, Liquid Measurements and Control, or 5.1.11.4, Free Flowing Solids - Measurement and Control. Methods 9 and 10 are described below.

9. Switch position indicators are snap-action switches located at various points where the presence of the material or its container will touch them and cause the switch to energize, or signal. These then show where material is and can be used to control its movement, its speed, or its position.

10. A mechanical indicator can take several forms:
-It could be an indicator fastened to a conveyor to show how far a certain point on the conveyor has moved.
-The mechanical indicator can be geared to drive a wheel to count revolutions and indicate the movement of material indirectly.
-The mechanical indicator can be a lever or a baffle moved either by the presence of material or by a certain amount of material at that location on the conveyor. The movement of the lever or baffle can then be used to operate controls to cut off power or material flow or as desired.

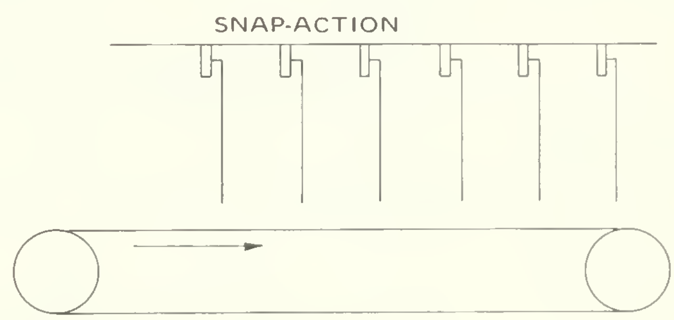


Figure 5.1.11.21 Snap-action switches indicating the position of material on conveyor

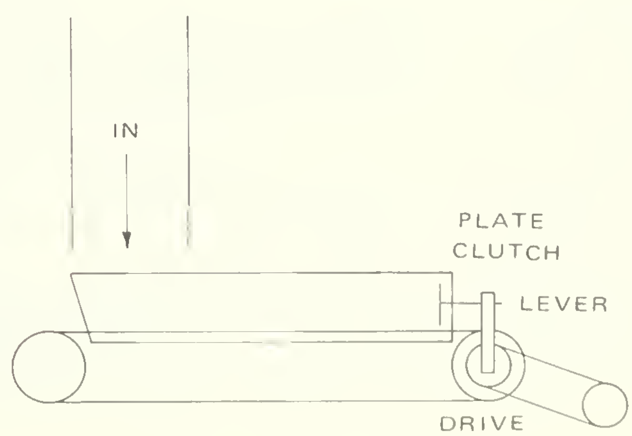


Figure 5.1.11.22 Mechanical clutch release to stop the conveyor when the trough is filled

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Publications of Control Manufacturers.

5.1.13 APPENDIX

Circuit Symbols

Current

 arrow indicates direction of current

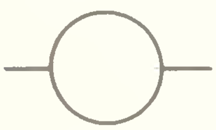
I current

i instantaneous current

Logic Symbols

See appendix, boolean algebra.

Magnet Coils

 letter designates the circuit contacts that the particular coil operates, i.e. M = motor, G = grinder

Overloads

 switches which open when the circuit overload protection acts

Switches

 normally open contacts

 normally closed contacts

 snap-action - contacts held open

 snap-action - contacts held closed

Time Delays

TDOE time delay on energization

TDODE time delay on de-energization

Voltages

 DC voltage, positive terminal at the arrow end

 AC voltage

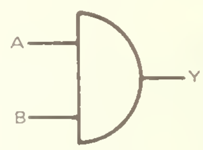
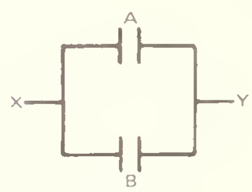
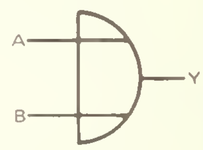
V DC voltage

E AC voltage (RMS)

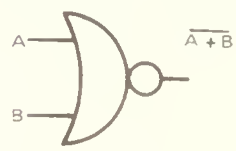
e instantaneous voltage

Boolean Algebra

In a complex circuit certain unnecessary redundancy* can exist. This can be checked mathematically by several methods. The simplest is the use of boolean algebra. Some of the boolean algebra rules are the same as those for regular algebra; others are different.

Switch Diagram	Logic Circuit	Symbol	Boolean Expression
	AND		A.B
	OR		A + B

NOR - This is a negative OR gate



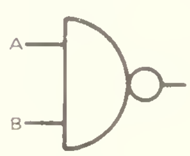
which by application of De Morgan's Theorem yields $\overline{A.B}$

Truth Table

A	B	T
0	0	1
1	0	0
0	1	0
1	1	0

Note: The output is the negated output of the standard OR (with the logical zeros replaced by logical I's and vice versa).

NAND - negative AND



*In some circuits redundancy is necessary to ensure a predetermined pattern of operation.

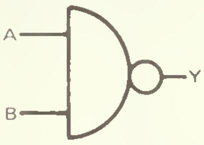
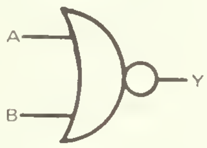
Truth Table

A	B	T
0	0	1
0	1	1
1	0	1
1	1	0

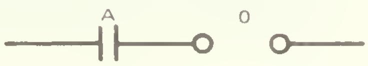
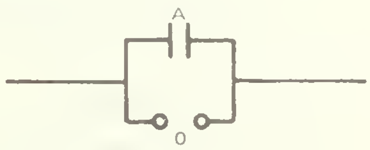
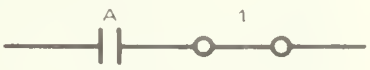
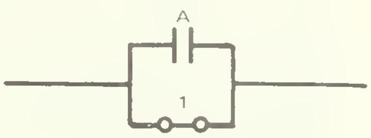
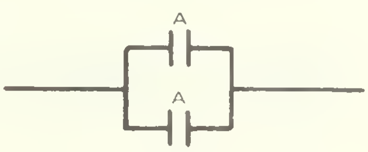
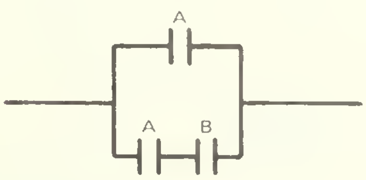
Output is the negated AND.

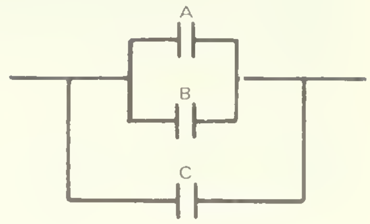
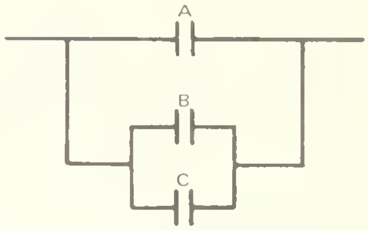
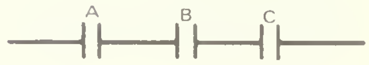
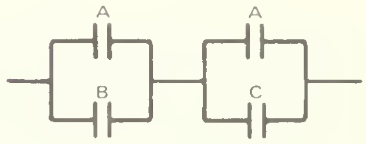
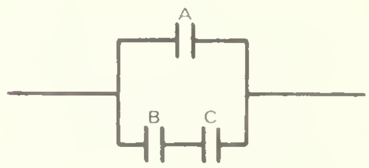
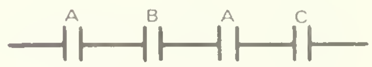
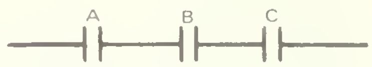
NOT - if only a single input of either a NOR or a NAND gate is used the gate will invert the input, i.e. become a NOT gate (provided the remaining inputs are connected appropriately).

AND functions realized by NAND gates.

Logic Circuit	Symbol	Boolean Expressions
NAND		$\overline{A.B}$
NOR		$\overline{A + B}$

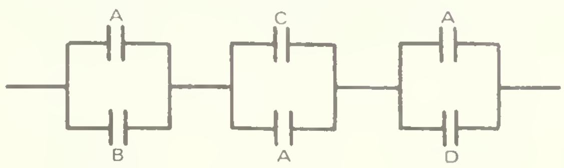
Rules of Boolean Algebra

Expression	Diagram
$A \cdot 0 = 0$	
$A + 0 = A$	
$A \cdot 1 = A$	
$A + 1 = 1$	
$A \cdot A = A$	
$A + A = A$	
$A + AB = A$	

Expression	Diagram
$(A + B) + C = A + (B + C)$	 
$(AB)C = A(BC)$	
$(A + B)(A + C)$ $= A + AB + AC + BC$	
$= A + BC$	
$AB \cdot AC = ABC$	 

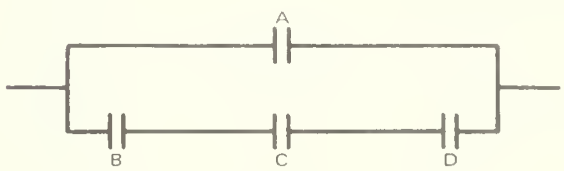
Examples

Simplify the following circuit:



$= (A + B)(A + C)(A + D)$

$= A + BCD$



De Morgan's Theorems

$\overline{A \cdot B} = \overline{A} + \overline{B}$

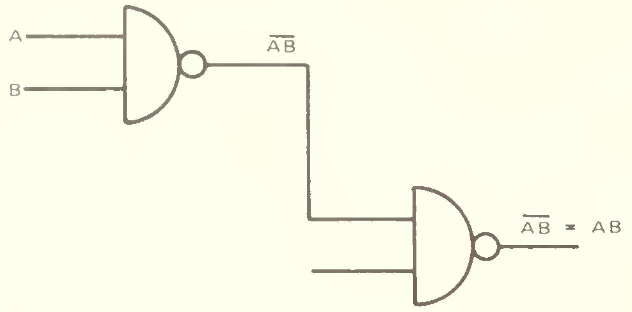
$\overline{A + B} = \overline{A} \cdot \overline{B}$

$\overline{\overline{A}} = A$

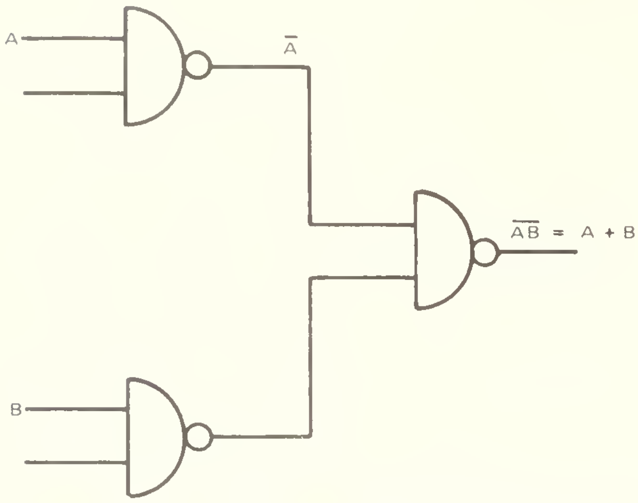
$\overline{\overline{A} \cdot \overline{B}} = \overline{\overline{A}} + \overline{\overline{B}} = AB$

$\overline{\overline{A} + \overline{B}} = \overline{\overline{A}} \cdot \overline{\overline{B}} = A + B$

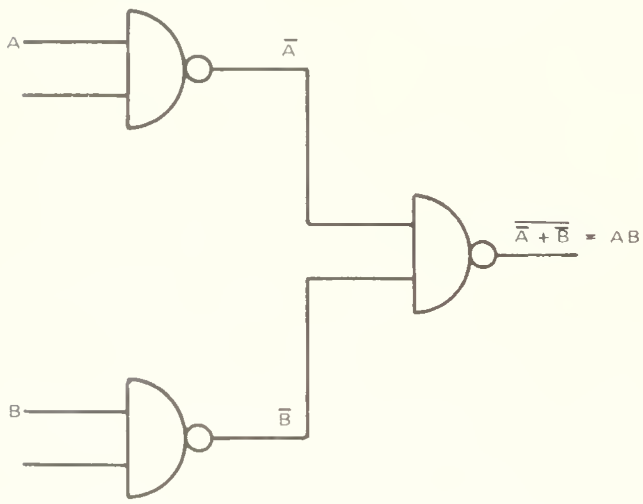
If these theories are applied any boolean function can be realized by the multiple use of a single type of negative gate*. Cost of circuitry is reduced since only a single type of gate is required.



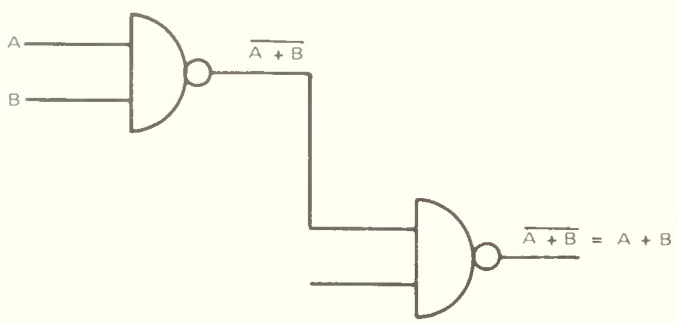
OR



AND functions realized by NOR gates



OR realized by NOR gates



It should be noted that while here the unused input to the gate being used for negation (inverting) is shown as open this may not be so in practice. The manufacturer's literature should be consulted. In some cases the two inputs may be strapped together; in others, the unused inputs may be returned to ground.

*Gate - term applied to a complete circuit, as, for example, an OR or an AND circuit.

Karnaugh Maps

A Karnaugh map is a graphical method of depicting a transmission function*. By utilizing properties of the map, the transmission function can be reduced to the minimum form required to realize the function.

A map for up to four literals (switching elements) is two dimensional but a map for five literals is three dimensional. Three dimensional maps are more difficult to use, therefore, other methods for reduction of the transmission function are used. These techniques are shown by Caldwell (1967), Maley and Earle (1963), Marcus (1967) and McCluskey (1965), in their texts. Maps can be used for three or more literals and take the form shown in Figure A1.

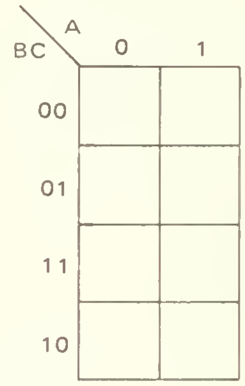


Figure A1 Karnaugh map for three variables

Binary Coded Decimal

A row of four switches is required to exemplify a decimal number. The decimal number could be coded into binary by putting each of the four switches into an on or off postion as required to encode the number. The right hand switch (fourth) would designate the presence or absence of 2^0; the third, 2^1; the second, 2^2; and the first (the left hand switch), 2^3. For example, if the first and third switches were on and the others were off, it would show the presence of 2^3 and 2^1, but not 2^2 or 2^0 (Maley and Earle 1963). The number then would be the summation of the four as follows:

$$2^3 + 0 + 2^1 + 0 = 8 + 0 + 2 + 0 = 10$$

A table can be built up (Table A1).

TABLE A1 Basic Binary-Decimal Conversion

2^3	2	2^1	2^0	Decimal Number
0	0	0	0	0
0	0	0	1	1
	0	1	0	2
0	0	1	1	3
0	1	0	0	4

and so on.

*A transmission function states the condition(s) necessary to provide a current path between two points. All possible current paths are included.

Sometimes, instead of 2^3, 2^2, 2^1, 2^0 the letters such as A, B, C and D or W, X, Y and Z are used. A would indicate the presence of 2^3 and A' (said as 'A prime') would indicate the absence of 2^3. Table A1 would appear as Table A2.

TABLE A2 Binary-Decimal Conversion

A'	B'	C'	D'	0
A'	B'	C'	D	1
A'	B'	C	D'	2
A'	B'	C	D	3
A'	B	C'	D'	4
A'	B	C'	D	5
A'	B	C	D'	6
A'	B	C	D	7
A	B'	C'	D'	8
A	B'	C'	D	9
A	B'	C	D'	10
A	B'	C	D	11
A	B	C'	D'	12
A	B	C'	D	13
A	B	C	D'	14
A	B	C	D	15

The fourth line of the table is read as A prime*, B prime, C, D.

Figure A2(a) shows a Karnaugh map for the four variables A, B, C, D. A study of the map shows that all the possible combinations of the four variables from Table A1 exist in the map. Suppose that you wanted to represent the expression AB'CD. Converted to 0's and 1's, AB'CD would

CD \ AB	00	01	11	10
00				
01				
11				
10				

Figure A2 (a) Karnaugh map for four variables

CD \ AB	00	01	11	10
00	0	4	12	8
01	1	5	13	7
11	3	9	15	11
10	2	6	14	10

Figure A2 (b) Karnaugh map showing decimal number equivalents for all entries

*Sometimes instead of saying 'A prime' the terminology 'not A', i.e. no value of A, is used.

be 1011. The headings for the columns of the map represent all the combinations possible for A and B. The row designations likewise give all the combinations for C and D. To locate the square that represents AB'CD, move along the headings for the columns until you locate, in the fourth column, the heading 10. Move down the row designations until you reach the 11 row. The square that represents AB'CD is where that column and that row intersect. If AB'CD were part of a transmission function a 1 would be entered in the square.

Each square represents one row of Table A2. Each row of the table designates a decimal number. Figure A2(b) shows the location of each decimal number of the table on the Karnaugh map.

At first, it would appear that the column headings or row designations are not in the right order; that these should be - 00,01, 10, 11. However, if the order as given is checked you will find that only one variable changes as you move from one column to the next or from one row to the next.

If the entire map is studied closely, it will be seen that in moving from one square to the next adjacent square in either direction, one variable only changes. Each map edge should be thought of as being adjacent to the opposite edge. Each square of the right hand column is one variable different than the corresponding square in the left hand column. The same is true for the top row in comparison to the bottom row.

A sample problem will indicate to you how the map can be used in the reduction of a transmission function to its simplest form.

T = A'B'CD + A'BC'D + A'BCD + AB'CD + ABC'D' + ABC'D + ABCD + A'BC'D'

The function is entered on the map by writing a 1 in each square of the map that is required to represent each section of the total transmission function.

Until you have had some experience it is useful to create a table to show: each section of the transmission function; that section's equivalence in binary code, i.e. 0's and 1's; and, the decimal number which the binary represents. Table A3 is such a table.

TABLE A3 Table of Equivalents

Function	Binary Equivalent A B C D	Equivalent Decimal Number
A'B'CD	0 0 1 1	3
A'BC'D'	0 1 0 0	4
A'BC'D	0 1 0 1	5
A'BCD	0 1 1 1	7
AB'CD	1 0 1 1	11
ABC'D'	1 1 0 0	12
ABC'D	1 1 0 1	13
ABCD	1 1 1 1	15

For clarity in this first example, the transmission function is entered on the map of Figure A3 using the decimal equivalents instead of 1's. This shows where each set of variables goes. With experience the variables are entered using 1's, as in Figure A4.

As stated, moving from one square to an adjacent square changes one literal (variable) only. In Figure A3 moving

CD \ AB	00	01	11	10
00		4	12	
01		5	13	
11	3	7	15	11
10				

Figure A3 Karnaugh map showing decimal entries from Table 3

CD \ AB	00	01	11	10
00		1	1	
01		1	1	
11	1	1	1	1
10				

Figure A4 Karnaugh map with 1's instead of decimal entries

from 4 to 5 changes the D literal from D′ to D. Such a change makes that literal redundant.

In Karnaugh mapping, if 1's appear in pairs or double pairs of adjacent squares these squares are circled to indicate redundancy of literals. Figure A5 (a) shows the part of the transmission represented by the entries in the two squares at A′B′C′D and A′BC′D. Squares 4 and 5 are thus circled. The transmission function reduces Figure A5 (a) to that of Figure A5 (b). However, D′ + D = 1 and the circuit becomes Figure A5 (c). It would be intuitively assumed that the hardware creating D or D′ is not needed since by boolean algebra D′ OR D = 1. The map shows this. Remember, in the circling process, that squares on the map edges are adjacent to squares at the opposite side. Such squares with 1's would be circled.

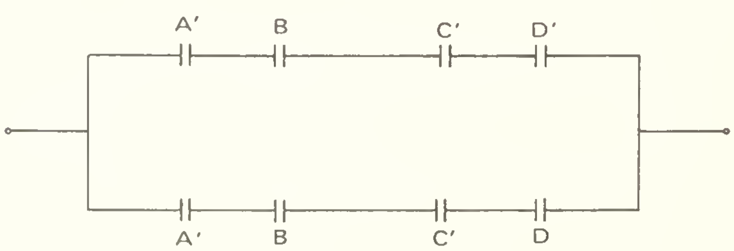


Figure A5 (a) Transmission function for A′BC′D′ and A′BC′D

Consider the parts of the transmission function 5, 13, 7, 15. Here the A literal changes from A′ to A and the C literal from C to C′. A and C are redundant and this part of the transmission function can be realized by the hardware for BC. The row 3, 7, 15, 11 is similar and can be realized by CD. The transmission function now becomes:

T = BC′ + CD

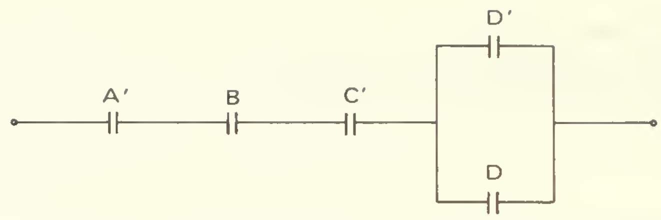


Figure A5 (b) Transmission function for A′BC′(D′ + D)

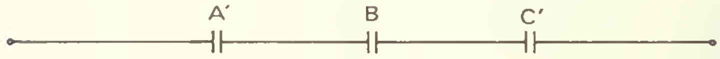


Figure A5 (c) Final reduction to transmission function for A′BC′

It might appear that one can go directly from the original transmission function to the second without the map. But, to prevent errors, the map is essential.

In using maps circle squares which can be blocked together, as shown in Figure A6.

Usually the transmission function is given as a summation of the decimal numbers equivalent to squares occupied by the members of the transmission function. The sample becomes then:

$T = \Sigma(3, 4, 5, 7, 11, 12, 13, 15)$

Sometimes, after reduction by the map, further reduction is possible by applying rules of boolean algebra or, as in this case, by inspection. The circuit for the reduced transmission function becomes Figure A7. It requires four sets of contacts. However, if one interchanges either the C and D literals in the bottom path or the B and C′ of the top

CD \ AB	00	01	11	10
00		1	1	
01		1	1	
11	1	1	1	1
10				

Figure A6 Showing the circling of sections of the transmission function

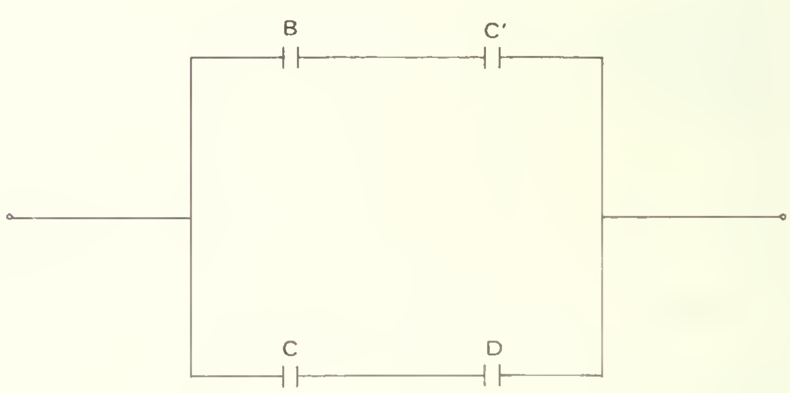


Figure A7 Circuit diagram for the reduced function T=BC′ + CD path, the circuit becomes Figure A8. One less set of springs is required since C and C' can be realized by utilizing a single-pole double-throw set of contacts (an exclusive OR circuit).

In transmission functions the outputs are certain combinations of the input variables. As stated previously, such control circuits are called combinational circuits. But other digital control circuits are not dependent solely on these inputs. In these there is a time element. Outputs are not only dependent on the current inputs but also on past states of the inputs. Such circuits are sequential control circuits and are discussed in the following section.

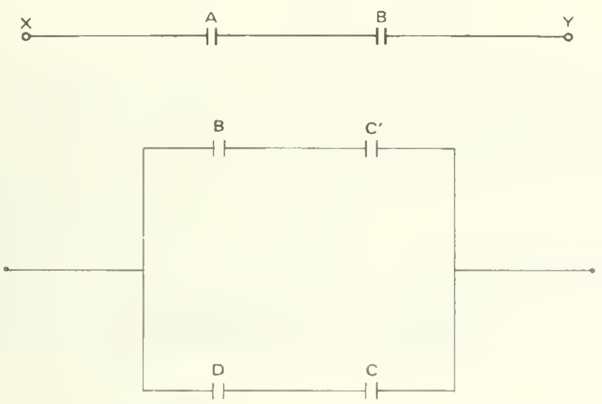


Figure A8 Circuit diagram showing a further reduction of the Function T=BC' + DC

Sequential Operation

Often control systems must perform several functions in a specific order. A system where: (1) a valve must open, (2) a pump start, and (3) a second motor start, would be an example of a sequential operation. Sometimes the sequence is more complicated.

Solution of a Problem in Sequential Operation

Suppose a sequential circuit has two inputs X_1 and X_2, and one output, Z, such that Z is turned on when both inputs are on providing:

1. that X_1 is on before X_2
2. That if either X_1 or X_2 turn off after the Z output is obtained both X_1 and X_2 must return to zero in order to restart the sequence.

First, one must produce a basic or primitive flow table which shows the condition of the output for all the conditions of the inputs X_1 and X_2. (The table is called a primitive flow table since it shows all possible changes or transitions.) The flow table shows the flow of the inputs — flow in the sense of possible changes in input conditions. For instance, both inputs could be off, a 00 input; both on, a 11 input, and, one or the other on or off, a 01 or a 10 input.

If, at the beginning, both inputs are open, the progression of events (sequence of events) required to obtain an output would be:

X_1 closes while X_2 remains open
X_2 closes while X_1 remains closed

The table will contain stable states and transition states. A stable state is a state of rest from which the circuit will not move unless there is an input change. If there is an input change a transition will occur as the system moves to a new stable state.

Using 0's or 1's to represent the condition of X_1 and X_2 the events would look like: 00, 10, 11. Although the above appears to take place in two moves there are actually four moves or operations if the transition states are considered as well as the stable states.

The flow table is constructed a row at a time. Each row shows one stable state. As well, each row will show all the possible transition states. Each row can contain only single variable changes, double changes being forbidden. The double change which cannot occur is shown in the row as a dash. Each row is numbered. In each row, row numbers are entered to show the row containing the stable state to which that transition would move the operation. In proceeding with the development of the table, the number of each change is entered on the table. It is desirable that the first change that occurs would be that X_1 turns on. Since the change indicated in one row is completed in a following row, then the number of the row in which it (the change) will be completed is entered in the column which indicates the change that is occurring. The stable state for the row is circled. Only when all possible changes have been considered is the table ended. At that time entries are entered in the blank spaces to complete the table.

TABLE A4 Partial Primitive Flow Table

Row	X_1X_2 0 0	X_1X_2 0 1	X_1X_2 1 1	X_1X_2 1 0	Z
1	1		-	2	0
2		-	3	2	0
3	-	4	3		1
4		4	5	-	0
5	-		5	6	0
6				6	0

In Table A4 the flow starts in the first row with all inputs zero. A 1 is entered under column 00. This is the stable state for row 1 and so the 1 is circled. Because the table is limited to one change per row the 11 condition is forbidden and shown by the dash. Two possible changes (transitions) could occur since either X_1 or X_2 could turn on. 10 is the desirable condition so a 2 is entered in this column. The output, Z, is zero. Column 01 is left blank at this time.

In row 2 the stable state is in column 10 and the 2 is circled. The next desirable change is that 11 occurs and a 3 is entered in that column. The double change to 01 cannot occur. Z is still zero.

In row 3 a 3 is entered in column 11 and circled to indicate the stable state. The forbidden change would be 00 and is indicated. Either a change to 01 or 10 could occur, either of which would create a new set of conditions. A 4 is entered under 01 (it could have been entered under 10, the other possible change). Z is now 1, but any subsequent change will make Z zero since the circuit requirements for an output of 1 are no longer met.

Row 4 shows the 4 in column 01 circled, 10 is not possible. The only possible new change would be for the inputs to change to 11. A change to 00 would reset the circuit to the required initial conditions of row 1. A 5 is entered in column 11. Z is zero.

Row 5 shows the stable state in column 11. 00 is not possible. If the inputs change to 01 the change will lead back to the situation in row 4. A change to 10 will result in a change which has not occurred before so that a 6 is entered under 10. Z is zero.

In row 6 a change cannot occur to 10 but 11 is possible, this leading back to row 5; or 00 is possible, re-establishing the initial conditions of row 1. Thus, a 5 would be entered under 11 and 1 under 00.

All that is necessary now is to go back through the table and fill the blanks with the numbers for the row towards which that change would direct the sequential flow. In row 1 a change to 01 would yield stable state 4. The completed table is given in Table A5.

TABLE A5 Completed Primitive Flow Table

Row	X_1X_2 0 0	X_1X_2 0 1	X_1X_2 1 1	X_1X_2 1 0	Z
1	①	4	-	2	0
2	1	-	3	②	0
3	-	4	③	6	1
4	1	④	6	-	0
5	-	4	⑤	6	0
6	1	-	5	⑥	0

In sequential circuits the term 'race' is often used. Under certain conditions the output of a circuit depends on which of two circuit elements operate the more quickly and a race condition is said to exist. If the output is the same regardless of the outcome of the race, the race is non-critical. If the output depends on the outcome of the race the race is called a critical race. Critical races must be guarded against unless one was designing the equivalent of an electronic roulette system. Races often exist if two variables are allowed to change in creating a new stable state in a flow table. This is why, that in the creation of the primitive flow table, a double variable change is said to be forbidden. Although the word forbidden is used these double changes can occur.

Examining the completed table shows that except for the conditions which cannot occur there is a similarity between certain rows as between rows 1 and 2 or rows 1 and 4 or rows 4, 5 and 6. A new table (Table A6) is made wherein these similar rows are combined or merged.

Rows may be merged if the entries in each row are the same or if, where the rows are not identical, there are blanks.

TABLE A6 Merged Flow Table

0 0	X_1X_2 0 0	X_1X_2 0 1	X_1X_2 1 1	X_1X_2 1 0
Rows 1,2	①	4	3	②
Row 3	-	4	③	6
Row 4,5,6	1	④	⑤	⑥

It would appear that there are contradictions to the rule that double changes cannot occur. However, on the first row the change from 3 to the stable 1 still cannot occur and likewise from 4 to 2.

There are other possible row combinations than those shown but these may not have the same advantages. Another type of diagram - a merger diagram - will help to show the best combinations. A set of numbered points each representing the stable state of each row in the table is laid out. Each pair of rows in the primitive flow table is examined to see if they can be merged and if so a line is drawn between those two points.

In Figure A9 1 is joined to 2 and to 4. 4, besides being joined to 1, is joined to 5 and 6 but 1 is not. Row 3 does not merge with any row. The merger then will include rows 4, 5 and 6. The table is now reduced to 3 rows.

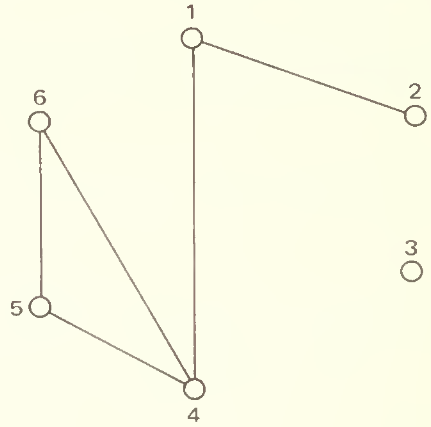


Figure A9 Merger diagram

Sometimes the minimum table is not the best. Since there will be two secondary variables required to develop the circuit there will be four possible combinations of these, 00, 01, 11, 10. Thus there will be four rows in the merged table instead of the three. The fourth row then has optional states and is comprised of the merger of rows 1 and 4. However, the order of the rows still has to be decided. The row order is decided by the stable state(s) in each row since the flow should progress from the first stable state to the second and so on. The completed table now appears as Table A7.

TABLE A7 Completed Merged Flow Table

x_1x_2 0 0	x_1x_2 0 1	x_1x_2 1 1	x_1x_2 1 0	Row
①	4	5	2	a
1	4	3	②	b
1	4	③	6	c
1	④	⑤	⑥	d

x_1x_2 are now lower case to show that they designate the contacts used, whereas the upper case X_1X_2 designated the primary variables.

Secondary excitation functions are now needed in order to implement the circuit. The states of the secondaries are shown by small y's and the excitation by large Y's. The first step requires a transition diagram.

A transition diagram, Figure A10, is used in order to ensure that in moving from one stable state to the next only one variable changes. The letters A, B, C, and D designate the rows or merged flow diagrams.

A line joining two points shows that a particular change (transition) exists in the merger table which requires the change designated by the line. For example, in moving from 3 in line b to 3 in line c requires a change of variables from the condition 01 to 11. Remember that the variables referred to are a set of secondary variables not previously considered and that they are not the input variables from

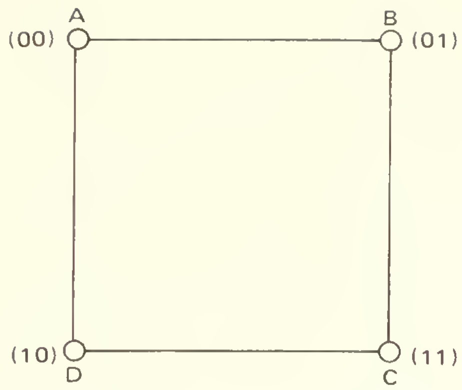


Figure A10 Transition diagram

which the merger tables have been designed. It is a coincidence if the change happens to be the same.

The flow matrix which includes the secondary assignments is Figure A11.

The excitation map developed from the flow matrix is developed in two stages. First, Figure A12, the requirements for the stable states are entered.

Y_1Y_2 \ x_1x_2	00	01	11	10
00	1	4	5	2
01	1	4	3	2
11	1	4	3	6
10	1	4	5	6

Figure A11 Merged flow table with secondary states

Y_1Y_2 \ x_1x_2	00	01	11	10
00	00			
01				01
11			11	
10		10	10	10

Figure A12 Partial excitation matrix

In a stable state the excitation must be the same as the state of operation. In other words, the entry in the column under x_1x_2 where the stable state occurs will be the state of y_1y_2 of that row. It is now necessary to fill in the remaining spaces. The unstable state in a particular location is directing the sequence toward the stable state of the same number. The 3 in row 01 column 11 directs the flow to stable state 3 which is a 11 state. The first 3 should be 11.

The table is now completed, Figure A13.

The map has double entries since it carries the excitation for both Y_1 and Y_2. The map is split into two maps for clarity, Figures A14 and A15.

Y_1Y_2 \ x_1x_2	00	01	11	10
	00	10	10	01
01	00	10	11	01
11	00	10	11	10
10	00	10	10	10

Figure A13 Completed excitation matrix

Y_1Y_2 \ x_1x_2	00	01	11	10
00	0	1	1	0
01	0	1	1	0
11	0	1	1	1
10	0	1	1	1

Figure A14 Excitation matrix for Y_1

Y_1Y_2 \ x_1x_2	00	01	11	10
00	0	0	0	1
01	0	0	1	1
11	0	0	1	0
10	0	0	0	0

Figure A15 Excitation matrix for Y_2

$$Y_1 = x_2 + x_1y_1$$
$$Y_2 = x_1x_1y_1 = x_1x_2'y_1'$$
$$= x_1 (x_2y_2 = x_2'y_1')$$

Referring to the flow map showing the secondary assignment the only place where the Z output occurs is in stable state 3 in row 11 column 11 inferring that Z = 1 when:

$$Z = x_1x_2y_1y_2$$

The circuit for this sequence will be that as shown in Figure A16.

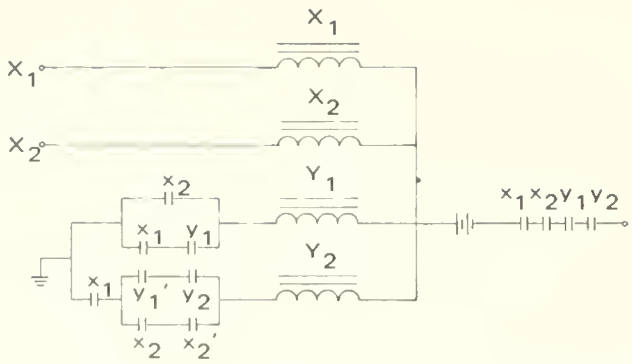


Figure A16 Diagram of completed sequential circuit

Summary of Sequential Circuit Design

1. Prepare and verify a primitive flow table for the problem.
2. Prepare a merger diagram.
3. From the merger diagram prepare a merged flow table.
4. Prepare the transition diagram and decide the secondary states.
5. Write the excitation matrix and, from this,
6. Prepare the output matrix.
7. Design the combinational circuits.

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