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Solid state control fundamentals

Basic control systems
All control systems share three common features: Inputs, logic functions and outputs. (Figure 2-1).

Figure 2-1a illustrates a common machine control diagram. The inputs are items such as limit switches and pushbuttons. The outputs are solenoids, motor starters or lamps. The logic for the system is provided by the sequencing of the machine.

Figure 2-1b shows the conventional relay control approach. The inputs are still such things as limit switches and pushbuttons. The outputs are still such things as solenoids, motor starters or lamps. The logic functions are performed by hard-wired relay contacts.

The solid state system shown in Figure 2-1c, however, is quite different. For one thing, the inputs and outputs are in two parts — external and solid state. The external elements are still the same limit switches, pushbuttons, solenoids, motor starters and lamps. These, however, operate at voltages that are too high for the solid state logic devices and, in addition, often operate on AC while the solid state logic requires DC. It is obvious, therefore, that conversion is needed from high voltage AC to low voltage DC on the input side, and from low voltage DC to high voltage AC on the output side.

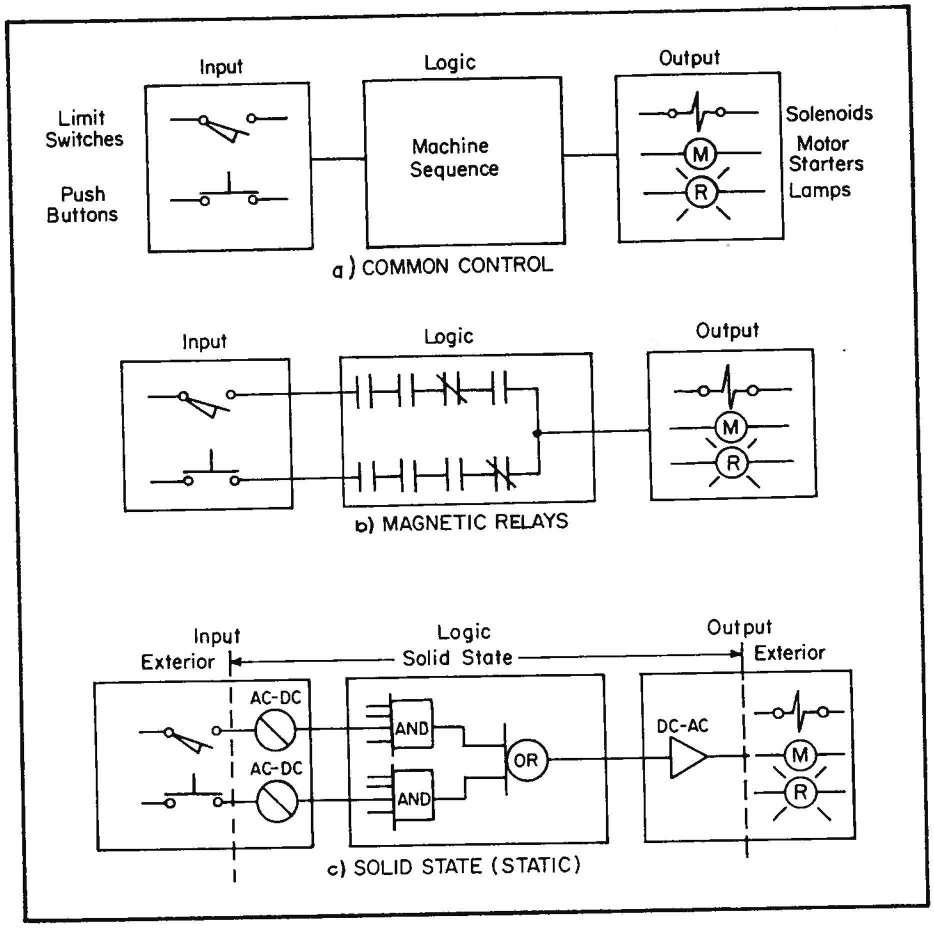


Figure 2-1: Block diagrams of basic control systems.

Logic equivalents
In order to work with solid state controls, one needs to understand the tools available . . . the functional building blocks. A good way to accomplish this is by first examining the relay control functions and then relate them to the solid state functions.

AND Function. The relay circuit shown in Figure 2-2 is a simple series contact circuit which represents the AND logic function. Contacts A AND B AND C AND D must be closed to energize relay coil E, closing contact E and opening contact $\bar{E}$ (NOT E). Or, putting it another way, the four contacts must be closed to provide an output at E and *not* an output at $\bar{E}$. Note that a normally-open contact is designated by a plain letter, while a normally-closed contact is designated by a letter with a line above it.

The equivalent solid state AND logic function operates similarly; when signals are present at inputs A AND B AND C AND D, an output is generated at E and the normal output at $\bar{E}$ is cancelled. Should any one or more of these inputs be removed, the AND gate will revert to its normal state of no output at E and an output at $\bar{E}$.

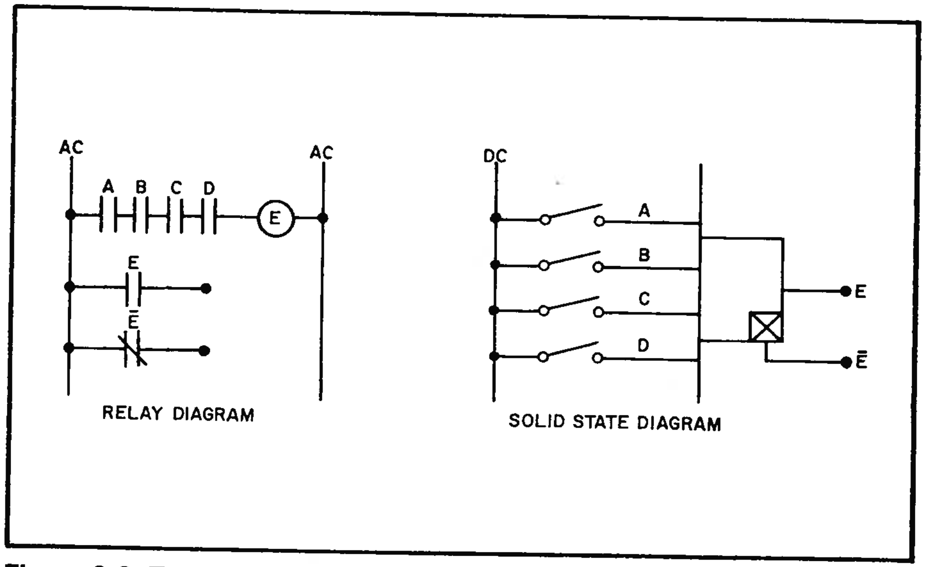


Figure 2-2. The AND function

OR Function. Figure 2-3 shows a basic parallel relay contact circuit, representing the OR function. With the relay circuit, closing contact A OR B OR C OR D energizes coil E, closing contact E and opening contact $\bar{E}$. Opening **all** contacts de-energizes coil E, opening contact E and closing contact $\bar{E}$.

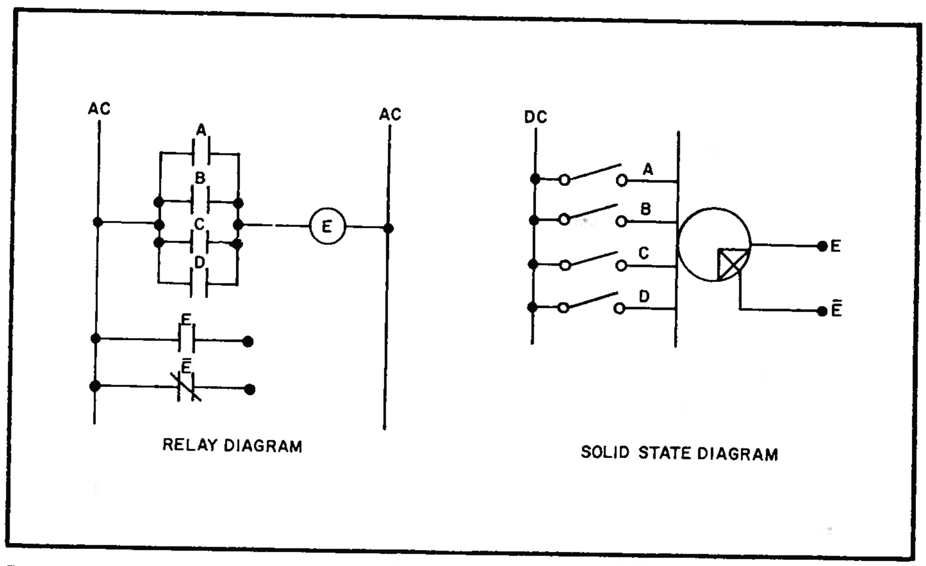


Figure 2-3. The OR function

Again, the solid state OR function operates in the same manner; closing switches A OR B OR C OR D, singly or in any combination, results in an output at E and no output at $\bar{E}$. Opening **all** switches cancels the output at E and reactivates the output at $\bar{E}$.

It should be noted with this or any other logic function that has two outputs (E and $\bar{E}$), both outputs do not have to be used. In fact, a logic function normally is considered as having only one output (E). The NOT output ($\bar{E}$) is added to 300 Series devices to provide greater convenience and flexibility. In actual practice, either or both outputs can be used depending upon the needs of the circuit.

TIME DELAY Functions. This function can be used either as an ON-DELAY or an OFF-DELAY. Using the ON-DELAY relay circuit in Figure 2-4, the coil TD-E is first energized and then, after a selected time delay, contact E closes and contact $\overline{E}$ opens. When coil TD-E is de-energized, contact E opens immediately and contact $\overline{E}$ closes. The OFF-DELAY relay circuit operates just the reverse; energizing coil TD-E immediately closes contact E and opens contact $\overline{E}$. Then, when the coil is de-energized, there is a time delay before contact E opens and contact $\overline{E}$ closes to their normal state.

Another way to designate the state of any logic input or output is to use "1" for on, and "0" for off. Thus, for the ON-DELAY logic function in Figure 2-4, when input A is operating at logic 1, a selected time delay will pass, and output E will be at logic 1 and $\overline{E}$ will be at logic 0. Then, when the input switches to a logic 0, output E immediately changes to logic 0 and output $\overline{E}$ changes to logic 1.

Likewise, with the OFF-DELAY function, when the input switches to logic 1, output E immediately changes to logic 1 and $\overline{E}$ changes to logic 0.

When the input is removed at logic 0, there will be a time delay before E changes to logic 0 and $\overline{E}$ changes to logic 1.

RETENTIVE MEMORY Functions. Certain control applications require that the result of an input be retained after the input is removed. This is illustrated by the relay circuit in Figure 2-5. Energizing coil E latches the memory, closing contact E and opening contact $\overline{E}$. Thus, when coil E is de-energized, the two contacts remain in their set positions. To return the contacts to their normal state, coil $\overline{E}$ is energized, unlatching the memory and reversing the state of the contacts. Should power be interrupted at any time, the output contacts will remain in their existing state.

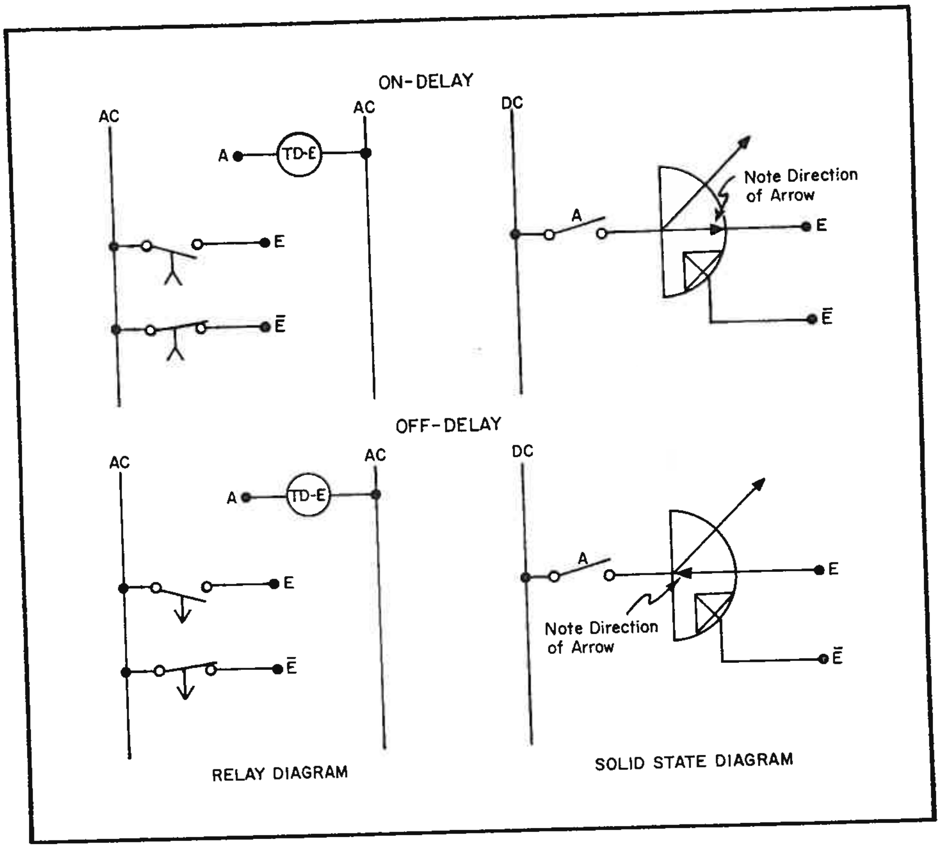


Figure 2-4: The TIME DELAY functions.

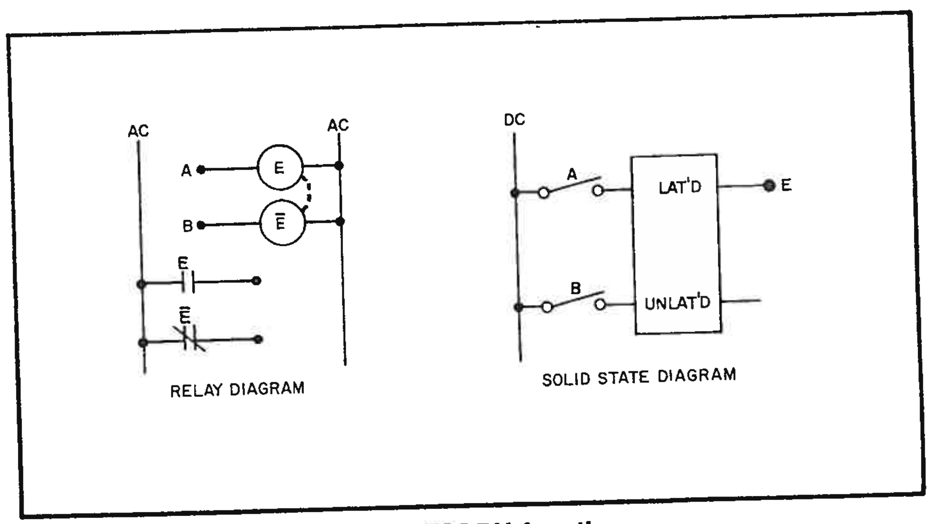


Figure 2-5: The RETENTIVE MEMORY function.

The solid state RETENTIVE MEMORY operates in much the same way. Momentary closing of switch A results in a continuing logic 1 output at E. Momentary closing of switch B returns output E to its normal logic 0 state and produces a logic 1 output at Ē. As with its relay counterpart, the existing output state at power interruption is retained.

Special Functions

Some control systems require functions which can be performed more economically with special devices. Such devices include: FLIP-FLOPS, PARALLEL and SERIAL INPUT SHIFT REGISTERS, TIMERS and ONE SHOTS. These special devices are described in Section 6 on the individual device specification sheets.

AC INPUT. Solid state logic devices operate on low voltage DC. Therefore, any external high voltage AC inputs must be converted to low voltage DC and conditioned to remove contact bounce and electrical noise before they can be fed into the solid state system. The symbol for such AC INPUT devices is shown in Figure 2-6.

Closing AC limit switch LS results in a DC logic 1 output at E. Conversely, opening switch LS results in a DC logic 1 output at Ē.

AC OUTPUT. In a similar manner, the low voltage DC outputs of the solid state system must be converted to high voltage AC to activate the external devices. This is accomplished by AC OUTPUT devices, whose symbol is shown in Figure 2-7.

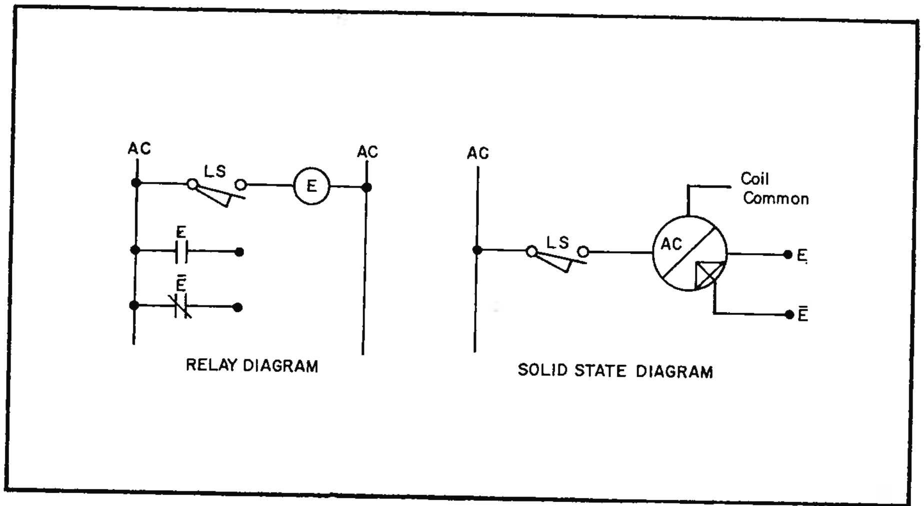


Figure 2-6: AC INPUT.

Energizing coil E closes contact E which energizes the AC solenoid. Removing the AC input at A de-energizes coil E which de-energizes the AC solenoid.

Closing DC switch A results in an AC output at E, energizing the AC solenoid. Opening switch A results in no output at E, de-energizing the AC solenoid.

A composite chart covering all the logic equivalents discussed above is included on the next page.

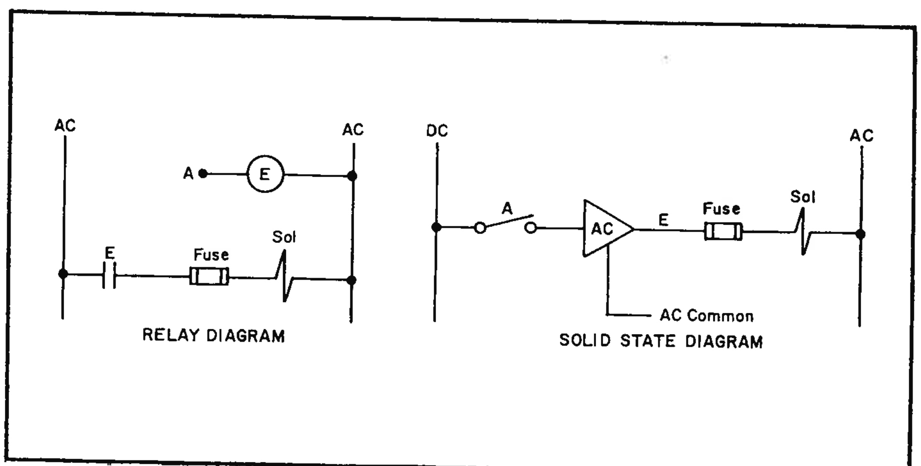
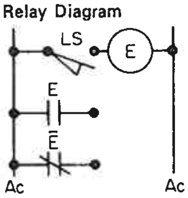


Figure 2-7: AC OUTPUT.

Glossary of Control Diagram Symbols

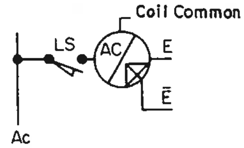
Relay Diagram | Relay Statement | English Logic | ANSI Y32.14 | English Logic Statement | Boolean Equation

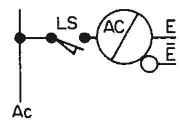


Ac Input
Closing LS energizes coil E, closing contact E and opening contact Ē

Opening LS de-energizes coil E opening contact E and closing contact Ē

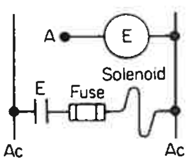
English Logic: **Ac Input**





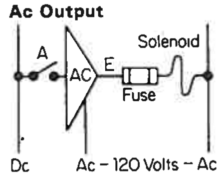
Closing switch LS results in an output at E — $LS=E$

Opening switch LS results in an output at Ē — $\overline{LS}=\overline{E}$

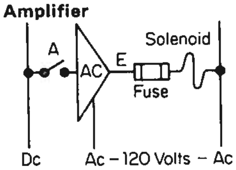


AC Output
Energizing coil E closes contact E and energizes the Solenoid

Ac Output

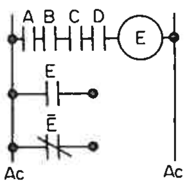


Amplifier



Closing switch A results in an Ac output at E — $A=E$

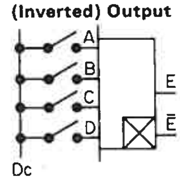
Opening switch A results in no output at E — $\overline{A}=\overline{E}$ (No Output)



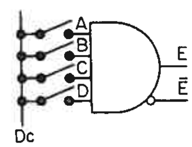
Series Contacts
Closing contact A AND contact B AND contact C AND contact D energizes coil E closing contact E and opening contact Ē

Opening any one Contact or combination de-energizes coil E opening contact E and closing contact Ē

AND Gate with NOT (Inverted) Output

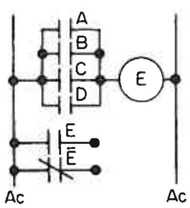


AND Gate with Inverted Output



Closing switches A AND B AND C AND D result in an output at E — $A \cdot B \cdot C \cdot D \cdot = E$

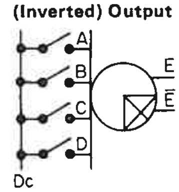
Opening any one switch or any combination results in an output at Ē — $\overline{A} \cdot B \cdot C \cdot D \cdot = \overline{E}$



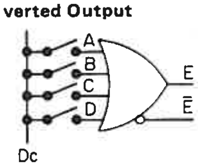
Parallel Contacts
Closing contact A OR contact B OR contact C OR contact D OR any combination of contacts energizes coil E closing contact E and opening contact Ē.

Opening all contacts de-energizes coil E opening contact E and closing contact Ē

OR Gate with NOT (Inverted) Output

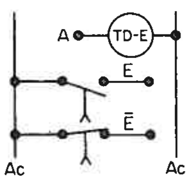


OR Gate with Inverted Output



Closing switches A OR B OR C OR D or any combination results in an output at E — $A+B+C+D=E$

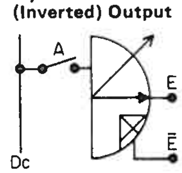
Opening all switches results in an output at Ē — $\overline{A} \cdot \overline{B} \cdot \overline{C} \cdot \overline{D} \cdot = \overline{E}$



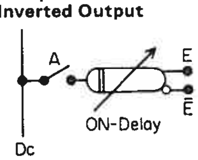
On-Delay Timer
Energizing coil of timer TD-E causes contact E to time closed after a period of time, and closed contact Ē times open.

De-energizing Timer coil TD-E Instantaneously opens contact E and closes contact Ē

Adjustable On-Delay Timer with NOT (Inverted) Output

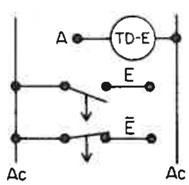


Adjustable On-Delay Timer with Inverted Output



Closing switch A results in an output at E after a time delay — $A=E$ (After Time Delay)

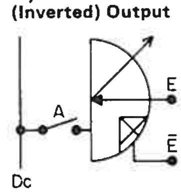
Opening switch A results in an instantaneous output at Ē — $\overline{A}=\overline{E}$



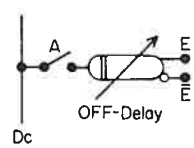
Off-Delay Timer
Energizing coil of Off-Delay timer TD-E instantaneously closes contact E and opens contact Ē

De-energizing the coil Off-Delay timer TD-E causes contact E to time open and contact Ē to time closed after a time delay.

Adjustable Off-Delay Timer with NOT (Inverted) Output

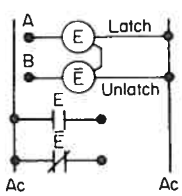


Adjustable Off-Delay Timer with Inverted Output



Closing switch A results in instantaneous output at E — $A=E$

Opening Switch A results in an output at E after a time delay — $\overline{A}=\overline{E}$ (After Time Delay)

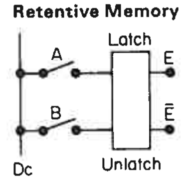


Retentive Memory
Energizing coil E latches the memory closing contact E

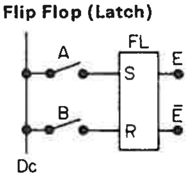
Energizing coil Ē unlatches the memory closing contact Ē

The existing output state at power interruption will be retained.

Retentive Memory



Flip Flop (Latch)



S=Set R=Reset

Momentary closing of switch A results in an output at E — $A=E$

Momentary closing of switch B results in an output at Ē, resetting E — $B=\overline{E}$

The existing output state at power interruption will be retained

Converting relay schematic diagrams to solid state diagrams

A relay schematic or ladder diagram is an excellent starting point for developing an equivalent solid state logic diagram. Although there are a number of methods to accomplish this, the "circle method" is one of the simplest and fastest. This method is explained through the following example:

Figure 2-8 is a pictorial representation of a drilling station on a simple machine. This example was chosen because such a drilling station is found on many machine tools, and the complexity of the circuit covers a large percentage of the relay diagrams you may encounter.

Start-up for the unit requires setting a selector switch to "automatic" or "manual" and energizing the spindle motor via a pushbutton.

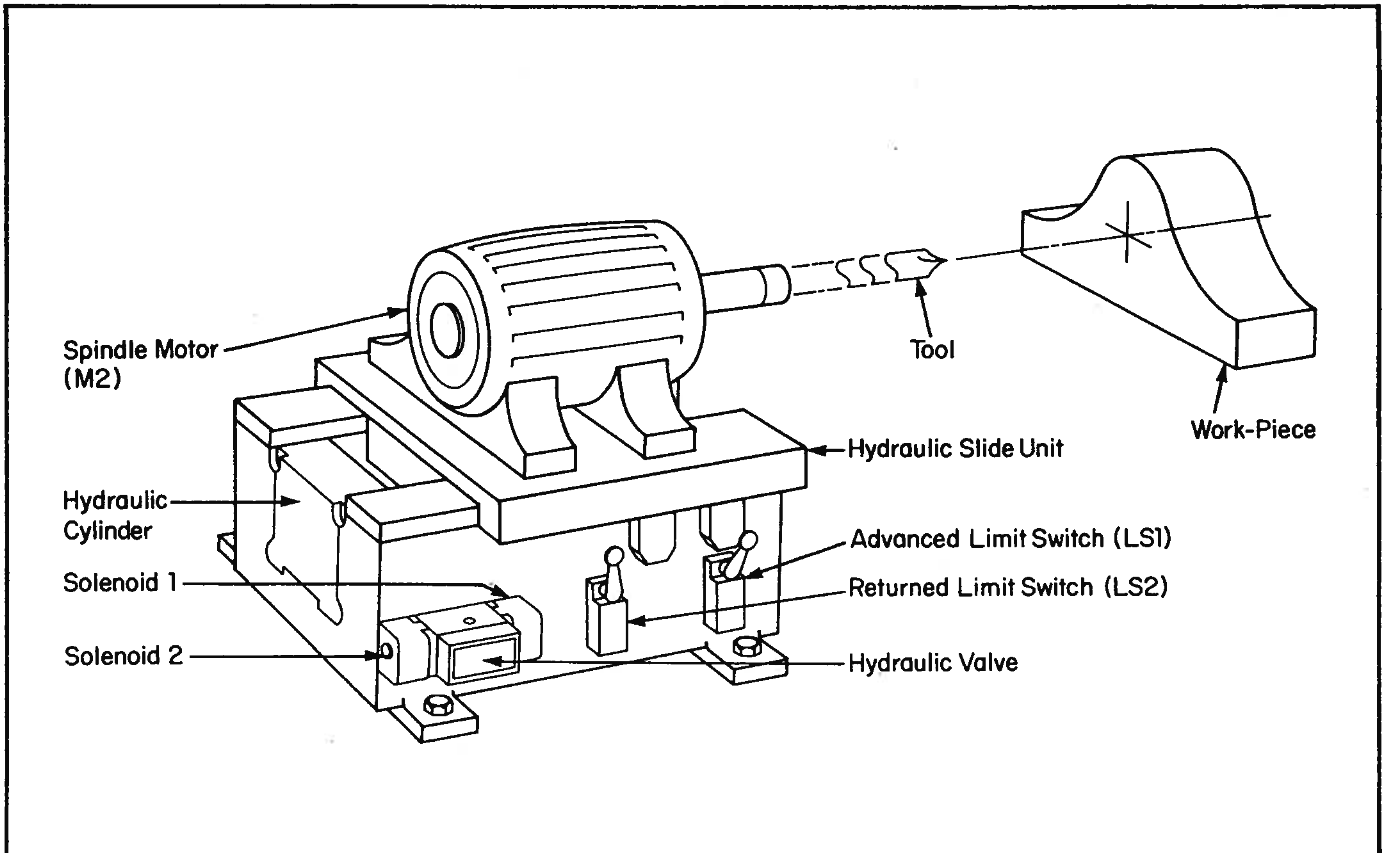


Figure 2-8: Typical machine tool drilling station.

When set for automatic operation, the unit cycles upon command from the central control (CR50) of the machine. First, the "advance" hydraulic control valve is energized by a solenoid, causing the unit to advance to the work piece. Second, when

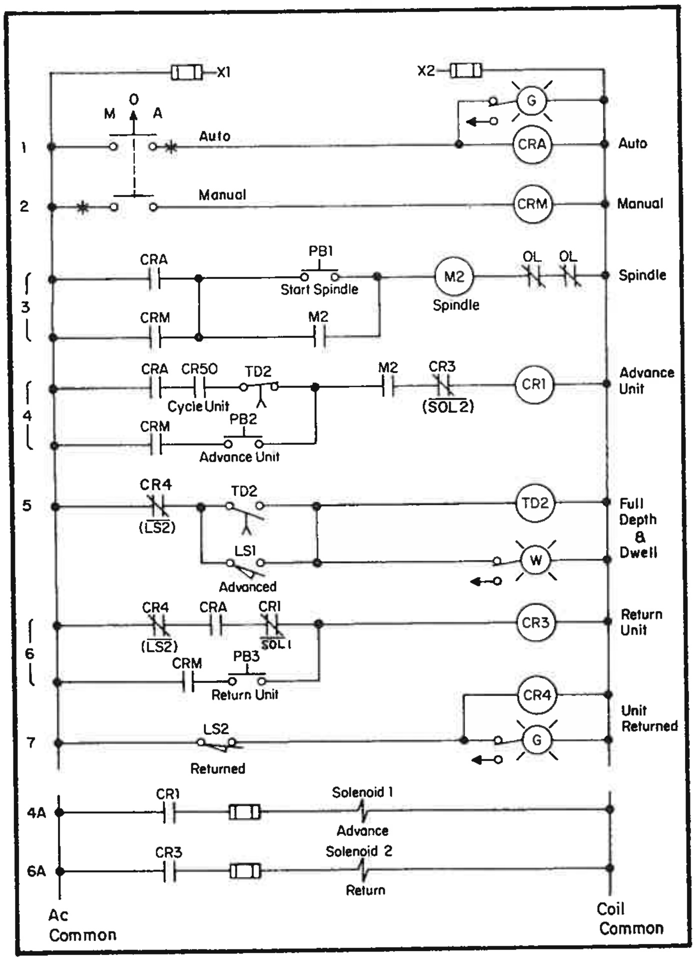


Figure 2-9: Original version of ladder diagram.

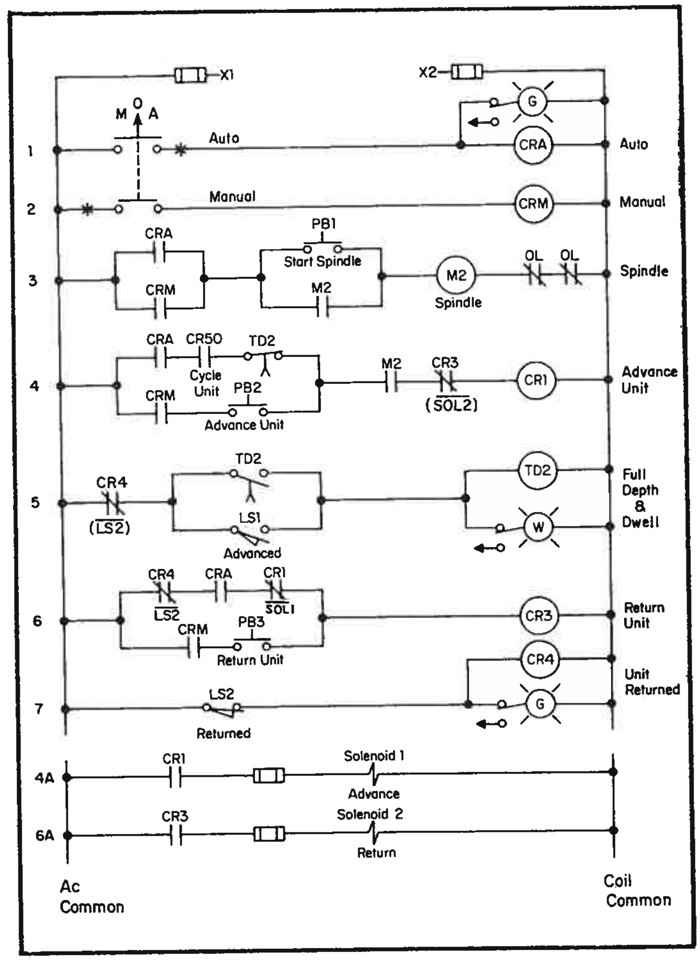


Figure 2-10: Revised version of ladder diagram.

the unit's full advanced position is reached, a limit switch is closed, energizing a dwell timer and a "full depth" indicator at the operator's station. Third, after a short time delay, the "advance" hydraulic valve is de-energized and the "return" valve is energized. Fourth, when the full return position of the unit is reached, a second limit switch is closed, de-energizing the "return" valve. All cycling controls are returned to normal and the unit is ready for the start of another cycle.

Figure 2-9 shows the ladder diagram for our example as it would be drawn normally. Since the circle method requires the grouping of series and parallel contacts, the diagram has been redrawn to make these circuits easier to recognize as shown in Figure 2-10. The line numbers on the left vertical bus provide the correlation between the two versions.

The first step in the conversion process is to select the "inputs". This is done by circling and numbering each input as shown in Figure 2-11. The primary concern is with identifying and counting the 120-volt AC pilot devices that are located outside

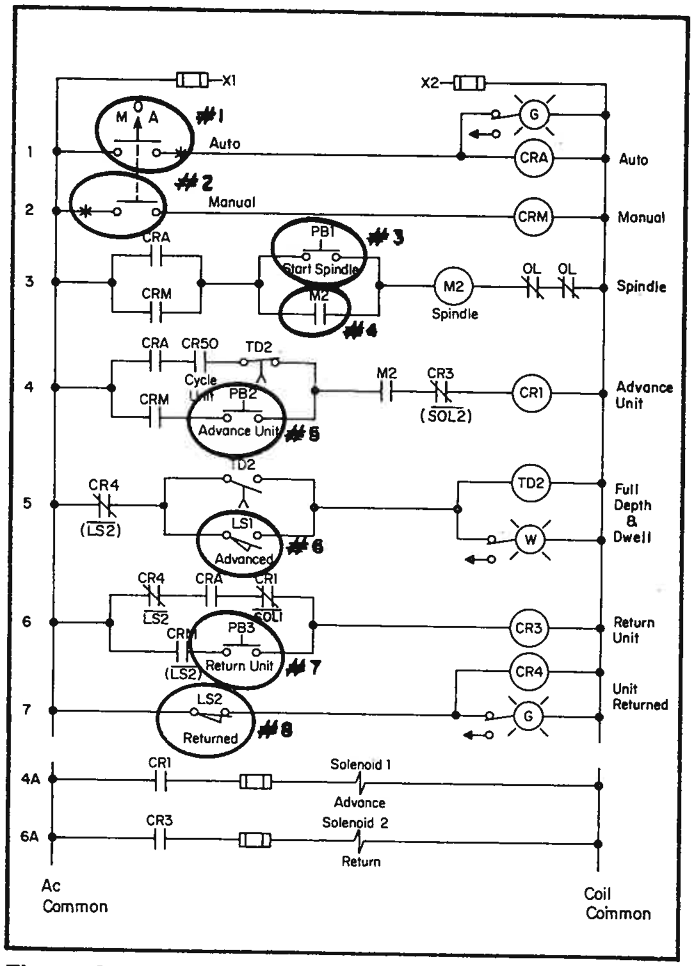


Figure 2-11: Selection of panel inputs.

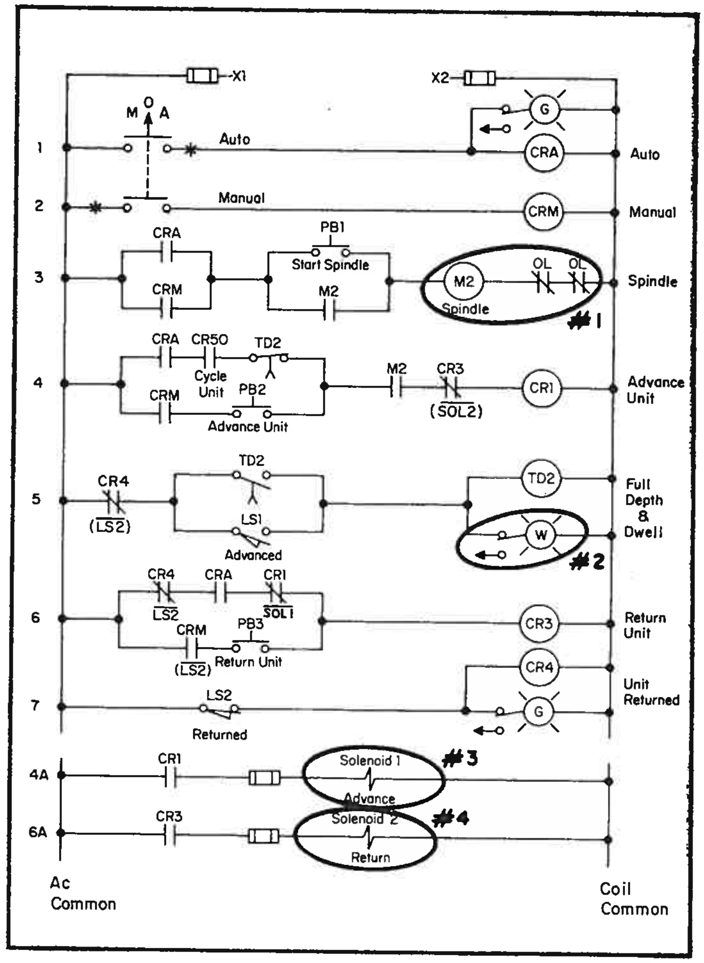


Figure 2-12: Selection of panel outputs.

the panel. The only exceptions to this are interlock contacts from other panels and the motor starter seal contacts within the panel. Generally, only one contact of each input pilot device need be wired to the solid state panel. The equivalents of the closed or open contacts are generated electronically in the AC input circuits by selection of the true or NOT function.

The second step is to select the "outputs". Here again, circle and number them as shown in Figure 2-12. The only things to be concerned with are the machine outputs driven from relay contacts. Outputs driven directly from limit switches or pushbuttons, such as lamps, remain as in the relay schematic and do not require solid state AC outputs.