MANUAL, AUTOMATIC AND REMOTE CONTROL

PROTECTIVE DEVICES FOR TRANSMITTERS

31RC

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STUDY SCHEDULE NO. 31

For each study step, read the assigned pages first at your usual speed. Reread slowly one or more times. Finish with one quick reading to fix the important facts firmly in your mind, then answer the Lesson Questions for that step. Study each other step in this same way.

☐ 1. Introduction; Switches . . . . Pages 1-5

This section discusses knife switches, brush switches, drum switches, and push-or-pull switches. Answer Lesson Questions 1 and 2.

☐ 2. Fuses; Circuit Breakers . . . . Pages 5-9

You study these two devices for automatically opening an electric circuit. Answer Lesson Questions 3, 4, and 5.

☐ 3. Remote Control Switches; The Magnetic Contactor Switch; Relay Applications; Review of Elementary Relays . . . . Pages 9-14

You learn how it is possible to obtain a completely automatic system by using a magnetic contactor switch along with a clock-controlled relay system. Answer Lesson Question 6.

☐ 4. Special-Purpose Electromagnetic Relays . . . . Pages 14-18

Multi-contact power relays, mechanical and electrical latch-in relays, two-coil relays, two-coil undervoltage relays, two-coil motor starting relays, and Rachet type sequence relays are discussed.

☐ 5. Time-Delay Relays; Induction Type Relays . . . . Pages 18-21

You study three widely used types of time-delay relays. Answer Lesson Questions 7 and 8.

☐ 6. Exact Remote Control; Motor Starting . . . . Pages 21-27

In this section you study manual d.c. motor starters, automatic starters for d.c. motors, a.c. motor starters, and resistance starters. Answer Lesson Questions 9 and 10.

☐ 7. Voltage Regulation . . . . Pages 27-29

Voltage regulation for d.c. and a.c. generators, automatic field excitation controls, Tirrill regulator for d.c. generators, Tirrill regulator for a.c. generators, and line voltage regulation are described.

☐ 8. Start Studying the Next Lesson.

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Manual, Automatic and Remote Controls

Protective Devices for Transmitters

Introduction

ASIDE from the numerous adjustments needed in a radio transmitter to meet normal operating requirements, there are the routine daily start-ups and shut-downs, emergency shut-downs, and auxiliary equipment to be placed in service. All of these operations require controls, which may be manual or automatic, local or remotely controlled.

Control devices may also be protective devices. During starting or stopping of equipment, a definite step-by-step procedure must generally be followed in order to prevent damage. Whether this procedure is carried out manually or automatically, protective devices will be needed to guard against accidental deviation from the required sequence of operations.

Protective devices are essential in practically every phase of equipment operation. Even during normal operation, there are possibilities of part failure which may result in damage to equipment unless automatic protective devices for immediately shutting down such equipment or removing high voltages, etc., are provided. During normal maintenance or emergency adjustments, a careless step might result in personal injury unless protective devices automatically remove high voltages. A fuse or a door interlock switch might mean the saving of a life.

The system of control of the protective devices will vary widely from installation to installation. In one installation the operator may be called upon to exercise a great deal of judgment and to assume considerable responsibility. He may be required to initiate every function of the station by pushing appropriate buttons or manipulating various controls. In the other extreme, the equipment may be remotely located and even automatically started or stopped, so that the operator's functions are reduced to watching and maintenance.

Specific written instructions for starting, running and stopping a transmitter are always available at the station. By mastering these instructions, a new operator who understands how standard control devices function should have no difficulty in "breaking into" the routine of duties at any radio station. The purpose of this lesson is to give you this essential information regarding the control and protective devices which you may encounter.

Switches

A switch is a device for mechanically opening and closing an electric circuit. When closed, a switch must carry the rated current with negligible voltage drop (of the order of 0.01 volt), without excessive heating (usually less than 30° centigrade rise). A switch must take care of overloads normally encountered in practice. Any arcs which are formed during the opening operation must be harmless. When open, a switch must isolate all live portions (and parts) of the circuit at the maximum voltage employed.

The current-carrying capacity of a switch is dependent upon *the area of the conducting contact surfaces*. The voltage capacity of a switch depends upon the insulation between the switch terminals. A large switch is necessary to handle higher voltages and higher currents. Other factors which control switch size are the means employed for blowing out the arc formed during opening of the circuit, the type of circuit in which the switch is used, the means (if any) for enclosing the switch, etc. Arcing is much more apt to occur in a highly inductive circuit than in a purely resistive circuit.

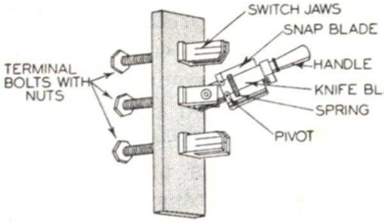


Fig. 1A. Quick-break single-pole, double-throw (SPDT) open-type knife switch.

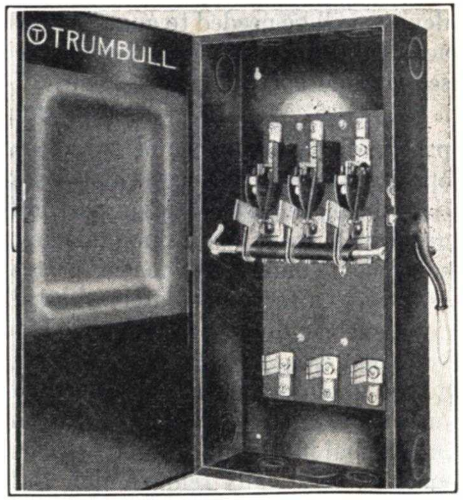
Switches may be classified as push-button and snap-type switches such as are used in home lighting circuits, *knife switches, brush switches, drum switches,* and *push-or-pull switches.* We will not consider ordinary push-button and snap type lighting-circuit switches in this lesson, for you can readily inspect them in your home.

Knife Switches. Knife switches are *open* or *enclosed* (depending upon whether the live parts are exposed or totally enclosed in a metal housing or box), *single-throw* or *double-throw* (depending respectively upon whether a circuit is closed only when the switch is thrown in one position or in either of two positions), *single-pole, double-pole, triple-pole,* etc. (depending upon the number of wires in a circuit which are controlled by the switch), and *single-blade* or *multi-blade* (depending upon whether one or more blades are required per pole to handle the current flowing in the circuit).

In general, the contact area of a knife switch must be large enough so that the current density at the contact surfaces does not exceed 75 amperes per square inch. Up to 1,000 amperes in capacity, a single blade per pole is generally sufficient.

The recommended minimum spacing between the poles of the switch is approximately 1 inch per 100 volts d.c. or 1 inch per 200 volts a.c. for switches having a current rating of 100 amperes or less. For switches of larger current-carrying capacities the minimum spacing between poles is increased by about 10% for each 100% increase in current.

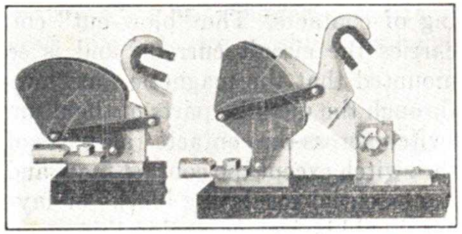
A single-pole, double-throw (abbreviated SPDT) open-type knife switch is shown in Fig. *1A.* A three-pole, single-throw (abbreviated TPST) enclosed type knife switch is shown in Fig. *1B.* The switch of Fig. *1A* is equipped with a quick-break attachment so as to make it impossible to draw a dangerous arc by opening the switch slowly. The main switch blade carries an auxiliary blade attached to the main blade by a hinge and spring. When the switch is opened, the auxiliary blade is held in the stationary switch jaw by friction until it is suddenly jerked out by the spring tension. The circuit is thus opened instantaneously even though the switch handle is moved rather slowly.



Courtesy Trumbull Electric Mfg. Co.

Fig. 1B. Enclosed triple-pole, single-throw (TPST) switch with quick-make, quick-break action, safety cover interlock and "snuf-arc" contacts for extinguishing arcs.

The switch in Fig. *1B* is equipped with both a quick-made and a quick-break attachment to minimize burning of contacts due to arcing. This type of switch is of the heavy-duty type, constructed to meet the electrical and mechanical demands of continuous operation. In the switch shown, the switch parts are mounted on a slate or asbestos base. A mechanical interlocking arrangement prevents closing of the switch unless the front cover is securely locked, and prevents opening of the cover unless the switch is opened first. Fuse posts provide for the insertion of suitably rated knife-contact type cartridge fuses. The fuse posts nearer the switch blades also serve as hinge posts about which the yoke (the blade-holding cross-bar) rotates. Complete enclosure of the switch provides safety to the operator, as well as freedom from fire hazards due to arcing.



Courtesy Trumbull Electric Mfg. Co.

Fig. 1C. The "snuf-arc" switch contact with blade in contact jaws (left), and blade leaving contact jaws (right).

A spring mounted between the box and the yoke lever provides a quick-make action by pulling the blades into the jaws suddenly once the external operating handle has been moved manually through a null position during closing.

An enlarged view of the switch jaws and blades and the means employed for preventing the formation of arcs is shown in Fig. *1C.* The large irregular-shaped part is the "snuf-arc." It consists of two identical plates hinged to the switch jaws and connected to the switch blade by bars (one on either side of the "snuf-arc"). The plates and bars are made of insulating, fire-proof material so that the switch jaws and blade are not electrically connected until the blade contacts the jaws. In closing or opening the switch, the blade moves between the plates of the "snuf-arc," so that any arc formed between the switch blade and jaws is prevented from flaring side-ways. The "snuf-arc" also incorporates a center barrier (of insulating material) fastened between the two plates. This center barrier is indicated by the dotted lines and is so shaped as to form a barrier between the switch blade and jaws, thereby interrupting any arc formed. The mechanical motion of the "snuf-arc" is such that the center barrier moves out of the way just before the blade and jaws begin to mesh.

Brush Switches. Brush switches have laminated copper brushes which press against solid copper blocks when closed. Contact details are shown in Fig. *2.* Brush switches are occasionally employed instead of knife switches for handling large currents at low voltages, since large knife switches with their large rubbing contact surfaces are sometimes difficult to manipulate.

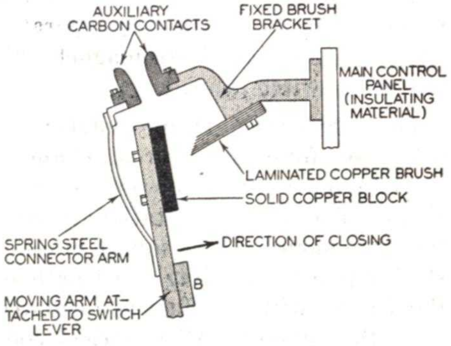


Fig. 2. Contact details of a typical brush switch. This becomes an automatic switch or magnetic contactor when the switch arm is made of iron and is part of a closed magnetic circuit containing iron block *B* and an electromagnet mounted to attract this block. Excitation of the electromagnet then serves to close the switch.

By using a toggle-operated lever to increase the pressure between the laminated brush and the solid contact block, sufficiently good contact can be obtained to permit current densities of up to 300 amperes per square inch (as compared with 75 amperes per square inch for knife switches). The switch is generally held in the closed position by either a mechanical or a magnetic latch.

Besides the main brushes, the closing lever often carries auxiliary tips which make contact with auxiliary carbon block contacts. During closing, the auxiliary tips and blocks serve to complete the circuit before the main brushes reach their contacting blocks; during opening, the auxiliary tips and blocks keep the circuit closed until after the brushes leave their contacting blocks. The purpose of these auxiliary carbon contacts is *to prevent the formation of arcs at the copper contacts* either during closing or during opening, by making all arcing take place between carbon blocks where it can do relatively little harm.

Brush contacts or contactors are generally used in remotely operated switches, in which electromagnet coils move the switch arms.

Drum Switches. Drum switches are often used for complex circuit changes. A common construction is shown in Fig. *3*. The fingers or stationary contacts are mounted on a square brass or steel support extending the length of the frame, with the fingers insulated from the support. All electrical connections are made to the stationary contacts (the fingers). A drum made from insulating material, mounted on the shaft for the switch handle, serves as a support for the moving contacts. The contacts usually consist of brass sections to which are screwed renewable copper faces. The contacts may be of any desired length, and may be arranged to make contact with any desired fingers at any desired position as the drum is rotated.

The drum switch is compact, may be readily enclosed, and is particularly adaptable to magnetic "blow-out" of arcs formed during the opening or closing of contacts. The "blow-out" coil carries the circuit current, and is so mounted that the magnetic flux flows through the metallic parts of the drum switch across the contacts (all parts of the switch except the contact faces and the essential insulating blocks or layers should be iron or steel in this case). As a contact is broken, an arc forms between the two contacts which have just separated. This arc, comprising a flow of electrons, sets up a magnetic field which is acted upon by the "blow-out" magnetic field. This forces the arc to one side, quickly elongating the arc to the length at which it normally goes out.

Summary of Arc-Controlling Methods. Although many different types of arc-controlling devices will be found in power switches for radio equipment, these devices will invariably fall into one of the following groups, depending upon the fundamental principles involved: *1.* Fast-acting switches, which depend upon speed to draw the arc out in the shortest possible time, so the arc cannot build up; *2.* Switches with auxiliary carbon contacts which take over the arc, (carbon is less affected by the heat of an arc than copper, but is unsatisfactory for the main contacts because of its high electrical resistance); *3.* Arc-blocking devices, which interpose insulating elements in the arc path in order to lengthen the arc path and eventually block the arc (the "snuf-arc" is an example); *4.* Magnetic blow-out devices, which employ a fixed magnetic field to bend the arc away from the contacts, thus lengthening the arc path rapidly; *5.* De-ion circuit breakers, which depend essentially upon specially shaped electrodes and contacts to make the arc produce its own "blow-out" magnetic field, driving the arc into barriers which break up the arc.

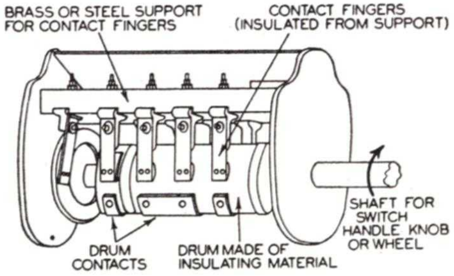


FIG. 3. **Simple drum switch.**

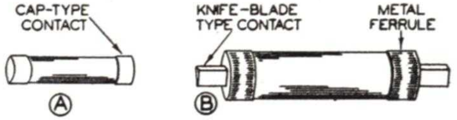


FIG. 4. **Cartridge fuses. *A*—cap contact; *B*—knife contact.**

Push-or-Pull Switches. There are many types of push-or-pull switches arranged to provide for a dead-front panel, with all of the live switch parts and wiring in back of the panel. With the push-switch type, pushing one lever or button closes the switch, while pushing a second lever or button opens it. The pull-type switches are similar except that the levers or buttons are pulled instead of pushed, thereby preventing accidental operation of the switches. Signal lights are generally provided to indicate the switch position.

Under this general classification also comes the fuse-puller switch, providing a dead-front panel. The cartridge fuses (one for each pole of the circuit) are mounted on the back of a bakelite panel which may be pulled out by means of a handle. With the panel in place in the "on" position, the cartridge fuses plug into jaws to complete the circuit. Pulling out the panel, rotating it either 90° or 180° (depending upon the particular design employed) and reinserting the panel gives the "off" position. The fuse clips then rest in "dead" holes, leaving the circuit open. Several fuses may be mounted on a panel, permitting complex switching.

Fuses

A fuse is a metal strip or wire which opens an electric circuit by melting or fusing when the current passing through it reaches a predetermined value. The power loss (I^2R loss) in the fuse link produces the heat which melts the metal fuse link and "blows" the fuse. The screw (plug) and the cartridge fuses are the two general types. The screw type fuse is so well known (being standard for home wiring systems) that it will not be discussed here.

The fuse links in cartridge type fuses may be enclosed in either glass or fiber tubes. Many different methods are employed for fastening the fuse clips to the fuse contacts; some of these methods permit replacement of "blown" fuse links.

Figure *4* shows renewable cartridge fuses which are available for voltages up to 250 volts, with various current ratings. The fuse dimensions depend not only upon the current rating but also upon the operating voltage. The fuse links, which are inserted in the cartridge holder by unscrewing the end caps, are of the form shown in Fig. *5*. Several links are sometimes used in parallel for the higher amperage ratings.

FIG. 5. **Typical renewable fuse links. The burn-out or fusing part in each link is marked *B*. The fuse rating depends upon the cross-sectional area at this point.**

The material used for the fuse links is generally zinc or aluminum for current ratings above about 5 amperes, and phosphor-bronze ribbon for currents below 5 amperes. These metals all have high conductivity, fairly low melting points and almost complete vaporization of the metal when blown.

Enclosing a fuse protects it from cooling drafts so that its temperature will depend solely on the current passing through it. Molten metal is not sprayed when the fuse blows. The heavy metal end caps cool the arc when the fuse blows, extinguishing it quickly. Non-renewable cartridge fuses are invariably filled with an insulating powder which takes up the disintegrated metal of the link when the fuse "blows," and helps to extinguish the arc.

The right fuse is a real investment; the wrong fuse is a waste of money, if not a real hazard. All fuses have an inherent time-delay feature because the current must heat the metal in the fuse link to its melting temperature. According to the National Electric Code, all fuses must be able to carry 10% current overload (above the fuse current rating) indefinitely but must *blow within a minimum specified time at 50% overload*. For ratings up to 30 amperes, this time is 1 minute; 31 to 60 amperes, 2 minutes; and 61 to 100 amperes, 4 minutes.

The time element in fuse operation makes fuses suitable for the protection of motors normally subject to very brief overloads which would open circuit breakers too frequently. If the time periods of the overload are on the average longer than the blowing time of the fuses, however, there will be too many fuse blow-outs, with their attendant high cost and loss of operating time.

Fuses are rated at the voltage which they will break without arcing or bursting. A d.c. supply with unlimited current capacity is assumed. (At lower currents, a fuse will safely break an a.c. voltage two or three times higher than the maximum safe d.c. voltage, but this difference becomes less at higher currents.)

Fuses are used to protect the rectifier tubes and filter networks in the rectifier power supplies of radio transmitters. Two types are shown in Figs. *6A* and *6B*. Both are enclosed in fiber tubes with bright brass end caps. The non-renewable fuse in Fig. *6A* is especially for aircraft use; the flanged ends prevent lengthwise slippage from holders. The fuse elements are phosphor-bronze ribbons rigidly supported inside the fiber tube. Each fuse is tested under vibration to insure proper operation on aircraft. Voltage ratings are up to 3,000 volts and current ratings from 1/16 ampere to 2 amperes.

The renewable fuse in Fig. *6B* is standard for transmitters at land stations. Voltage ratings are up to 10,000 volts (10″ long at 10,000 volts), and current ratings are from 1/16 ampere to 2 amperes. This fuse employs two principles of arc suppression. By using multi-break fuse wire having blow-out points one-half inch apart along its length, a number of small arcs are produced; these are suppressed more easily than one large arc. By forcing the arc to pass through small holes in the steel baffle plates, the hot ionized gases which form the arc are cooled (the steel plates conduct heat away from the arc), and additional arc suppression is obtained. As many as five baffle sections are used in the 10,000-volt sizes.

Courtesy Littelfuse Incorporated

Vacuum-enclosed "VIDEO" Littelfuse, designed for use in high-voltage television circuits. The fuses are available in the following ratings: 1/1000, 1/500, 1/200, 1/100, 1/32 and 1/16 ampere, with all sizes capable of breaking up to 15,000 peak volts on a.c. and up to 5000 volts on d.c. These fuses are used primarily to protect the equipment against damage when failure of insulation or of some part sends excessive currents through the circuits; the 1/200, 1/500 and 1/1000 ampere sizes also serve the important function of protecting human beings from shock, for these sizes will "blow" before the current reaches a dangerously high value.

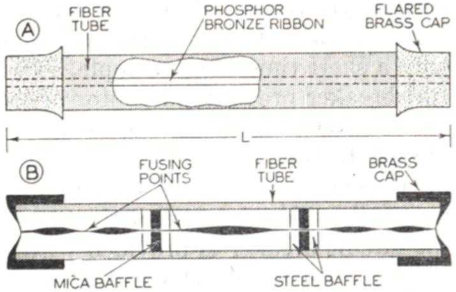


FIG. 6. Details of fuses made by Littelfuse Incorporated for high-voltage circuits in transmitters. *A*—inexpensive non-renewable type; it is made in 1000, 2500 and 3000-volt sizes, with *L* being 3″, 4½″ and 5½″ respectively. *B*—renewable fuse with special arc-extinguishing features; *L* is 3″, 5″ and 10″ long for 1000, 5000 and 10,000-volt sizes respectively.

Circuit Breakers

A circuit breaker is a device for opening an electric circuit automatically when the current or voltage in the circuit becomes abnormally high or low. The principal application for circuit breakers is in opening a circuit when the current reaches a certain predetermined value. For overloads a circuit breaker is superior to a fuse, for a circuit breaker is ready for use again as soon as it is reset after an overload. Breakers may be made to open a circuit when either the current or the voltage exceeds a certain maximum value or drops below a certain minimum value. If circuit breakers are classified according to their function, there are five distinct types: *overload, underload, overvoltage, undervoltage* and *reverse current* circuit breakers. A reverse current circuit breaker opens the circuit when the current in the circuit reverses, a condition encountered in battery charging.

A circuit breaker which combines *overload* and *undervoltage* functions as required for some battery-charging applications is shown in Fig. 7. Under normal operating conditions, the circuit breaker is in the closed position as shown in the illustration. Note the following essential elements: the overload electromagnet *OL*, consisting of a coil of wire (on an iron core) through which the load current passes; an undervoltage electromagnet *LV*, consisting of a coil of wire connected across the line through resistor R_1 and through contacts *CC;* a brush switch, the movable arm of which pivots about *P* and carries laminated copper brushes *B* which make contact with copper contact blocks *D* and *E;* an auxiliary carbon brush *G* which contacts auxiliary carbon contact block *F* just after contact *D* is made and just before contact *E* is made, thereby preventing burning of the copper contacts; a lever mechanism for securing high contact pressures; a latching arrangement for holding the switch in its desired closed position; a lever and plunger mechanism, controlled by electromagnets *OL* and *LV*, which trips the latching arrangement to open the circuit during overload or undervoltage conditions respectively.

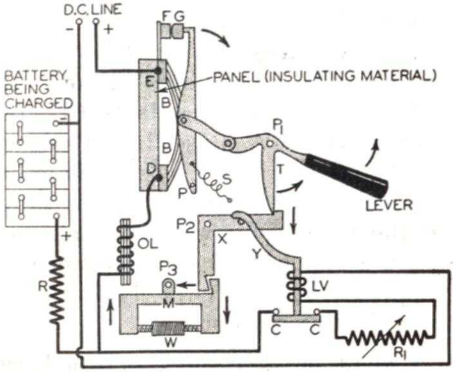


FIG. 7. Battery-charging circuit with overload and undervoltage circuit breaker. P, P_1, P_2 and P_3 are stationary pivot points. Arrows indicate directions of part movements when circuit breaker opens.

In case of an overload, magnet *OL* attracts the left-hand end of the pivoted iron armature *M*, drawing it upward. This lowers the right side of *M*, forcing the lower end of rightangle trigger X to the left and thereby releasing switch lever T at the other end of trigger X. Spring S then draws the arm carrying the laminated contacts away from the corresponding copper blocks, opening the circuit. The circuit breaker may be reset (closed) by pushing the handle down; trigger X will reset itself automatically in some types of breakers, while in others it must be reset by hand.

The heavy knurled nut W on the threaded rod provides a means for adjusting the value of overload current at which the breaker will open. Moving the nut to the left increases the current value, for the electromagnet then requires more current to pull up the extra weight.

In case of a drop in the line voltage (which would cause the batteries to discharge through the line), the force of electromagnet LV on its associated plunger decreases, and the plunger drops. In dropping, arm Y strikes trigger X, releasing lever T and opening the main circuit breaker contacts. Arm Y also opens contacts CC, removing coil LV. Resetting of trigger X when the breaker is closed will automatically close contacts CC. The value of the voltage for which the plunger of the undervoltage electromagnet drops out may be accurately controlled by adjusting resistor R_1.

Circuit breakers may take a large variety of forms, but all will operate in accordance with the fundamental principles just outlined. In some circuit breakers, the overload electromagnet is associated with a plunger passing through it, this arrangement taking the place of armature M in Fig. 7. Setting the breaker to operate at a predetermined overload is accomplished by adjusting the initial position of the plunger with respect to the coil or by adjusting the effective weight of the plunger.

It is often desirable to set a circuit breaker to trip at a definite value of current yet remain closed for a much higher current value which exists for only a short time. For example, a circuit breaker protecting a motor might be set at 150% of the full-load current; during starting, this motor might draw up to 600% of full-load current momentarily. To take care of this surge, the circuit breaker is provided with a time-delay element. One arrangement involves having the overload plunger move through an oil dashpot, thereby slowing up its motion. The plunger carries a disc which just fits into the cylindrical oil container; one or more small holes are bored through the plunger disc, so that the plunger rises only as rapidly as the oil can be forced through the small holes.

In circuit breakers carrying heavy currents, from 70 amperes up, time delay is obtained by means of a coil surrounding a bi-metallic strip which bends when heated by the current in the coil. The mechanism can be adjusted so the bi-metallic strip trips a latching trigger, allowing the circuit breaker contacts to open, when the desired breaker-opening current value flows through the coil. In addition to the thermal overload coil, breakers of this type also have an auxiliary magnetically-operated trip to provide protection against excessive overloads during short-circuit conditions. The magnetically-operated trip is set to operate at from 8 to 10 times the current value for the thermal trip, and operates *practically instantaneously*. A circuit breaker of this type is shown in Fig. 8.

The current rating which a given circuit breaker should have depends upon what its function is to be. In general, in any network such as a radio transmitter or a system of feeders supplying current to motors, transformers, etc., each component to be protected (such as a rectifier tube in a transmitter power supply or a motor) should be protected for from 115% to 125% of full-load current. Either a fuse or a circuit breaker may be used; both should have time-delay features so that momentary overloads which will not damage the circuit do not cause unnecessary interruptions. A short time delay action is necessary in circuit breakers protecting mercury vapor rectifier tubes, however, since these tubes are damaged even by momentary overloads.

There are applications, however, where the circuit breaker (with time-delay feature) is adjusted for protection at from 125% to 250% of full-load current of a device, for example, when a motor is protected by an overload coil built with the motor starter. This protects the motor during running, opening the motor starter when the current exceeds 125% of full-load. If the current runs up to several hundred per cent of full-load (during locked-rotor condition of the motor either running or starting), a circuit breaker inserted into the circuit, adjusted to operate at from 125% to 250% of full-load current, provides protection.

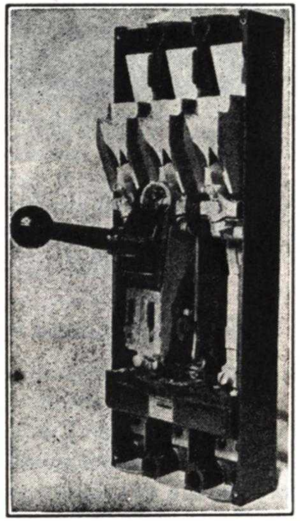
The time delay interval for a circuit breaker or a fuse *decreases* as the amount of overload increases; in other words, the higher the overload, the less time it takes for a circuit breaker to operate or for a fuse to blow. This characteristic prevents damage to contacts, component parts and wiring of a system during excessive overloads.

Remote Control Switches

As the complexity of an electrical system increases, the need for remote control and automatic switches becomes correspondingly greater. It may be necessary to close or open a circuit at a remote point (often over a telephone line or radio system), or start a sequence of operations resulting in the adjustment of a circuit merely by pressing a button or throwing a switch Often, it is desirable to dispense even with the pressing of a button, and make the change in the condition of a system itself start a sequence of operations which results in full compensation for the change.

The equipment developed for these applications includes a wide range of devices falling under the general classification of *switchgear*. However, most of the devices consist of or include two elementary components: the *magnetic contactor* and the *relay*. The National Electrical Manufacturers' Association defines them as follows:

A magnetic contactor is a magnetically actuated device for repeatedly establishing or interrupting an electric power circuit.

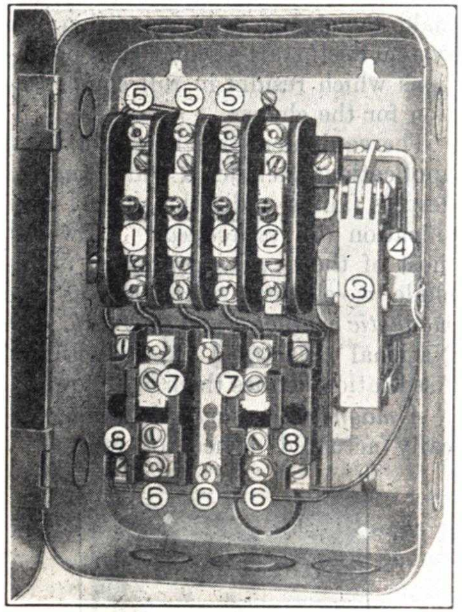


Courtesy Westinghouse Elec. & Mfg. Co.

Fig. 8. Circuit breaker combining a thermal overload tripping mechanism and an electromagnetic short-circuit tripping mechanism.

A relay is a device which is operated by a variation in the characteristic of one electric circuit to effect the operation of other devices in the same or another electric circuit.

A little consideration will show that the magnetic contactor is in reality a super-power relay—that is, the final relay in a control system. It is an automatic switch which allows the closing or opening of a circuit handling considerable power, through the medium of circuits handling considerably lower power.



Courtesy Trumbull Electric Mfg. Co.

FIG. 9A. Typical magnetic contactor switch.

The Magnetic Contactor Switch

A photograph of a magnetic contactor for closing and opening a three-phase circuit is shown in Fig. *9A*. The three movable contacts which form the three poles of the switch are shown at *1*. A fourth contact *2* serves as a holding-in contact. The contacts (see Fig. *9B*) are of the dual contact type. They are controlled mechanically by a lever operated by magnetic armature assembly *3*, and this in turn is controlled by magnetic operating coil *4*. The three-phase line enters the switch at line terminals *5*. The three-phase load, which may be a motor, connects to the switch at load terminals *6*.

The magnetic contactor switch is generally controlled from a push-button station (such as that shown in Fig. *9C*) which is located at a point remote from the switch. The push-button station is generally of the momentary contact type, in which each button carries a disc which bridges two stationary contacts (or a bar which bridges two fingers). The simplest push-button station employs two buttons, one (*START*) for closing the control circuit and the other (*STOP*) for opening the control circuit. The magnetic contactor must include elements which respond to the momentary making or breaking of the circuit at the push-button station.

Connected in series with the power contacts of the switch (on the load side) are the parts which provide overload protection (identified as parts *7* and *8* in Fig. *9A*). Two relay heaters are used, in series with two of the load leads (see Fig. *9D* and part *7* in Fig. *9A*); the two thermostatically controlled relays (Fig. *9E* and parts *8* in Fig. *9A*) are mechanically in contact with their relay heaters, and the relay contacts are in series with the magnet coil.

On overload in any phase, one heater at least will get excess current, increasing the temperature of its bi-metallic strip. The rate at which the temperature is raised will depend on the magnitude of the overload. The bi-metal strip bends because of the difference in expansion of the two metals of which it is comprised, and trips the mechanism in the relay. This in turn opens the circuit to the magnetic operating coil, opening the main switch. To close the switch it is necessary to reset the trip mechanism by hand in case of a hand-reset overload relay such as is shown at the upper right in Fig. *10*. With self-reset overload relays, an electromagnet built into the relay resets the trip mechanism automatically. In either case, the magnetic contactor switch remains open until the *START* button at the push-button station is pressed.

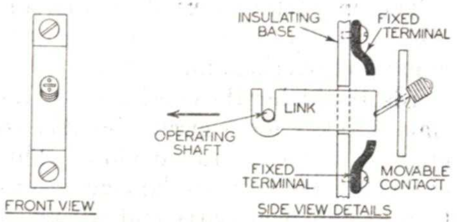
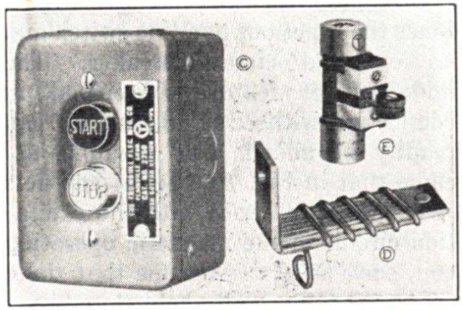


FIG. 9B. Details of one of the movable contactors employed in the magnetic contactor switch shown in Fig. *9A*. When the link is forced to the left by the shaft attached to the relay armature, the movable contact slides into position against the fixed terminals in such a way as to make the contacts self-cleaning.



Courtesy Trumbull Electric Mfg. Co.

FIGS. 9C, 9D and 9E. A typical push-button station for remote control starting and stopping is shown at *C*. At *D* is one of the relay heater units employed in the magnetic contactor type unit shown in Fig. *9A*; it consists essentially of a bi-metallic strip on which are wound a few turns of resistance wire. An overload relay unit of the hand reset type is shown at *E*.

The operation of the control circuit for the magnetic contactor switch will now be explained in connection with the schematic diagram of Fig. *10*. Power goes into the switch at terminals *1*, *2* and *3* at the top of the diagram, and goes to the load (provided the switch is closed) from terminals *1′*, *2′* and *3′*. Voltage for exciting the magnetic operating coil is obtained between lines *2* and *3*. The circuit to the magnetic operating coil is completed by pressing the *START* button at the push-button station; this connects together contacts *i* and *j*. The *STOP* button of the push-button station normally bridges across contacts *d* and *e*, while contacts *n-o* and *p-q* are closed under normal load conditions. Operating coil current thus takes path *2-a-b-x-c-d-e-f-g-n-o-p-q-h-i-j-k-3*, setting up a magnetic field which pulls over the armature and moves to the right the insulated lever arm on which the four movable contactors are mounted. (The lever system to accomplish this is simplified in the diagram.) The three-phase circuit to the load is now closed, and the holding-in contactor is bridging contacts *l* and *m*. The circuit through the magnetic operating coil is now *2-a-b-x-c-d-e-f-g-n-o-p-q-h-l-m-3*, and the *START* button can be released with-

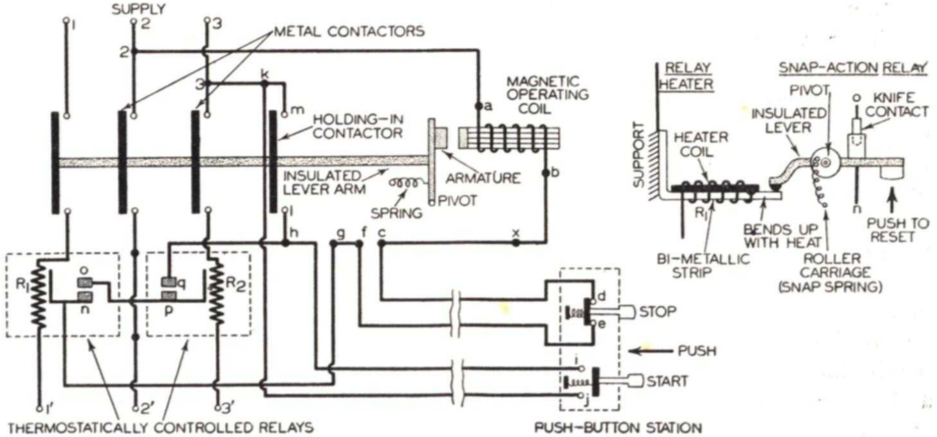


FIG. 10. Schematic circuit diagram of an automatic remotely-controlled magnetic contactor. The insert at the upper right shows details of the heater relay and the thermostatic (snap) relay.

out opening the circuit. The function of the holding-in contactor is thus evident.

To open the switch, the *STOP* button at the push-button station is pressed, thereby opening contacts *d-e* momentarily. This opens the circuit to the magnetic operating coil, and the spring pulls the armature away from the core of the coil. This moves the four contactors away from their respective contacts, opening the three-phase circuit to the load and opening the holding-in circuit containing contacts *m* and *l*. The switch can be reclosed only by pushing the *START* button again.

Now let us consider the operation of the overload relay. Assume that the switch is closed and that an overload occurs. Excessive current flows through heater resistors R_1 and R_2, causing the associated bi-metallic strips to bend. The first relay to trip its contacts (either contacts *o-n* or *p-q*) will open the excitation circuit of the magnetic operating coil, and this in turn will open the switch. After a cooling period of a few minutes, the bi-metallic switch will return to its normal position since the load has been disconnected and the heaters are no longer carrying current.

The lever system is such that the contacts do not automatically remake; the lever system must first be reset by some means. To eliminate the need for manual resetting, a small magnetic coil can be placed in each overload relay and connected across the secondary of a step-down transformer excited from the supply lines. In series with the small magnetic coil is a set of contacts which are made when the bi-metallic strip is in its normal position and broken when the bi-metallic strip bends due to overload. Thus, as soon as these contacts are remade after an overload, the coil is excited and the tripping lever is reset. Everything is then in readiness for the main switch to be reclosed by depressing the *START* button.

It is of interest to note that the magnetic contactor switch of Fig. *9A* combines the functions of a line switch and an overload circuit breaker. The undervoltage feature (discussed in connection with circuit breakers) can readily be added. For example, assume that in Fig. *10* a set of contacts were added in series with the excitation circuit of the magnetic operating coil, such as at *x*. Assume that these contacts are normally held closed by a small magnetic coil which is connected between lines *2* and *3*, but that this coil is designed so that it does not have enough magnetic pull to keep the contacts closed when the line voltage drops below a certain value. Opening of these contacts breaks the circuit to the main magnetic operating coil, thus opening the switch. Pressing the *START* button will close the switch again, provided that line voltage has returned to normal again.

Any number of push-buttons in widely separated locations may be used independently to control the switch. To obtain completely independent action for the individual push-button stations, it is necessary to wire *all the START contacts in parallel* and *all the STOP contacts in series*. Then, pressing any *START* button will close the excitation circuit, and pressing any *STOP* button will open the circuit.

Relay Applications

It is obvious that by using a magnetic contactor switch of the type shown in Fig. *9A* along with a clock-controlled relay system to replace the push-button stations, a completely automatic system can be obtained. For example, suppose that it is desired to start a transmitter promptly at predetermined times and to stop it at other predetermined times. It would be a simple matter to control the relays with an electric time switch so as to give operation at the specified times. The *START* relay would obviously be of the *make* type (contacts close when relay is operated) and the *STOP* relay would be of the break type (contacts open when relay is operated). Power would be supplied to the transmitter automatically at the desired times, and power would be removed at the desired times. If for any reason the voltage dropped so low as to be harmful or unsatisfactory for transmitter operation, the switch would automatically open. This would also be the case if the transmitter, for any reason, drew too much current.

If the contacts on the electric time switch were designed to close only for short periods of time, the relays would operate only for brief intervals and would be practically equivalent to push-button stations. Independent automatic control of the transmitter could thus be secured at more than one control point, and a time schedule which was set up at one control point could be modified at the others.

The foregoing hypothetical example is included only to illustrate the possibilities of automatic control. It represents only a first step as to what may be done, since it considers only the automatic closing and opening of the power circuit and the protection of the load *as a whole* against overload and undervoltage.

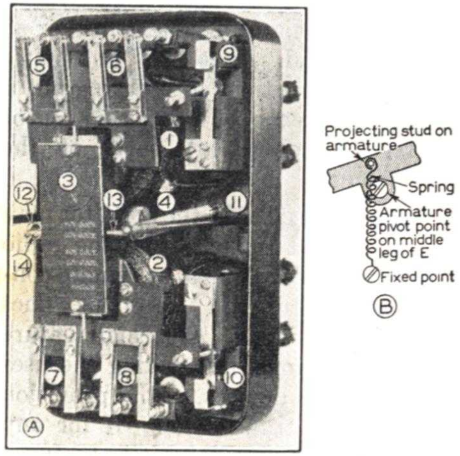
In a typical radio communication station, the load may comprise a rather complex set-up of component units, each of which requires a different sequence of operations for starting and stopping, along with varied forms of protection while running. While it is not necessary to have complete automatic operation of such a complex set-up, nevertheless the trend is toward reducing the actual labor of manual operations so as to obtain greater speed and efficiency of communication. This is particularly true at stations used for communicating with aircraft, where a single radio frequency channel must be used for an entire chain of ground stations and for a whole group of aircraft. It is also true at point-to-point stations handling commercial traffic. At such stations, efficiency requires that the station operators devote themselves to actual handling of messages insofar as possible, and leave to automatic means the functions of carrying out a desired sequence of operations or of protecting component parts of the equipment.

In many instances, the operator may be at a point remote from the radio equipment, operating it by remote control equipment via telephone lines several miles long. A special feature at some stations, illustrating the uses of automatic devices, is the provision of duplicate transmitters. If for any reason one transmitter fails to function properly once it is started by remote control, devices automatically come into play which shut the transmitter down and put the duplicate transmitter into operation.

To meet the needs for remote control, automatic operation and protection, a large and varied line of relays has been developed. The relay art has become highly specialized, so that there is a relay or combination of relays suitable for the solution of nearly every problem in electrical and radio system control.

There are relays which open or which close when the electromagnet is actuated, relays which are actuated by values of current or voltage exceeding predetermined values or falling below predetermined values; relays which require definite narrow ranges of cur-

rent or voltage for their operation; relays which operate in response to the net power in a circuit rather than to the current or voltage, relays requiring a predetermined time to close or open; relays for which the time of closing or opening bears a desired relationship to the load voltage or current; time-delay relays; relays responsive to the change in impedance of a circuit; relays responsive to change in frequency; step relays depending on incremental changes in voltage or current for step-by-step and final action; differential relays; directional relays; selective relays; reverse-phase relays; phase-balance relays; periodic reclosing relays; circuit-restoring relays; transfer relays, and many others.



Courtesy Westinghouse Elec. & Mfg. Co.

FIG. 11. Special multiple-contact power relay providing simultaneous opening and closing of independent power circuits. A spring acting on a rocker armature provides automatic latch-in action for both armature positions; details of this latch-in spring are shown at *B*.

Review of Elementary Relays

Ordinary electromagnetic relays can be classified as to their required operating power: *super-sensitive, sensitive* and *power* relays. The power relay, often called the *auxiliary relay*, may be of the magnetic contactor type just considered.

All electromagnetic relays operate on a definite *pull-in* current and disconnect at a definite *drop-out* current. The drop-out current for an electromagnetic relay is always *less than* the pull-in current; as a rule, the drop-out current is *about one-half the pull-in current*. By careful design, a 10% differential between pull-in and drop-out currents can be attained. Each value can be changed by adjusting the spring tension and the air gap. The electromagnets can be designed to operate on either a.c., d.c. or both.

An important consideration in any relay is the current and voltage capacity of the contacts. This will depend on the nature of the load and upon whether a.c. or d.c. power is being controlled. As a rule, greater power can be handled if the load is non-inductive and a.c. power is used.

Another classification may be made on the basis of the *relay position* in the control system when a sequence of relay actuations is necessary to carry out a specified switching procedure. The relay which responds to the initial change is the *primary relay;* the final relay controlling the power circuit or the magnetic contactor is the *power relay;* the intermediate relays are the *transfer relays*. Transfer relays may be made to have special characteristics such as time delay.

Special-Purpose Electromagnetic Relays

Ordinary electromagnetic relays with direct pressure-type silver contacts, with snap-action contacts in air, with snap-action contacts in a vacuum and with mercury contacts, along with bi-metallic time-delay relays, and gaseous tubes used as relays have been discussed elsewhere in the course, and need not be presented again. In circuits handling large amounts of power, however, special relays are often used. Some of the important special types will now be considered.

Special Multi-Contact Power Relay. Figure *11A* shows a power relay having two coils, (*1* and *2*), one on each outer leg of an E-shaped magnetic circuit (the ends of the three bars of the *E* are pointing upward, facing you, in this photograph). The moving element is rocker armature *3*, pivoted at the end of the center bar of the E-magnet (at *4* in Fig. *11A*). Two sets of moving contacts are mounted at each end of the rocker arm (*5-6* and *7-8*), and corresponding stationary contacts are mounted on insulating blocks attached to the frame of the relay. The application of voltage to one of the coils serves to pull the rocker armature to that coil, closing its contacts and opening the contacts associated with the other coil.

At the right of each coil is a single-pole switch, connected in series with the coil and opened mechanically when the coil is excited (*9* and *10* in Fig. ***11A***). **Springs** *11* and *12*, **looped over** studs *13* and *14* on the armature, serve to hold the armature against the coil toward which it last moved, even though the associated coil circuit is interrupted by the single-pole switch. With this arrangement, the two coils may be connected in independent circuits or may be placed in parallel, and only the coil associated with the open relay contacts can be excited at any given time. Large chemically pure silver contacts, increased contact pressure and increased travel enable the contacts to handle high currents and voltages, up to 5 amperes at 440 volts a.c.

Mechanical and Electrical Latch-In Type Relays. It is often desirable to insure that when contacts have either been closed or opened through the operation of a relay, they remain in that position until the relay is reset by hand or electrically. Various mechanical and electrical mechanisms called *latch-in mechanisms* are used for this purpose.

The holding-in contacts in Fig. *9A* represent one type of electrical latch-in arrangement. You will recall that these contacts insured continuity of the circuit to the magnetic operating coil once the switch was closed, thereby *latching-in* the switch. Pressing the *STOP* button at the push-button station breaks the circuit including the latching-in contacts, thereby opening the magnetic operating coil circuit.

The relay of Fig. *11A* employs a mechanical latch-in mechanism, consisting of the spring acting on the rocking armature. In this case the reset is electrical, being accomplished by excitation of the second field coil.

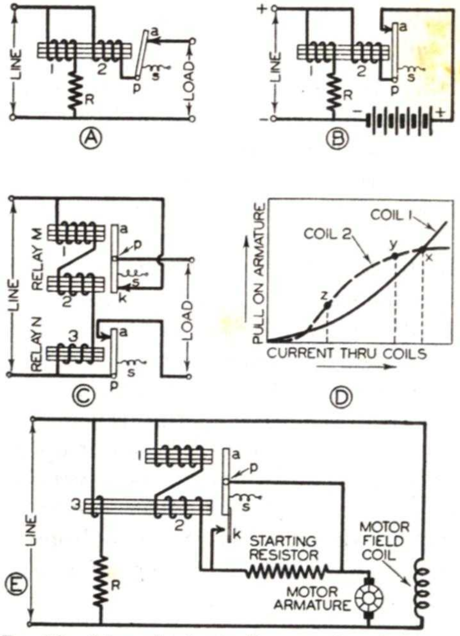


FIG. 12. Schematic circuit diagrams of typical two-coil relays. The springs which hold the relay armatures in their off positions are indicated as *s*. Fixed pivot points are designated *p*, and armatures as *a*.

An electrical latch-in arrangement employing two coils is illustrated in Fig. *12A*. The relay provides overload protection. Coil *1* is voltage fed; coil *2* is current fed. The magnetic forces of the two coils are additive; at normal loads, the two forces are not sufficient to pull over the armature, hence the relay contacts (in series with the load) are normally closed. At a predetermined overload current value, the force due to coil *2* has increased sufficiently so that the resultant force pulls over the armature, breaking the load circuit and reducing the current in coil *2* to zero. However, since it takes less force to hold the armature against the core than it does to pull it over, coil *1* will continue to keep the circuit open (unless line voltage drops way below the normal value). To release the armature, a second relay may be used to short-circuit coil *1*. Resistor R in series with coil *1* prevents shorting of the supply line during this releasing action.

Two-Coil Relays. The use of two-coil relays makes possible a wide variety of actions. For example, in Fig. *12B* the magnetic forces of the two coils are additive so long as the line voltage is greater than the voltage of the batteries being charged. As the battery voltage comes up to line voltage, the current in coil *2* decreases. The relay may be adjusted to open the circuit when the current drops to a predetermined value, or it may be adjusted to require an actual reversal of current through coil *2*, before it opens (giving what is known as a *reverse current relay*). The latter condition would exist if the line voltage dropped below the battery voltage for any reason.

Two-Coil Undervoltage Relay. An undervoltage protective relay using the combined effect of two coils is shown as relay M in Figs. *12C* and *12D*. Coils *1* and *2* (wound on independent magnetic circuits) here form a single relay and are connected in series with coil *3* of a second relay (N) across the line voltage. The armature of relay M is pivoted at its center and held by an off-center spring in a position whereby contact k is closed whenever there is no current through the coil system. When current flows, the pull which coil *1* exerts on the armature opposes the pull of coil *2*. The relay operates only when coil *2* develops a sufficiently greater force than coil *1* to pull the lower part of the armature over, breaking contact k and opening the circuit to the load. The manner in which relay M acts as an undervoltage relay can now be explained.

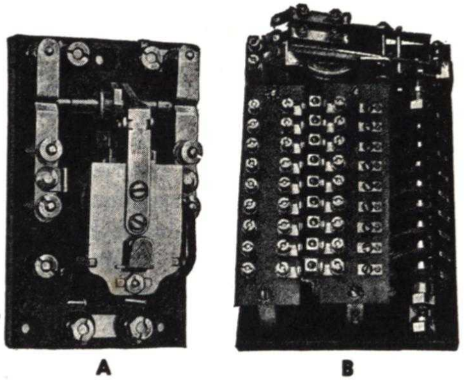
The magnetic circuit of coil *1* is of high-grade iron, with an air gap in series so that it does not saturate in the range of currents passed through the coil. The relation of the magnetic force (or pull) on the armature to the current in coil *1* is shown by the solid-line curve in Fig. *12D*. The magnetic circuit of coil *2* is easily saturated; the relation of pull on the armature to the current in coil *2* is shown by the dash-dash curve in Fig. *12D*. Since the coils are in series, identical current flows through them at all times. The relay is designed so that at normal voltage (and hence normal coil current) the pull exerted by one coil is equal and opposite to that of the other coil (point x in Fig. *12D* could be the operating point). As line voltage decreases, the pull provided by both coils decreases, but the pull for coil *2* decreases less rapidly than for coil *1*. At a voltage which produces a current corresponding to point y, the pull exerted by coil *2* is sufficiently larger than the pull provided by coil *1* so that the armature is pulled towards coil *2*, opening contact k. In this way the relay may be designed to open at a definite undervoltage value.

You will note from Fig. *12D* that if the line voltage continued to decrease, a point would be reached (at z) where the difference in torque is no longer sufficient to keep the armature pulled over; the circuit would then reclose. Relay N serves to prevent this from happening. This relay keeps its contact closed when excited but opens up when the voltage drops to about half normal value, interrupting the load circuit. Although relay N would serve as an undervoltage relay, any attempt to make it open at slightly below normal voltage would make it a critical device. Two coils provide this close tolerance feature without trouble.

Two-Coil Motor-Starting Relay. An example of a case where both coils are in series with the load is shown in Fig. *12E*. Here a motor is to be connected across the line with a resistor placed in series with the armature to limit the armature current during starting. The starting current may be two to four times full-load current, even though the starting resistor is used. It is desired to keep the resistor in the circuit until the motor builds up enough back e.m.f. so as to reduce the current to some safe value over full-load current; when this occurs, the resistor is to be shorted out by the relay.

Referring to Fig. *12D*, you will see that coil *2* will exert less pull than coil *1* when a large line current, greater than x, exists. This condition exists at starting in Fig. *12E*, keeping contact k open. When the line current drops to value y, contact k will close, shorting out the starting resistor. To prevent the relay from opening again in case of very light motor loads, an extra winding *3* is employed on the same core at coil *2*. This winding is connected across the line, and provides just enough torque to hold the armature against the core once it has been pulled over by coil *2*.

Ratchet Type Sequence Relays. For some automatic circuits, it may be necessary to open and close a network repeatedly without the use of latch-in and release mechanisms, or it may be necessary to close or open many circuits in a definite order or sequence. Figures *13A* and *13B* show ratchet sequence relays which meet these requirements. Energizing the relay coil moves a pawl which, through a ratchet, rotates one or more cams a definite amount, thereby moving the switch arm either up or down and either opening or closing the contacts. Thus, energizing the coil might move the switch arm down. Interruption of coil current would allow the pawl to go up again. The next excitation would cause the pawl to rotate the cam another fraction of a revolution in the same direction, moving the switch arm up. The third excitation and every *alternate* succeeding excitation would move the switch arm down. Any combination of contacts can be incorporated on the switch arm, such as: single-pole, double-break; double-pole, single-break; or single-pole, double-throw, single-break.



Courtesy Struthers Dunn, Inc.

Fig. 13. **Ratchet type sequence relays.**

The relay of Fig. *13B* has nine single-pole, double-throw circuits each operated by its own cam on a main shaft. (A cam is a circular disc with a small cut-out which releases its switch mechanism.) The ratchet wheel has nine teeth, so that nine excitations of the relay coil are required to rotate the main shaft one revolution and complete the cycle of the relay. Each cam can be adjusted so as to close (or open) its particular contact at any one of the nine steps in the cycle. Each contact, when closed (or opened) by the operation of the ratchet magnet, stays in position until the next time the magnet is energized. It may then continue to remain closed (or opened) for as long a portion of the complete sequence as desired.

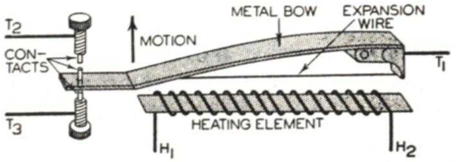


FIG. 14. Essential features of a bow-type thermal time delay relay as designed by Struthers Dunn, Inc. Contacts are of the SPDT type. H_1 and H_2 go to the heater current source and the control switch, while T_1, T_2 and T_3 go to the circuit which is to be controlled.

This relay has great flexibility. Any nine circuits may be controlled in sequence, or nine switching operations may be performed in a single circuit.

Time-Delay Relays

In some switchgear it may be desirable to delay the action of a relay a short interval of time after excitation, or to have the closing of a single main power switch initiate automatically the closing of several other switches in a definite sequence and with a definite time delay between each switching operation. Time delay in connection with fuses, circuit breakers and magnetic contactors has already been covered, so we can concentrate our attention on the methods used for securing time delay in transfer relays.

The three widely-used types of time-delay relays are: *1. The bimetallic strip relay*, heated by a coil, (this will not be considered here since it has been fully covered in this and other lessons); *2. The thermal bow type relay; 3. The motor-driven time-delay relay.*

Thermal Bow Type Time-Delay Relay. The action of this relay depends upon the simple fact that a length of metal wire expands (increases in length) when heated. One possible arrangement is shown in Fig. *14;* here the expansion wire is held taut by a thin metal bowed strip which has the same expansion coefficient. Slow changes in ambient temperature, such as may be expected from day to day, will not change the position of the bow (and hence of the movable contact which it carries at its end) since both the bow and the "string" (wire) will expand or contract equally. A thermal bow-type time-delay relay is thus *unaffected* by gradual changes in room temperature.

The quick application of heat to the "string" (by means of current passing through the heating element mounted just under the "string" or possibly also by passage of current through the expansion wire itself) makes the "string" alone expand. This releases the tension on the bow, allowing its free end to move upward and make contact. The time delay obtainable with the arrangement of Fig. *14* ranges from 25 seconds minimum to 3 minutes maximum. Some of the factors affecting the amount of time delay are: the size (heat-producing ability) of the heater element; the length, size and type of wire used for the bow "string"; the positions of the contacts.

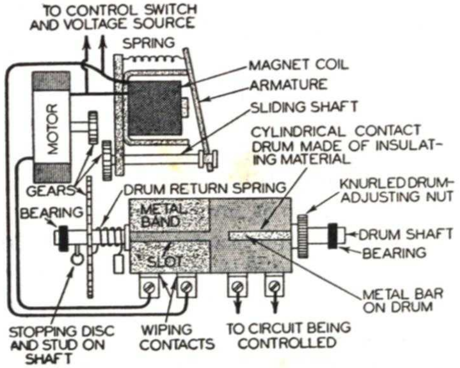


FIG. 15. Diagram showing essential details and circuit of a Struthers Dunn motor-driven time delay relay.

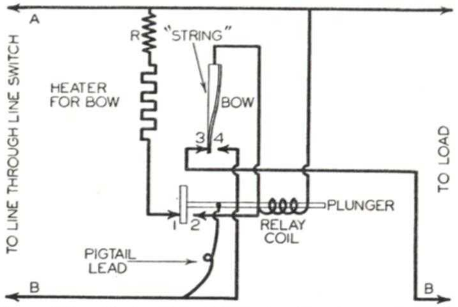


FIG. 16A. Basic time delay circuit using a thermal bow-type timer and a plunger-type electromagnetic relay. (This type of relay consists essentially of an iron rod or plunger sliding longitudinally inside a solenoid. Current through the solenoid coil causes the plunger to be "sucked into" the coil, thereby moving the plunger from one contact to the other.)

Motor-Driven Time Delay Relays. A time-delay relay which makes use of a midget self-starting synchronous motor is shown in Fig. *15.* As soon as the control switch in the primary circuit is closed, the motor starts. At the same instant, a small magnet operates to mesh the gears through which the motor drives the contact drum. Around the left half of the drum is a slotted metal band against which the two motor contacts rub. On the right-hand half of this insulating drum is a metal bar, in line with the slot in the metal band and also the same width as the slot. The metal bar is served by the two wiping contacts for the circuit being controlled. Note that the motor circuit is conductive (closed) except for a small fraction of the revolution when the slot is under the motor contacts, while the circuit being controlled is closed only for that same small fraction of a revolution when the metal bar on the right half is directly under its contacts.

For a given set of gears, it takes the drum a given time to rotate (100 seconds in the standard unit). The actual time for the closing of the load circuit (after application of power to the motor) depends upon the initial position of the drum; this can be adjusted by means of the knurled nut on the right, so that the arc of travel until the load circuit is closed may be as little as 1/20 of a revolution. The time-delay range is thus from 5 to 100 seconds.

At the end of the delay time interval, the slot and metal bar are both under their contacts. The circuit being controlled is thus closed, and the motor circuit is automatically opened at the same instant. The magnet remains energized, however, keeping the gears and hence the drum in their final positions so the load circuit remains closed.

When the control switch is opened, the magnet drops out, disengaging the gears. A spring on the drum shaft then returns the drum immediately to its starting position. The drum stops when a projecting stud on the drum shaft rests against a stopping disc mounted on the relay frame. The relay is now ready for another cycle of operations. The time delay of this relay is as accurate as an electric clock, since the same type of constant-speed synchronous motor is employed in both cases.

Time Delay for Closing a Load Circuit. Figure *16A* shows a basic circuit arrangement using the thermal bow-type device for introducing a time delay between closing of a power switch and application of line voltage to the load. Current flows from line *A* through the heater to contact *1* on the plunger-type relay, then through the relay plunger and through a pig-tail (flexible) lead to line *B*. In a predetermined time, the heat produced by the heater will make the bow bend over to contact *4*. This applies excitation to the relay coil; it closes, disconnecting the heater and pulling the plunger over to contact *2*. The relay coil is now permanently excited through its own contacts, and the bow is directly connected to line *B*. With the heater disconnected, the expansion wire cools and pulls the bow from contact *4* back to contact *3*. This connects the *B* side of the load to the *B* side of the line, thereby placing the load directly across the line and completing the time delay cycle.

Time Delay for Rectifier Plate Voltage Application. A typical use for a timer is in conjunction with rectifier supply systems using hot cathode mercury vapor rectifier tubes. The timer is used to interpose a time delay between application of voltage to the filaments and application of voltage to the plates of the rectifier tubes. This time delay allows the mercury vapor in the tube to attain its normal pressure, so that there is no danger of excessive voltage drop in the tube.

The circuit diagram for a suitable time delay arrangement using a thermal bow-type timer is shown in Fig. *16B*. When the line switch (not shown) is closed, filament transformer T_1 is excited at once since it is connected directly across lines *A* and *B*. One side of the primary of plate transformer T_2 is connected to line *A*, but the other side goes to contact *3* of the plunger-type relay, which is still open. Closing of the line switch also sends current through the heater for the bow-type timer, as one heater terminal connects to line *A* through voltage-dropping resistor *R*, and the other heater terminal connects to line *B* through contact *1*, the relay plunger, and the pig-tail lead. When the "string" of the bow is sufficiently heated, the bow touches contact *4* and thus connects the relay coil across the line. The relay plunger is immediately pulled to the right, performing the following operations: Contact is broken at *1*, interrupting heater current so the bow can cool and break the contact at *4*. The plunger now makes contact at *2* and *3*. This gives a complete circuit for the relay coil from line *B* through the pig-tail connection and through contact *2*, keeping the coil excited even though contact at *4* is broken when the bow "string" cools. Finally, contact between the plunger and *3* connects the primary of plate transformer T_2 across the line through the pig-tail lead, applying voltage to the rectifier plates.

Door Interlock. In order to provide protection to personnel, the contacts of a second relay may be inserted at *x* in Fig. *16B*, in series with the relay coil. The field coil circuit of the second relay may be arranged to be excited only when all doors of the transmitter are closed. Opening of a door on the transmitter rack for servicing breaks the field coil circuit of the second relay, opening its contacts at *x* and thus opening the field coil circuit of the relay in Fig. *16B*. The net result is that the plate voltage is removed from the rectifier tube and high d.c. voltages are removed from all portions of the transmitter. Upon closing the door switch again, the high voltage is immediately supplied to the transmitter.

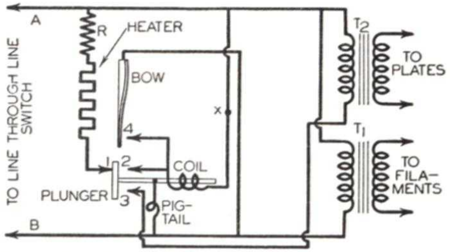
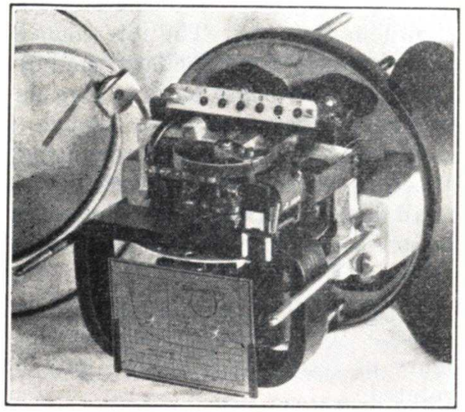


FIG. 16B. Time delay applied to a mercury vapor rectifier tube system.

Induction Type Relays

A relay finding wide-spread use in commercial power supply systems, but as yet used rather meagerly in radio work, is the *induction type relay*. It looks much like a watt-hour meter; in fact, it derives its motion in the same basic way. Eddy currents are induced in a pivoted aluminum disc by coils fed with alternating current, producing a torque which can be made proportional to voltage, current or both (power). The rotation of the disc is retarded by a spring which also returns the disc to normal non-active position, and magnetic braking is provided by permanent magnets mounted so the disc rotates between their poles. The contacts of this relay are opened and closed by the disc shaft, either directly or through gears. With this electromechanical relay system it is possible to provide overload, undervoltage, time delay and other basic relay functions.



Courtesy Westinghouse Elec. & Mfg. Co.

Typical induction relay, with glass cover and metal ring removed to show construction. Relays like this are used to disconnect circuits or apparatus when the current flowing through them exceeds a given value. The aluminum disc which rotates between the poles of permanent magnets can be seen just above the calibration chart; eddy currents induced in this disc react with the fixed magnetic field to slow up relay action.

Exact Remote Control

There are occasions where some circuit constant must be varied at a distance without actually extending the circuit to the remote point. An example of this requirement exists in a television studio, where it must be possible to adjust the brilliancy and contrast controls in the video frequency amplifier from the monitoring desk even though the controls are actually on a rack in another part of the room or in a different room. To extend the circuit leads could easily destroy the frequency response of the amplifier. An exact remote control is often needed for tuning a radio circuit from a remote point. Another example exists at airport stations, where a wind vane located on top of a building operates a wind direction indicator, and a bridle anemometer on top of the building operates a wind velocity indicator; to bring the indicators into the station requires an exact remote control.

The device most frequently used for exact remote control is the Selsyn motor developed by the General Electric Company. The fundamental principle of operation is as follows: If two coils, P_1 and S_1, are placed side by side and P_1 is excited from an a.c. source, voltage will be induced in S_1. Let S_1 be free to rotate about its center, and let its terminals be shorted. The induced voltage will now set up a current which will produce its own magnetic field, and this field will react with the primary field to produce motion of S_1. The coil will swing about its center until it is at right angles to the first coil. In this position there is no voltage induced in S_1, and hence no force acting to rotate it.

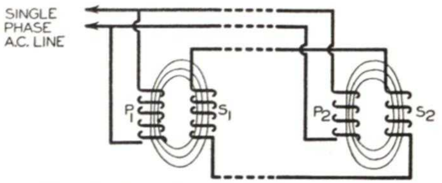


FIG. 17A. Basic action of a Selsyn remote control motor.

Referring now to Fig. *17A*, assume that primaries P_1 *and* P_2 of two sets of such coils are connected to a common single-phase a.c. line, and secondaries S_1 and S_2 are connected in series; the four lines connecting together the two sets of coils may be miles in length.

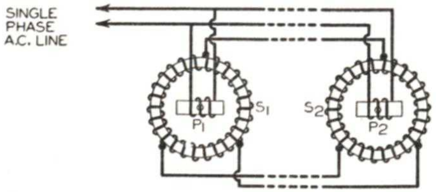


FIG. 17B. Selsyn remote control arrangement for a single-phase a.c. line.

If the two secondaries are in the same relative positions with respect to their primaries, their induced voltages will be identical in magnitude and phase and, since they are connected in opposition, no current will flow in the secondary circuit. The secondary windings will therefore remain at rest. Now, when one secondary winding (say S_1) is moved angularly, there will be a difference between the voltages induced in S_1 and S_2, and current will flow. Since S_1 is held stationary at the control station, S_2 will be acted on by a magnetic force which swings this coil to the same position as S_1; the difference voltage in the secondary circuit will again become zero, and the two secondaries will remain in their new positions.

In actual practice it is necessary to distribute the secondary windings over 360° in order that the interlocking torque developed will be uniform for all angles. (In Fig. *17A*, no voltage is induced in either of the secondaries when they are at right angles to the primaries, and the voltage produced when one secondary is rotated a small amount either way from 90° is so small that the resulting torque may not be sufficient to overcome friction and rotate the other secondary.)

To provide uniform torque at all angles, the secondary windings are distributed in slots around a stationary magnetic circuit, and the primary takes the form of the conventional single-phase induction motor rotor, as shown in Fig. *17B*. The interconnections between the secondary windings are on a three-phase basis to give improved performance, even though a single-phase power source is employed. When a three-phase power line is available, the primary windings may be connected for true three-phase operation, as shown in Fig. *17C;* the controlling power is then materially increased. In any case, either the primary or secondary windings may be rotated.

The control device may be operated at any speed, and the controlled devices (there may be any reasonable number) will follow exactly. Where the speed is very low, as in the wind direction-indicating application previously mentioned, it is customary to gear up the rotor at the control point and to gear down again at the controlled point. In this way, high angular rotation of the Selsyn motors is obtained for very small angular rotation of the control and the controlled devices, leading to better control.

Motor Starting

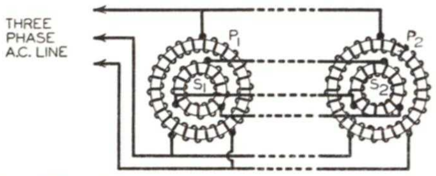


FIG. 17C. Selsyn remote arrangement for a three-phase a.c. line.

Small motors can, as a rule, be connected directly to the supply line, allowing them to gain speed and build up a back e.m.f. prior to normal operation. The high starting current will last only for an instant, and little harm will be done. Some small a.c. motors have starting circuits and starting mechanisms, but these have been considered elsewhere, and need not be reconsidered here.

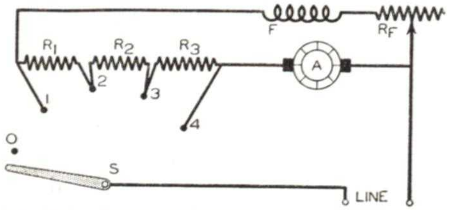


FIG. 18A. Essential elements in a d.c. motor starter. *F*—field winding; *A*—armature; R_F—field rheostat; R_1, R_2, and R_3—current-limiting resistors; *S*—starter control switch arm.

Although large motors could in some cases be started by connecting them directly across the line, this is rarely done because of the tremendously high starting currents. The armature windings on large motors generally have a phase or winding resistance of less than .2 ohm; the application of 220 volts to such a winding would cause an initial current of more than 1,000 amperes. This would blow fuses, open circuit breakers, burn out the windings, and might even place such excessive force on the machine as to cause physical breakdown.

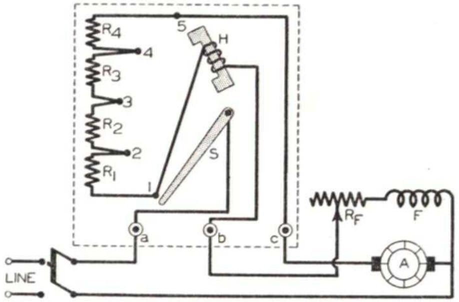


FIG. 18B. A three-terminal d.c. motor starter.

As soon as a motor picks up speed, back e.m.f. is generated and the current is reduced to the normal value which will produce the torque required for the load. When starting up a large motor, it is necessary to provide some means for limiting current to a safe value during the period when the motor is building up its speed and back e.m.f. In both a.c. and d.c. motors, a resistor having a high ohmic value and a high current-carrying capacity is placed in series with each armature winding before applying voltage. As the motor gains speed and the current drawn by it drops, the ohmic values of the current-limiting resistor are gradually reduced, usually in steps. Finally, all the resistance is removed, placing the windings directly across the line.

With some induction motors, the windings are fed with reduced voltage until the motor gains normal speed. Other induction motors are thrown directly across the line at starting, with high-capacity fuses in series; when normal speed is attained, the large-capacity fuses are replaced with fuses of normal rating.

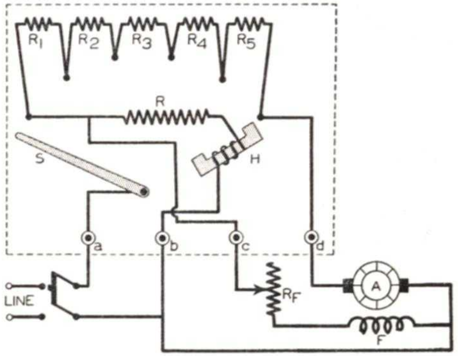


FIG. 18C. A four-terminal d.c. motor starter.

Manual D.C. Motor Starters. The essential elements in a starting device for a d.c. motor are shown in Fig *18A*. When rotary switch *S* is placed on contact *O*, the motor is disconnected from the line. Placing *S* on contact *1* excites the field *F*, and connects the armature *A* to the line through resistor elements R_1, R_2 and R_3. As the motor gains speed, *S* is placed in turn on contacts *2*, *3* and finally *4*, where the motor runs normally. Observe that as *S* is moved from *1* to *4*, more and more of the starting resistance is introduced into the field circuit; this reduces the field current, causing the motor to speed up.

The elements of a practical d.c. motor starter are shown in the dash-dash rectangle in Fig. *18B*. This is a 5-step starter (there are five running positions), with three terminals, *a*, *b* and *c*. The switch arm has an iron face at one point, this being attracted and held by electromagnet *H* when the arm is in the last or running position, on contact *5*. This is an added protection, for field current flows through H. If the field should open up for any reason, electromagnet H will release the switch arm S, and a spring will then return the

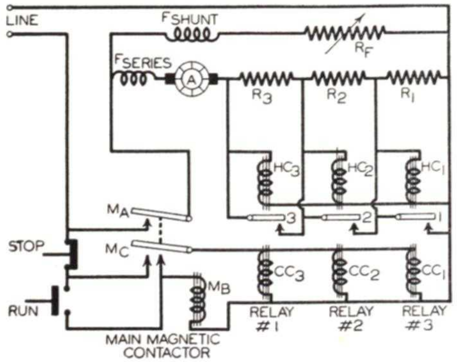


Fig. 19. Automatic d.c. motor starter of the current-limit acceleration type. The current drawn by the motor determines the rate at which the starter shorts out the starting resistors. A compound motor having both shunt and series field windings is shown. Each starting relay has two coils—a hold-out coil HC and a closing coil CC.

arm to the off position, stopping the motor. This prevents the motor from reaching an excessive and dangerous speed.

A manual d.c. starter having four terminals is shown in Fig. *18C*. This starter differs from the three-terminal unit in that the holding magnet H is not in series with the motor field, but rather is across the line (in series with the starting resistors). With this arrangement, the holding magnet current is independent of the setting of field rheostat R_F, hence R_F can be increased to any desired value (for higher speed) without reducing the magnet current to the point where the starter opens.

In some starters, the starting arm also has a trip mechanism which can be excited by a coil carrying the full motor current; an overload condition trips the starter, stopping the motor before it can overheat or burn out.

Automatic Starters for D.C. Motors. Manual starters of the type just described may be replaced by a large number of different relay arrangements which carry out the motor-starting procedure automatically. Automatic starting has additional advantages in that it affords much closer control of the motor acceleration, making the motor come up to normal speed much more smoothly.

Automatic motor starters can be divided into two general classes, according to the manner in which the motor acceleration is controlled: *1. Current-limit acceleration starters; 2. Time-limit acceleration starters.* With current-limit acceleration, each resistor step has dropped to a pre-determined value somewhat above full-load current. With time-limit acceleration, each resistor step is shorted out a definite time after the motor circuit is closed, so that the motor comes up to speed in a definite time interval even though the motor load is variable.

Figure *19* shows one method of current-limit acceleration. Contacts M_A of the main magnetic contactor close when coil M_B is excited by closing the *RUN* push-button, thereby applying full voltage to the shunt field and reduced voltage to the armature and series field of the motor. M_C is an electrical interlock, also actuated by coil M_B, which keeps the circuit closed after the *RUN* button is released. R_1, R_2 and R_3 are the fixed resistors in series with the d.c. motor armature; *1, 2* and *3* are relay contacts connected across the individual resistors. Each relay has two field coils, one for closing the relay and another for opposing the closing. Thus, relay *1* has closing coil CC_1 (which tends to close contacts *1* when excited) and hold-out coil HC_1 which opposes the closing coil. The closing coils are connected across the line by interlock M_C and the *RUN* button

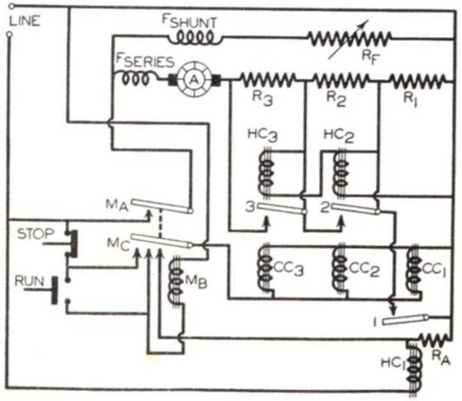


Fig. 20. Automatic d.c. motor starter of the time-limit acceleration type. The self-induction of the hold-out coils HC determines the definite time intervals between each step of the starting procedure.

When the *RUN* button is pressed, the initial rush of current passes through all of the resistors in series with the armature (through R_1, R_2 and R_3). The resulting high voltage drops across resistors R_1, R_2 and R_3 send sufficient current through hold-out coils HC_1, HC_2 and HC_3 to keep all three relays open. When the armature current drops to just above the full-load value, the voltage across HC_1 (being due only to the drop across R_1) drops sufficiently to allow closing coil CC_1 to close contacts *1*, shorting out resistor R_1. The resultant sudden increase of armature current keeps the voltage drop across HC_2 sufficiently high to keep the relay *2* open even though HC_2 is now connected only across resistor R_2. Soon the armature current begins to decrease again (because of motor acceleration and building up of the back e.m.f.); when it reaches just above full-load, the drop across HC_2 is low enough so closing coil CC_2 closes contacts *2*, shorting resistor R_2. The armature current jumps up again, and the identical process is repeated until relay *3* operates, shorting out the last resistor (R_3) and applying full line voltage to the motor.

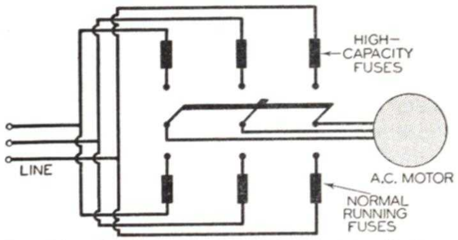


Fig. 21. Simple starting switch for a small three-phase induction motor.

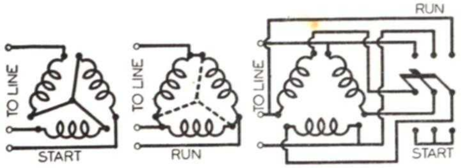


Fig. 22. Star-delta change-over switch for starting medium-size three-phase induction motors.

Figure *20* shows one method of time-limit acceleration. It utilizes the self-inductance of the hold-out coils to introduce fixed time intervals between the operation of one accelerating relay and the operation of the next one. The symbols are the same as for Fig. *19*. The closing coils operate on line voltage, and the hold-out coils are connected across one or more steps of the starting resistance. The sizes of the coils are so proportioned that the relays will be held open when full line voltage is applied to the closing coils if 1% or more of the line voltage is fed to the holding coils.

In the OFF position, hold-out coil HC_1 is energized through series resistor R_A. When the main magnetic contactor is closed by a momentary pressure on the *RUN* button, the following actions occur: Contacts M_A close, applying reduced voltage to the motor; contacts M_C close, connecting contactor coil M_B directly across the line to insure that the contactor stays closed after the *RUN* button is released; contacts M_C also short out HC_1, but because of the self-inductance of this coil it takes some time for current to drop low enough to allow closing coil CC_1 to close the contacts at *1*. When this happens, resistor R_1 is shorted out, and the hold-out coil HC_2 is also shorted. It takes a fixed time for the current in HC_2 to drop low enough to allow CC_2 to close the contacts at *2*. When this happens, the entire process is again repeated, and finally the contacts at *3* are closed.

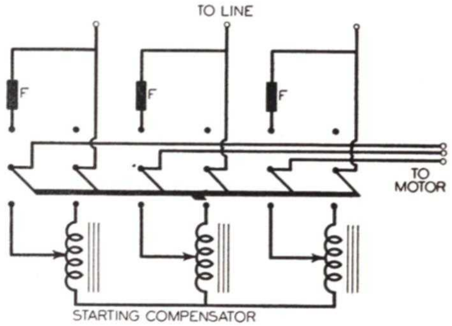


Fig. 23. Auto transformer used as a starting compensator for starting three-phase induction motors.

When an inductive relay of the type used in this starter is open, the magnetic gap between the armature and the core of the closing coil circuit is relatively large, and the gap between the armature and the core of the hold-out coil circuit is very small. Actual distances are about ⅜ inch for one as compared to a few thousandths of an inch for the other; this gives the desired ratio of operating forces. When the relay closes, the magnetic gap in the closing coil circuit becomes small, and that in the hold-out coil circuit becomes large, reversing the ratio of operating forces. During closing, the pull provided by the closing coil increases, while that provided by the hold-out coil decreases; this means that we have a two-position relay with a decided snap action in changing from one position to the other.

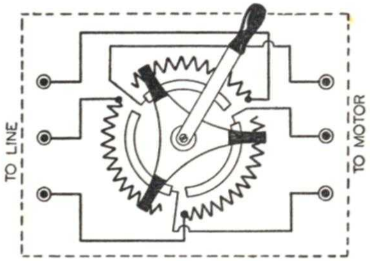


FIG. 24. Three-phase resistance starter, used for starting three-phase squirrel-cage and wound-rotor induction motors.

A.C. Motor Starters. Small a.c. induction motors (less than 5 horsepower) may be started by direct connection across the line. A 3-pole, double-throw switch is used for a 3-phase induction motor, as shown in Fig. *21.* At starting, an induction motor acts like a transformer having a short-circuited secondary and a large amount of primary leakage flux. *The high primary leakage flux keeps the starting current fairly low* (down to only 6 to 8 times line current), making across-the-line starting possible for three-phase induction motors smaller than 5 h.p. The regular motor fuses would blow during starting if left in the circuit; for this reason, a switch is employed to change over from regular fuses to higher-capacity fuses which will withstand the normal high starting currents for a reasonable period of time. These starting fuses will blow, however, if the motor refuses to start because of too great a load on it. When the motor has reached approximately full speed and the current has become more normal, the switch is thrown to the other side; this side is fused for protection under normal running conditions. The same switching arrangement is possible with automatic magnetic contactors.

A.C. motors larger than 5 h.p. require limiting devices to control the line current during starting. In medium-size motors, advantage is taken of the fact that the 3-phase windings may be connected either in "Y" or delta fashion.

If the terminal voltage of a particular a.c. motor, let us say, is 110 volts and the motor is designed to use a delta connection when running, the voltage across each phase when running will be 110 volts. If this motor is connected in "Y" for starting, the starting voltage across each phase will be 110 ÷ 1.73, or approximately 63 volts. Under this condition, the current through each phase will be considerably less than if full voltage were applied at starting. Figure *22* shows the starting arrangement, the running arrangement and a special switching scheme for changing over from the "Y" connection for starting to the delta connection for running.

Starting Compensators. Another common method of starting induction motors is that involving the use of a starting compensator. This is, strictly speaking, a 3-phase step-down transformer of the autotransformer type. The main supply voltage is fed into a "Y" arrangement of chokes; taps are taken off at ½ or ¼ voltage, with each tap feeding the input of the motor.

The arrangement is shown in Fig. *23.* When the 6-pole, double-throw switch is thrown down, the starting compensator is connected to the line and ¼ to ½ voltage is fed to the motor. When the motor reaches normal speed, the switch is released and the contact blades are immediately thrown by a spring to the running (upper) position. The motor then is connected directly to the line and is protected by the regular line fuses *F.*

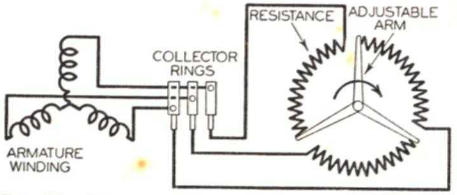


FIG. 25. Method of varying the rotor resistance of a wound-rotor induction motor by means of a resistance starter.

Resistance Starters. Figure *24* shows a resistance starter used for low-power 3-phase squirrel-cage motors. When the starter is set in the position shown, a high resistance is placed in series with each of the feeder lines, reducing the voltage applied to the motor. The starting current is thus limited to a safe value. As the motor gains speed, the starting device is turned clockwise gradually, until finally all resistance is out of the circuit and normal voltage is applied to the motor.

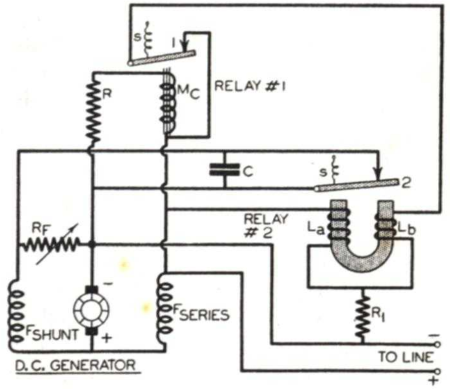


FIG. 26. D.C. form of Tirrill voltage regulator, connected to a d.c. generator. Springs are designated as *s.*

In wound-rotor induction motors, resistor starters of this type are used in series with the rotor windings, as indicated in Fig. *25.* Speed control as well as resistance starting can be obtained; the same resistor serves for speed control once the motor has come up to speed.

Each of the manual methods of a.c. starting just described has its counterpart in automatic starting. As in the case of d.c. motor starting, the automatic methods provide for closer control of acceleration.

Voltage Regulation

Voltage Regulation for D.C. and A.C. Generators. In order to maintain practically constant voltage on d.c. and a.c. generators, or to have the voltage output of these machines increase automatically to take care of line drop due to extra loads, control of either the generator speed or the field excitation is required. Either method may be used with d.c. generators, but with a.c. generators where constant frequency is desirable, field control should be used. Either manual or automatic control of the field excitation is possible. Manual control simply involves the manipulation of field rheostats.

Automatic Field Excitation Controls. Perhaps the best known of the automatic field controls is the Tirrill regulator. This regulator depends for its operation upon the rapid opening and closing of a circuit which shunts the field rheostat, and thus changes the resistance in the field circuit of the generator. For d.c. service the regulator usually acts upon the main generator field, while for a.c. service it acts upon the field of the d.c. exciter. The regulator automatically shunts the rheostat when the output voltage drops to a predetermined value, and opens the shunt when the voltage rises above this value.

Tirrill Regulator for D.C. Generators. The connections for the d.c. Tirrill regulator are shown in Fig. *26.* Coil M_c of relay *1* is connected across the generator terminals, hence this relay is fully excited when the generator output voltage is normal. The two coils of relay *2* are differentially wound (one opposing the other); one winding, coil L_a is connected directly across the generator terminals, and coil L_b is connected across the generator terminals through the contacts at *1.* In both cases, R_1 limits the current. Coil L_a is thus excited at all times, and holds the armature of relay *2* down when acting alone. When

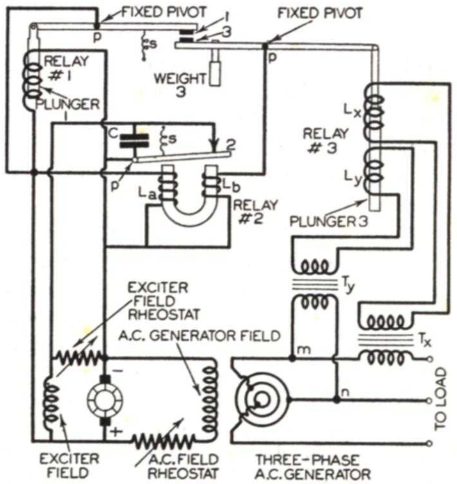


FIG. 27. A.C. form of Tirrill regulator, connected to a three-phase a.c. generator.

L_b is excited, however, the two coils oppose each other and the armature is released; this closes the contacts at *2*, shorting the field rheostat. Condenser *C* is connected across the contacts to minimize sparking.

When the generator voltage drops below a predetermined value, relay *1* releases its armature and thus closes its contacts. This applies excitation to coil L_b, causing relay *2* to release its armature, close the contacts at *2*, and short out the field rheostat. The generator voltage now rises; relay *1* pulls down its armature, opening the contacts at *1* and thereby removing excitation from L_b. L_a now pulls down the armature of relay *2*, opening the contacts at *2* and thereby inserting the rheostat in the field circuit again. This action is repeated cyclically at a rapid rate, so that the relay armatures are practically vibrating. The generator voltage naturally seeks a level depending on the setting of the field rheostat and on the voltage at which relay *1* drops out. Very close regulation (plus or minus 1%) is obtained.

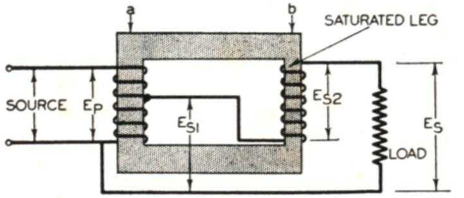


Fig. 28. Simple auto transformer which utilizes a saturated core and leakage flux to hold the output or load voltage essentially constant despite variations in the load or in the source voltage.

Tirrill Regulator for A.C. Generators. The connections for the a.c. Tirrill regulator are shown in Fig. *27*. This regulator acts on the field rheostat of the d.c. generator which excites the three-phase a.c. generator.

Except for the presence of plunger-type relay *3*, this a.c. regulator functions essentially like the d.c. regulator. Coil L_T, the main coil on this relay, is connected across the alternator output through potential transformer T_T, and hence the excitation on this coil is proportional to the output voltage which we desire to control. Coil L_X is excited in proportion to load current by current transformer T_X, the connection being such that L_X aids L_T. With normal output, L_T and L_X together exert enough lifting pull on plunger *3* so that, with the aid of weight *3*, contacts *1-3* are held open.

When the a.c. output voltage between points *m* and *n* drops, the lowered excitation on L_T allows plunger *3* to drop, closing contacts *1-3*. This applies excitation to coil L_b of differential relay *2*, counteracting the permanent excitation on coil L_a; as a result, the contacts at *2* close, shorting the exciter field rheostat. The exciter voltage goes up, as also does the alternator output voltage. As the exciter voltage goes up, the coil of relay *1* gradually pulls contact *1* upward, but as long as the alternator voltage is below normal, contact *3* follows. When the alternator voltage is above normal, coil L_T pulls *3* away from *1*, interrupting the excitation on L_b and thus allowing L_a to open the contacts at *2*. The exciter field rheostat is now in the circuit again. The entire process repeats itself each time the alternator output voltage drops below normal.

Increased load causes increased excitation of L_X, thereby raising automatically the a.c. output voltage level to compensate for the increased line drop. In other words, winding L_X serves to insure a constant voltage *at the load* rather than at the generator terminals. A similar compounding winding could be placed on relay *1* in the d.c. regulator of Fig. *26* to keep the load voltage constant despite variations in the voltage drop due to current flow through a long transmission line.

Line Voltage Regulation. When voltage regulation is required on a main transmission line and it is not possible to vary the generator output voltage, booster schemes may be employed. These are practicable only on a.c. circuits, since transformer action is involved.

One arrangement involves the use of tapped power transformers between the line and the load. The transformers may be single-phase or three-phase, and may be tapped either on the primaries or on the secondaries. Auto transformers may also be used. Special drum-type switches are available for changing the transformer connections without disconnecting the load. The switching operations may be manual or may be carried out automatically by relays responsive to variations in the voltage across the load.

Another arrangement which is widely used in radio power supplies to provide an essentially constant a.c. voltage at low power (less than 10 kilowatts) makes use of saturation in transformers and reactors. The diagram in Fig. *28* will illustrate the principles involved. Leg *a* of the core-type magnetic circuit has an auto transformer winding; leg *b* has an extra secondary winding, so that for any input voltage E_P, the secondary or output voltage E_S will be the sum of the voltages E_{S1} and E_{S2}. At normal input voltage, normal output voltage is obtained. However leg *b* is nearly saturated (the flux through this leg is at the bend or knee of the flux density-magnetizing force characteristic). Not all of the flux produced by the primary winding on leg *a* links through the coil on leg *b*; some of the flux leaks into space, causing the primary to have leakage reactance. This leakage flux does not induce a voltage in the coil on leg *b*. Now let us see how this device holds the output voltage nearly constant.

Assume that E_P rises. Current in coil *a* tends to rise, and so does the core flux; voltages E_{S1} and E_{S2} tend to rise. But leg *b* is now very nearly saturated, so the flux through it cannot increase appreciably. This means that voltage E_{S2} rises only a slight amount. At the same time, saturation causes more flux to leak out of the entire core, increasing the leakage reactance of coil *a*. Leakage flux therefore causes more reactance drop in the primary, causing less primary current and less core flux. As a result, E_{S1} and E_{S2} do not increase as much as they would if core *b* were not saturated, and increases in input voltage do not cause proportional increases in output voltage.

When the output voltage drops, the reverse action takes place. Core *b* becomes less saturated, allowing the induced voltage E_{S2} to rise greatly. At the same time, less leakage occurs in the primary, and E_{S1} rises. Both effects tend to hold up the output voltage.

TEST QUESTIONS

Be sure to number your Answer Sheet with the *number* appearing on the front cover underneath the title of this text.

Place your Student Number on every Answer Sheet.

Most students want to know their grade as soon as possible, so they mail their answers immediately. Others send in two sets of answers at a time. Either practice is acceptable to us. However, don't hold your answers too long; you may lose them, or run out of Lessons before new ones can reach you.

1. What determines the current-carrying capacity of a switch?
2. Why are auxiliary carbon contacts used in brush type switches?
3. According to the National Electrical Code, at what per cent overload should a fuse blow within a minimum specified time?
4. Name five types of circuit breakers, classified according to their function.
5. Does the time delay interval for a fuse or circuit breaker *increase, decrease,* or *remain the same* as the amount of overload increases?
6. In an electromagnetic relay, is the drop-out current *equal to, less than,* or *more than* the pull-in current?
7. Name the three widely-used types of time delay relays.
8. Is a thermal bow type time delay relay affected by gradual changes in room temperature?
9. Into what two general classes may automatic motor starters be classed?
10. What makes across-the-line starting possible for three-phase induction motors smaller than 5 h.p.?

COURTESY

Truly big men are always courteous. It is only "small" men, men with inferiority complexes, who are rude or thoughtless. And smaller than small are those who are over-courteous to their superiors and intentionally rude to those over whom they have some authority.

Practice courtesy in all your contacts, business as well as social. Establish courtesy as one of your life habits. Be polite and kind to every one you meet, rich and poor alike, and soon courtesy will become second nature for you.

The best place to test yourself is right at home. Are you always courteous to members of your immediate family, or do you shout at them on the slightest provocation? Are you considerate of their feelings, or do you delight in saying things and doing things which you know will hurt them?

If you develop the habit of being courteous to your own folks, your away-from-home courtesy will ring true. It won't appear "put-on," as is so often the case when a man reserves his courtesy for only special occasions.

J. E. SMITH