CHAPTER 9

ELECTRICAL DEVICES USED IN LAUNCHING SYSTEMS

INTRODUCTION

In this chapter we discuss the basic operating principles of switches and relays. Also, we take up the application of these units in launching system control circuits. To maintain electrical and electronic circuits efficiently and effectively, you must have this background knowledge.

In most missile launching systems, the equipments are normally located at considerable distances from each other. For example, the launcher captain's control panel is more than 50 feet from the launcher, yet he must be able to control the launcher without leaving his station. How is this particular problem solved? Remote control is the answer. Remote (indicating and control) circuits are made up of switches, relays, and other devices, which control the output from the ship's generators and utilizes this source for GMLS motors and control circuits.

> NOTE: The use of d-c motors and generators in GMLS is in the form of synchros or tachometers, except Mk 12 which has motor, generator sets.

The electrical components mentioned above are explained in detail in Basic Electricity, NavPers 10086-B.

Remote control circuits not only eliminate the wasted energy of rushing about from equipment to equipment, but they also permit equipment to be operated from several control points about the ship. Thus, the missile launching process can be started by closing a key in the weapons direction system or by turning a switch on a panel at the launching site.

Missile launching operations (loading, unloading) are normally performed automatically. But other types of control are also available. Most systems can operate in "Step" control. System operation in this mode is in a series of interlocked steps and individual parts of the installation can be used without "cutting in" the entire system. Relay and switch arrangements provide switching from one type of control to another.

Some launching systems are capable of stowing mixed loads. For example, several kinds of Terriers such as BT-3 and HT-3 are stowed in the same ready service ring. Mixing of missiles implies that some method is provided to locate and to select a desired missile for loading and firing. Special devices, which incorporate switches and relays, are used to perform the missile stowage locating and selecting function. The Mk 9 GMLS uses a stepping switch to select a cell from which a missile can be selected. In the Mk 10 GMLS, this action is one of the functions of the load status recorder, and in the Mk 13 GMLS a ratchet relay is utilized. Though the names of these devices differ, they all operate to perform the same general purpose.

SWITCHES

A basic understanding of switches and their function in control circuits is most important. Circuits using switches are sometimes more complex than electronic circuits. Therefore, to troubleshoot effectively you should have some background knowledge of switches. In this chapter a great deal of simplification has been used. And, in general, only the less complex switches and switching circuit arrangements are included here. But enough basic information is included to give you the necessary background for further study about the subject.

A switch is a device used for making, breaking, or changing the connections in an electric circuit. Switches are used extensively in launching-system control circuits to start and stop motors, to turn indicating lights on and off, to channel information from one point in the system to another, and to shift system mode of operation, to name a few of their many uses.

An essential function of any switch is to maintain a good, low-resistance contact when the switch is closed. A poor connection between switch elements produces considerable resistance. This results in overheating the contact area. When heavy current is being carried by the switch, and the switch contacts are opened, an arc is produced. Therefore, switches should be opened and closed quickly to minimize arcing. Usually, they are designed to have snap action.

Switches are frequently classified by the number of poles, by the throw, or by the number of positions. The pole of a switch is its movable blade or contactor. A switch may have one or several poles. The throw of a switch indicates the number of circuits each pole can complete through the switch. The number of positions a switch has in the number of places at which the operating device (toggle, shaft, plunger, and so on) will come to rest, and, at the same time, open or close a circuit. As you can see in figure 9-1, switches through which only one circuit can be completed are called single-pole, single-throw switches. Switches with two poles, through each of which one circuit can be completed, are described as double-pole, single-throw switches, while those with two poles through each of which two circuits can be completed are described as double-pole, double-throw switches.

Another way of classifying switches is by the method of actuation, that is, pushbutton, toggle, pressure, and the like. Switches can also be classified by using the trade name of the manufacturer. Two examples are: Micro, and Iron Fireman switches.

ROTARY SWITCHES

A rotary switch can take the place of several switches. As the knob or handle of a rotary switch is rotated, it opens one circuit and closes another. This can be seen from an examination of figure 9-2. Most rotary switches have numerous layers, called wafers or pancake sections. By adding wafers, the switch can be made to operate as a large number of switches. Rotary switches are used in launching system equipment to select modes of operation and for many other functions.

Type J Rotary Switch

The type J rotary switch (fig. 9-2) consists of an equal number of rotors and pancake sections. The number of sections required in the switch is determined by the application. A shaft with an operating handle extends through the center of the rotors. The movable contacts are mounted on the rotors, and the stationary contacts are mounted on the pancake sections. Each section consists of eight stationary contacts, designated A to H, and a rotor with two insulated movable contacts spaced 180° apart.

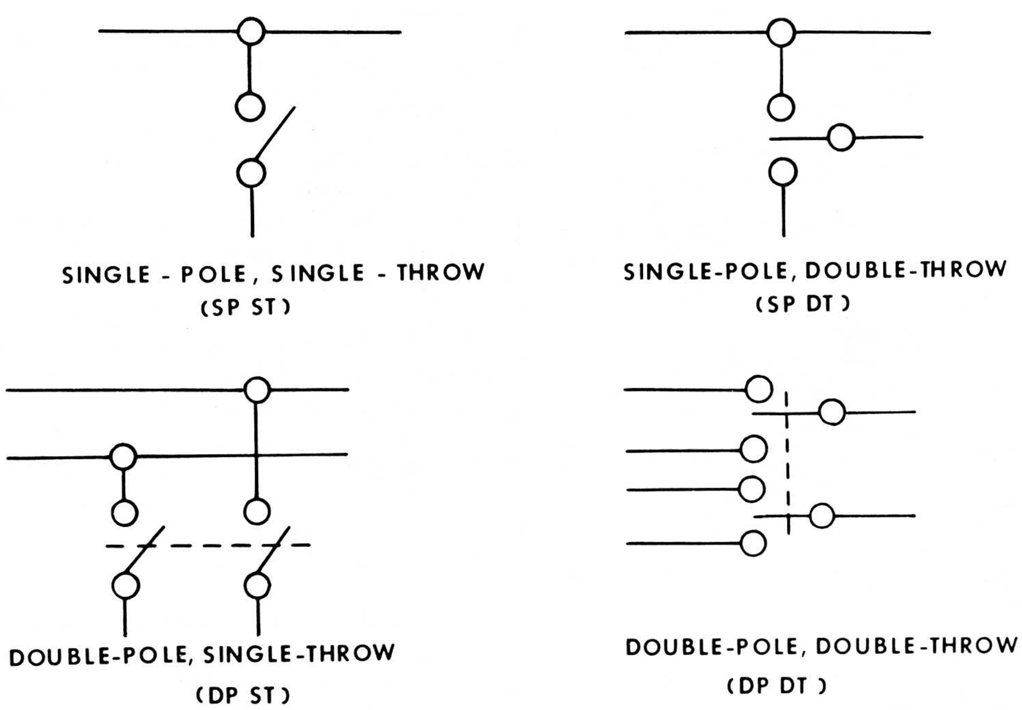

Figure 9-1.—Switch classification according to number of poles and throws. 12.66

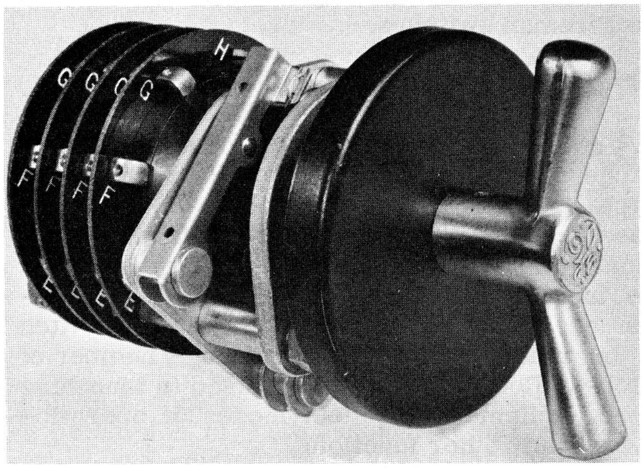

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Figure 9-2.— Type "J" multipole rotary switch.

Figure 9-3 shows the contact array for all pancake sections. Each movable contact is arranged to bridge two adjacent stationary contacts. The switch has eight positions. A detent mechanism properly aligns the contacts in each position of the operating handle. In one position, the rotor contacts bridge segments A-B and E-F; in the next position, the rotor contacts bridge segments B-C and F-G. Diagonally opposite pairs of contacts are subsequently bridged for the

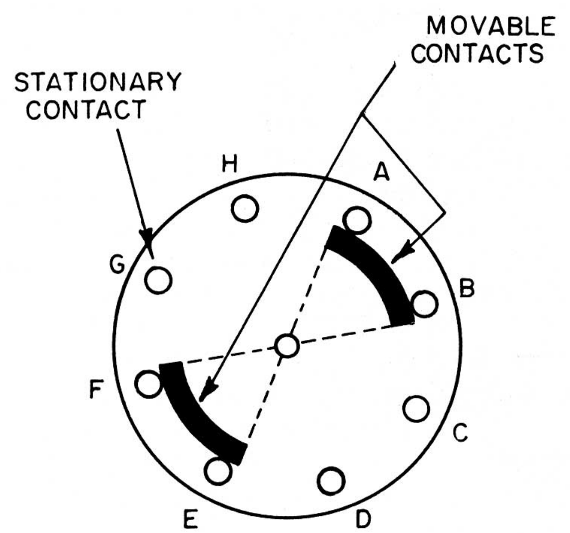

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Figure 9-3.— Type "J" switch contact arrangement.

remaining positions. The various circuit leads are connected to the proper pancake terminals. To transfer circuits you just turn the handle.

JR Type Of Rotary Switch

The letters JR are the designation for a family of rotary switches. These switches (fig. 9-4) control by a single motion a number of switches, called pancakes or wafers, located on the same shaft. To do this, the switch is built in layers, or wafers, along the shaft of the switch handle (fig. 9-4A). Each wafer is in itself a separate switch. See figure 9-4C. The number of contacts determines the type of switching circuit. Usually all the wafers in the JR type switches are identical. That is, they may be all make-before-break or break-before-make (fig. 9-4B).

Make-before-break means that as the switch is rotated, the rotor contacts touch the next pole before breaking the previous contact. Break-before-make means that as the switch is rotated, the rotor contacts leave the original pole before the movable contacts touch the new pole. In rare cases you will find a switch on which a few wafers permit break-before-make while the rest are of the other type. Extra wafers are provided for use as spares.

As the handle of the switch is turned, the rotor blades in all wafers turn simultaneously to make and to break the circuits. A detent wheel is incorporated in each switch assembly to ensure proper positioning. Also, a stop plate (fig. 9-4A), limits the rotation of the switch by means of a stop pin. The pin is fixed in the stop plate to prevent overtravel.

The JR switch is smaller in size and more readily disassembled than the J switch. These features result in a saving of space and also facilitate repairs. The JR switch is classified as 1 JR, 2 JR, 3 JR, or 4 JR type.

The 1 JR switch has only one movable contact per section. This movable contact bridges two adjacent stationary contacts.

The 2 JR switch is the same electrically as the J switch and is the type used for general ordnance applications. The 2 JR switch has two movable contacts per section, 180° apart. Each movable contact bridges two adjacent stationary contacts.

The 3 JR switch uses one of the stationary I contacts as a common terminal. This stationary contact is connected in turn to each of the other stationary contacts of the section by a

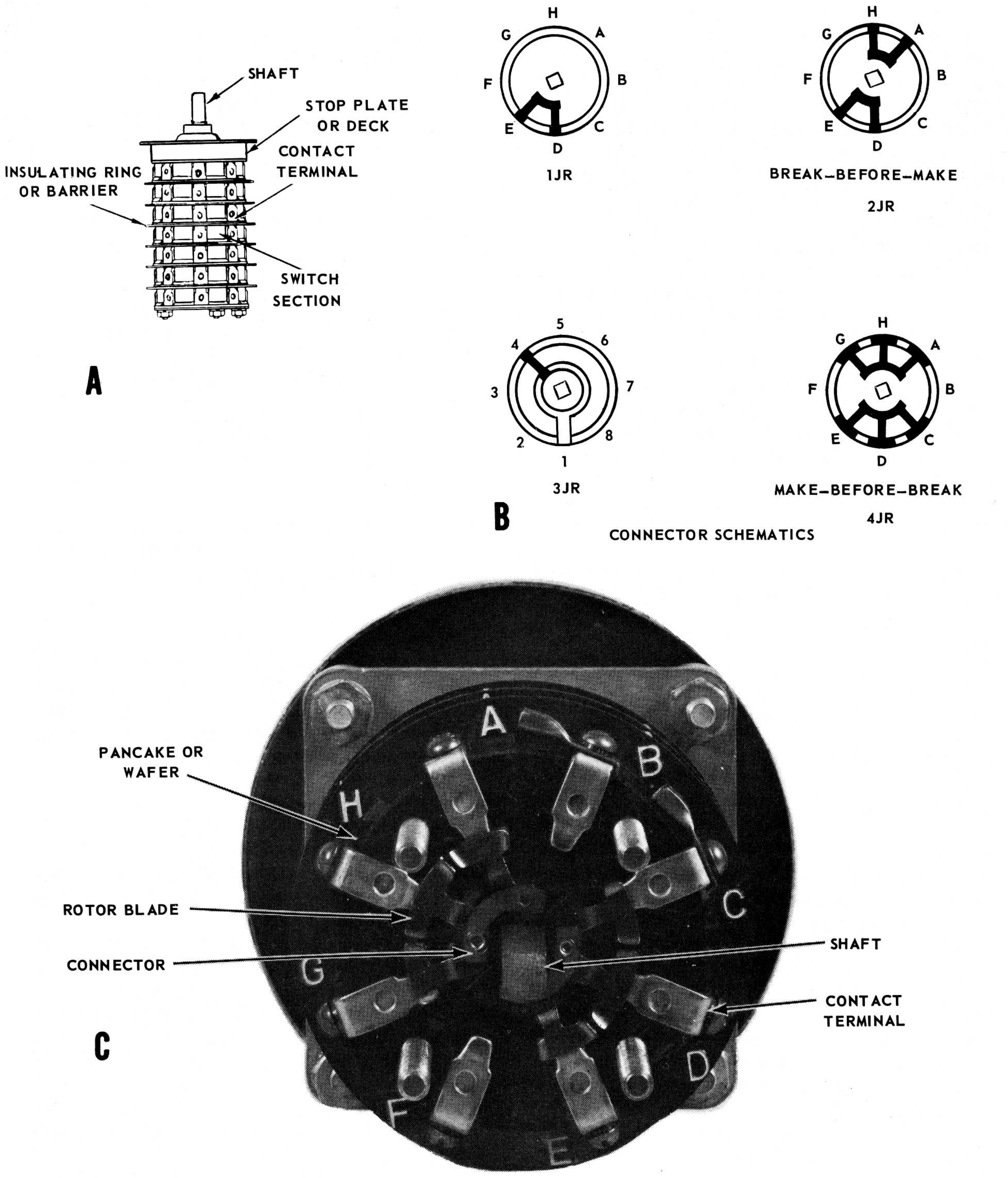

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Figure 9-4.— JR rotary switch: A. Typical rotary switch arrangement; schematic; B. JR switch contact arrangements; C. Face view.

single wiper contact. The 3 JR is used for selecting one of several (up to seven) inputs.

The 4 JR switch has two movable contacts in each wafer. The movable contacts bridge three adjacent stationary contacts.

The JR switch is stacked in multiples of 5 sections (up to 25 sections). In some cases, a switch with a number of sections (not a multiple of five) has been installed. If this switch must be replaced, a switch with the next largest number of sections that is a multiple of five should be installed if space permits. It is preferred to have all sections of a switch the same, but, if absolutely necessary, a switch with some sections of one type and some sections of another type can be provided.

Type JR switches are rated at 115 volts, 60 hertz, and 10 amperes. The switch should not be used on d-c circuits because of the possibility of severely burned contacts when operated slowly (teased). The switch is of the non-shorting type.

Barriers are also provided between sections to prevent terminals from turning and shorting to adjacent terminals.

If the sections are not uniform the switch will be designated "JRSP", followed by the number of sections.

The stop deck on the JT switch (fig. 9-4A) permits setting the switch to the number of positions desired. By inserting pins or screws in the stop deck immediately after the desired last position, you can keep the switch from moving beyond that point.

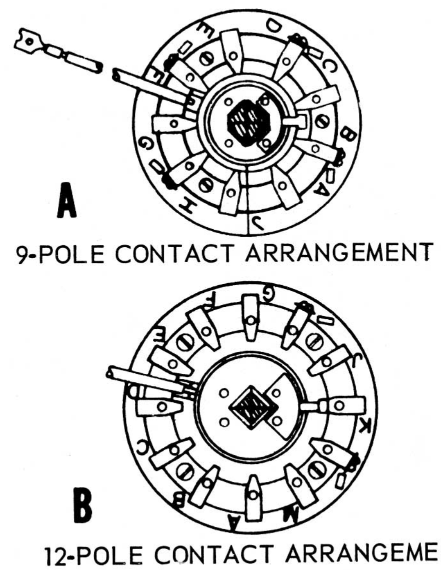

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Figure 9-5. — Barrel switch contact arrangement: A. 9-pole contact arrangement; B. 12-pole contact arrangement.

Barrel Switches

Barrel switches are used in some ordnance installations. The contactor-carrying shaft on this type of switch is manually rotated. Each contact wafer level has an external electrical input to a slip ring. (Slip rings have been mentioned several times in preceding chapters.) From the slip ring, electrical distribution is made to the contactor blade and then to the contact for the external distribution.

There are three types of contactor blades used in barrel type switches: double, offset, and straight.

Figure 9-5 shows a straight blade arrangement for 9-pole and 12-pole barrel switches.

INTERLOCK SWITCHES

Interlock switches include a large group of switch types that are actuated by mechanical linkage or hydraulic fluid. They act as control or protective devices and are numerous in missile launching systems. Their use permits action to take place only in the ordered sequence. For example, switch SI102 cannot be actuated ahead of SI101.

Sensitive Switches

The most common type of interlock switch is the sensitive switch. There are various kinds of sensitive switches with different means of actuation.

These are small, short-traveling, snap-action switches. See figure 9-6. They are manufactured as normally open, normally closed, and double throw. The latter has no OFF position. The Microswitch is frequently used in referring to this type of switch. The term Micro is a trade name for the switches made by the Micro Switch Division of Minneapolis Honeywell Regulator Company. However, many other companies also make sensitive switches.

Sensitive switches are usually of the push-button variety and are often used as interlock switches. These switches usually depend on one or more springs for their snap action. For example, the heart of the so-called Micro switch

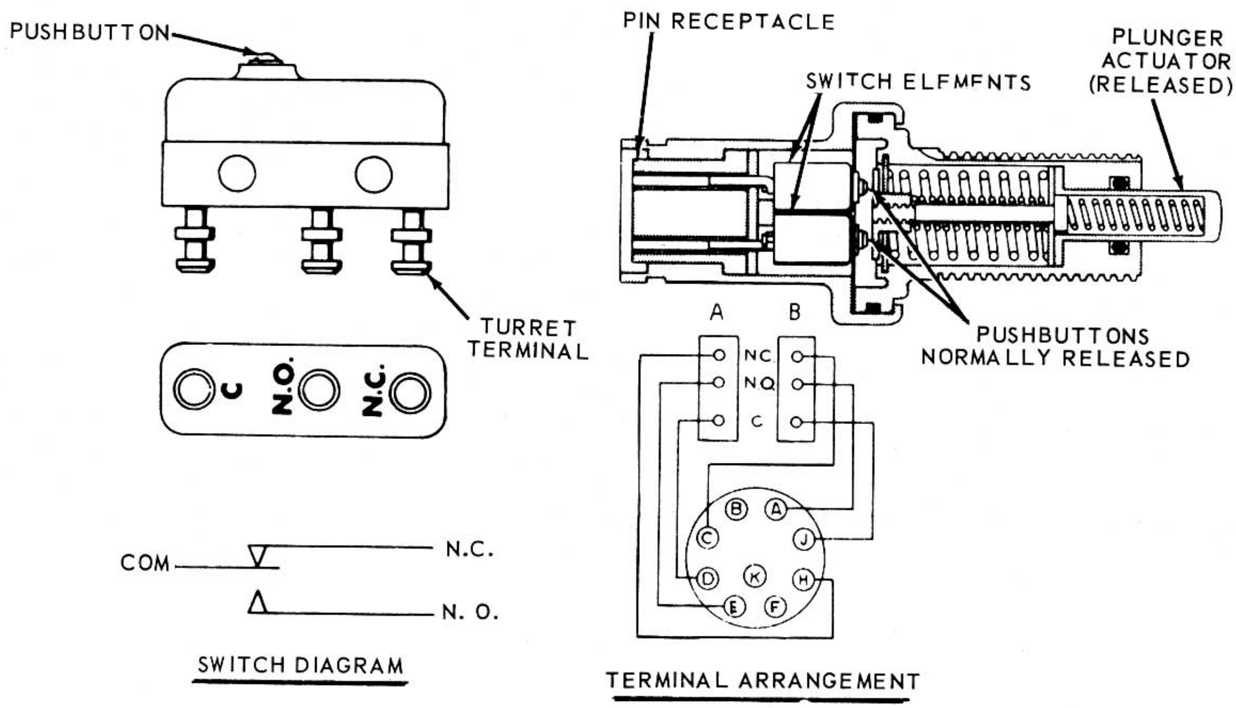

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Figure 9-6.—Sensitive switch, showing terminal and element contact arrangement.

is a beryllium copper spring, heat-treated for long life and reliable action. The simplicity of the one-piece spring contributes to the long life and dependability of this switch.

When a sensitive switch is used as an interlock, the plunger (pushbutton) is actuated by mechanical means. The device for moving the plunger can include either a rotating cam, lever, wedge, or bellows arrangement. Figure 9-7 shows some of the ways of applying operating force to the plunger.

Other Types of Interlock Switches

A snap or snap-lock switch is another type of interlock switch. It is used mostly on older ordnance equipment. It is usually actuated by a mechanical cam. The contact lever snaps into contact with the stationary contacts, as the torsion spring inside the switch overcomes the latch. See figure 9-8.

The stepper switch, sometimes called a stepping relay, is a rotary switch driven by a coil and latching arrangement. This combination switch and relay is used in the missile selection circuits of launching systems. Its action is described in the section on relays.

RELAY PRINCIPLES

A relay is simply an electromagnetically operated switch. It is designed to open or close a circuit when the current through its coil is started, stopped, or varied in magnitude. The main parts of a relay are a coil wound on an iron core and an armature that operates a

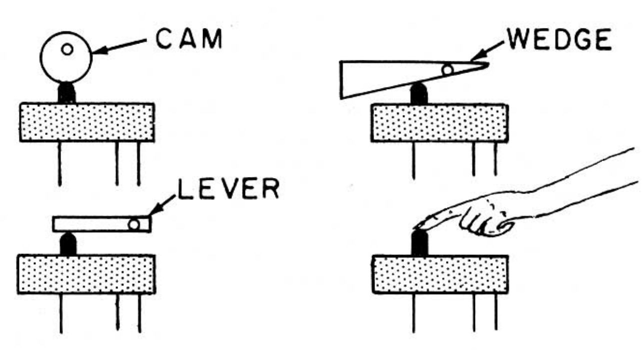

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Figure 9-7.—Methods of applying operating force to pushbutton (sensitive) switch plunger.

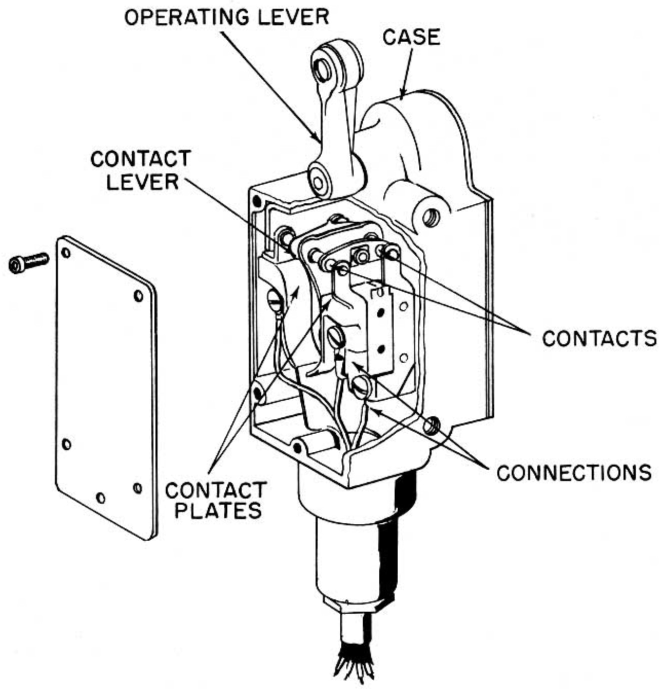

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Figure 9-8.—Snap-lock switch.

set of contacts. A simple relay and circuit are shown in figure 9-9.

If you close switch 81, current flows through the coil, energizing the electromagnet, and drawing the armature upward. The action of the armature closes the contacts and power is applied to the load. More contacts can be added to the armature so that other functions may be accomplished.

The operating speed of a relay is determined by the time between the closing of the coil circuit and closing of the relay contacts. In small, specially designed relays, like the ones in launching system control circuits, the operation speed may be as low as one millisecond. The operating speed of a relay may be increased by any technique that reduces eddy currents in the core. Making the core of laminations is one method of reducing eddy currents and thus increasing the operating speed of a relay.

Another method is to place a resistor in series with the relay coil and increase the operating voltage. This will increase the speed of closing because at the instant power is applied to the relay all the voltage will appear across the coil and the magnetic field will build up faster. The speed of relay operations can be reduced by placing a heavy copper sleeve over the core of the coil. This has the effect of a shorted turn. Current flow in the sleeve opposes the field in the coil as it builds up or collapses, thus delaying the relay's operation.

The type of material used for contacts depends on the amount of current to be handled. Large power relays usually have copper contacts and use a wiping action to make sure of a good connection. Small relays may use silver or some silver alloy, while in some applications tungsten or some very hard material may be used which will prevent contact burning or oxidation. In general, relays that open and close with a fast positive action cause much less trouble than those that operate slowly. Relays that malfunction or fail completely should be replaced. It is not good practice to repair them.

POWER RELAYS OR CONTACTORS

Heavy-duty relays called contactors are used extensively for remote control switching of high voltage and current. A case in point is the application of 440 volts to an electric motor. For this application and similar ones, a relatively small amount of control power (generally 115 volts) may be used to energize the coil of a contactor whose contacts are made heavy enough to handle the required amount of power.

Figure 9-10 shows a typical contactor of the armature type. This type contactor comes in three sizes and all are for 440 volt, 60 hertz operation.

Main components of the contactor are a 115 volt coil, a magnet, an armature, a stationary four contact assembly, a movable four contact

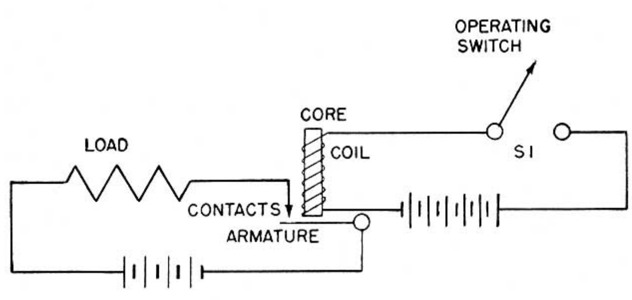

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Figure 9-9.—Simple relay circuit.

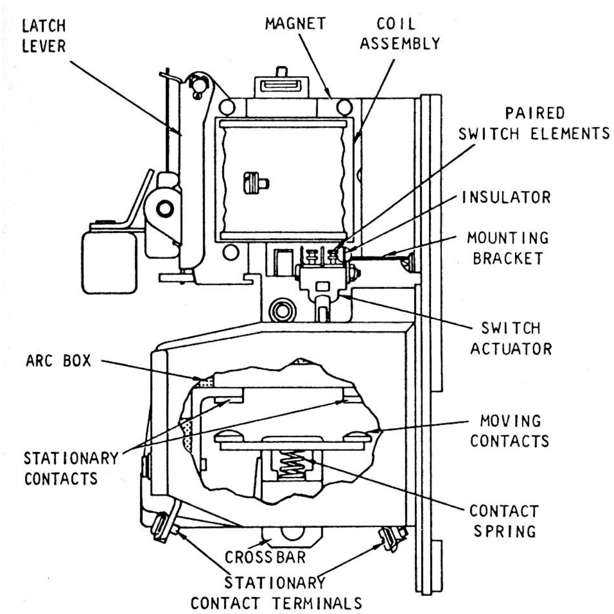

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Figure 9-10.—Size 1 contactor.

assembly that is linked to the armature through a crossbar, two switch elements, and an inertia- type shock latch.

When the coil is energized the armature movement pulls the crossbar which in turn moves the contact assembly to close the motor circuit.

When the coil is deenergized, a kickout spring breaks all the contacts.

The inertia latch prevents the contactor from closing (if deenergized) or opening (if energized) under shock. In the event of shock, the weight on the latch moves a slider bar to momentarily lock the contactor plunger in position.

Figure 9-11 shows another type of contactor known as the solenoid relay. It operates with a vertical motion. When the coil is energized, the plunger or armature snaps upward, closing the contacts. These are mounted on springs to ensure an even pressure where more than one set of contacts are used. Contactors of this type usually have silver alloy contacts which do not oxidize easily and so require little attention.

CIRCUIT BREAKERS

Circuit breakers (fig. 9-12), used in launching systems, are comparatively small devices that play the role of guardian over the electrical system" The circuit breaker is designed to open the circuit automatically under short circuit or overload conditions without injury to itself. Thus it performs the same function as the fuse, but has the advantage that it is capable of being reset and used again. Like the fuse, the circuit breaker is rated in amperes and voltage. The thermal-magnetic breaker permits temporary light overloads. such as an in rush starting current; permits medium overloads for predetermined lengths of time; and trips instantly on exceedingly high overloads. There are three basic types of circuit breakers, thermal, magnetic, and thermal-magnetic. The thermal type is the most universally used.

In their usual forms the circuit-breaker contacts are closed by a hand operated lever. Since some form of automatic switch opening device is needed to replace the human operator. a switch tripping device is included in the circuit breaker. The complete contact assembly consists of the main bridge contacts and arcing contacts (fig. 9-12).

Trip Mechanism

The trip mechanism is actuated by a release. or relay. Release devices are a combination of

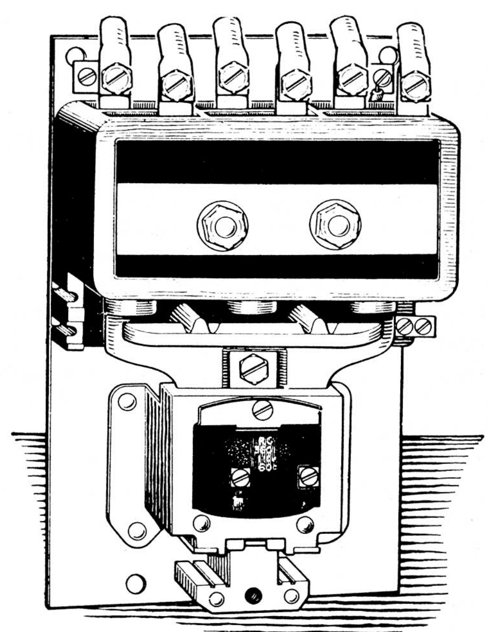

Figure 9-11.—Power contactor, solenoid relay type. 83.94

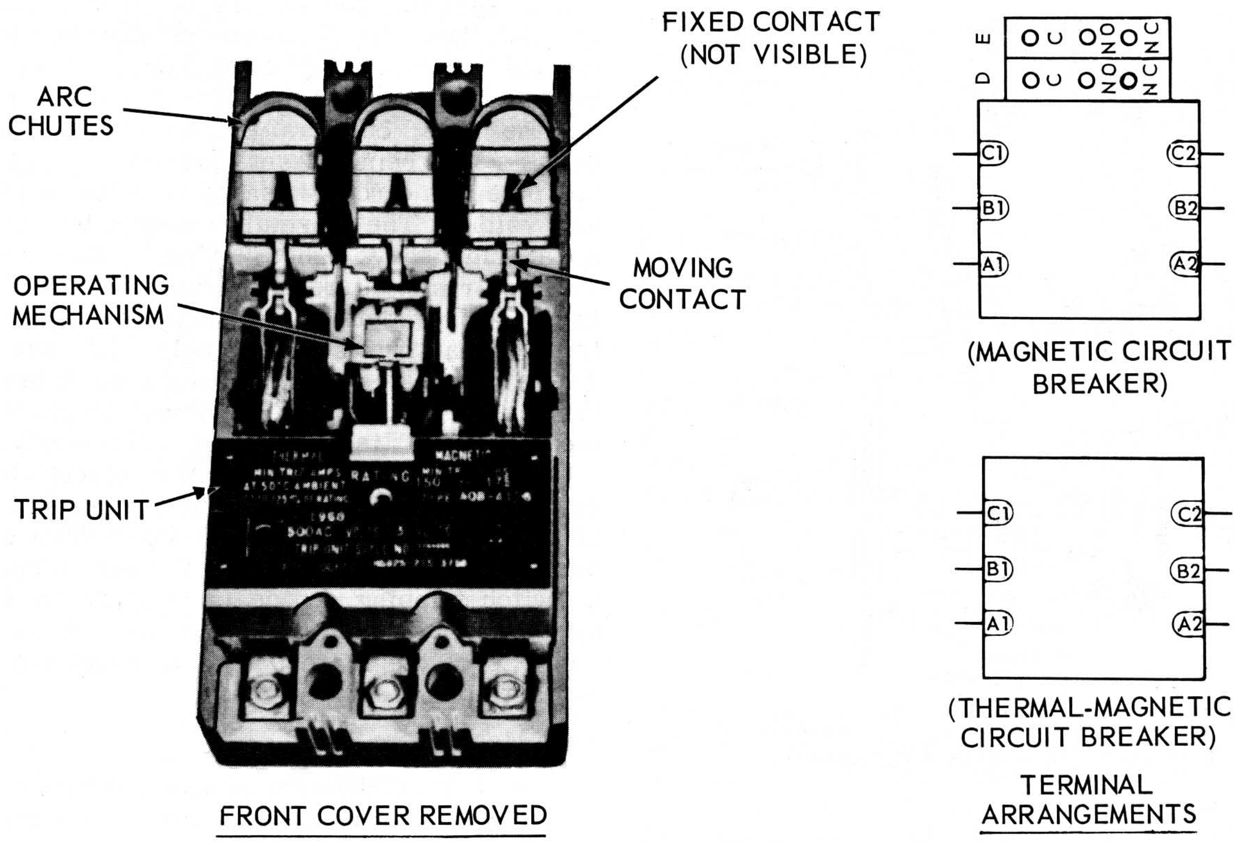

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Figure 9-12.—Circuit breaker: A. Front cover removed; B. Terminal arrangements.

the thermal and magnetic types. A thermal release is used for overload protection, and depends upon the deflection of a bimetallic element that is heated by the circuit current. As current flows through the bimetallic strip, heat is generated and the strip bends. Under sufficient heat it bends enough to interrupt the circuit by releasing a trip, which opens the contacts. The magnet release uses an electromagnet which acts directly on the trip mechanism of the circuit breaker. The magnetic part operates on short circuits. Most circuit breakers also have a manual means of resetting.

Another type of thermal circuit breaker is shown in figure 9-13. This breaker consists of a conductive bimetallic snap-acting disk which bridges two electrical contacts. When the disk is heated by an excess current, it snaps into reverse position, opening the contacts and the circuit. In circuit breakers having low ampere and voltage ratings, a resistance wire is inserted in the circuit. The resistance wire provides the heat necessary to snap the disk. The breaker is reset by pressing the button which restores the disk to its original position. Once this type of circuit breaker is closed it cannot be reopened manually. They are also nonindicating; that is, the position of the breaker (open or closed) cannot be determined by visual inspection.

The automatic-reset type circuit breaker is similar to the bimetallic disk type just described, except that it has no reset push-button; it resets itself automatically. After a short time, when the disk has cooled sufficiently. it will bend back and close the circuit, resetting itself. If a constant overload exists, the breaker will intermittently break the circuit.

Besides the protection against high current overloads, many circuit breakers can be opened or closed by means of a switch or lever to isolate circuits for maintenance or repair purposes.

An electromagnetic circuit breaker is described and illustrated in chapter 8, Basic Electricity. NavPers 10086-B.

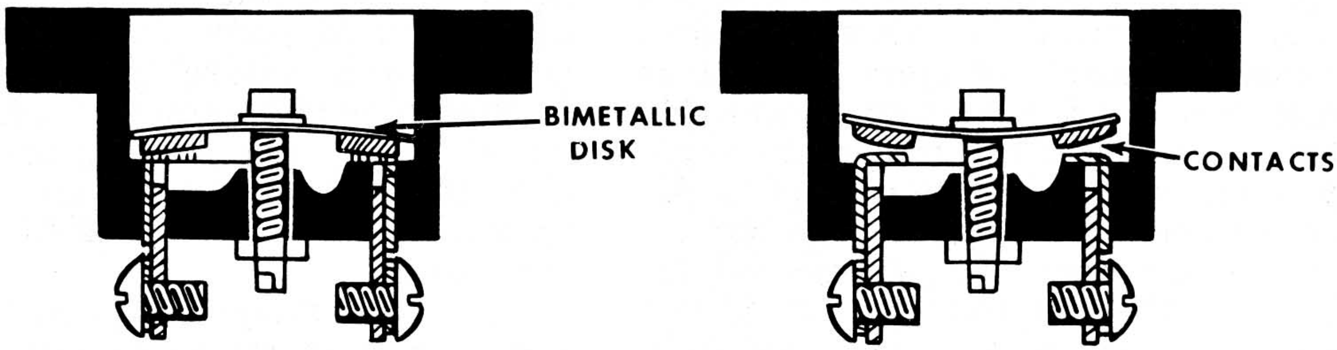

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Figure 9-13.—Thermal circuit breaker.

STEPPING RELAYS

Stepping relays are used in control circuits to locate, to identify, and to select missiles for warmup and loading. Figure 9-14 shows a simple stepping relay assembly and its principle of operation. It consists of two principal parts: a relay and a rotary switch. Stepping relays are sometimes called stepping switches or stepper switches.

To start stepping, the relay coil is energized. The Y-shaped pawl is attached to the relay armature and the pawl is moved about its pivot. When this happens, the left prong of the pawl presses the ratchet tooth in a counterclockwise direction. The ratchet gear also turns counterclockwise. Consequently, the shaft of the wiper arm which is attached to the ratchet gear turns through the same angle and in the same direction. As the ratchet tooth passes the end of the pawl, the interrupter contacts open. These contacts are connected in series with the relay coil. When the interrupter contacts open, the relay is deenergized. The pawl is then returned to its manual position by the spring.

The right prong of the pawl engages the ratchet tooth which has been moved. Thus the right prong holds the ratchet gear locked in its new position. But when the pawl is in this position, the interrupter contacts close again and the switch takes another step.

When the stepping process is repeated, the left prong of the pawl engages the next ratchet tooth. Since the ratchet gear in our example has ten teeth, the ratchet and shaft have ten specific positions. This indicates that 10 external circuits can be connected to and controlled by the switch. Each step cycle makes a different switch contact. In a missile launching system, the cycle continues until the proper switch connections are made for the type of missile selected.

Control Relays

Control relays are used where circuit functions become so numerous that throwing switches manually would be complicated and time-consuming. Performing switching operations with relays causes the various functions to take place automatically and in the proper sequence.

Control relays come in a wide variety of sizes and shapes. Since there is such a wide variety, we will discuss only some of the more common ones. These are:

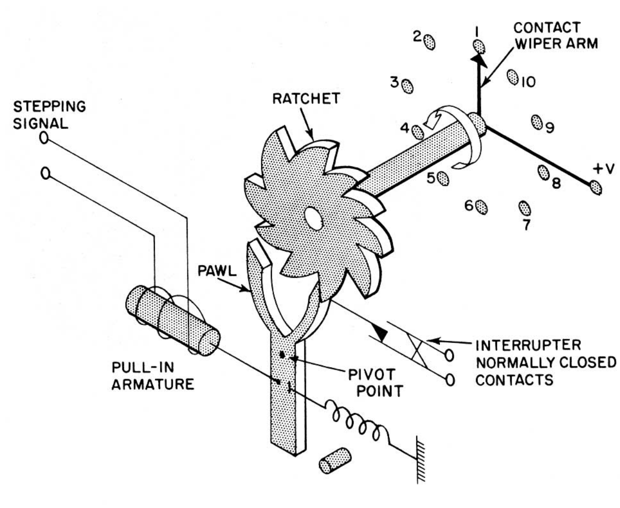

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Figure 9-14.—Stepping relay operation.

1. The rotary-type control relay. Figure 9-15 shows a typical rotary relay. You can see that it is heavily constructed to withstand shock. The coil housing consists of steel laminations with external coil input terminals. A movable coil armature is attached to a contactor-carrying shaft that extends through the contact levels. (Notice that the contact arrangement is similar to the manually operated JR switches we described earlier.) Each of the stacked contact levels (wafers or pancakes) is insulated from the other and has an eight-pole contact arrangement. When the contactor or shaft is moved, the contactor at each position provides a shorting path between two or more contacts. Deenergizing the coil allows the armature to spring back to its original position, if the relay is a nondetented type like the switch illustrated in figure 9-14. If the relay is a detented type, a second set of coils (instead of a spring) returns into armature to its former position.

Figure 9-15B shows a nondetented relay in its energized and deenergized positions. When it is deenergized, the HA and DE elements are closed, when energized, the AB and EF elements are closed.

2. Rotary relays also come in miniature and microminiature sizes. Functionally they are the same as the large rotary type we just talked about. The main difference is that the miniature and microminiature relays can be plugged in like a vacuum tube. The plug-in type is also much smaller. It has a lower current capacity and is hermetically sealed (air tight) in a can.

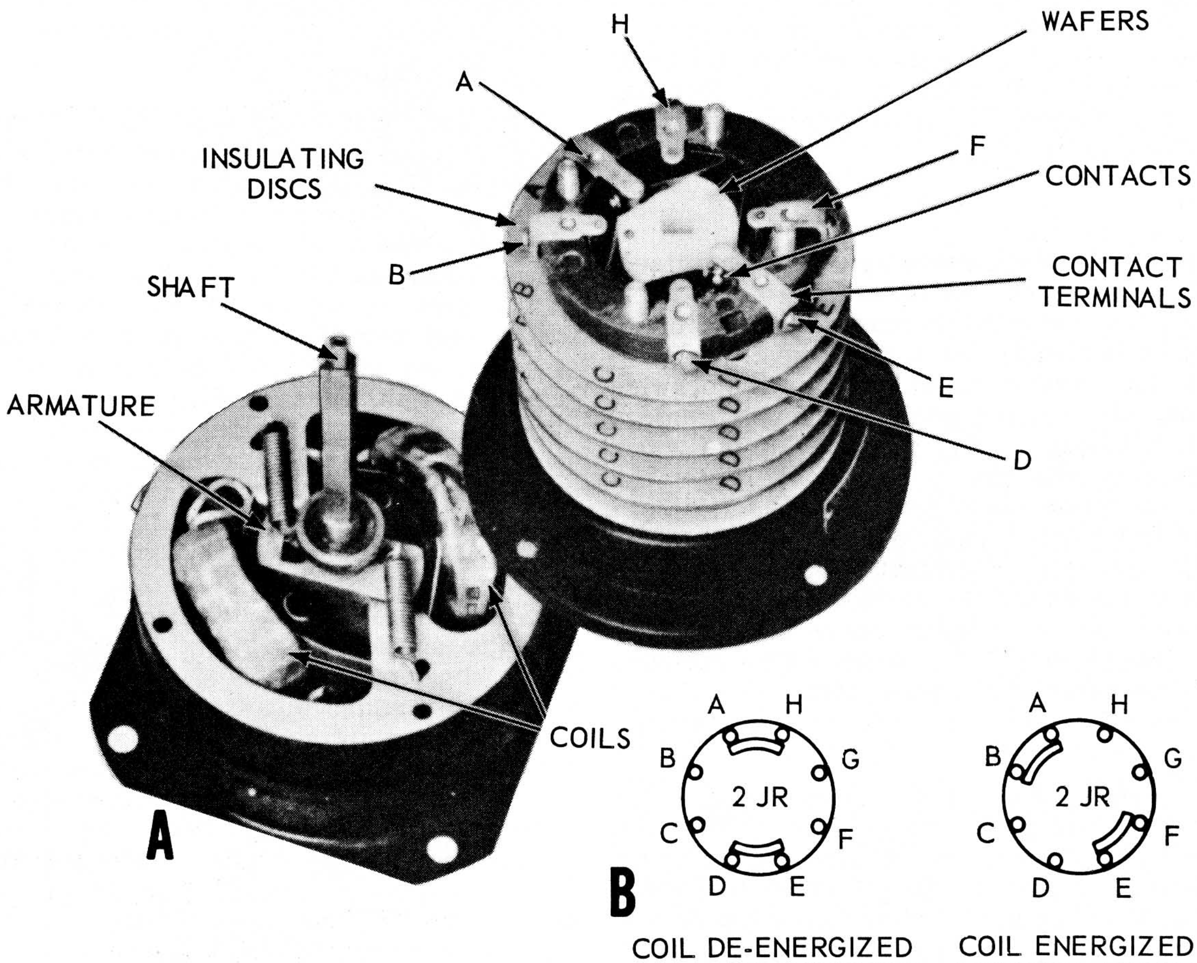

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Figure 9-15.— Typical rotary relay: A. Nondetented type; B. Position of elements in energized and deenergized states.

Another type of miniature relay, not as widely used as the plug-in type, is a solder-in type known as the hi "G" relay. This relay is extremely rugged and operates on 115-v, 400-hertz current. As indicated in the schematic in figure 9-16, this relay contains only two normally closed contacts. When the relay is deenergized, a red dot is visible at the relay base.

OVERLOAD Relay

An overload relay is designed to break a circuit when the current through it reaches a predetermined value. An overload relay (fig. 9-17 shows a typical one) consists of a coil and a plunger. The plunger is attached to a disc. The disc itself is enclosed in an oil-filled chamber called a dashpot. You learned about dashpots in Fluid Power, NavPers 16193-B, so we won't cover the operating principle here.

The coil is connected in series with the device the relay is to protect. During normal operation, the magnetic flux induced by the coil is not enough to raise the plunger. But if there is an overload, the current increases through the coil. Increased current induces a stronger magnetic flux (field) in the coil and the plunger is drawn upward. If the plunger is fully drawn up into the frame, the attached disc pushes the normally closed contact for the control circuit upward. This action opens the control circuit which, in turn, controls a contactor relay in, say, the 440-volt supply to a motor. You'll see more clearly how this works when we cover the application of relays and switches in typical circuits.

During an overload, the circuit is not broken instantaneously, although the greater the overload, the faster the relay action. Since the oil holds back disc movement, the size of the disc orifice through which the oil must pass determines the delay time for a given amperage. The size of the orifice can be adjusted by turning the cap at the top of the relay housing. (See fig. 9-17.)

A thermal overload relay has a heater element (instead of a dashpot) which deflects when heated by the current passing through it, and triggers the trip latch that opens the overload contacts. As soon as the cause of the overload is corrected, the relay must be reset. Reenergization of the motor run or "start" circuit energizes the reset relay coil, and solenoid action moves the plunger, resetting the tripping latch mechanism.

Overload relays may be single or double coil. The single coil overload relay may be obtained with or without a manual latching control.

TIME-DELAY RELAYS

The time-delay relay is used to provide a time interval between separate operations. One common form of time-delay relay uses a bimetallic element which bends as it is heated. The element is made by welding together two strips of metals having different expansion rates. A heater is mounted around or close to the element. Contacts are mounted on the element itself and, as the element is caused to bend by the different expansion rates, these contacts close to operate a relay (fig. 9-18). The delay

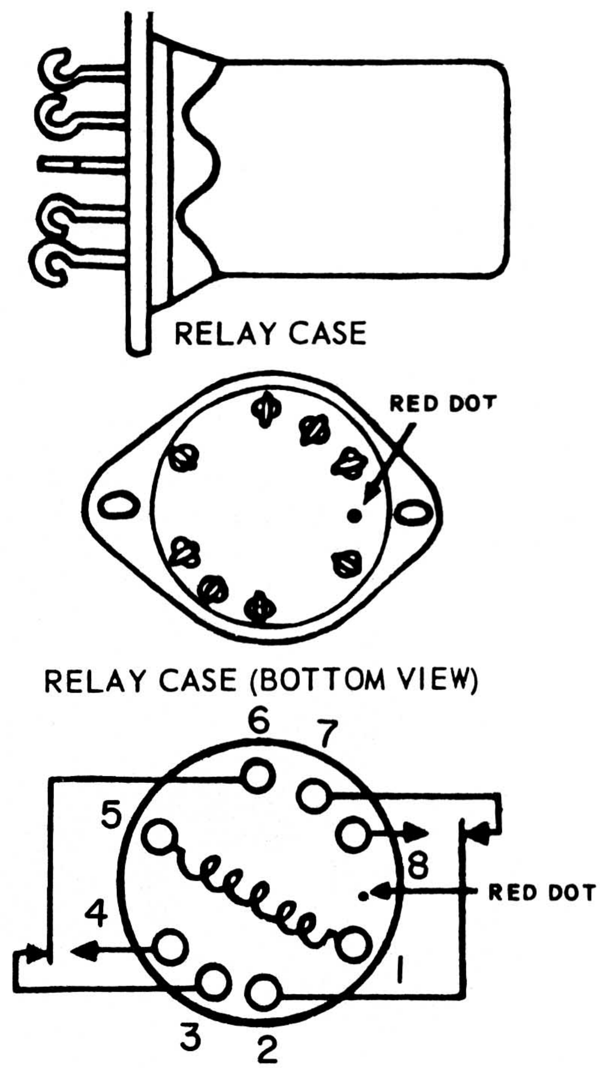

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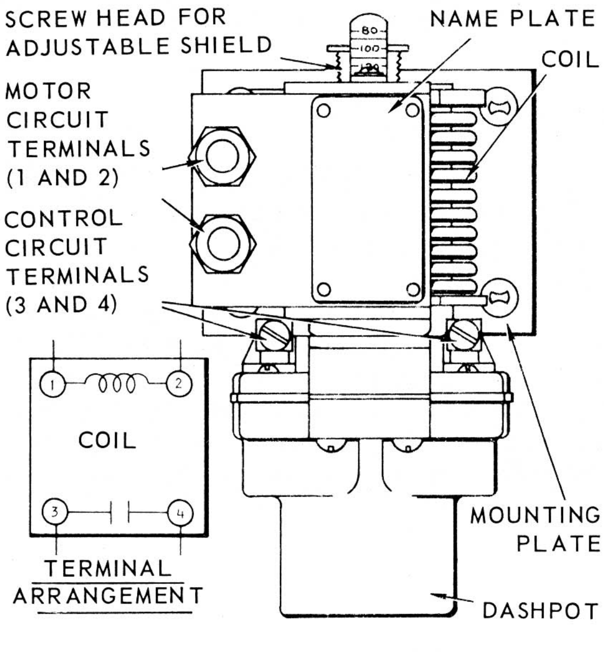
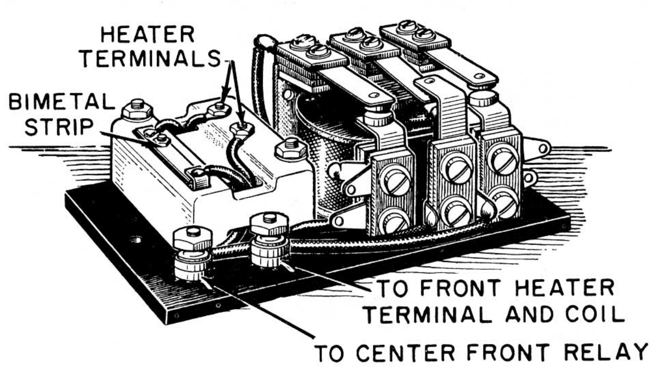
Figure 9-16.— Hi "G" relay.



83.98
Figure 9-17. — Typical magnetic overload relay.

time for bimetallic strips is usually from 1/2 to 1 1/2 minutes and is varied by using metals with different expansion rates or by increasing or decreasing the distance between the fixed and moving contacts.

Motor-driven time-delays are frequently used. This type of relay employs a small synchronous motor and a gear train to obtain the desired delay time. A set of movable contacts is mounted on the last gear of the train, and the circuit is closed when this set of contacts is turned



83.99
Figure 9-18. — Bimetal time-delay relay.

enough to touch the stationary contacts (fig. 9-19). Other motor-driven time-delay relays utilize a spring action to close the relay contacts. The spring is released by the gear train after a given time interval.

The air dashpot type (fig. 9-20) is used in many time-delay applications. It has many applications in missile launching systems. A magnetic coil pulls a plunger through a dashpot filled with air, the air passing through a small hole in the plunger. The time delay can be varied by changing the size of the hole in the plunger. To make a relay of this type trouble-free, a snap action of some kind must be provided for closing the contacts.

Sensitive Meter Type Relay

Meter relays are used in synchro changeover circuits and rocket firing. This type of relay has a moving element similar to the D'Arsonval element in a voltmeter. The moving element consists of a signal coil, a locking coil, and a contact arm.. Meter relays are extremely sensitive and accurate. Because they are used in rocket firing circuits to prevent firing a rocket whenever the launcher fine error signal exceeds, say, 20 minutes of arc, no inaccuracy can be tolerated.

Figure 9-21 shows the parts and operating principle of a typical meter relay. The relay is shown in its deenergized position. Deflection of the contact arm is proportional to the

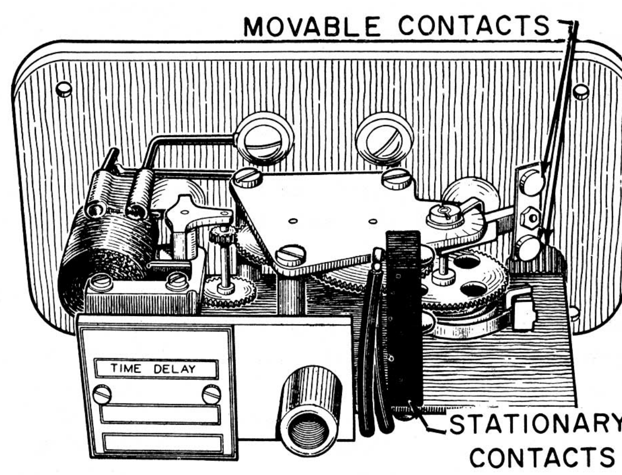


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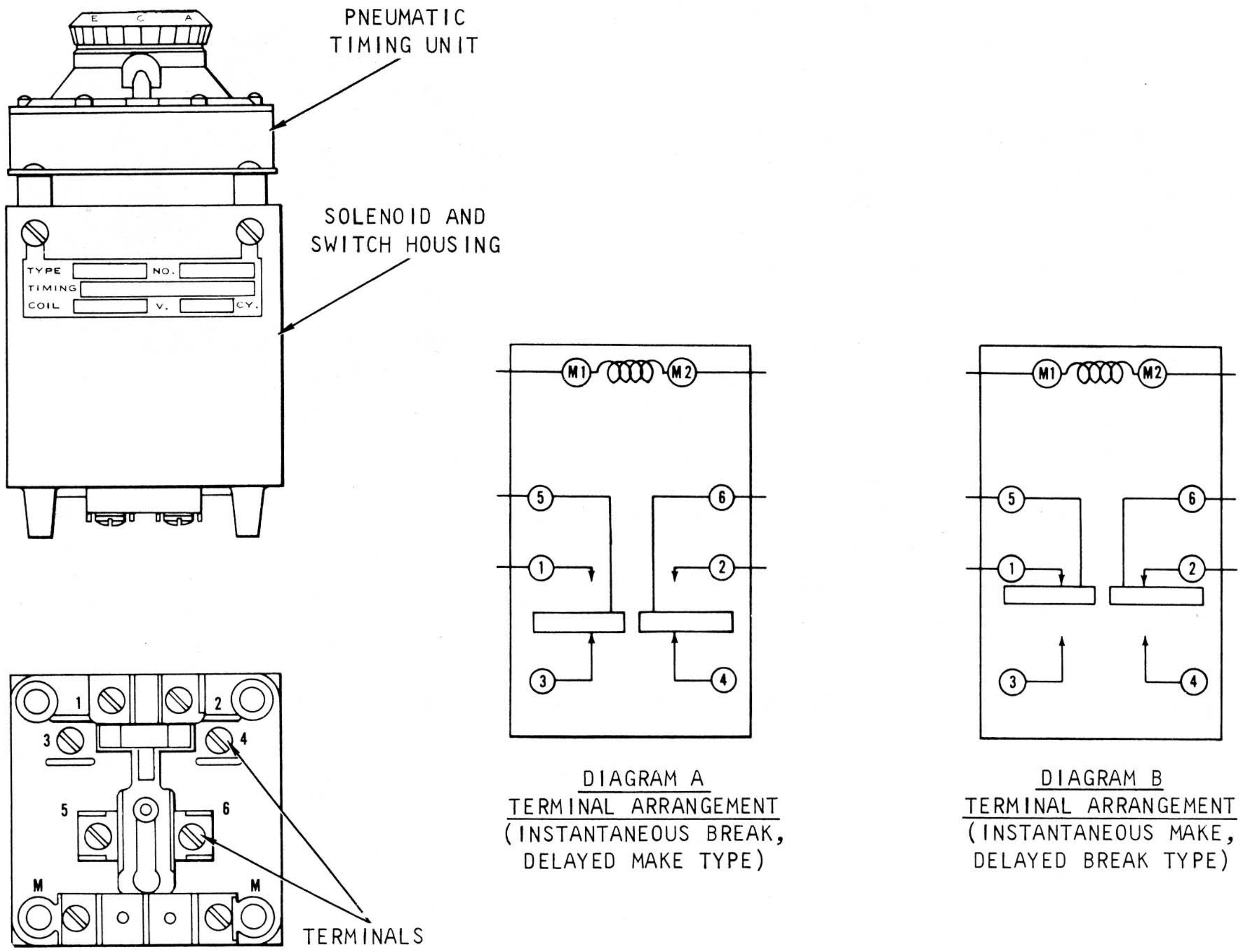
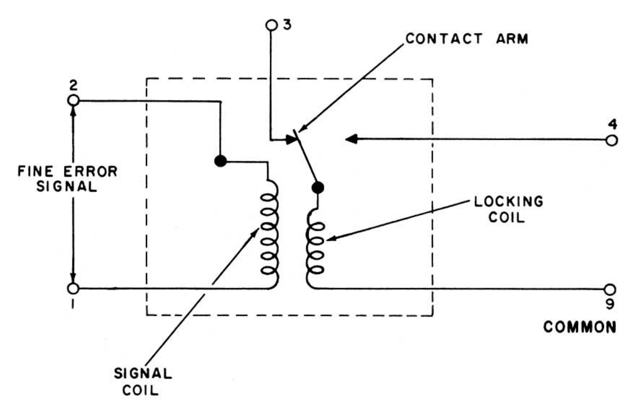
Figure 9-19. — Motor-driven time-delay relay.



83.100.2
Figure 9-20.—Air dashpot time-delay relay.



83.102
Figure 9-21.—Meter type relay; schematic.

current flow through the signal coil. The contact arm will not make contact with contact 4 until a certain current is reached. In a firing circuit the amount of current that will move the arm to contact 4 (and therefore lock out the firing circuit) is proportional to 20' of launcher position error. The locking coil helps to increase contact pressure between the contact arm and contacts 3 and 4. When either contact is made, the locking coil is energized, and this increases contact pressure.

Automatic Reset Timing Relays

In some missile launching systems, such as GMLS Mk 11, automatic reset timing relays are used to provide accurate, adjustable delay periods between operation of a control circuit and subsequent closing of one or more load circuits. This relay can also be used as an automatic reset, as an interval timer, or for opening an electrical circuit at a selected interval after simultaneously energizing the load and control circuits.

This type of relay is a precision-made timing instrument. It consists primarily of a synchronous motor, a coil-operated clutch, a motor switch, a reset spring, a timing-gear-reduction unit, a red and a black pointer (fig. 9-22), a calibrated dial, and a knurled adjusting knob. Two types of timers are in use. One type resets when power is interrupted and the other type resets when power is applied.

The timing pointer (black) starts moving away from the manually preset pointer (red) when the coil-operated clutch shifts to connect power to the synchronous motor. When the black pointer reaches zero, the delay circuit is restored. The time delay may be reset immediately, or reset may be delayed until the starting impulse for the next delay cycle arrives.

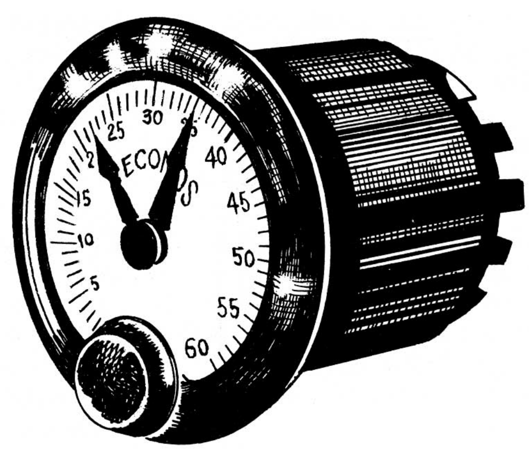


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Figure 9-22. — Automatic reset timing relay.

LAUNCHING SYSTEM CONTROL CIRCUITS

As you know, a guided missile or rocket launching system usually consists of three major components:

1. Launcher
2. Feeder
3. Launching system control

The latter component is made up of electrical panels, relays, solenoids, switches, and other electrical devices located throughout the launching equipment. All the mechanical, electrical, and hydraulic mechanisms in a launching system are electrically controlled by the action and interaction of the various relay and solenoid circuits of the launching system control subsystem. The control circuits regulate the application of power and the time it is applied to motors and to solenoid-operated hydraulic valves. Operation of the launching system is performed sequentially. No action - hydraulic or electric - can occur out of sequence because of the interlocking arrangement of switches and relays.

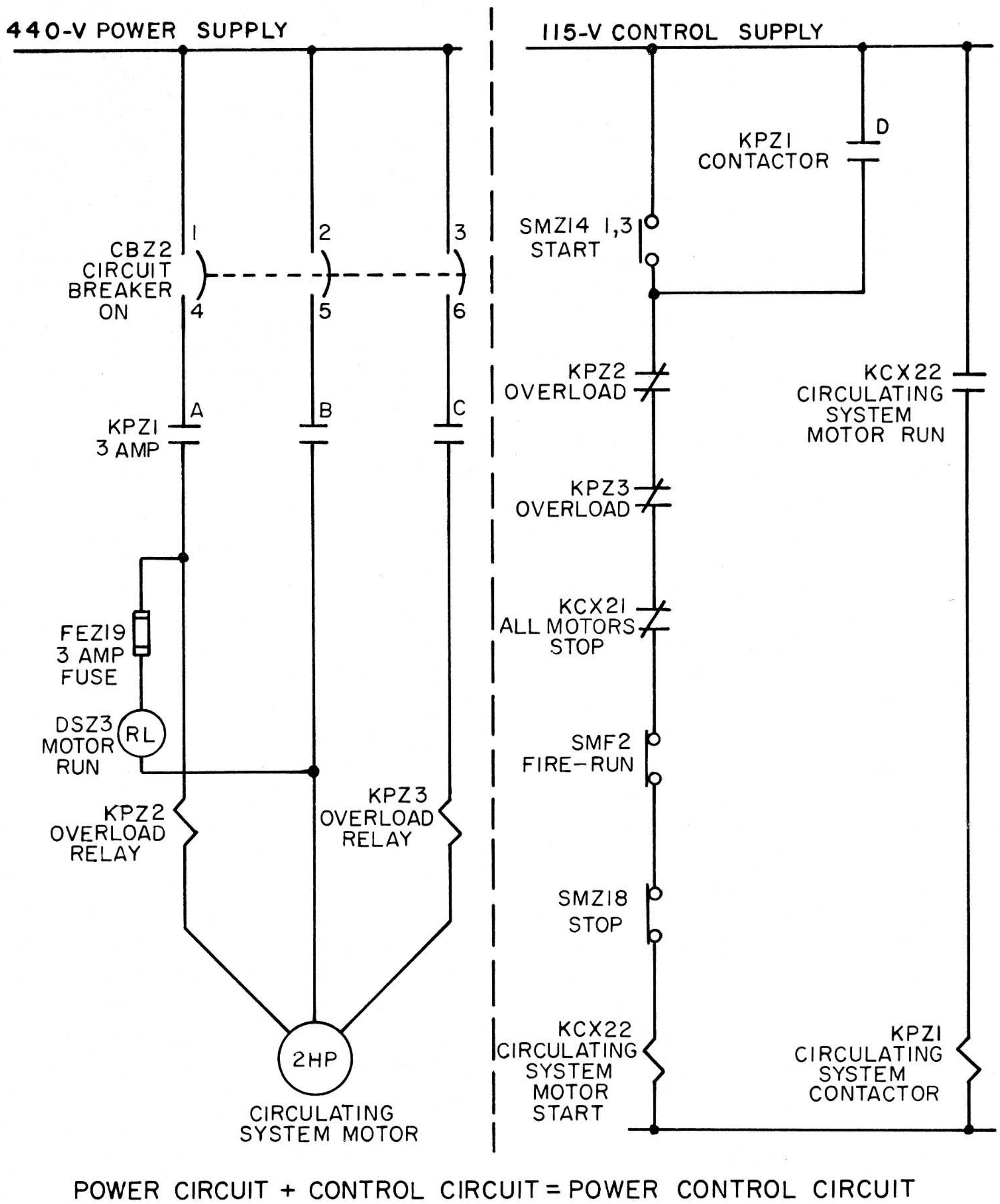
We can't show in this chapter all the various types of control circuits. There are hundreds of them in a single launching system. But we can discuss some typical examples, and show you the application of switches and relays in these circuits.

Here we will discuss a circuit using most of the basic electrical devices described earlier. In this way you will see how a circuit which looks fairly complicated at first glance is actually made up of smaller circuits. These, in turn, are made up of just a few electrical devices and their associated wiring.

POWER CONTROL CIRCUIT

The circuit we will talk about is a power control circuit. Its job is to connect or disconnect the weapons system 440-v, 60-hertz power to start and stop a motor. In figure 9-23 the power control circuit is shown in its deenergized state. You can see that all the individual circuits are arranged in ladder fashion across 440-volt a-c, and 115-volt a-c control supply lines. No electric action can take place until certain conditions have been met. Now, assume we want to start the motor. Before we can do this, all conditions imposed by the circuit must be satisfied. For example, all relays with normally opened (NO) contacts must be energized. And we must close all switches with normally opened (NO) contacts. Also, all relays with normally closed (NC) contacts must remain deenergized. When these and other conditions not mentioned are fulfilled, the circuit between the supply lines is completed. The motor then energizes and starts turning.

Let's go through the diagram step-by-step, starting from the 440-volt supply at the top of the illustration. Keep in mind as we trace through the circuit that our objective is to apply power to the motor. The first element is CBZ2,



83.103

Figure 9-23. — Typical power control circuit (motor start-run circuit).

a circuit breaker. You will remember that this electrical device provides overload protection for the motor. The 440-volt supply lines are sometimes called feeders. Notice that there are no fuses between CBZ2 and the motor. The circuit breaker in our circuit is used instead of fuses because it can operate a great number of times without injury. Then, too, the action of the circuit breaker may be controlled to a greater degree of accuracy than a fuse. Fuse FEZ19, protects the light, not the motor.

CBZ2 is hand operated. It has a handle which can be turned to either one of two positions, ON or OFF. For easy access, the handle of the circuit breaker is on the front of an electrical power panel. If we turn the handle to the ON position the three sets of contacts, 1-4, 2-5, and 3-6, will close.

The trip device in CBZ2 is a combined thermal and magnetic type of unit in which the thermal part operates on sustained overloads, and the magnetic part operates on short circuits. The tripping action allows momentary surges of current. When the motor is first started, it draws a lot more current than when it is running at normal speed. Therefore, the circuit breaker is designed so that it will not trip open when the motor is first started and line current surges. But if the circuit is overloaded for a sustained period of time, the thermal part of the tripping device will open the circuit. On the other hand, if a short circuit is present, the magnetic part of the tripping device will act instantaneously.

When an overload of any kind trips the circuit breaker, the handle moves to a point between the ON and OFF positions. The breaker is reset by moving the handle first to the OFF, and then to the ON position.

So far, we have 440-volt power to contacts A, B, and C of KPZ1, an electrically operated power contactor. Before we can apply power to the motor, we must close these contacts and then the 440-volts will have a clear path to the motor. Since KPZ1 is a line contactor, its operation is controlled from the 115-volt control circuit. You will find the coil of KPZ1 at the bottom right-hand side of the drawing. A glance at KPZ1's circuit shows that it is controlled by the normally open contacts of KCX22. Therefore, the next step in our circuit tracing procedure is to find the coil of KCX22. It is directly to the left of the coil of KPZ1.

A quick study of KCX22's circuit shows that it is a simple series-parallel circuit containing contacts of relays in the 440-volt circuit (KPZ2 and KPZ3) and in the 115-volt control circuit (KPZ1). Also included in the circuit are several switch contacts and the normally closed contacts of "All Motor Stop" relay, KCX21.

You can see now that to energize KPZ1 which, in turn, will start the motor through the closed contacts of KPZ1, we must energize KCX22. If we start tracing KCS22's circuit you can see that the contacts of the first five elem.-ants in the circuit are normally closed.

SMA18 is a pushbutton actuated sensitive switch. It is shown in its normally closed position. (The motor stops when the switch is open.) SMF2 is in its FIRE-RUN position as indicated in the drawing, and its contacts are closed. KCX21 is controlled by a switch not shown in the diagram,. and the contacts of this relay are also normally closed. Finally, the contacts of KPZ3 and KPZ2 are closed. The coils of these overload relays are in the 440-volt power circuit to the motor, as you can see at the left side of figure 9-23. Since no current is flowing at present in the motor circuit, these thermal overload relay coils should be cool, and the contacts associated with them should be closed. And they will stay closed when the motor is energized unless there is an overload in the motor or in its power circuit.

Now we have reached a point in KCX22's circuit where we can branch. We can go to the right, or we can go directly ahead to reach the high side of the 115-volt control supply. Let's go to the right. And if we do, we are immediately stopped by the open contacts of KPZ1. This relay is not energized yet. It is controlled, as you saw a moment ago, by KCX22. So, obviously we have no other choice but to back up and then go through the other parallel branch. To get through this leg of the circuit, we must close SMZ14. It is another pushbutton switch. And its contacts are spring loaded to the open position.

If we press it, its contacts close and the switch is in the start position. Turning SM Z14 to START sets off a relay chain reaction; KCX22 energizes. And its contacts in the KPZ1 circuit close. Then KPZ1 energizes. Now the normally open A. B, and C contacts of KPZ1 in the motor 440-volt supply lines close and the 440-volt supply is impressed across the motor. Then it starts rotating. Also, the light, DSZ3, glows, indicating to an operator that the power circuit to the motor is completed.

So far, so good. We have the motor running, which was our original objective. But if we release the pushbutton on SMZ14, the motor would stop if it were not for the holding circuit that bypasses SMZ14. Remember that the contacts of this switch are normally open because it is spring loaded to its OFF position. Therefore, when SMZ14 is released, it springs from its closed or RUN position to its normally open or OFF position. But releasing the switch does not stop the motor in our circuit. Notice that the D contacts of KPZ1 are in parallel with the contacts of SMZ14. So, if you release the pushbutton of SMZ14, KCX22 will remain energized, thus keeping the 440-volt supply to the motor through the contacts of KPZ1, because KCX22's circuit remains completed through the D contacts of KPZ1.

In review, there are several ideas you should remember particularly from this discussion. First, the power control circuit in figure 9-23 is typical of the ones you will find in missile launching systems. Some power control circuits will differ in the number and types of components. But, by and large, these circuits operate on the same general principles.

Second, the power circuit is interlocked with the control circuit, and vice versa. You will find contacts of devices operated by the heavy power current in the lighter control circuit, and conversely, contacts of control circuit relays are in the power circuits. Thus, the operation of one circuit affects the operation of the other.

Third, most power control circuits will contain a holding or lock-up circuit so that the start button or switch can be released and be in a position where it can initiate another start cycle.

Finally, notice that in the circuit we have been talking about, as well as others like it, the energizing and deenergizing of relays occur in a certain order, or sequence. For example, after we manually turned the circuit breaker, CBZ2, to its ON position and then pressed SMZ14 to START, KCX22 energized. Then KPZ1 picked up (energized), and the motor started. Based on this description, you could call our network of switches, relays, and other electrical devices, a sequencing circuit.

TYPICAL FIRING CIRCUIT

Firing circuits, as you know, are used to launch missiles. Before these weapons can be launched, certain conditions in their respective weapon systems must be met. Take a missile firing situation, for example. A launcher with both arms loaded slews to synchronize with the train and elevation orders generated by the missile fire control computer. When the launcher is synchronized with the orders, a light glows on a panel within the launching system, and on the Weapons Assignment Console (WAC) at the Weapons Control Station. These burning lights indicate that the launcher is pointing the missiles in the direction ordered by the computer and not at some part of the ship or into the sky. Missiles still cannot be launched, however, unless other conditions are met. For instance, the blast doors must be shut. The launcher must be in a safe firing zone. The launcher contactor must be extended and the missiles must have been receiving warmup power for a specified length of time, 20 seconds or so. When all of these conditions exist in the missile, launcher, and feeder, another light (Ready To Fire) glows on the Weapons Assignment Console.

Now the weapons control officer can make a tentative decision to fire. He checks the tactical situation and the panel face of the WAC. And, if everything is in order, he signals the WAC operator to fire. The operator sets the Salvo Select switch, and closes the firing key. The missiles are now activated. This term means that the missiles shift from ship's warmup power generated by the missiles. Also each missile goes through a set sequence of operations preparatory for flight. Then, when the missiles are ready, the boosters are ignited. But booster ignition does not occur at the same time for each missile. First the A rail is activated on intent to launch and the time delay is activated on A rail clear (empty), 2.5 seconds later the B rail is activated. Both missiles are indicated "Ready" prior to closing the firing key.

We've just described, in a very sketchy way, equipment, circuit, and tactical conditions that must exist before missiles can be fired. To perform and to indicate that the events have taken place to meet firing conditions, thousands of major and minor physical operations (hydraulic, electrical, mechanical, and to a lesser degree, pneumatic) must take place within the launching system as a whole. Each of these operations is interlocked with another. And to describe each operation and how it affects overall system operation takes hundreds of pages of written material and many drawings.

Obviously, we cannot cover an entire missile firing operation here. Numerous circuits must be activated to get the missiles in position for firing. The firing circuit is the electrical method for igniting the primer, which, in turn, ignites the propelling charge.

Tartar Firing Circuit, General

In the Tartar GMLS, the common firing circuit includes an auxiliary power supply (APS) squib firing circuit, an intent-to-launch firing circuit, and a missile motor-squib firing circuit.

The intent-to-launch and auxiliary power supply firing circuits are applied to the missile through the launcher-to-missile connector located on the inboard fin erector arm.

The missile motor squib firing circuit is completed by the firing contacts located on the front guide. When the guide arm is loaded, the firing contacts on the front guide mate with identical contacts on the missile.

The intent-to-launch circuit consists of the power supply for the APS squib firing transformer and the APS isolation transformer.

When the APS squibs are ignited, the missile starts operating on its own internal power, independent of the ship's power supply. When the necessary conditions within the missile are met, intent-to-launch and APS firing voltage is available to the missile motor squib firing transformer, and ignites the missile motor squib. The motor squibs ignite the booster propellant in the missile. When enough thrust is produced by the burning propellant to overcome the restraining force of the forward motion latch (about 0.03 sec.), the missile is launched.

The same sequence is followed for the missile on the other arm, which is fired shortly after the first. The missiles are not fired simultaneously, but the interval is short.

Tartar Mk 13 GMLS Firing Circuit

This rundown on the firing sequence ignores the action of the electrical components. To illustrate further how relays and switches are used to interlock and sequence events, we have taken a segment of the "Big Missile Firing Picture." Figure 9-24 shows a portion of the Mk 13 GMLS firing circuit. We have drawn only that part of the firing circuit needed to fire a Tartar missile from the arm of the launcher. For simplicity, firing mode switching circuits have been deleted. The circuit that remains performs a single function. It initiates the firing process of a Tartar missile from the arm of the launcher.

The main event in the operation of any missile launching system is the launching phase. Just before launch the missile is an integral part of its launching system. Only after launch is the weapon no longer married to the launching complex. How does this divorce take place? You will remember from chapter 3 that to ignite the booster the firing squibs are set off electrically. Squib ignition, in turn, ignites booster propellant and the resultant thrust sends the missile on its way.

Before we start discussing the circuit, we'll make a few assumptions:

1. The entire launching system is ready for operation. All power buses are energized, and hydraulic pressures are available.
2. A Tartar (DTRM) missile-booster combination has been loaded on the arm of the launcher.
3. Only a single salvo will be fired.
4. The blast door is closed.
5. The launcher is following a remote signal in train and elevation.

When the firing key on the WAC is closed, the normal firing channel is enabled. The APS electrical and hydraulic squibs will be ignited through the normal firing channel if the launcher has been assigned to a fire control system, safe firing conditions exist, and the launching system is ready to fire. The following launcher conditions must be present before the ready-to-fire relay can be energized:

1. Launcher synchronized.
2. Fins unfolded.
3. Blast door closed.
4. Launcher rail extended.
5. Launcher in safe firing zone.
6. Launcher assigned minimum of 1.8 seconds.
7. Missile warmup applied on launcher or at least 1.8 seconds.
8. Launcher warmup power enabled for 24 seconds.
9. Launcher power unit pressure normal.
10. Proper code matching between missile and selected FCS-2 or FCS-3 local oscillator in signal comparator.
11. DUD firing not ordered.

All these conditions must be fulfilled before there can be a complete path through SMF2 and SMF3 to energize KCF11.

With the Tartar missile on the launcher rail, the firing safety switches closed at the EP2 panel and at the Safety Observer's position, and the launcher assigned and synchronized to the remote signal, the electrical sequence of normal firing is as shown in figure 9-24.

Now we can start tracing the circuit. We must state that our ultimate objective is to ignite the squibs shown in the lower part of the drawing. We could start from the squibs and work back as we trace the flow of current but, by convention most GMMs start at the high side of the line, shown at the top of the page. Then they trace through the maze of switch and relay contacts until they reach the common or low side of the line. Starting at the top, left side, of the drawing the first break in the circuit is the open contacts of switch SMF2. We will consider the contacts closed because it is standard procedure for the launcher captain to turn this switch to the FIRE position after he has started up the system.

The contacts of SMF1 are also closed. SMF1 is in its normal position because this is a normal firing situation, not an emergency one. This takes us through the first and second steps in the electrical sequence.

1. With the conditions in circuit 3-3A satisfied, the ready-to-fire relay (KCF11) is energized, and this is indicated on the EP2 panel and in Weapons Control.
2. Circuit 2 is closed by Weapons Control by closing the Normal Firing Key. This energizes relay KCF7.

Now let us look at the conditions set in circuit 3B. When the contacts of relay KCY5 are closed, it indicates that the launcher is synchronized with the computer order signals, and the firing key on the weapons assignment console is closed. Again, logical events have taken place. No one in his right mind would give the order to launch a $25,000 missile if he didn't know where the launcher was pointed. But the Navy leaves very little to chance. People do get excited when under stress and then they do some illogical things. Therefore, a "launcher- is-synchronized" interlock circuit is provided. This circuit' 'tells" the firing circuit that the launcher is, or is not, pointing the missile in the proper direction to score a hit.

As we trace further down the page we run into the contacts of KCM2 (blast door closed). On a launcher with two guide arms, the blast doors for both must be closed. Interlock switches, closed when the blast door closes, indicate to the firing circuit and other circuits that the blast door is closed.

There are several obvious reasons for interlocking the blast doors in the firing circuit. If a missile were fired with them open, blast, flame, and hot particles from the booster's jet could enter the missile magazine. The result of this we will leave to your imagination. Also, it is possible for the launcher as it trains and elevates with a missile sticking out from the arm to hit an opened blast door.

The electrically controlled, hydraulically operated fin openers automatically erect the missile control fins before the firing sequence through relays KCU3A and B. A contactor in the right-hand opener housing supplies external electrical power to the missile on the launcher.

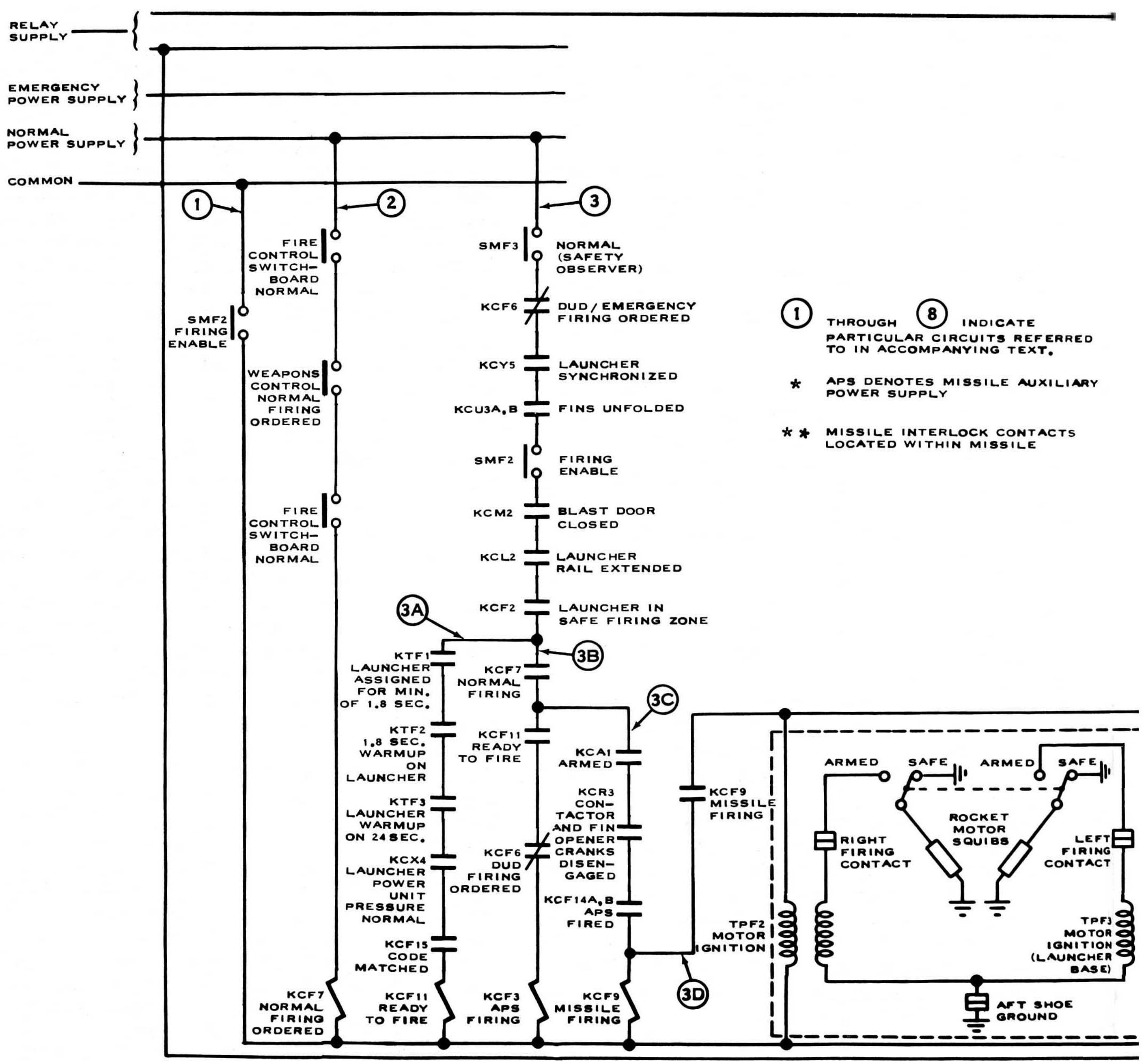
When relay KCF2 energizes, it indicates that the launcher is pointed in a safe firing zone. Closing of the firing key indicates to the firing circuit that a human decision to launch a missile has been made. In other words, there is an "intent-to-launch" present in the firing circuit. Whether this intent will be carried out is up to the missile and various components in the launching system. In fact, as you will soon see, the missile tells the launching system and the weapons direction equipment that the missile is ready to fire.

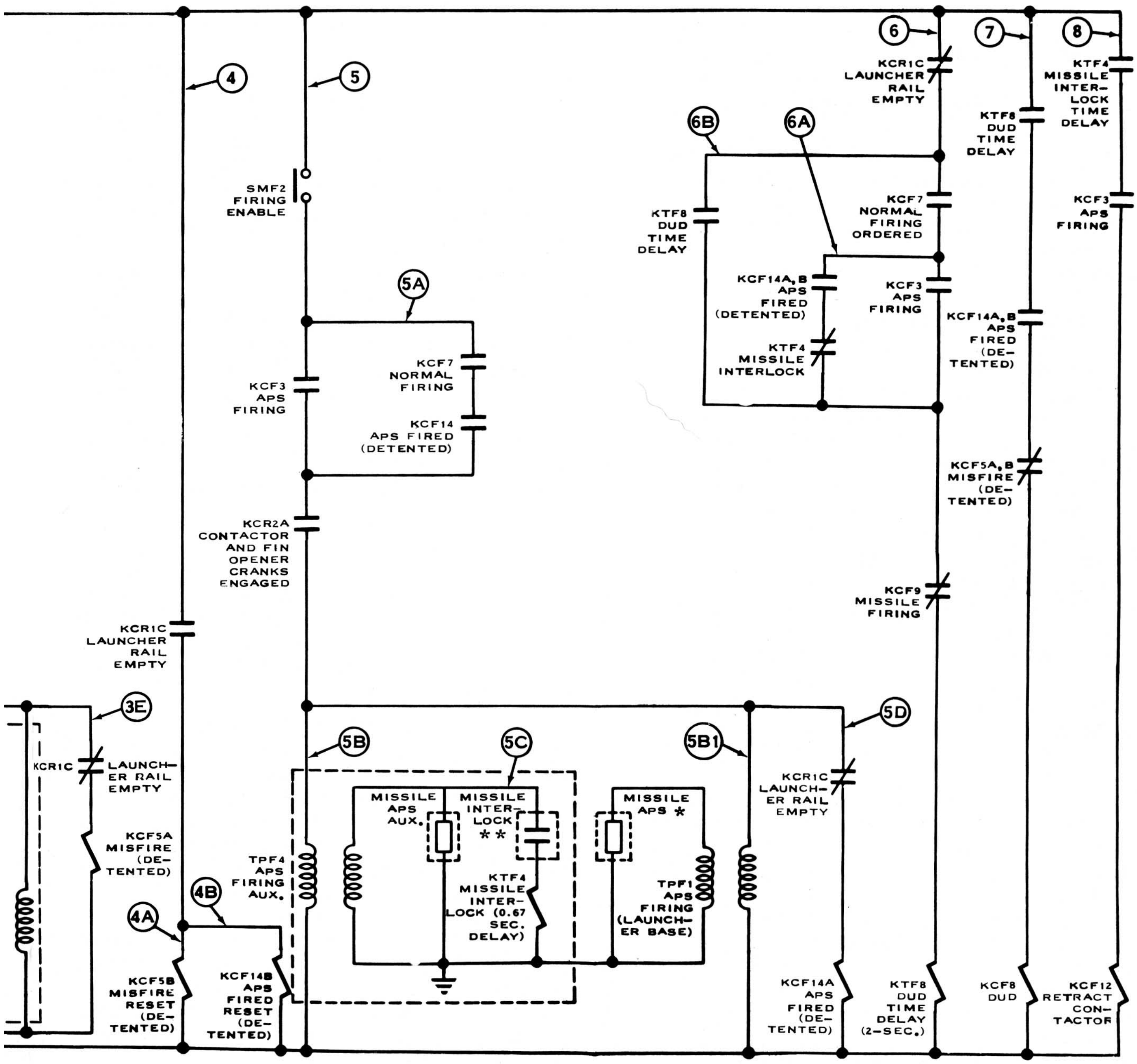
So far, we have traced the circuit up to the ready-to fire point. It is apparent that this part of the circuit is a series circuit. Also, the circuit tells a story about events that happen in the launching system. Notice that the story up to now can be told like this: When SMF2 is positioned at "FIRE", AND SMF1 is on NORMAL, AND KCM2 is energized, AND KCU3A, B and KCL2, and KCY5, are energized, AND KCF2 is energized, there is a complete path for current from the high side of the line to circuit 3B. You can see that in our short summary of circuit operation the connective word AND was used frequently. It was used to connect the description of a series of logical events that must take place before a closed path is available for current to flow from one point to another. This type of circuit is called an AND circuit. It is a term frequently used in the digital computer field and you will hear of it more and more in the missile launching system literature of the future as digital techniques continue to invade your technical area.

This brings us to step 3 in the Tartar firing circuit.

3. With the conditions in circuit 3B satisfied, relay KCF3 is energized, causing four simultaneous operations: firing of the missile APS activation squibs (circuit 5), arming of the missile and releasing the lock for the forward motion latch (circuit 3C), energizing relay KCF14A in the detented position to record that the missile squibs have been fired (circuit 5D), and energizing relay KTF8 (circuit 6) to start timing a 2-second delay. If the rocket motor squibs fail to fire within the 2 seconds, the missile is considered a dud. The dud relay is energized and the dud indications appear on the EP2 panel and in Weapons control.

The Missile Activate relay (Intent-To-Launch (ITL) relay), when energized, indicates to the missile that it should begin getting itself ready to fly. As soon as the launcher is loaded with a missile, the arming tool engages the missile arming lever on the forward shoe. When KCA1


RELAY SUPPLY
EMERGENCY POWER SUPPLY
NORMAL POWER SUPPLY
COMMON
1
2
3
FIRE CONTROL SWITCH-BOARD NORMAL
SMF2 FIRING ENABLE
WEAPONS CONTROL NORMAL FIRING ORDERED
FIRE CONTROL SWITCH-BOARD NORMAL
SMF3 NORMAL (SAFETY OBSERVER)
KCF6 DUD / EMERGENCY FIRING ORDERED
KCY5 LAUNCHER SYNCHRONIZED
KCU3A, B FINS UNFOLDED
SMF2 FIRING ENABLE
KCM2 BLAST DOOR CLOSED
KCL2 LAUNCHER RAIL EXTENDED
KCF2 LAUNCHER IN SAFE FIRING ZONE
3A
3B
KTF1 LAUNCHER ASSIGNED FOR MIN. OF 1.8 SEC.
KTF2 1.8 SEC. WARMUP ON LAUNCHER
KTF3 LAUNCHER WARMUP ON 24 SEC.
KCX4 LAUNCHER POWER UNIT PRESSURE NORMAL
KCF15 CODE MATCHED
KCF7 NORMAL FIRING
KCF11 READY TO FIRE
KCF6 DUD FIRING ORDERED
3C
KCA1 ARMED
KCR3 CON-TACTOR AND FIN OPENER CRANKS DISEN-GAGED
KCF14A, B APS FIRED
3D
KCF9 MISSILE FIRING
TPF2 MOTOR IGNITION
KCF7 NORMAL FIRING ORDERED
KCF11 READY TO FIRE
KCF3 APS FIRING
KCF9 MISSILE FIRING
1 THROUGH 8 INDICATE PARTICULAR CIRCUITS REFERRED TO IN ACCOMPANYING TEXT.
* APS DENOTES MISSILE AUXILIARY POWER SUPPLY
** MISSILE INTERLOCK CONTACTS LOCATED WITHIN MISSILE
ARMED
SAFE
ARMED
SAFE
ROCKET MOTOR SQUIBS
RIGHT FIRING CONTACT
LEFT FIRING CONTACT
TPF3 MOTOR IGNITION (LAUNCHER BASE)
AFT SHOE GROUND



83.188
Figure 9-24. — Normal firing circuit, Mk 13 Launching System (Tartar).

picks up, its normally open contacts in the parallel branch (circuit 3B) close. When contacts for KCR3 (contactor and fin opener cranks disengaged) are closed, then the launcher-to- round contactor is joined with the warmup pad (missile-to-launcher connector) on the top, located between, and aft of, missile fins Nos. 3 and 4. You remember from chapter 3 that while a missile is on the launcher waiting to be fired, the missile receives warmup power and information from sources outside itself. When KCF1 picks up, this tells the missile to get ready to switch from external power and start generating its own power.

When KCF3 picks up, it starts a lot of activity in the missile. The squibs in the missile's APS ignite (Don't confuse these squibs with the rocket motor squib), and the missile begins the power changeover process.

4. If the missile is not a dud (is activated), the firing sequence continues. The missile interlock in circuit 5C is closed which activates relay KTF4 and starts timing the O.67-second delay. This delay permits the weapon seeker head to stabilize along the axis of the missile before contactor retraction is initiated.

5. After the delay, relay KCF12 in circuit 8 is energized to retract the contactor.

6. With the missile activated and armed, and the contactor retracted, it is time to energize the firing relay, KCF9 in circuit 3C. Circuit 3D is closed to ignite the rocket squibs.

When the missile has developed enough internal power to operate efficiently, it shifts to its own power and signals this to the launching system and Weapons Control.

When the missile gives the ready-for-flight signal, the arming tool winds. This winding or rotating action arms the booster firing circuit. Completion of the arming process is indicated by the closed contacts of circuit 3E. If there were no indication to the firing circuit that the booster was armed, it would be possible to attempt to fire an unarmed booster. The Launcher Assignment Console operator would make frantic attempts to fire, but nothing would happen as he repeatedly closed his firing key. Little would he know that the booster firing circuit was open because it failed to arm. But as the circuit stands now, he knows, and the closed contacts of circuit 3E tell him that the booster firing circuit has been armed.

The contacts between the booster squibs and booster shoe firing contacts are closed when the arming tool completes its winding operation. At the end of the arming process, the arming tool and the launcher contactor retract. Now these two devices are clear of the missile and safely housed inside the launcher arm, the contacts are closed, indicating that these two events have taken place.

We assumed in the beginning of our discussion that the launcher was in a clear firing zone. So these contacts are closed. Now there is a clear field ahead for current to flow. The only resistance in its path is the coil of the booster firing relay. Now the coil energizes, and the relay picks up. To the right of the relay you will see a transformer.

When the relay is energized, a sudden surge of current flows through the primaries of both firing transformers. Then, voltage is induced in the secondaries of the firing transformers. This voltage flows through the booster shoe's firing contacts and the closed booster armed contacts to the booster firing squibs. The squibs ignite the booster propellant, and the missile round leaves the rail. (In the Tartar missile, the booster propellant is in the center of the DTRM.)

It takes only a fraction of a second for the burning propellant to build up sufficient thrust (about 2300 lbs) to overcome the restraining force of the forward motion latch and send off the missile. When the missile has left the launcher, the rail-clear lights on the EP2 panel and in Weapons Control go on.

If there is any failure, the sequence stops and appropriate action m"-1st be initiated. If the missile is a dud, it may be returned to the magazine or it may be dud fired. If it is a misfire (The APS squibs fire but the rocket motor fails to ignite.), the missile must be handled as determined by ship's doctrine.

Loss of launcher synchronization will break the firing sequence. This may occur while clearing the blind zone. If synchronization is regained in a short time, the firing operation resumes where it left off but, if the loss of synchronization is for an extended period of time, it may be necessary to fire the missile. The decision will be made by Weapons Control.

Several times we have "back-tracked" to take up the details of a portion of the complete circuit. The sequence of action is similar in different firing systems, but some may have more switches and relays than others. If you have a good concept of order of action, you can follow the action on any circuit.

SAFETY

Probably more deaths occur from electrical shock than from anyone type of accident aboard ship. Preventing electric shock necessitates strict compliance with all safety requirements for the various work areas and strict' adherence to all prescribed safety precautions for the type of job concerned.

Current flow through the body is the cause of electrical shock. Factors determining the extent of the body damage due to electrical shock are the amount and duration of the current flow, the parts of the body involved, and the frequency of the current if a-c. In general, the greater the current or the longer the current flows, the greater will be the body damage. Body damage is also greatest when current flow is through or near nerve centers and vital organs. Sixty- hertz current is considered slightly more dangerous than current of lower frequency or d-c. This difference is small, however, and the same precautions that apply to 60-hertz a-c also apply to d-c.

Men differ in their resistance to electric shock. Consequently, a current flow that may cause only a painful shock to one man might be fatal to another. After an accident has happened, investigation almost invariably shows that it could have been prevented by the exercise of simple safety precautions which are then posted for future guidance, but which never undo the consequences of the accident that has gone before. Always observe safety precautions and keep accidents from happening.

Always remember that:

1. Electricity strikes without warning.
2. Hurrying reduces caution and invites accidents.
3. Taking time to be careful saves time in the end.
4. Taking chances is an open invitation to trouble.
5. If you do not know the safe way, it pays to find out before exposing yourself to danger.
6. Every electrical circuit, with but insignificant exceptions which definitely do not include circuits even as low as 35 volts and possibly even lower, is a potential source of danger and must be treated as such.
7. Except in cases of emergency, never work on an energized circuit. It must be considered that the circuit is energized until a personal check has been made to see that the switch is opened and tagged, and the circuit has been tested with a voltmeter, or voltage tester.

The following additional safety precautions should be helpful to you in avoiding injury to yourself and to others and in preventing damage or loss of equipment.

Always have one person available who is familiar with first aid procedures for electrical shock. See OP 2645 for first aid instructions.

Before undertaking maintenance work on launching system components, except where power-on condition is needed, position power-transfer device to OF F. This cuts off the 440- volt power source.

When working on live circuits, exercise as much care to avoid contact with low voltages as with high voltages. Assign the responsibility of energizing the equipment to a qualified operator.

Avoid unnecessary disassembly or adjustment of equipment. And when disassembling or adjusting equipment, follow instructions given explicitly.

When such items as switches, relays and solenoid coils malfunction, do not attempt to repair them. Simply replace the faulty unit with a functional spare.

Before performing work on electrical components, check yourself-wear no articles that might catch on equipment or act as a conductor.

Check the working area-be sure the deck is clean and dry; if possible, stand on a special insulator such as a rubber mat.

Check procedures - study the entire procedure before taking the first step; consult circuit diagrams frequently; know what is in the equipment.

Be aware that high voltages may be present (because of equipment breakdown) across terminals that are normally low voltage.

In general, use only one hand when servicing live equipment.