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CHAPTER 7

APPLICATIONS OF SERVOMECHANISMS

Servomechanisms, called servos for short, are the basic building blocks of power drives. In this manual what we mean by a power drive is an electric or electrohydraulic machine which positions a launcher or other device in accordance with a relatively weak electrical signal. We will consider a power drive as a big servo made up of smaller ones.

First we will define a servo and talk about its characteristics. Then we will describe some of the devices used in servos. Then we will put these devices together to form a basic power drive. And finally, we will cover some techniques used to make power drives more accurate.

The principles of servomechanisms are discussed in your basic text, Synchro, Servo, and Gyro Fundamentals, NavPers 10105. The uses of servos in missiles and missile launching systems concerns us most in this chapter. The review material will serve to relate the principles to the missile applications.

WHAT IS A SERVO?

Figure 7 -1 shows a block diagram of an elementary servo. It consists of two blocks and some connecting lines. If you are not familiar with it already, study the diagram carefully and memorize it. From this simple concept of a servo will spring one of the most important ideas you will ever encounter in your naval career as a technician - the feedback principle. Not only is feedback important in understanding servos, but it also has important applications in the electronic and hydraulic fields. Therefore, if you know how feedback is used in servos, you can better understand how it is used in electronics and hydraulics.

At this writing there is no standard definition of a servo. (Chapter 4 quotes one definition.) For the purpose of this chapter, we will call a servo any electrical, electronic, mechanical, or hydraulic system which uses feedback. But a rigorous definition is relatively unimportant. What is important is that you know what makes a group of parts a servo. Regardless of their physical form - electric, electronic, mechanical, hydraulic, or combinations of these - all servos have the following characteristics.

A SERVO IS A CONTROL DEVICE. - The basic job of the servo in figure 7-1 is to position a load. The load can be a launcher guide or carriage, a rammer, a hydraulic valve or piston, a dial, an electric motor, a mechanical linkage, etc. The load is attached in some manner to the output of the servo. Consider a launcher guide. Its position is controlled in accordance with launcher train and elevation orders which are inputs to the servo.

A SERVO IS A POWER AMPLIFIER. - The input to a servo is usually a very small signal. It is too weak to move the load by itself, so some sort of power amplification must take place within the servo. Again take as an example a servo used to position a launcher guide. The input to the servo is sometimes so small it can be measured with a milliammeter. To develop enough power to move the great weight of a guide arm requires currents in the ampere range. Therefore, every power drive you will work with has one or more amplifying stages in it. The amplifier may be electrical, electronic, hydraulic, or one or more of these types of amplifiers in combination.

A SERVO IS A CLOSED LOOP SYSTEM. - A servo is called a closed loop system because it uses feedback. Feedback is a principle upon which the operation of all servos is based. Look again at figure 7-1. You can see that the feedback line runs from the output to the block marked error detector. This feedback is a communication channel which reports the condition (speed, position) of the output back to the error detector. To see how feedback works,

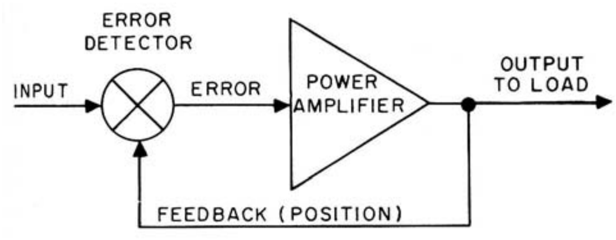

Figure 7-1.—Elementary servo in its simplest form: block diagram.

assume the input is a mechanical signal telling the output to move to a certain position. If the output is not at the ordered position, the feedback signal reports the position of the output to the error detector. The error detector measures the difference between the ordered position (input) and the actual position of the output. Also, the error detector performs a simple mathematical operation: it subtracts the output from the input to get the amount of difference, or error, as it is called. Thus the error is the actual input to the amplifier, not the quantity marked input.

Also notice that when the feedback equals the input, the error signal is zero and no signal is given to the servo. But whenever the feedback differs from the input, an error signal is developed. The error signal drives the output in such a manner as to reduce the error signal.

Since the principle of feedback is used in servos, they are often called closed loop systems or servo loops. Keep in mind that feedback can be transmitted electrically, hydraulically, or mechanically in a servo. Feedback is also called response by many technicians. When the feedback line defines the position of the servo's output shaft or its load, the feedback is called position feedback.

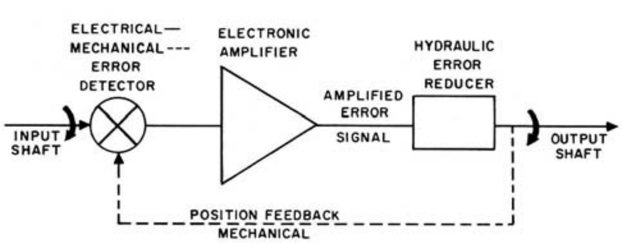

Figure 7-2.—Elementary electromechanical servo.

A SERVO IS AN ENTIRE SYSTEM. - It cannot consist of a single component. It must have the minimum number of components we have shown in the block diagram in figure 7-1. There is no law against a servo having more sections than the ones we have shown. And they usually do. But regardless of the number of parts in a servo, they all work together as a system or team. And this system concept is important. A servo is not an isolated motor or power amplifier, but must be considered as an entire system of interconnected components. Together, these components measure, transmit, compare, amplify, and control quantities.

EXPANDED VERSION OF A SERVO

So far, we have talked about the essential elements in servos, the "bare bones" of a servo, so to speak. We reduced a servo to its minimum number of functional blocks and still made it work. But this compressed view of a servo does not allow us room to expand the discussion of its operation. So we will expand our servo horizon by increasing the number of working blocks from two to three and then discuss each in turn.

Figure 7-2 is a block diagram of the elementary servo shown in figure 7-1. Instead of two functional blocks, there are three. Each is labeled with a name that aptly describes the block's function.

Our new block diagram of an elementary servo differs from the previous one in that the power amplifier has been divided into two parts: an AMPLIFIER and an ERROR REDUCER. The amplifier increases the weak error signal, and it controls the error reducer. We have coined the term error reducer because the name closely describes the function of this servo section, which is to drive the output of the servo until it is equal to the input, thus reducing the error toward zero. Keep in mind that there can never be zero error. The error reducer must receive an error signal before it can control the output. However, the error signal should be kept as small as possible.

Also notice that we have identified each part in the servo as either electrical, mechanical, electronic, or electromechanical. The input, output, and feedback devices are mechanical shafting; the error detector is an electric-mechanical device; the amplifier is an electronic type; and the error reducer is an electrohydraulic unit.

Earlier, we described a servo as any device that uses the principle of feedback. It can also be defined as a mechanism whose output faithfully tries to reproduce its input. Let's look at how the servo blocked out in figure 7-2 works, based upon this point of view. Assume the input shaft and the output shaft are at the same position. When this is so, there is no error between them and so there will be no error signal to the amplifier. Therefore, the error reducer will not receive a correcting signal and the servo will not move. But if the input shaft is suddenly turned to a new position, there will be an instantaneous angular difference between the positions of input and output shafts. Where is this difference discovered (detected) and measured? The answer is, of course: at the error detector. The input and feedback shafts are both inputs to the error detecting device, which, as we said before, is an electromechanical device. Since the feedback shaft is geared to the output shaft, the feedback shaft duplicates any position and motion of the output shaft. In other words, knowledge of what the output shaft is doing is fed back over the feedback line to the error detector. Here, the positions of the input shaft and output shaft are compared. The error detector measures any difference between them and then it does something more. It transforms (changes) mechanical position error into an electrical error signal. The electrical error output of the error detector is directly proportional to the angular difference between the input and output shafts.

The electrical error signal is relatively weak. So, it must be amplified. This may be done by a vacuum - tube amplifier, a magnetic amplifier, or a combination of these. After it is amplified, the error signal is sent to the error reducer. Here, it is changed from its electrical form to a proportional hydraulic signal. Now the error reducer drives the output shaft in a direction which reduces the error between the output and input shafts. As the output shaft turns, so does the feedback line. But it turns in a direction that reduces the angular difference between the input and output shafts. When the output and input shafts are in agreement, the output of the error detector is zero. The amplifier "sees" no signal and its input, and the servo stops.

Now if we turn the input shaft at a constant velocity, the output shaft should turn to the same position as the input shaft, and follow it at the same speed and in the same direction. If the input shaft were to speed up, then reverse its direction, the output shaft should faithfully reproduce these mechanical gymnastics; and all the while the two shafts should remain closely aligned. If at any time they do not, then the error detector will produce an error signal. This signal is amplified and sent to the error reducer. It then drives the output shaft until the error between the input and output shafts is as nearly zero as possible. When this condition exists, the servo is said to be "nulled." Other terms that describe zero or nearly zero error are: synchronized, in synchronism, or in correspondence.

COMPONENTS OF A LAUNCHER POWER DRIVE

To understand power drive operation, you must have background knowledge of servos. In the preceding pages of this chapter we have given you a general idea of the functional sections and what they do. You learned that the input is the controlling quantity. We described it as the displacement of a shaft. In practical servos or power drives the input is generally an electrical quantity which represents a shaft position. The servo error is the difference between the input and output of the servo. The error detector is the device which compares the input with the servo output. The error reducer is essentially the prime mover of the servo. It is controlled by the amplifier section, which simply increases the size of the error signal so that it is strong enough to actuate some device in the error reducer. The load mentioned earlier, strictly speaking, is not a component of the servo. However, load characteristics (size, weight, etc.) have an important bearing on the design and operation of the servo.

Now we will discuss some of the components that make up each block of a power drive. We'll start off with the error detector, and synchro data transmission.

ERROR DETECTOR

In the operation of automatically controlled equipment such as launcher power drives, it is necessary to have angular motion of a shaft follow accurately the motion of another shaft some distance away. In earlier chapters of this book you learned that launchers are normally controlled by launcher order signals that originate in fire control computers. These orders are transmitted over synchro data transmission circuits. Figure 7-3 shows a typical launcher train order synchro system. The system contains a synchro transmitter (CX) which is inside the fire control computer, and a control transformer (CT) located at the launcher. These two units, together with their connecting wires, are called a synchro data-transmittion system. Synchro systems are described in Synchro, Servo and Gyro Fundamentals, NavPers 10105, so we won't cover their basic operating principles here. But we will see how a synchro system is used in launcher power drives. The synchro transmitter changes the movement of its rotor shaft into equivalent electrical signals. These signals represent the position of the rotor shaft and are sent over the three stator wires to the synchro control transformer. The CT has a dual role in this particular circuit arrangement: It acts as an error detector and also as a receiver. Because this unit is the heart of most servos, and especially of power drives, we should closely examine its purpose.

Control Transformer

Look at the block diagram shown in figure 7-3 and you will see the major components in a launcher power drive. Take particular notice of the control transformer. The synchro transmitter in the fire control computer supplies launcher position order to the control transformer. The CT compares the orders with the actual position of the launcher, and determines the error. The electrical error signal is fed

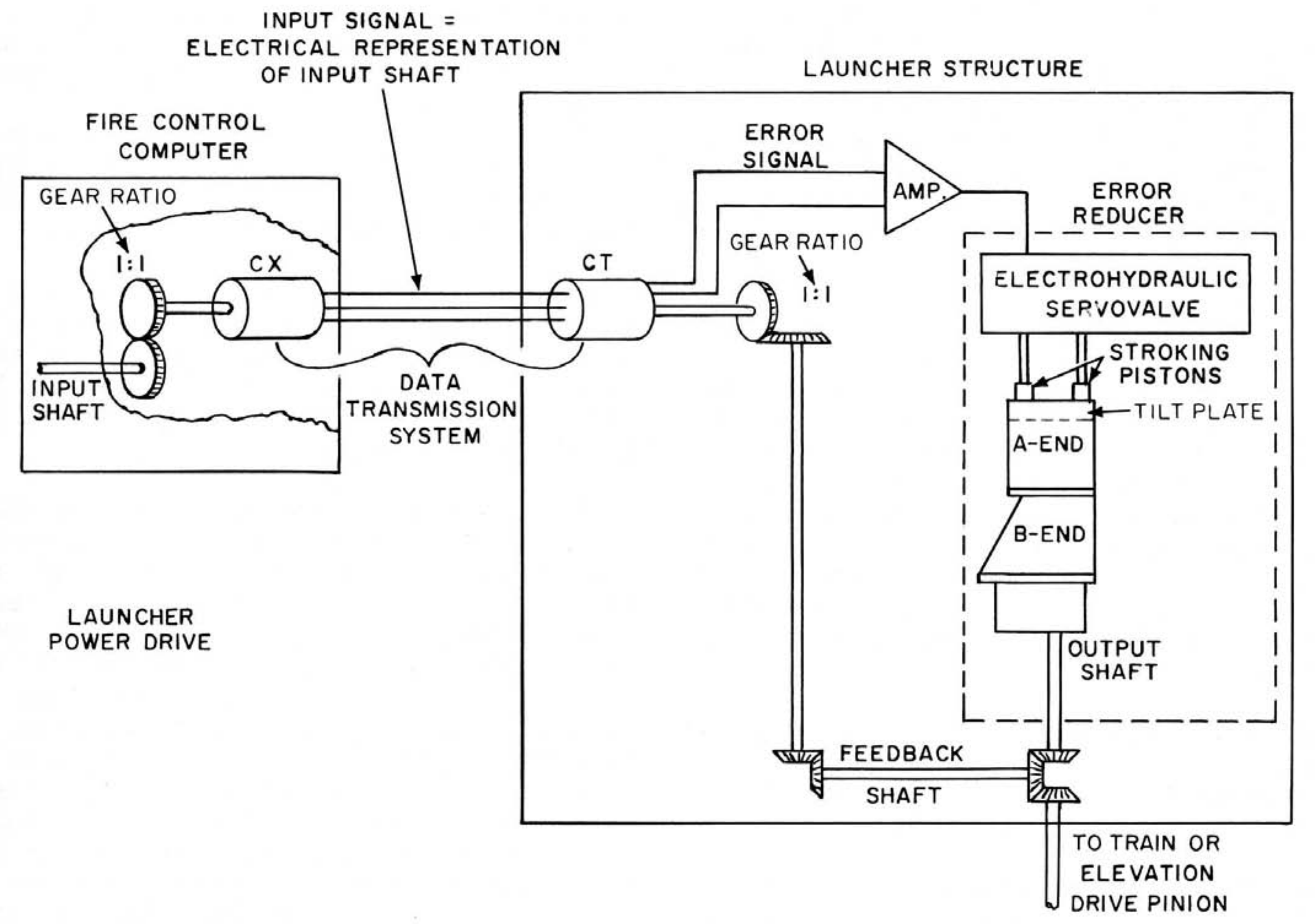

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Figure 7-3.—Typical synchro data transmission system (train or elevation launcher orders).

to the electronic amplifier. The amplifier amplifies the input from the CT and applies the amplified error signal to an electrohydraulic servovalve. The servovalve converts the electrical error signal to a proportional hydraulic signal. The hydraulic output of the servovalve flows to the A-end stroking pistons. The stroking pistons move the A-end tilt plate off neutral, and the A-end pumps fluid to the B-end. The B-end then turns and supplies a mechanical output which trains or elevates the launcher in the direction indicated by the error signal. Any B-end output (drive shaft rotation) is transmitted through feedback $hafting to the CT rotor. This feedback completes the servoloop. When the launcher train or elevation position agrees with its position order, the synchro rotor will be in a position which produces minimum output voltage across its rotor leads (R1 and R2).

We will not cover synchro transmitters and control transformers here because they are treated in detail in the Military Standardization Handbook (Synchros), MIL-HDBK-225 (AS) and in the basic training manual Synchro, Servo and Gyro Fundamentals, NavPers 10105. If you need a review about how synchro transmitters and control transformers work, individually or as a team, you should read the texts listed above before continuing this present chapter. Here we will present additional or amplifying information about CTs and synchro systems that is not included in the previously mentioned courses.

Synchro Errors

A perfect synchro has never been made. Synchros will always contain some errors due to manufacturing inaccuracies and assembly. As you know, for every physical position of a synchro rotor there is a corresponding electrical position. For example, if you put the rotor of a perfect synchro transmitter at 30°, as shown in figure 7-4A, the voltages you will read across the stator terminals will be as follows:

S1 to S2 - 90 volts and 180° out of phase with R1-R2.
S1 to S3 - 45 volts and in phase with R1-R2.
S2 to S3 - 45 volts and in phase with R1-R2.

These stator voltages and phase relationships are unique for 30° rotor position. (See fig. 7-4B.) You won't get these quantities at any other position of the rotor. But, as we said before, synchros are not perfect. Any difference between the actual physical position of the rotor and the electrical position is known as electrical error. (Sometimes the electrical error is called static accuracy.) It is possible to get the voltage readings and phase relationships listed above when the rotor of a real synchro is at, say, 30° and 18 minutes. Therefore the synchro has an electrical error of 18 minutes. This is a typical error for a control transformer. The electrical error for synchro transmitters can be that high, but usually it is in the order of 8 to 15 minutes.

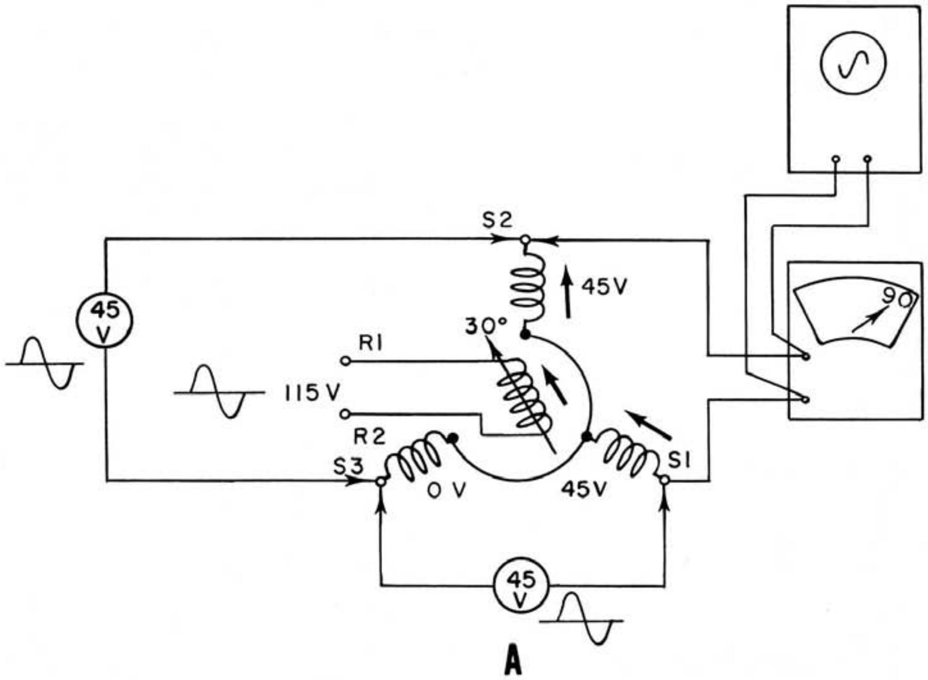
Consider a practical synchro system consisting of a control transformer and transmitter like the system shown in figure 7-3. If both units have an electrical error of 18 minutes, the total possible electrical error is 36 minutes, or a little over half a degree.

What can cause errors in synchros? Briefly, here are some of the causes:

1. It is impossible to make the three stator windings the same. Each winding could have a different number of turns, for example.
2. The rotor and stator assemblies must be exactly round. If they are slightly elliptical, an electrical error results.
3. The rotor of a synchro must be put in the exact center of the stator bore. If the rotor is off center by just a small fraction of an inch, then there will be an electrical error.

A servo is only as accurate as its error detector. If there are electrical errors in the servo's data transmission system, the servo output will reflect the electrical error. Now let's see how electrical errors show up in a simple synchro system.

The pictorial diagram in figure 7- 5A shows a synchro transmitter and control transformer connected in the conventional way. We will assume it is a perfect system. It has no electrical error. Both units are perfect. Notice particularly that all gear ratios are 1:1. That is, if we turn the transmitter handcrank one revolution, the transmitter rotor will turn one revolution (360°). Similarly, if you turn the CT's handcrank one revolution, the control transformer rotor will turn one revolution. Furthermore, assume that the dials on both rotor gear faces are so accurate that we can read angular position of the respective rotor in minutes of arc as well as degrees of rotor angular position.



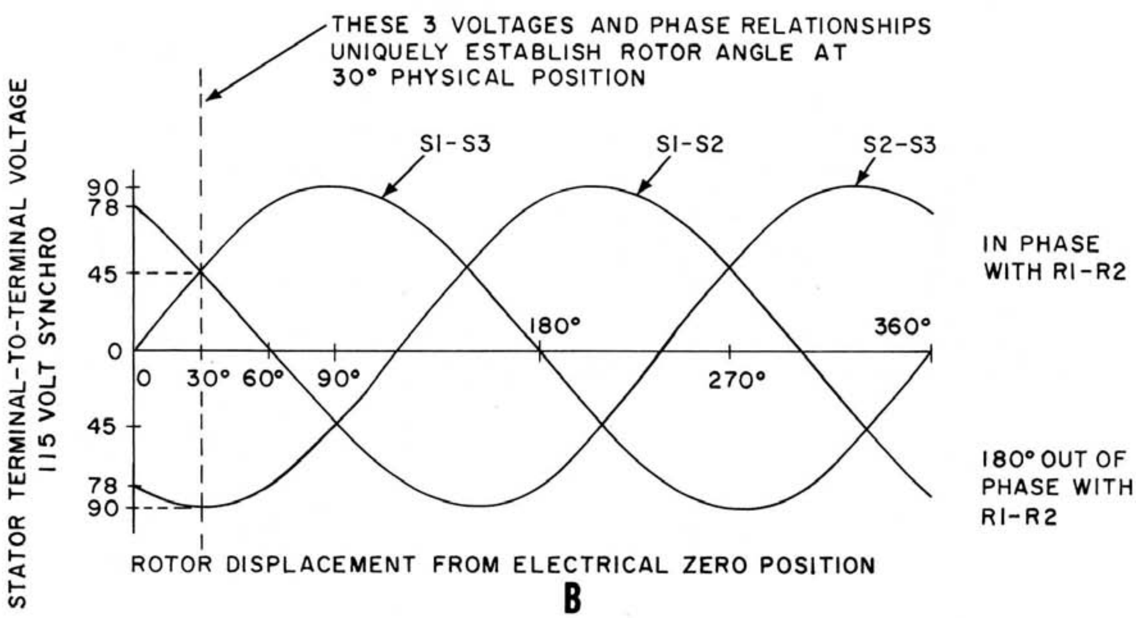


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Figure 7-4. — Synchro electrical error: A. A perfect synchro transmitter at 30°; B. "Error" or rotor displacement from electrical zero position.

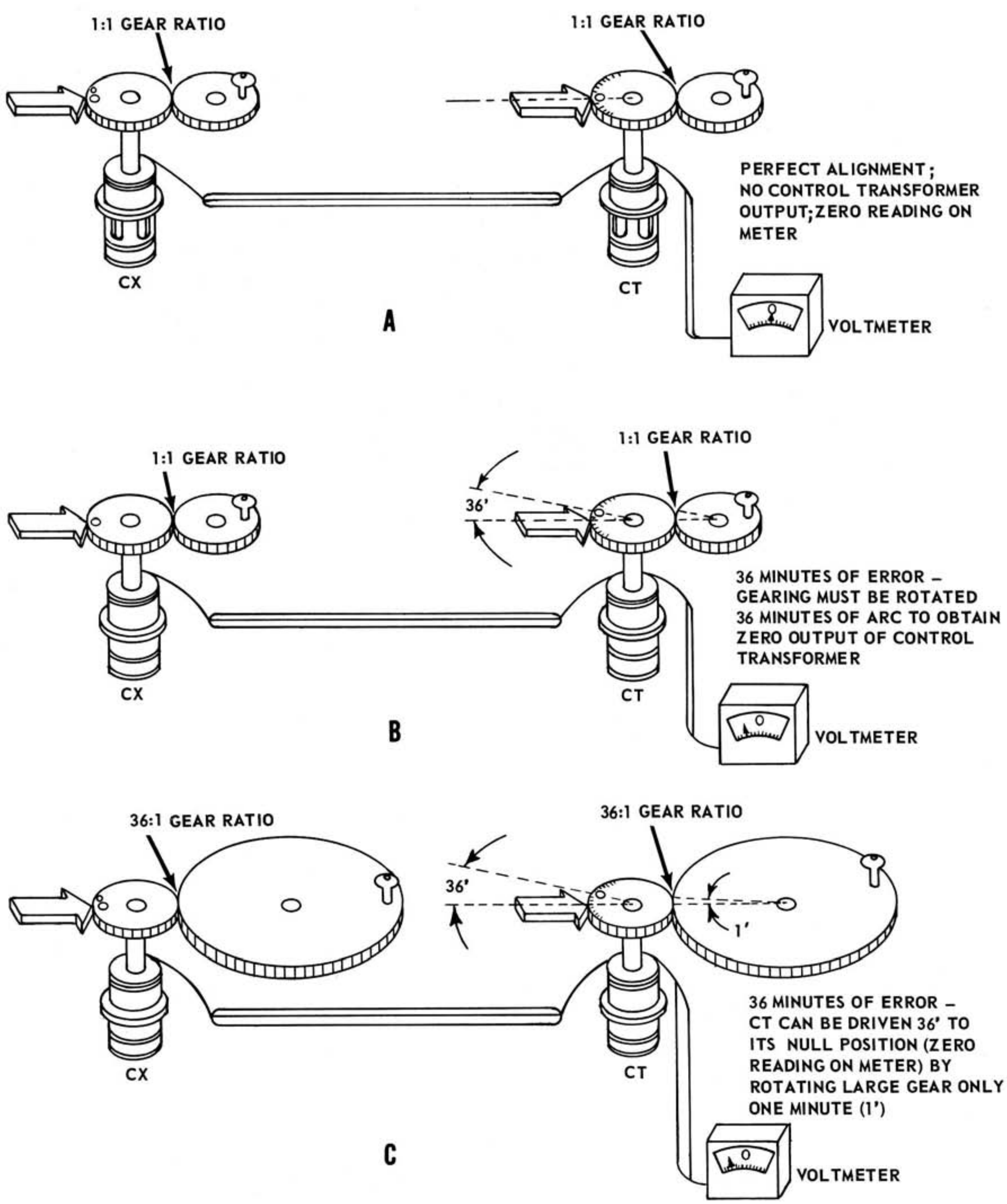

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Figure 7-5.—Electrical error in a synchro system: A. A perfect synchro transmitter connected to a perfect control transformer; B. Synchro transmitter and control transformer each with electrical error of 18 minutes; C. "Fine" synchro system using 36:1 gear ratio to reduce error.

Since we have a perfect system, if we put the rotor of the transmitter on zero, and then turn the crank at the CT end of the system, a voltmeter connected across the CT R1-R2 leads will read zero when the CT dial reads zero. If we turn the rotor of the transmitter to 5°, as read on the CX rotor dial, and then turn the control transformer handcrank until the voltmeter reads zero volts, a glance at the CT dial will show that it reads exactly 5 degrees. You can repeat this experiment for every position of the dial and the result will be that the transmitter rotor is at a selected position, the CT rotor will be at the same position when the voltmeter reads zero. In other words, we have perfect transmission of data.

But now look what happens when we use actual synchro units in the system. Assume that the synchro system contains an accumulated electrical error of, say, 36 minutes. The pictorial diagram in figure 7-5B shows the same setup as we had before. But instead of perfect synchros, we have replaced them with ones that have an electrical error of 18 minutes apiece. If we put the dial of the transmitter at zero, we will transmit what we think is an electrical signal proportional to zero degrees. But to get a null (minimum or zero reading of the voltmeter), the CT rotor must turn through an angle of 36 minutes. At null it is obvious that the two rotors are not in the same angular position. The transmitter rotor is at its zero position and the control transformer rotor is 36 minutes away from zero. Now turn back to figure 7-3. Assume that the data transmission system shown there also has a 36 minute electrical error. If the launcher order computing section in the missile fire control computer turned the CX rotor shaft to the position corresponding to zero launcher train order, the power drive servo would position the launcher at zero degrees and 36 minutes. The launcher is certainly not at the ordered position. It is close to it, maybe, but it is not exactly on. For this reason the system we are talking about here is called a COARSE system. It transmits approximate angular position information because the system contains electrical error. But launcher power drives must receive very accurate aiming information so that the launcher guide can be pointed in the right direction. Therefore, an additional synchro system, called the FINE system, is used along with the coarse system.

Operation of a FINE
Synchro System

To show how a fine system works we can make one out of the coarse system we've just talked about simply by changing gear ratios.

In figure 7-5C we have done just that. Instead of a 1:1 gear ratio between the synchro rotors and their handcranks we have installed gears with a ratio of 36:1. If we turn either handcrank one revolution, its associated rotor will turn 36 times. Also, it follows that if we turn either crank one minute, then the rotor geared to the crank will turn through 36 minutes of arc. Now mentally place both dials at zero. Assume that we have a 36 minute electrical error in the synchro system. With the increased gear ratio, we have to move the control transformer handcrank only one minute to null the voltmeter, even though we have a 36 minute error in the system. So, by increasing the gear ratio we have reduced the effect of the error 36 times. Remember, in an identical situation using a coarse (1:1 ratio) system we had to move the CT rotor 36 minutes to get system null.

In the preceding discussion about synchro system electrical error we have taken the part of a servo. We manually turned the CT handcrank which moved the CT rotor until we saw a zero reading on the meter dial. Now let's replace the human operator with a servo and show how increased gear ratios improve the accuracy of the synchro system and its associated servo. The diagram in figure 7-6 shows a launcher power drive servo controlled by a fine synchro system. Assume there is a 36 minute accumulative error in the synchro system. If we put the input shaft (CX rotor shaft) at its ZERO physical position and the launcher at its zero position, the servo will drive the launcher through a ONE minute angle. But, because of the 36:1 stepped-up gear ratio between the launcher and the CT's rotor, the rotor of the CT will turn 36 minutes, canceling out the 36 minute electrical error. At this point, the voltage at the amplifier input is zero, and the servo stops. The important point is that the launcher has moved only one minute even though the error in the synchro transmission system is 36 minutes. Or, you can say the angular position between the input and output of the system (data transmission system and servo) is one minute. If we had used a coarse transmission system with a 1:1 gear

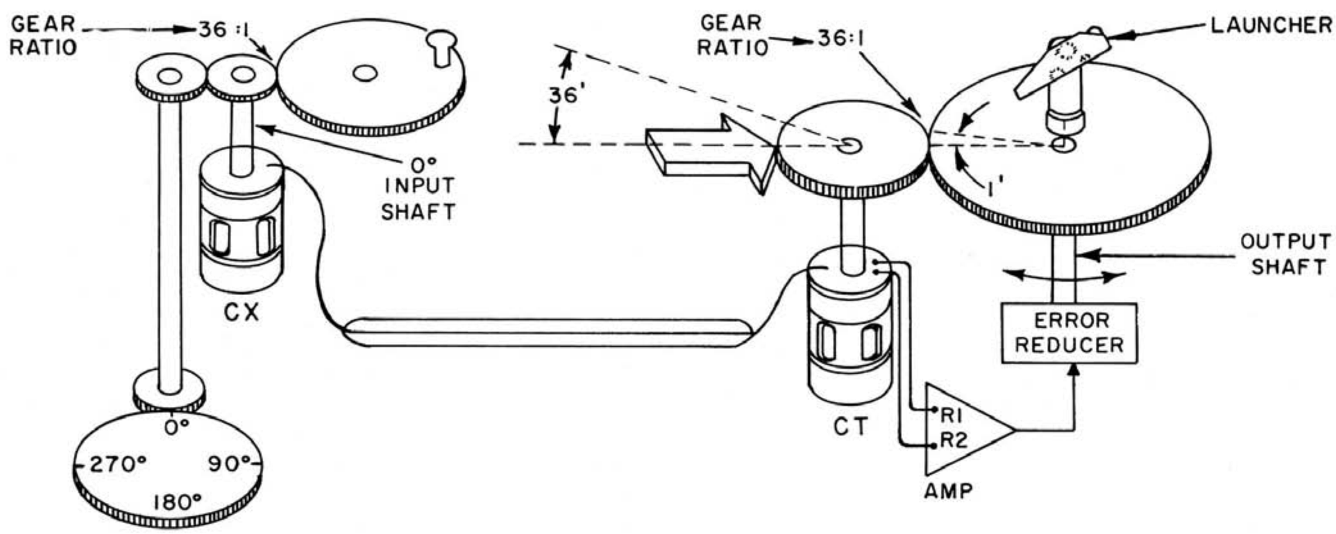

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Figure 7-6.—Launcher power drive using a fine synchro system.

ratio, the difference between the input shaft and the output shaft would have been 36 minutes when the servo stopped driving the launcher.

DISADVANTAGES OF 36:1 SYNCHRO TRANSMISSION

The main disadvantage of the 36:1 transmission is that the servo is no longer self-synchronous. In the 1:1 transmission system the output shaft is synchronized with the input shaft at only one point. In other words, there is only one position the output shaft can assume which will allow correspondence between the rotors of the CT and the transmitter. However, in the 36:1 transmission system the output shaft can be in correspondence at 36 different positions for any one position of the input shaft. For example, if the rotor of the transmitter is at 0° (see fig. 7-7), the output shaft, and consequently the launcher, could be synchronized at 0°, at 10°, at 20°, and so on, in steps of 10 degrees. In each of these positions of the output shaft, the position of the control transformer is stepped up 36 times so that it is an integral multiple of 360°, thus bringing the CT into false correspondence with the transmitter in each case.

Combining the Fine and Coarse Systems

Although the fine system provides high accuracy in a power drive servo, it is never used by itself, since, as you have seen, it does not provide true synchronization of the input and output at all times. We certainly would not want a launcher pointed at 80 degrees, when the synchro transmitter rotor shaft was at, say, 10 degrees. Therefore, the fine system is always combined with a coarse system. The fine synchro system provides a very sensitive control at times when the error between the order signal and the servo output is small. Since this is a 36-speed synchro, however, it can bring the launcher to anyone of 36 positions. It is the job of the coarse synchro system to bring the launcher close enough to the true synchronous position so that it is within the range of the fine synchro.

Therefore, you must have some way for the coarse synchro to take control and drive the launcher into correspondence whenever the error exceeds a certain amount - in most cases about 2 degrees. The circuits that accomplish this have many names. Some of these are:

1. Synchro changeover network or circuit.
2. Synchro crossover network.
3. Synchronizing circuit.

Figure 7-8 shows where these circuits are located in a typical power drive servo.

Since a switching function is called for in these circuits, what more perfect devices could be used than relays and diodes.

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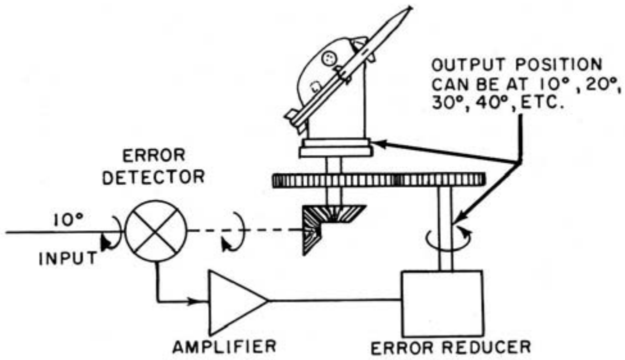

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Figure 7-7.—Fine synchro system (36:1 gear ratio) causes launcher to synchronize at any multiple of 10 degrees.

Figure 7-9 shows a schematic of a typical synchronizing network which uses a relay to switch the fine and coarse synchro control signal inputs to the servoamplifier. Follow the two signal paths from their control transformers to the amplifier. Notice that both signal circuits are opened and closed at the contacts controlled by the relay.

Start out by tracing the fine signal from the fine CT to the servoamplifier. In figure 7-9 it looks as if the fine signal isn't going anywhere. However, the relay coil pulls the contact arm down. This closes the upper contact, and the fine signal is fed directly to the servoamplifier. You may be wondering how the relay was energized to pull the arm down.

Before you can answer that, you'll have to remember what you've learned about the operation of a triode tube. You will recall that the potential on the control grid determines whether or not the tube will pass current. With a strong negative potential on the grid, the tube has a high resistance, and very little current passes. With a weak negative potential on the grid, the tube has a low resistance, and current flows across the tube whenever the plate goes positive. The grid potential is developed across R2. It is this voltage across R2 that determines whether or not the tubes will pass current.

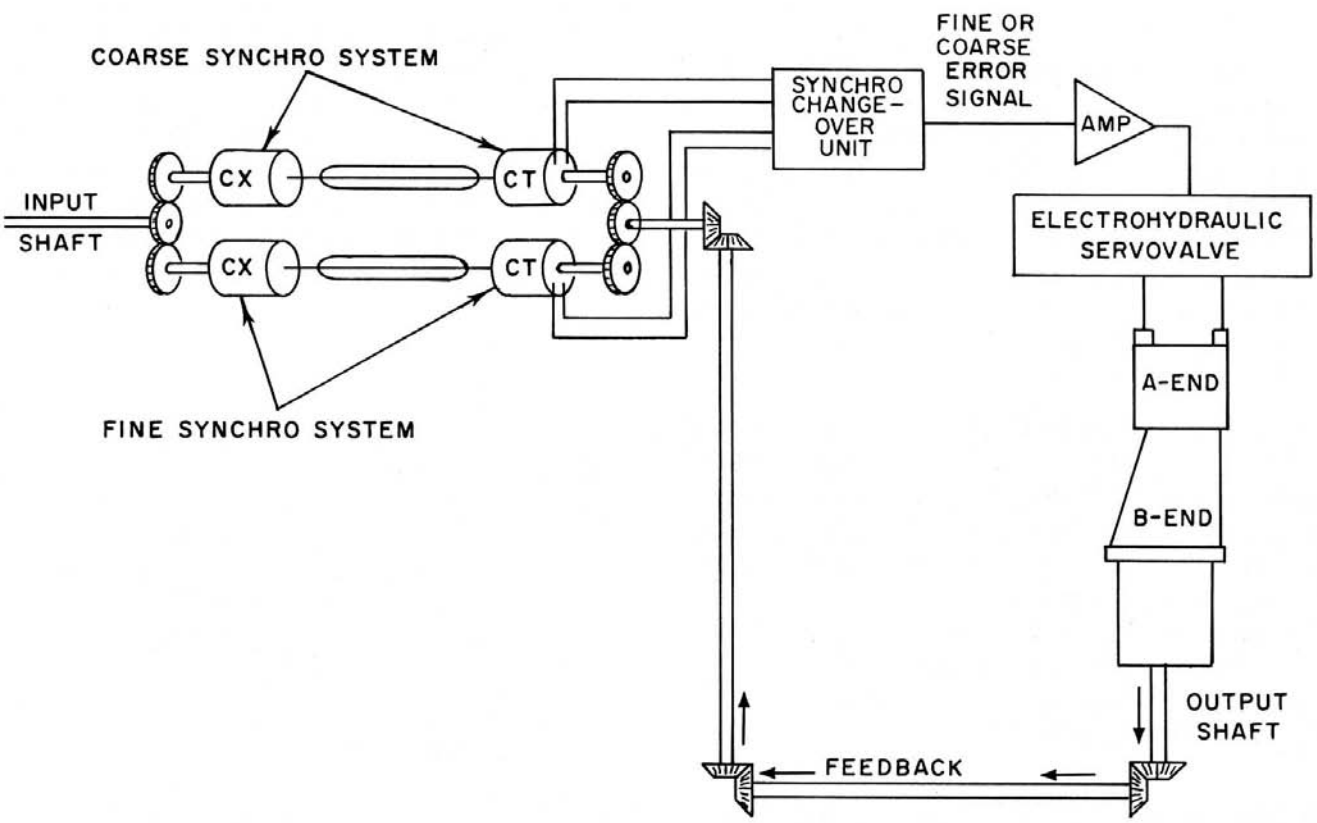

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Figure 7-8.—Location of synchro changeover network in a power drive servo.

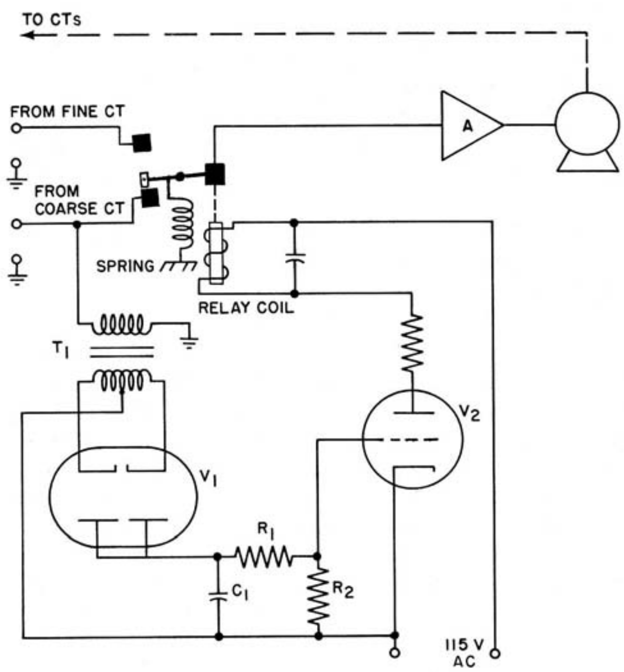

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Figure 7-9.—Relay synchro changeover circuit.

Now trace the coarse signal circuit. The coarse signal appears across the primary of the transformer, TI. The secondary voltage of TI goes to VI for full-wave rectification. The rectified output of VI is filtered by RI-R2 and CI. Part of the rectified and filtered coarse signal is developed across R2, making the top of R2 negative. Thus the coarse signal controls the grid bias of V2.

When the coarse signal is small, the bias at R2 is small; V2 conducts current on every positive alternation of the supply voltage. This current flows out of the V2 plate, through the relay coil, and back to the source of supply. Then the relay pulls the contact arm down and closes the upper contacts. The fine signal goes to the amplifier. The capacitor in parallel with the relay keeps the relay operated during negative alternations of the supply voltage.

When the coarse signal is large, the bias at R2 is large and V2 conducts very little current. With very little current through V2, the relay coil releases the contact arm and opens the fine signal circuit. Then the spring pulls the contact arm down and closes the lower contacts. The coarse signal is then fed to the servoamplifier.

(If you've forgotten the meaning of any of the electrical symbols used in figure 7-9 and other figures, review the basic texts referred to previously.)

OTHER SYNCHRONIZING NETWORKS. - There are many variations of the circuit just described, but they all operate in much the same manner.

The semiconductor diode synchronizing network is fairly common, so let's take a look at another circuit using this technique. This circuit is illustrated in figure 7-10. Within a range of approximately 2° on either side of the synchronizing point, the coarse signal is effectively blocked because of the high impedance of the series diodes, CR3, CR4, CR5, and CR6. With the coarse signal blocked, the fine signal is fed into the summing network and is in control of the servo. However, this signal is limited to a very low voltage by the parallel diodes, CR1 and C R2.

Both the fine and coarse voltage inputs will increase as the error in correspondence is increased. Remember that the resistance of the diode rectifier decreases with an increase in current flow across it. CR1 and C R2 develop the fine signal. A point will be reached (about 3° error) when CR1 and CR2 will be incapable of dropping a voltage greater than the coarse voltage. Any increase in current gives us a decrease in resistance and a decrease in the fine voltage output to the summing network.

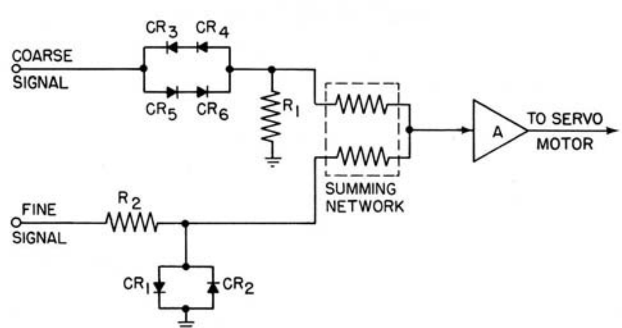

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Figure 7-10.—Semiconductor diode synchro changeover network.

Now let us look at the coarse signal. In figure 7-10 you will notice that the coarse signal is developed across R1. Also notice that the diode network of CR3, CR4, CR5, and CR6 is in series with R1. Errors in correspondence which are less than 2° will cause some current to flow across R1 and the diode network. However, this current is small and will cause the diode network's resistance to be high. Therefore, most of the coarse signal voltage is dropped across the diode network and very little voltage is developed by R1. In this condition the resultant voltage in the summing network is predominantly from the fine synchro. As we get further out of synchro correspondence, the current through the coarse signal diode will increase resistance, causing a decrease in the diode network's voltage output. A smaller percentage of voltage will be dropped across the diode network and thus more signal voltage developed across R1. Circuit resistance is selected so that the voltage developed across R1 (coarse signal) will override the voltage across CR1 and CR2 (fine signal) when the synchro correspondence error is 2° or more. The coarse signal now has control of the servo. When the servo error becomes less than 2°, the fine signal resumes control.

SERVOAMPLIFIER SECTION

So far you have seen how two small signals (coarse and fine) control a servo and its load- a launcher in most of our examples. You know where they come from originally - from a synchro control transformer. The output of such a synchro is a single alternating voltage, normally very weak. The size of the voltage indicates the size of the error-the difference between launcher or other load position and the order signal. The direction of the error - right or left; elevate or depress- is indicated by the phase of the small voltage. If it is in phase with the 115-volt a-c synchro supply, the error is in one direction. If it is out of phase, the error is in the other direction.

The principal job of the amplifier section is to make the error signal bigger. However, this section may have other jobs to do. For instance, if the output of the amplifier controls a d-c device, then the a-c error signal must be converted into a d-c voltage somewhere in the amplifier section. Sometimes, servo designers select an a-c amplifier to amplify the error signal. Then the amplified signal is converted into d-c after it is amplified. This technique is illustrated in figure 7-11A, The electronic stage in the amplifier section that changes the a-c signal into d-c is called the demodulator. On the other hand, the designers may change the error signal first to d-c, and then use a direct coupled (d-c) amplifier instead of an a-c amplifier. This arrangement is shown in figure 7-11B. Part C illustrates another method of changing signals from one form to another as they pass through the amplifier section. A demodulator changes the a-c error signal to a direct one because the amplifier has a network which operates on direct voltage. The d-c output of the network is fed to a modulator, which changes the d-c voltage to an alternating one. The a-c error signal is then amplified to operate an a-c control device.

Now you can see that electrical error signals in a servo can be either a-c or d-c. Since some system components may require d-c, and other components in the same loop may require a-c, it is desirable to have some devices which can convert signals from a-c to d-c, and vice versa.

In this section we will show how modulation and demodulation work. We will not include material about the actual stages in the amplifier that amplify signals, because these stages are discussed in detail in the basic electrical and electronic courses. Power drive servos use vacuum tubes, tubes, transistors, or magnetic amplifiers. And you will find all the information you need to know about them in the basic courses mentioned previously.

Modulators

In some power drive servos the error signal may take several forms before it reaches the error corrector. The error detector, as we said earlier, is usually a control transformer which of course, is an a-c device. So its output is an alternating voltage. But there are cases when a circuit which operates on d-c is placed between the error detector and the amplifier. (Look again at figure 7-11C.) Then the a-c error voltage must be changed to direct current. A demodulator performs this voltage conversion. Its output is the error signal in d-c form. The d-c error signal is fed into, say, a stabilizing network that operates on direct voltage. If designers have chosen an a-c amplifier, the d-c output of the stabilizing network must be changed to alternating current. Modulators change d-c signals to alternating ones.

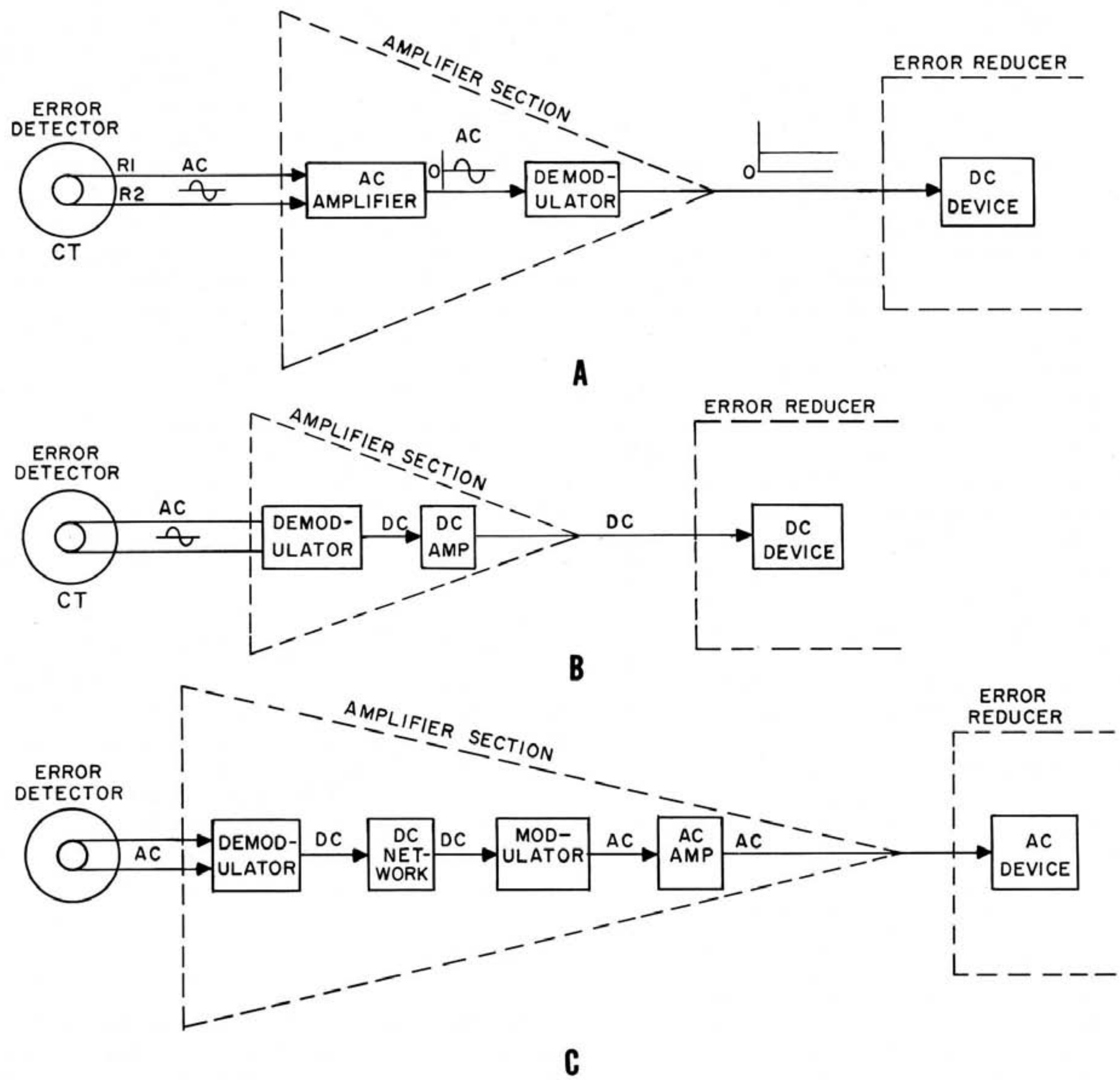

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Figure 7-11.—Changing the form of the error signal: A. A-c amplified signal converted to d-c; B. D-c signal amplified; and C. A-c error signal changed to d-c, then changed to a-c and amplified.

Don't get the idea that modulators are only used to change the form of error signals. Modulators, as well as demodulators, are also used in feedback and auxiliary circuits in servos.

When a d-c signal is converted to a-c, both direction (Polarity) and magnitude of the d-c signal must be contained in the alternating output. The circuit or device that changes (converts) a d-c voltage to a-c is called a modulator. Modulator circuits use elements that act as synchronous switches. Examples of these elements are crystal diodes, vacuum tube diodes, triodes, transistors, and mechanical contactors (vibrators). The "switches," regardless of type, are operated at the supply voltage frequency (the frequency of the reference voltage, usually 60 or 400 hertz and the resulting a-c is a series of pulsating voltages with amplitudes proportional to the d-c error voltage. The phase of the a-c output corresponds to the polarity of the d-c input voltage.

CRYSTAL DIODE MODULATORS.-A typical crystal diode modulator is shown in figure 7-12. This circuit, or a variation of it, is found in power drive servos. This particular circuit is called an electronic chopper or ring modulator. The main parts of the modulator are the reference transformer (T1), output transformer (T2), and a crystal diode bridge consisting of two sets of diodes. One set, CR1 and CR4, work together; the other set, CR2 and CR3, also form a team.

The diodes hold the key to circuit operation. Each set of diodes can be compared to a switch that opens and closes at the frequency of the alternating reference voltage. On one half-cycle of the reference voltage, CR1 and CR4 conduct and act like a closed switch. Then on the next half-cycle, CR2 and CR3 conduct and simulate a closed switch.

If we apply a 60 or 400 hertz reference voltage to the circuit, the diode pairs will open and close at 60 or 400 hertz. This vibrating action will allow an applied d-c signal to pass through the bridge when either set of diodes conducts. Notice, too, that when either set conducts, they connect the top terminal of the d-c input to one or the other ends of the output transformer (T2). These ends have the terminal markings of A and B. As the diode switches open and close, they alternately connect the A and B terminals of T2 to the d-c input's ungrounded terminal. When a diode pair conducts, it acts as a closed switch, and any d-c voltage appearing at the d-c input terminal is alternately placed at, say, first point A, and then at point B, back to point A, and so forth. The effect of this vibrating switching action produces an alternating voltage in the primary of T2. This is what we want. The modulator has taken a DIRECT VOLT- AGE and changed it into a ALTERNATING output which has the same frequency as the reference voltage.

Now that we have the overall idea of what the modulator is supposed to do, let's see how it does it. When the instantaneous polarity of the reference transformer is as shown in figure 7-12A, CR2 and CR3 conduct, and act like closed switches. At this point, the d-c error signal voltage is placed at point A on the output transformer. Figure 7-12B shows the electro- mechanical equivalent of circuit conditions at this point. Neglecting d-c voltage drops across resistors, diodes, and windings (these parts have low ohmic values anyhow), point A is at about the same potential as the error signal.

On the next half-cycle of the reference voltage, the polarities at the reference transformer change, and CR1 and CR4 conduct. Now point B of T2 is at the same potential as the d-c error signal. Look at the equivalent circuit in figure 7-12C to see this instantaneous action. You can see now that on successive alternations of the reference voltage, the d-c error potential is transferred from one end of the output transformer primary to the other. Thus the voltage induced in its secondary is an alternating voltage corresponding to the d-c error voltage.

ELECTRONIC (VACUUM) TUBE MODULATORS. - You learned in your basic courses that electron tubes may be vacuum type or gas-filled type, and that the vacuum type is most commonly used. The operation of both types and of variations of each, such as diode, triode, pentodes, and others, is described in Basic Electronics, NavPers 10087-B. Chapter 1 of Basic Electronics describes the operating principles of electron tubes, and chapter 10 explains their application in modulation and demodulation. To qualify for E-4 you must know the function of electronic circuit components, and the operating principles and characteristics of electron tubes. Since all this information is available in your basic texts, it will not be repeated here.

DEMODULATORS

Some devices that control the error reducer operate on direct current. But the input signal to the servoamplifier is usually an a-c synchro voltage. Therefore, the a-c signal must be converted to direct current. A demodulator is used to accomplish this. Demodulators are often referred to as phase-sensitive rectifiers, phase- sensitive detectors, phase discriminators, converters, discriminators, or simply detectors. These are high-sounding names for a circuit that is fairly simple. If you understand the operating principles of modulators, demodulators will be easy for you to learn.

Diode Demodulators

A typical diode demodulator (phase detector) is shown in figure 7-13. As illustrated, an a-c supply voltage serves as the reference voltage for the detector. This voltage must come from the same source that is supplying a-c excitation to the synchro system, or whatever type of a-c error detector is used, and must be in phase

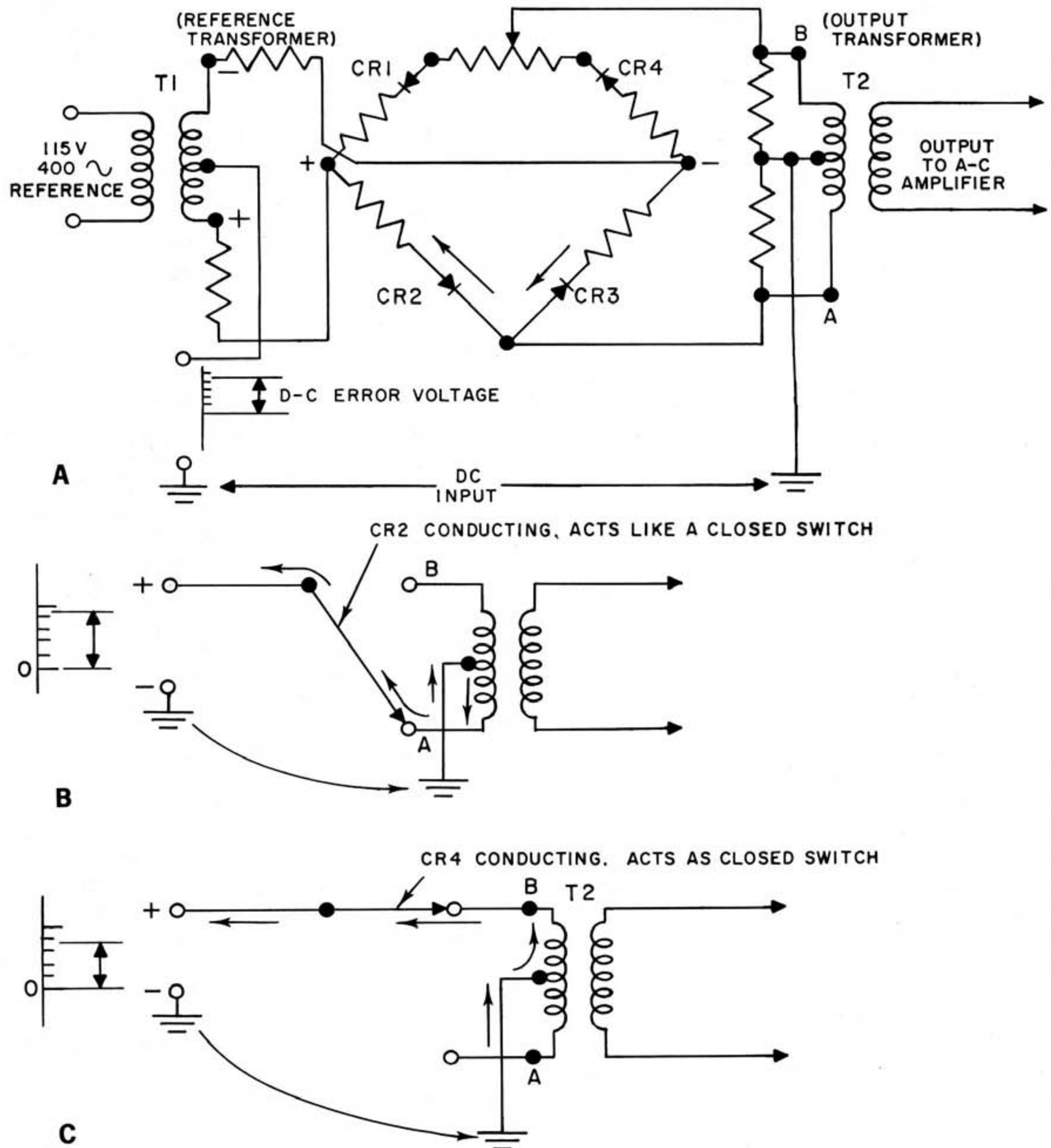

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Figure 7-12.—Modulation operation: A. Acting as closed switches, CR2 and CR3 conduct; B. Electromechanical equivalent of circuit conditions in A; C. Equivalent circuit when CR1 and CR4 conduct.

with the common supply voltage. This permits a phase comparison of the error voltage with the reference voltage. The plates of the two diodes are supplied with this reference voltage so that the two plates will be in phase. Assume that there is no error signal from T2 to the plates of the diodes at the time the plates are on a positive half-cycle. The two diodes will conduct equally. The voltages produced across R1 and R2 are equal, making the cathode of V1 and

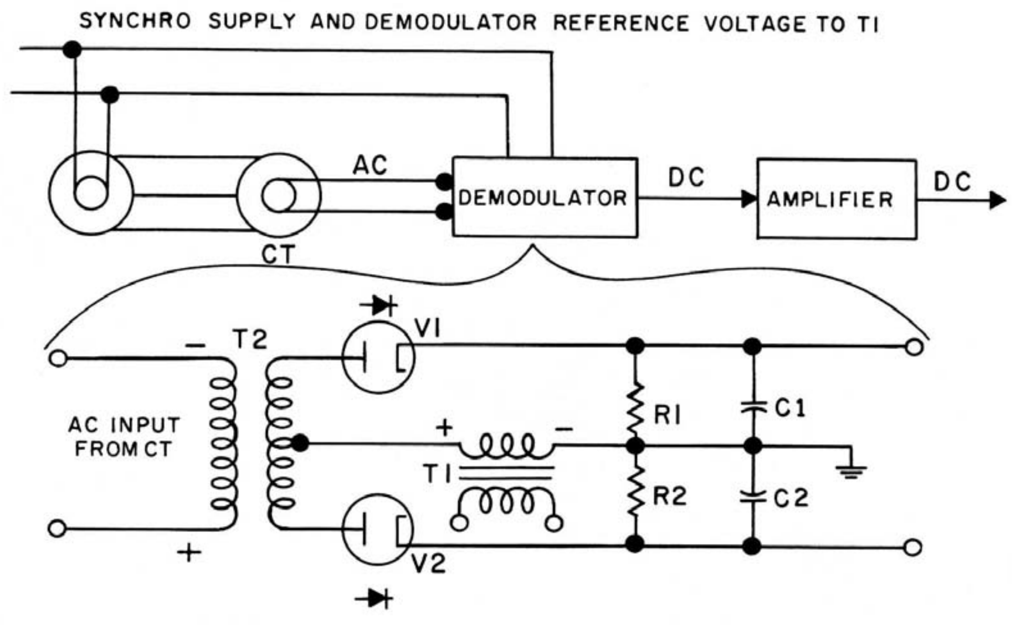


Figure 7-13.—Diode vacuum tube demodulators.

V2 at equal potential with respect to ground. With the two output terminals at the same potential, the output voltage will stay at zero as long as no error signal is applied.

If an error signal is applied to T2, making the plate of V1 positive at the same time that the reference voltage on the plates of V1 and V2 is on its positive half-cycle, V1 conduction will be increased and V2 conduction decreased over the no-signal condition. The top of R1 would become more positive and the bottom of R2 less positive. This would result in a positive output at the top with respect to the bottom. Since the voltages applied to the plates are both alternating, the voltage developed across R1 and R2 would also be alternating. However, R1-C1 and R2-C2 have a long time constant compared to the input frequency, and therefore filter most of the ripple, giving a d-c output.

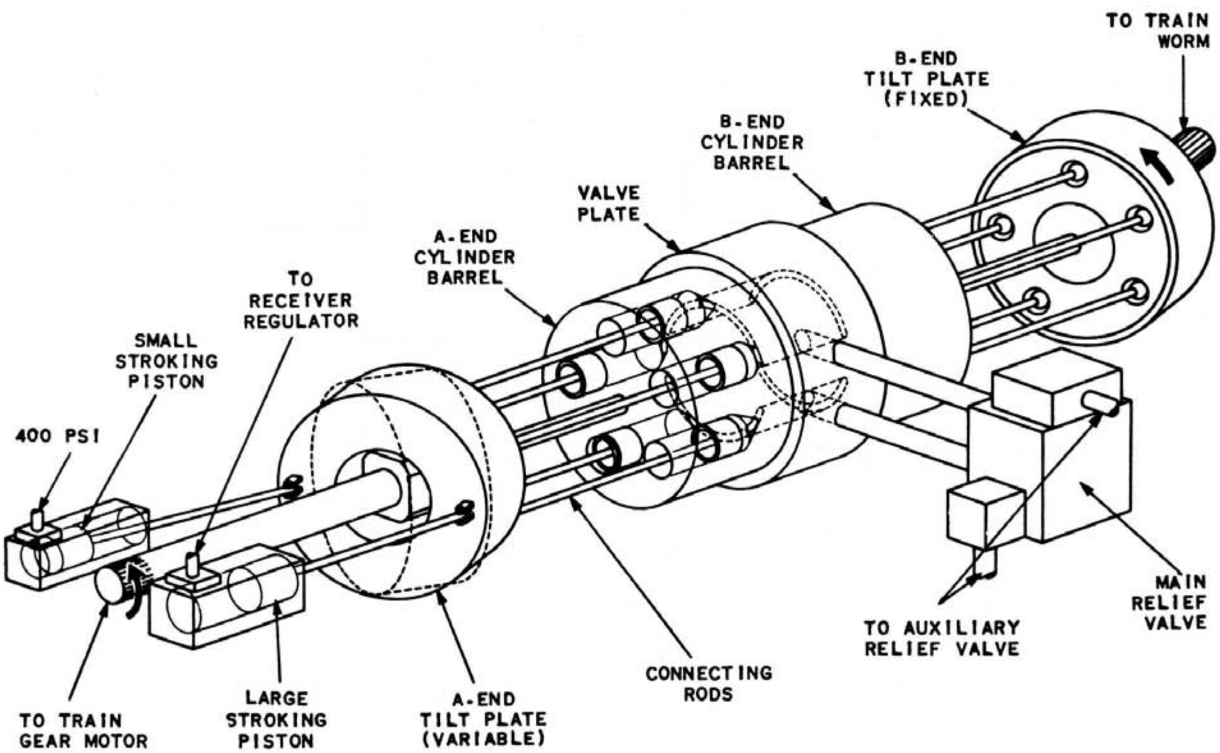
If the error signal applied to T2 is changed by 180 degrees, V2 would now increase its conduction while the conduction of V1 would be reduced. This would result in an output voltage of reversed polarity. Variations of the diode phase detector may be encountered. You will find that some demodulators use crystal diodes instead of vacuum tube diodes. However, they all work on the same basic principle.

Triodes too, are similar to diodes, but have the additional ability to amplify. Amplifiers are explained in the basic courses in electricity and electronics, and will not be covered here. Transistors also are described in those texts. Transistors are able to do many of the things for which electron tubes have been used, and their small size makes them preferable in many instances.

THE ERROR REDUCER

The devices which you will study in this section are those which belong in the third block of figure 7-2. We gave the functional name of error reducer to this block. Here you will find the components that accept the amplified error signal and then change it from its electrical form into mechanical or hydraulic action. This action, in turn, controls the tilt of a hydraulic A-end. An axial-piston pump (A-end), as you know from your study of Fluid Power, NavPers 16193 (current revision), is a variable delivery hydraulic pump. The A-end applies hydraulic fluid pressure to a hydraulic motor called the B-end which, in turn, converts the hydraulic pressure into a rotary motion. Output of the B-end is mechanically coupled to the train and elevation drive gears that position the launcher.

Figure 7-14 shows an A-end and B-end that is enclosed in the same housing and are separated by a common valve plate. This type unit is a



83.81(53C)
Figure 7-14.— (combination A-end and B-end).

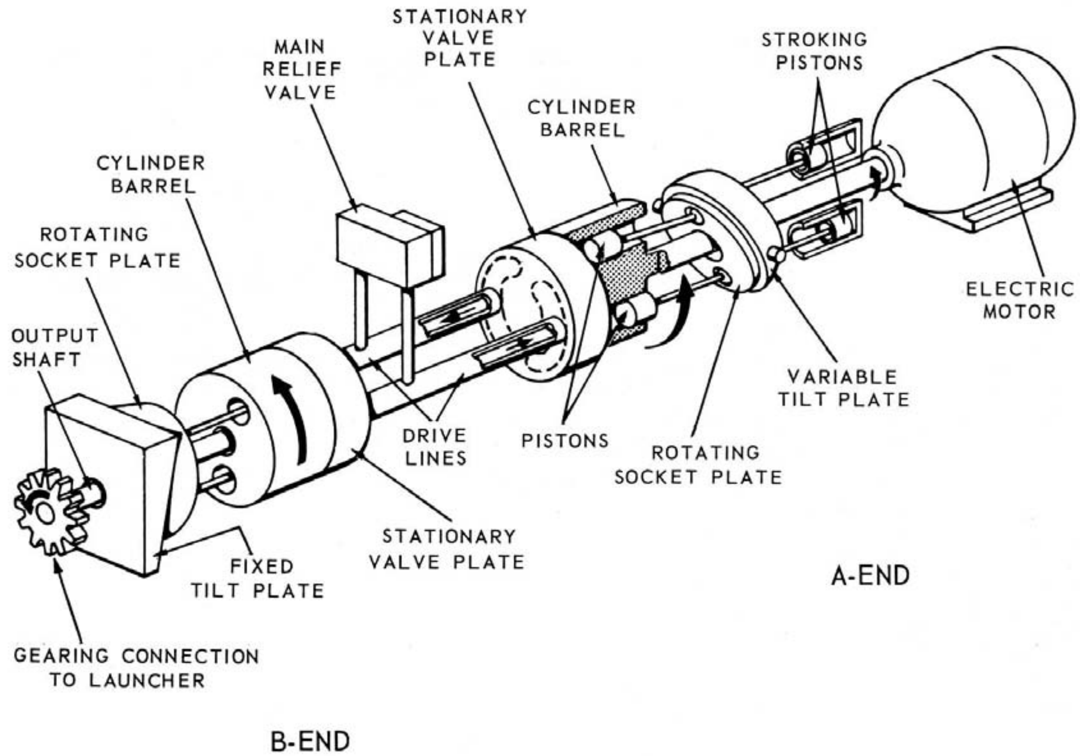
Type-C or CAB (combination A-end and B-end) installation which is most frequently used in launcher train and elevation systems. (See figs. 5-19A and 5-19B for location of train and elevation CAB units in Talos launching system, and fig. 5-26 for a block diagram of the train drive system.)

There are times when it is convenient to install the two units in separate spaces. In this case the units are connected by piping with each unit having its individual valve plate. This is the Type-K installation (fig. 7-15). Regardless of the physical arrangement, each installation works similarly to the system we will discuss in the following paragraphs.

Hydraulic A-end and B-end Type

The major elements of this type of drive are shown in figs. 7-15 and 7-16. The A-end (pump) is driven by a constant-speed electric motor. The output is made variable by action of the tilting plate or box, which is moved by the stroke piston (or pistons). In figure 7-3 you can see that the stroke pistons are, in turn, controlled by the electrohydraulic servovalves when they are actuated by error signals from the amplifier. The B-end (motor) is driven by the fluid output of the A-end. The speed of the B-end is dependent on the amount of fluid pumped by the A-end pistons. The more tilt applied to the A-end the m,:)re fluid pumped by the pistons and therefore the Greater the speed of B-end rotation. The direction of rotation of the B-end is determined by which transmission line is high pressure and which is return. The output of the B-end is mechanical rotation. In the case of a launcher it is directly connected to the launcher train or elevation gearing. The unit that moves the launcher in train is geared to the training circle (fig. 5-20) and the elevation unit is geared to the elevation arc (fig. 5-18). The same type of system is used in gun mounts and turrets to train and elevate guns.

B-end operation is demonstrated in figure 7-17. Only two pistons (usually there are nine) are shown. High pressure fluid from the A-end is shown being applied to the top of the piston. The force is carried through the piston rod to the tilted ring. The only way for the socket ring to yield is downhill. This causes the socket ring to rotate. Since the socket ring is joined,



83.81(83A)
Figure 7-15. — Type-K installation.

by a universal joint, to the drive shaft, the shaft rotates with it. Through gearing, this moves the launcher.

As the unit continues to rotate, the piston moves uphill, sliding deeper into its cylinder, forcing low pressure fluid into the return transmission line.

If the direction of fluid flow from the A-end were reversed, the low pressure return line would become the high pressure line, and vice versa. Rotation of the B-end would reverse.

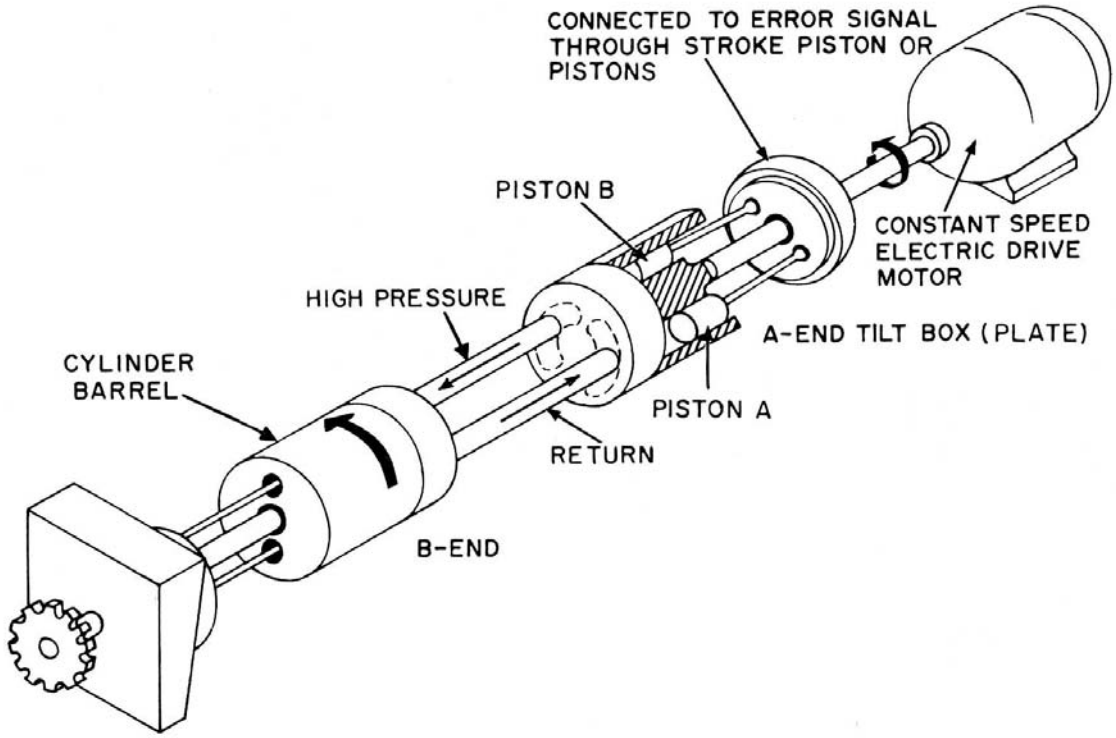
The A-end is constructed somewhat like the B-end, except that the tilt of the socket ring is variable, not fixed. In action it is just the reverse of the B-end. Its input is mechanical and the output is fluid pressure. Very simply, it operates like this:

In figure 7 -16 tilt has been applied to the A-end. As piston A rotates upward, it is forced into its cylinder, pushing oil ahead of it. The other pistons as they ride up this half turn will do the same. The oil is collected at the sausage-shaped port and sent out through the transmission line marked HIGH PRESSURE to the B-end, where it forces the hydraulic motor to rotate. Piston B, as it rotates downward, is drawn outward from its cylinder. This helps draw oil in from the return line.

If the tilt of the A-end is removed entirely (0° tilt) the pistons will continue to be rotated by the electric motor, but they will not move back and forth in their cylinders. This means no fluid flow, and the system is at neutral. If the tilt box is tilted on past neutral in the opposite way from +.hat in the illustration, the pressures in the lines reverse. The line which has been the high pressure line becomes the return line and vice versa. This changes the direction of B-end rotation and the direction of launcher movement.

Control of the tilting plate then controls launcher movement. The stroke piston (or pistons) (fig. 7-18) is the connection between our amplified order signal and the A-end tilt box. Figure 7-18 shows two methods used in power drive servos to control A-end tilt, and both function on the differential working area principle.

In figure 7-18A you can see that the' stroke piston is being acted upon by two hydraulic pressures. The 1000-psi side is held constant and



83.81(83)
Figure 7-16.—A-end and B-end operation.

works on a certain size piston face area. The left side of the stroke piston is acted upon by a force made variable by our error signal. This force works on twice the stroke piston face area as that of the constant 1000 psi. In this case 500 psi would balance it, and the stroking piston would remain motionless. Raising the pressure on the left side of the piston above 500 psi moves the piston right, and puts tilt on the A-end. Reducing the pressure below 500 psi shifts the piston and the tilt box the other way, reversing the direction of fluid flow.

In figure 7-18B you see practically the same actions. Here are two stroke pistons. The face of the larger one is twice the size of the smaller one. Hydraulic pressure on piston A is held constant, and varying the smaller pressure acting on piston B will cause tilt to be applied.

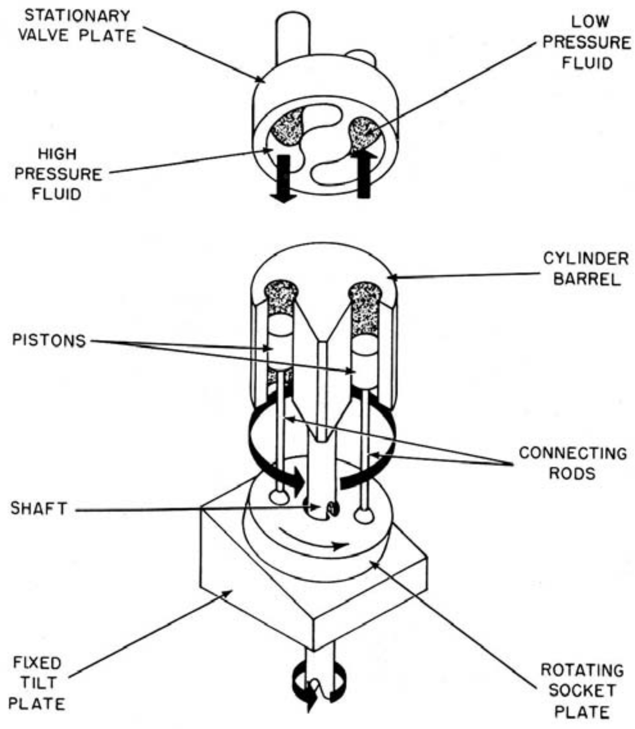
Electrohydraulic Servovalve

Train and elevation power drive servos have hydraulic error reducers. So, the principal power units in this section are hydraulic. But you will always find some electrohydraulic device which converts the electrical output of the servoamplifier into a proportional hydraulic fluid flow. An electrohydraulic servovalve performs this function. It is made up of two basic sections: a force motor and a hydraulic amplifier. The output of the unit ports hydraulic fluid to the two stroking pistons which position the A-end tilt plate.

Figure 7-19 shows a typical electrohydraulic j servovalve. Hereafter we will call it simply a servovalve. The main hydraulic unit is a spool valve which is positioned by a hydraulic circuit. The fluid flow in this circuit is controlled by a reed flapper valve. A small unit made up of a force motor and two permanent magnets control the reed. The spool valve is free to move in the enclosing cylinder, subject to the restraining forces of the centering springs. The spool valve moves in one direction or the other when unbalanced pressures are developed in the two pressure chambers. A chamber is located at each end of the spool.

How The Servovalve Works

There are several variations of the servo-, valve but they all work on the basic principle described in the following paragraphs.



83.82
Figure 7-17.—B-end operation.

The electrohydraulic servo-valve shown in figure 7-19 converts an electrical signal to proportional hydraulic order. A servovalve consists of a force motor and a hydraulic amplifier. The force motor transforms the electrical output, a differential current, into a proportional force on the motor reed.

The force motor consists of two permanent magnets, two pole pieces, two coils, and the reed. The reed can be pivoted in a flexture tube, which serves as a centering device, or in a flapper valve that is clamped at one end. The reed extends through the solenoid windings of the force motor into the mixing chamber between the nozzles. Position of the reed is changed according to the differential of current flowing in the coils. You will recognize this as push- pull action.

The position of the reed regulates the flow of fluid through the nozzles. For example, if the reed moves toward the right, the flow through the right nozzle is restricted, while the fluid flow through the left nozzle increases.

The fixed orifices work somewhat like a current-limiting resistor in an electric circuit. The resistor develops a voltage drop proportional to the value of current through it. Similarly, the fixed orifices function as restrictions and develop pressure drops proportional to the rate of fluid flow in the lines containing them.

The action of the reed, nozzles, and orifices is as follows. When the reed moves to the right, blocking fluid flow to tank through the

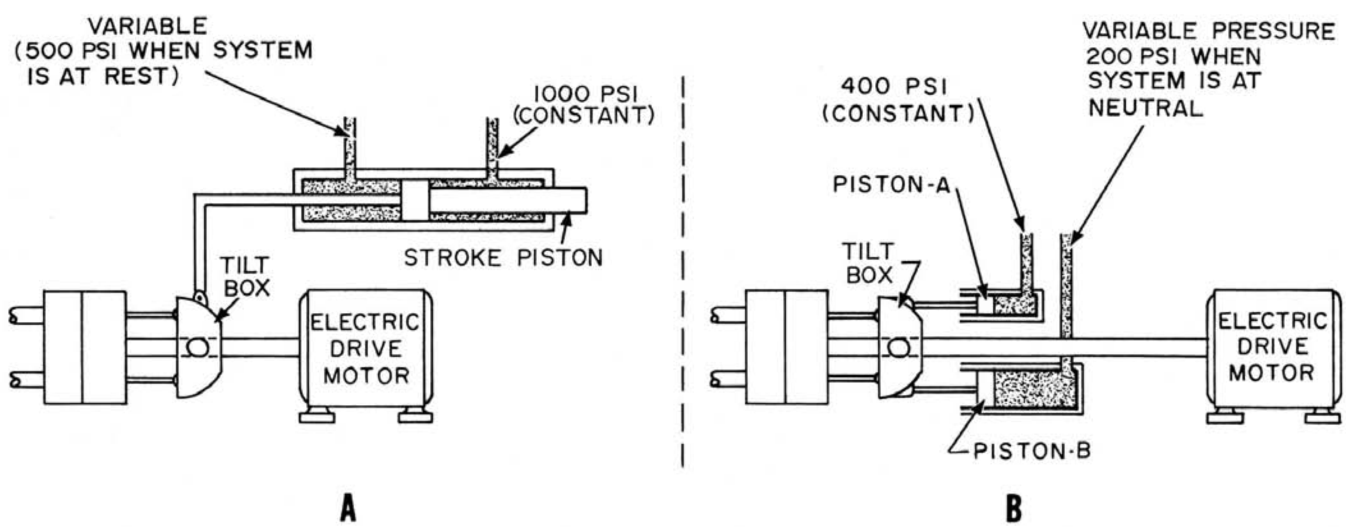


Figure 7-18.—Putting tilt on the A-end: A. Pressure on one piston; B. Pressure applied to two pistons. 83.83

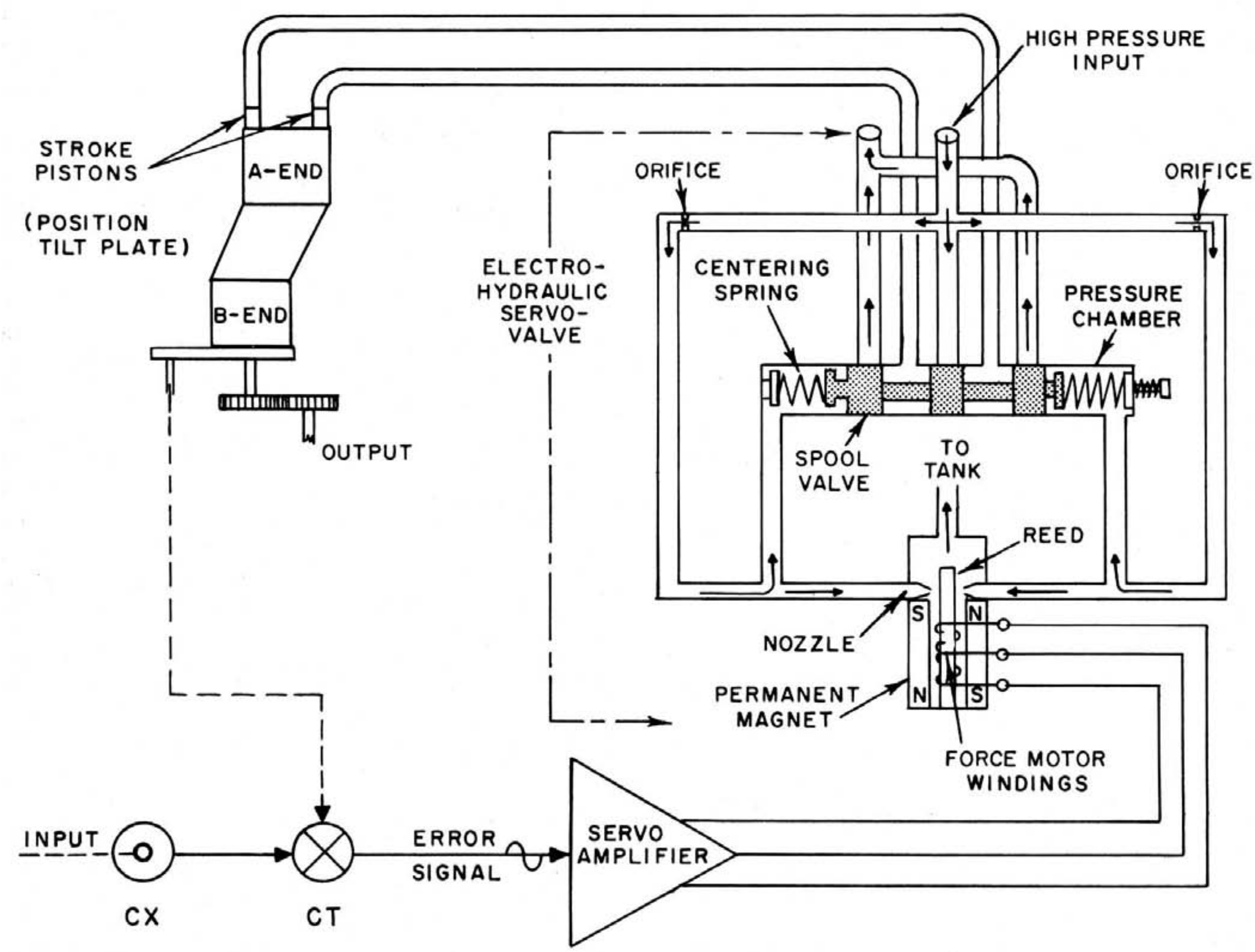


Figure 7-19.—Electrohydraulic servovalve operating in a control system.

right nozzle, fluid pressure in the right pressure chamber increases. At the same time, the fluid flow through the left nozzle increases. Fluid pressure in the left pressure chamber cannot be maintained due to the restriction to fluid flow of the left orifice. The differential in pressures set up at the ends of the spring- centered spool valve upsets the balance of the valve, causing it to shift to the left. The motion of the spool valve is reversed when the reed moves toward the left nozzle since this causes higher pressure in the left-hand pressure chamber than in the right. In this manner the spool valve is centered or moved to the right or left, depending upon the position of the reed.

When in the center, or neutral position, the spool valve prevents liquid from entering either of the two lines leading to the A-end stroking pistons. This action puts the A-end tilt plate on neutral and there is no B-end output. When the spool valve moves to the left, for example, the center land of the spool valve admits high- pressure fluid to the right stroke piston line: while at the same time the left land opens the low-pressure line to the left stroke piston line. This puts tilt on the A-end. Motion of the spool valve in the opposite direction results in a reversal of connections so that A-end tilt responds in the opposite manner.

IMPROVING THE QUALITY AND PERFORMANCE OF SERVOS

A power drive servo must operate smoothly, rapidly, and with as few errors as possible. Ideally, the motion and position of the output, shaft should duplicate the motion and position of the input shaft. But we never get ideal performance from servos because they do not react immediately to a changing input signal. The output will always lag the input. Any action, regardless of what it is, requires time to take place. The action of a servosystem is no exception to this principle. The electrical, mechanical, hydraulic, and pneumatic reaction times in a servo cause the output to lag behind the error signal producing it. Any slack or bending in mechanical linkages will produce a delay. A hydraulic unit will produce a delay. Expansion and contraction of hydraulic lines will cause a lag. Also, it takes time for fluid to flow through valves and lines. Air is compressible, and this causes a delay. Electric and hydraulic integrators produce delays. In the electrical parts of the system, any components that affect the phase of an a-c signal have some effect on the response time of the signal. For example, all coupling and filter capacitors and inductances contribute to a time difference between the input and output.

One method of increasing the speed with which a servo answers an input signal is to increase the gain of the servoamplifier. But if the gain is made too high, the servo output will oscillate. We can reduce the servo's tendency to oscillate by decreasing the gain of the amplifier. But if we cut it down too far, the servo will overshoot the input signal. Therefore, servos are provided with devices that directly and indirectly control automatically the gain of amplifiers. In this manner servos are prevented from overshooting and oscillating. Let's explore the meaning of these two terms further because they are very important in the study of servo operation.

OSCILLATING

Oscillating, frequently called hunting, occurs when the output shaft drives back and forth across the ordered position in short rapid swings, as though the output shaft were looking for a place to stop but never finds it. Hunting is also characterized by its continuous action; it never stops or dies out. And it can be dangerous. If the output shaft oscillates at a rapid rate for a long time, it is possible to shake a launcher or other load to pieces. Oscillation can take place when a launcher is synchronized with a fixed or a moving order signal. But you won't see its effects in a properly designed and adjusted power drive servo.

Overshooting

Overshooting is similar to hunting. But the oscillations of the output shaft die out after a short period of time. They start out as large over-travels and progressively get smaller until eventually the output shaft stops.

To get a better idea of overshooting, we will look at how a servo without damping reacts to a fixed input signal. Assume that the input shaft - (synchro transmitter rotor shaft) is stationary and at zero degrees, and the output shaft is positioned at, say, 10 degrees. The output of the error detector is an electrical signal proportional to 10 degrees. When the servo is energized, the error reducer will drive the output shaft to reduce the error to zero. The error reducer continues to drive the output shaft until the desired position is reached. At this point, the error is zero, or as some technicians say, the system is nulled. But because the load and error reducer have inertia and momentum, the output shaft continues driving beyond the desired position. When the output shaft crosses the desired position, the error detector generates an error signal which tends to reverse the direction of the output shaft. However, it takes the error signal some time to bring the output shaft and load to a stop. In other words, because there are components in the servo that do not react immediately to a signal, some time elapses before the output shaft can respond to the error signal. During this response lag the output shaft continues to drive in the original direction. When it does stop, the error signal immediately starts it back toward the desired position. At correspondence the output shaft and the load have acquired enough speed in the reverse direction to again pass the desired position. The result is a series of progressively smaller over-travels until finally the servo stops.

REDUCING OSCILLATION

To reduce overshooting and hunting, servos are provided with damping devices or circuits. These circuits are frequently called stabilizing or antihunt circuits, and usually use some form of feedback. Feedback, you will remember, is the method by which a sample of an output is returned or fed back to the input to be added to or subtracted from the input, thereby changing and controlling the output. The damping or stabilizing circuits in power drive servos are capable of acting as positive feedback to increase the gain of the servo amplifier when the error signal is increasing. It also acts as a negative feedback to reduce the gain of the amplifier when the error signal is decreasing. In this manner servos are prevented from overshooting and oscillating.

We will talk about three of the many methods of reducing overshooting and hunting in power drive servos. First, we will cover the technique of using a control transformer with a movable stator to prevent a launcher from overshooting a fixed order signal. Then we will explain the use of a tachometer generator for damping out oscillations. Finally we will cover integration control, which increases the ability of a servo to follow slowly changing error signals and reduces velocity error. Usually you will find all three methods used in a servo, in addition to others which we will not cover here.

Movable CT Stator Method

So far in our discussion of servos we have assumed that the stator of the control transformer error detector is fixed. The CT rotor, of course, is driven by the feedback line. When the output shaft, and thus the load, is at the ordered position, the electrical output of the CT is zero volts. And the load stops.

In figure 7-20A, however, you see a different setup. Here there are two responses to the CT. The stator is geared to B-end output launcher position feedback (response) and the rotor is geared to the rotary piston. The purpose of having two responses is to cause the A- end tilt plate to start removing tilt before the launcher arrives at its ordered position. The following is a brief discussion of how this is accomplished.

As in a conventional CT, the error signal is produced by rotating a resultant of the three CT stator field voltages. The error voltages induced into the rotor windings are sent to an amplifier and on to a torque or force motor. Rotation of the generator moves a rotary valve. This switches hydraulic circuits to the rotary piston, causing it to turn in a direction equivalent to the desired movement of the launcher (train or elevation). Rotary piston movement sets the hydraulic regulating devices in motion, causing tilt to be put on the A-end pump. This, you will recall, causes the launcher to move.

Even while this is happening, however, the moment the rotary piston moves, it turns the rotor of the CT in such a direction as to cancel out a portion of the original error. Now, as the launcher moves toward its ordered position, B-end response moves the CT stators, also in a direction to cancel out the error. When the stators overtake and pass the rotor, a phase shift occurs in the signal voltage. The result of the phase shift is an output from the rotor in an opposite direction from the first error signal. In other words, if the first signal called for right train and tilt is put on the A-end, the electrical phase shift will cause the error signal to call for, in effect, left train. Hydraulic actions reverse in the regulator, and tilt begins to be removed from the A-end. Theoretically, the A-end tilt box should reach neutral when the launcher arrives at its ordered position. As you can see, these actions will prevent any prolonged overswings of the launcher. Figure 7-20B shows in four steps the action described above.

Output-Rate Damping (Feedback Method)

Feedback is commonly used to reduce overshooting and hunting. One method of providing feedback is to use a d-c tachometer generator. This device is commonly called a "tach". Its application is shown in figure 7-21A, The tach is geared to, and rotates with, the servo's output shaft. The tach's output is a d-c voltage whose amplitude is proportional to output shaft speed. Also, the polarity of this voltage indicates the direction of output shaft rotation. Therefore, the output of the tach represents load velocity (rate). This velocity voltage is connected to the amplifier so that it opposes the error signal. Whenever the error signal changes, the rate feedback signal opposes any change in the error signal. In other words, the error signal is damped. The effect on the servo is as though you increased the friction on the output shaft.

This method of using a feedback signal proportional to the velocity of the output of a servo is also called velocity feedback. It is used in some missile and rocket launcher power drive servos to prevent overshooting when the launcher is synchronizing to a fixed input order signal (STOW, LOAD, DUDJET). Under these circumstances, launcher velocity increases as it approaches synchronism and, therefore, the effect of velocity feedback is to slow down the launcher before it approaches this point.

Figure 7-21B shows another method of using velocity feedback to prevent overshooting. Instead of a tach, a potentiometer whose slider is connected to the A-end stroke mechanism provides a velocity signal which opposes any

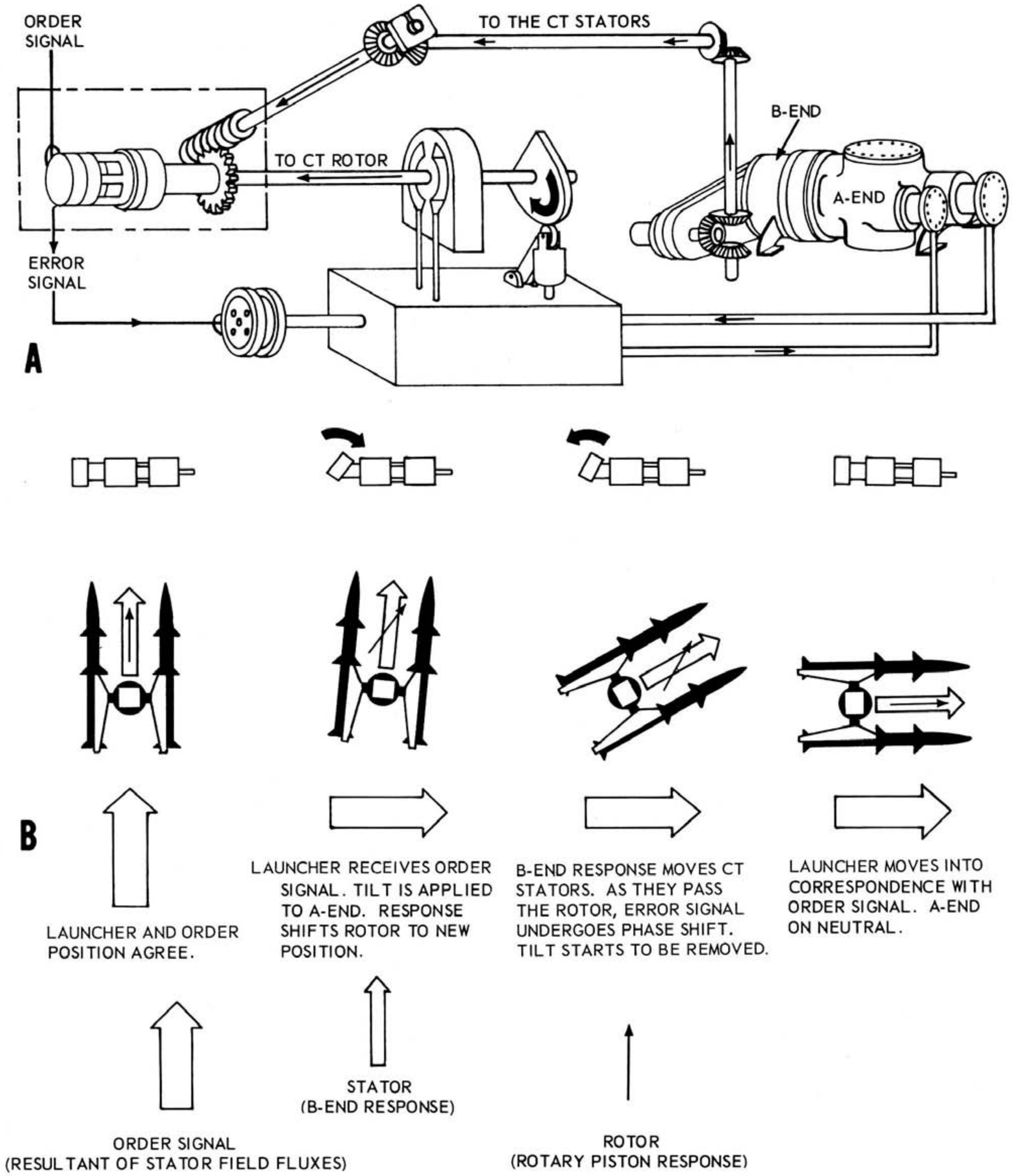


Figure 7-20.—Reducing hunting and overshooting of power drive servos: A. By using control transformer with a movable stator; B. As launcher synchronizes, CT acts to remove tilt.

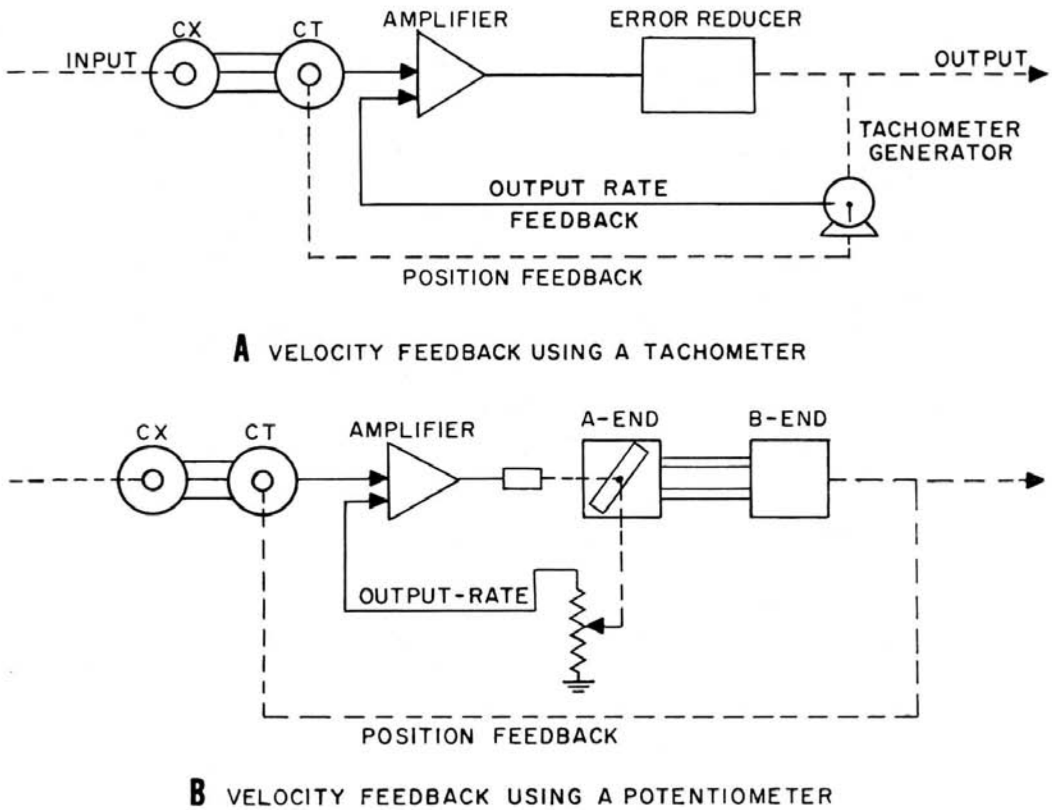


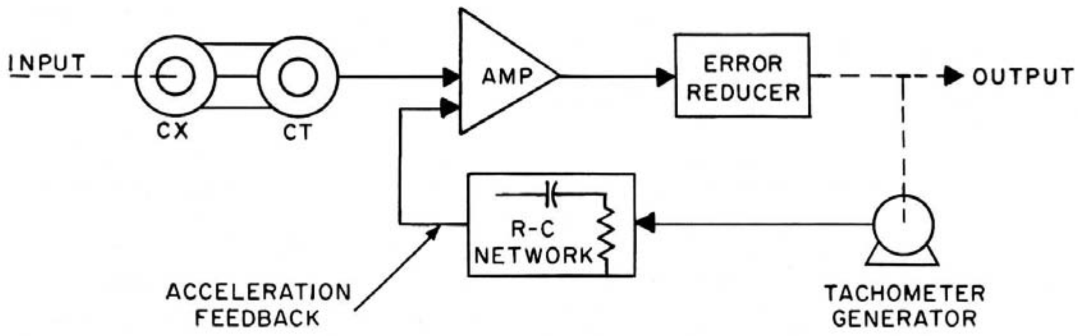
Figure 7-21.—Feedback method to reduce overshooting and hunting: A. Velocity feedback using a tachometer; B. Velocity feedback using a potentiometer. 83.86

change in the position error signal. Since the direction and amount of A-end tilt is a close approximation of launcher velocity, a pot can be used in place of a tach to get the same damping effect. Both methods produce the same result -they slow down the load before it reaches synchronism.

Acceleration Feedback

When you solve one problem, usually another arises. Such is the case with velocity feedback. It causes velocity error. Here's why. When the servo is following a CONSTANT VELOCITY input signal, the tach or the pot puts out a velocity signal even if the input and output shafts are in agreement. At this point there is no position error signal, but there is a velocity feedback signal at the input of the servoamplifier. And this velocity signal causes the output shaft to lag the input. The faster the constant velocity signal, the faster the servo moves, and the greater the velocity feedback signal, and, therefore, the further the output shaft will lag behind the input shaft. This velocity lag problem can be solved with integral control circuits (you'll study them next) which are used in conjunction with velocity feedback circuits. But there are other ways of skinning a cat. We can use the same feedback arrangement illustrated in figure 7-21A, and insert a simple resistor- capacitor network between the tach and the amplifier. Our new circuit is shown in figure 7-22. Also, it has a new name - acceleration feedback. But it is still classified as output-rate damping because the tach senses the output velocity of the servo.

The resistor is connected across the output of the tach, and the capacitor is in series with the tach. The capacitor is the key to circuit operation. When the servo is following a constant velocity input signal, the output of the tach is a steady d-c voltage. Now from your study of electricity you know that a capacitor blocks



83.87
Figure 7-22.—Reducing hunting and overshooting: Acceleration feedback.

the flow of direct current. Therefore, no velocity signal gets through to the amplifier when the output shaft is moving at the same speed as the input shaft. The velocity feedback signal from the tach is blocked, and does not oppose the error signal. But if the output shaft suddenly changes its speed (accelerates), then the tach puts out a fluctuating d-c signal which looks like a-c to the capacitor, and it passes the feedback signal on to the amplifier. Here the feedback signal opposes any change of error signal. Thus the output shaft is restrained from changing its speed (accelerating).

Integral Control

Power drive servos, as we've said before, are sometimes required to follow constant velocity order signals. These signals occur, for example, when the tracking radar is following a target whose speed and range remain fairly constant. The input shaft of the launcher train order transmitter turns at a constant velocity (speed and direction) for a substantial percentage of time. Therefore, the power drive servo must respond to this type of input with as small an error as possible. But because there is always friction present in the servo, a velocity error will be present: the output shaft position lags the position of the input shaft when both shafts are rotating at the same velocity. For instance, the input shaft is rotating at 10°/sec and the output shaft is moving at the same velocity but the angular position between them is, say, 1 degree.

To correct for velocity error, servos use integral control circuits. This type of circuit, like the output rate method, reduces velocity error to a minimum. The integral circuit modifies the error signal so that it is proportional to the length of time it exists, multiplied by the amplitude of the error signal. For example, suppose the output of the circuit is four volts and it was produced by a constant error signal which lasted for one minute. If the same error signal had lasted for only one-half minute, the output would have been two volts. You can see that if an error signal exists for a long time its amplitude increases. Therefore, the amplifier output increases and an exaggerated error reducing action takes place. Or, to say it another way, the servo overcorrects the error. The speed of the output shaft increases more than it normally would and thus it catches up with the input shaft.

Figure 7-23A shows a simplified block diagram of an actual power drive servo. Figure 7-23B shows an integral control circuit (also called a compensating network) used in the servo in fig. 7-23A. We have reduced this circuit to its simplest form as shown in fig. 7-23C. Briefly, here is how the circuit works.

The integral control circuit is made up of a combination of two resistors and a capacitor. Notice that the network is in series with the error detector and the servoamplifier. Since the integral control circuit operates on direct voltage, the amplifier must contain a demodulator to change the a-c error signal to a proportional d-c form. The size of the components in the network is such that the capacitor voltage does not change when the error voltage changes rapidly. Only that portion of the changing error signal developed across R1 is impressed on the amplifier. But, with an error signal of longer duration, the capacitor will charge, increasing the voltage input to the amplifier. Therefore,

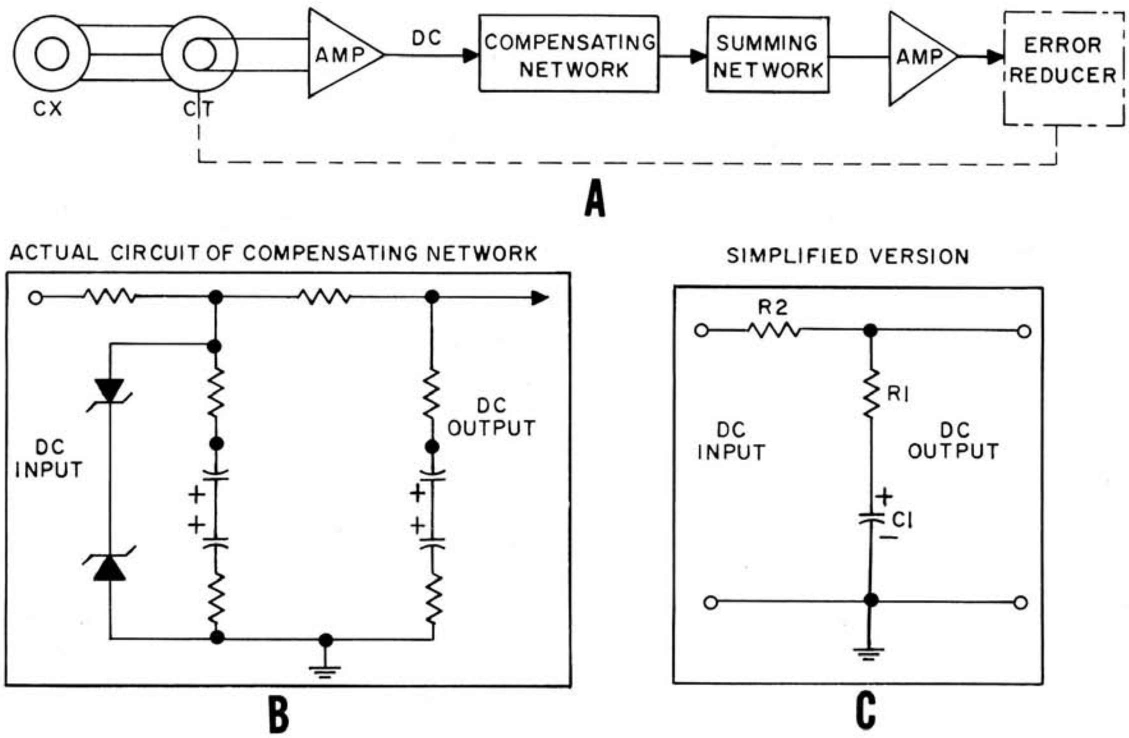


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Figure 7-23.—Integral control: A. Simplified block diagram of power drive servo; B. Integral control circuit of compensating network; C. Simplified circuit of compensating network.

this circuit is sensitive to constant or slowly changing error signals of the type you would expect from a velocity error.

On the other hand, the integral control circuit ignores rapidly changing error signals. Remember, the higher the frequency of the voltage impressed across an R-C circuit, the more the capacitor acts like a short circuit. Rapidly fluctuating d-c signals will be split between R1 and R2 because the capacitor acts like a short circuit or zero resistance. R2 is much larger than R1, so most of the fluctuating voltage is dropped across R2. A much smaller portion of the rapidly changing error signal appears across R1. Since R1 is in parallel with the input to the amplifier, only a small signal voltage is applied to the amplifier.

Now look what happens in the circuit when the error signal is steady or changes slowly. This is the kind of signal you would get when a velocity error exists. Initially, all of a constant error voltage would be distributed between R1 and R2. But the longer the error voltage is applied, the more C1 charges up. The increasing voltage drop across C1 adds to the drop across R1 and. since these two components are in parallel with the amplifier, their combined voltage will appear at the input terminals of the amplifier. In effect, the error reducer will overcorrect the error signal and the output shaft will catch up with the input.

In many power drive servos, hydraulic devices perform the same function as integral control circuits. When hydraulic integral control is used. a potentiometer picks off a voltage from the hydraulic integrator and feeds this signal to the servoamplifier. But regardless of the technique used - hydraulic or electrical - the main purpose of integral control remains the same - to minimize the effect of velocity error on servo operation. Also, you will generally find that integral control circuits and devices operate on the fine error signal and not the coarse.

CHAPTER 8

HYDRAULICS AND PNEUMATICS IN MISSILE SYSTEMS

INTRODUCTION

You have been using hydraulic, electrohydraulic, and pneumatic power to operate different equipments almost from the day you entered the Navy. Deck equipment for loading and unloading, and equipment for raising, lowering, or otherwise moving heavy objects such as anchors, use hydraulic power. Your basic military texts (Seaman, NavPers 10120-E; Basic Military Requirements, NavPers 10054-C; Military Requirements for Petty Officer 3/2, NavPers 10056-C) did not tell you how these equipments were powered. But now you need to understand the power behind the machine. Look at the quals on hydraulics and pneumatics. Note that all of the knowledge factors are required of the E-4 and E-5. Much of this information that you need may be found in Fluid Power, NavPers 16193-B. We will try to show how fluid power is used in missile systems. The preceding chapter told how fluid power is actuated through servomechanisms. Wherever you need a large force, controllable by a small force, hydraulic power can fill the need. It is the chief source of power for operating equipment and machinery used by the GM ratings. Keeping the hydraulic systems in peak operating condition is a major part of the GMM's work. The more you understand about how hydraulic systems work the better able you will be to keep them working.

HYDRAULIC TERMS COMMONLY USED BY GMMs

The terms defined may be used as an introduction to the subject of hydraulics, and for later reference. These terms may have more than one meaning, but we will give only the meaning which applies to hydraulic systems.

ACCUMULATOR. - A device for storing hydraulic fluid under pressure. It is usually a spherical or hemispherical hollow object (fig. 8-1) with diaphragms, bladders, valves, and other accessories to control the fluid. Its purpose is to store enough fluid at, or close to, the working pressure of the system to meet short demands for excess fluid. It also smoothes out surges and pulsations in the hydraulic system, and meets low-capacity demands without operating the high-capacity pump (except intermittently to charge the accumulator).

AIR BREATHER. - A device which allows air to enter or leave a hydraulic tank as the oil level changes. An air filter is normally installed in the breather. See figure 8-8.

ANNEALING. - Method of softening pipe and tubing so that it can be bent or formed more easily. Only copper tubing is annealed. The process is also used to restore flexibility to tubing to prevent splitting or cracking.

BAFFLES. - Plates or partial plates which extend into hydraulic tanks to reduce sloshing and foaming and to aid in cooling the fluid.

BUFFER. - A mechanism used to retard moving equipment or bring it to a smooth stop. See figure 8-2. It is not necessarily a hydraulic device, but may be pneumatic or mechanical. In the buffer illustrated, forcing the fluid through the deceleration grooves causes the slow down.

CAB UNIT. - Combination A-end and B-end. The A-end and B-end are located in the same housing and are separated by a valve plate (fig. 7-16).

CAVITATION. - Partial vacuum in hydraulic fluid caused by lack of full volume of fluid at the pump intake. Collapse of such cavities produces very large impulsive pressures that may cause considerable mechanical damage to neighboring solid surfaces.

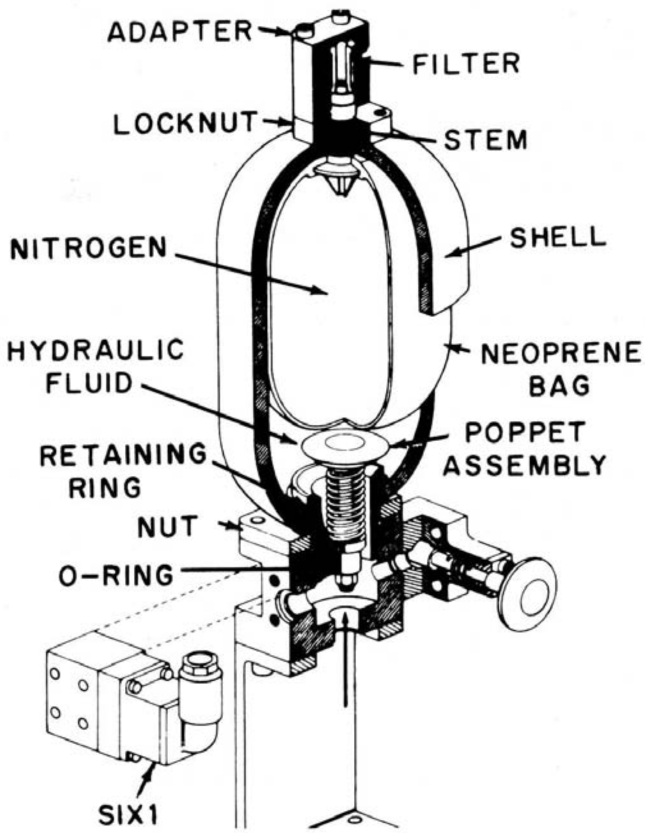

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Figure 8-1.—Bag type amcumulator.

CONTROL FLUID. - (Control pressure). Hydraulic fluid, other than transmission fluid, under pressure and used to control the operation of the hydraulic power unit.

CYLINDER AND PISTON. - A linear motion device for converting fluid energy into mechanical energy (fig. 8- 3).

DASHPOT. - A device to cushion the last portion of the stroke and prevent metal-to-metal contact of pistons and plungers when they reach the ends of travel (fig. 8-4).

DRAIN LINES. - Lines that return hydraulic fluid to the sump, supply, or header tanks.

DRAIN PLUG. - Plug used to drain hydraulic fluid from a hydraulic system or tank. See figure 8-8B.

FILTER. - A device for removal of dirt, sludge, and lint from a hydraulic fluid where the resistance to motion of such solids is in a tortuous path. (Compare with Strainer.) Filters are installed at various points in the hydraulic system. See figure 8-5. The one shown has a single element of the "micronic" type, constructed of a pleated cellulose material, to be discarded when clogged.

FITTINGS. - Devices used to interconnect hydraulic pipes and tubing. Fittings may be screwed, flanged, or compression type. See Fluid Power, NavPers 16193-B, and chapter 12 for different types and uses of each.

FIRE POINT. - The temperature at which a substance, if ignited, will burn for at least 5 seconds. The fire point is always higher than the flash point.

FLASH POINT. - The temperature at which a fluid (such as gasoline) gives off sufficient vapor to form a flammable mixture with air.

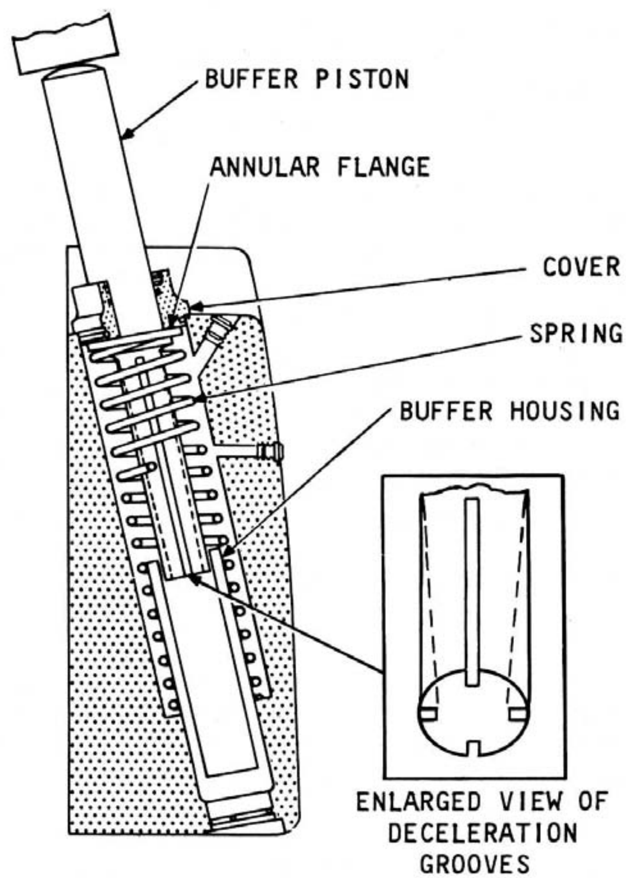

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Figure 8-2.—Hydraulic buffer.

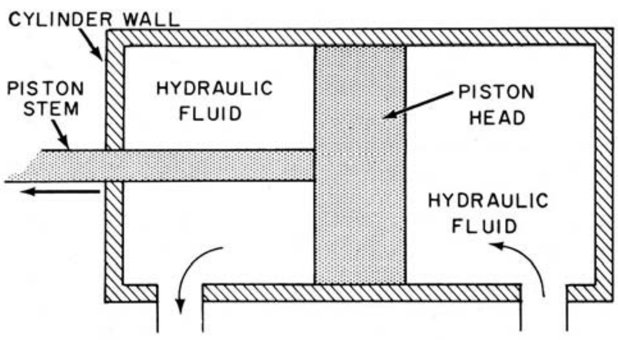

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Figure 8-3. — Cylinder and piston.

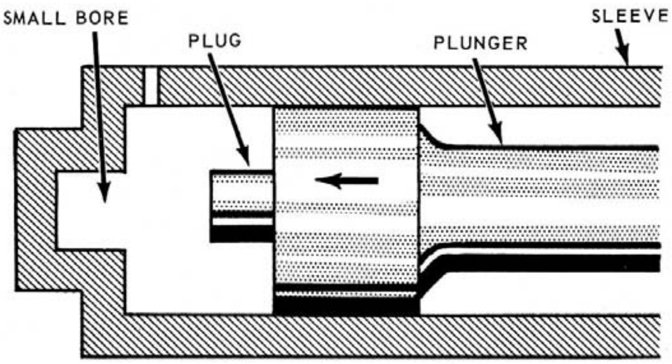

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Figure 8-4. — Dashpot.

FLOW RATE. - The number of units of volume of fluid passing through any channel in one unit of time. See Volume of Flow.

FLUID LEVEL GAUGE (GAGE). - An instrument which indicates the fluid level in a hydraulic system.. Sometimes called Tank Window. Refer to figure 8-8.

GASKET. - Material placed between mating surfaces of hydraulic fittings (flanges, etc.) to increase tightness of the seal.

GPM (GALLONS PER MINUTE). - The normal way of measuring the volume of flow rate in a hydraulic system.

HEAD OF FLUID. - Hydraulic fluid in a system that is maintained above the power drive level.

HOSE. - Flexible hydraulic lines.

HYDRODYNAMICS. - Study of liquids in motion.

HYDROSTATICS. - Study of liquids at rest, particularly regarding pressure and equilibrium.

INHIBITORS (OR ADDITIVES). - Chemicals added, during the manufacturing process, to hydraulic fluid to improve its ability to retard corrosion and foaming and to resist oxidation.

JIC SYMBOLS. - Graphic symbols for fluid power, used on hydraulic schematic diagrams. These symbols were originated by a Joint Industrial Conference of manufacturers of commercial hydraulic equipment. They are now included in MIL-STD-17B-2.

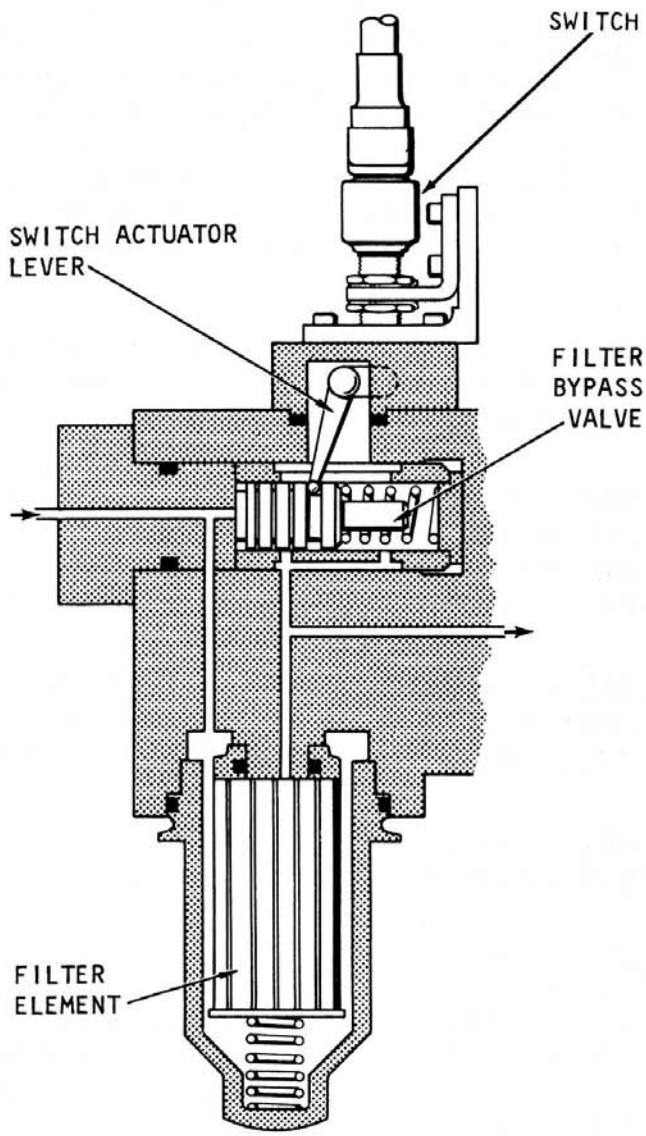

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Figure 8-5. — Filter.

ORIFICE. - An opening of relatively small size in a fluid passageway that controls or limits the rate of flow; a restriction. See figure 8-9D.

OXIDATION. - Chemical change in hydraulic fluid caused by oxygen which combines with the fluid during high temperature operation.

PACKING. - Hydraulic seal to prevent leakage around a moving part) such as a piston rod.

PASCAL'S LAW. - This law states that pressure applied anywhere to a body of confined fluid is transmitted undiminished to every portion of the surface of the containing vessel. This transmission of pressure through a fluid is the principle on which all hydraulic operation is based.

PASSAGE. - A machined hole or channel which lies in or passes through a hydraulic component and acts as a conductor of hydraulic fluid.

PICKLING. - A method of removing scale from the inner surfaces of piping and tubing. It is described in Fluid Power, NavPers 16193-B.

PISTON, CYLINDER OR BUFFER. - The moving part of a hydraulic cylinder or buffer. See figures 8-2 and 8-3.

PISTON, PUMP OR MOTOR. - The mechanical component of a pump or motor. The piston works in a cylinder and either moves the hydraulic fluid or is moved by it. Refer to figure 8-3.

PORT. - Opening in a surface of a component, usually where hydraulic fluid enters or leaves the mechanism" such as a valve, piston, or pump.

POUR POINT. - Lowest temperature at which a liquid will pour or flow.

PSI. - Pounds per square inch (pressure).

PUMP. - A device which converts mechanical energy to hydraulic energy. Following are short definitions of several kinds of pumps used in hydraulic systems.

Constant Delivery Pump. - A pump that delivers a fixed volume of fluid in a given time.

Axial Piston Or Parallel Piston Pump. - A pump in which the pistons rotate on a shaft in such a way that the pistons are driven back and forth in their cylinders in a direction parallel to the shaft. See figure 7-15.

Gear Pump. - A constant delivery pump with two or more intermeshing gears acting as the pump rotor (fig. 8-6).

Positive Displacement Pump. - A pump that discharges the fluid in volumes separated by a period of no discharge. A definite volume of liquid is delivered for each cycle. Pump types such as axial piston, gear, and vane may be considered to be several separate positive displacement pumps combined in one unit to smooth surges caused by periods of no discharge.

Rotary Pump. - A pump with rotor which carries the fluid from intake to discharge on a curved path. Vane and gear pumps (fig. 8-6) are classified as rotary pumps.

Variable Delivery Pump. - A pump that delivers a variable volume of fluid without changing the speed of rotation of the source of power..

REPLENISHING FLUID. - (Also called Supercharge Fluid.) Fluid that is used to replace any volume loss in power drive transmission lines (lines between A-end and B-end).

RESTRICTION. - (Also called Choke or Orifice.) A device which produces a deliberate pressure drop in a line or passage by means of a reduced cross-sectional area (fig. 8-9D).

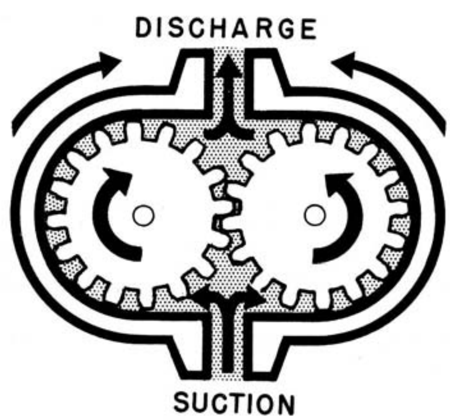

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Figure 8-6.—Gear pump.

SEAL. - A part or assembly of parts used to prevent leakage of hydraulic fluid. Compare with Gasket and Packing.

SERVO FLUID. - Control pressure fluid in the hydraulic portion of the servosystem.

SLUDGE. - Gummy deposit caused by hydraulic fluid breakdown, mainly due to oxidation.

STRAINER. - A device for removal of dirt, sludge, and lint from fluid wherein the resistance to motion of such solids is in a straight line, as when pouring fluid into the system. A strainer is sometimes called a screen (fig. 8-7). It may be simply a funnel with a 200-mesh wire screen fitted in it.

STROKE PISTON. - Normally, a hydraulically controlled piston that controls the output of an axial piston variable delivery pump (fig. 7-15).

SURGE. - A transient rise of hydraulic pressure in a hydraulic system.

TANK. - Container for the hydraulic fluid in the system. Several types are described below and illustrated in figure 8-8.

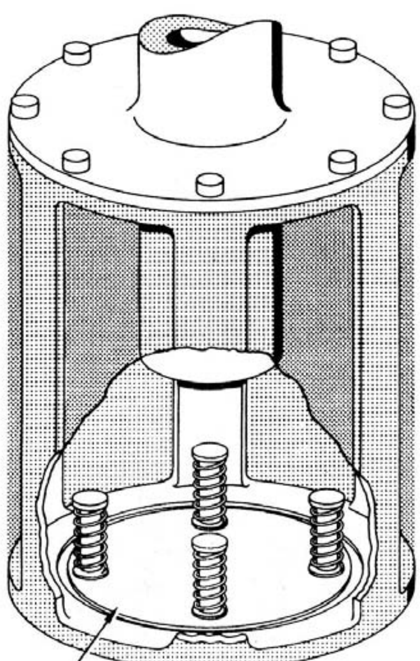

Figure 8-7.— Pump intake strainer (screen).

Expansion Tank (Header Tank). - This tank, located above the hydraulic system, provides space to allow for expansion and contraction of the hydraulic fluid in the system due to temperature changes. It also maintains a head of fluid to prevent entry of air into the system.

Reservoir. - (Also called Supply Tank.) The power drive tank used to maintain a supply of working fluid which may be drawn from as needed.

Sump Tank. - A tank usually enclosed within a power drive reservoir or supply tank to ensure available space for drainage from the receiver regulator.

TILT PLATE (OR TILT BOX). - The plate which is suspended by two trunnions and is moved by the stroke piston(s) to control the output of a variable delivery radial piston pump (fig. 7-14).

TRANSMISSION FLUID. - Hydraulic fluid located in the lines between the A-end and the B-end.

TUBING. - Copper, brass, or steel hydraulic lines. It is common practice to call small hydraulic lines tubing and large lines piping. However, there is no official distinction made.

VALVE. - A device for controlling flow rate, flow direction, or flow pressure. Some types of valves commonly used in hydraulic systems are described below. Numerous variations are designed for specific applications.

Valve Block. - Several closely associated valves can be organized into a valve block so they can be more readily controlled, and coordinated. Many combinations are possible.

Bypass Valve. - A valve used to let a volume of fluid bypass a hydraulic component (fig. 8-5).

Check Valve. - A device which permits hydraulic fluid to flow in one direction only (fig. 8-9A).

Directional Control Valve. - A valve which directs the flow or passage of fluid in a hydraulic system (fig. 8-9B).

Dump Valve. - A valve which, when actuated, dumps hydraulic fluid trapped in an accumulator system. It is normally manually operated. (See fig. 8-9C). The fluid is returned to the supply tank.

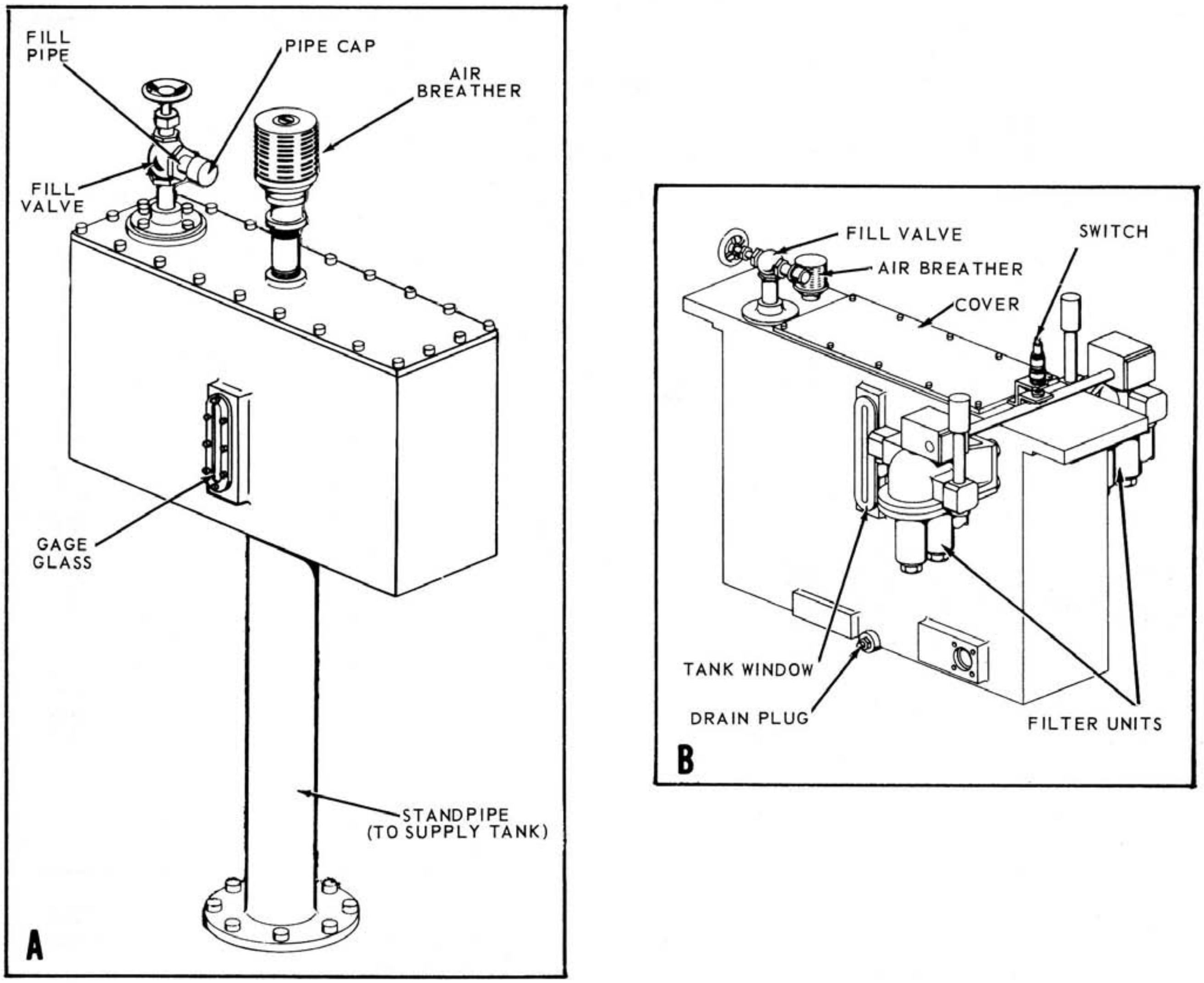

Figure 8-8.—Types of hydraulic fluid tanks in missile systems: A. Expansion (header) tank; B. Reservoir (supply tank). 83.178

Flow Control Valve. - This valve maintains a preset rate of flow regardless of pressure variations at the inlet or outlet (fig. 8-9D).

Gate Valve. - A manually operated valve that controls the flow of fluid by means of wedge (gate) which can be moved up or down across the line of flow. It is usually operated by a hand- wheel.

Globe Valve.-A manually operated valve that controls the flow of fluid by means of a plug, ball, or disk, which may be raised from or lowered into the valve seat.

Pilot Valve. - A valve that controls the action of another valve.

Poppet Valve. - A valve in the hydraulic end of a bag accumulator (fig. 8-1). It prevents the synthetic bag (containing the pressurized gas) from extending into the hydraulic manifold when there is no (or very little) hydraulic fluid in the accumulator flask. See fig. 8-9E.

Relief Valve.-A valve which limits the maximum pressure applied to the portion of a hydraulic system to which it is connected. If the

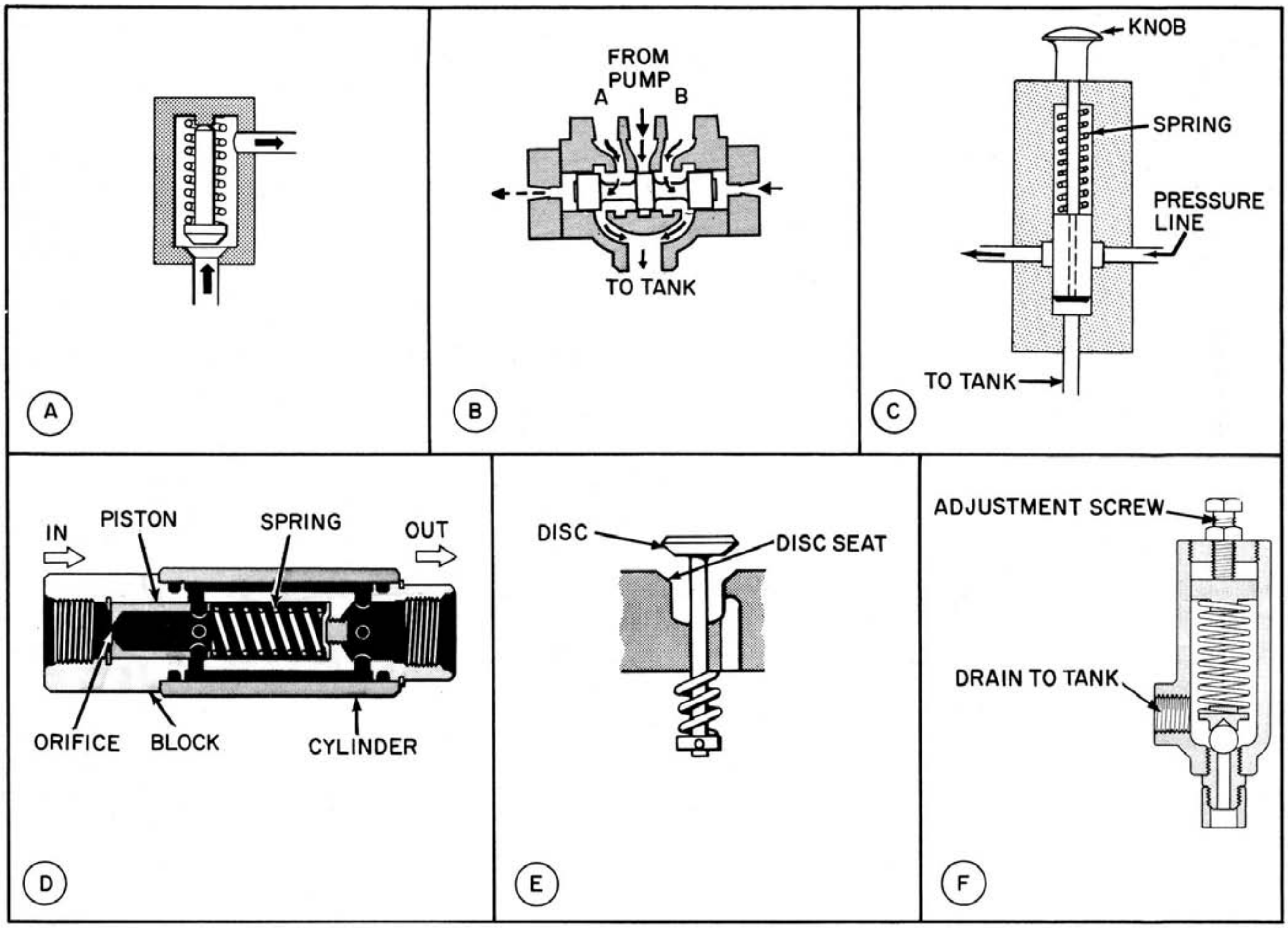

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Figure 8-9.—Some common types of valves: A. Check valve; B. Directional control valve; C. Dump valve; D. Flow control valve; E. Poppet valve; F. Simple relief valve.

pressure exceeds this limit, the valve opens and releases some of the hydraulic fluid. Figure 8-9F shows a simple relief valve.

Servo Valve. - Also called Pilot Valve or Control Valve. This valve is in the hydraulic portion of a servosystem that is normally controlled by an electrical error signal and that originates the hydraulic control signal.

Unloading Valve. - A valve used in accumulator power drives. It directs pump output to the accumulator or tank, in accordance with system demand. Fluid in excess of pressure requirements is returned to the tank.

VELOCITY. - Rate or speed at which fluid is moving at a given point in a hydraulic system.

VENT (Verb). - To remove air from a hydraulic system.

VENT (Noun). - A threaded plug or needle valve used to remove air from a hydraulic system.

VISCOSITY.-Measure of a hydraulic fluid's resistance to flow. Temperature affects the viscosity of hydraulic fluids.

VISCOSITY INDEX (V.I.). - Rate at which the viscosity of a fluid changes with the temperature.

VOLUME. - Quantity of hydraulic fluid.

VOLUME OF FLOW. - The quantity of fluid, usually measured in gallons per minute (GPM) that passes a given point in the hydraulic system in a given time.

LAUNCHER POWER DRIVES

Chapter 7 discussed the launcher power drives from the standpoint of electrical and electronic action required. The hydraulic components were given only incidental mention, with the exception of the operation of the A-end and B-end. This chapter will emphasize the work of the hydraulic parts of the power drives.

MAIN COMPONENTS OF POWER DRIVE SERVOLOOP

As described and illustrated in chapter 7, you know that there are two separate systems for moving the launcher; one power drive system moves the launcher in train, another system moves it in elevation (or depression). Each one has a prime mover (which is an electric motor) an A-end hydraulic pump, a B-end, mechanical shafting and gearing, and means of transmitting signals received. The operation of the A-end and the B-end was described in the preceding chapter and in Fluid Power, NavPers 16193-B, so there is no need to repeat it here.

Electric Motor

The electric motor not only drives the A-end but also the replenishing pump, the control pressure pump, and the sump pump and oscillator. Since the speed of the A-end is much less than that of the electric motor, it is necessary to use reduction gears between them. (Basic Machines, NavPers 10624-A, explains how reduction gears work.) Reduction gears are also used between the electric motor and the pumps it operates.

A-end and B-end Response Linkage

The response is the quantitative output resulting from the input. If the response is linear, the output is the same quantity as the input.

The transmission lines between the A-end and the B-end are the hydraulic lines that carry the hydraulic fluid, and the valves and gears that control the quantity of flow. Pipes, tubing, and passages (defined at the beginning of the chapter) form part of the transmission lines.

Components of Components

Each of the main components of a hydraulic system is made up of many parts, similar in many respects in different systems. A supply of hydraulic fluid is required; the tank containing it may be called a reservoir or a supply tank. See figure 8-8B. As the system operates, the fluid becomes heated and expands. An expansion tank receives overflow of fluid so that pressure does not build up in the lines. See figure 8-8A. Leakage can drain into a sump tank. Filters are located at several points. Filters have to be cleaned when they become clogged; follow the instructions in the applicable OP when you need to do this. Some filters have a replaceable filter unit that is discarded when it becomes clogged. If it is not possible to take care of the filter at the time, the filter assembly valve block will bypass fluid around the filter element to the system to prevent starving the system of fluid. When this occurs a filter bypass switch actuated by the bypass valve will close, to complete a circuit to a filter clogged indicator light on the control panel. The trouble should be remedied as soon as possible, for unfiltered fluid can cause further trouble such as scored valves which, then must be removed and repaired or replaced.

The definitions at the beginning of the chapter listed and illustrated several kinds of valves and briefly gave the function of each type. This is far from a complete list; many more are described in Fluid Power, NavPers 16193-B. Some of them operate automatically, as when pressure reaches a certain point; others are operated manually. The operating power maybe hydraulic, pneumatic, or electrical which may use mechanical devices to actuate the valve. A spring- actuated valve is an example of use of a mechanical device to open or close a valve. The successful operation of any hydraulic system is dependent on its valves. You need to learn the location and use of each valve in the system on which you work. Whenever a hydraulic system is not operating properly, one of the first things to do is to check the valves involved. You need to learn how to dismantle, clean, and reassemble valves. Some general instruction on the installation and maintenance of valves may be found in Fluid Power, NavPers 16193-B, but you need the appropriate OP for your equipment for directly applicable instructions.

When reading chapter 5 you may have noticed how many of the launching system components are operated hydraulically- magazine rail latch, positioner, hoist, speed reducer, retractable rail, power-off brake, and many more. To be operated hydraulically, each part must be connected to pipes or lines that carry the hydraulic fluid. That means there are a great many connecting lines behind the scene. You can see why you need to know types and uses of pipes, fittings, seals, and gaskets. Replacement of gaskets and seals or sections of pipe are frequent assignments for the GMM.

Gear Pumps

The dual gear pump (fig. 8-10) is operated by the electric motor. It draws hydraulic fluid from the supply tank and supplies both servo and supercharge pressure fluids. A dual gear pump actually consists of two gear pumps in one housing. The gears differ in width, which allows for difference in fluid volume, although both are driven at the same speed. It is also called an auxiliary gear pump, and it ports the hydraulic fluid to the control mechanism.

Control Mechanism

The control mechanism is not actually a part of the power drive itself but is directly related to its operation. It governs the operation of the CAB unit. It uses the pressure fluid ported to it by the gear pump. The servo pressure is used to shift valves, release the power-off brake, and position the stroking pistons. The supercharge pressure is used to replenish fluid lost through slippage and leakage and to supply the main relief valve. The control mechanism is mechanically linked to the A-end and the B-end and continually receives indications of tilt angle and B-end motion. When the control assembly receives a signal (from the computer) ordering the driven equipment to a new position, it establishes the difference between the existing position of the equipment and the ordered position.

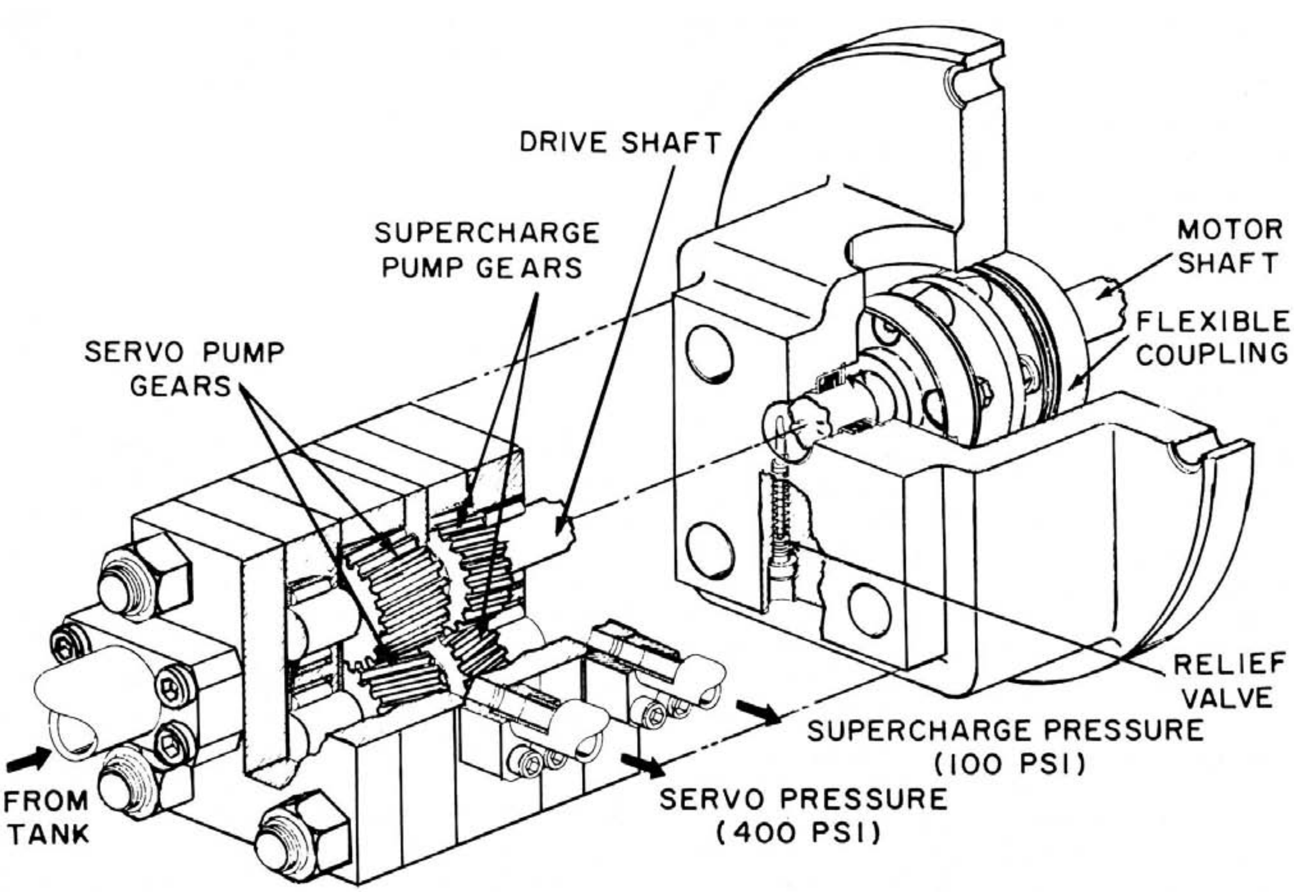

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Figure 8-10. — Dual gear pump on typical CAB power drive.

This error is then translated into valve movement. Regulated pressure fluid is ported to the stroking pistons. This moves the A-end tilt plate to the desired angle. The A-end then supplies pressure fluid to the B-end, which drives the equipment to the ordered position.

Control assemblies are generally mounted on top of the power drive, but may be mounted on the side.

Main Relief Valve

This valve is connected to the two lines between the A-end and the B-end (fig. 7-15). It is a compound valve designed to prevent excessive pressure in the high pressure line or A-end discharge line. When the pressure in one line exceeds the preset limit, the valve ports the excess to the other, or low pressure, line.

Power-Off Brake

The power-off brake, an associated component of the CAB unit, secures driven equipment against pitch and roll of the ship when the system is inactive, holds and secures the equipment in event of a power failure, and provides a manual means of operation (handcrank or air motor) for emergency operation, or installation and maintenance procedures. The brake usually is located adjacent to the B-end, fig. 8-11, and mounted to a geared speed reducer coupled to the B-end drive shaft. The brake shaft is driven by the speed reducer' shaft before the gear train increases the torque.

Figure 8-12 shows a cut-away of a typical power-off brake. Principal components of the brake assembly are the brake shaft, friction disc, disc housing, the worm and worm wheel, the worm shaft and clutch assembly, brake release piston, and the brake housing.

One end of the brake shaft is geared to the B-end output shaft. The other end, as shown in fig. 8-12, is splined to the inner discs. These inner friction discs alternate with the outer friction disc, and the outer disc are splined to the disc housing.

Since the disc housing is fastened to the worm wheel and can only be turned through handcrank operation, the outer friction disc are classed as stationary (whereas the inner friction discs rotate with the brake shaft).

Braking occurs when the spring-loaded pressure plate presses the rotating discs into contact with the stationary discs. Since the brake shaft has a positive gear-drive relationship with the B-end output shaft, this action also holds associated driven equipment.

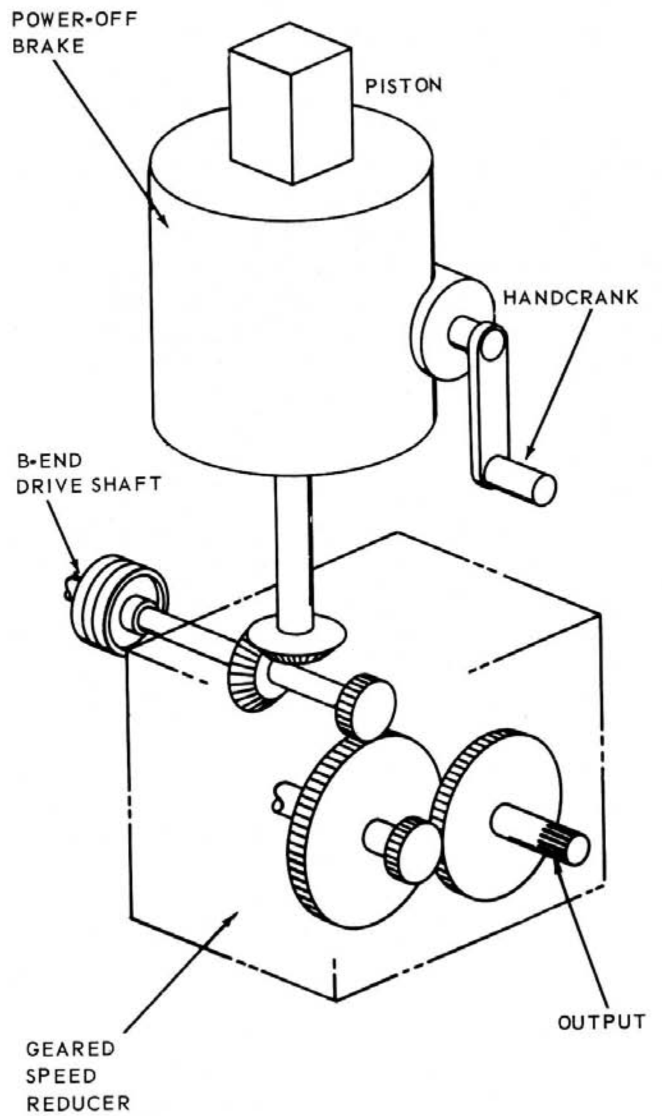
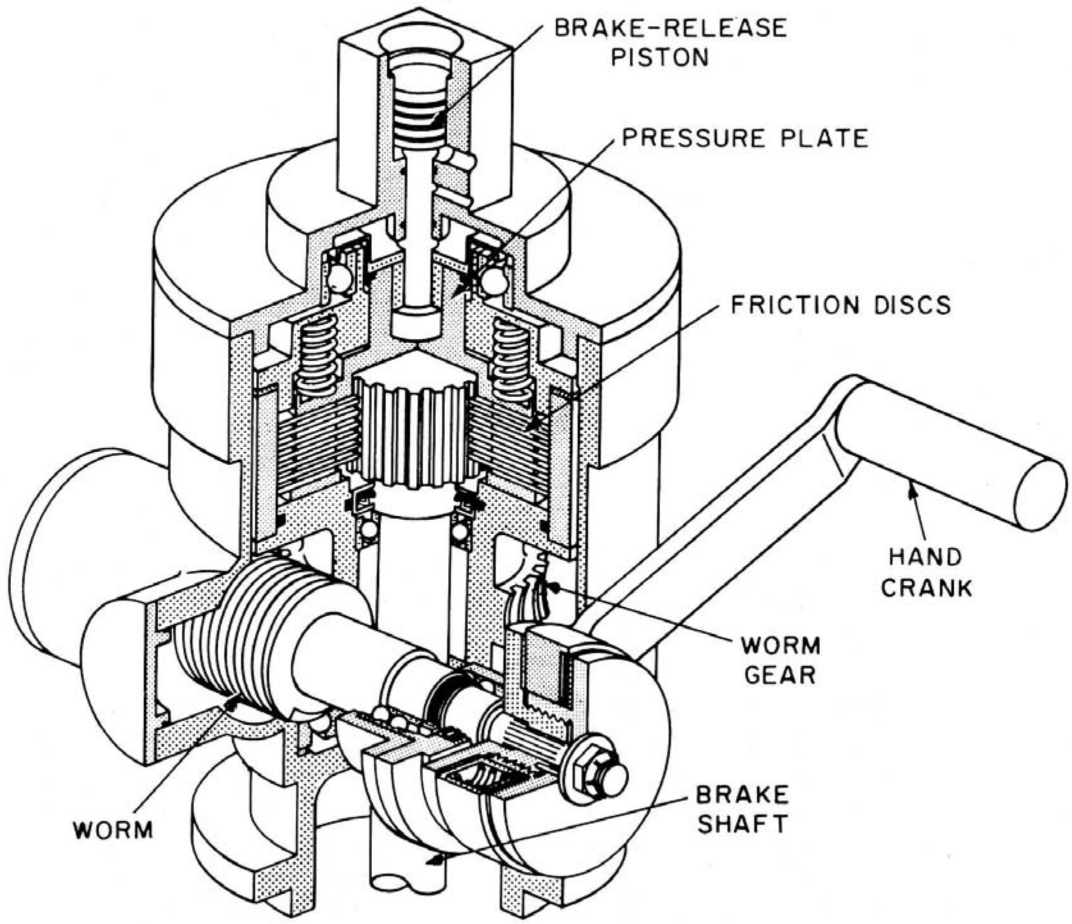


Figure 8-11.—Power-off brake location.

During normal CAB unit operation (B-end rotating), hydraulic pressure is ported to the power-off brake and acts on a brake-release piston which is attached to the pressure plate through a connecting rod. The subsequent force exerted by the piston compresses the pressure springs. This action releases the friction discs to permit free rotation of the brake shaft.

When the CAB unit is shut down, the resultant pressure drop to the release piston allows the spring-loaded pressure plate to force the friction disc into braking engagement.

Whenever the brake is set, the worm wheel is connected (through disc contact) to the brake shaft. Consequently, the brake shaft can be turned only by handcrank rotation of the worm.



83.201
Figure 8-12.— Power-off brake (typical).

The worm is the mechanical counterpart of the hydraulic check valve. Both transfer motion in one direction but not in the reverse direction. The worm self-locks in one direction of motion because of the low helix angle of the worm thread.

Most power-off brakes are designed with a manual drive input to which a handcrank or air motor may be attached for emergency operation, or for installation and maintenance procedures. The train and elevation system have separate power-off brakes. The brakes differ somewhat in different applications. The number of friction discs varies with different mods but they function in the same manner.

LAUNCHER RECEIVER-REGULATORS, TRAIN AND ELEVATION

A receiver-regulator is a component of a gun mount or launcher power drive that receives order signals from a remote or local station, compares these signals with the train and elevation positions of the launcher (or gun), and generates error signals to control the movements of the power drives to correct the launcher position. Most of the receiver regulators used with launchers are similar in design and operation.

In normal operation, remote orders are supplied by the assigned fire control system. The principal function of the receiver-regulator and the servo amplifier is to convert electrical order signals into hydraulically powered movements. These movements control the velocity, acceleration, deceleration, and position of the launcher carriage and guide arms. The B-end output of the train system .drives the launcher carriage, while the B-end output of the elevation system drives the launcher guide. When the launcher is synchronized to the director orders, the missile is ready to be fired.

The launcher receiver-regulators (train and elevation) are part of the basic power drive servoloops, each of which also includes a hydraulic pump (A-end), hydraulic motor (B-end), and the A-end and B-end response linkage.

The receiver-regulator is mounted on a stand, directly over the A- and B-ends (CAB unit). In outward appearance, the receiver-regulator is a metal box with connections to other units, and a dial (fig. 8-13). The inside is packed with

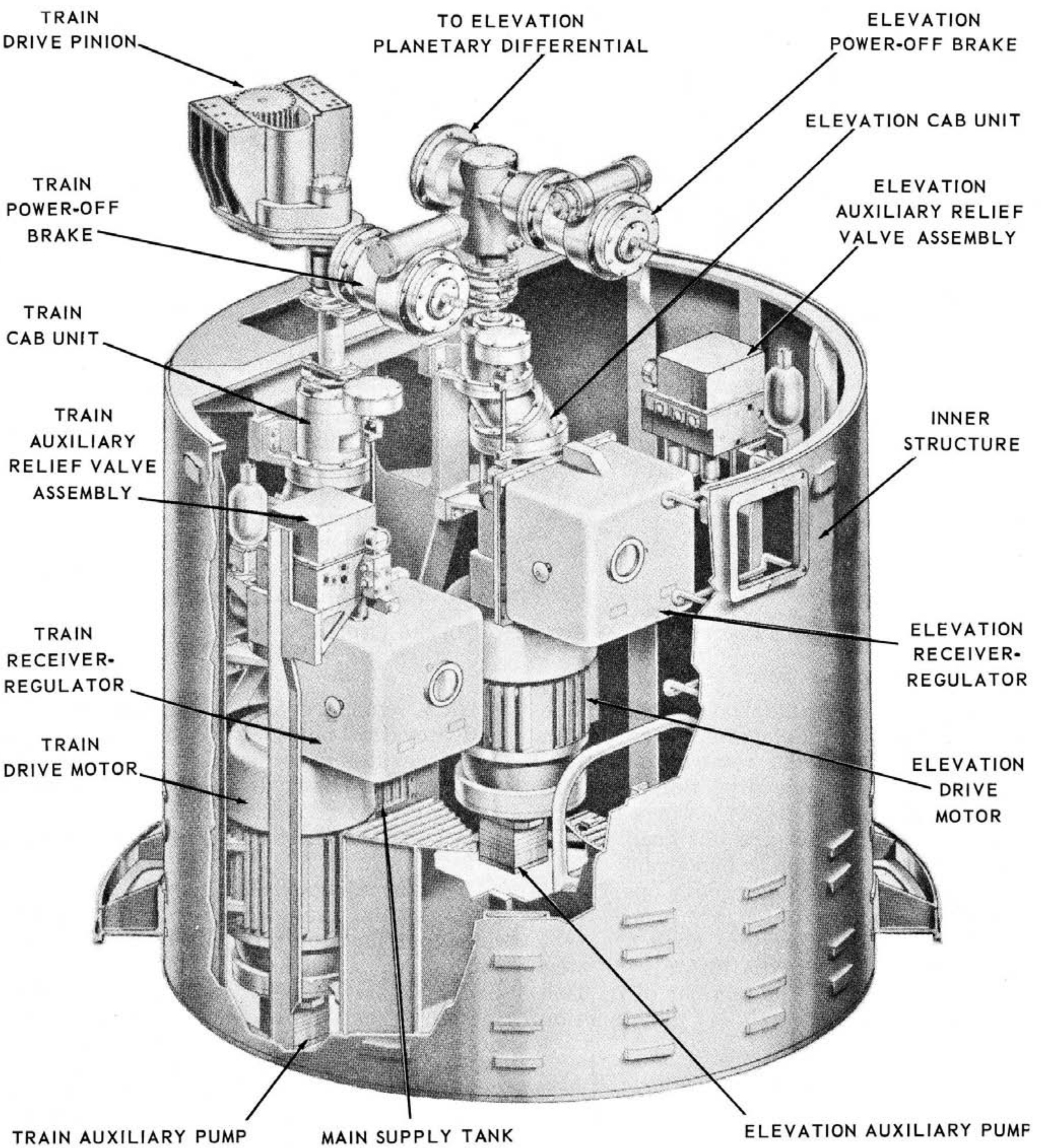


Figure 8-13.—Train and elevation power drives, Mk 13 Mod 0 launching system (Tartar).

an assortment of complex equipments. In figure 8-14, locate the parts described in the next few paragraphs. These components are connected to components outside the receiver-regulator to perform their functions. The operation is intricate and we will give only briefly the work of the main components.

Main Valve Block

The main valve block of the receiver regulator contains the components (valves, pistons, switches) that are used by the primary, velocity, integration, and stroke servosystems. Only a few of the parts (there are about twenty valves, etc.) are visible in figure 8-14. The dither transformer (TPTD2) is mounted on top of the valve block along with its adjustment, the dither potentiometer (RATD4), which controls the amplitude of the dither input. The stroke control and integration actuating levers, not seen in figure 8-14, are mounted on the right-hand end of the valve block. The primary electrohydraulic servovalve (BCTD1) converts the amplified primary electrical error signal to a hydraulic signal.

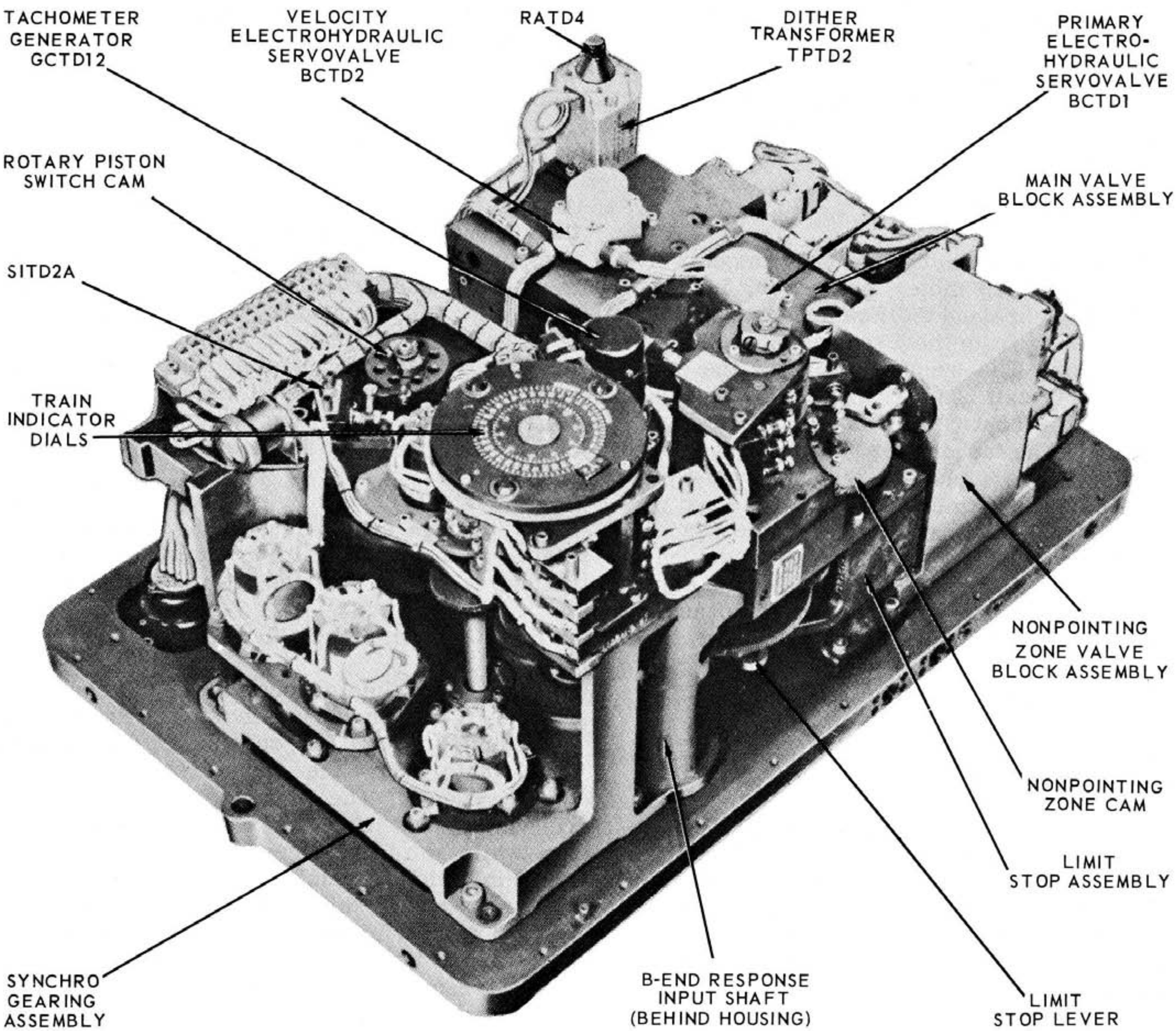


Figure 8-14.—Train receiver regulator, Mk 5 launcher, Mk 10 launching system (Terrier).

The velocity electrohydraulic servovalve (BCTD2) converts the amplified electrical velocity and integration signal to a hydraulic signal.

Rotary Piston

The rotary piston is located below the rotary piston switch cam. It consists of a cylinder, piston vane, piston stop, piston cam, two response gears, and a switch cam with its associated switch. Two hydraulic fluid ports lead to the piston cylinder which is divided into two hydraulic chambers by the piston vane and piston stop. If the pressure is equal in both chambers, the piston vane remains stationary. If the pressure is unequal, the cam moves toward the lower side. This moves the rotor shaft which is connected to the rotors of the 1-speed and 36-speed control transmitter (CX). The indicator dials show what movement has taken place.

Synchro Gearing Assembly

The synchro assembly (fig. 8-14) mounts five synchros, the tachometer generator, indicator dials, the switches and their cams, a transformer, and the gearing from the B-end response and the stroke piston. The synchros receive the order signal (electrical) and transmit the launcher position to the control panels and the fire control system. The tachometer generator transmits a launcher speed (velocity) signal for test purposes. The transformer steps down the a-c voltage for dial illumination. The indicator dial indicates the launcher position and is driven by the B-end response. The switch cams are driven by the B-end response and are used to actuate the switches that indicate the launcher train position. Although train and elevation synchro assemblies appear identical, there are differences.

Limit-Stop System

The train limit-stop system includes the limit-stop assembly, the nonpointing zone valve block, and a part of the A-end response assembly. This system acts as a safety device to stop launcher movement whenever it is necessary for safe or proper operation. The elevation limit-stop assembly is similar to the train limit-stop assembly except that it has a gear and rack (instead of a nonpointing zone cam). The cams must be designed and cut for each ship so the missiles will not be pointed into any part of the ship's structure.

Non-Pointing Zone Valve Block

This is also known as the tracking cutout valve block. It contains nonpointing zone pistons and their associated valves and solenoids. The limit stop actuating shaft leads through the base of the valve block and connects to the servovalve linkage. Each piston is controlled by one of the nonpointing zone solenoid valves; the train valve block has two and the elevation valve block has three.

The nonpointing zone components prevent the launcher with loaded guide arms from training or elevating into any part of the ship's structure, stopping the train power drive if necessary and introducing an elevation order that elevates the launcher above the nonpointing zone.

A-End Response Assembly

Figure 8-14 does not show the lead-in for the A-end response assembly but does show components to which it transmits. The movement of the A-end tilt plate is transmitted to the limit stop assembly and the train limit stop valve. The A-end response also positions the sleeve of the stroke control servovalve and a switch cam. When it is not necessary to operate the limit-stop systems, transmission of launcher position and launcher velocity continue.

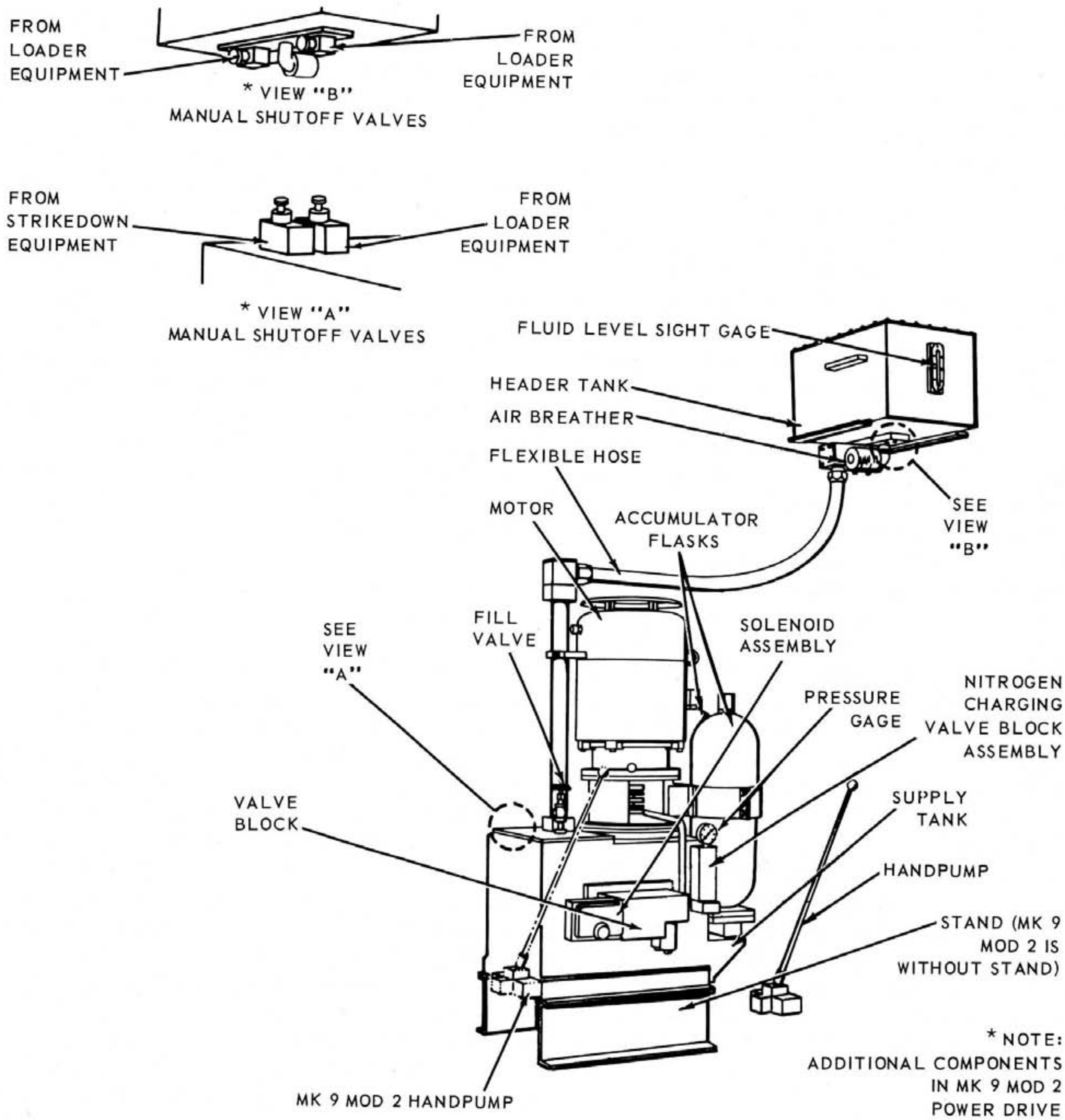
The shaft of the A-end response assembly leads through an opening in the regulator base plate, approximately in the center of the regulator, inboard of the limit-stop assembly.

B-End Response Assembly

The approximate location of the B-end response input shaft is shown in figure 8-14. It extends through an opening in the regulator base plate near the lower center section of the regulator. The lower gear of the B-end response input shaft drives the synchro gearing while the upper gear of this shaft drives the limit-stop assembly. When the B-end rotates, it drives the launcher, through a gear reduction unit, at the speed and in the direction determined by the error signal. A mechanical B-end response signal is fed back to the CTB stator in the receiver regulator. This response signal cancels the order signal when the order has been satisfied. The B-end response is often referred to as "position."

OTHER POWER DRIVES IN LAUNCHING SYSTEMS

Not all the hydraulic systems in the launching system belong to the A-end- B-end type. Hydraulic power for operation of the launching system is not furnished by one big hydraulic system, but by several independent systems. Several of these systems are of the accumulator type. The main components of the accumulator type are: (1) electric motor; (2) gear pump; (3) control valve block; (4) accumulator; and (5) accumulator charging valve and pressure gage. See figure 8-15. Of course, it also has to have a supply tank for the hydraulic fluid. An important difference between the accumulator type and the CAB type described previously is in the use of accumulator flasks, such as the one shown in figure 8-1, to keep a supply



83.183
Figure 8-15.—Accumulator type power drive system for loader (Terrier).

of hydraulic fluid ready for instant use at the desired pressure. Most systems have two or more such accumulator flasks. The accumulators are pressurized with nitrogen. The bladder inside the flask is charged with nitrogen through the nitrogen charging assembly (fig. 8-15). Nitrogen is used because it is not a fire hazard where oils are used.

On Terrier systems, the loader has two types of power drives, a CAB type which operates the loader chain, and an accumulator power drive, which is in the strikedown area and provides power for the spanning rail, blast doors, floating tracks, tilting rail, and other loader components. The magazine power drive is also of the accumulator type. It supplies the power to the ready service rings, tray shifts, hoist drive, load status recorder, magazine doors, and, in the Mk 10 Mod 7, to the lower ready-service ring under inter-ring transfer conditions.

The guide arm components on the Mk 5 launcher (used in the Mk 10 launching system) are operated by an accumulator type hydraulic system. Its electric motor is sometimes called "launcher rails motor" on electrical diagrams. Older mods of the accumulator had manually operated shutoff or dump valves, but Mk 5 Mod 3, and later launchers, have solenoid operated dump valves for the accumulators. Functionally, the different mods are the same and use the same major components.

A load status recorder was mentioned above. There is a load status recorder for each ready service ring in the magazine. It shows what type of missile is loaded in each space in the ready service ring. If a missile is moved from a tray, the change is shown on the recorder (also called an indicator). No personnel are stationed in the magazine so these indications on a recorder in the magazine are of no use is anyone. The information must be displayed where it will be of use; this is on the control panels. "Load status" indication is not shown as such on any panel except through the various circuits which may, in turn, indicate loaded, empty, or dud stations on the circular light patterns on the panels (EP2 and EP4, EP5). See figure 5-17. The load status recorder is operated hydraulically and mechanically but the information is sent to the panels through electrical relays.

POWER DRIVES FOR SMALLER LAUNCHING SYSTEMS

"One-armed" launchers such as the Mk 13 and the Mk 22 (Tartar) might be considered "smaller" launchers. They use hydraulic power for the same operations as the largest launching systems although they do not need as many systems nor such large ones. The power supply for the magazine of the Mk 13 system uses one A-end hydraulic pump to drive two B-end hydraulic motors. One B-end drives the ready service ring and the other drives the hoist chain, but not simultaneously. The train and elevation systems on the launcher each have an A-end and a B-end type power drive to train and elevate the launcher, but share one header tank, which is mounted in the stand. (The header tank for the magazine power supply is also mounted in the stand.) In the Mk 22 launching system, the train power drive system also drives the hoist and operates the associated latches and pawls. The train system and the hoist system have separate controls and separate gear reducers but one power drive system. During hoisting operations the training mechanism is latched, and vice versa.

The Mk 13 (Tartar) system has an additional power system to operate the launcher guide arm and the blast door. The header tank is a part of the guide arm; the main tank is a part of the base ring, and the other components are mounted to the underside of the base ring weldment. There is an electric motor which drives the rotary gear pump, the control valve block and three accumulator flasks, a solenoid valve assembly, and a plunger. The rotary gear pump is submerged in the main tank.

HYDRAULIC POWER IN STRIKEDOWN, MATE, AND LOADING OPERATIONS

The same power system is used for loading a missile on the launcher and for returning it to the ready service ring. Automatic unloading in just a matter of reversing the steps (Each installation has charts posted at the control panel, listing each step.) However, if the missile is to be struck down to any other area, such as testing and checkout areas, other power systems are involved. Periodic tests are required for all is just a matter of reversing the steps in the loading process. (Each installation has charts posted at the control panel, listing each step.) However, if the missile is to be struck down to any other area, such as testing and checkout areas, other power systems are involved. Periodic tests are required for all missiles and, for these, the missile must be unmated from the booster (except Tartar and Standard) (MR). This work is done in the strikedown and checkout area. This area has been identified in several illustrations.. See figures 5-1, 5-4, 5-8, and 5-11. The location with relation to the rest of the launching system varies with the weapon system and the ship, but it is as close as possible to the ready service rings. (The Tartar systems do not have such an area as the weapons are checked out on the launcher arm.)

As you can see in figure 5-4, a missile brought up from the magazine (ready service ring) can be sent to the strike down and checkout area instead of to the launcher. Step control must be used for this operation. The loader trunk sections extend into the strikedown area (fig. 5-11). Here the strikedown car receives the weapon. The hoists, cranes, checkout car, booster cart, and other equipment in the strikedown area are operated from ship's power source which can be either electric, pneumatic, or hydraulic.

The checkout mode is also used for removing missiles from the ship. Terrier and Talos rounds must be unmated and the missiles and boosters transferred separately.

When received by the ship, Terrier, Standard (ER) and Talos missiles and boosters are in separate containers, except when transferred by Fast system, in which case they are not containerized. They are moved to the strikedown and checkout area by a hydraulically operated elevator where they are handled with the aid of the checkout car and the booster cart.

Chapter 14 will tell you more about your work in this area. This will include missile replenishment, missile mating and unmating, and preparing missiles for tests.

PNEUMATIC POWER

Although hydraulic power is used for moving most of the parts of a missile launching system, from positioning heavy missile launchers to nudging tiny valves to open or close, there are some items that use pressurized air for power. Connections to the ship's pressurized air system are available in some of the spaces, especially where testing and checkout are to be done. Cylinders of compressed air may be used in some instances.

AIR OPERATED POWER UNIT

When Tartar missiles are struck down to the magazine for replenishment or are off-loaded, the launcher is used but auxiliary equipment is needed. The strikedown gear used (fig. 8-16) with the Tartar missile consists of an air-driven chain fixture, a manual control valve (portable), and an electrical control box. The electrical control box is a hand-held, portable apparatus that permits the launcher captain to be on deck in full view of the launcher while controlling the launcher by means of the pushbuttons and switches on the control box. It is used for positioning the launcher during strikedown, checkout, or E-section removal. Illustrations may be seen in the OP. The strikedown gear is removed and stowed when not in use.

The power for the unit is supplied by the ship's compressed air system. Flexible hoses are used to make the connection to the ship's supply.

The compressed air is not used directly in the same form in which it is stored but is converted to mechanical energy. The potential energy in the compressed air is changed to mechanical energy through an air motor, located adjacent to the chain drive, where it drives a gear train. An air motor, when coupled to an electric generator, may also be used to supply the electrical energy to drive a hydraulic system.. Figure 8-17 A is a sketch of a basic pneumatic system. The air is led from the compressed air flask or the ship's supply line, through a pressure reducer, then to the air motor or air turbine. On the Tartar strikedown unit shown in figure 8-16, the pressure regulator reduces the air pressure to 20 psi.

The air motor shown in figure 8-17B works on the principle of differential areas. (This is not the one used in the Tartar system.) The motor consists of a rotor with freely sliding vanes mounted in recesses around its outer edge. The rotor is eccentrically mounted in its housing as shown in the figure. When the rotor is in motion the vanes tend to slide outward due to centrifugal force. The distance they can. slide is limited by the eccentricity of the rotor housing. When the compressed air is ported into the inlet, its pressure is exerted equally in all directions. Since area "A" is greater than area "B", the rotor will turn counterclockwise. Each vane in turn assumes #1 and #2 positions and the rotor turns continuously. The potential energy in the compressed air is thus converted into kinetic energy. The air at reduced pressure is exhausted to the outside. The shaft of the motor is directly coupled through gearing to the unit it is to drive (in fig. 8-16, the chain drive unit).

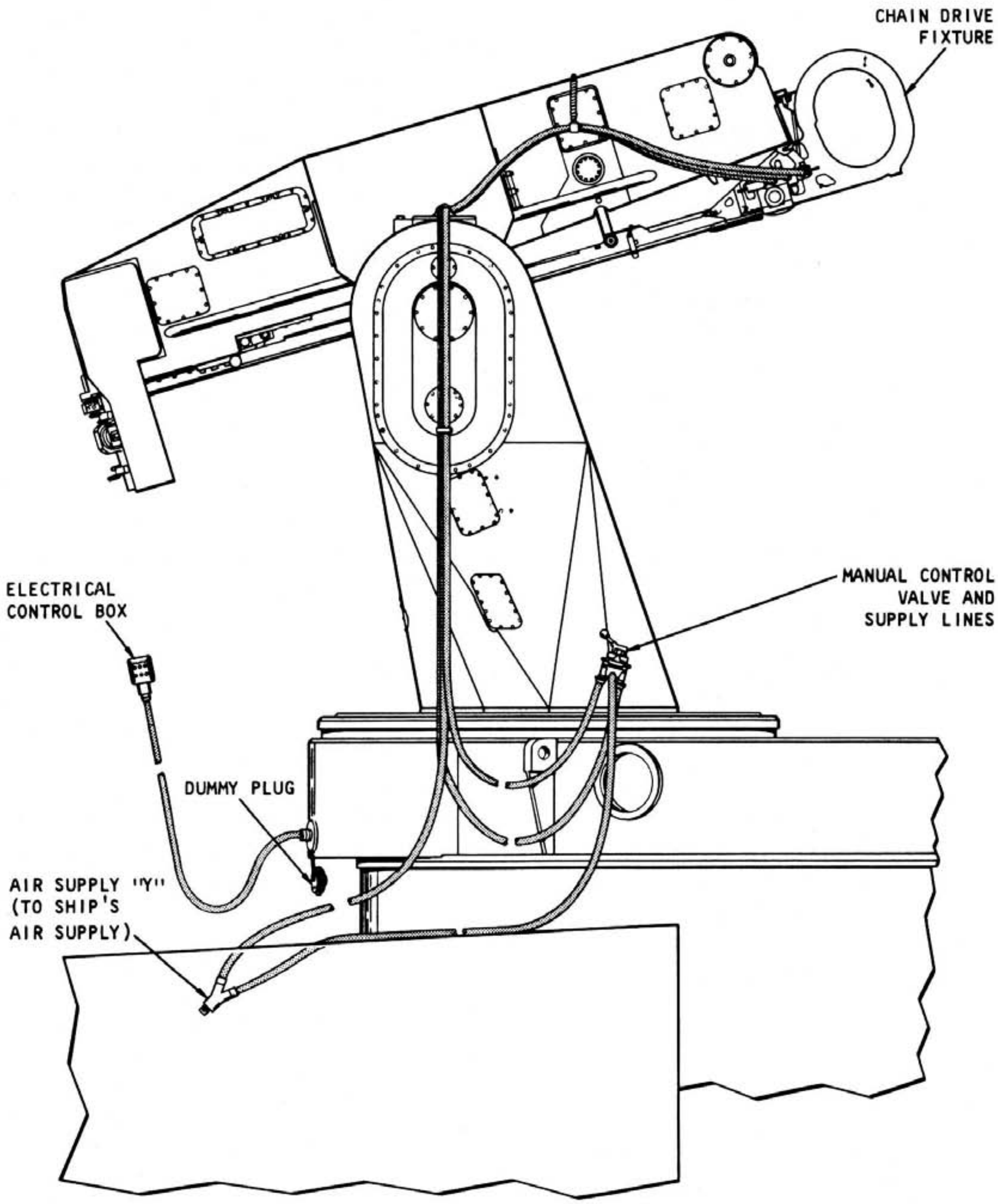


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Figure 8-16.—Strikedown gear attached to Tartar launcher (Mk 13 Mod 0 system).

DUD JETTISON DEVICES

There are several methods of disposing of dud missiles. Most often the missile is returned to the magazine to be checked out, tested later, and defective parts replaced. When it is necessary to rid the ship of a dud missile, the launcher is used with the dud jettisoning unit. The Talos system uses an emergency igniter injector on the launcher (fig. 5-23), but other systems have a jettisoning unit that pushes the missile overboard without firing it. The Terrier systems and the Tartar Mk 11 system use dud jettison units that are hydro-pneumatic systems powered by compressed air from the ship's high pressure air supply. The Mk 13 launching system (Tartar) uses compressed nitrogen from an accumulator. The installation arrangements vary

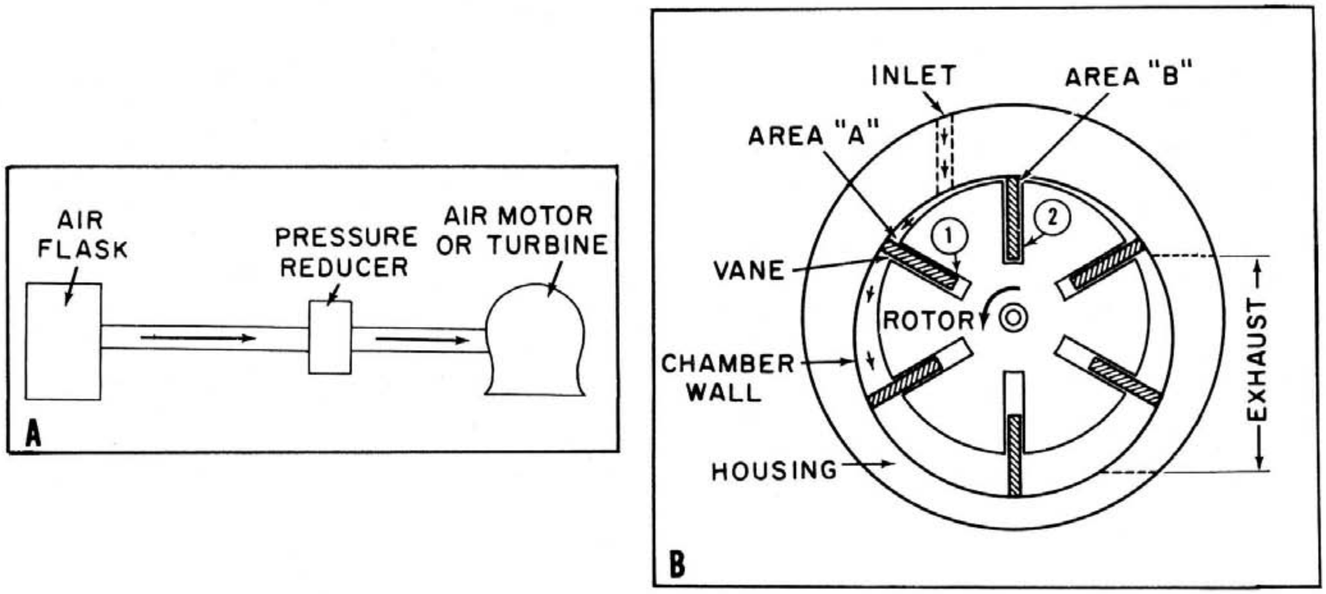

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Figure 8-17.—Pneumatic power: A. Basic pneumatic system; B. Air motor.

for the different Terrier mods but the operating principles are the same. The deck location of the dud ejector is shown in figure 6-5. and in several of the illustrations in chapter 5. The major portion of the dud ejector is below deck when not in use (not extended). The launcher holding the dud missile is trained and elevated to align with the dud ejector. The dud jettison unit is operated from the dud jettison control panel (fig. 6-5) when orders have been received to use it. The compressed air is used directly, without conversion to electrical energy; that is, it is a static system.

PNEUMATIC OPERATED HANDLING EQUIPMENT

The cranes and hoists used to handle missiles on deck and below deck are under the cognizance of Naval Ships Systems Command. Descriptions of these equipments may be found in NAVSHIPS publications. You will be using cranes and hoists in handling missiles during replenishment and in off-loading. Some of them are operated by the ship's compressed air supply. Guided missile handling equipment such as missile skids, handling dolly, transfer dolly, handling attachments, storage cradles, hoisting slings, and similar machines are described and illustrated in OP 2173, volumes 1 and 2, Handling Equipment for Ammunition and Explosives.

Apart from the cargo handling gear listed above, the strikedown car, booster cart, receiving stand, and transfer car are used for missile checkout. The installations vary on different ships. You are responsible for safe attachment of the missile or booster, and you operate the equipment, but other personnel are responsible for the maintenance and repair of the equipment. All Talos, Terrier and Standard (ER) missiles must be unmated (separating the booster from the missile) each time they are checked out, and mated again for return to the ready service ring. (Talos missiles and boosters are stowed separately except those that are in the ready service.) The electrically operated checkout car in the Mk 10 launching system is used to receive missiles and boosters from the strikedown elevator and to move these components to the loader rail. A movable platform on the car is used for missile and booster mating/unmating operations. Not all the handling equipment is power operated. The transfer car and some of the handling hoists for the Tartar missiles are operated by hand power. On a CV A you will have an elevator to move the missiles to the checkout room.

PNEUMATIC TEST SETS

Testing of missiles aboard ship is done at prescribed intervals, according to the appropriate OP for the equipment. Special test sets have been developed for each type missile. The Guided

Missile Test Set (GMTS) programs the missile through a simulated flight sequence, comparing missile response to known standards. A missile systems test is made up of a number of individual tests. The test set is in the checkout room.. Chapter 14 has an illustration (fig. 14-23) of a missile with connections to the test set. There are electrical, hydraulic, electronic, and pneumatic connections to be made (which you do) ~ There is also a pneumatic test set that is used to test certain internal components of missiles. It uses high pressure air but controls it and reduces it to the pressure needed.

Example of the carrying out of the tests will be given in chapter 14. As a GMM 3 or 2, you will prepare the test setups, making the connections to the power source and to the proper component of the missile.

MAINTENANCE OF PNEUMATIC SYSTEMS

In general the same periodic inspection and precautions required for hydraulic systems are also valid for maintenance of pneumatic equipment. The micronic filter elements of a pneumatic system must also be inspected for cleanliness and replaced at regular intervals. Pneumatic units which become contaminated cannot be flushed as can hydraulic systems but must often be disassembled and cleaned as described in the appropriate maintenance publications.

Leaks in air or nitrogen systems can usually be found with the aid of a soap solution applied to the joints. The presence of a leak is revealed by the formation of bubbles. Tightening of connections or replacement of O-rings usually takes care of the leakage problems. A bit of dirt in a valve may require dismantling of the valve to clear it.

HYDRAULIC PNEUMATIC POWER USED INSIDE MISSILE

CONTROLLER DEVICES

In earlier chapters, statements were made about control surfaces moving a certain way upon signal, and about other movements in the missile. There has to be some power to cause these movements. Hydraulic power is used for many of them. It should be remembered that hydraulic fluid contains no energy in itself. It merely provides a means for transferring energy within a mechanism. Since, for all practical purposes, hydraulic fluid is incompressible, it can be used to transfer energy with negligible losses.

Since hydraulic fluid normally moves through a closed system, several methods have been devised for moving it. Axial piston and rotary hydraulic pumps, driven by turbines, are commonly used in guided missiles. The hydraulic pumps are of the same types as those used in the launching systems, though not of the same size. The principles of a simple hydraulic system are shown in figure 8-18. The reservoir or sump acts as a storage tank for the hydraulic fluid. A motor or other prime mover is connected directly to the hydraulic pump. The relief valve ports excessive pressure to the sump.

ENERGY CONVERSION

To cause the work piston to move up, we must position the directional valve as shown in the upper portion of the figure. This permits the oil to exert pressure against the bottom of the work piston, causing an upward movement. The oil on the top side of the work piston is returned to the sump as shown.

The lower portion of the figure shows how we can cause the work piston to move down. In this case, we must move the directional valve to the left so that the oil will be forced to take a path leading to the top of the work piston. This will cause the work piston to move down. The oil on its lower side will pass back to the sump.

In both cases the controlling factor was the position of the directional valve. In the operation described, the hydraulic fluid, which has no energy of its own, merely translated rotary motion of the motor to linear motion at the work piston. This is one form of energy conversion unit used in the auxiliary power supply (APS) of missiles to provide a source of power to the many devices required for successful flight of the missile. The APS is in addition to the main missile engine (propellant) required for thrust.

Early mods of the Terrier missile used compressed air cylinders as the source of power, but these limited the range and also gave a slow reaction due to the time it takes to compress the air in the actuator to a pressure sufficient to move it. Hydraulic power

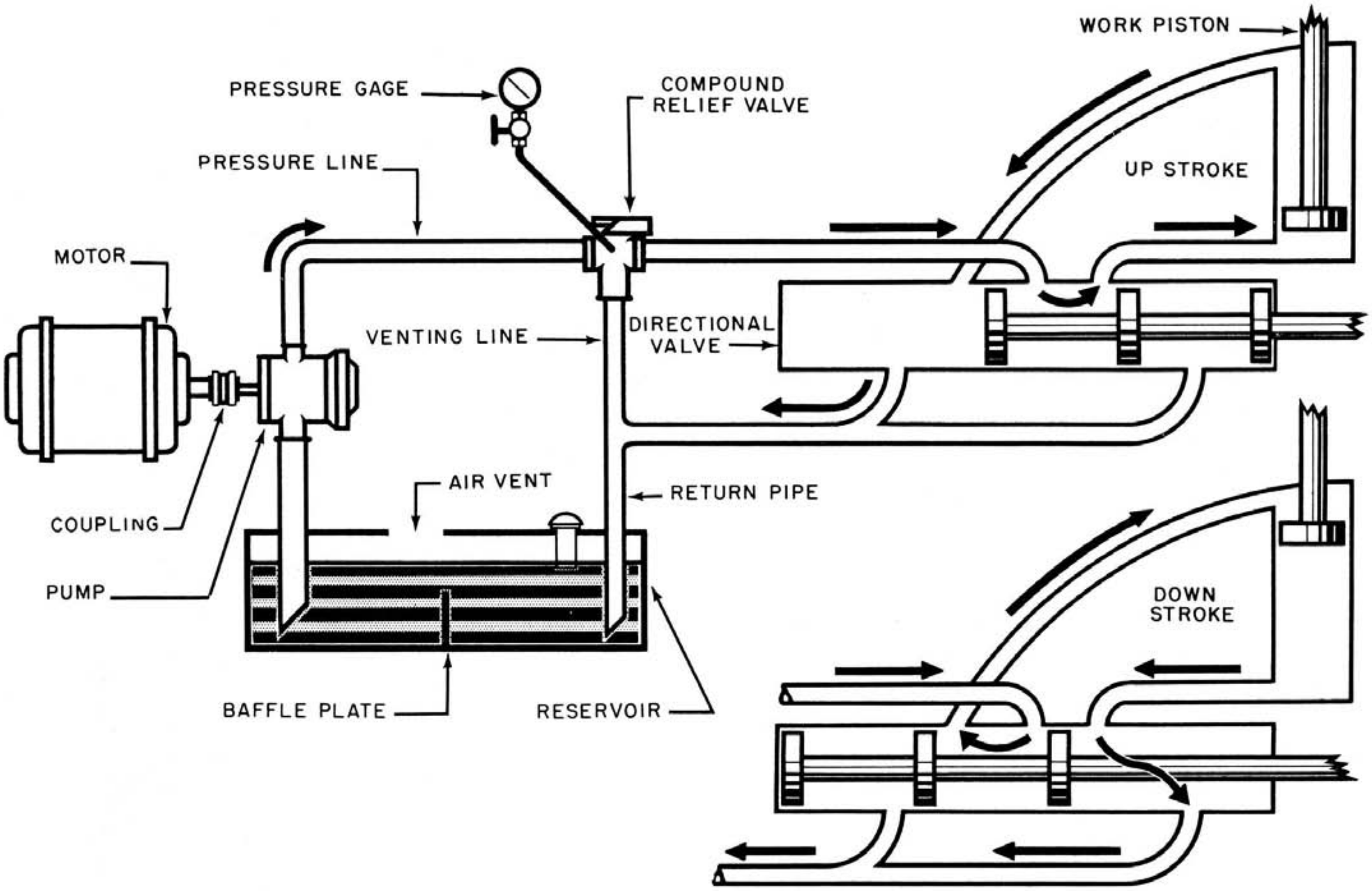

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Figure 8-18.—Transfer of power in a simple hydraulic system.

will produce a faster reaction on an actuator. as hydraulic fluid transmits the power almost instantly.

Turbines

Turbines may be driven by air or by hot gas. Both Terrier and Tartar missiles use auxiliary hot-gas systems. The Terrier and Tartar missiles have two hot-gas generators. each with its package of solid propellant. The hot gas exhaust from one is fed to the missile's turbohydraulic system and the other goes to the turboelectric system. They are placed in the aft section, near the tail, which is controlled by the hydraulic system. The Talos missile uses an air-driven hydraulic pump that makes use of air taken in through the diffuser section in the missile nose.

AIR TURBINES. - One type of air turbine is the pinwheel turbine shown in figure 8-19. This turbine is a mechanical jet similar in principle to a garden sprinkler. Compressed air is led into the pin wheel hub through the hollow shaft. It eventually passes through the diametrically opposed nozzles where its velocity is increased. The reaction to the exhaust causes a rotation of the pinwheel just as the reaction to the ejection of exhaust gases causes thrust in the main propulsion system. As with the air motor, the shaft of the air turbine is coupled to another device- usually an electric generator.

HOT GAS OR COMPRESSED AIR TURBINES. - Hot gas turbines are used in dynamic systems in which the energy source is solid or liquid fuel. These turbines may also be used to convert the potential energy in compressed air to kinetic energy. One type of turbine found in these systems is the Terry turbine, shown in figure 8-20B. The turbine wheel is a solid piece of steel having semicircular recesses (buckets) milled into its

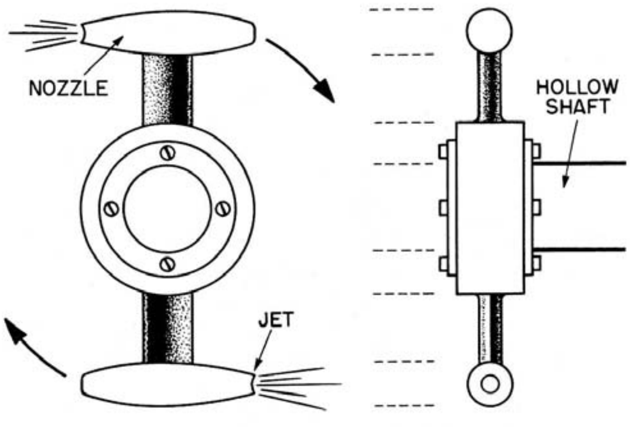

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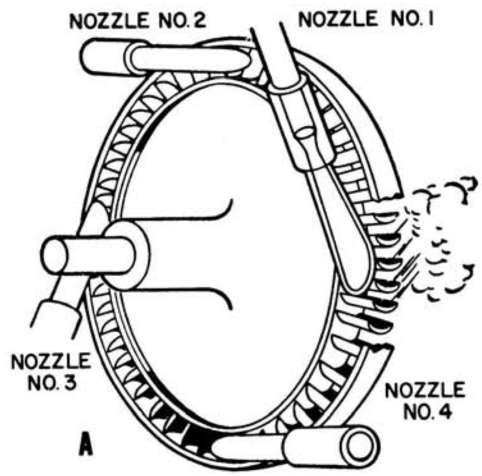
Figure 8-19.—Air-operated pinwheel turbine.



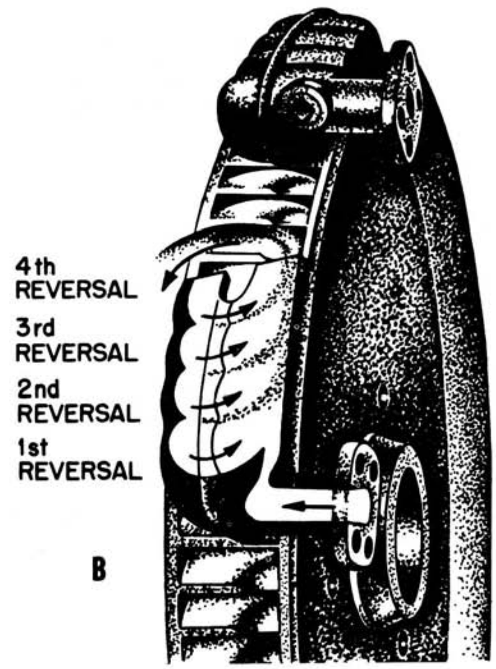


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Figure 8-20.—Turbines used in auxiliary power supply (APS) A. Impulse turbine; B. Terry turbine.

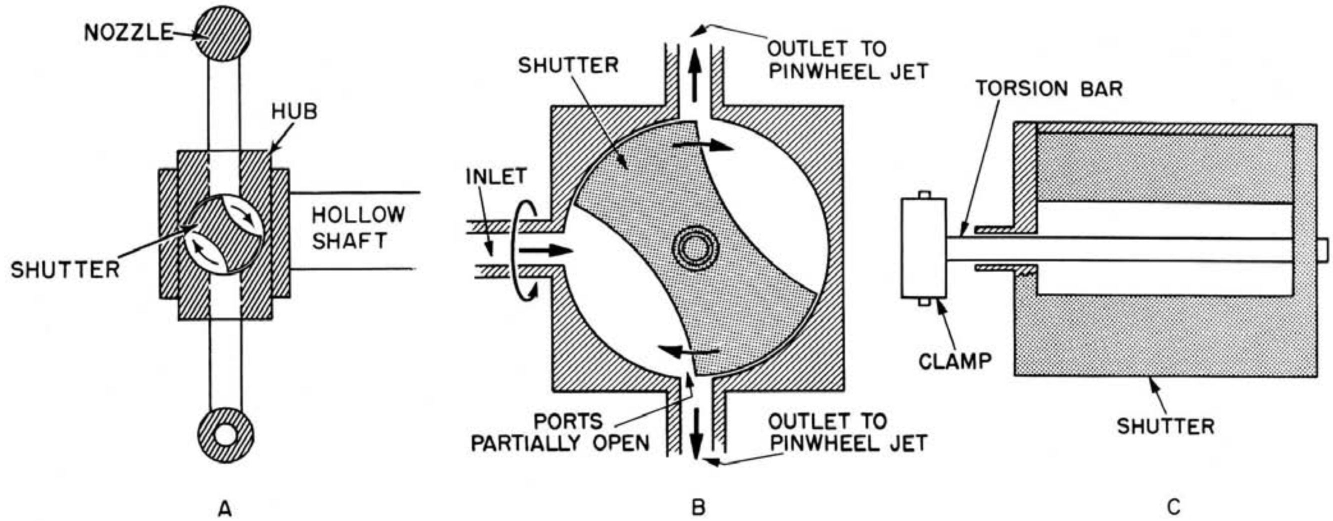
periphery. Mounted on the casing around the wheel are four nozzles spaced 900 apart. Within the casing are a series of stationary semicircular reversing chambers. The products of combustion are led through a gas manifold ring and pass through the nozzles. The gases then impinge at high velocity on the buckets. In passing through the buckets the direction of flow is reversed 180 degrees. The gases are then caught by a semicircular reversing chamber in the casing, where they are again reversed 1800 and returned to the wheel. The process is repeated five times through a 900 arc of the turbine housing, after which the gases are exhausted. Reversing the hot gases several times gives a multiple-stage effect, thereby using more of the potential energy in the gases.

Another type of turbine is the single-stage impulse turbine shown in figure 8-20A. In this turbine the gases expelled through the nozzles are not reversed in direction, but make only one pass through the turbine blades. You will find variations on the turbines discussed, but their basic principles of operation will remain the same. Both Terrier and Tartar use this type in their APS systems.

Governors

As mentioned earlier, turbines are often coupled to an a-c or d-c electric generator. To provide a constant electrical output, a governor is commonly used to control turbine speed within very close tolerances. One type which may be used is the moving shutter governor, which controls the speed of the pinwheel turbine.

MOVING SHUTTER GOVERNOR. - The moving shutter governor is mounted in the hub of the pinwheel turbine, as shown in figure 8-21A and 8-21B. Compressed air entering the turbine through the hollow shaft must pass through the



33.47
Figure 8-21.—Moving shutter governor.

governor before it can pass through the jet nozzles. The governor consists of a shutter secured to a torsion bar (fig. 8-21C). As the turbine rotates, centrifugal force causes the shutter to attempt to align itself in the plane of turbine rotation. In figure 8-21B the shutter tends to turn clockwise and block the flow of air to the nozzles. The torsion bar restrains the shutter from blocking the outlets. As turbine speed approaches a specified limit, the force on the shutter begins to overcome the restraint of the torsion bar, thus permitting the shutter to turn clockwise and partially block the outlets to maintain speed at the specified limit. If turbine speed decreases, the torsion bar overcomes the centrifugal force, and the shutter moves counterclockwise to uncover the outlets. Thus the moving shutter governor continuously controls turbine speed by metering the airflow to the nozzles.

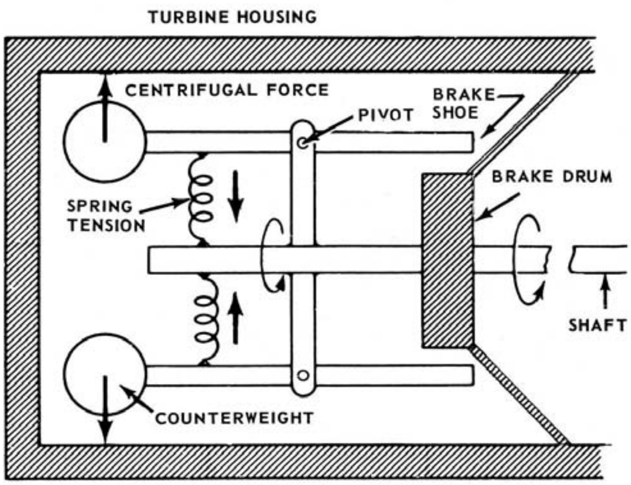
FLYBALL GOVERNOR. - A very common type of turbine governor is the flyball governor shown in figure 8-22. The coiled springs provide a restraining force on a pair of pivoted counterweights mounted on the turbine shaft. When shaft speed reaches design speed, centrifugal force overcomes spring tension. The counterweights pivot, causing the brake shoes to bear on the brake drum. When design speed is exceeded, the centrifugal force and the braking action increase. At decreasing speeds the centrifugal force lessens, and the braking action decreases. Thus a constant turbine speed is maintained.

Another type of flyball governor controls turbine speed by metering the flow of air or hot gases to the turbine. Its springs and counterweights are coupled to a valve on the input side of the turbine. Centrifugal force causes the weights to open and close the valve, thereby controlling turbine speed directly.

Miscellaneous Devices

Devices other than those described in this chapter are found in many APS systems. For example, air systems may include dehydrators which prevent moisture from reaching system components. Hydraulic systems contain devices for bleeding off entrapped air. (Entrapped air in hydraulic lines can cause serious problems. System failure often results because of the compressibility of air.) Sight gauges are often provided for indicating pressure and fluid levels. Speed reduction gears are often found between high speed turbines and the machinery they drive. The technical manuals concerning the missile you are working with will describe the applicable APS system in detail.

Certain auxiliary devices are included in all APS systems to aid in smooth and safe operation. These devices include check valves, starting valves, reducer valves, filters, and various types of flow regulators.



33.48
Figure 8-22.—Flyball governor.

One of the simplest devices for restricting or regulating flow is a fixed orifice or restriction in the hydraulic line. A more complex device is an adjustable orifice restrictor, such as a needle valve.

ADVANTAGES AND DISADVANTAGES

The disadvantages of compressed air power for movement of control surfaces of missiles were mentioned earlier. Hot gas APS systems took the place of the compressed air systems. All of them actuated a hydraulic system to cause the movement of control surfaces as required for missile flight. A disadvantage of the hydraulic system is that it is bulky and heavy. This offsets the advantages of smooth, speedy response. The new missiles are being equipped with all-electric systems to replace the hydraulic components.

MAINTENANCE OF HYDRAULIC AND PNEUMATIC EQUIPMENT

The maintenance and repair of hydraulic and pneumatic units in missiles and in missile test equipments pose no special problems if the instructions given in the appropriate maintenance publications are followed closely. However, there are two general precautions of importance which apply to work with fluid systems. The first of these is the need for cleanliness of work areas, tools, and related equipment. The second (but not second in importance) is the need for constant observance of safe work practices.

The need for cleanliness results from the fact that the moving parts of hydraulic and pneumatic devices are machined to very close tolerances and must be perfectly free of foreign matter. The smallest impurity in these systems can damage the precision components, impair the operation of the overall system, and cause missile failure.

PERIODIC INSPECTION

To prevent impurities from entering missile fluid systems, inspections are made of hydraulic and pneumatic equipments at regular intervals. Both the units which supply fluids for testing the missile and those which charge it prior to actual flight are closely inspected.

At intervals specified by technical manuals, and as summarized and codified in the 3-M system, the input and output filters of missile hydraulic systems should be removed and examined. The filters are usually of the micronic type mentioned earlier in this course. The elements in these filters cannot be cleaned. If there are signs of excessive impurities, they must be replaced.

SYSTEM FLUSHING

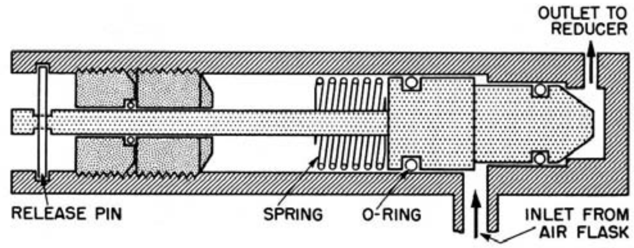
Flushing of test equipment pumping systems is performed to remove any contamination which might be present. This is always done both after the initial fluid system installation, and following any major repair in which the principal connections have been broken and remade. When the initial system installation has been completed and given an electrical checkout, or when repairs have been completed, the equipment is turned on and the hydraulic fluid is allowed to circulate for a specified period of time.

The equipment is then turned off an the fluid is removed from the system and discarded. The input filters are then replaced and the reservoir refilled with the proper fluid. When the reservoir is filled to the correct level, the system is then ready to supply oil to the missile for testing purposes or for charging the system for flight.

If hydraulic components within the missile become contaminated, they must be removed and reworked in a repair shop. This type of repair is done only at a major shore repair station-not aboard ship. A unit, such as shown in figure 4-33, is removed in its entirety and is replaced with a new unit.

HYDRAULIC TROUBLESHOOTING

Except for the electrohydraulic components, most troubleshooting in hydraulic systems is accomplished by visual means. The most frequent cause of trouble is leakage caused by poor connections or faulty O-rings. When a connection shows evidence of leaking, tightening will usually stop the loss of fluid. When the leak results from a bad O-ring, it may be necessary to disassemble the unit and replace the ring. If a leak cannot be repaired by one of these methods, the faulty section is usually replaced.



33.53
Figure 8-23. — Starting valve.

CARE OF PNEUMATIC EQUIPMENT

As in the case of hydraulic components in the missile faulty pneumatic components may be removed in their entirety and sent to a repair facility.

VALVES

Many types of hydraulic valves are described and illustrated in Fluid Power, NavPers 16193-B plus general instructions and cautions for installing and maintaining such valves. That material will not be repeated here as the basic text should be readily available to you.

Pneumatic systems use many of the same type valves as those used in hydraulic systems, but there are some that are special for use with air systems, either compressed or free air.

Starting Valves

Starting valves are commonly used in pneumatic systems. These valves provide a positive block on the discharge (output) side of the air flask. Many of these are designed to be opened by retracting a pin, either by hand or electrically. Retraction of the pin permits air to pass from the flask, thus starting operation of the pneumatic system. Figure 8-23 shows the operation of a starting valve. When the pin is released, inlet pressure acting on the valve shoulder causes piston movement to the left. The function of the spring is merely to absorb the shock of the rapid piston movement.

Relief and Safety Valves

Relief valves and safety valves (fig. 8-24) are used in all closed systems. Their function is to prevent excessive pressures from rupturing hydraulic and air lines, or damaging machinery. Most of these are spring-loaded valves in which spring compression is set according to the maximum allowable pressure in the system. If pressure becomes excessive, the spring is compressed and the excess pressure is vented to the atmosphere. An adjusting screw is normally provided to set the spring pressure.

Although safety and relief valves operate on the same principle, their function is slightly different.. Relief valves are usually small in comparison to safety valves, and are designed to relieve occasional excess pressures during normal operating conditions. Safety valves are designed for emergency or breakdown, and can take care of the entire load.

Air Pressure Reducer Valve

It is usually necessary to reduce air flask pressure (about 3000 psi) to a much lower operating level.

In the reducer valve shown in figure 8-25 pressure is reduced to 300 psi prior to reaching the turbine. To start with, assume that atmospheric pressure exists in chambers A and B before the starting valve is opened. At this time, the spring pressure against the diaphragm holds the reducer valve open. At the instant the starting valve is opened, air at 3000 psi rushes into chamber A and passes through the valve into chamber B. The pressure in chamber B immediately begins building up from atmospheric pressure. When it exceeds 300 psi it is sufficient to overcome spring tension; thus the diaphragm moves to the right, compressing the spring, and the valve closes. Note that the spring tension is set by the adjusting screw so that pressure in chamber B must exceed 300 psi to move the diaphragm to the right, permitting the valve to close. If the pressure in chamber B drops below 300 psi,

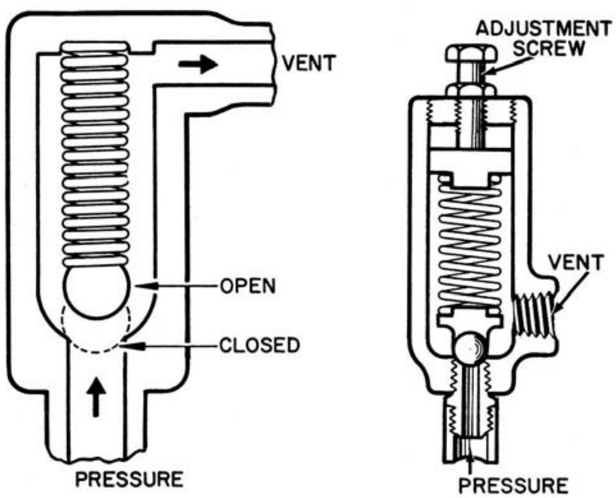


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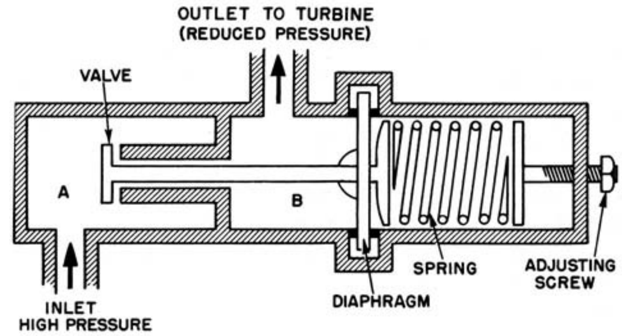
Figure 8-24.—Relief of safety valves.



33.55
Figure 8-25.—Air pressure reducer valve.

spring pressure pushes the diaphragm to the left, causing the valve to crack open, admitting air to chamber B. When the pressure in chamber B is exactly 300 psi, a point of balance is reached wherein the valve will remain open just enough to permit constant pressure in chamber B. Although it may appear that the spring pressure would be insufficient to overcome the high pressure in chamber A to open the valve, the valve is designed so that even a relatively low spring pressure will crack it against 3000 psi in chamber A.

This valve will maintain a constant outlet pressure of 300 psi as long as the inlet pressure exceeds 300 psi.

Although pneumatic systems have been designed for missile control systems, none is in use. The valves described above are types that may be used in other applications, as in a pneumatic-electric control system. The illustrations of the basic parts of each type can help you when you have to dismantle and clean a valve. You need to have the parts drawing that will show all the parts, not just the main parts as in these sketches but, if you understand how the valve operates, it will help you to put it together correctly.

A pneumatic valve that you need to know is the PRP valve in the sprinkling system in the magazines. (It will be described in detail in chapter 10 and illustrated in fig. 10-35).

SAFETY

Safety is everybody's job. Awareness of danger, knowledge of how to avoid it, and constant vigilance are the three basic requirements for the prevention of accidents while you are working on or operating a launching system.

Safety is both a result and a reflection of good training. The crews of missile launching systems may be trained so that every man thoroughly knows how to do his job; however, the crew still cannot be considered well trained unless every man is safety conscious. Safe working habits must be impressed upon every crewman through proper instructions, constant drills, and continuous supervision. Carelessness, cockiness, and lack of training have led to disaster while working with all types of ordnance equipment and material.

Each piece of ordnance equipment has a specific list of safety precautions to be observed during operation and/or maintenance. Study these thoroughly before attempting to operate or repair any piece of equipment with which you are not familiar.

Hydraulic systems operate under hydraulic pressures ranging from approximately 100 psi to 2,000 psi. Some pneumatic systems operate in approximately the same range of pressures as hydraulics. These pressures are dangerous and can be hazardous to personnel.

The following safety rules are but a few of the many that must be observed when operating or working on hydraulic or pneumatic systems.

Never disconnect hydraulic lines or disassemble hydraulic equipment when the hydraulic system power motor is running.

Never disconnect hydraulic lines or disassemble hydraulic equipment until the accumulators have been manually dumped to tank.

Never manually actuate switches, solenoids, relays, or valves on hydraulic systems under pressure unless you are competent and qualified to perform these actions.

Report hydraulic leaks immediately so that they may be repaired at the first opportunity.

If clothing becomes drenched with hydraulic fluid, immediately change into dry clothing for hydraulic fluid is injurious to health when in prolonged contact with skin. It is also a fire hazard. Immediately wipe up all spilled fluid.

Do not direct a high-pressure air jet at any part of the human body; this may be fatal.

Safety precautions must be observed when performing maintenance, testing, and operating ordnance hydraulic and pneumatic equipment. The high pressure liquid or air can cause major injuries to your face, hands, and other parts of the body by jets of air or liquid escaping from valves or pipe connections which are highly pressurized.

Don't think that once you have learned all applicable safety precautions you can sit back and take things easy. Review them periodically, particularly those for jobs seldom performed. Try to improve upon any rules in effect. Safety is everyone's responsibility, not just those who drew up the regulations. Most accidents are caused by men who are so familiar with their job they think they can take short cuts; by men who don 't know the applicable precautions; by practical jokers; or, in the majority of instances, by plain carelessness.

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.

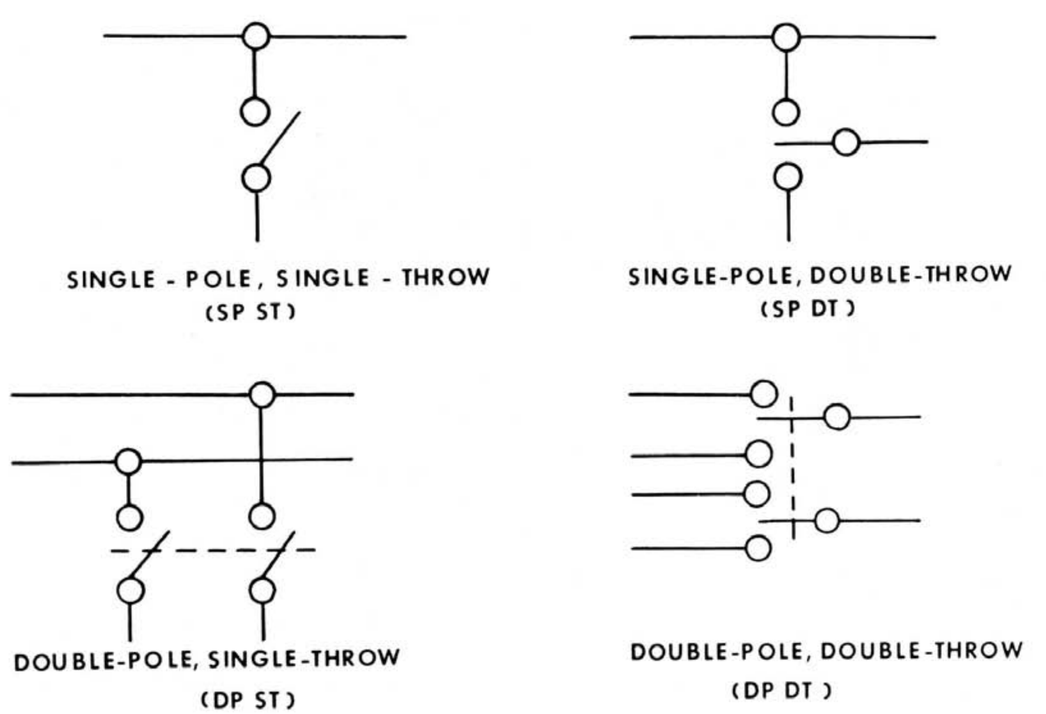
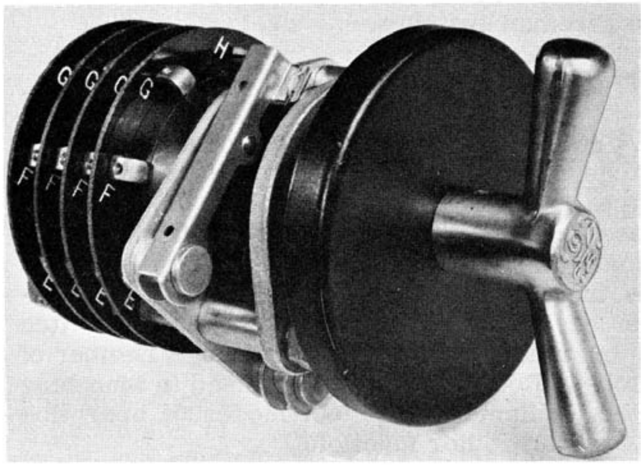


Figure 9-1.—Switch classification according to number of poles and throws. 12.66



12.70
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 remaining positions. The various circuit leads are connected to the proper pancake terminals. To transfer circuits you just turn the handle.

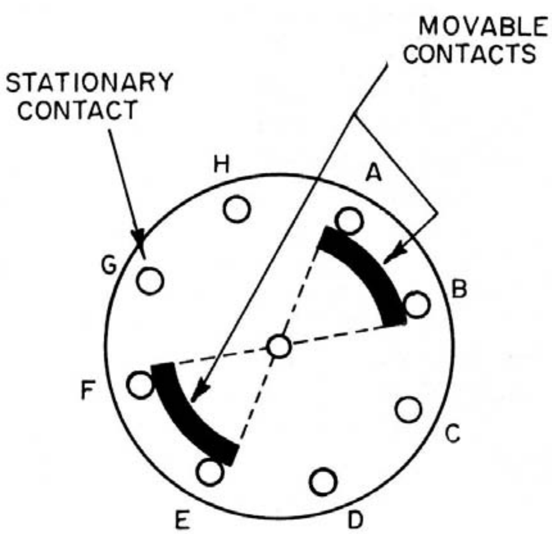


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Figure 9-3.— Type "J" switch contact arrangement.

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.

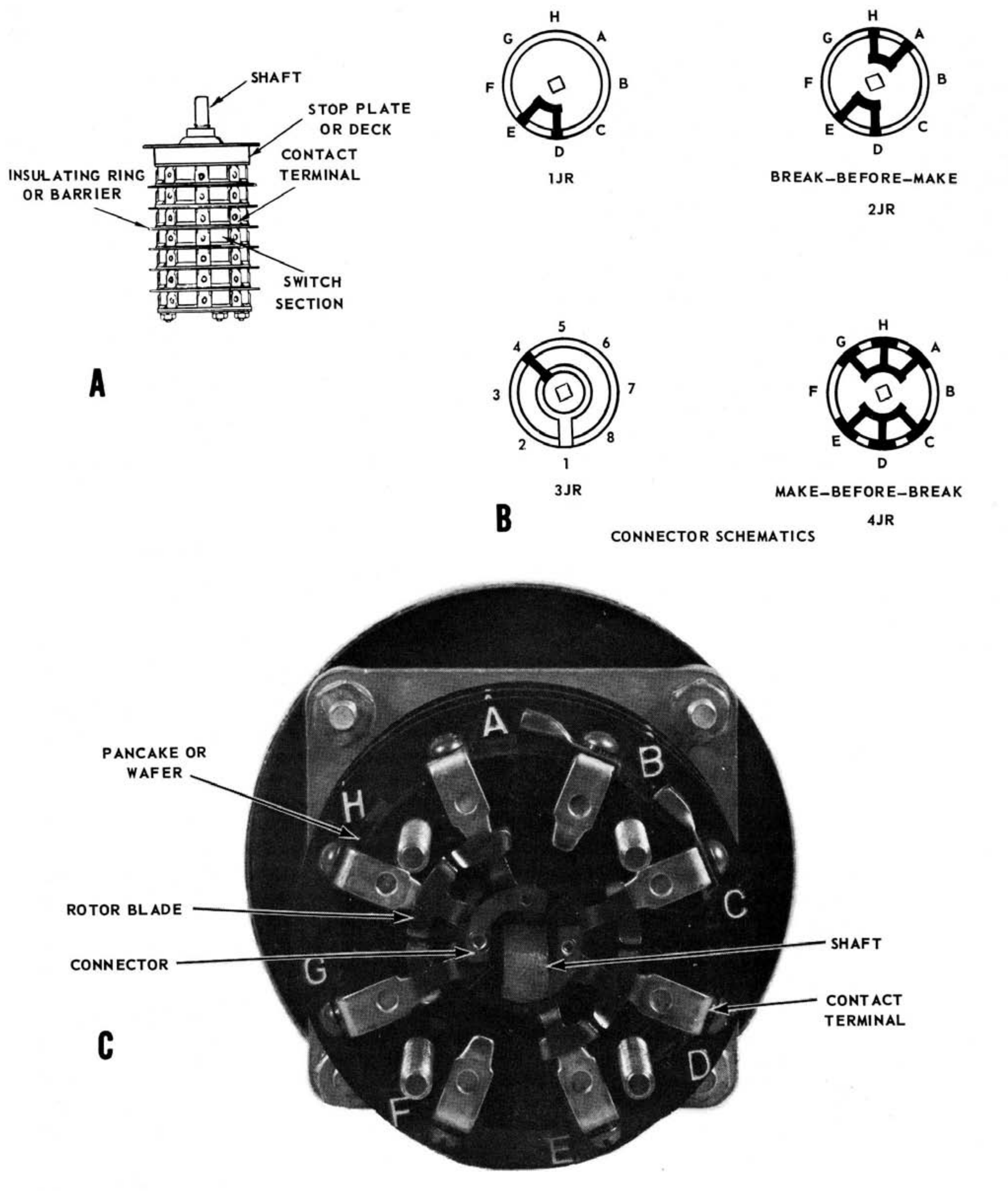
As the handle of the switch is turned, the rotor blades in all wafers turn simultaneously to make and to break the circuits. A detent wheel is incorporated in each switch assembly to ensure proper positioning. Also, a stop plate (fig. 9-4A), limits the rotation of the switch by means of a stop pin. The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



12.71
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.

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.

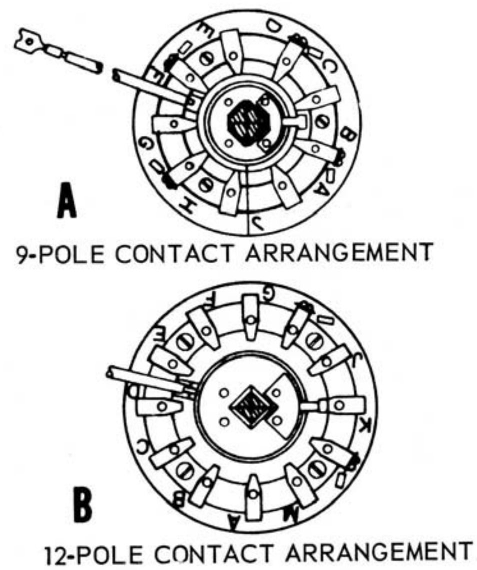


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Figure 9-5. — Barrel switch contact arrangement: A. 9-pole contact arrangement; B. 12-pole contact arrangement.

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

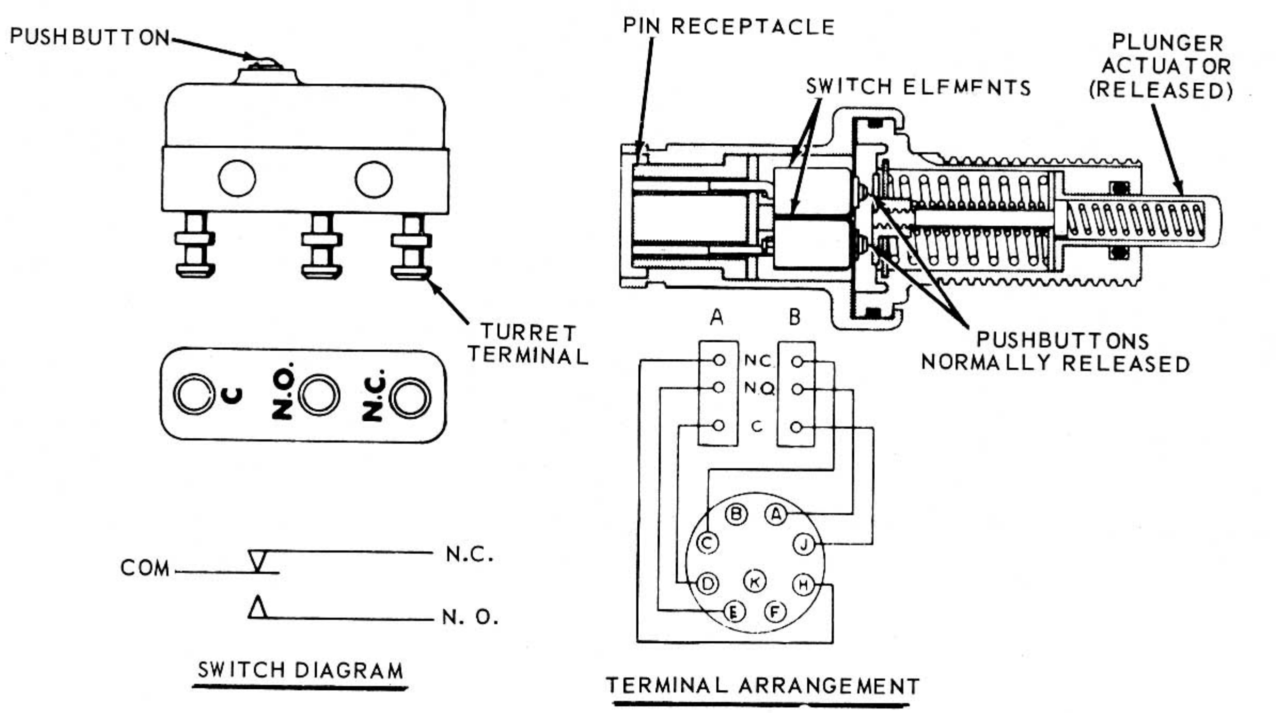

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Figure 9-6.—Sensitive switch, showing terminal and element contact arrangement.

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

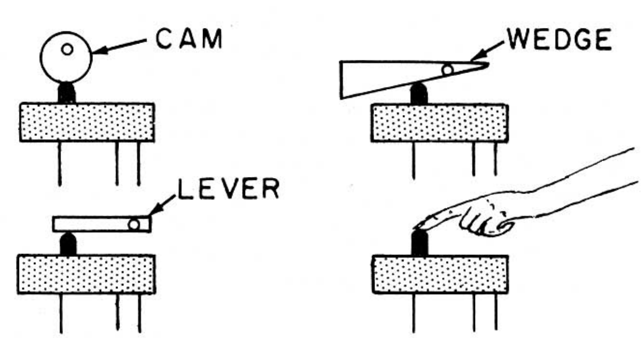

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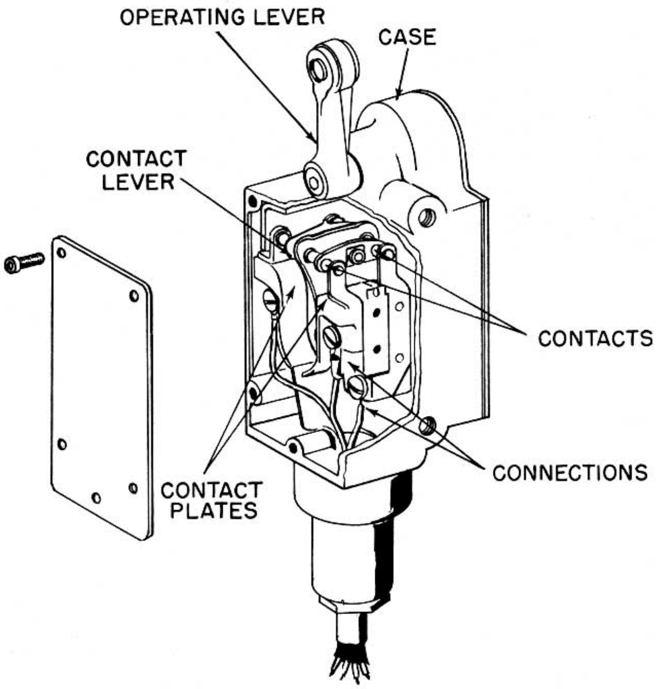
Figure 9-7.—Methods of applying operating force to pushbutton (sensitive) switch plunger.



83.185
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.

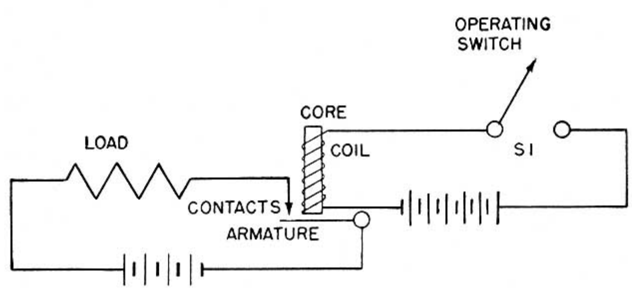
The type of material used for contacts depends on the amount of current to be handled. Large power relays usually have copper contacts and use a wiping action to make sure of a good connection. Small relays may use silver or some silver alloy, while in some applications tungsten or some very hard material 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

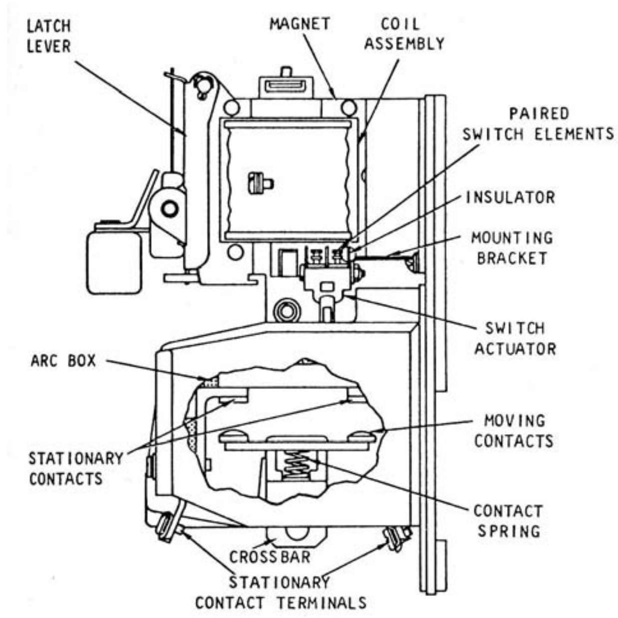
Heavy-duty relays called contactors are used extensively for remote control switching of high voltage and current. A case in point is the application of 440 volts to an electric motor. For this application and similar ones, a relatively small amount of control power (generally 115 volts) may be used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



83.92
Figure 9-9.—Simple relay circuit.



83.202
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

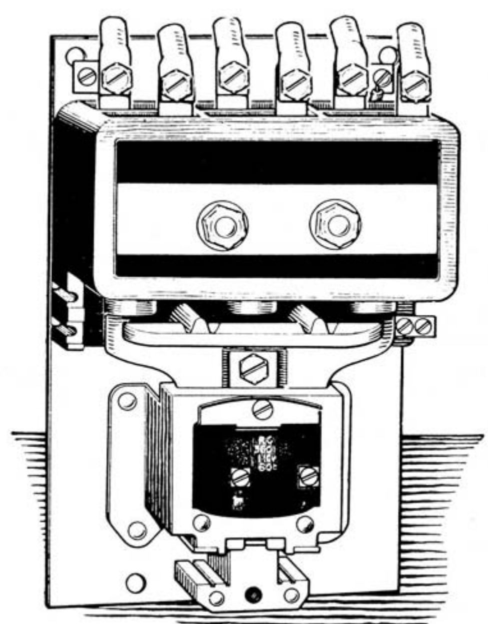
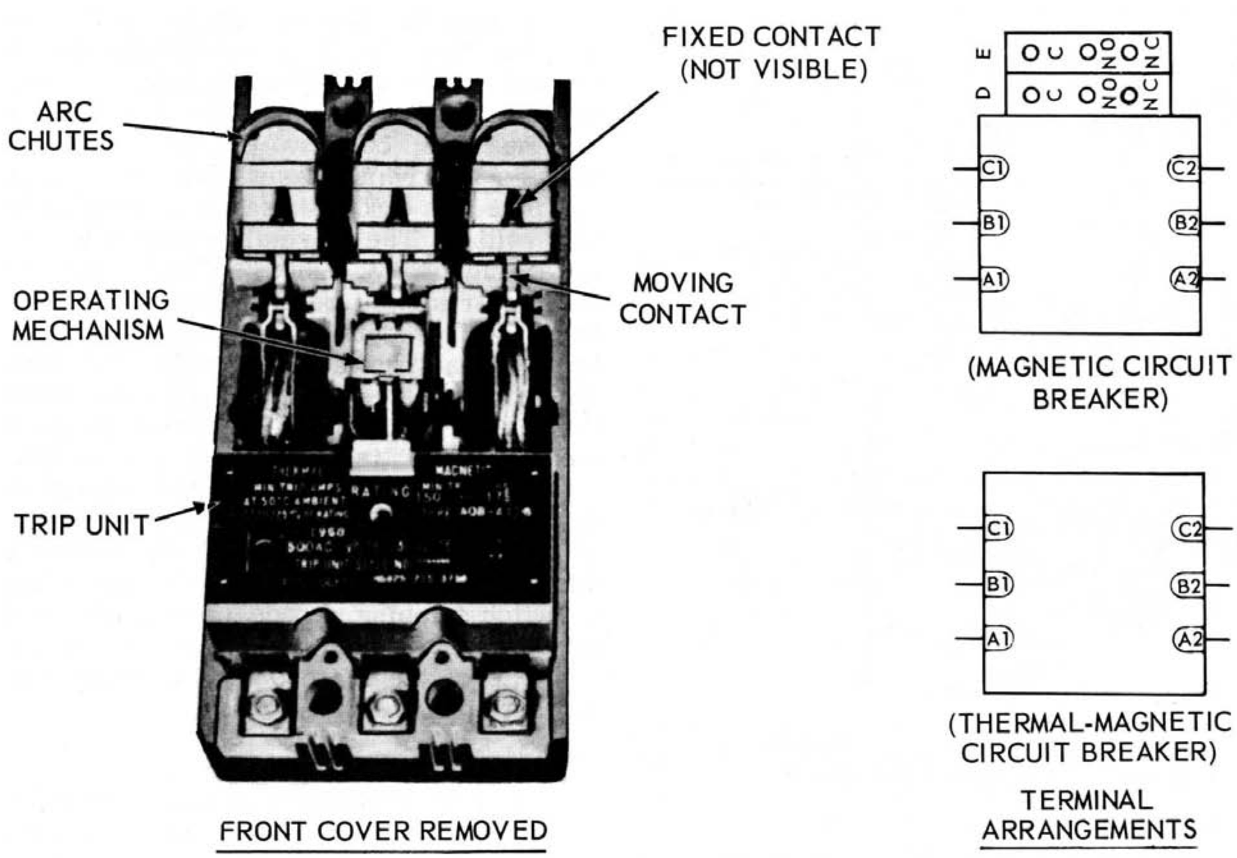


Figure 9-11.—Power contactor, solenoid relay type. 83.94



83.95

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

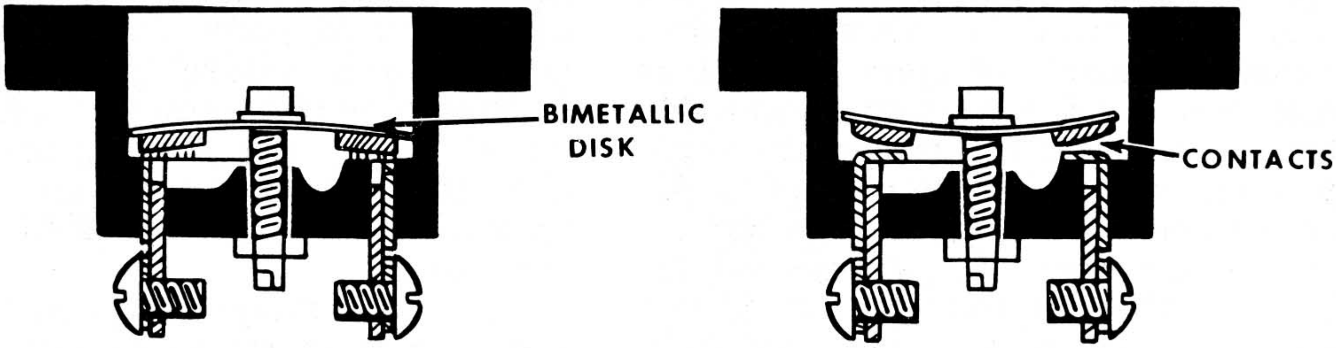
the thermal and magnetic types. A thermal release is used for overload protection, and depends upon the deflection of a bimetallic element that is heated by the circuit current. As current flows through the bimetallic strip, heat is generated and the strip bends. Under sufficient heat it bends enough 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.



5.82A
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.

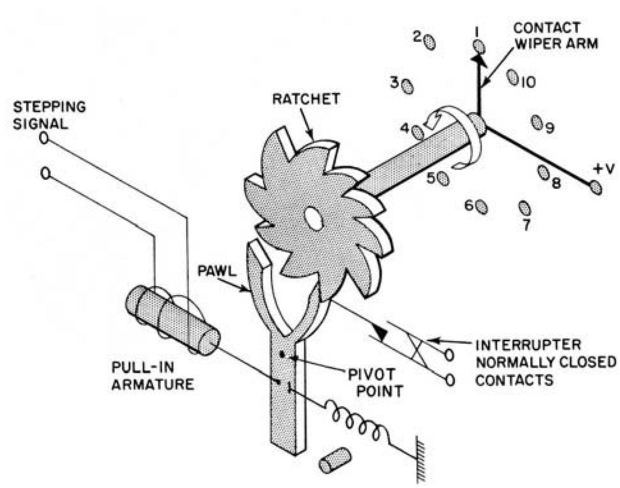
The right prong of the pawl engages the ratchet tooth which has been moved. Thus the right prong holds the ratchet gear locked in its new position. But when the pawl is in this position, the interrupter contacts close again and the switch takes another step.

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:

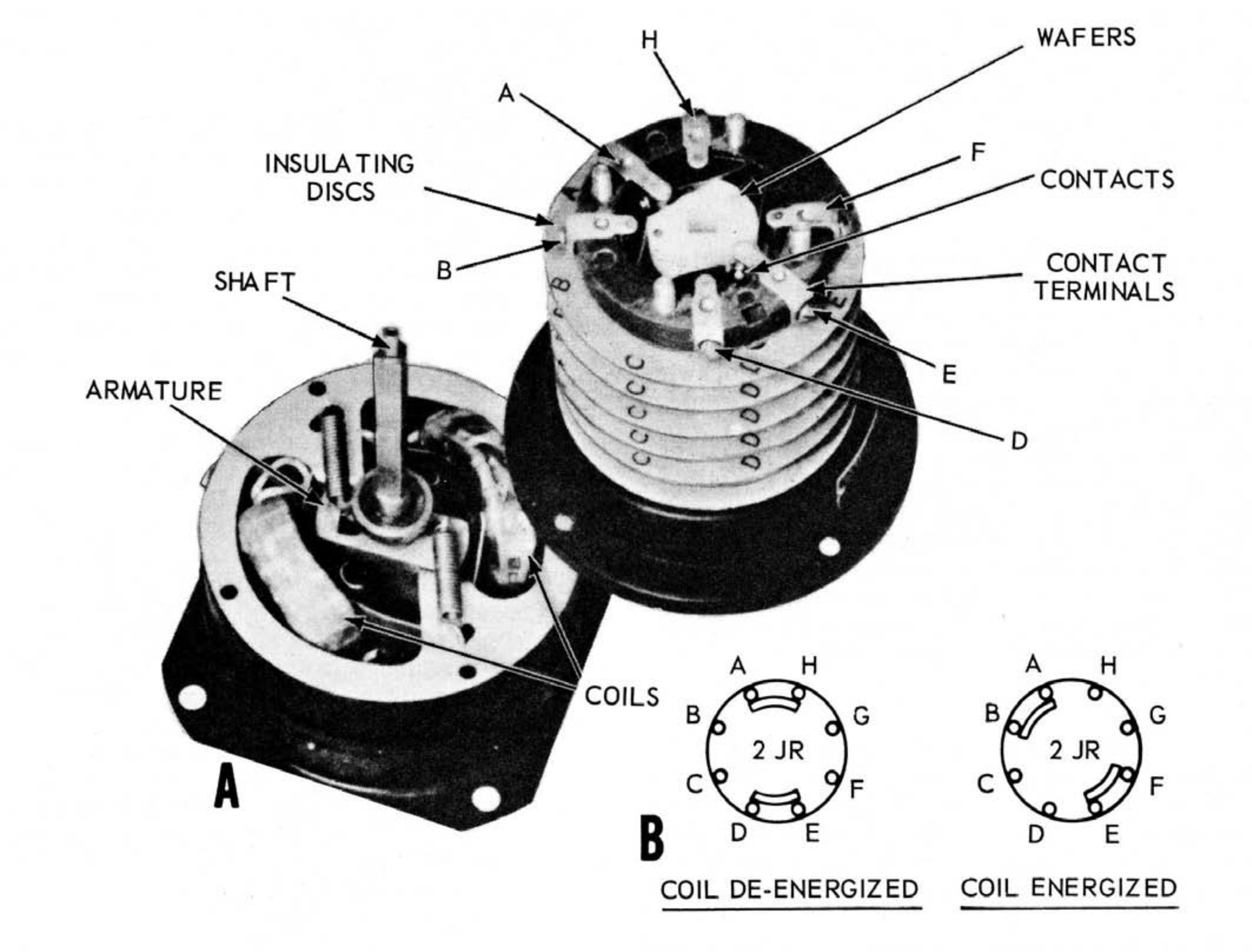


83.96
Figure 9-14.—Stepping relay operation.

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.



83.97

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.

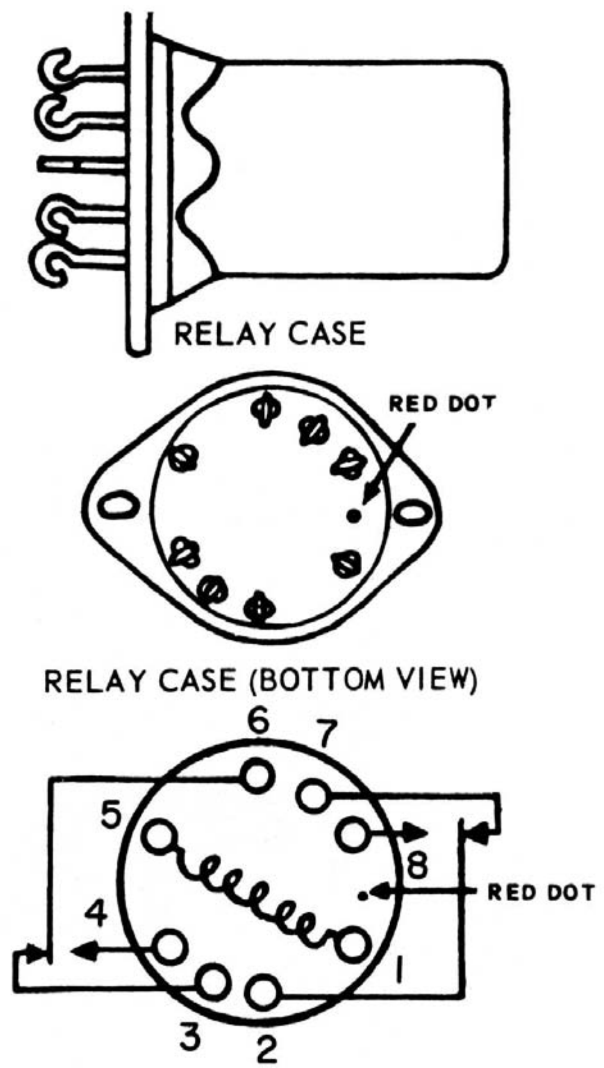
During an overload, the circuit is not broken instantaneously, although the greater the overload, the faster the relay action. Since the oil holds back disc movement, the size of the disc orifice through which the oil must pass determines the delay time for a given amperage. The size of the orifice can 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.

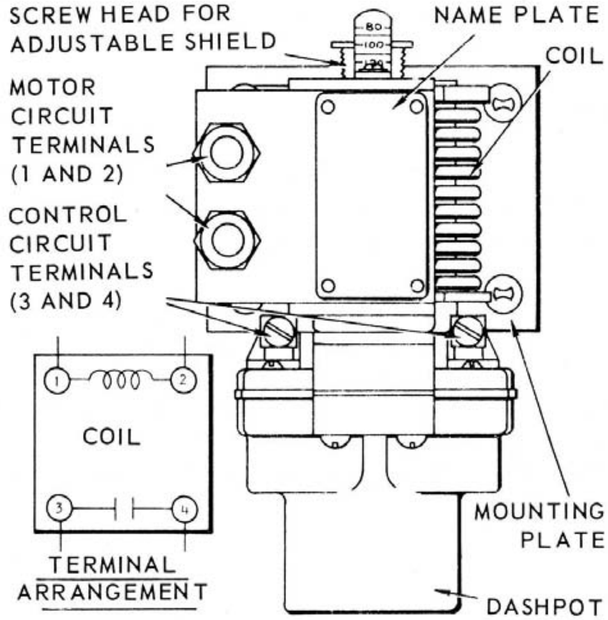
Overload relays may be single or double coil. The single coil overload relay may be obtained with or without a manual latching control.

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



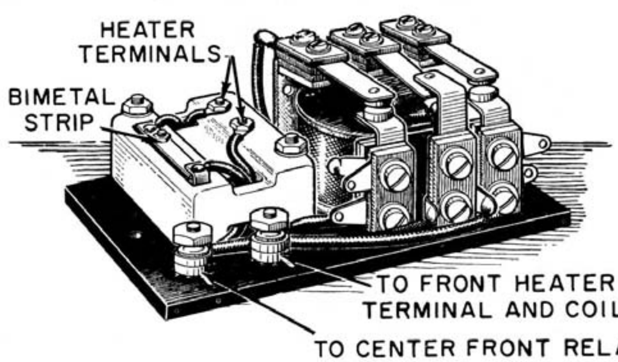
83.186
Figure 9-16.—Hi "G" relay.



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.

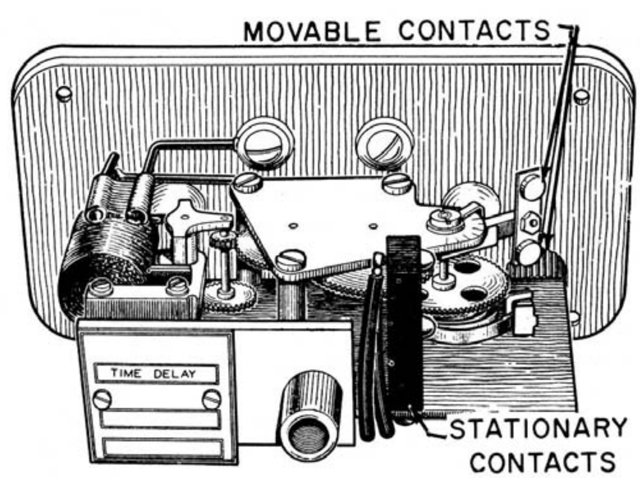
enough to touch the stationary contacts (fig. 9-19). Other motor-driven time-delay relays utilize a spring action to close the relay contacts. The spring is released by the gear train after a given time interval.

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.

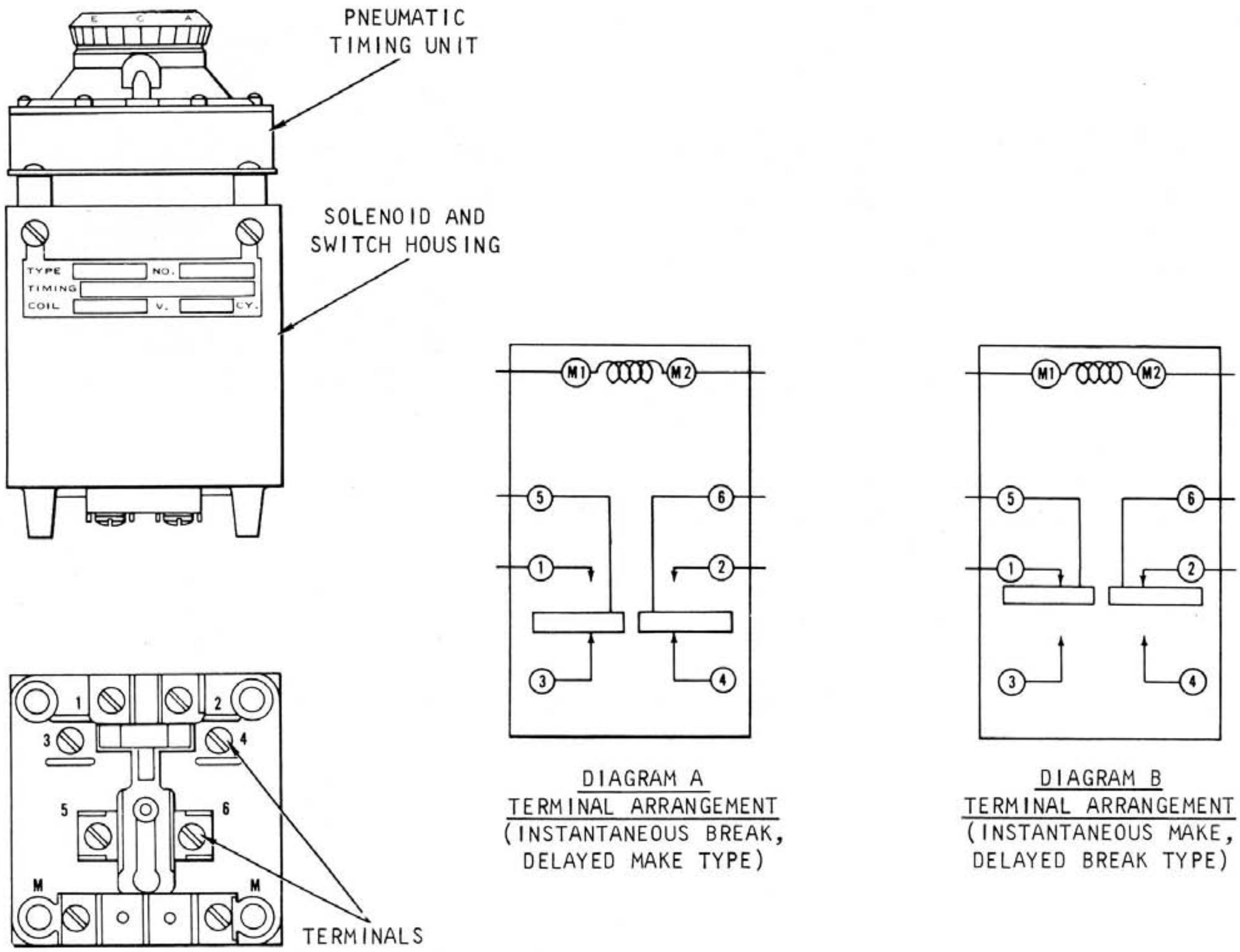
Sensitive Meter Type Relay

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.

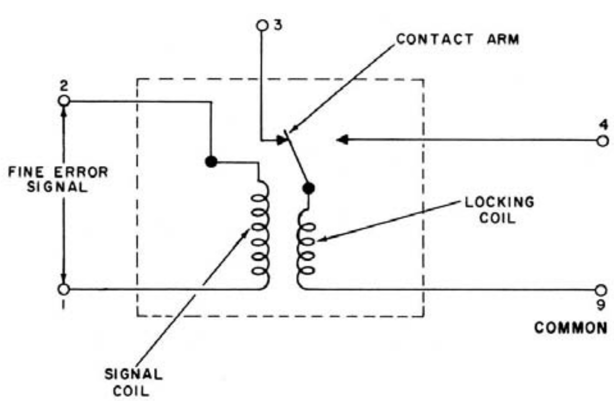
Figure 9-21 shows the parts and operating principle of a typical meter relay. The relay is shown in its deenergized position. Deflection of the contact arm is proportional to the



83.100.1
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.

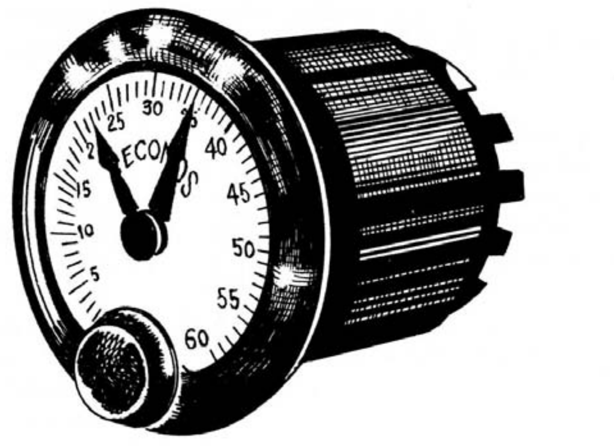
current flow through the signal coil. The contact arm will not make contact with contact 4 until a certain current is reached. In a firing circuit the amount of current that will move the arm to contact 4 (and therefore lock out the firing circuit) is proportional to 20' of launcher position error. The 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.



83.187
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.

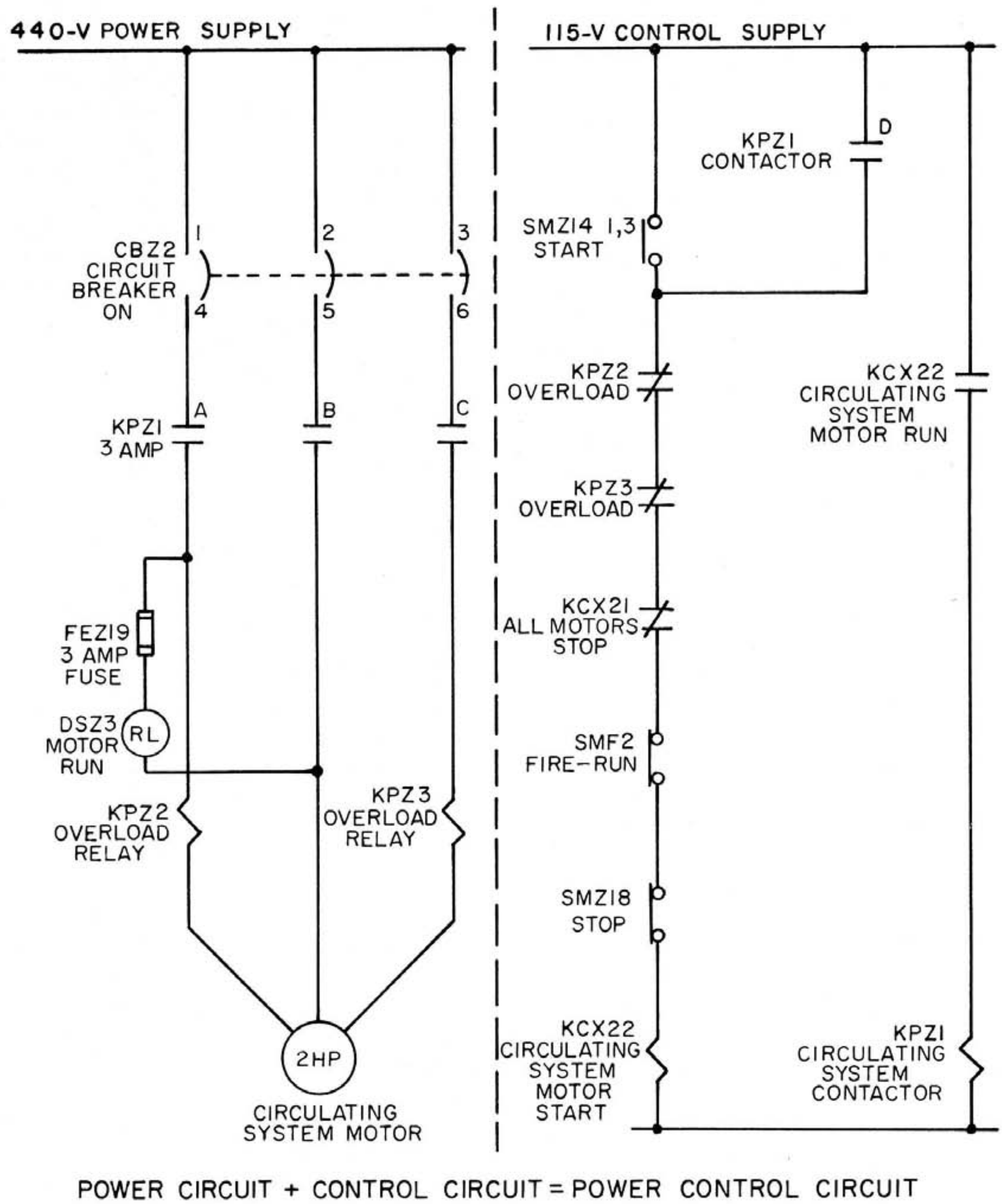
We can't show in this chapter all the various types of control circuits. There are hundreds of them in a single launching system. But we can discuss some typical examples, and show you the application of switches and relays in these circuits.

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.

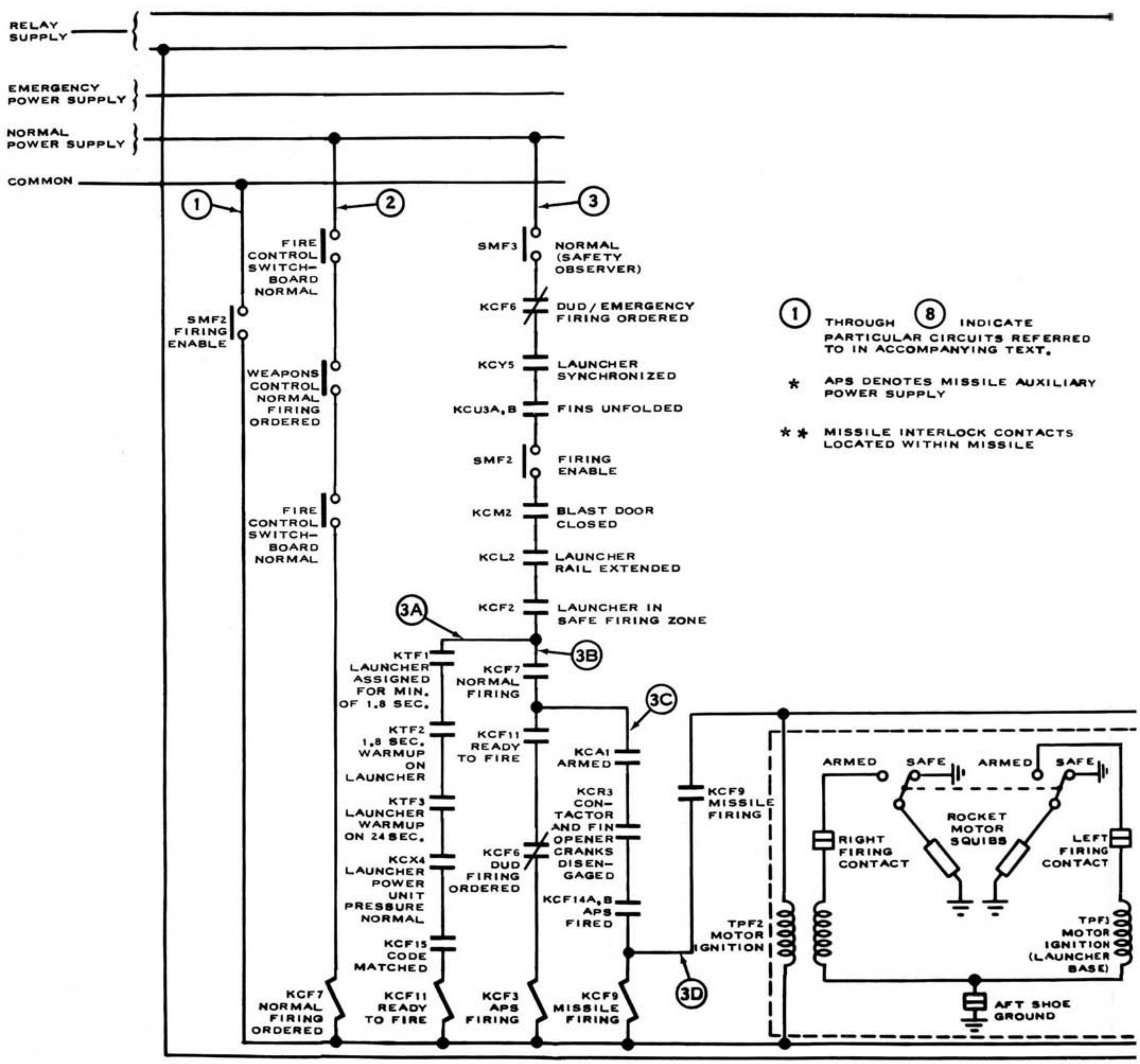
When relay KCF2 energizes, it indicates that the launcher is pointed in a safe firing zone. Closing of the firing key indicates to the firing circuit that a human decision to launch a missile has been made. In other words, there is an "intent-to-launch" present in the firing circuit. Whether this intent 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
SMF2 FIRING ENABLE
FIRE CONTROL SWITCHBOARD NORMAL
WEAPONS CONTROL NORMAL FIRING ORDERED
FIRE CONTROL SWITCHBOARD 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
KTF1 LAUNCHER ASSIGNED FOR MIN. OF 1.8 SEC.
KCF7 NORMAL FIRING
KTF2 1.8 SEC. WARMUP ON LAUNCHER
KCF11 READY TO FIRE
KCA1 ARMED
KTF3 LAUNCHER WARMUP ON 24 SEC.
KCR3 CONTACTOR AND FIN OPENER CRANKS DISENGAGED
KCX4 LAUNCHER POWER UNIT PRESSURE NORMAL
KCF6 DUD FIRING ORDERED
KCF14A,B APS FIRED
KCF15 CODE MATCHED
KCF9 MISSILE FIRING
TPF2 MOTOR IGNITION
KCF7 NORMAL FIRING ORDERED
KCF11 READY TO FIRE
KCF3 APS FIRING
KCF9 MISSILE FIRING
ARMED
SAFE
ARMED
SAFE
ROCKET MOTOR SQUIBS
RIGHT FIRING CONTACT
LEFT FIRING CONTACT
TPF3 MOTOR IGNITION (LAUNCHER BASE)
AFT SHOE GROUND
1
2
3
3A
3B
3C
3D
1 THROUGH 8 INDICATE PARTICULAR CIRCUITS REFERRED TO IN ACCOMPANYING TEXT.
* APS DENOTES MISSILE AUXILIARY POWER SUPPLY
** MISSILE INTERLOCK CONTACTS LOCATED WITHIN MISSILE

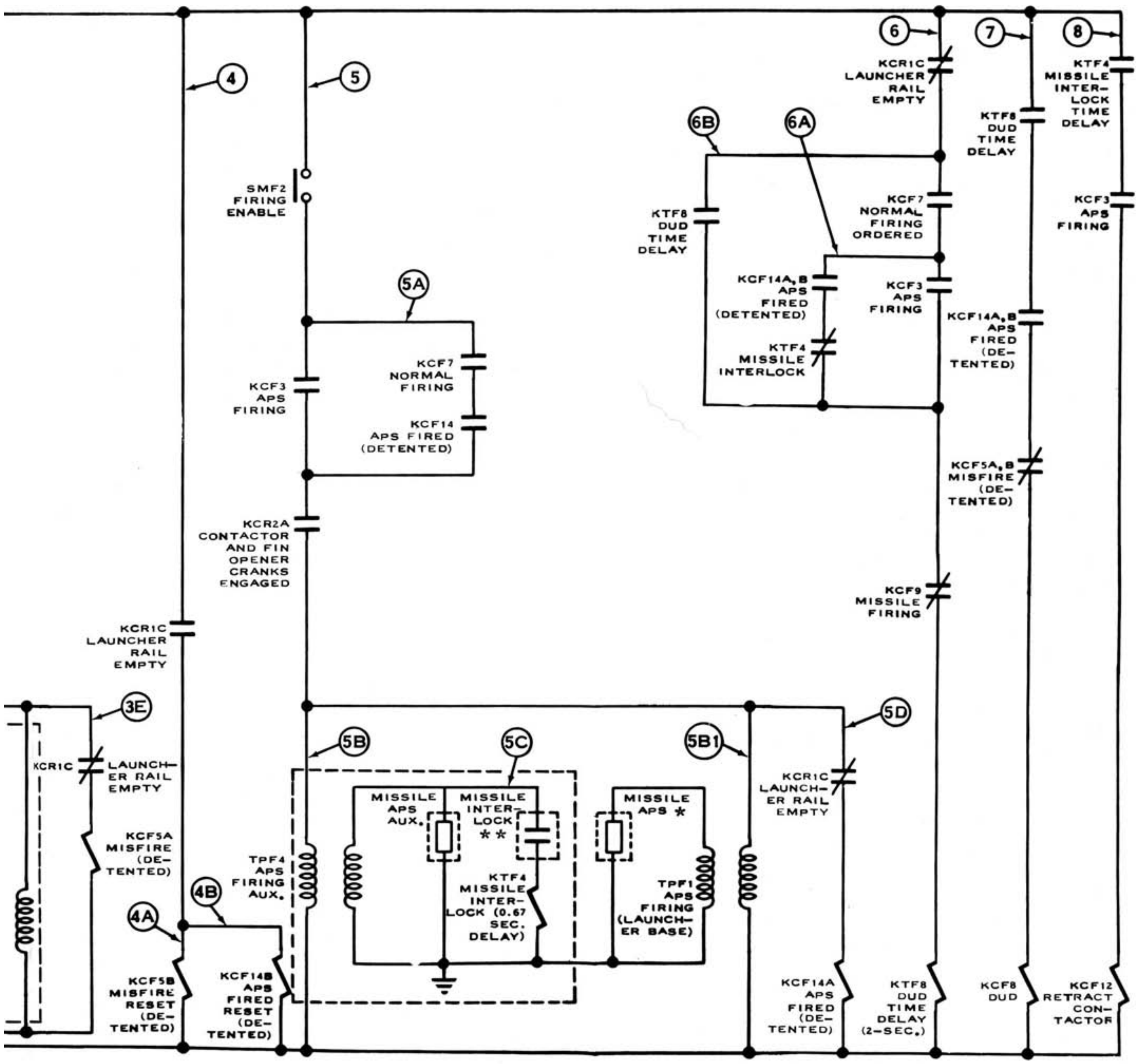


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Figure 9-24.—Normal firing circuit, Mk 13 Launching System (Tartar).

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.

CHAPTER 10

EXPLOSIVES, PYROTECHNICS AND MAGAZINES

One of the most important developments in the history of ordnance was the discovery of explosives. Explosives have advanced from the weak and unstable gunpowder of Roger Bacon to many types of specialized explosives. This chapter will give you a brief history and discussion of the characteristics, uses, and handling of explosives currently used by the United States Navy. It is expected that when you have learned the characteristics of the principal military explosives and something about how they work, you will handle them with respect.

It could be said that naval ordnance is the science of delivering a large quantity of explosives to the enemy and making the material explode where it will do the most damage. Your duty as a GMM in time of war will be to have the missiles assembled and checked and the launching system in top working order to launch warhead-carrying missiles.

What do you do in peacetime? You keep your skills and knowledge abreast of the system so you can keep the missile system in a "go" condition, ready for any service use.

You may already have had experience in handling explosives. You probably have operated the equipment that handles explosive-loaded missiles and their explosive components. If you are stationed where there are other types of explosives, you have probably helped with torpedo warheads, gun type ammunition, and bombs. In any case, it is wise for you to know something about explosives, as you will be associated with them throughout your career as a GMM.

Some general safety precautions to be observed in the handling and stowing of explosives are given in chapter 8 of Seaman, NavPers 10120-E. It's a good idea to review them.

DEFINITIONS

NONMILITARY EXPLOSIVES

The popular nonmilitary definition of an explosion is anything that goes BANG. It is caused by the rapid expansion of gas, accompanied by a noise. For example, when you inflate a tire, you compress the air in it. If you should have a blowout, the air expands again, and you have a small explosion.

In a nonmilitary sense, a mixture of two gases can sometimes explode. An explosive mixture can be formed by hydrogen and air. When you ignite this mixture the reaction gives off gas and heat, and the heat makes the gas expand rapidly, causing an explosion similar to a blowout.

Your car runs by BURNING a mixture of gasoline vapor and air. But under some conditions, this mixture will EXPLODE in the cylinder of your car. When a cheap gas is used, the mixture will start to burn in the cylinder when the spark ignites it. But as the gas burns, pressure inside the cylinder increases. And when this pressure reaches a certain point, the rest of the mixture explodes, making the motor "knock."

You may ask, "What's the difference between burning and exploding?" They both release energy. But the difference is in the SPEED at which they release the energy. A pound of coal has a lot more energy than a pound of TNT. But a missile warhead filled with coal would be a dud. The coal cannot release the energy fast enough to cause an explosion.

Sometimes, however, coal dust (or any other dust that will burn) can explode if it is suspended in the air. Maybe you've read about dust explosions in coal mines, flour mills, or threshing machines.

MILITARY EXPLOSIVES

None of the examples we have given are military explosives. What, then, is a military explosive? Many explosives have been studied for possible suitability for military use. But only a few of them can meet the requirements. Some desirable properties of a _military explosive are:

1. Relative insensitivity to friction and shock; not liable to be detonated by small arms fire.
2. Proper detonating velocity for intended purposes.
3. High power per unit weight.
4. Sufficient stability to retain usefulness for a reasonable time in any climate.
5. High density (weight per unit of volume).
6. Positive detonation by easily prepared primers.
7. Suitability for underwater use.
8. Convenient size and shape to facilitate packaging, shipping, and handling.

PROPELLANTS

The term PROPELLANT is frequently used in connection with guided missiles and space craft. Often it is called fuel. In older military texts it was called a low explosive. As such, it was defined as a slow-reacting explosive which burned rather than exploded. In missiles, the booster propellant is what gives the push or boost to the missile to start it on its way to the target, and the sustainer propellant carries on after booster burnout. Actually, it is not slow at all, it only seems slow in comparison with a high explosive. The example of the Tartar, in the previous chapter, illustrates this. A buildup of nearly 2300 lbs. thrust in a fraction of a second of burning is not slow. A propellant must burn, however, and not explode. The amount of thrust per unit weight of propellant varies with the type of propellant. See chapter 3 on thrust buildup. The search for a more powerful propellant is continuous, and is needed especially for space launchings.

In addition to being powerful, the propellant must be safe to handle and store. With few exceptions, solid propellants have been used in missiles because they are easier to handle and store than liquid propellants.

Now that you know some of the properties of a military explosive, let's take a quick look at the development of explosives.

HISTORY OF EXPLOSIVES

For many centuries black powder was the only known explosive. It was in the 13th century that Roger Bacon, an Englishman, discovered black powder. There is evidence that the Chinese knew the effects of gunpowder several centuries before this era. The Greeks used a product related to gunpowder, called Greek fire, and a number of experimenters in Europe had made combinations of chemicals that made explosive substances, but the mixture made by Roger Bacon was the beginning of our modern product.

In the 14th century. Berthold Schwarz. a German, invented a gun and used black powder to propel stones from it. This may be considered the real beginning of the history of military explosives. In spite of other developments, black powder remained a major military explosive through the 19th century.

Modern history of explosives began in 1838 when Pelouze, a French chemist, prepared nitrocellulose by nitrating paper. But it was not until. 1845 that Schoenbein, a German chemist, discovered guncotton. He found that nitrated cotton burns quietly in the open, but when confined in a small space, it can explode violently.

Shortly after the discovery of guncotton, Sobrero, an Italian chemist, experimented with nitroglycerin. He found that even a small shock or jar would make it explode. This sensitivity factor makes nitroglycerin useful commercially, but of no use for the military.

But in 1866, Alfred Nobel of Sweden found that he could make nitroglycerin safe to handle by soaking it up in Kieselguhr - a porous kind of earth. He called the mixture DYNAMITE. Today there are many types of dynamite, but they are all nitroglycerin soaked up in some kind of porous material. Dynamite is one of the most important commercial explosives today, but it has little military value.

Black powder has many disadvantages as a projectile propellant. For one thing, it made big clouds of black smoke that blocked the gunner's view of his target, and interfered with his aim for his next shot. For another, it fouled the gun barrel with unburned particles and with glowing coals that made reloading dangerous. It also revealed the location of the gunner.

So chemists began trying to make a smokeless powder that would not foul the gun bore. The Prussians were the first to succeed. About 1884, the French produced the first practical military smokeless powder. They called it Poudre B. It consisted of nitrated cotton, gelatinized and mixed with paraffin or vaseline.

In 1887, Nobel invented BALLISTITE, a double-base smokeless powder made of nitrated cotton and nitroglycerin.

(This is the Alfred Nobel who set up the trust fund and established the conditions for the Nobel Peace Prize awarded each year to some person adjudged to have done outstanding work in the promotion of peace.)

In the same year, the British began producing CORDITE. Cordite has the same ingredients as ballistite, with vaseline added.

Picric acid was probably the first high explosive to be used extensively as a bursting charge. For over a hundred years after it was discovered (1771), picric acid was used as a yellow dye, before it was found that it was a high explosive. During World War II, the Japanese used picric acid as their favorite bursting charge. The American Forces used a related compound - ammonium picrate, better known as Explosive D.

Prior to World War II, all mines, depth charges, depth bombs, and torpedoes were loaded with TNT. To provide a larger explosive force, Torpex was developed; it is far more powerful than TNT. Torpex proved to be unstable and was replaced by HBX. The need for powerful blast effect led to further developments of such explosives as Tritonal, Minol, and RDX. RDX is used extensively in mixtures with other explosives as a filler for missile warheads.

The expanding techniques of modern warfare lead to more and more specialized requirements for explosives. Future developments may be chiefly mixtures of currently known explosives with other materials. But in some cases, the requirements can be satisfied only by new and more powerful explosives, which are presently being sought.

CHEMICAL NATURE OF AN EXPLOSION

The chemical reaction that takes place during an explosion can be either of two types, depending on the nature of the explosive.

Black powder, for example, explodes by oxidation. As you've probably heard, it's a mixture of potassium nitrate, charcoal, and sulfur. All three are solids. To produce an explosion, you apply heat to the mixture. What happens? At the point where you apply heat, the potassium nitrate (KNO_3) gives up its nitrogen and part of its oxygen. The sulfur and charcoal combine with oxygen to form sulfur dioxide, carbon dioxide, and carbon monoxide. All three of these are gases.

In burning, the sulfur and oxygen release heat that does two things. First, it increases the pressure of the gases. Second, it spreads the reaction to all the nearby particles of powder. The reaction continues through the mixture, at the rate of several hundred feet a second, until all the powder has burned.

Other explosives, such as TNT and nitroglycerin, have a different reaction. Each is a chemical compound, rather than a mixture. (In a mixture, two or more ingredients are commingled but not changed; in a compound there is a union of two or more ingredients in a definite proportion, resulting in a new substance.) But the molecules of the compound are highly unstable. You might say there's a "tension" inside them. You start an explosion by applying a shock or a sharp jolt, rather than heat.

When it gets jolted, the unstable molecule flies apart, releasing energy in the form of heat. It usually releases two gases - nitrogen and nitrous oxide. It may also release oxygen, which combines with hydrogen and carbon in the molecule to form gases. The heat not only increases the pressure of the gases, but converts all the other products of the reaction into gas. The sudden release of energy applies a jolt to all the nearby molecules, so that the reaction travels through the whole mass of explosive. (In TNT and other high explosives, the reaction travels through the mass at a speed of several miles a second.)

CLASSIFICATION OF MILITARY EXPLOSIVES

We can classify military explosives by their composition, the nature of their reaction, their sensitivity, the way we initiate the reaction, and by the way we use them in service.

COMPOSITION

By composition, we can divide military explosives into two groups - explosive mixtures and explosive compounds.

An explosive mixture always includes a substance that can burn (such as carbon or sulfur) and a substance that can supply the oxygen for burning (such as a nitrate or a chlorate). We can change the characteristics of the explosive, within limits, by changing the proportion of its ingredients. The most familiar example of an explosive mixture is black powder.

An explosive compound has a fixed chemical composition. So we can't change its characteristics by changing the proportion of ingredients. (But both the degree of purity and the size of the particles affect its explosive characteristics.)

To make these explosive compounds, the manufacturer usually starts with a hydrocarbon- an organic compound of hydrogen and carbon. He then makes the molecules unstable by a process called nitration, which adds nitrates or nitro compounds to various parts of the molecules. A detailed description of the manufacturing process, replete with pictures, is given in OP 5, Vol. 2, Ammunition Ashore, Production and Renovation. Familiar examples of explosive compounds are TNT, cellulose nitrate (used in making smokeless powder), ammonium picrate, and tetryl.

(There are some explosives that won't fit in either of the above classes. For example, dynamite is a mixture of nitroglycerin and some absorbent substance such as sawdust. Ballistite (used as a rocket propellant) is a mixture of nitroglycerin and cellulose nitrate.)

NATURE OF THE REACTION

We can divide military explosives into low and high explosives, according to the speed at which the reaction takes place.

In low explosive, the change to gas is comparatively slow; actually, it's fast burning. We call this reaction deflagration. In this reaction, the particles burn in rapid succession. The heat from one burning particle ignites the unburned particles next to it, and so on until all the explosive has burned. Black powder, smokeless powder, and ballistite are all low explosives. The term low explosive, however, has been dropped from military terminology in favor of the term propellants. Propellants are distinguished from explosives (in military usage) by their function, which is to propel projectiles, rockets, guided missiles, depth charges, and other munitions from guns or launchers, to the target. They can be made to burn at controlled, predetermined rates to produce the gases which develop the high pressure and provide the propulsion force. Propellants can be made to detonate under certain conditions, mentioned below.

When you set off a high explosive, the first particles to explode send a shock wave through the whole mass of explosive, and the change to gas is almost instantaneous. We call this reaction detonation. Dynamite, nitroglycerin, TNT, HBX, and RDX are all high explosives.

The violence of an explosion depends on how fast the explosive detonates, how much gas it produces, and how hot the gas is. The speed of detonation depends on the kind of explosive, how dense it is, and how tightly it is confined. For example, a thin layer of black powder in the open will burn without exploding. In the barrel of a torpedo tube, an impulse charge of black powder will burn fast enough to furnish the necessary push for firing the torpedo. But if it's very tightly confined, black powder will sometimes detonate like a high explosive.

When a low explosive (propellant) deflagrates, the hot gas gradually builds up pressure and applies a pushing force to anything around it. When a high explosive detonates, the pressure builds up so fast that it has a shattering effect, rather than a pushing effect. The shattering effect of an explosion is often called brisance. A brisant explosive is one in which the pressure builds up rapidly.

SENSITIVITY

Explosives differ greatly in the amount of energy it takes to set them off. The most sensitive explosives will detonate if you give them a small jolt. The least sensitive will usually absorb a lot of punishment without detonating. (But you can't depend on it; all explosives must be handled carefully.)

A good example of an insensitive explosive is ammonium picrate (Explosive D), which is used to fill armor-piercing projectiles. An armor-piercing projectile must not explode until it's detonated by its fuze, after it has penetrated the enemy armor. Ammonium picrate is insensitive enough to resist the shock of firing from a gun, and the shock of impact against armor plate. But when it does go off, it's almost as powerful as TNT.

Some of the most powerful explosives are among the least sensitive. HBX, for example, is a powerful explosive, but it usually takes a severe shock to make it detonate.

When we select an explosive for any special purpose, sensitivity is an important thing to consider. The main charge in a warhead must be fairly insensitive, so that it will be reasonably safe for you to handle. A booster charge must be more sensitive than the main charge. And a primer or a detonator must be quite sensitive, so that a fairly small shock will start the explosion.

But even primers and detonators can't be too sensitive. They must be safe to handle; and in a missile warhead, they must resist the shock of launching. A few explosives are too sensitive to be of any military use at all. Nitrogen tri-iodide, for example, is so sensitive it will explode if you touch it.

Figure 10-1 shows you the explosive train that takes place in an armed missile warhead when the firing system is actuated by a proximity fuze. (The proximity fuze is actuated by the target.) The detonator is then fired by the electric current from the fuze. The detonator in turn fires the booster charge. The shock from the booster causes the disrupting (main) charge to explode, causing the explosion that destroys the target.

The safety and arming device (S&A) makes sure that the warhead cannot detonate until the missile is a safe distance from the ship.

METHOD OF INITIATING THE EXPLOSION

The two most common ways to initiate an explosion are by heat and shock. We use heat to initiate the low explosives used for propellants and impulse charges. In guns, torpedo tubes, and depth charge projectors, the flash of flame from a primer provides the heat. The primer contains a small amount of extremely sensitive explosive. It may be set off by a spark from an electric squib, by the shock of a firing pin striking it, or by other means. The flash of flame ignites the propellant. A primer may be used to initiate a detonator.

Only the most sensitive of high explosives can be reliably detonated by heat alone. To initiate the high explosive charges of projectiles, torpedoes, depth charges, and missile warheads, we apply a strong, sudden shock. To provide the shock, we use a smaller charge of a more sensitive high explosive, either in contact with the main charge (burster, fig. 10-1) or very near it. The smaller charge can be detonated by heat, or by the shock of a firing pin.

AUXILIARY CHARGES

In many instances an intermediate or auxiliary charge is needed between the initiator and the main

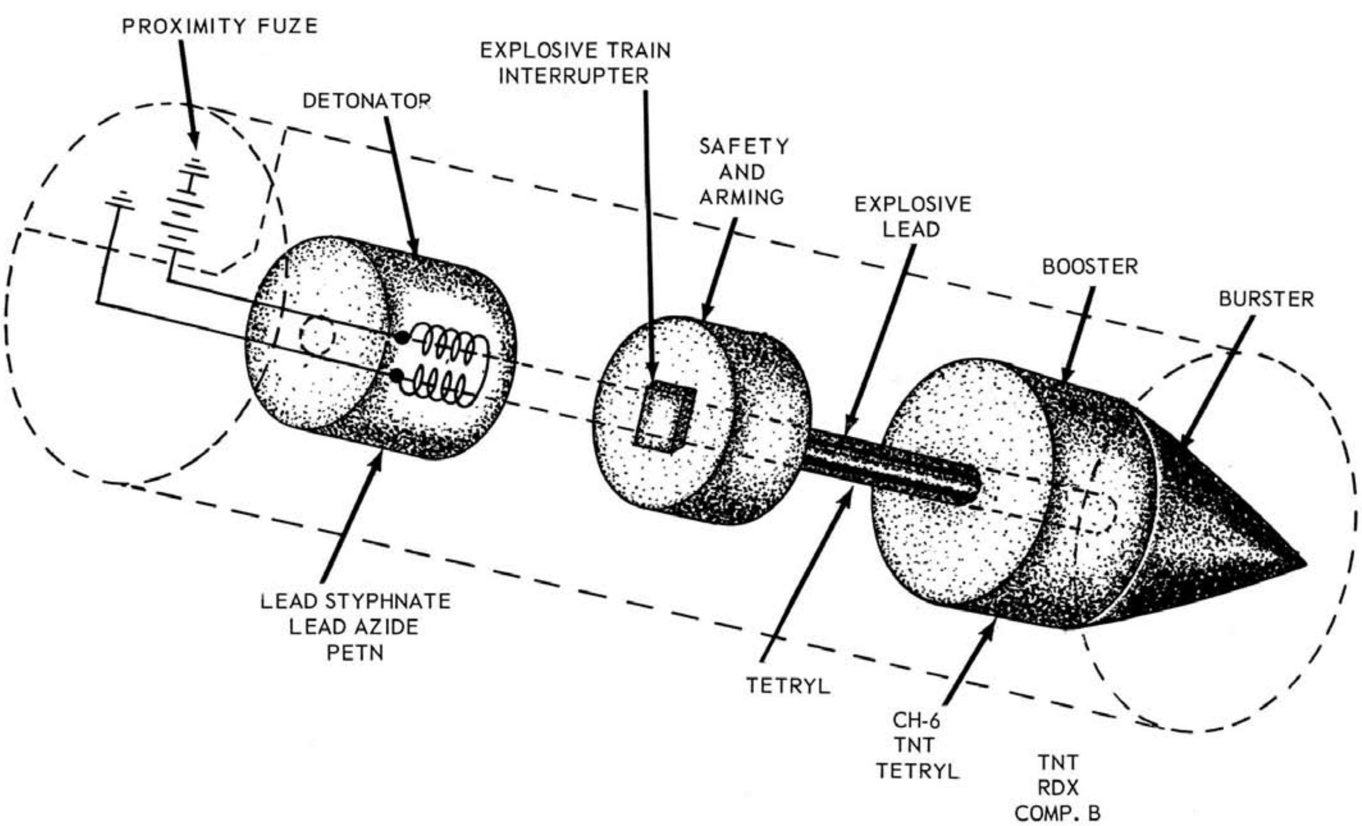

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Figure 10-1.—Explosive train in a missile warhead system.

charge of explosive to ensure successful initiation. An auxiliary charge used with a bursting charge is called a booster (fig. 10-1). It consists of a moderately sensitive high explosive to increase the shock of the detonator. Thus, the basic high explosive train consists of the detonator, booster, and bursting charge, but often there are auxiliary parts. Such a train might include a primer, delay pellet, detonator, booster, auxiliary booster, and burster.

INFLUENCE DETONATION

A third way to initiate an explosion is by influence. You can sometimes detonate a charge of a high explosive by exploding another charge near it. In that case, we say that the second charge explodes by sympathetic detonation. (But it is the shock provided by the first explosion that causes the second one.) This is the technique used in missile warheads.

The distance at which an influence explosion can occur depends on several things: first, the amount and brisance of the first explosive; second, the sensitivity of the second explosive; and third, the material that lies between the two charges. For example, the shock wave will travel a considerable distance through steel, a shorter distance through water, and not far at all through air.

SERVICE USE OF EXPLOSIVES

According to their use in service, military explosives can be divided into four classes:

1. Propellants and impulse explosives
2. Disrupting explosives
3. Initiating explosives
4. Auxiliary explosives

We use propellants and impulse explosives when we want a steady PUSH. For example, when we fire a projectile from a gun we want a pushing force. We want this force to continue as long as the projectile is in the bore, so we use a low explosive-smokeless powder. For the impulse charge in torpedo tubes and depth charge projectors, we use black powder, another low explosive. To propel a missile, we use a double-base compound; that is, a combination of two propellants bound together by small amounts of other ingredients. Figure 3-23 shows different shapes of propellant grains and the text discussed methods of controlling burning rate.

We use a disrupting explosive when we want a shattering effect. When we fire a missile at an aircraft, we want the missile's warhead to shatter into fragments, so we use a disrupting explosive.

High explosives such as TNT J RDX, and HBX are all disrupting explosives.

We must choose explosives carefully, so that each will do the job we want it to do. Both a low and a high explosive may release the same amount of energy, but there is a difference in how fast they release it. Here is an example. Suppose your car is stalled with a dead battery, and you ask your friend for a push. What you need is a steady push, applied over a distance of 20 or 30 yards, so that you can accelerate to starting speed. Your friend could apply the same amount of energy to your car by crashing into the back of it at 50 miles an hour, but that wouldn't help you get started.

For this same reason, you wouldn't use TNT for a propelling charge in a missile booster. If you did, it would blow the booster case to bits. You'd think twice before you tried it again, if you were still alive.

As we explained earlier, you must apply energy to make a charge explode. For that purpose we use an initiating explosive. To ignite a propellant, we need a flame. To detonate a disrupting charge, we need a shock. We often use lead azide mixed with some flame producing material as an initiator for both propellants and disrupting charges, because it produces both a shock and a flame.

We use a primer to ignite a propellant. A common primer is a small container that holds a pellet of fulminate of mercury and a small charge of black powder. When you fire it, it produces a long spear of flame that ignites the propellant.

We use a detonator to set off a high explosive charge. The detonator usually contains a charge of lead azide or fulminate of mercury, either alone or combined with granular TNT or tetryl. When it's fired, it provides the shock that detonates the main charge.

With a big charge of propellant explosive, or with relatively insensitive high explosives such as TNT, we need an auxiliary explosive between the initiator and the main charge. The auxiliary explosive provides enough heat or shock to make sure the main charge goes off properly. The intermediate charge we use with propellants is called an ignition charge. It consists of granular black powder. With high explosives, the intermediate charge is called a booster.

It consists of a moderately sensitive high explosive, such as granular TNT, tetryl, or CH-6 (fig. 10-1).

Look back at chapter 3 and 4 and the illustrations of the main components of missiles. Several of the pictures point out the booster, which contains propellant. Figure 3-27 shows the location of the igniter in the BT-3 missile. Figures 3-30 and 3-31 show the booster propellant and the sustainer propellant in the Tartar missile. The booster, sustainer, and warhead are pointed out in several of the drawings in chapter 4.

CHARACTERISTICS OF MILITARY EXPLOSIVES

Here are some of the most common military explosives, and some of their characteristics. Many of them you will actually handle, either as impulse charges or in the warhead, booster, or detonator of missiles. We've included a few others in the list, just to give you some background information on other explosives the Navy uses. The list is in alphabetical order, so you can use it for future reference.

AMATOL is a high explosive, made by mixing TNT and ammonium nitrate in various proportions. The Navy has used it from time to time as a bursting charge for projectiles. A 50-50 mixture is just as powerful as TNT, and it's cheaper. Its chief disadvantage as a projectile filler is that it is very hygroscopic (absorbs moisture readily), although it stores well if protected against moisture. When fired, it makes practically no smoke. A TNT explosion produces a cloud of black smoke, which makes spotting easy. In wartime, if there were a shortage of other high explosives, the Navy could use amatol as the main charge in mines.

AMMONIUM NITRATE is a high explosive. The Navy has little use for it, except in making amatol. Ammonium nitrate is quite insensitive, yet it is a powerful explosive. It is used extensively in making commercial dynamite.

AMMONIUM PICRATE. (See Explosive D.)

BALLISTITE is a low explosive mixture, of almost equal parts cellulose nitrate and nitroglycerin. It was one of the first military smokeless powders, and at one time it was widely used as a propellant. But as a propellant, it causes serious erosion of the gun bore. The Navy no longer uses it, except as a rocket propellant and in some guided missile boosters and sustainers.

It is very useful for that purpose, since it burns evenly and uniformly at the low pressures developed in a rocket motor.

BLACK POWDER is a low explosive mixture that burns very fast when it's confined, even slightly. For many years black powder was the universal military explosive. It served not only as a propellant, but also as the bursting charge for projectiles and torpedo warheads.

Black powder is now obsolete for both these uses. As a propellant it burns too fast; as a bursting charge it burns too slowly. Figure 10-2A shows a profile of one of the old-time guns that used black powder. The breech end of the barrel had to be thick, to keep the sudden force of the explosion from breaking it. And the barrel had to be short; the gas from a black powder explosion can't maintain its pressure for any great distance of projectile travel.

Figure 10-2B shows the profile of a newer gun. Since smokeless powder burns slower than black powder, the thick breech is no longer necessary. And the barrel is much longer.

The Navy still uses black powder for some purposes. You can change the burning speed to some extent by changing the size of the grains. The bigger they are, the slower they burn.

At present, the Navy uses five different sizes of black powder grains. The largest ones are 6-sided grains with rounded ends. The next smaller size is called cannon powder. We use it as an ignition charge for turret-gun powder bags. We use the three smaller sizes either alone or combined with other explosives - as burster charges for special projectiles, in primers, and in fuze delay trains.

If kept dry, black powder will remain stable almost forever. Moderately high temperatures don't affect it. But black powder deteriorates when it's damp.

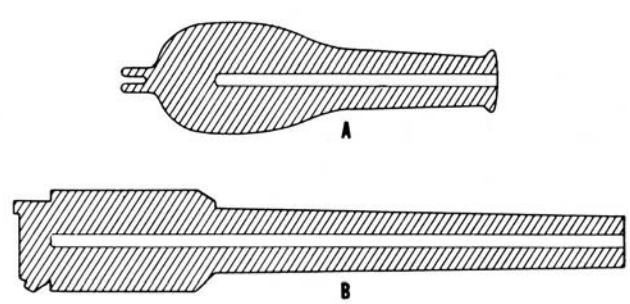

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Figure 10-2.—Gun barrel profiles: A The old look, for black powder; B. The new look, for smokeless powder.

When it's exposed, black powder is probably the most dangerous explosive you'll find aboard a Navy ship.

It's extremely sensitive to shock, friction, and sparks - including those too small to see. If spilled on the deck, you can ignite it by walking On it. So, if you should spill any, you'll have a dangerous situation. Wet the powder immediately, scoop it up, and heave it overboard. Be sure the powder is thoroughly wet before attempting removal. A small spill can be covered with a dripping wet cloth to saturate it before wiping it up. All work in the area must be suspended until the powder is cleaned up.

CH-6 is a mixture of RDX (97.5%), graphite, and other chemicals which reduce the mixture's sensitively.

COMPOSITIONS A, B, C, (See RDX.)

CORDITE is a smokeless powder. It is the standard British propellant. It is cheaper than our smokeless powder, and it has a more uniform action in the gun. But we don't use it because it quickly wears away the gun bore.

CORDITE N (SPCG), a later development, avoids this drawback. Cordite N is very cool burning with very little smoke and no flash. It is a triple-base propellant, rather new in the U. S. Navy. It is an opaque, chalk-white color, and yellows with age.

CYCLONITE. See RDX.

DYNAMITE is too sensitive for military use. We rarely use it even for demolition work, because a stray rifle bullet could make it detonate.

EXPLOSIVE D (ammonium picrate) comes in the form of red or yellow crystals. It's almost as powerful as TNT, but not nearly as sensitive. That makes it useful as a burster charge in armor-piercing projectiles and armor-piercing bombs. (A projectile gets a very severe shock when it strikes armor plate. But, to be effective, it must not detonate because of that shock. It must be detonated only by its fuze, after the projectile has penetrated the armor.)

For a long time the composition of Explosive D was a secret. That is why we spoke of it in code, rather than by its right name.

FULMINATE OF MERCURY (mercury fulminate) is a yellowish-white crystalline powder. It's the most sensitive explosive in common service. We can use it for only one purpose: to initiate the action of other explosives, either directly or through an auxiliary explosive. In primers, it may be mixed with other flame-producing materials.

GUNCOTTON, a form of cellulose nitrate, was the first modern bursting charge. Its early uses included loading into mines and torpedo warheads. Because of its sensitivity when dry, its susceptibility to deterioration, and its relatively low power, guncotton has generally been replaced by TNT and other explosives.

HBX is one of the most important developments in the field of explosives. It was developed by the U. S. Navy to take the place of torpex because torpex is too sensitive. HBX is very nearly as powerful as torpex, but much less sensitive. It is chemically stable and noncorrosive, and is in the same general class as TNT for safety in handling. HBX-1 and HBX-3 are used as explosive fillers in underwater ordnance, replacing TNT filler.

LEAD AZIDE has a high temperature of ignition and is less sensitive to shock and friction than mercury fulminate. The brisance of lead azide increases as the pressure applied to it increases. It is less brisant and has less explosive power than mercury fulminate.

Lead azide is poisonous, slightly soluble in hot water and in alcohol, and very soluble in a dilute solution of nitric or acetic acid in which a little sodium nitrate has been dissolved. Lead azide reacts with copper, zinc, cadmium, or alloys containing such metals, forming an azide which is more sensitive than the original lead azide. Because it does not react with aluminum, detonator capsules for lead azide are made of this metal. The hygroscopicity of lead azide is very low. Water does not reduce its impact sensitivity, as is the case with mercury fulminate. (See OP 5, Vol. 1 for instructions if you must destroy some lead azide. Ammonium acetate and sodium dichromate are used to destroy small quantities of lead azide.) The velocity of detonation of lead azide is approximately 17,500 feet per second. Its color varies from white to buff.

Lead azide may be used where a detonation is caused by flame or heat. It has been adopted as the detonator of major caliber base-detonating fuzes, of point-detonating fuzes, and of auxiliary-detonating fuzes. It is also used in priming mixtures.

Lead azide is completely stable in storage, even at high temperatures. However, it produces an intensely poisonous, highly flammable gas when enclosed.

LEAD STYPHNATE comes in two forms - (1) the normal, which appears as six-sided monohydrate crystals, and (2) the basic, which appears as small rectangular crystals. Lead styphnate is particularly sensitive to fire and the discharge of static electricity; when dry, styphnate can be readily ignited by static discharges from the human body. The longer and narrower the crystals, the more susceptible the material is to static electricity. Lead styphnate does not react with metals. It is less sensitive to shock and friction than mercury fulminate or lead azide. Lead styphnate is very slightly soluble in water and methyl alcohol and may be neutralized by a solution of sodium carbonate. The velocity of detonation is approximately 17,200 feet per second. The color of lead styphnate varies from yellow to brown. Lead styphnate is used as a component in primer and detonator mixtures. It is stable in storage, even at high temperatures.

NITROGLYCERIN is a colorless, oily liquid, a little heavier than water. It is very simple to make; and after it is made, it is very easy to blow yourself to pieces with it. Some experimenters say it takes a small jolt to detonate nitroglycerin; others say it takes only a dirty look.

Nitroglycerin is an important commercial blasting explosive, but it is too sensitive for military use. It is, however, one ingredient of double-base powder, which is colloided so that the nitroglycerin is desensitized. These powders are used by the U. S. Navy as gun and rocket propellants. It is also colloided with guncotton or mixed with inert material to make commercial dynamite, frequently used for construction blasting.

PETN (pentaerythritoltetranitrate) was one of the compounds developed in the search for an explosive more powerful than TNT. It is one of the most powerful of all modern high explosives. The Navy sometimes uses it in detonating and priming mixtures. PETN is used in the explosive train detonators in many U. S. Navy missile warhead systems. It is often used in primer or detonating cords in demolition work. During World War II, a mixture of PETN and TNT was sometimes used as the main charge in mines and torpedoes.

PICRIC ACID (tri-nitro-phenol) comes in pale yellow crystals. It was probably the most important projectile-bursting charge used during the Spanish-American War and World War I. Since its melting point is too high for safe casting, it was usually mixed with other explosives to lower the melting point. When it was used alone, it was press-loaded in the projectile cavity. The British call picric acid lyddite. The French name is melinite; the Japanese name is shimose, the Italian name is pertite. It is most generally used in its converted form, ammonium picrate, or Explosive D.

RDX is a powerful high explosive, of greater brisance than TNT. In pure form, it is too sensitive for military use. To make RDX safe for military use, it is mixed with oils, waxes, or less sensitive explosives. It is important because of its high power and good chemical stability.

The Navy uses different mixtures containing RDX:

1. Composition A is a mixture of RDX and wax. This mixture has about the same sensitivity as Explosive D, but it is more powerful. It is beginning to replace Explosive D as a projectile filler.
2. Composition B is a mixture of RDX, TNT, and wax. It is used for filling projectiles, bombs, and missile warheads.
3. Composition C is a plastic explosive mixture - you can mold it by hand into any desired shape. It is often useful in demolition work, since you can mold it around the object you want to destroy. Composition C-4, the one you'll most likely find in use, is white in color and has a texture like putty. Composition C-4, like Composition C-3, is manufactured in 2 1/2- pound blocks. But C-4 does not exude oil like other Composition Cs do. These compositions are about 25% stronger than TNT.
4. HBX, described earlier, contains 40 percent RDX, plus TNT and some other ingredients.
5. Another explosive has been developed, designated H-6. It is similar to HBX but is considered superior to it. It is used in bomb type ammunition, and is a cast filler.

SMOKELESS POWDER is a low explosive. It is the standard propellant for all Navy guns. It comes in the form of cylindrical grains, in a variety of sizes, with one or more perforations running the length of the grain to increase its burning rate (fig. 10-3). When they're fresh, the grains are gray or buff colored, with a translucent, horny appearance. Older powder may be brown or black.

Chemically, smokeless powder is cellulose nitrate, or pyrocotton, prepared by putting ordinary cotton through several processes, then colloiding with ether and alcohol.

The manufacturer of smokeless powder, after washing and boiling the pyrocotton, extracts as much water as possible by passing it through wringers. He then adds alcohol, and extracts the remaining water. After removing the excess

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Figure 10-3.—Smokeless powder grains.

alcohol, he adds the proper amount of ether. The ether and alcohol, working together, soften the pyrocotton into a colloidal mass. This soft material is then extruded in the form of perforated rods, which are cut into grains of the desired length. These grains of smokeless powder must dry for several months before they're ready for service use.

The stability and useful life of smokeless powder are affected adversely by moisture and heat. The storage conditions for smokeless powder are therefore very important.

TETRYL comes in yellow crystals or granules. Its chemical name is tri-nitro-phenyl-methyl-nitramine. It's a high explosive, more powerful and more sensitive than TNT. The Navy uses tetryl extensively as a booster, especially in mines, and torpedo and missile warheads. A mixture of tetryl with fulminate of mercury is sometimes used as a detonator. Tetryl is also used in explosive leads.

Tetryl is a derivative of methyl-aniline and is classified as a nitro aromatic compound. It is a fine crystalline material practically insoluble in water, but soluble in acetone, ammonia, ether, carbon tetrachloride, and benzol. Tetryl melts at about 130°C. Heated above its melting point, it undergoes gradual decomposition, and explodes when exposed to a temperature of 260°C for five seconds. Tetryl will corrode steel when in the dry or moist state. It is practically nonhygroscopic (after proper drying) but moisture does interfere with its effectiveness. Tetryl is chemically stable at ordinary temperatures. It is more sensitive to shock or friction than TNT, arid more powerful than TNT. Tetryl is more sensitive to detonation by mercury fulminate or lead azide than TNT and is readily exploded by penetration of a rifle bullet. It can be initiated from flame, friction, shock, or sparks, burns readily; and is quite likely to detonate if burned in large quantities. The velocity of detonation of tetryl is approximately 24,400 feet per second. When pure, tetryl is light yellow, but is usually gray after loading because of the graphite mixture used in the loading process.

Tetryl is sensitive to mechanical shock, and it is used as a booster charge between the fulminate of mercury or lead azide detonators and the high-explosive bursting charge. It is also used as a filler in small-caliber projectiles. Tetryl is loaded in pellet form, the pellets being pressed after being mixed with small quantities of graphite which serves to lubricate it while it is being pressed.

Tetryl is poisonous when taken internally and causes dermatitis on contact with the skin. Precautions are therefore necessary regarding the handling and packing of the dry material. Special precautions must be taken to prevent ignition or explosion from friction or blows resulting from rough handling. Tetryl should be kept dry and protected from high temperature and sparks.

TNT (trinitrotoluene) is probably the best known of all military high explosives. When it is pure, TNT is a white crystalline substance. When impurities are present, its color varies from yellow to dark brown. It is chemically stable as long as you protect it from moisture and extremely high temperatures. You can store it for years without any chemical change. And, compared with most high explosives, TNT is relatively insensitive and safe to handle.

An advantage of TNT is its low melting point. It can be melted and poured into mines, torpedo warheads and projectile cavities, where it will harden when it cools. In its cast form, TNT is hard to detonate. It needs a powerful booster of tetryl or granular TNT. However, components containing TNT, such as bombs, depth charges, warheads, and similar munitions containing TNT bursting charges, are subject to sympathetic detonation. This makes it necessary to store such munitions separately, especially away from fuzes, detonators, and fire hazards that could start a detonation. Also, it cannot be roughly handled without danger.

Instances on record show that it can be detonated very easily if the combination of conditions is just right for it.

WARHEADS AND FUZES

Like any other vehicle, the guided missile must carry some form of useful burden if it is to accomplish the intended objective. In missile terms, the useful burden is called the payload. Physically, the payload merely occupies one or more of the sections of the airframe, and it contributes nothing to the functions of the vehicle, such as guidance, propulsion, or control. But in the total system, it is the component of greatest value, since all the actions of the missile serve as the means for ensuring the effective delivery of the payload.

In research and test missiles, the payload often consists of telemetering units, which collect data during flight, convert the information into radio signals, and transmit them to receivers at a recording site. In some test missiles, dummy payloads are carried which have the same physical characteristics as the corresponding devices which the missile will carry as an operational weapon. But in its military role, the guided missile is launched with a payload composed of one or more warheads and one or more fuzes. The warhead is a device capable of destroying or damaging an enemy target. The fuze is a triggering mechanism used to initiate the actions of the warhead and determines the exact moment of release of the destructive forces.

In the discussion of explosives you have seen two spellings, FUSE and FUZE. The Navy makes a distinction in their meaning. Fuze was defined earlier. A FUSE is a protective device inserted in series in an electrical circuit. An explosive fuse is a conduit that leads fire from one place to another. A firecracker fuse is a familiar example. Primacord, used to detonate explosives in mining and quarrying, or for demolition is another example. When the fuse is lighted, the flame follows the train of powder in the center of the cord.

The fuze used to detonate weapons is a mechanical or electrical device but may include a fuse train of black powder.

TYPES OF WARHEADS

Many of the warheads developed for other kinds of weapons can be modified or adapted for use in guided missiles. Some of these may present special problems to the missile designer, but almost any sort of destructive device employed in conventional weapons may also be carried by guided missiles. Among the types of warheads which might be used are: external blast, fragmentation, shaped charge, explosive pellet, biological, and atomic.

External Blast Warheads

This type of warhead causes damage by means of a high pressure wave, or blast, which results from the detonation of an explosive substance. When set off by a suitable impulse, the explosive material undergoes a sudden chemical change in which energy is released almost instantaneously. Gaseous products are formed and large quantities of heat are generated. The destructive effect results from the high pressure produced by the rapid heating of the gases.

Blast warheads are very effective against ground targets, and have been used in many surface-to-surface and air-to-surface missiles. They are less effective against aircraft, since in the atmosphere the pressure wave dissipates rapidly with distance, and the explosion must take place very near the aircraft in order to damage it. Large blast warheads can cause great damage to ground installations, which must be of special construction to withstand them; and damage occurs hundreds of feet from the point of detonation. The V-1 buzz bomb, which carried a warhead consisting of about 2,000 pounds of high explosive, caused destruction and damage over an area equal to an average city block.

Torpedoes use a blast type of warhead. Since water is incompressible and relatively dense, the pressure waves created by the explosion are transmitted to the target practically undiminished, and damage it.

Fragmentation Warheads

These warheads operate by bursting a metal case containing a high-explosive charge. Upon explosion, the container is shattered into hundreds of fragments which fly out at high velocities; and these are capable of damaging targets at considerable distances from the point of detonation. For this reason, this sort of warhead is very effective against aerial targets and is often employed in air-to-air and surface-to-air missiles. Usually the warhead does not penetrate the target but is detonated by the fuze at some distance from the target. This increases the chances of a hit. See figure 10-4.

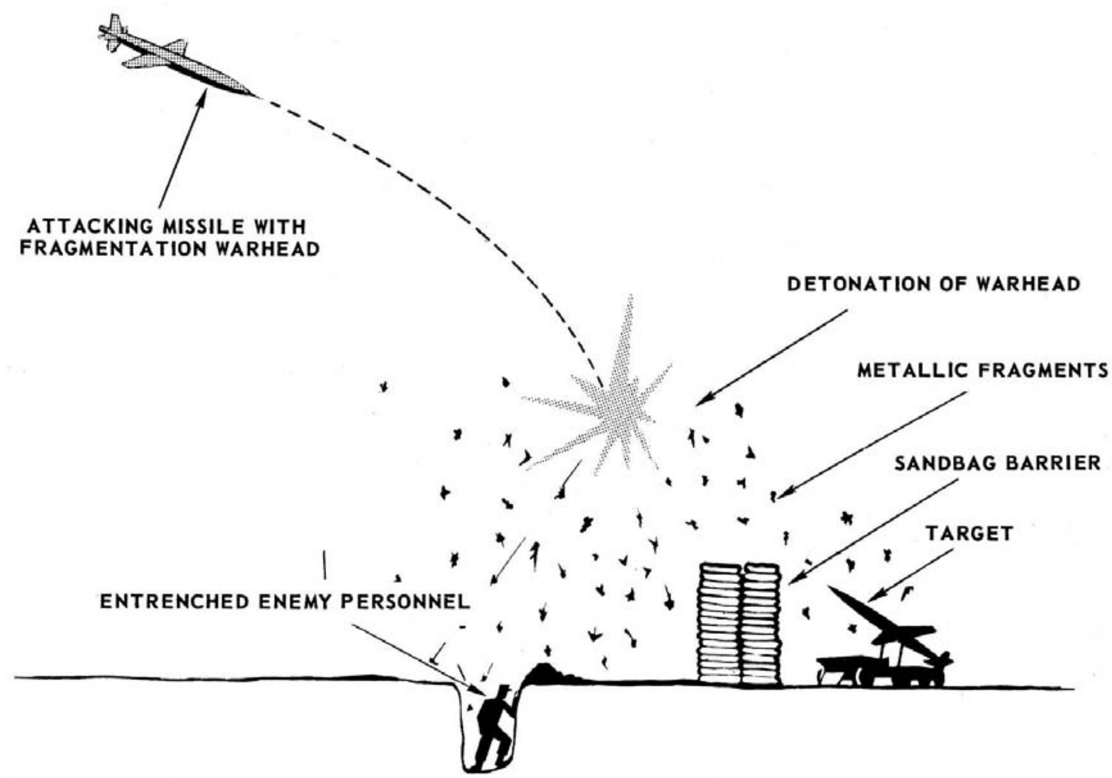

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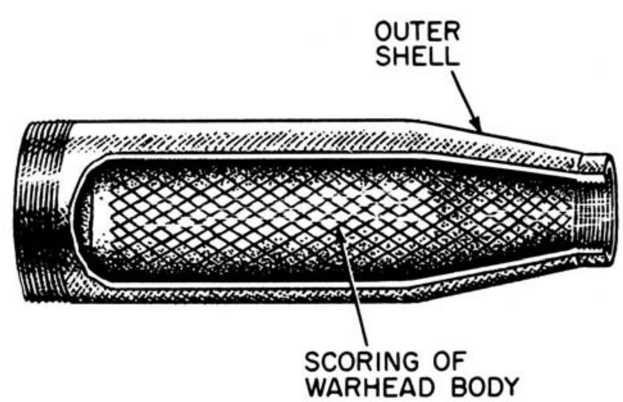
Figure 10-4. — Effect of fragmentation warhead on surface target.

The factors which influence the destructive action of the warhead are the size of the fragments, their velocity, and the angle at which they ~re ejected. Fragment size is controlled by the designer by weakening the case at certain points. The fragment velocity is controlled by the shape of the container, the ratio of explosive weight to metal weight, and by the type of explosive used. The angle at which most of the fragments are emitted depends on the shape of the container and the point within it at which the detonation takes place. On modern missiles fragmentation is not a hit-or-miss affair. Theories are checked out on scale models and test firings substantiate the value of controlled designs. Various shapes and sizes of fragments have been tested against different targets. Figure 10-5 depicts one type of controlled fragmentation warhead.

Shaped Charge Warheads

Shaped charges, also called cavity charges, make use of the Munroe effect, in which the explosive power is concentrated by shaping the explosive material. Experiments show that if a regular cavity such as a conical hole is molded into the side of an explosive charge nearest the target, the effect on the target is increased over the effect obtained with the same charge without the cavity. The presence of the hole brings about a concentration of the



144.16
Figure 10-5. — Controlled fragmentation warhead.

explosive force similar to the way in which light can be focused into an intense beam by a glass lens.

In the explosion of a shaped charge, a beam of very hot gas, called the jet, is ejected. In it, the gas particles have an extremely high velocity. If the cavity is lined with some material that can be broken into small pieces or can be melted by the explosion, the efficiency of the charge is greatly increased. The small particles of the liner are carried by the jet, which is increased in weight, and as a result, it can penetrate a thick target, acting somewhat in the manner of a needle. Among the applications of the Munroe effect are the Army's bazooka projectile and also certain types of demolition charges used to blow holes through reinforced concrete structures.

When employed in guided missile warheads, shaped-charge explosives have possibilities of great effectiveness against both aircraft and heavily armored surface targets.

Explosive Pellet Warheads

A warhead of this type contains a number of small explosive charges, or pellets, each of which is separately fuzed. When the main warhead is detonated, the pellets are ejected but withstand the force of the explosion and are hurled intact toward the target. The pellets then detonate either on impact or after penetrating the target skin. The total destructive effect combines both blast and fragmentation effects, since blast damage is great when the individual charge is exploded, regardless of whether the explosion occurs at the skin of the target or after penetrating it.

The explosive pellet is an ideal weapon for use against enemy aircraft. Its full development is dependent upon perfecting a fuze for the individual charges that can withstand the initial blast of the principal warhead while still ensuring explosion on or within the targets.

Chemical Warheads

This type may contain either war gases or incendiary materials. Warheads containing gases may liberate any of the well-known types such as mustard gas, lewisite, or some newly developed chemical. The effects produced are either denial of the use of the target area or personnel casualties within the area. Missiles equipped with chemical warheads also serve as possible counterthreats to initiation of gas warfare by the enemy.

A variety of disabling gases have been developed. The length of disability and the type of disability can be varied with the type of agent used, the method of application, the terrain, the weather, and other factors. Agents dispersed as a vapor or aerosol usually have a short period of effectiveness. In the category of riot-control chemicals are the tear gas type and those that produce nausea and vomiting.

The most important advantages of chemical agents are the area coverage and penetration effects. Agents dispersed as gas or aerosol penetrate structures and incapacitate hidden enemies that could not be reached by conventional weapons. At the same time, the lives of the innocent are spared. The effects of the disabling chemical wear off before long, and without after effects. This is far different from the gas warfare of World War I, when deadly chlorine gas and mustard gas were used.

It takes no great depth of thought to realize that it is much more humane to overcome the enemy by disabling him temporarily (and maybe making him uncomfortable for a few hours) than by blasting him to bits.

Another type of chemical warhead is the incendiary warhead. It contains a material that burns violently and is difficult to extinguish, while covering a large area after release from the warhead. Incendiary weapons are useful principally against ground targets. There are several types of chemicals used to cause fires, and different rules for handling apply to each.

There are many more chemical agents used in warfare. Disaster Control (Ashore and Afloat), NavPers 10899-B, has a lengthy chapter on the different types of chemical agents used, their effects, and how to protect yourself against them. Reading that chapter can be very enlightening. You may be sure that all major nations have an arsenal of chemicals to use in warfare. You need to know how to protect yourself against the different varieties.

Biological Warheads

A biological weapon delivered by a missile would contain living organisms capable of disrupting personnel activities in the target area by causing sickness or death to the inhabitants. Not only can micro-organisms be used against people, but also against animals and vegetation. Such use could destroy or greatly reduce the food supply and the raw materials for factories. Water supplies can be contaminated. Biological agents are difficult to detect. For a revealing discussion of the possibilities of this type of warfare, plus methods of detection and protection, read chapter 4 in Disaster Control (Ashore and Afloat), NavPers 10899-B.

Atomic and Thermonuclear Warheads

In this type, destruction and damage result from the processes of atomic fission or fusion. The destructive effects are blast, heat, and liberation of radiation. The detonation results in death, sickness, and the denial of the use of large areas as a result of the release of radioactive elements.

Volumes have been written about the effects of nuclear weapons, all based on the results of the two bombs dropped on Japan in World War II. Some information has been added from the experimental tests made since then but the statistics of human and material destruction hark back to the original drops. All other figures on human destruction are estimates of what could happen, however accurate those estimates might be. We know that nothing can survive at ground zero, where the weapon strikes. The area of total destruction varies with the size of the weapon. Beyond this area of complete devastation, shelters can save the lives of many, by protection against falling buildings, fires, thermal radiation, and nuclear radiation. One of your basic texts, Basic Military Requirements, NavPers 10054-C, devotes a chapter to Nuclear, Biological, and Chemical (NBC) defense.

Several of our Navy missiles are capable of carrying a nuclear warhead. This means that we can send this destructive force far into enemy territory, away from our own personnel. We know, too, that other major powers have nuclear missiles. Therefore, you must learn what means of protection against their effects you have aboard ship, as well as how to fire the lethal missiles.

Continuous Rod Warheads

Fragmentation-type explosive devices such as fragmentation grenades, bombs, and projectiles are well known and have a long tradition of use in conventional weaponry. They are effective, but they do leave something to chance. The pattern of fragment distribution is necessarily random, and the fragments tend to be irregular in size (and hence in lethality) in spite of pineapple like or waffle-like patterns in the fragmenting body.

The purpose of the continuous rod warhead is to menace aircraft within a lethal radius. In this type of warhead, the warhead energy is used to expand rods radially into a ring of metal which can lengthen and thus increase its diameter rather than produce an expanding shell of small fragments. Upon detonation the continuous rod warhead expands radially into a ring pattern. The intent is to cause the connecting rods, during their expansion, to strike the target and produce damage by a cutting action.

Other Types of Warheads

Several other types of special warheads may be used. These include: radiation, anti radiation, illumination, psychological, exercise, and dummy warheads.

RADIATION warheads may use radiological material in the same manner as chemical or biological agents, scattering the radioactive material according to plan. The possibilities and ramifications of this type of warfare will not be explored further here.

ANTIRADIATION WARHEADS carry material that will jam enemy radars. The Shrike missile is of this type. It is intended to home on enemy radar installations and silence their transmitters. The ARM-l missile being developed is similar to the improved Shrike.

ILLUMINATING warheads have long been used in projectiles during night attacks to point out or silhouette enemy fortifications or other targets. This has been especially useful during shore bombardment. Illuminating warheads are also used in aircraft bombs and rockets to assist in the attack on ground targets and submarines. No application has been made in guided missiles.

PSYCHOLOGICAL warheads do not carry lethal or destructive agents, but carry material designed to create a psychological effect on the enemy, rather than actual physical damage. Payloads may be propaganda leaflets, mysterious objects that appear dangerous, or inert or dummy warheads. Decoy warheads may carry "window," which causes false radar echoes or noise-makers to confuse sonar operators of antisubmarine ships.

A dummy warhead has only the outward appearance, the size, shape, and weight of a real warhead. It is used in training and practice operations.

EXERCISE or training warheads do not contain any explosive material but otherwise contain parts of a real warhead, so they can be assembled, disassembled, tested for electrical continuity, and other wise used for training exercises.

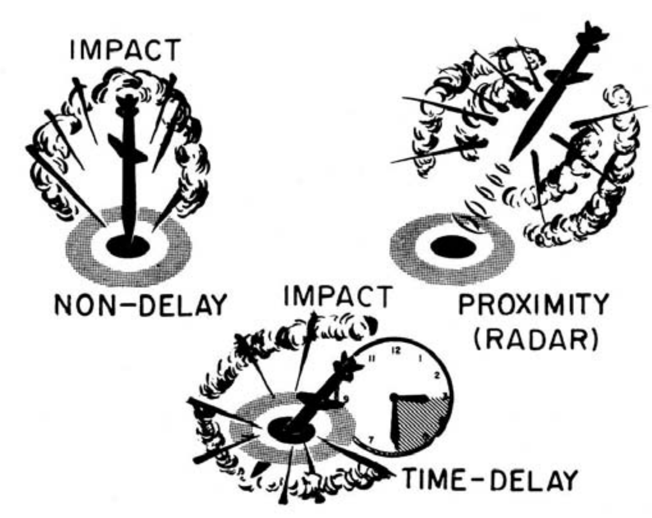
The ASROC (Rocket Thrown Torpedo) uses a torpedo for its warhead.

TYPES OF FUZES

The missile warhead is activated by tile actions of one or more fuzes, which release tile destructive forces after certain conditions have been fulfilled. The type of fuzing employed determines whether tile warhead is detonated at a distance from the target, upon impact with it, immediately following penetration, or at some fixed time after penetration of tile target skin. The missile warhead is generally detonated in one of the three relations with the target shown in figure 10-6.

The most effective type of fuze for a given missile depends upon the nature of tile target and the possibilities of tile warhead for causing damage. The type often employed in missiles are the impact, time ground-controlled, and proximity fuzes.

Fuzes may also be classified according to their location, as nose fuzes, tail fuzes, or other.



12.37
Figure 10-6.—Types of missile fuzing.

Impact Fuzes

Impact fuzes are actuated by the inertial force exerted when the missile strikes the target. If detonation takes place at the moment of impact, the fuze is of the non-delay, or instantaneous type. If the detonation takes place some time after impact the fuze is said to be of the delay type. This short delay time permits the weapon to penetrate the target before it explodes. Impact fuzes are also called contact fuzes.

Ground-Controlled Fuzes

In ground-controlled fuzes, some device is used for measuring the distance from the missile to the target. The control device is not mounted in the fuze but on the ground; and when the proper space relationship exists between the missile and its target, a signal is sent to detonate the fuze from the control point on the ground.

Time Fuzes

Time fuzes, or time-delay fuzes are fuzes that are preset to detonate the warhead after a specified lapse of time after launching. One type has a burning powder train' another type has a clocklike mechanism. In either type, the time cannot be changed after the missile is launched. A missile may have to maneuver to intercept its target, and the variation in time, however slight, precludes the use of a fuze with preset timing. However, Subroc uses a timer that closes the firing contacts when the preset time (in the water) has elapsed. The timing device is actuated when the depth bomb strikes the water.

Proximity Fuzes

Fuzes of this type are actuated by the influence of some property of the target and are detonated at a distance which allows maximum damage to take place. Five general classes of proximity (also called VT, or variable-time) fuzes can be distinguished according to the property to which the device responds. These are electromagnetic (radar and radio), pressure, acoustic, photoelectric, and electrostatic fuzes.

ELECTROMAGNETIC FUZES. - These fuzes may operate with radio, radar (microwave), infrared, or ultraviolet waves. The basic proximity fuze must have a transmitter-receiver, a means of amplifying the return signal so it will be strong enough to activate the detonator, electrical safety devices to prevent premature detonation, and a power supply to set off the fuze. The miniature transmitter in the fuze transmits high-frequency radio waves, which are reflected from the target as the missile approaches it. Because both the missile and the target are moving with respect to each other, the reflected signal, as received at the missile, is of a higher frequency than the transmitted signal. The two signals, when mixed, will generate a Doppler frequency, the amplitude of which is a function of target distance.

At the proper time, the action of the reflected waves causes an electronic switch to close and fire the detonator. Fuzes of this kind have been developed to a high degree of accuracy and dependability. They operate effectively both in darkness and daylight and in all kinds of weather. However, they are subject to jamming by false information from the target. This can make the fuze inoperable or, worse yet, cause it to detonate before it comes within lethal range of the target. Some counter-countermeasures have been devised to offset the effects of enemy countermeasures. One method is to add a contact fuze so that if the proximity fuze fails the other fuze will act. Two of our missiles, Sidewinder and Sparrow, use such a system.

PRESSURE FUZES. - The pressure that activates these fuzes may be air pressure or water pressure. Those that are actuated by water pressure are called hydrostatic fuzes. Some of our depth charges have fuzes preset to actuate at a certain depth, where the preset pressure is reached. Another type is actuated by the variations in pressure in the ocean caused by the passing of a ship or submarine. They must be so designed that they will not be set off by the natural movement of the waves.

Fuzes that are actuated by air (barometric) pressure might be used against stationary ground targets. As barometric pressure over different parts of the earth is subject to frequent change, it is difficult to use a preset altitude (or barometric pressure) as the triggering quantity for a guided missile whose target may be a considerable distance from its launching point. Polaris is one missile that is detonated at a preset height above the target, with the fuze activated by the barometric pressure.

Fuzes acted upon by the surrounding medium (air or water) are also called ambient fuzes. Proximity fuzes which respond to changes in pressure generally lack the sensitivity and reliability required for guided missile applications, but in some cases they are useful against surface targets.

ACOUSTIC FUZES. - These are actuated by sound waves from the target. They must react only to specific sounds, not to all sounds. The problems of the acoustic proximity fuze were studied by the Germans at Peenemunde to determine the characteristics of these devices in supersonic missiles. Their wind-tunnel experiments proved that sound waves can be received readily by missiles traveling at speeds in excess of sound velocity. The acoustic fuze has the valuable property of all-weather, day-or-night effectiveness; but it also has the disadvantage that it is subject to local vibration and noises generated within the vehicle as well as to the sound waves by which it senses the target. The need for sensitive but selective acoustic fuzes is one of the reasons for the Navy studies on sounds made by fish and sea mammals. Acoustical sensors are still used to activate mines and torpedoes.

PHOTOELECTRIC FUZES. - Photoelectric fuzes react to external light sources, and ordinarily they are inoperable at night or in conditions of low visibility.

ELECTROSTATIC FUZES. - The Germans also investigated the possibilities of the electrostatic system of fuzing in which the detonating influence is the electric field of the target. Attempts to develop the fuze were unsuccessful - probably because of the variable nature of the electrostatic field surrounding possible targets, Air targets become electrostatically charged as they pass through the air, but water vapor or rain dissipates much of the charge, which poses a problem for the fuze. Electrostatic fuzing has application over short distances.

MAGNETOSTATIC FUZING. - Magnetic sensors measure changes in the earth's magnetic field or the presence of a source of magnetic flux. The magnetic field of the earth at any given point remains practically the same unless disturbed by some other force. Any steel ship has a permanent magnetic field of its own, peculiar of itself. Such a ship passing over a magnetic mine would detonate it. Degaussing or deperming was made a requirement for all Navy ships to reduce losses from mines. These processes remove much but not all of the magnetic charge of a ship, Magnetostatic fuzing is being developed for use in missiles. Equipment to measure the intensity of the earth's magnetic field at a point or in a reference frame is still in the developmental stage. It would be used with the guidance system.

Of these various types of proximity fuzes, the radio system appears to be the most reliable and effective for missile applications. Future developments may change this.

SAFING AND ARMING (S&A) DEVICES

Each fuze has a safing and arming (S&A) device to control the detonation of the payload so that there will not be a premature detonation, or a dud. The safety devices included in the S&A must prevent accidental activation, so the missile can be transported, stored, handled, tested, and launched. The purpose of the primary safety mechanism is to prevent accidental activation. The secondary safety device must overcome countermeasures and false signals and permit activation only upon receipt of the specified signal. The increase in enemy countermeasures has made this more complex.

Since the arming device is actuated by a specific signal, such as radar waves from a target, the countermeasure may supply a false signal by a decoy or some other method to deceive the arming device. The safety device must prevent arming by the false signal. This is a complex problem that requires constant study. To increase the chances of detonation at the best time and place, the weapon designer may put in duplicate systems (redundancy), or he may put in two types of fuzes so that if one fails there is another to take over.

PYROTECHNICS

PYROTECHNICS is a Greek word for fireworks. The Navy uses fireworks not for celebration, but for illumination, screening, marking, and signaling. An example is the illuminating projectile or star shell (SS) used to illuminate targets for gunfire. This is actually a pyrotechnic device, even though it is encased in a projectile body of standard external shape, and is fired from a standard rifled gun.

In the following sections we shall take up pyrotechnics launched by hand or from special projectors, or simply held by hand. All the pyrotechnics we shall study here are intended for signaling.

The Navy issues pyrotechnics not only for use aboard its surface combat ships, but also for use by aircraft, submarines, motor torpedo boats, and merchant ships, as well as for use ashore. However, we can here discuss only those issued as ship's pyrotechnics. For the others, see OP 2213 (second revision) Pyrotechnic, Screening, and Marking Devices.

The pyrotechnic units we shall take up are-

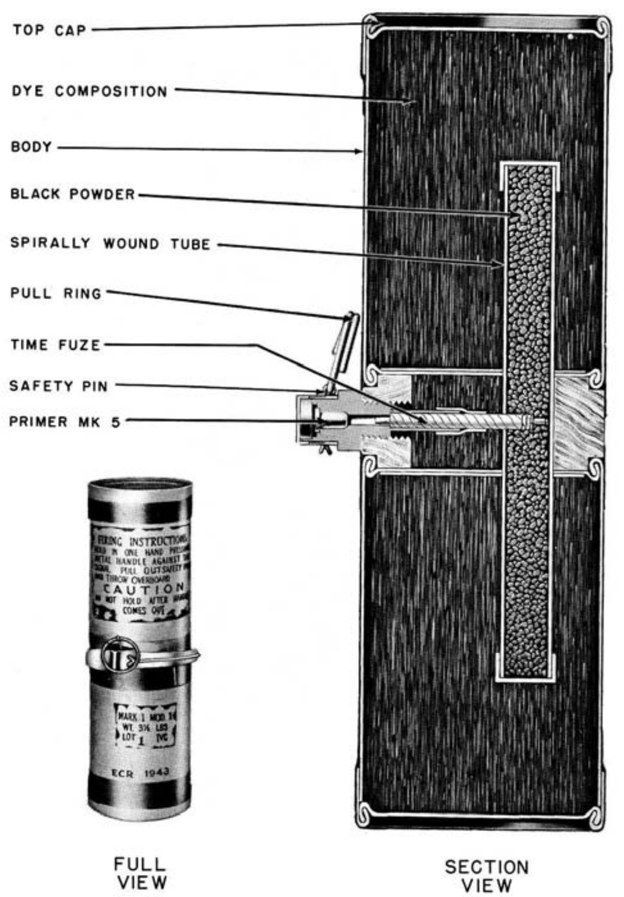
1. Markers, location, marine
2. Signal lights, and the pyrotechnic pistols and projectors used in firing them
3. Distress and hand signals
4. Navy lights
5. Flash signals
6. Smoke and flare markers

MARKERS, LOCATION, MARINE

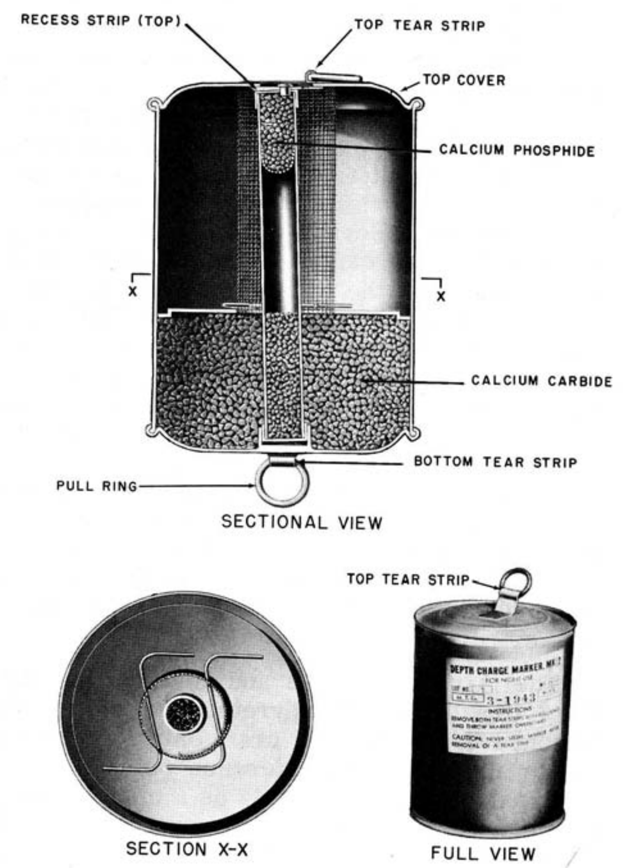
Markers, location, marine (formerly called Depth Charge Markers) are of two general types - those for day use (Mk 1 Mod 3) and those for night use (Mk 2). The marker for daytime use spreads a patch of chrome yellow dye on the water; the night type burns with a yellow flame for 45 to 55 minutes. Both types are used to indicate the point of discharge of depth charge barrages and to provide a reference point for further antisubmarine attack. (A Mk 1 Mod 2 marker, still occasionally used, has green dye. It should be used only for practice sessions since green is the distress signal used to mark downed aircraft in search and rescue operations at sea.)

The Marker, Location, Marine Mk 1 Mod 3 (fig. 10-7) is a cylindrical waterproofed container about 12 inches long and 3.5 inches in diameter. When you pull the ring attached to the safety pin and release the safety lever, the primer ignites the time fuze. Fifteen seconds later the black-powder charge bursts the two dye containers and scatters the dye. The marker is dropped about 25 yards from the actual point where the depth charge itself was launched, so that the depth charge's "boil" when it bursts will not dissipate the slick of dye. Never pull the pin until the marker is to be launched. After the pin is pulled, keep the safety lever firmly against the marker body until it actually leaves your hand.

WARNING: If the marker is accidentally dropped after the pin has been pulled, clear the area. Don't try to retrieve the marker and make it safe again; it cannot be done.



83.107
Figure 10-7.—Marker, location, marine Mk 1 Mod 3 (day).



83.108
Figure 10-8.—Marker, location, marine Mk 2 (night).

If exposed to moisture, the dye in the marker cakes and doesn't spread very well in the water. The markers should, therefore, be kept dry. Markers, location, marine can also be launched from aircraft.

The Mk 2 (night) marker is a sealed metal cylinder 7 inches high and 5 inches in diameter, shown in figure 10-8. It contains two chemicals. One of them is calcium carbide, used back in the horse-and-buggy days for carriage lamps. When wet, calcium carbide gives off acetylene, a gas that smells bad but burns well. The other chemical (calcium phosphide), when wet, gives off a gas that ignites by itself, without help from matches, ignition charges, or the like. This ignites the acetylene, which burns with a white flame.

To operate the marker, pull the rings on the marker to open the holes which allow water to get to the chemicals. Then throw the marker overboard, allowing a short time lag, so as to avoid the depth charge "boil." The flame should appear within no more than 90 seconds. Don't remove the tear-strip rings until ready to cast the marker overboard. Never handle or carry the markers by their tear-strip rings.

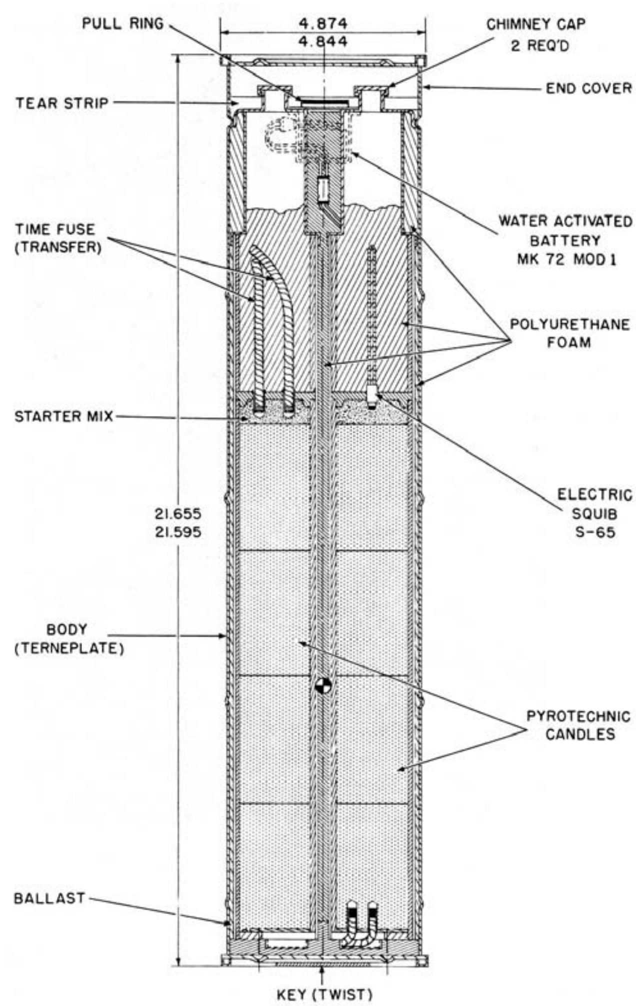
The Mk 2 (night) marker should be inspected while in stowage for damaged tear strips. Markers with damaged strips should be disposed of immediately as unserviceable.

This marker may also be launched by hand from aircraft at altitudes up to 3000 feet.

SMOKE AND FLARE MARKERS

For night or day reference marking on the ocean's surface, Marker, Location, Marine Mk

58 Mod 0 is used chiefly by aircraft patrols in ASW but also is used for search and rescue operations, man-overboard marking, and similar applications. It can also be dropped over the side from surface ships. It is approximately 21 1/2 inches long and weights about 12 3/4 pounds. It contains a battery that is activated by sea water, an electric squib, some starter mix, two pyrotechnic candles, and a transfer fuse between the two candles. Before launching, the tear tapes over the water port must be removed so that the sea water can enter to activate the battery. The battery current then energizes the electric squib which ignites the starter mix, which in turn lights the pyrotechnic candle. When the first candle has burned out, in about 20 minutes, the second candle is started by the transfer fuse. Figure 10-9 illustrates this marker. Several other types of markers are in use, but the present modifications require launching from aircraft to provide the force needed to rupture the dye marker or to activate the smoke and fire marker.



83.189

Figure 10-9. — Cross-section view of Marker, location, marine Mk 58 Mod 0.

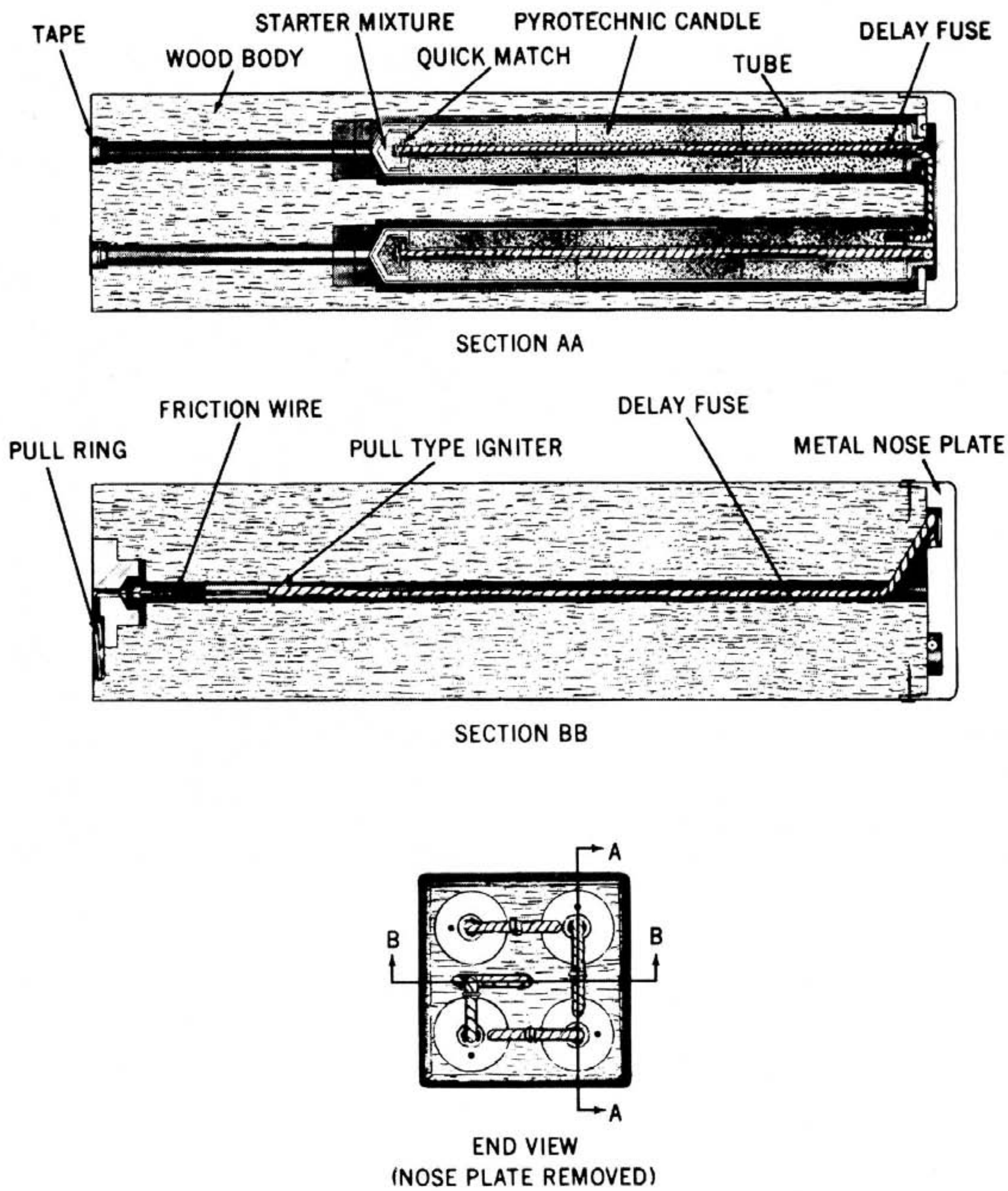
The Aircraft Smoke and Illumination Signal Mk 6 (fig. 10-10) is a pyrotechnic device that is launched from surface craft only to produce a 4 day or night floating reference point. One of its ~ principal particular uses is as a man-overboard ~ marker. It was previously approved for launching from low performance aircraft as a long-burning marker but has been superseded for these purposes by Marine Location Marker Mk 58.

This device consists of a wooden body with a flat, die-cast metal plate affixed to one end to protect it from water impact damage and to maintain it in the correct floating attitude. There are four flame and smoke emission holes in the opposite end, each capped and sealed with tape. The pull wire ring, also at the emission end, is likewise covered with tape.

The Mk 6 signal has a direct-firing ignition system. Ignition results from pulling the pull ring. The pull ring is pulled by hand, and the device is thrown into the water immediately. The pull wire ignites a 90-second delay fuze which ignites the quickmatch at the top of the first of four candles. The quickmatch ignites the first candle starting mix which, in turn, initiates burning of that candle. Expanding gases of combustion force the cap and tape from the emission hole, allowing smoke and flame to be emitted. When the first candle is nearly burned out, a transfer fuze carries the ignition to the quickmatch of the next candle in series. This process continues until all four candles have burned. The yellow flame and gray-white smoke are produced for a minimum of 40 minutes.

After the tear strip on the shipping container has been removed, the following rules shall apply:

1. The tape over the pull ring shall not be disturbed until immediately before hand launching the signal. This tape not only prevents an accidental pull on the pull ring, but also protects the igniter assembly from moisture which might render the signal useless.



83.203

Figure 10-10.—Aircraft smoke and illumination signal Mk 6.

WARNING: This signal is initiated by the physical movement of a friction wire through ignition compound. Extreme care must be taken to prevent tension on the pull ring during all handling operation.

2. If this device is prepared for launching and is not launched, the pull ring must be securely retaped into position at the top of the signal without exerting any pulling force on the pull-wire igniter.

3. Under no circumstances shall these signals be stowed or restowed with their pull rings exposed or with any wires, strings, or other material of any kind joined to their pull rings.

All safety precautions pertaining to this signal shall be observed. In addition, the following specific rules apply:

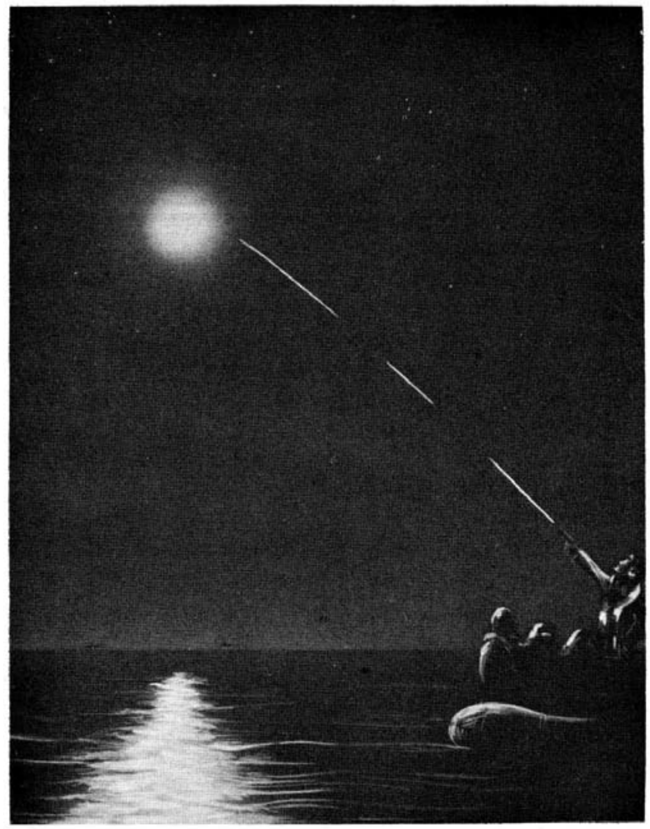
1. Do not remove the tape over the pull ring until immediately before launching.

2. The Mk 6 signal must be thrown over the side immediately after pulling the pull ring. This device contains a maximum 90-second delay element between initiation and candle ignition.

3. In all handling, extreme care must be taken to avoid pulling on the pull ring. Any slightest movement of the friction igniter may start the ignition train.

SIGNAL LIGHTS

Signal lights, often called Very lights (not because they are very light. but because that is what they were called by the French. who originated them), are similar to standard shotgun cartridges in appearance. When fired from the proper pistol or projector, a burning star (somewhat like a star from a Roman candle) shoots high into the air, as shown in figure 10-11. The one shown also has a tracer.



83.109
Figure 10-11.—Signal light with tracer, fired from a pyrotechnic pistol.

The Mk 2 signal light is available in three colors - RED, GREEN, and WHITE. Each cartridge has a percussion primer and a propelling or expelling charge of ten grains of black powder, which projects the burning star to a height of about 200 feet. The star charge is a tightly packed cylinder wrapped with a quick match (a fast-burning fuse), which ignites it when fired. The star charge is separated from the expelling charge by a shock-absorbing wad of hard felt. The cartridge is closed by a wad which is marked so that the color of the star can be determined by feeling it, as shown in figure 10-12, so the correct shell can be selected in the dark.

The RED star may be identified by its corrugated closing wad, the GREEN star has a smooth closing wad, and the WHITE star has a small conical boss on its closing wad. Each of the three colors may also be identified by the corresponding color of the paper on the cartridge.

The burning time for each of the stars is approximately 6 seconds.

The lights are available in combination kits known as Service Box, Signal Pistol Mk 5; and Reserve Box. Signal Pistol Mk 5. Unless packed in kits, signal lights are packed in a metal can in units of ten; and 100 cans, or 1,000 signals, are packed in a wooden case for shipment purposes.

Signal pistol Mk 5, for firing signal light Mk 2, is a single-barrel, breech-loading pistol, 11 inches long. Metal parts are mounted on a plastic frame. A cartridge belt (Mk 1) and holster are issued for use with the pistol. Figure 10-13 shows how to use the pistol.

1. To load the pistol, depress the latch button below the barrel. At the same time pull the barrel downward, as in part A of the figure. Then insert the signal light shell (as in part B of the figure). Push the barrel upward again until it latches closed. The pistol is now ready to fire.

2. To fire the pistol, aim it upward at the desired angle, but clear of other ships or personnel. Pull the trigger, as shown in figure 10-13C. Keep your elbow slightly bent when firing, to absorb the shock of recoil without having the pistol knock itself out of your hand.

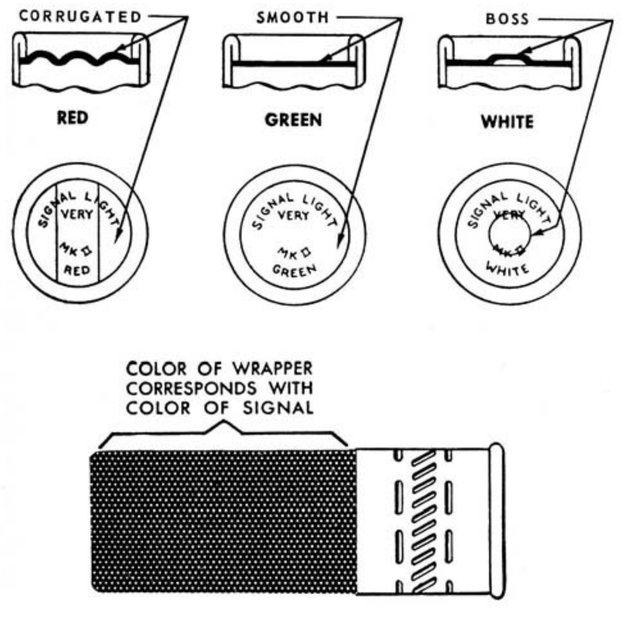


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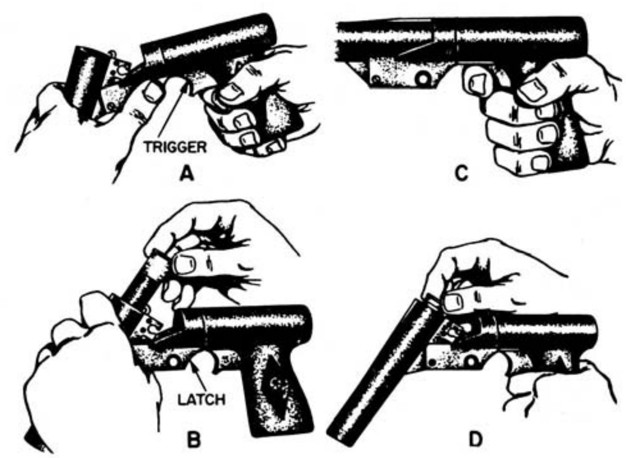
Figure 10-12.—Markings on Signal light Mk 2 Mod 0 (Very light).



83.111
Figure 10-13.—Operation of Signal Pistol Mk 5: A. Depress latch and pull down barrel; B. Insert Signal Light Mk 2; C. Barrel latched closed, finger on trigger; D. After firing, open pistol and extract shell.

3. To extract the expended shell, break the pistol open again as in step 1, and pull it out of the chamber, as in figure 10-13D.

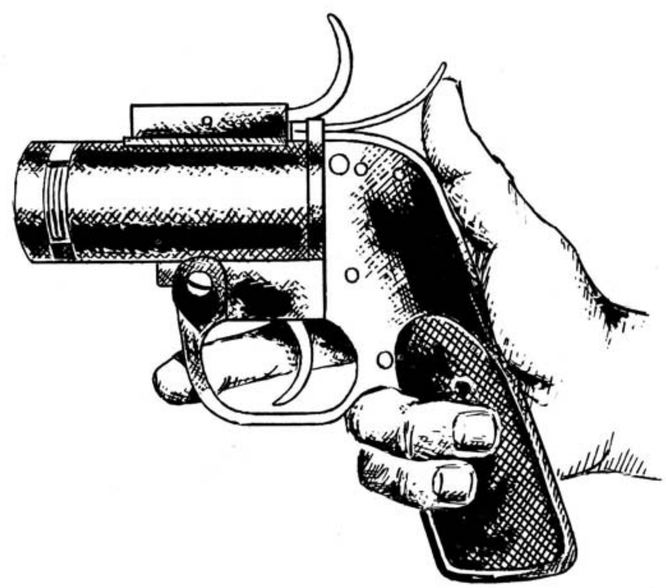
Signal pistol Mk 5 must be kept in serviceable condition at all times. Clean it thoroughly after each time it is used. Wipe down all parts with a cloth impregnated with light machine oil. After assembly, wipe the exposed parts with a dry cloth. Swab the barrel with a cloth dampened with acetone or other solvent to remove powder residue.

While loading, firing, or unloading a pyrotechnic pistol, care must be taken to avoid pointing the muzzle in the direction of the users body, other personnel or vessels.

If a pyrotechnic pistol is loaded and not fired, it must be unloaded immediately because it has no positive safety features. The pistol is always cocked as long as the breech is closed.

Pyrotechnic Pistol AN-M8

A pistol similar to the Mk 5 signal pistol is Pyrotechnic Pistol AN-M8 (fig. 10-14). It can be used with a number of signal lights of shotgun-shell shape. Some of these shells



83.190
Figure 10-14.—Pyrotechnic Pistol M8; tripping breech lock.

have paper cases and some have aluminum cases. Aircraft Red Star Parachute Signal M11 is fired only to denote aircraft distress, but the other signals that can be fired from Pyrotechnic Pistol AN-M8 are used for signal and identification purposes, and may be fired from aircraft or surface ships. The use of the different colors of signals was outlined in the text Seaman, NavPers 10120-E, particularly with regard to their use in lifeboats.

DISTRESS SIGNALS

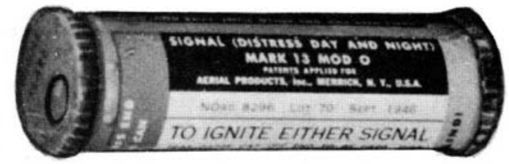
There is something Biblical about the distress signal Mk 13 Mod O. Like the famous pyre in EXODUS, it provides by day a pillar of smoke, and by night a fiery light. It's mighty comforting to have in a life raft or life vest. The signal kit in inflatable lifeboats has 12 of these signals.

The Mk 13 Mod 0 signal (fig. 10-15) is a metal cylinder about 5 1/8 inches long and 1 5/8 inches in diameter. It weights between 6 and 7 ounces. One end contains a canister which, when ignited, produces orange smoke for about 18 seconds. The other end contains a pyrotechnic flare pellet which will burn 18 to 20 seconds.

Each end of the metal tube is enclosed by a soldered cap with a pull ring through which you can put your finger. When you pull the cap loose, a brass wire attached to its inside surface moves through a cap coated with a composition that ignites by friction, setting off either the flare or the smoke canister (depending on which ring you pull). The metal caps of the signal are covered with paper when issued; you must remove the paper before the pull rings are accessible.

The signal body carries illustrated instructions for use. The flare end has embossed projections extending around the case to identify it as the right end to use at night. When you use the signal, point it away from the face and hold it at arm's length at a 30° angle after it ignites. After one end of the signal has been used, douse the signal to cool the metal parts. Keep it so that the other end can be used if necessary. Each end is separately insulated and waterproofed. N ever try to use both ends at once. When using the smoke signal, keep it to leeward.

These signals are shipped in wooden boxes containing 100 units, and are also available in metal cans containing four units, for stowage in life boats, floater nets, etc. Avoid rough handling. Stow in a cool, dry place, in accordance with standard pyrotechnic stowage rules.



3.246
Figure 10-15.—Distress Signal Mk 13 Mod 0.

Signal, Illumination, Marine AN-M75 is an emergency rescue signal small enough to be carried in the pockets of life vests or flight suits and on liferafts. It contains two pyrotechnic stars that are projected by ejection charges. The igniter assembly is thrown about 10 feet from the signal, and the first delay charge is ignited. This ignites the expelling charge for the first star. After ignition, the first star burns 4 to 6 seconds. The used signal (or one that fails to fire) should be thrown overboard.

NAVY LIGHTS

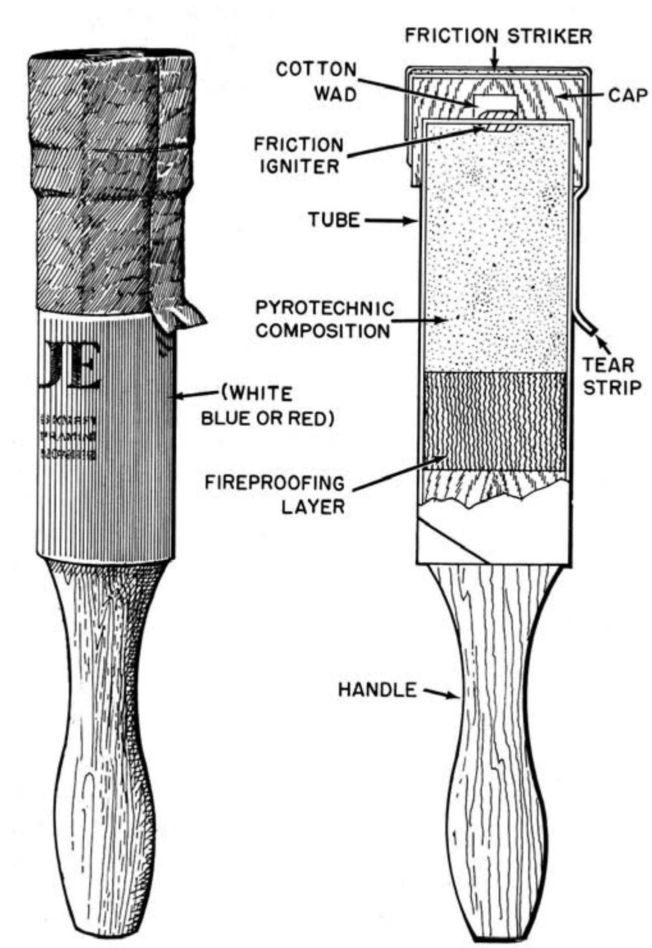
Navy lights are hand torches which burn with a brilliant light visible at night up to 3 miles away. They come in three colors; blue, white, and red. Navy blue light Mk l Mod l burns between 60 and 90 seconds; Navy red light Mk 1 Mod 0 burns between 150 and 180 seconds, and Navy white light Mk 1 Mod 2 burns 60 to 70 seconds. The three lights are similar in appearance and construction (fig. 10-16).

Navy lights consist of a paper tube, which contains the pyrotechnic substance, with a wooden handle at one end, and at the other end a cover with an exterior coating of abrasive like that on the scratching side of a safety match box. A tear strip protects the cover's exterior.

The upper end of the paper tube, beneath the cover, is capped by a fabric impregnated with igniting compound similar to that on the head of a safety match.

To ignite the Navy light, tear off the protective strip, remove the cover, and scrape the inverted cover across the top of the paper tube. When you do this, it's advisable to hold the light pointing AWAY from you at an angle of about 45°, to avoid contact with hot particles falling off the pyrotechnic candle. Hold the light at that angle throughout the burning.

Navy lights Mk 1 Mods 0, 1 and 2 are shipped in metal containers with 6 or 12 lights packed in



83.112
Figure 10-16.—Navy lights.

each, and enclosed in cardboard cartons holding 12 boxes (72 to 144 lights). Navy blue light Mk 1 Mod 1 is also shipped as part of the Reserve Box, Signal Pistol Mk 5. These lights deteriorate when exposed to moisture. Do not remove them from their containers until ready for use. For the same reason, keep them away from water or moisture. Lights which have been left in open containers for more than 6 months should be turned back to the nearest ammunition depot or magazine at the earliest opportunity. Lights which have become chemically encrusted, or which give off an acetic acid (vinegar) odor, should be immediately disposed of. Put them in a weighted sack and dump them overboard in 500 fathoms of water and 10 miles from shore. Note the following SAFETY PRECAUTIONS in the use of Navy lights:

1. Select carefully the place at which the lights will be burned, because burning particles dropping from the lighted candles can start fires.
2. Always hold the light up at an angle of 45° and point it to leeward while it's burning.

It must be remembered that all pyrotechnic and screening devices, while designed and tested to be safe under normal conditions, are subject to accidental ignition because of a wide variety of circumstances. The general rule to follow is: "Be constantly aware that pyrotechnics contain chemical components that are intended to burn with intense heat, and act accordingly."

FLASH SIGNALS

Missile targets used in training are expensive. To prevent destroying a practice target, an exercise head is put in a missile in place of a warhead. Since we want to know if an exercise missile has approached within lethal range of a target, flash signals are installed in the exercise head. These signals contain pyrotechnic material. When the material is ignited it produces puffs of smoke, and you get a visual indication that the missile has passed close by the target. The flash signal contains a primer and some flash powder. At intercept, an electrical impulse from the fuze ignites the primer, which fires pyrotechnic material (black powder and coated magnesium powder).

STOWAGE OF PYROTECHNICS

The dangerous nature of pyrotechnics was appallingly demonstrated by the catastrophic fire on the USS Oriskany, which started from a pyrotechnic flare, dropped in handling.

The extreme sensitivity of pyrotechnic material makes it mandatory to store it in special pyrotechnic lockers away from other ammunition. Pyrotechnics are, in general, a fire hazard. Many of them deteriorate under high or variable temperatures. Some are badly affected by moisture. The storage place must be dry, well ventilated, not subject to direct rays of the sun or other heat source, and must have firefighting equipment handy. Since many pyrotechnic items can be set off by a blow, they must be handled with great care. Be very careful not to bump or drop them; remember the Oriskany. Flash signals and flares can be set off by electromagnetic radiation. They must not be exposed in line with radars or other sources of electromagnetic radiation. (The radiation is also harmful to you; see chapter 12.) Missiles are .not stored with the flash signals in them. The flash signals must be installed just before the missile is to be used for practice, and if not expended, must be removed before the missile is returned to the magazine. The men who do this work must be instructed in the precautions necessary. See OP 4, Ammunition Afloat, Volume 2, (second revision). (Flash signals are restricted to research and development use.)

Pyrotechnic and screening devices are normally equipped with some type of safety pin, lock, or tape that is designed to prevent accidental activation of the initiation mechanism. Such equipment must not be tampered with, struck, bent, or otherwise damaged or removed until immediately before it is intended to launch the device. Any devices that show signs of damage to safety features are considered unserviceable and must be carefully segregated for prompt disposition in accordance with current instructions.

If a pyrotechnic device should be accidentally ignited, its functioning will, in all cases, result in a fire hazard. In a confined area, the gases generated by this combustion could present a serious toxic hazard. Signaling devices containing propellant charges which are designed to propel the pyrotechnic candle into the air create an extremely dangerous missile hazard if they are accidentally ignited. Pyrotechnic compositions characteristically contain their own oxidants and therefore do not depend on atmospheric oxygen for combustion. For this reason, the exclusion of air, by whatever means, from a pyrotechnic fire is usually ineffective. Many pyrotechnic mixtures" particularly illuminating flare compositions, burn with intense heat (up to 4500°F). Normally available extinguishers are of little or no value in fires of this kind. Carbon dioxide extinguishers, in addition to being ineffective, are potential sources of danger in that they tend to produce oxygen which supports combustion. Foam type extinguishers are equally ineffective because they work on the exclusion-of-air principle. It is recommended, therefore, that water, in flooding quantities and at low pressure, be used to cool the surrounding area and thus prevent spread of the fire.

Pyrotechnics that are activated by water, such as markers, location, marine, must not be stowed in compartments where there are sprinkler systems. Do not fight fires in them with water.

As most pyrotechnics deteriorate with age, the oldest ones should be stowed nearest the front of the locker so that they will be used first.

APPLICATION OF EXPLOSIVES IN RIM

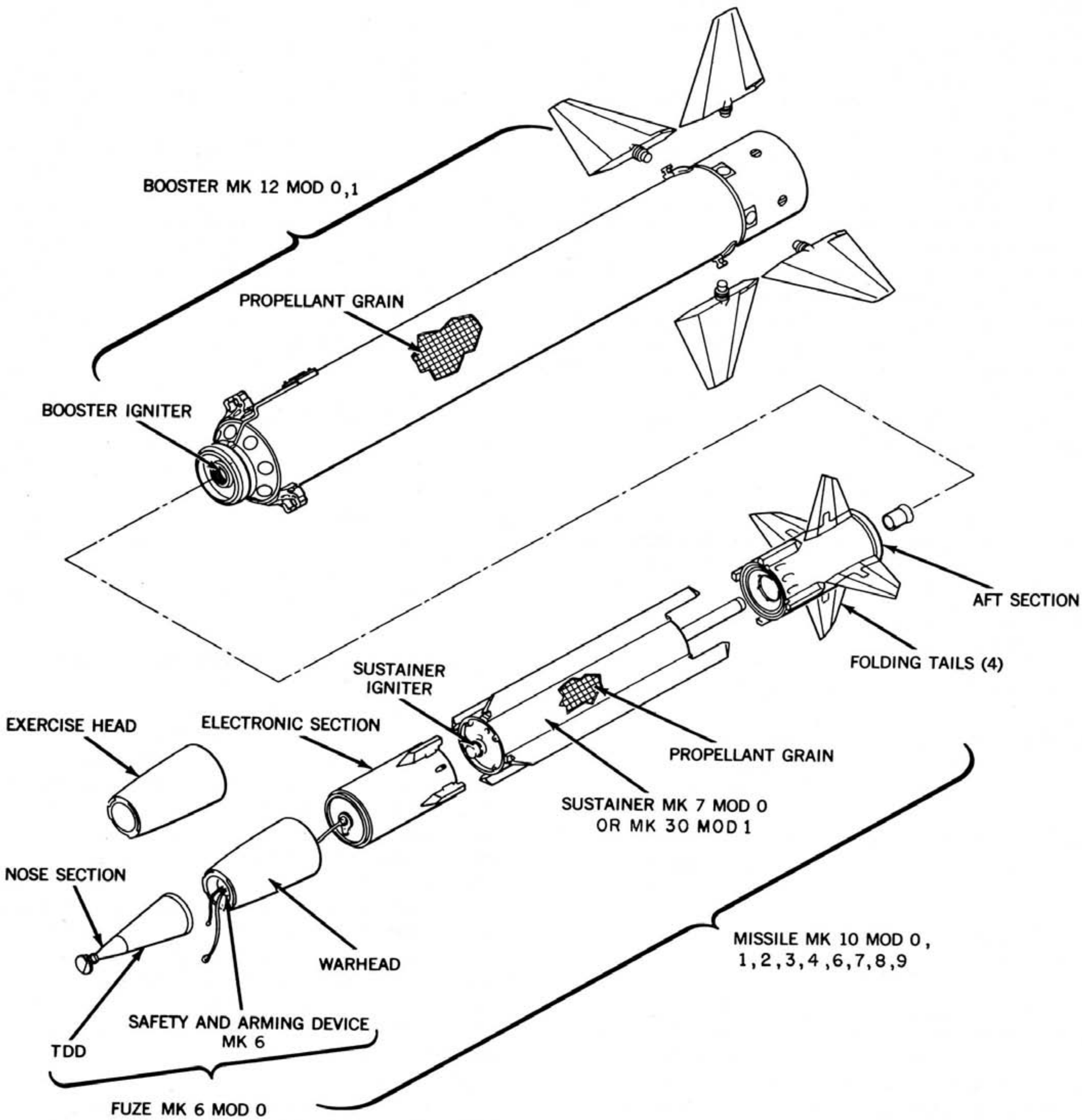
So far in this chapter we have discussed the "raw materials" used in explosives. Also we have covered, in a general way, types of warheads and fuzes. With this background, we can turn our attention to specific applications of explosives in missile components. Figure 10-17 shows a breakdown by sections of the TERRIER BT-3 missile round. The complete round is designated as Mk 2, and is made up of Guided Missile Mk 10 Mods 0,1, or 2 mated with booster Mk 12. The numbers of the round, sustainer, and missile used with improved versions of the BT-3 missile (BT-3A, and BT-3B) are indicated on the illustration, but the basic outlines of components are not changed. The HT-3 and HT-3A use the same booster and sustainer but have a different missile, which is not indicated on the illustration. One of the big differences not shown in figure 10-17 is the fact that the BT-3A and BT-3B can carry a nuclear warhead. Because the BT-3 and its later versions are widely used in the fleet, we are using it as a study example. Other TERRIER types, TARTAR, TALOS, and STANDARD missiles contain functionally similar components; so what you learn here also applies to these missiles.

MISSILE SECTIONS AND THEIR EXPLOSIVES

The BT-3 is composed of six sections:

1. Nose section
2. Fuze section
3. Warhead section
4. Electronic section
5. Sustainer section
6. After section

Explosives are used in all sections except the nose and electronic sections. The fuze section



83.113
Figure 10-17.—Location of explosives in Terrier BT-3 (and modifications) missile rounds.

contains the Target Detecting Device (TDD for short). Inside the warhead is the Safety Arming Device (more frequently called the depth charge S&A device). The S&A device is electrically connected to the TDD. These two units make up the fuze. As you learned earlier, the sustainer contains the propellant that keeps the missile flying after booster burnout. The aft section contains two gas generators. One generator drives a hydraulic pump which provides hydraulic power for the steering control system. The other generator drives an electrical alternator which provides electrical power to electrical and electronic circuits in the missile.

Table 10-1 lists some of the explosives, propellants, and pyrotechnics in the principal hazardous units of the BT-3. We have not listed all the hazardous units but just enough of them are mentioned to show the application of the . basic explosive compounds you studied earlier in this chapter. For a complete list, look in the OP for the missile weapon system on your ship. One volume is devoted to general and specific safety precautions applicable to missile components. Here you will find a table which lists all the hazardous components in the missile of interest and the type of explosive in each component. pyrotechnic magnesium powder

Table 10-1.—Explosive, Propellant, and Pyrotechnic Material of BT-3 Round.

ITEM	DESCRIPTION
1. Warhead explosive charge	Composition B
2. Fuze booster	CH-6
3. Sustainer igniter	Composition B—KNO_3 (potassium nitrate)
4. Flash signal pyrotechnic	Black powder and magnesium powder

BT-3 FLIGHT TERMINATION SYSTEM

Before we leave the subject of explosives, we should discuss in more detail warheads and fuzes. Earlier we discussed the many types of warheads and fuzes, but now let's look at a specific application for them. The BT-3 is still a good representative example, so we'll stick with it. Other missile warhead systems are similar to the BT-3s. They differ only in detail.

Flight Termination with a Warhead

A warhead system consists of a warhead and a fuze. The warhead system is only part of a larger system called the Flight Termination System. As its name implies, the purpose of the flight termination system is to end a missile's flight. And it usually does, with a big bang. When the missile intercepts the target, a firing pulse from the fuze sets off the warhead. Also, should the flight of the missile become uncontrolled for any reason, a firing pulse from the flight limiter circuit will detonate the warhead. Figure 10-18 shows a block diagram of the flight termination system. In the diagram you will find the two units - flight limiter and fuze - that start the action to detonate the warhead. The flight limiter will send out a firing pulse if there is a failure in the missile receiver or missile power supply, or if the missile flies out of the beam. These are unplanned failures, but you can deliberately make similar failures occur. For instance, you can cut off guidance beam transmission at the radar. The missile does not see a beam and the flight limiter circuit senses a receiver failure. The warhead is subsequently detonated. You can see that essentially the flight limiter is a safety device. If a missile goes out of control, it will automatically destroy itself before it endangers your ship or others in the task force.

Flight Termination with an Exercise Head

The same principle applies if the missile is fitted with an exercise head instead of a warhead. An exercise head is used for missile flight evaluation. The exercise head contains telemetering equipment which sends information about the missile's performance back to the firing ship. This type head contains a small destructor charge. When this charge is detonated, the force from the charge blows out bits of the exercise head. These jagged edges of the exercise head left after the explosion make the missile aerodynamically unstable. The surface of the missile is no longer streamlined, and the missile is torn to pieces by the force of the air stream.

When the exercise head is used, the fuze firing pulse (at intercept) ignites two pyrotechnic flash signals. These signals are mounted in the exercise head and give visual indication of target interception. Sometime later the flight limiter circuit initiates the explosive train to detonate the destruct charge. This destructor charge in the exercise head is not the same as the self-destruct unit in the warhead which destroys the missile if it gets off course (or if for some other reason the missile will miss

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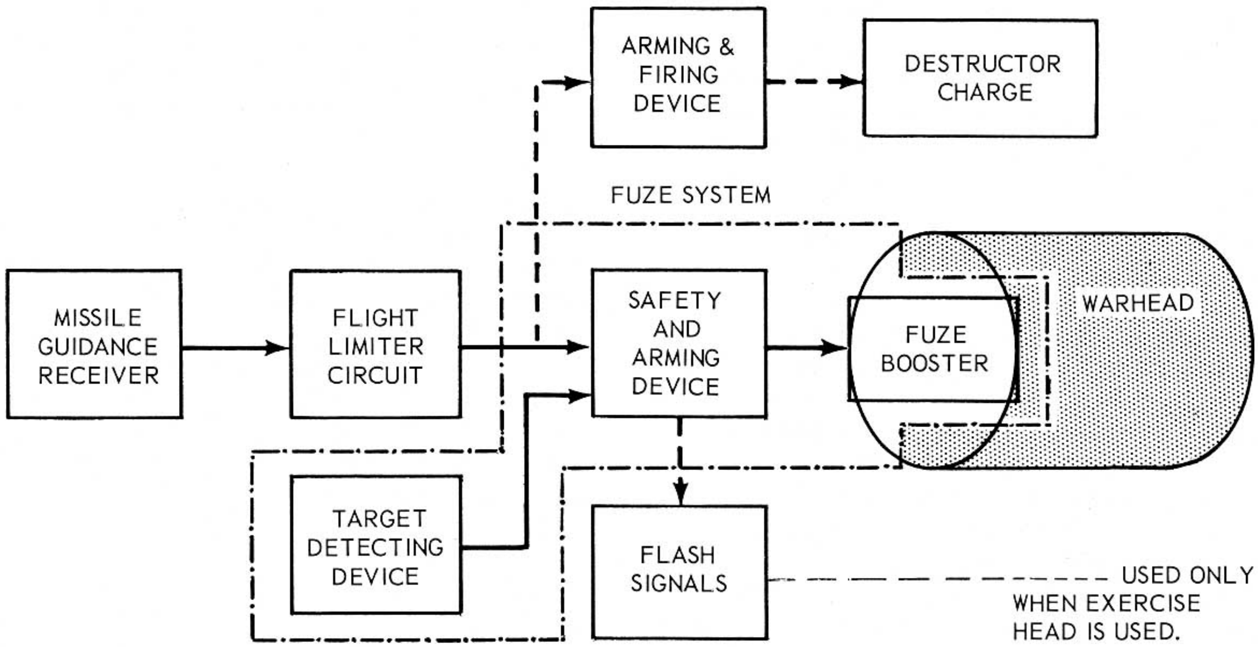

83.114
Figure 10-18.—BT-3 flight termination system.

the target and must be destroyed). Some recoverable missiles have been designed for training use, and they represent a great saving. They are especially useful for antimissile target practice.

DISPOSING OF DAMAGED OR DEFECTIVE EXPLOSIVES

In the paragraphs above we talked about missiles destroying themselves, and you have read in the newspapers about destruction of the huge rockets used in satellite launching. Is it the fault of the explosive or of some part of the mechanism, electrical or electronic systems? Can the flaws be determined and corrected before launch? We will consider here only the possibilities with explosives.

You cannot test an explosive because to do so would destroy it. You can look at it, feel of it, smell it, but you cannot try it out. Your missiles come aboard with the explosives enclosed, so you cannot see the explosive nor feel it. Visual surveillance is all the inspection you can give it. Examine the exterior of the rocket motor, the sustainer, and the warhead for any signs of exudates or corrosion. Also take note of any dents or breaks in the container. A dented component may have to be returned to the depot. With care, corrosion, if not too deep, can be removed. The removal of exudates is more of a problem. Low grades of TNT exude a dark oily substance that is highly flammable. It is much more sensitive than the TNT itself, especially if it is absorbed by wood, rags, or other cellulose material.

Since most of the TNT now used in explosives is high grade, there is little likelihood of exudates. If you find any, carefully collect a sample to be sent to the U.S. Naval Ordnance Station, Indian Head, Maryland, for analysis. Use a wooden spatula to scrape up your sample; scraping with metal can cause an explosion. Exudate can be washed off with acetone or alcohol, but IN NO CASE should soap, washing compound, or other alkaline substance be used. In the meantime, separate the components in question from other explosives until you receive word about what to do with them.

The solid propellants used for rocket motors and sustainers in missiles are as stable as smokeless powder or more so. No tests are authorized for shipboard use. Proper stowage conditions, careful handling, and visual inspection are required. If a case has been punctured or severely dented, or has been dropped (specified in the OP; usually over 5 feet), it shall not be used but must be returned to the depot. If it is considered too unsafe to hold until it can be shipped it should be dumped in deep water without delay, or segregated until safe disposal is possible. A warhead that shows signs of physical damage or corrosion should be returned to the depot. If an exercise head is accidentally dropped, it should be sent to the depot.

Very Sensitive Explosive Components

Fuzes, S&A devices, and pyrotechnics are more sensitive than propellants. A fuze or an S&A device that has been dropped from a height of over 5 feet shall not be used; return it to the depot with a written explanation of what happened. If a fuze or an S&A device becomes armed, it must be dropped in deep water (over 500 fathoms deep and at least 10 miles from shore).

Any pyrotechnic material that appears damp or deteriorated must not be returned to the locker but must be expended as soon as possible by dumping in deep water or by returning it to the depot. You remember that we covered pyrotechnics that may not contact water. Smoke- making devices that have been in the water or have misfired may not be taken on the ship.

Signals with cracked bodies, bent fins, deformed tail tubes, or with any other visual defect that might make them unserviceable must be discarded for disposal, either by deep water submergence or return to depot. Do not attempt to disassemble or repair faulty signals.

MAGAZINES

The term "magazine" applies to any compartment, space or locker which is used, for the stowage of explosives or ammunition of any kind.

The term magazine area includes the compartments, spaces, or passages on board ship containing magazine entrances, which are intended to be used for the handling and passing of ammunition. The term is also used to denote areas adjacent to, or surrounding explosive stowages, including loaded ammunition lighters, trucks, and railroad cars, where applicable safety measures are required.

Since missile magazines are not common cargo or living space, but are used for storage of missile rounds, they are protected by their location in the ship, usually below the waterline. They are insulated against moisture and excessive heat. Besides, they are equipped with sprinklers for protection against fire and possible explosion, as well as for emergency cooling. Smothering equipment is provided to put out electrical and oil fires. And they may be equipped with heating and air-conditioning units to keep the spaces within certain temperature limits.

No matter how effectively the above systems work, the only way you can be sure of safe missile stowage is by routine effective inspection and maintenance of the magazines.

The magazine is intended for storage of live missile rounds and for the equipment used to handle them - and for these only. It is no place for empty paint or grease cans nor for stowing paint brushes, oily waste rags, or similar fire hazards. And what goes for material also goes for men. Nobody but those authorized should ever be admitted to a magazine. Even they should be there only when they have business there, a magazine is no place to sit around and "shoot the breeze."

Missile magazine maintenance is chiefly a matter of inspections, cleaning, sprinkler and smothering systems testing, and occasional painting, replacement of lights, fixtures, etc. Magazines are inspected daily; other magazine work is done in accordance with rules laid down by the weapons officer, and will vary from ship to ship.

MAGAZINE TEMPERATURE CHECKING

The main item of daily routine inspection is to check the most important and single factor that affects powder and propellant stability - the temperature - and record it.

To check the temperature, you need a thermometer, of course. But an ordinary thermometer won't be enough. Temperature readings are customarily taken in magazines only once a day. The common type of thermometer tells you what the temperature is at the time you read it. But what was it when you weren't around? You need a thermometer which can record the HIGHEST temperature reached up to the time the reading was taken.

You'll find on the magazine bulkhead, therefore, a MAXIMUM-MINIMUM THERMOMETER (fig. 10-19). This instrument is a U-shaped mercury-filled glass tube with two bulbs. It shows the extreme temperatures, both high and low, indicated since the thermometer was last ZEROED.

You read the PRESENT TEMPERATURE on the instrument by noting the level in either arm of the tube. (Both sides should read approximately the same.) The temperature recorded

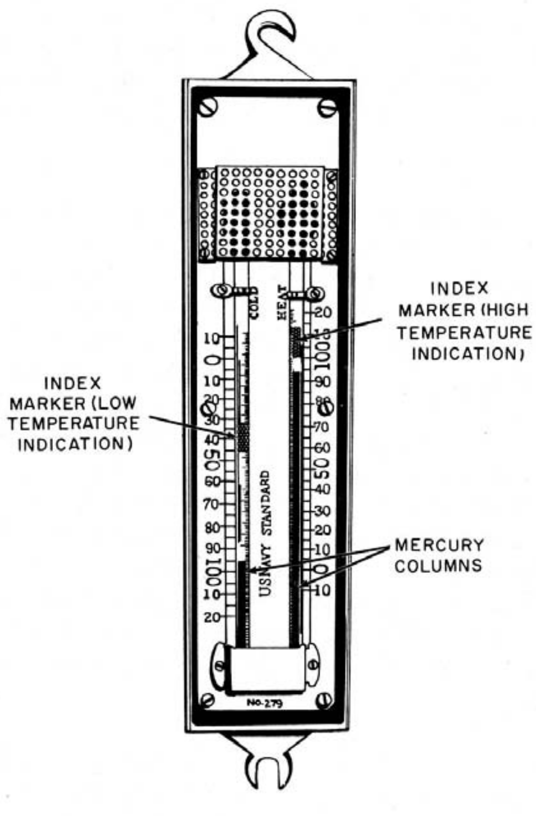

Figure 10-19. — Maximum-minimum thermometer. 5.65

in the pictured instrument is around 95°, which would call for some drastic action if it were actually on a magazine bulkhead.

You read the MAXIMUM TEMPERATURE by noting the level of the BOTTOM edge of the little steel index marker against the right-hand scale, which increases UPWARD. (The picture shows it at just over 100°, another excessive temperature for a magazine.)

You read the MINIMUM TEMPERATURE (here a little over 45° similarly, on the lefthand scale against the bottom edge of the little steel marker. The minimum scale increases DOWNWARD.

To zero the instrument, you run a little horseshoe magnet against the glass tube to draw each steel index marker down to the level of the mercury. Zero the thermometer on both sides AFTER you have recorded the maximum and minimum readings.

Magazines are usually equipped with two maximum-minimum thermometers - one in the coolest part of the magazine, and one in the warmest. Others may be used where it is considered necessary to have additional data on parts of the magazine that may get too warm-bulkheads near steam lines, for example.

RELATIVE HUMIDITY INDICATORS

Because many types of explosives are adversely affected by humidity, there must be some form of humidity control in the storing of guided missile explosive components. Many of the individual components, before assembly into the missile, are packaged in sealed containers in which there is a quantity of desiccant, usually silica gel, to absorb the moisture. Each container has a humidity indicator which changes color as the humidity increases. If the container has been properly sealed there should be no appreciable change. If there is no directive or instruction that specifies, your officer will decide whether to ret-urn the component to the depot or to repackage it. The OP for your missile prescribes the frequency of inspection (perhaps weekly), and gives instructions for replacing the desiccant.

The humidity of the magazine must also be checked regularly. One method is by use of a wet-bulb thermometer or psychrometer. The thermometers must be calibrated, and if properly used, they can give fairly accurate results.

ALARM AND SENSING DEVICES IN MISSILE MAGAZINES

Alarm systems are provided on most ships to indicate the presence of fires, overheated conditions in the magazine, or water leakage through the sprinkling system main control valve. The alarm indicator may be a buzzer, a light, or a small drop type enunciator. The water leakage alarm system is activated by a water switch on the dry side of the sprinkling system main (group) control valve.

Another type of alarm system used is actuated by heat. The alarm sounds when the temperature in an ammunition storage area rises to a danger point. Due to this warning, the temperature can be reduced before sprinkling becomes necessary.

A later development in alarm system now in use is the pry-a-larm. This system functions according to an entirely different principle: The trigger of the pry-a-larm detector is activated by minute particles of combustion. NOTE; Formation of combustion particles occurs in all types of fires and in smoldering or overheated materials. The small combustion particles are invisible, but they are usually present before there is any other evidence of fire; the larger particles are visible in the form of smoke.

However, most of the particles are too small to be seen by the naked eye.

The pry-a-larm system has several advantages which are as follows:

1. The system provides an early warning which permits safe evacuation from the damaged area and gives the damage control time to fight the fire while it is still small and controllable.
2. The system may be adjusted (calibrated), to ensure proper operation, regardless of its location onboard ship.
3. A standard two-wire circuit is used with the electrical circuit associated with the pry-a-larm system. Due to the low current used in the circuit, a thin-walled conduit can be used.
4. Any failure of wiring or of other essential parts is immediately indicated on a trouble board.

The most important part of the pry-a-larm warning system is the sensing element called the detector head. Basically, the detector head consists of two ionization chambers and a cold-cathode tube.

The specially designed cold-cathode tube is connected in parallel with two ionization chambers. The trigger-electrode of this tube is connected to the junction point of the two chambers. When combustible particles are present, the current in the outer chamber decreases, causing the voltage at the trigger-electrode of the tube to increase. The increased voltage on the trigger-electrode causes the tube to conduct sufficient current for operating the alarm system.

An automatically operated alarm system is tripped when the temperature reaches a preset degree, or, in another system, by the rate of rise of the temperature.

In some magazines the sprinkler system is turned on automatically when the temperature reaches a certain point. A pneumatic release pilot valve (PRP) opens the valve to the sprinkler pipes when the temperature reaches the critical point. The valves for electrical operation are motor operated, with hand-controlled or thermostatically controlled switches. If water-activated explosives have to be stowed in a magazine where there is a sprinkler system, the sprinkler system must be secured so there cannot be accidental sprinkling.

Testing Alarm Systems

On a periodic basis, sprinkling system alarm circuits should be tested. These tests involve checking the electrical continuity of the switch circuits. The leakage alarm (water switch) shown in figure 10-20 is activated by water, when water enters the switch housing the contacts of the switch are shorted and the alarm is energized. To test this type of switch proceed as follows:

1. Notify all personnel concerned that a test of the alarm system is being conducted.
2. Obtain a bulb-type battery filler, and a small container in which to catch water.
3. Partly fill syringe with fresh water.
4. Remove drain plug on water switch (fig. 10-19) and place syringe stem flush against the drain opening. Slowly squeeze the syringe to force enough water into switch housing until the two contacts are shorted. This will energize the leakage alarm; the alarm should be located in the ship's damage control central.
5. When verification from D.C. central has been received that the alarm system is working properly, drain the switch housing and replace drain plug.

Moisture within the switch housing can cause the alarm system to be activated. Ensure that the water switch (leakage alarm) is completely dry after testing.

FIRE SUPPRESSION SYSTEMS

In the following discussions the Mk 13 launching system will be used as a representative example of fire suppression systems because the magazine contains three of the four systems we will describe. The fire suppression system in the missile magazine consists of two carbon dioxide systems, a sprinkling system, and a missile water injection system. Fire or extreme heat in either of the protected areas activates the associated carbon dioxide system, blanketing the equipment or missiles with carbon dioxide. The sprinkling system sprays seawater on all missiles in the magazine during a fire or extreme heat. This system activates only if the temperature continues to rise after the carbon dioxide system activates. The missile water injection system directs a stream of water into the rocket motor of any missile that inadvertently ignites in the magazine.

Three of the fire suppression systems described in this chapter activate automatically and all four are independent of each other. In addition, the carbon dioxide systems and the

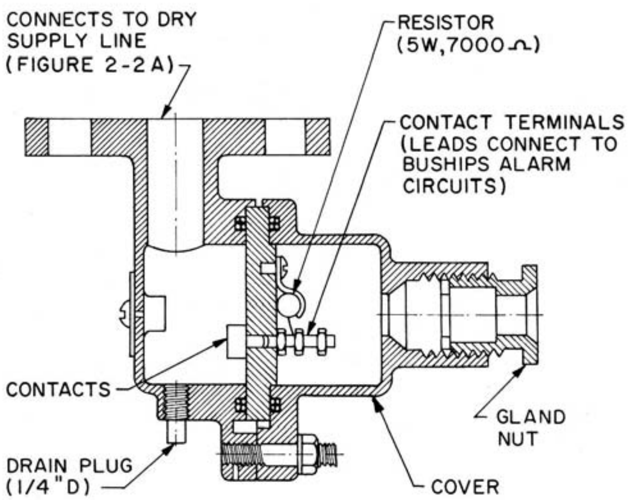

Figure 10-20.—Sprinkling system water switch SIZ2.

sprinkling systems have independent controls for manual activation.

SPRINKLER SYSTEMS

The sprinkling system in the magazines below decks for the spare components is usually part of the sprinkling system that includes the ammunition magazines. The piping system technical manual or the damage control manual should be consulted for information on the specialized systems provided for missile spaces.

The sprinkling systems are supplied from the firemain. The efficiency of operation depends on maintaining full working pressure in the firemains and keeping the system free of debris. Marine growth can foul the firemains, particularly in tropical waters, where weekly flushing may be necessary. Acid cleaning of firemain piping is done at overhaul.

Magazine sprinkling systems consist of the following components: a gate (root) valve provided with a device (not a padlock) for securing it in the open position, a globe valve type sprinkling valve (normally closed), either a separate test casting or a testing feature incorporated in the sprinkling valve, a sprinkling alarm device (circuit FH), and the distribution piping in the form of a grid. The magazine group control valve may serve one or more magazines and may be located either in the handling room, in the adjacent passageway, or in one of the magazines. Whenever a group control valve serves more than one magazine, a stop valve and check valve or stop-lift-check valve is provided in each branch line. This prevents back flooding through the system in the event one of the magazines of the group becomes flooded as result of damage. The valve can also be used for isolating the sprinkling system in a particular magazine when desired. The stop-lift-check valves should be locked (not padlocked in the check position).

SPRINKLERS IN MISSILE MAGAZINES

As a typical example of the sprinkling systems installed in missile magazines (for the assembled rounds), the Mk 13 launching system, Guided Missile Magazine Mk 8 Mod 0, will be used. The system may be actuated automatically by one or more heat-sensing devices, or manually by local or remote controls. The sprinkler heads shower salt water spray down into the ready service area. The pneumatic release pilot (PRP) valve is connected by pneumatic lines to the heat-sensing devices (of which there are 12). Normal temperature variations do not cause the PRP valve to open, but a sudden rise in temperature will. When the sprinkling system is actuated, a sprinkling alarm sounds. If there is leakage into the dry supply line, a leakage alarm sounds. Figure 10-21 shows schematically some of the components of the sprinkler system in this magazine. The piping can deliver 10 gallons of water per minute to each sprinkler head, and the whole ready service area can be quickly saturated. Drains at the base drain off the water.

SALT WATER SPRINKLING SYSTEM

The main control valve in the salt water system shown in figure 10-22 functions similarly to the valve operated by hydraulic fluid used in most gun and turret sprinkling systems except that the salt water operated valve cannot be opened or closed mechanically. The water operated valve contains a sight tube that indicates the condition (open or closed) of the valve.

Note: On some ships the salt water system was installed without changing the main control valve.

A local control panel for a typical missile magazine sprinkling system mounts four manually operated valves: a manual control valve, a pressure cutoff valve, an automatic operation cutoff valve, and a pressure gage cutoff valve.

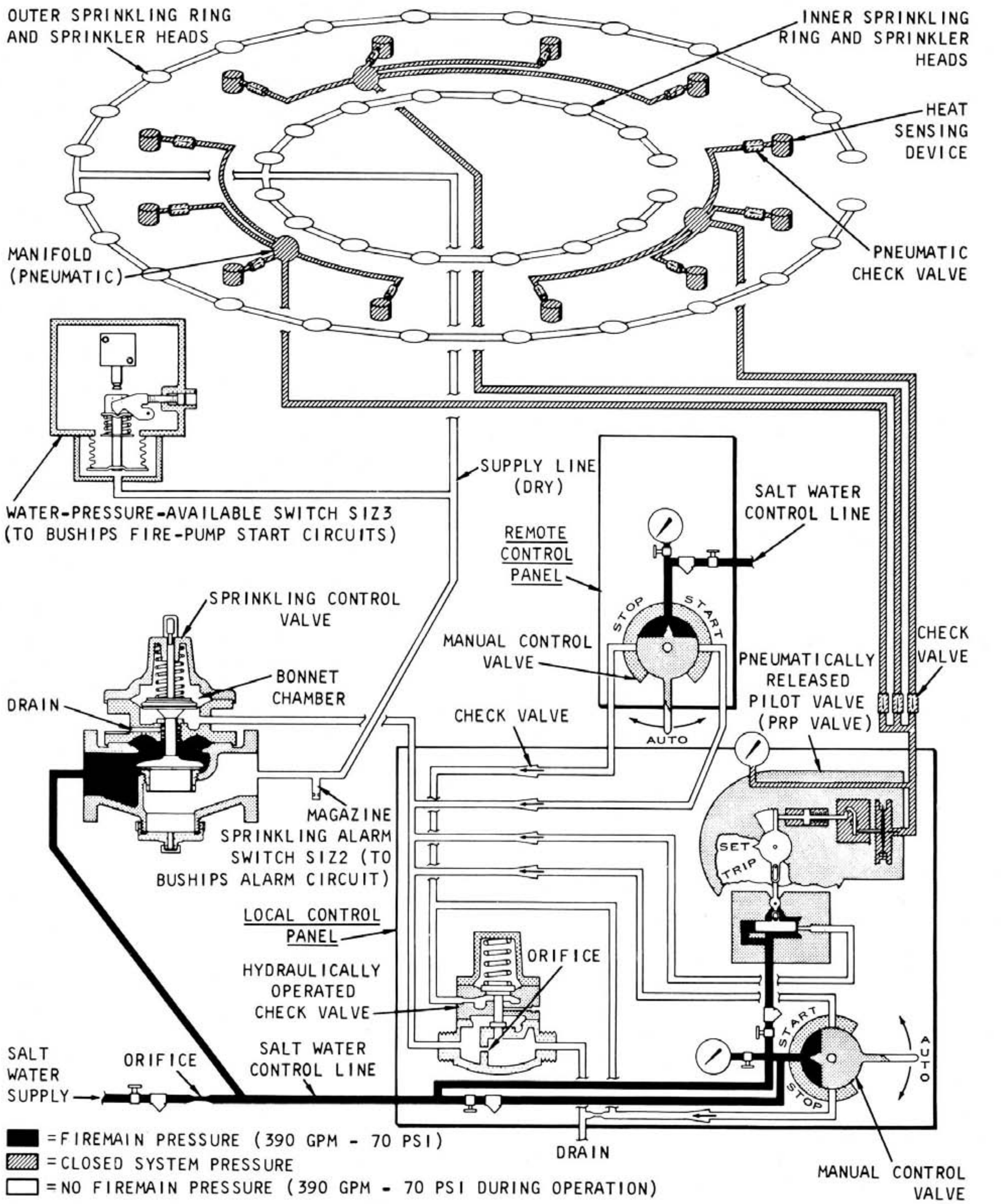

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Figure 10-21.—Sprinkler system operation (schematic), Guided Missile Magazine Mk 8 Mod 0. Launching System Mk 13 Mod 0.

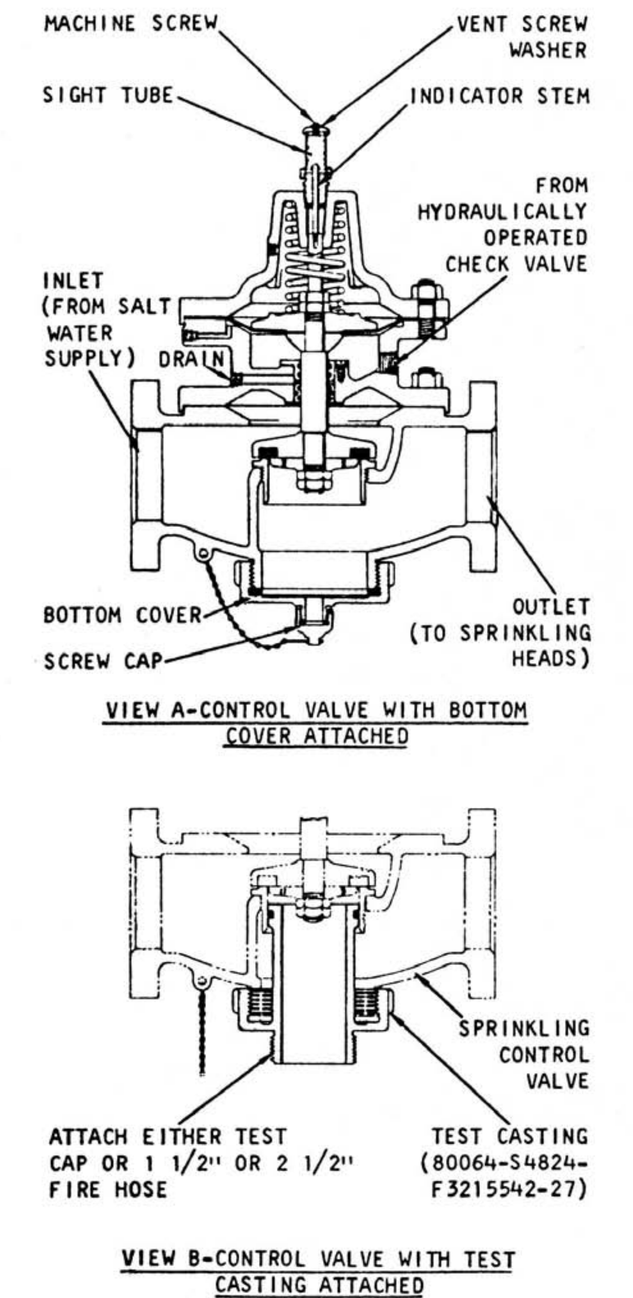


Figure 10-22.—Salt water operated sprinkling (main) control valve. 84.314

The panel shown in figure 10-23 also mounts five 1-way check valves, a hydraulically operated check valve, a pneumatically released pilot (PRP) valve, and a pressure gage.

The manual control valve is a 3-position and a 3-way valve. The three positions and functions of the valve are as follows:

1. AUTO - Permits automatic operation by blocking the passage of water through a manual control valve.

2. START - Permits water from the firemain to be ported up through a one-way check valve to the piston of the sprinkling system main control valve located in the magazine, thus initiating sprinkling action.

3. STOP - Permits water from the firemain to be ported down through a one-way check valve to the hydraulically operated control valve (pressure-operated check valve). With firemain pressure on this valve, the pressure from the sprinkling system main control valve piston is vented to tank, thus preventing any further sprinkling.

The pneumatically (air operated) released pilot (PRP) is normally closed. When actuated, it directs water from the firemain to the piston of the sprinkling system main control valve. The pilot valve is actuated by sensing devices in the magazine area (see fig. 10-21). This valve and the sensing devices will be described later in this chapter.

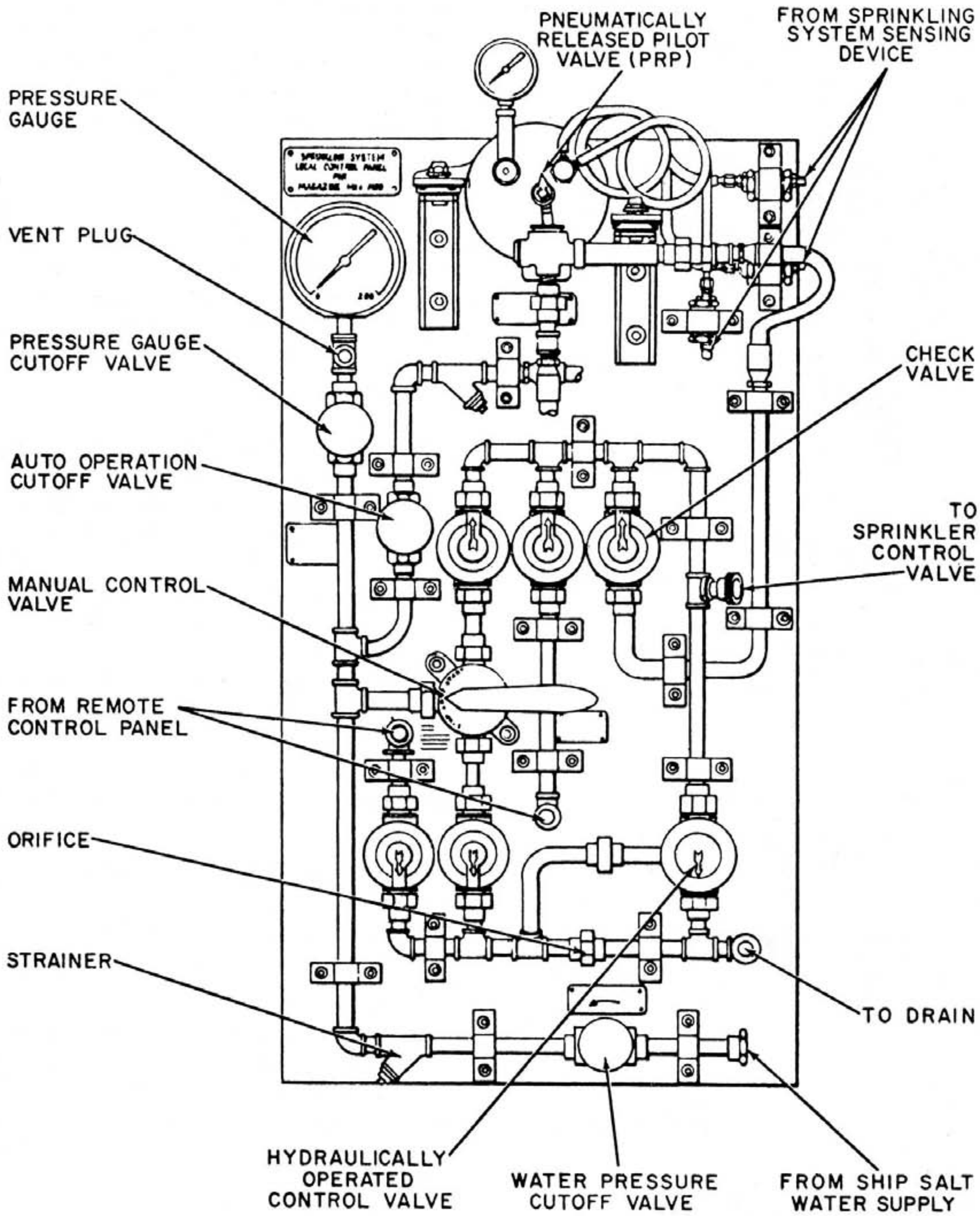
The pressure gage at the control panel shown in figure 10-23, indicates the firemain pressure. A manually operated cut off valve and a vent plug are provided to isolate the gage and to vent any air trapped in the pipe leading to the gage.

Salt water strainers are provided in the firemain input line and in the line to the automatic pilot valve (PRP). Drain cocks are usually provided to drain off any sediment collected in the strainer.

The remote control station shown in figure 10-24, which works in conjunction with the local control station, consists of a gage, firemain water pressure connection, strainer, two cut off valves, and a three-way manually operated control valve.

The three-way manually operated control valve of the remote control station functions like the manual control valve of the local control station and is operated in the same manner.

To follow the operation of the sprinkling system refer to figure 10-21. Firemain pressure which operates the main sprinkling control valve is shown leaving the wet side of the main control valve and passing through a cut off valve and strainer to the three-way manually operated control valve and the PRP valve. If the automatic pilot valve is actuated or the three-way valve is positioned to START, firemain pressure



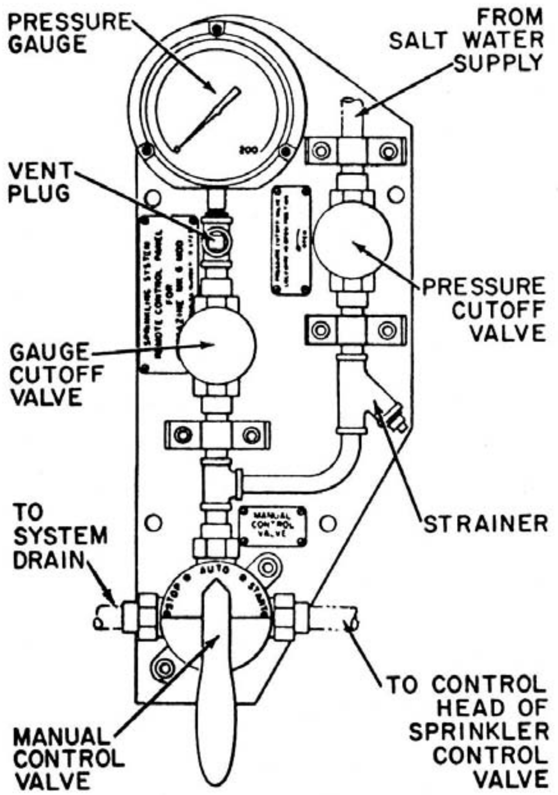
84.315

Figure 10-23.—Sprinkling system, local control panel.

is ported through a one-way check valve to lift the main sprinkling control valve and activate the sprinkling system.

Once the sprinkling system has been activated, it can be stopped by positioning either one of the three-way control valves to STOP. This action ports water from the firemain to the hydraulically operated check valve, causing the check valve to lift and connect the line from the main control valve to drain. Note there is no stop line from the PRP valve to the hydraulically operated check valve; therefore, if the sprinkling system is activated by the PRP valve, it must be manually stopped by one of the three-way control valves.

The orifice that connects the main sprinkling control valve and the three-way control valves to



84.316
Figure 10-24. — Sprinkling system, remote control panel.

drain is too small to prevent operation of the sprinkling system, but large enough to prevent possible leakage around the three-way control valves and PRP valve from building up pressure and activating the sprinkling system.

The function of the pressure switch, leakage alarm, and air-charged lines will be described later in this chapter.

The latest improvement in automatic sprinkling systems involves the use of firemain pressure to activate a wet type system. The wet type sprinkler system differs from the dry type, in that the sprinkler pipes between the magazine sprinkling control valve and the sprinkling heads are filled with nonpressurized fresh water. A combination valve and sprinkler head replaces the open orifice type of spray head. The sprinkler head valve is held closed by 50 psi water pressure which is supplied from a 20 gallon fresh water accumulator tank. Actuation of the PRP valve or operation of the manual three-way valve, immediately releases the 50 psi control pressure and blocks off the accumulator tank. At approximately the same time, the main sprinkling control valve opens allowing water at firemain pressure to wet down the magazine.

Testing The Sprinkling System

Once a month air test the pneumatic lines in the sprinkling system for tightness and operability of the heat-sensing devices, and test the sprinkling system for proper operation of the valves.

Once each quarter, air test the dry lines for unobstructed flow between the sprinkling control valve and the sprinkling heads, flush the associated firemains for unobstructed flow, clean the salt water strainer and clean the drain hole in the sprinkling control valve.

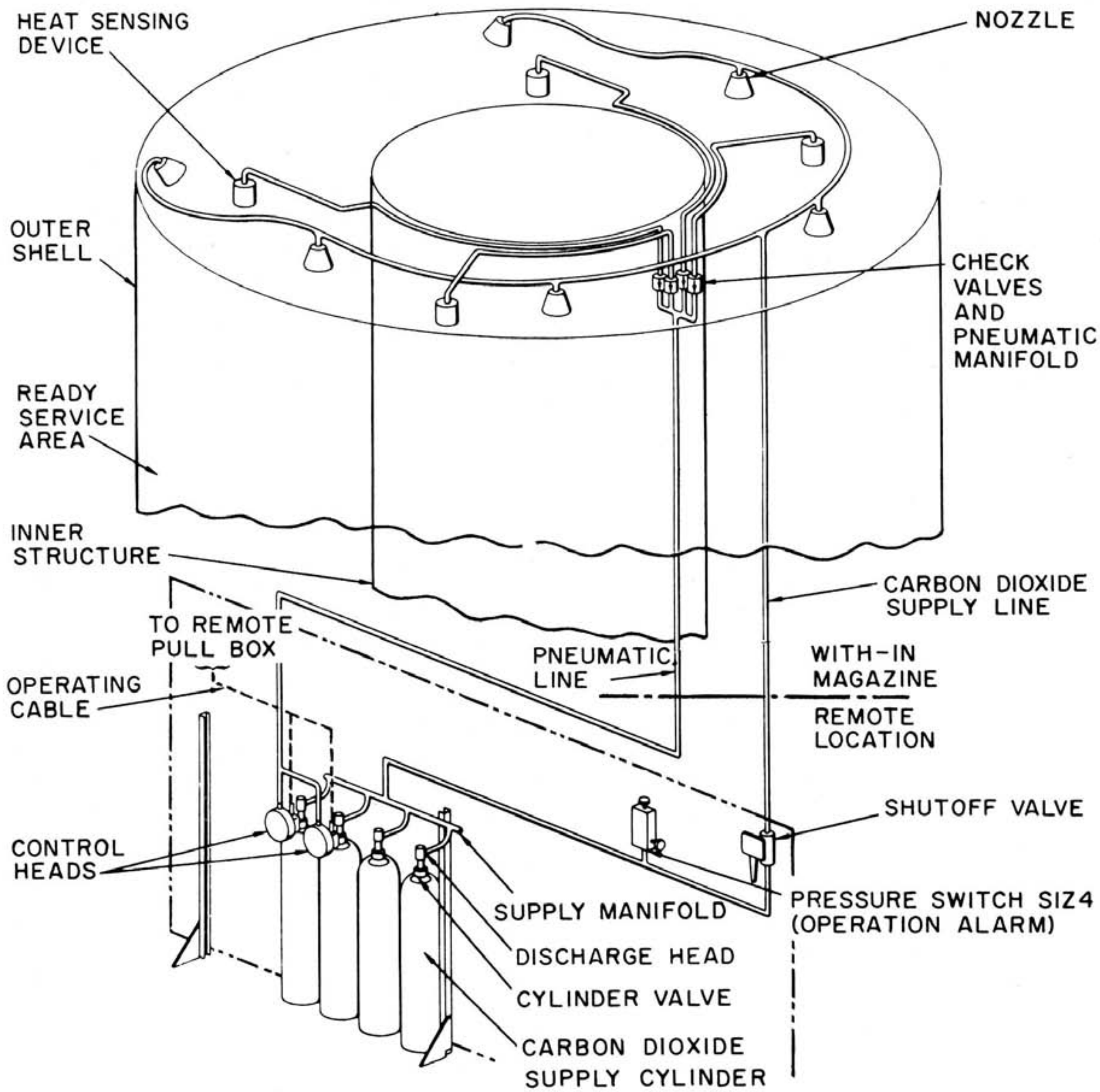
Of course, you are not going to turn on the sprinkling system and wet down the magazine each time you test the sprinkling system. For both the airtightness test and the operational test you will need a test casting, a spanner wrench, a firehose or a test cap of the correct dimensions (fig. 10-22), and a small container to catch any salt water drip. The OP for the system will tell you the items needed. The OP also gives the step-by-step instructions for each test.

The man doing the testing must be inside the magazine and therefore the magazine must be immobilized until he is finished with the test and is out of the magazine. [Before entering the magazine, position the Magazine Safety Switch on SAFE and remove the switch handle so the magazine power drive cannot be inadvertently started. Also, close the two shutoff valves that serve the magazine carbon dioxide systems. These valves are located adjacent to the magazine access land are normally locked open; unlock and close them before entering the magazine.

When automatic sprinkling systems on ships are performing improperly, assistance from the designated contractor may be requested according to NavShipInst 9480.13.

CARBON DIOXIDE (CO_2) SYSTEMS

The primary components of the carbon dioxide systems are six heat-sensing devices, six supply cylinders, three pneumatic control heads, eight discharge nozzles, two shutoff valves, two operation alarm switches, and two remote control pull boxes. The components of the outer and inner carbon dioxide systems are identical; the systems differ only in the number of components that are needed.



83.116

Figure 10-25. — Outer CO_2 system arrangement, Mk 13 Mods 0, 1, 2, and 3 launching system, Guided Missile Magazine Mk 8 Mod 0, and Mk 108 Mods 1, 2, and 3.

The magazine of the Tartar launching system has an installed carbon dioxide system, which is really two independent systems, one for the inner ring and another for the outer ring of the magazine. The outer system has more components than the inner system because it covers a large area. Each system automatically floods its area with carbon dioxide if its heat-sensing devices detect excessive temperatures. Each system can also be manually or remotely actuated.

The carbon dioxide supply cylinders, figure 10-25, located below decks near the magazine structure, contain liquid carbon dioxide at 850 psi at 70°F. Each cylinder has a 50-pound capacity and weighs approximately 165 pounds when fully charged. Each cylinder is equipped with a discharge head to which is connected a supply hose that leads to a common manifold. Control heads are installed on two of the four discharge heads. Pneumatic lines connect the control heads to a pneumatic manifold. Pressure originating in one or more of the heat-sensing devices is transferred through the pneumatic manifold to the control heads on two of the cylinders.

Each control head has a lever for manual operation. A safety locking pin secures the operating lever. A line to the top of each control head contains an operating cable that goes to a remote control box shown in figure 10-25.

When tripped, a discharge head on each cylinder directs carbon dioxide into the supply manifold and on to the discharge nozzles. The control heads trip the discharge heads on the control cylinders. Carbon dioxide flowing through the supply manifold trips the other two discharge heads.

When carbon dioxide is released, it operates a pressure switch outside the magazine; the switch operates an alarm. The pressure switch can also be operated manually and reset. As the liquid CO_2 is released from the orifices it becomes "snow" which quickly cools the magazine and puts out the fire. (The "snow" will blister the skin; do not touch it.) WARNING: Close shutoff valves (one for the inner system and one for the outer system) on carbon dioxide systems before entering the magazine. Areas flooded with carbon dioxide cannot sustain life.

WARNING: If a fire occurs in the installation. do not enter it, do not open hatches, and do not start the ventilating system for at least 15 minutes after the system has been flooded with carbon dioxide. After the 15-minute wait for the cool-off period, thoroughly ventilate the installation for 15 minutes before entering. Post another person outside as an observer and standby. If it is necessary to enter the magazine before it is thoroughly ventilated, wear a fresh-air mask or other type of self-contained breathing apparatus. Do not use a filter type mask or a canister gas mask.

The entire supply of carbon dioxide is released when the system is activated. Afterward, the empty cylinders have to be replaced with filled cylinders, and the control heads (fig. 10-26) have to be reset manually. A large screwdriver is needed to turn the reset shafts clockwise until the arrows point to SET.

Although the base structure of Magazine Mk 108 Mods 1, 2, and 3 has been extensively redesigned, there has been no change in the carbon dioxide system.

Testing CO_2 Systems

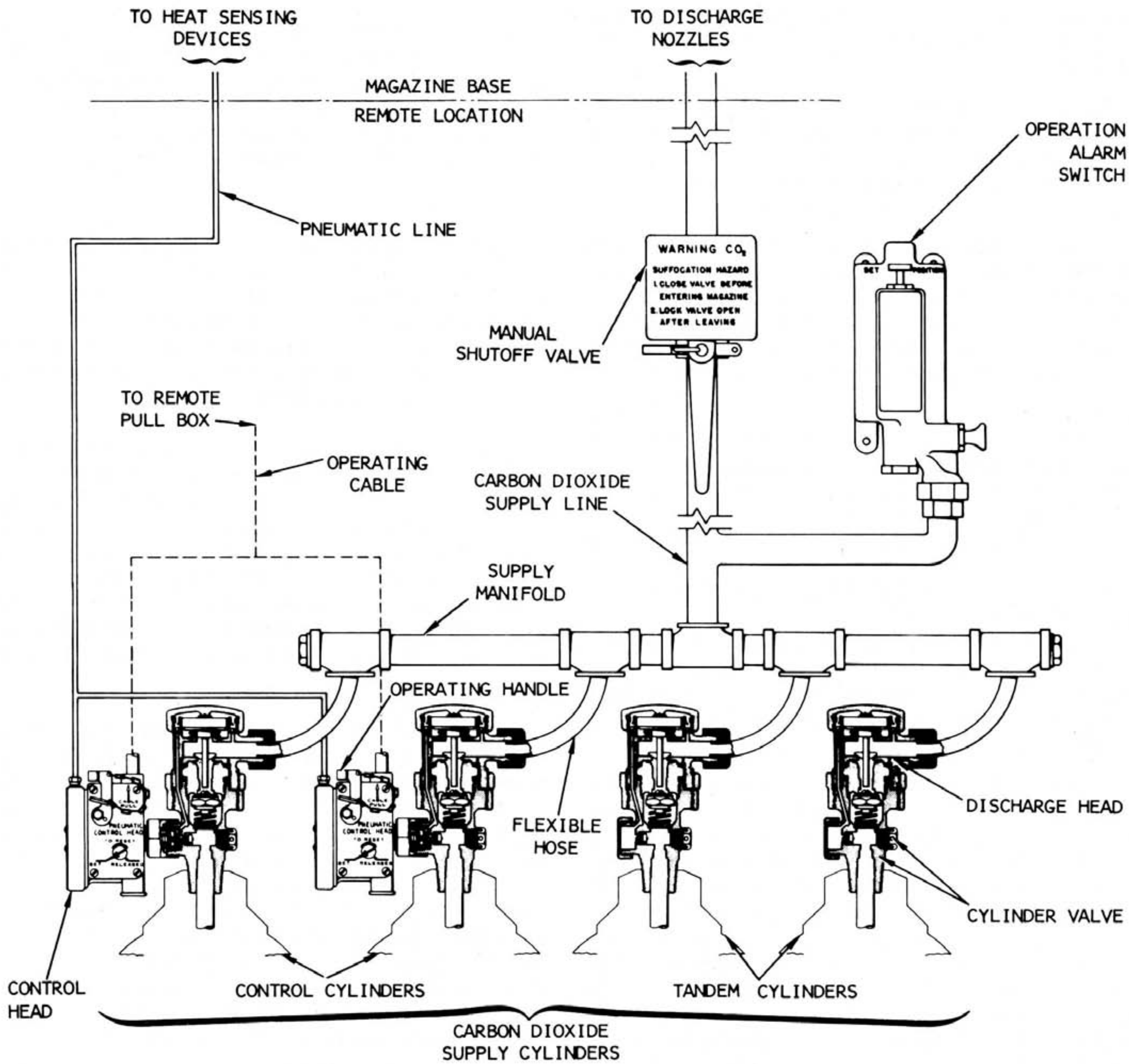
Carbon dioxide systems must be inspected and tested monthly. Inspect for breakage in tubing, pipes, and hoses. Check that all tubing is properly supported and strapped in place. Replace any damaged parts immediately, using only the special, heavy tubing required for the pneumatic lines.

Air testing the CO_2 systems for tightness and operability of the heat-sensing devices also checks the automatic operation of the alarm switches. Checking the manual operation of the alarm switches is done separately. The operability of the control heads and the pneumatic check valves is also tested.

No carbon dioxide is used in making the tests - the CO_2 supply must be closed off before beginning the tests. To perform the air test you will need test caps for all the nozzles, an air pressure gage, a hand pneumatic pump, an adapter to connect the ship's air supply line and air gage to the Navahos carbon dioxide supply manifold, and an adapter to connect" the air gage and the pneumatic hand pump to the pneumatic line.

The outer and inner carbon dioxide systems are tested separately. Remove the nozzles and insert the test caps. Disconnect the discharge heads on the CO_2 cylinders and connect the air gage and the ship's air supply line, using the adapter, to the carbon dioxide manifold, apply 20 psi air pressure to the carbon dioxide line. This should activate switch SIZ4 (fig. 10-25), an audible alarm should sound, the visual alarm should light, and the ventilation systems should shut down. If any of these do not function, you will need to get the NavShips instructions for repair, and correct the trouble. Next, apply 90 to 100 psi air pressure, secure the air supply, and hold for 5 minutes. If there is any drop in pressure, look for leaks by applying soap suds at the joints of fittings. Replace leaky parts and test again.

When testing the operation of the control heads on the carbon dioxide cylinders and the pneumatic check valves, be sure to observe all the cautions in the instructions in the OP, and perform the steps in the order given. Do not let the carbon dioxide discharge from the cylinders during the test.



83.204
Figure 10-26. — Carbon dioxide system controls.

USE OF FOAM IN FIREFIGHTING

You learned about the use of foam on class B fires (involving substances like oil, gasoline, kerosene, other liquid fuels, and paint) when you studied Basic Military Requirements, NavPers 10054-C, and you have had training in using the foam equipment. In addition to the standard oils and liquid fuels, various rocket fuels now have to be considered in the same fire category. For fighting fires in some type of nuclear warheads, a blanket of foam has been found most effective.

Foam protection is provided for Talos magazine areas, assembly areas, and mating and checkout areas by means of nozzles near the deck level, supplied through a fixed piping. A cutout and a visible indicator are provided. The foam systems are not automatic in operation. On CG class ships, foam is provided to the magazine deck only.

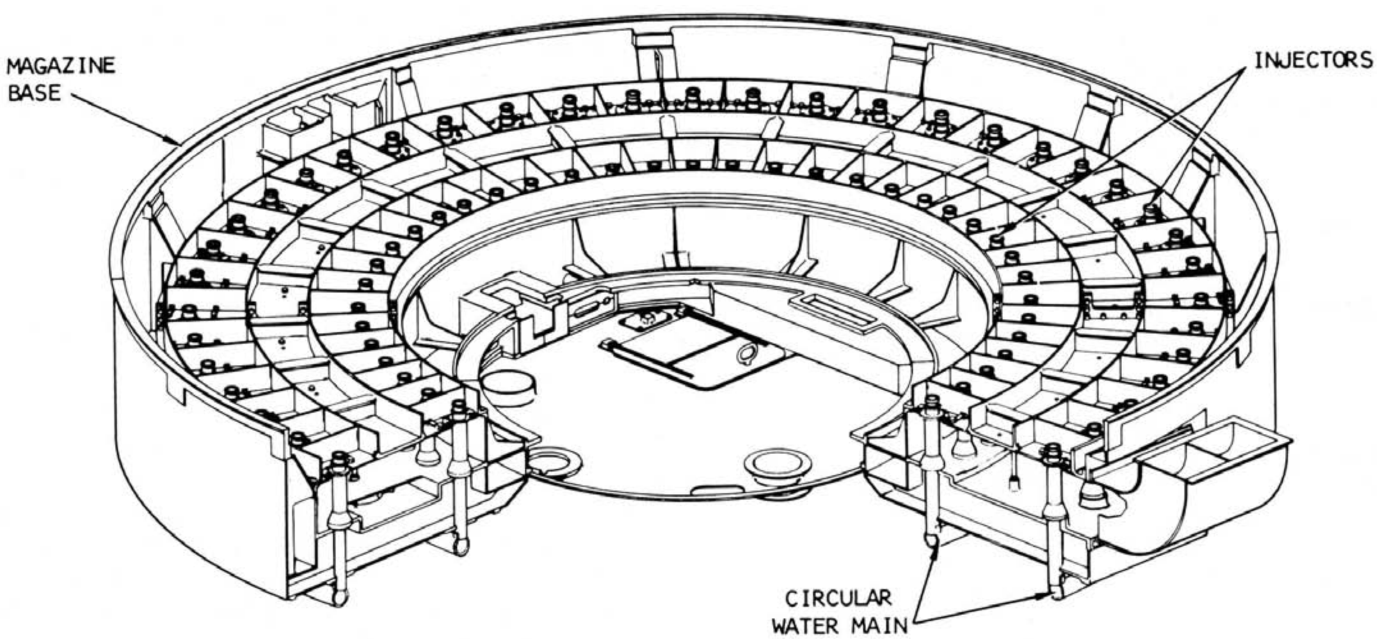
For the Terrier missile system, nozzles near the deck level, supplied through fixed piping, give foam protection to the magazines. Foam protection for the assembly compartments and for the strikedown and the checkout compartments is provided by foam hose lines. Foam systems are nonautomatic; but they are interlocked with the access door, and have interior and exterior indicators.

Mechanical foam is produced by mechanical mixing of foam fluid dissolved in water with air, making a tough blanket of air-filled foam bubbles. Chemical foam is the result of a chemical reaction between chemical powders in contact with water, or by mixing two fluid chemicals. The foam-producing equipment is under NavShips cognizance, and descriptions of installation will be found in NavShips publications. Chapter 93 of NavShips Technical Manual 0901-930-0003 (formerly NavShips 250-000, now issued as a pamphlet) describes the methods of producing foam for firefighting. It also describes the use of spray or fog in firefighting. These two methods, foam and fog, are used most on deck and on hanger decks and elevators. The fog is very effective in cooling and smothering a fire but there is danger of the fog nozzle coming into contact with electrical equipment.

WATER- INJECTION SYSTEM

The purpose of the water injection system is to provide an instantaneous and continuous jet spray of water toward the exhaust of any missile accidentally ignited in the magazine.

In the Mk 13 Mod 0 launching system the missile water injector system contains 96 water injector units (fig. 10-27) in the magazine base. Each unit consists of a standpipe, that is threaded into one of the Circular water mains, and a water injection nozzle threaded into the standpipe. A fresh water tank is charged at approximately 200 psi until injector actuation at which time pressure is reduced to firemain pressure. The connecting line from the fresh water supply to the firemain contains a check valve as does the firemain line. Water from the fresh water tank or the firemain goes through a water main to a manifold, which distributes water into the two circular water mains in the magazine base. The mains supply water to the standpipes and detector nozzles.



94.87
Figure 10-27.—Base of magazine Mk 8 Mod 0, launching system Mk 13 Mod 0, showing water injectors.

The nozzle body contains a closure piston, an actuation piston, lock balls, and a cover diaphragm secured by a cover sleeve shown in figure 10-28. Three lock balls in the throat of the nozzle hold the closure piston in place against water pressure from inside the nozzle. This piston blocks the flow of water out of the nozzle until the system activates. A gold-wire spring holds the actuation piston in place above the closure piston until missile exhaust activates the system and breaks the spring. A cover diaphragm keeps the nozzle clean.

If a missile ignites in the magazine, exhaust from the missile exerts pressure on the actuation piston in the nozzle. This pressure breaks the gold-wire ring, allowing the actuation piston to move down. The three locking balls then fall out of the throat and into the center of the nozzle.

As the locking balls disengage from the nozzle throat, water pressure from the fresh water tank forces the closure piston, the lock balls, and the actuation piston out of the nozzle, along with the stream of fresh water. A flow detector, in the line between the fresh water tank and nozzles, responding to the flowing water, closes contacts in the circuit to start the firepump, to energize the alarm system, and to activate the drain eductor system.

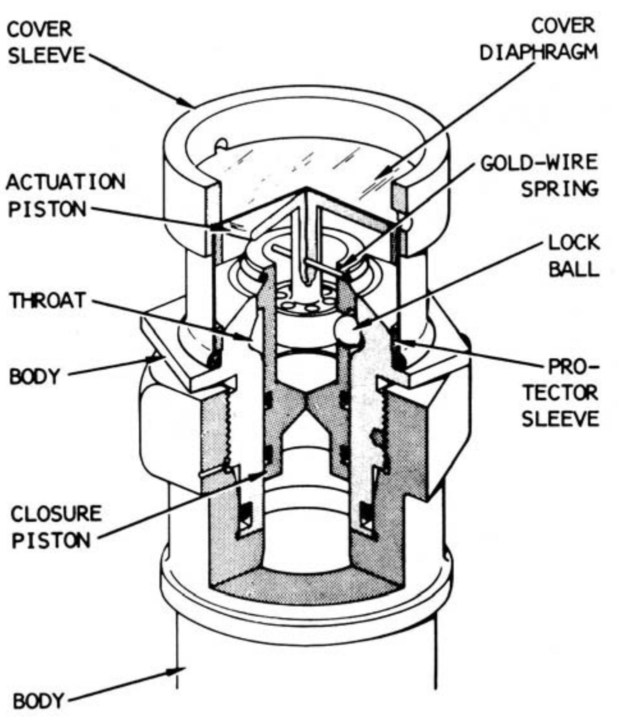


Figure 10-28.—Water injection detector nozzle.

With the firepump started sea water is available to the injection system. When the water pressure from the tank decreases to firemain pressure, sea water from the firepump opens a check valve and starts flow into the injection system. At 70 psi firemain pressure, the injector nozzle will discharge at the rate of 180 gallons per minute.

During burning of an electrically ignited missile motor, the missile exhaust is forceful enough to prevent water flow for a fraction of a second. During this brief period, the injection system obstructs the missile exhaust flow. For this reason the nozzle has been made small and the cover sleeve purposely made of a material (nylon plastic) that will break away when subjected to the exhaust stream.

To stop the flow of water into the water injection system, a remote shutoff valve must be closed, and the firepump circuit must be opened at the switchboard. After components of activated nozzles are replaced and the compression tank is filled and recharged, the system must be reset.

The water injection detector nozzle in the Mods 1, 2, and 3 is the same as in the Mod 0, but the stand pipes and associated piping have changed due to the changes in the base structure of the magazine. The stand pipes extend below the bottom plate of the base structure. The associated piping is below the base structure, passing under it, not through it. The base structure has been strengthened and provisions made for mounting the elbow-shaped exhaust duct for the plenum chamber.

Testing Water Injection Systems

The injection system has to be inspected and tested at intervals determined by ship's policy. Maintenance is then performed as shown necessary by the inspection and tests.

The inspection of the nozzles has to be performed inside the magazine, working in an empty cell. If no cell is empty at the time, hoist one missile onto the launcher. Then set the Magazine Safety Switch to SAFE on the panel to inactivate the power drives, and remove the switch handle from the panel. Also, before entering the magazine, close the shutoff valves on the CO_2 system, and shut off the water pressure in the firemain leading to the injectors.

One crew member, on instructions from the man in the magazine, manually indexes the ready service ring to position him over the next nozzle, and so on until all nozzles have been inspected. Each nozzle is removed for inspection, using a special wrench. Be careful not to apply force or drop anything on the nozzle end. A force of 16 pounds will trigger it.

After all nozzles have been inspected, turn on the water pressure in the firemain and proceed to bleed each standpipe. To do this, loosen the nozzle with a special wrench, two or three turns, until water appears. Then, tighten the nozzle again until leakage stops. Inspect the rubber cover on the face of the nozzle, and replace it if it is damaged. It is cemented in place.

When all this is completed, recharge the compression tank (62-1/2 gallons of fresh water and 200 psi air pressure). When the crewman is out of the magazine, return the switch handle to the panel, replace the handcrank on the power-off brake, open and lock the two shutoff valves on the C~ system, and, if a missile was placed on the launcher to empty a cell, return it to the cell.

If there is a drop in the air pressure in the fresh water compression tank, check for leakage in the system by checking each nozzle and standpipe. Observe the same precautions for working in the magazine as you did for inspecting the operability of the nozzles and standpipes.

Some instructions require only a spot check of nozzles, and a complete check is not made unless one or more faulty ones are found in the spot check. Review the latest instructions for your system.

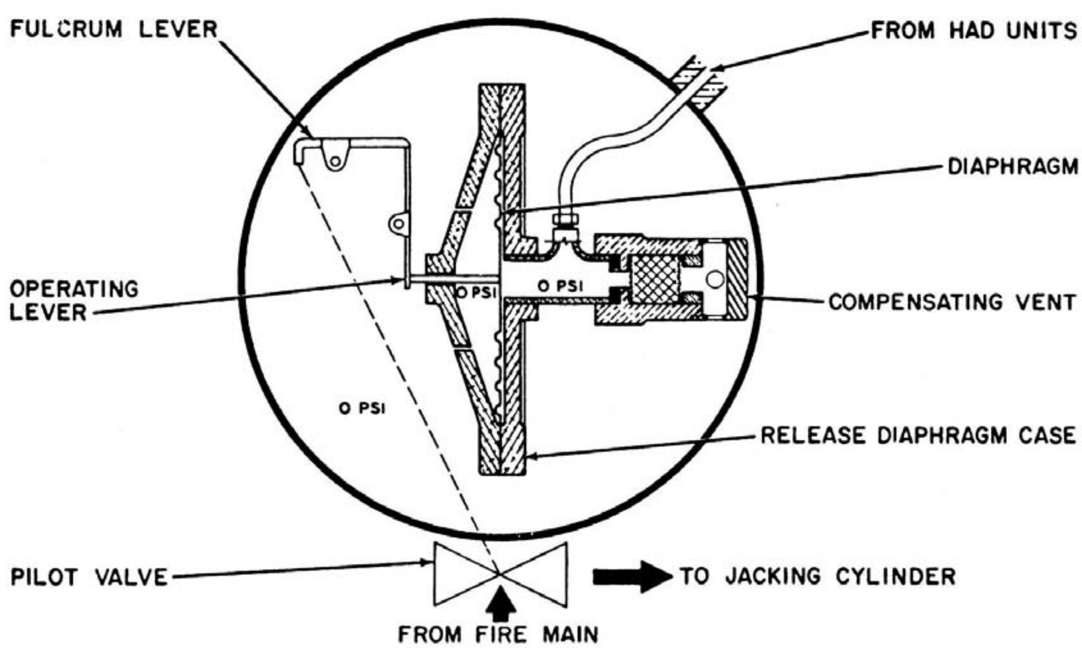
AUTOMATIC CONTROL DEVICES

Most missile magazine sprinkling systems are equipped with some type of automatic control device. These control devices are actuated by heat-sensing elements in the magazine area.

The automatic control devices actuate the same sprinkling system main control valve which is operated by the remote and local control stations. The devices are designed to actuate when a rapid rise in temperature occurs or when the heat exceeds a fixed temperature.

PRP Valve

The PRP valve assembly (fig. 10-29) consists of a bronze case which encloses a release diaphragm, chamber, linkage, springs, and a pilot valve shaft and levers. The shaft and levers are connected to the PRP which opens and closes to control the main control valve. The shaft and levers are arranged so that any sudden pressure



84.320

Figure 10-29. — Pneumatically released pilot valve (PRP) schematic.

increase causes the diaphragm to extend into the diaphragm chamber and to trip the operating lever out from under the fulcrum lever. When the fulcrum lever is released, the pilot valve is opened by spring action.

Slow changes in pressure between the inside and outside of the diaphragm chamber are equalized by the compensating vent shown in figure 10-30. This vent is installed in the line connecting the manifold fitting to the inside of the diaphragm chamber and discharges into the bronze case on the outside of the diaphragm chamber.

One side of the release diaphragm case is open to the interior of the bronze pneumatically released pilot valve case. The other side of the release diaphragm is connected to the tubing from the compensating vent fitting and from the HAD's.

A lever is provided on the front of the PRP case to reset the PRP after operation. An air valve and gauge are also provided on the front of the PRP case to pressurize the system by means of a hand pump when testing for air leaks. The cap covering the adjustment for water side of the PRP valve is locked in position by the manufacturer so that valve setting cannot be tampered with and the cap will not vibrate loose. A metal tag is also attached to the case by the manufacturer warning personnel not to open casing for adjustment.

HAD Unit

The earliest application of automatic control for sprinkling systems is the heat actuated device (HAD) shown in figure 10-31. The device, encased in wire guards, is a pneumatic thermostat which consists of a hollow brass-chamber whose capacity is about 14 cubic inches. One or more HAD's are located in the protected compartment and create the pressure necessary to actuate the PRP valve when the rate-of-rise of the temperature becomes excessive.

The excessive heat is absorbed by the HAD and is utilized to heat the air trapped in the system. The heated air expands and creates a pressure which is transmitted through 1/8 inch tubing to the PRP diaphragm, causing the PRP valve to trip and actuate the sprinkling system. The device functions when the internal pressure is equivalent to the pressure produced by 6 to 10 inches of water within 10 seconds after the HAD has been exposed to external heat.

When the heat is absorbed by the device at a slower rate than the one previously mentioned, the system does not function, since provision is made within the pneumatic release pilot valve (PRP) to allow for normal temperature changes within the compartment.

Fixed Temperature Unit

The fixed temperature units (FTU's) are designed to actuate the automatic control device when the temperature reaches a predetermined value.

Note: The temperature rise must be slow, otherwise the HAD unit will actuate the automatic control device before the FTU can function.

An FTU shown in figure 10-32, consists of a spring-loaded cap which is held in place by indium solder. This solder is made of such material that it melts at the predetermined maximum setting for the protected compartment.

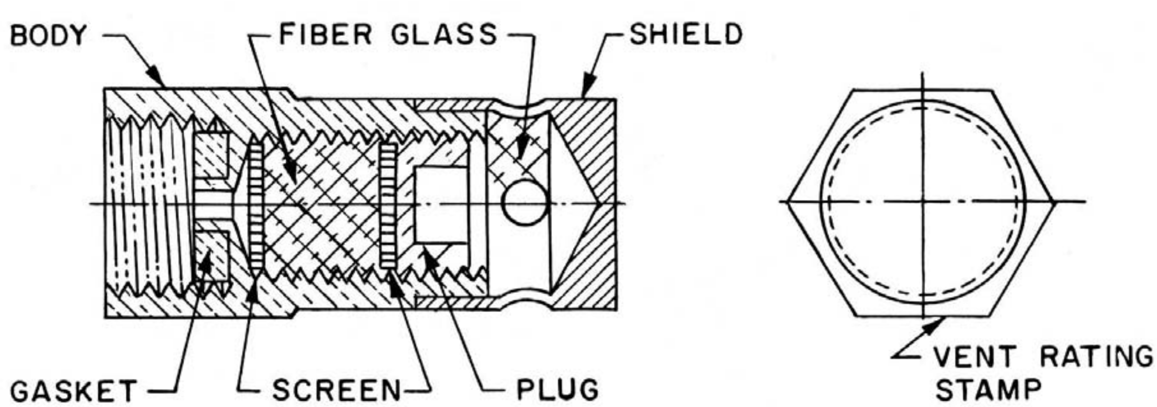


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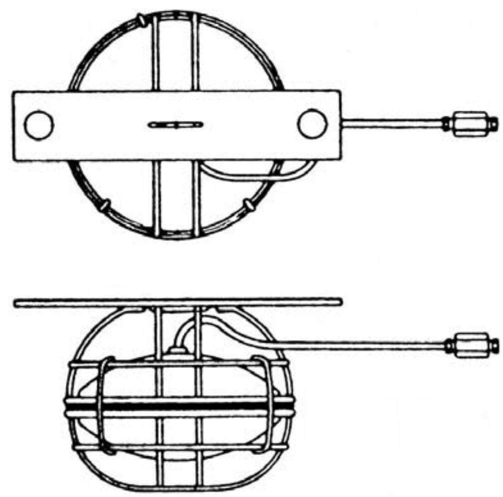
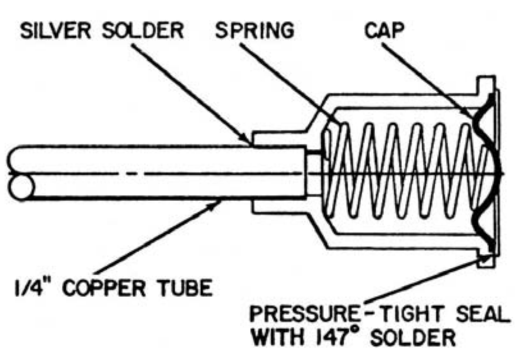
Figure 10-30.—Compensating vent.



84.321
Figure 10-31.—Heat actuated device (HAD).

When the FTU cap is freed, the pressure in the PRP valve case is released, causing the automatic control device to actuate.

A schematic of an automatic control system consisting of a PRP valve, HAD units, and FTU units is shown in figure 10-33. In figure 10-32 it is assumed that the temperature in the protected compartment rises at a slow rate. As the temperature rises, the HAD's respond by transmitting the heat in the form of air-pressure to the PRP diaphragm. Since the air-pressure rise is slow, it is equalized within the PRP diaphragm case by the compensating vent, thus preventing the PRP valve from being actuated. However, when the temperature in the protected



84.326
Figure 10-32.—Fixed temperature unit (FTU).

compartment reaches the predetermined maximum level, the FTU opens and vents the air pressure built up in the diaphragm case, causing the PRP valve to trip.

Thermo-Sylphon Unit

The latest control device for automatic sprinkling systems combines the features of a HAD and an FTU. This device, known as the thermo-sylphon heat sensing device, is used on many of the newest types of sprinkling systems.

A thermo-sylphon heat sensing device shown in figure 10-34, consists of a bellows normally enclosed in a mesh cage. The bellows are expanded and held by a fusible link against spring pressure. The device, automatically actuates a PRP valve when there is a rapid temperature rise or when the fusible link melts.

When a rapid temperature rise occurs in a magazine or ready service area, the resultant sudden pressure increase in the bellows is transmitted to the PRP valve causing it to activate the sprinkling system. Normal temperature changes also cause air in the bellows to expand and contract. However, these normal pressure changes are vented by the compensating vent in the PRP valve.

When the temperature in a magazine area reaches a predetermined value, it causes the fusible link to melt, releasing the compressed spring, and causing the bellows to collapse. As the bellows collapse, a pressure is developed that actuates the PRP valve.

Note: The fusible pin (link, lug, slug) of a heat-sensing device, in a particular sprinkling system, will melt at a predetermined temperature. For example; the Mk 13 launching system magazine has sixteen heat sensing devices. Twelve of these devices are used with the salt water sprinkling system. The fusible pins in these devices will melt at 174 degrees F. The four remaining heat-sensing devices are used with the carbon dioxide (CO_2) system. The fusible pins in these devices will melt at 158 degrees F.

It is imperative that when replacing a fusible pin on a device that has been activated, a pin with the same melting point as the original pin must be installed.

TEST SPRINKLING SYSTEM

Once a month (1) airtest the pneumatic lines in the sprinkling system for tightness and operability of the heat sensing devices, and (2) test the sprinkling system for proper operation of the valves.

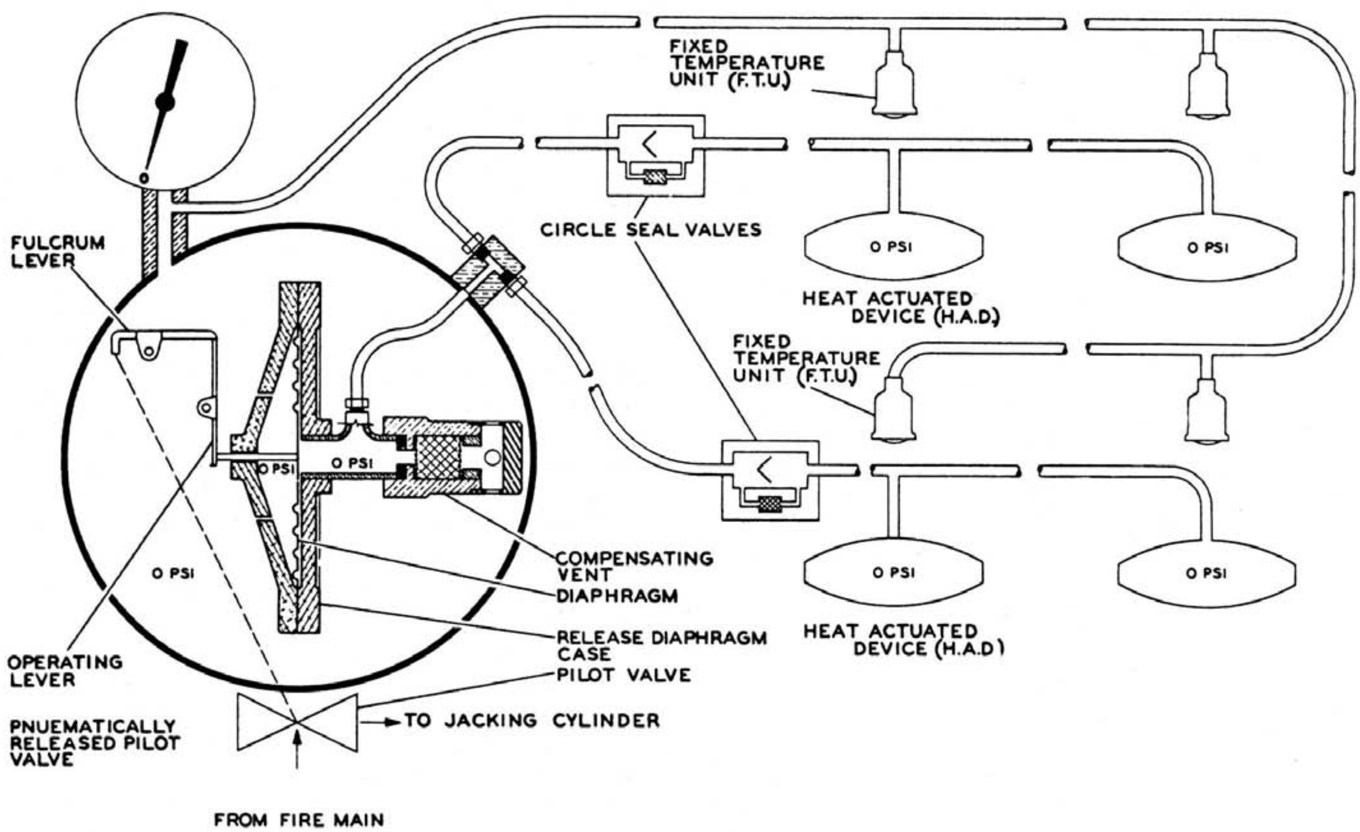


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Figure 10-33. — Sprinkling system automatic control system, schematic.

The once every quarter airtests of the dry lines for unobstructed flow between the sprinkling control valve and control heads and flushing the firemains for unobstructed flow was covered earlier in this chapter.

Airtest (Tightness)

To airtest the sprinkling system monthly for tightness and operability of the heat sensing devices, proceed as follows:

1. Obtain the following equipment:

a. A test casting
b. A spanner wrench
c. A hand pneumatic pump
d. Either a 1-1/2 inch fire hose or a test cap (2-1/2 - 7-1/2 N.H. thread) having a petcock
e. A small container in which to catch salt water

2. Using the spanner wrench, remove the bottom cover of the sprinkling control valve. Then screw in the test casting, shown in figure 10-22B.

3. To the threaded end of the test casting, attach either a fire hose or, if available, the test cap. If the fire hose is used, the hose should be led to a convenient drain.

4. Close the normally locked open globe valve in the 3-1/2 salt water supply main.

5. Connect pneumatic pump to air valve on PRP valve (fig. 10-35). Remove cap at the bottom of gage to get to the air valve to connect pneumatic pump to PRP valve.

6. Slowly pressurize system until a pressure of at least eight ounces is obtained. Because of the slow passage of air through the vents, some additional pumping of air may be required before obtaining a balance.

7. After the balance is obtained, stop pumping and hold the pressure for five minutes. The pressure should not drop during this period - even the slightest drop in pressure is serious,

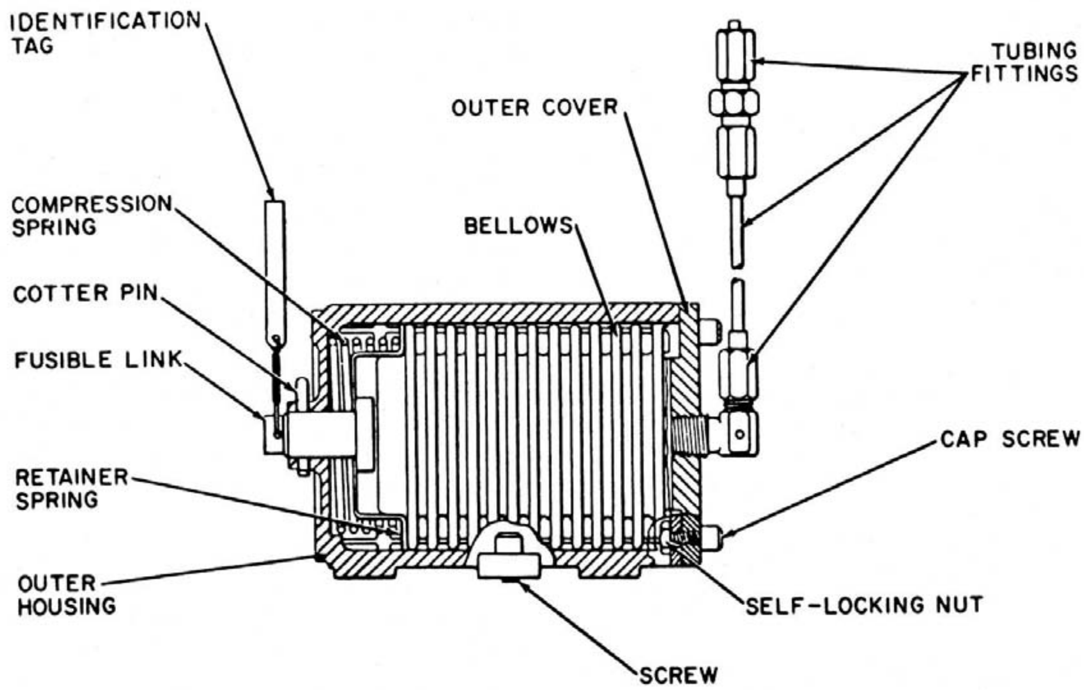

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Figure 10-34. — Thermo-sylphon heat sensing device.

for it indicates a leak which may prevent automatic operation of the system at the time of a fire. If the gage does not retain eight ounces of pressure for five minutes, first check the fitting on the hose line for the pneumatic pump to be sure it is not the type that holds the air valve open, thereby permitting pressure to escape. Look for a leak by applying soap suds to the fittings near the PRP valve and subsequently at the fittings near the heat sensing devices. Do not use a movable jaw wrench when tightening fittings. NOTE: If the leak is within the PRP valve, replace this valve with a new unit. Do not open the PRP valve case under any circumstances. Turn in defective valve to the nearest naval stocking activity. Repeat airtest with replacement valve.

8. To test action of the heat sensing devices, punch the air valve fully open. Sudden release of pressure in the PRP valve case and pneumatic lines should trip the sprinkling main control valve; allowing water to flow into the test casting. (Actuation of the PRP valve simulates the condition created when the sealing disc (cap) of an FTU is ejected when the indium solder melts or the bellows of the thermo-sylphon device collapses due to melting of the fusible link.)

9. Wait about two minutes (see note below), and then reset the tripping mechanism on PRP valve by gripping the reset lever with the reset key and turning the lever to SET (fig. 10-35). Be sure the lever latches at SET before removing key. Note: The two minutes wait is necessary to allow time for pressure on both sides of the valve diaphragm to equalize. Unless the pressure is equalized the PRP valve will not latch at SET. If after two minutes the valve does not set, again slowly pressurize the system as in step 6, wait five minutes, then punch the air valve wide open. Wait another two minutes, and then reset the valve. If the valve still fails to reset, or will not trip to begin with, replace it with a new unit. DO NOT OPEN THIS VALVE UNDER ANY CIRCUMSTANCES. Turn in the defective valve to nearest naval stocking activity. Repeat airtest with replacement.

10. With the PRP valve reset and the air vented from the system, totally immerse the most remotely located accessible HAD in a container of water. (Water temperature should be at least 200° F.) The PRP valve should trip in a maximum of 5 seconds. Check the sprinkling main control valve to ensure that it is open. To expedite the test, cool the HAD with cold water or ice. Reset

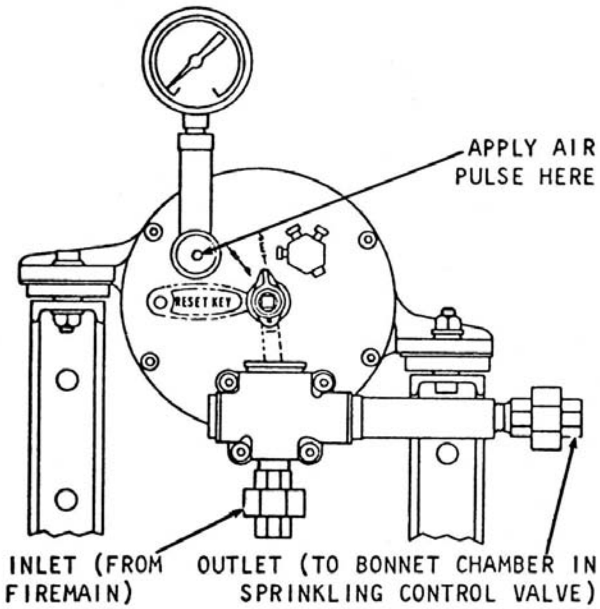

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Figure 10-35.—Pneumatically released pilot valve.

the PRP valve and check to ensure the sprinkling main control valve is closed.

10a. (Figure 10-35 apply air pulse here approximately 8 ounces). This does the same thing as if the heat actuated device (HAD) had functioned or the thermo-sylphon device had functioned due to a fast rise in magazine temperature.

11. Open globe valve in the 3-1/2 inch salt water supply main and lock open. Remove fire hose or test cap from the test casting on the sprinkling main control valve. Have a small container available to catch salt water trapped within test casting. Then remove test casting, check to see that there is no leakage past valve seat, and screw on the bottom cover to the valve, using the spanner wrench.

GENERAL INSTRUCTIONS AND SAFETY

In a study of safety precautions, it is difficult to cover every possible situation that may arise and which, if improperly handled, may produce serious results. However, if a thorough understanding of the basic ideas behind the precautions is developed, unsafe conditions can be recognized and corrected and further suitable action can be taken instinctively when the unexpected occurs.

Safety is everyone's responsibility. Awareness of danger, knowledge of how danger can be avoided, and constant vigilance are the three basic requirements to prevent accidents when working with explosives, including missiles and missile components.

Safety precautions, rules, and regulations for handling explosives should be made the subject of frequent instruction, and the necessity for strict compliance with these procedures should be so firmly fixed in the minds and habits of new men that they will invariably and subconsciously thereafter react in an emergency according to the instructions previously received. Attention is especially invited to the fact that in the early stages of the use of explosives, experience was gained at a great price- not only in dollars, but in human lives.

No relaxation should be tolerated, since this tends to create the impression that the rules are arbitrary. Men tend to become careless and indifferent when continually engaged in work with explosives and, as long as no incident occurs, are inclined to drift gradually into neglecting the necessary precautions. Nothing but constant vigilance on the part of officers and petty officers in charge will ensure the steadfast observance of the safety rules and regulations which experience has taught to be necessary.

It is of primary importance in the safety program that all persons should be thoroughly indoctrinated before their first occasion of working with explosives. This indoctrination must include personal safety, material protection, accident prevention, and initial actions to be taken if a dangerous situation starts to develop. THERE IS NO VALID REASON FOR FAILURE TO COMPLY WITH SAFETY REGULATIONS.

Missiles, as well as gun ammunition, bombs, rockets, and torpedoes, are extremely dangerous; therefore, constant vigilance and intelligent supervision must be exercised during handling and storage of these items.

Handling of missiles and explosives shall be kept to a minimum and performed only with authorized handling equipment. Live missiles shall never be used to check out the equipment.

Missile boosters shall be handled with extreme care. A slight blow may crack the propellant grain and cause an explosion when the weapon is fired. Care shall be taken that no heat is applied to or near boosters.

Missile warheads are classified as bomb-type ammunition; therefore all general safety precautions for handling high explosive and bomb-type ammunition shall be exercised when warheads are being handled.

Warheads must be grounded at all times when outside their shipping containers. The container shall be grounded before it is opened prior to removal of the contents. Empty containers must be grounded before a warhead is inserted. Physical contact of a container to ships metal deck would be an adequate ground.

Steel instruments or tools that may cause sparks shall not be used for cleaning or scrapping exudite from, or for assembly or disassembly of warheads.

A warhead that is cracked, dented, bent, or that otherwise shows signs of physical damage or corrosion shall not be used. Warheads that cannot be used should be returned to a depot.

Only authorized personnel shall remain in the area when a warhead is being installed or removed.

When fuzing a warhead, ensure that the threads are clean and in good condition; the fuze must not be forcibly screwed into or out of, its cavity. Place a light film of silicone grease on threads and fuze body for lubrication; do not use an excessive amount of grease.

Any warhead, live or inert, that fails to mate for any reason should be returned to a depot.

Exercise heads shall be handled in accordance with the greatest hazard posed by the material contained within.

If an exercise head is accidentally dropped, it should be returned to a depot.

A fuze or an S&A body that is cracked, dented, bent, or that shows other signs of physical damage shall not be used; it should be free from rust or other corrosion.

An S&A device shall be in the SAFE condition before installation. It shall not be installed into a warhead unless the warhead is assembled in a missile, except where otherwise directed.

Any fuze or S&A device that has been dropped from a height of over five feet shall not be assembled to a missile or warhead, but should be returned to a depot, with attached explanation.

Fuzes and S&A devices shall not be tested aboard ship; neither shall they be disassembled for any reason. They are a sealed assembly and shall not be repaired, modified, or broken down.

Fuzes, boosters, detonator, etc. are loaded with explosives which are sensitive to shock and friction. They must be handled with care at all times.

No explosive shall be removed from a wooden container by inserting a wire, nail, or sharp instrument.

No explosive component shall be disassembled, nor shall any attempt be made to modify or repair it, except by specific approval from NavOrd.

As explosives go, black powder is one of the most dangerous. It must always be handled with the greatest care. A few of its properties and precautions that should be observed in handling it are:

1. It possesses practically unlimited stability if stored in tight containers and kept dry. (Black powder, and assemblies containing it, should be regarded as unserviceable if they have become damp or wet.)
2. It deteriorates irregularly when moist.
3. It is not affected by moderately high temperatures. 4.

It is highly flammable and sensitive to shock, friction, and sparks.

5. If you can, avoid opening containers of black powder in the presence of other explosives or ammunition. The maximum limit that you can expose in a magazine is 25 pounds.

Pyrotechnics and pyrotechnic ammunition (except illuminating projectiles) shall be stored in cool, dry magazines below decks, preferably above the water-line, or in special pyrotechnic lockers located on the weather decks of surface ships. Submarines shall stow pyrotechnics and pyrotechnic ammunition in approved designated places.

If the quantity of any type pyrotechnic ammunition is large, it shall be stored separately from other types of pyrotechnics.

That part of signaling pyrotechnics for boats shall be packed in watertight boxes and may be stowed in boats as required by existing instructions.

Smoke bombs, float lights, smoke boxes and similar pyrotechnic smoke-making ammunition shall be stored, preferably, in dry, cool locations above decks, owing to the difficulty of combating the objectionable smoke in case of fire in these materials.

Chemical ammunition, as a rule, shall be stored in dry, well-ventilated enclosures on the upper decks, convenient for jettisoning in an emergency.

The different types of chemical ammunition shall, if practicable, be stowed separately. Separate stowage is mandatory if the quantity of any type chemical ammunition is large.

Smoke signals are subject to spontaneous combustion if they become moist. Their stowage in compartments below the waterline is, in general, undesirable because of the relative inaccessibility of many such compartments.

Aboard ship, smoke and gas producing pyrotechnics should be stowed above decks. Pyrotechnics such as Marker, Location, Marine Mk 2 and others which generate flammable gases when moist, should also be stowed topside and separate from other pyrotechnics.

NUCLEAR SAFETY PRECAUTIONS

Since the warheads of some of your missiles contain a nuclear component, you need to know how to handle nuclear materials. The nuclear component is enclosed in explosives, so the rules for safety in handling explosives are applicable. If something happens that causes the explosive to detonate, some nuclear material will be released and there will be a radiation problem. If there is a fire it can cause the explosives to detonate and thus break the container of nuclear material. This does not mean there will be a nuclear explosion. The chances of full nuclear detonation occurring unintentionally are almost infinitesimal, but there can be an escape of some nuclear radiation in an accident or incident. Observe the two-man rule whenever you assemble, disassemble, test, package, unpackage, or handle a weapon containing a nuclear component. Wear your dosimetric device (film badge or other personal type dosimeter) to measure any radiation present. If there is a nuclear accident or incident. get out of the area quickly, holding your breath to avoid inhaling particles, and secure the area. Call for the decontamination team to take care of the radiation problem.

The rules for procedures in case of nuclear accident or incident are given in OPNAVINST 8110.16C. Part of it deals with procedures in case of nuclear-loaded plane crash-lands and burns. First, rescue personnel if at all possible. Then proceed with firefighting. A GM T should safe the fuzing and firing system as quickly as possible. If the fire cannot be controlled before it engulfs the weapons, push the weapons overboard.

In summary. THINK SAFETY. Study the intent of safety regulations.

Safety is a state of mind, develop it so safety becomes second nature to you in your work as a GMM.

It is well known in the Navy that almost all fatal accidents are caused by carelessness on someone's part. A man who violates safety rules risks not only his own life, but the lives of his friends and shipmates.

Remember. "ETERNAL VIGILANCE IS THE PRICE OF SAFETY."