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,

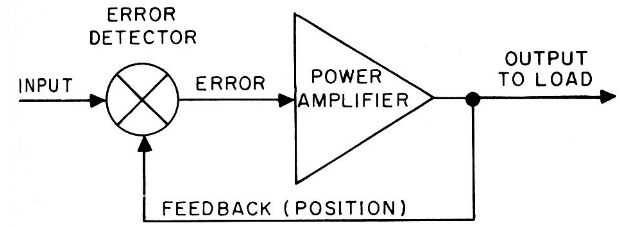

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Figure 7-1. — Elementary servo in its simplest form: block diagram.

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.

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

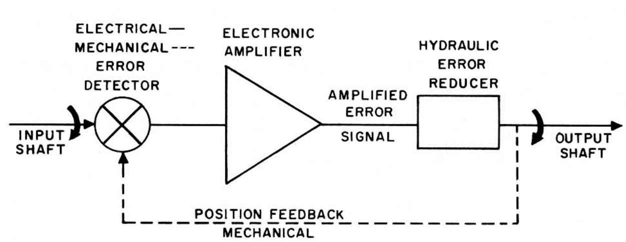

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Figure 7-2. — Elementary electromechanical servo.

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

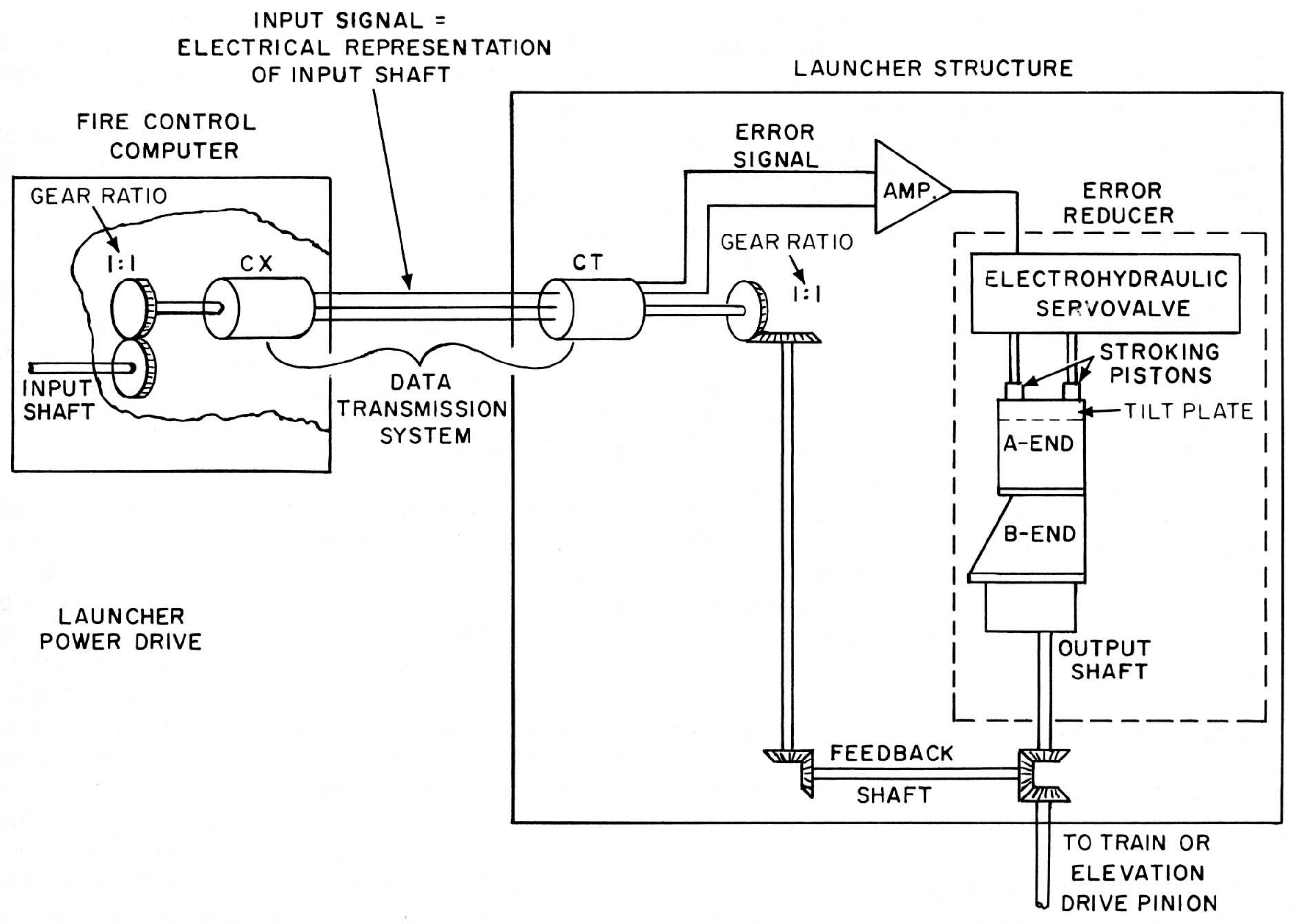

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Figure 7-3. — Typical synchro data transmission system (train or elevation launcher orders).

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.

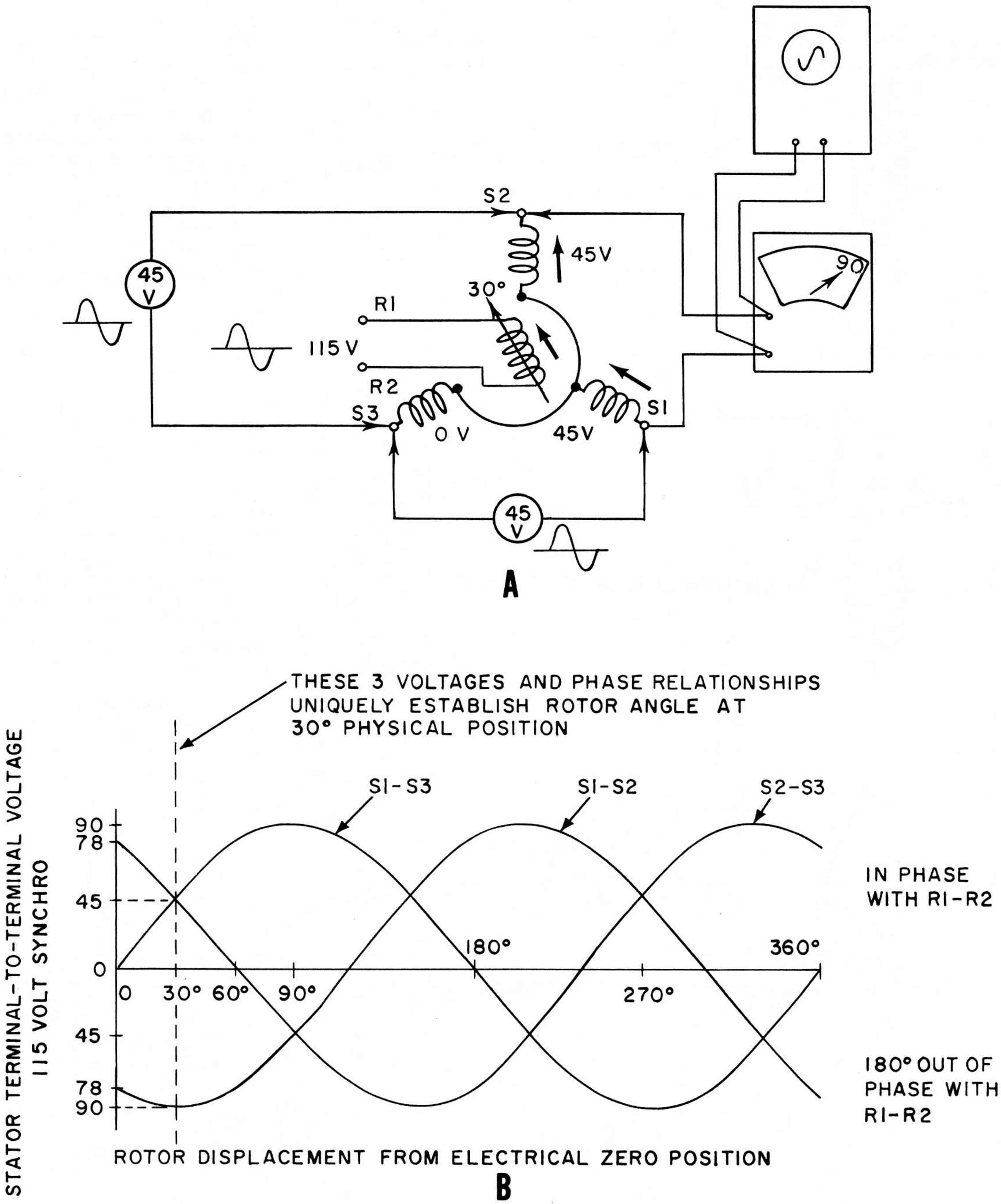

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Figure 7-4. — Synchro electrical error: A. A perfect synchro transmitter at 30°; B. "Error" or rotor displacement from electrical zero position.

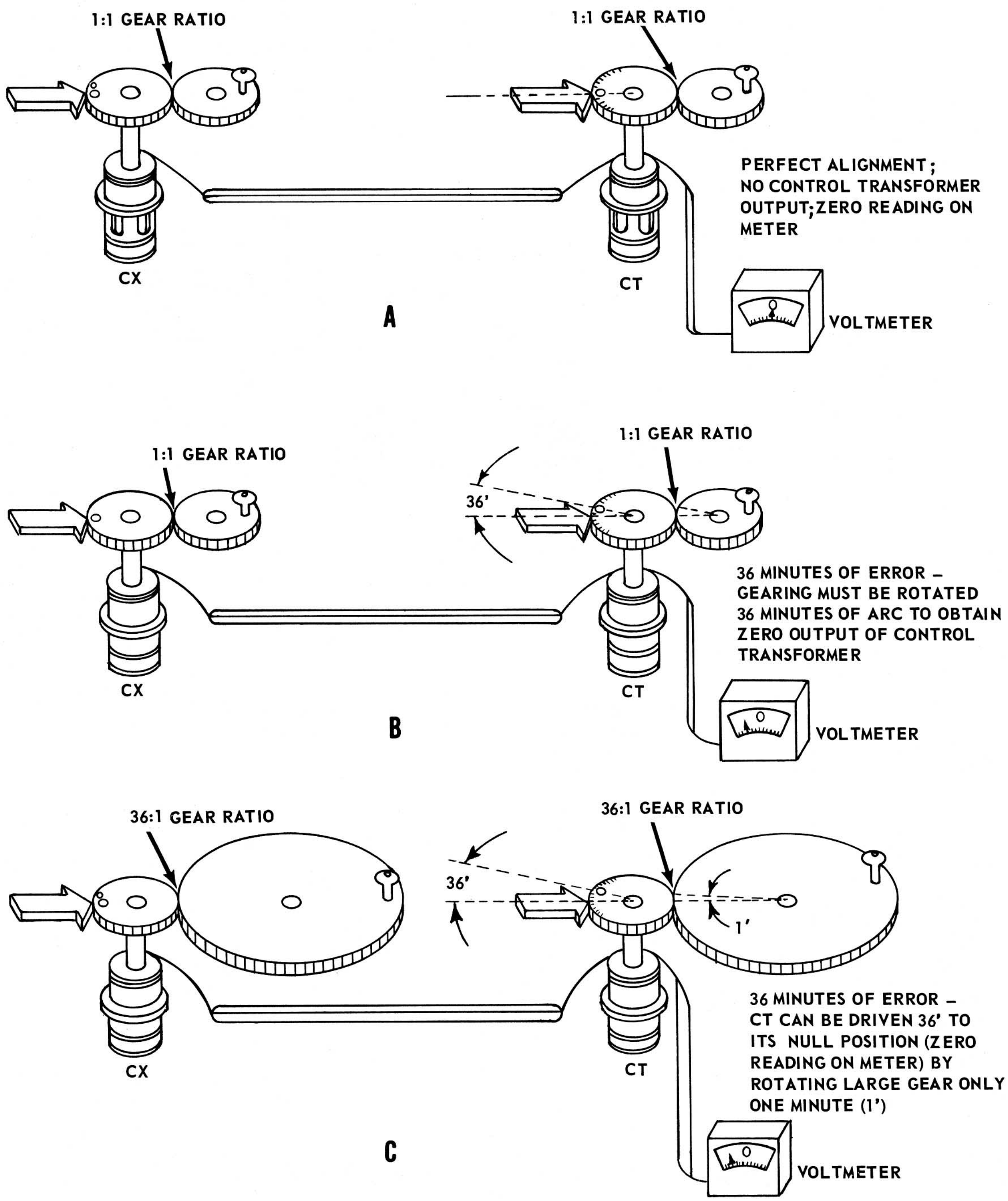

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Figure 7-5.—Electrical error in a synchro system: A. A perfect synchro transmitter connected to a perfect control transformer; B. Synchro transmitter and control transformer each with electrical error of 18 minutes; C. "Fine" synchro system using 36:1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

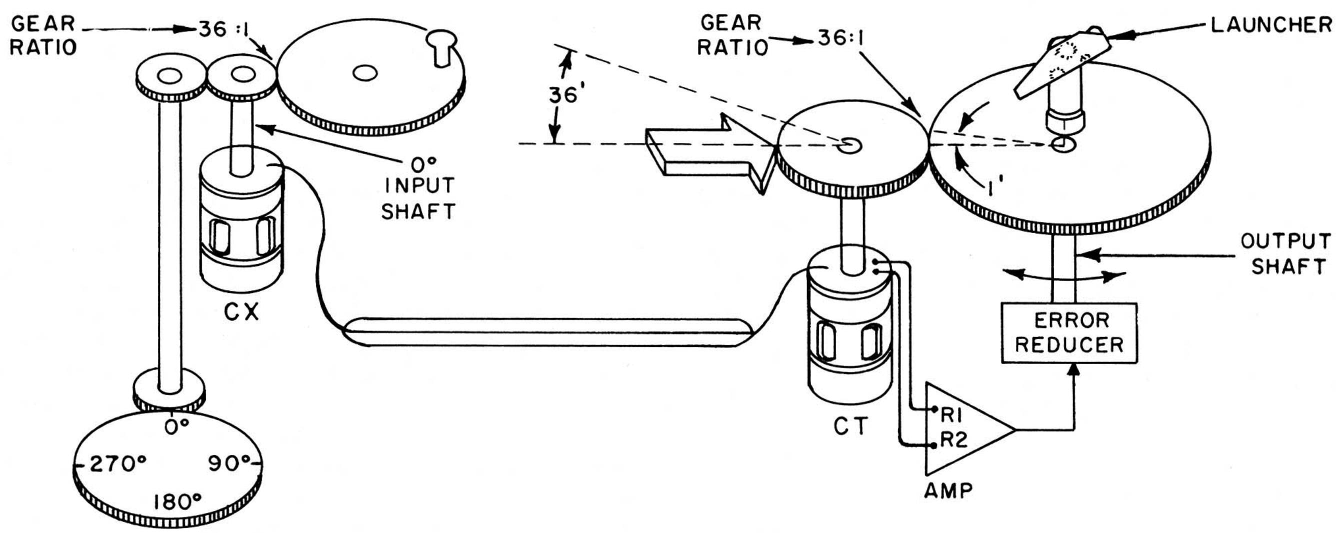

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Figure 7-6. — Launcher power drive using a fine synchro system.

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.

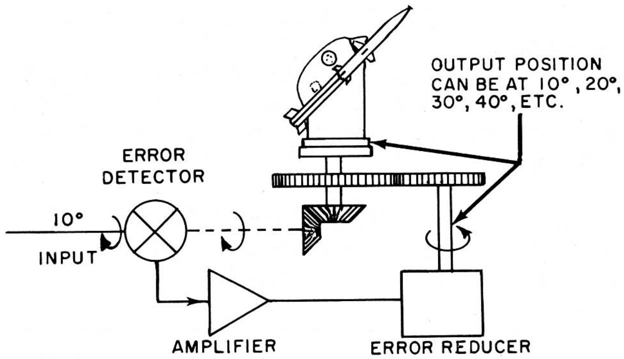

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Figure 7-7.—Fine synchro system (36:1 gear ratio) causes launcher to synchronize at any multiple of 10 degrees.

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.

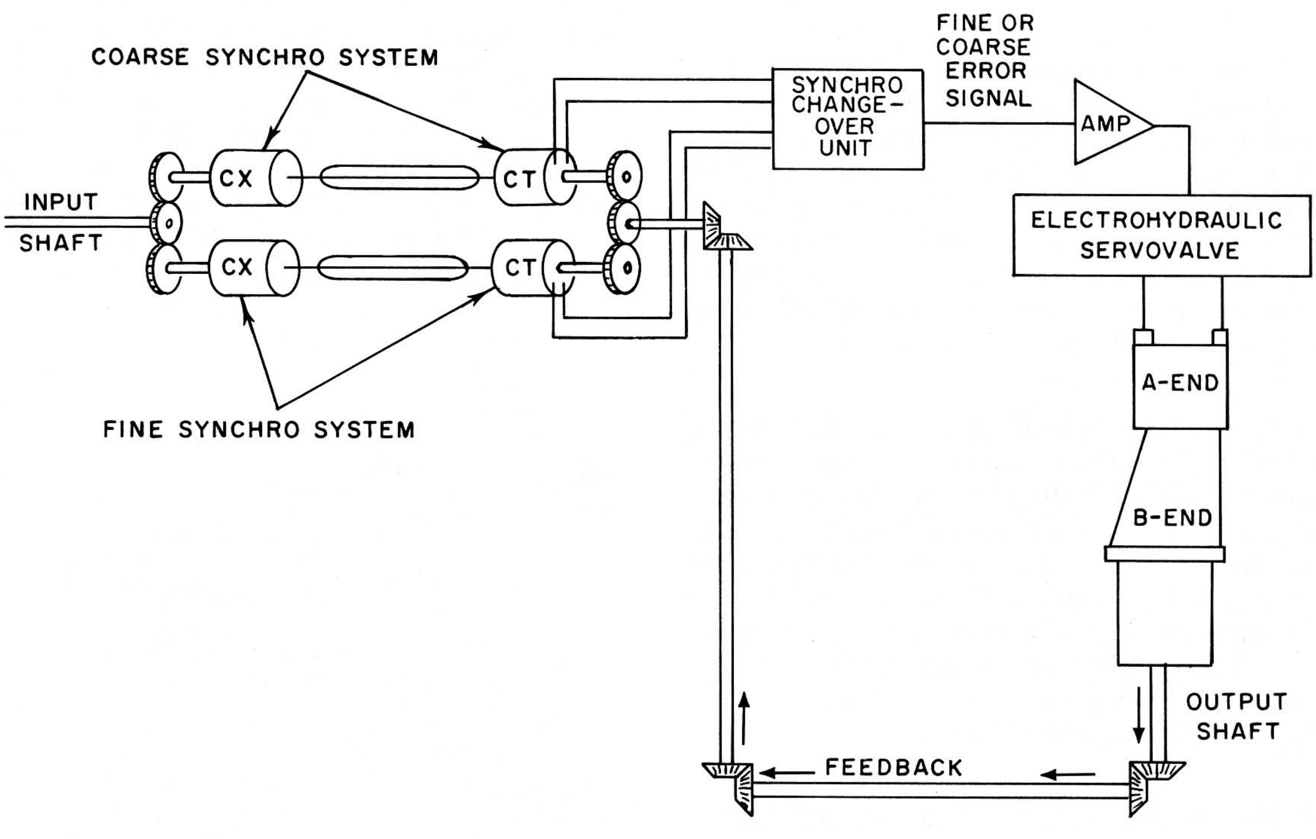

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Figure 7-8.—Location of synchro changeover network in a power drive servo.

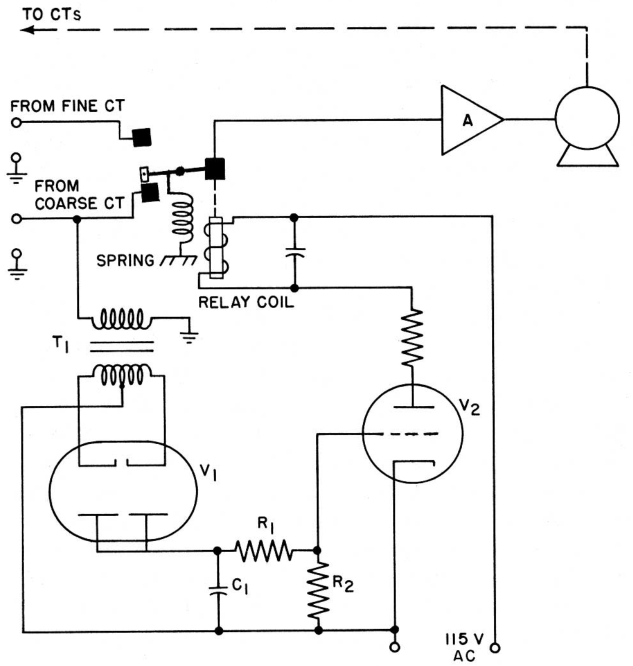

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Figure 7-9.—Relay synchro changeover circuit.

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.

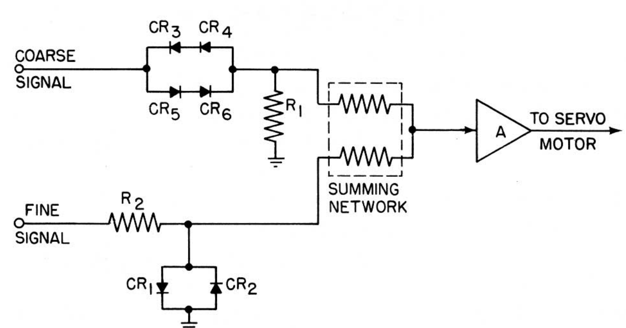

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Figure 7-10.—Semiconductor diode synchro changeover network.

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.

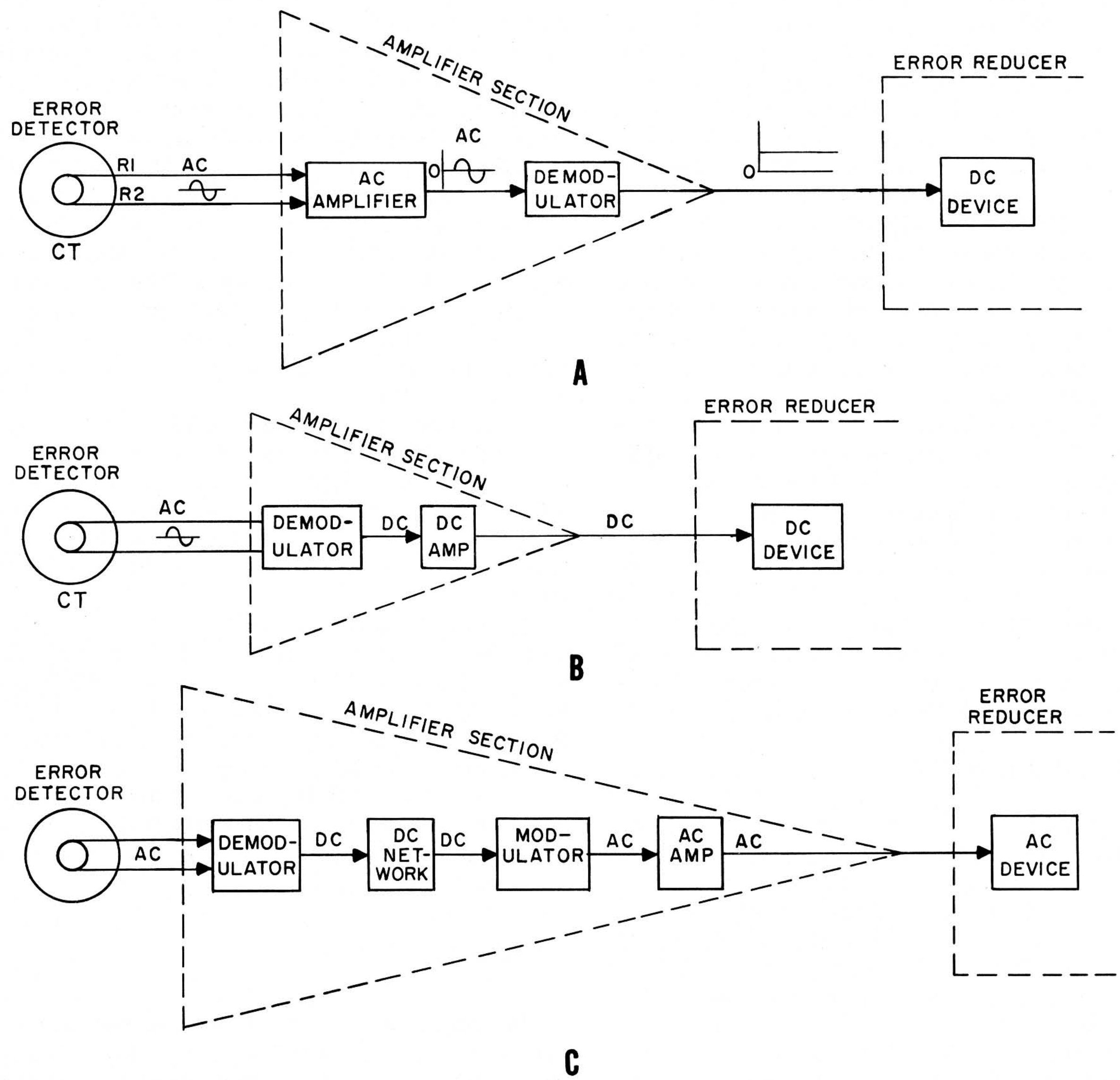

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Figure 7-11.—Changing the form of the error signal: A. A-c amplified signal converted to d-c; B. D-c signal amplified; and C. A-c error signal changed to d-c, then changed to a-c and amplified.

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.

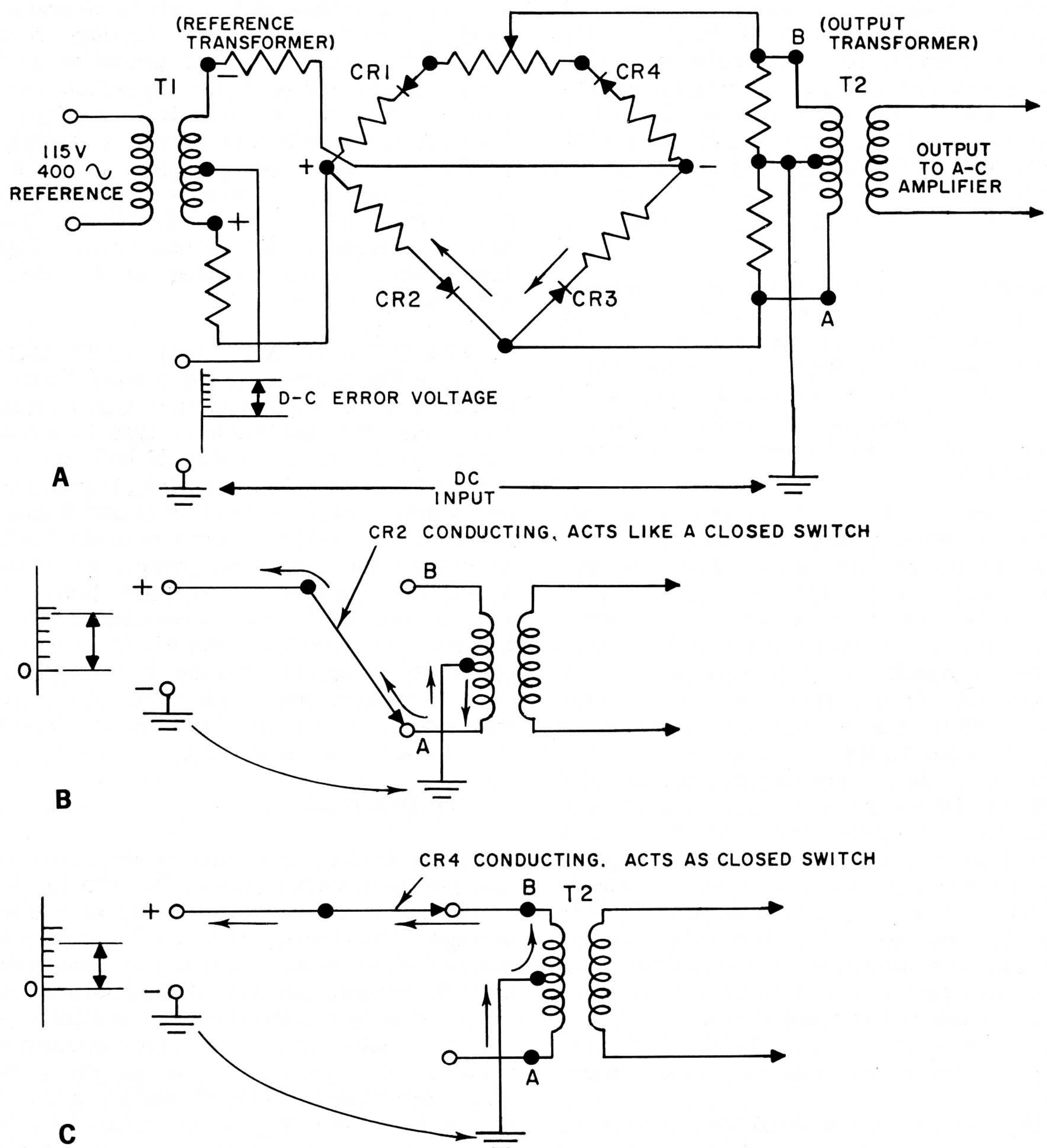
ELECTRONIC (VACUUM) TUBE MODULATORS. - You learned in your basic courses that electron tubes may be vacuum type or gas-filled type, and that the vacuum type is most commonly used. The operation of both types and of variations of each, such as diode, triode, pentodes, and others, is described in Basic 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

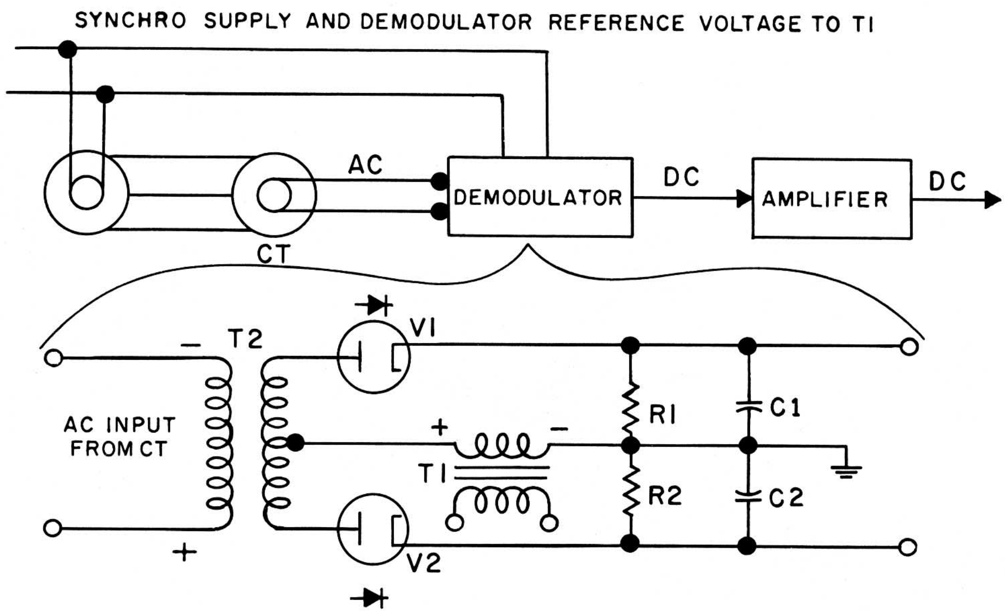
A typical diode demodulator (phase detector) is shown in figure 7-13. As illustrated, an a-c supply voltage serves as the reference voltage for the detector. This voltage must come from the same source that is supplying a-c excitation to the synchro system, or whatever type of a-c error detector is used,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



83.79

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



83.80
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.

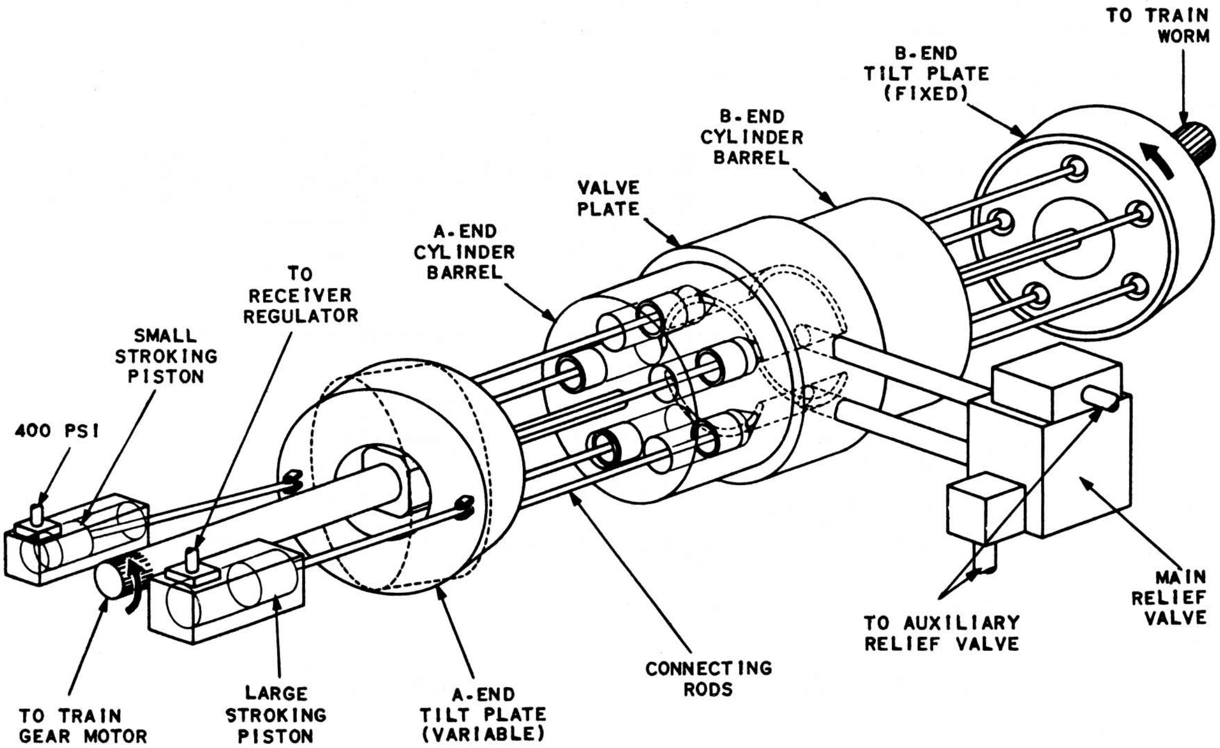
If the error signal applied to T2 is changed by 180 degrees, V2 would now increase its conduction while the conduction of V1 would be reduced. This would result in an output voltage of reversed polarity. Variations of the diode phase detector may be encountered. You will find that some demodulators use 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).

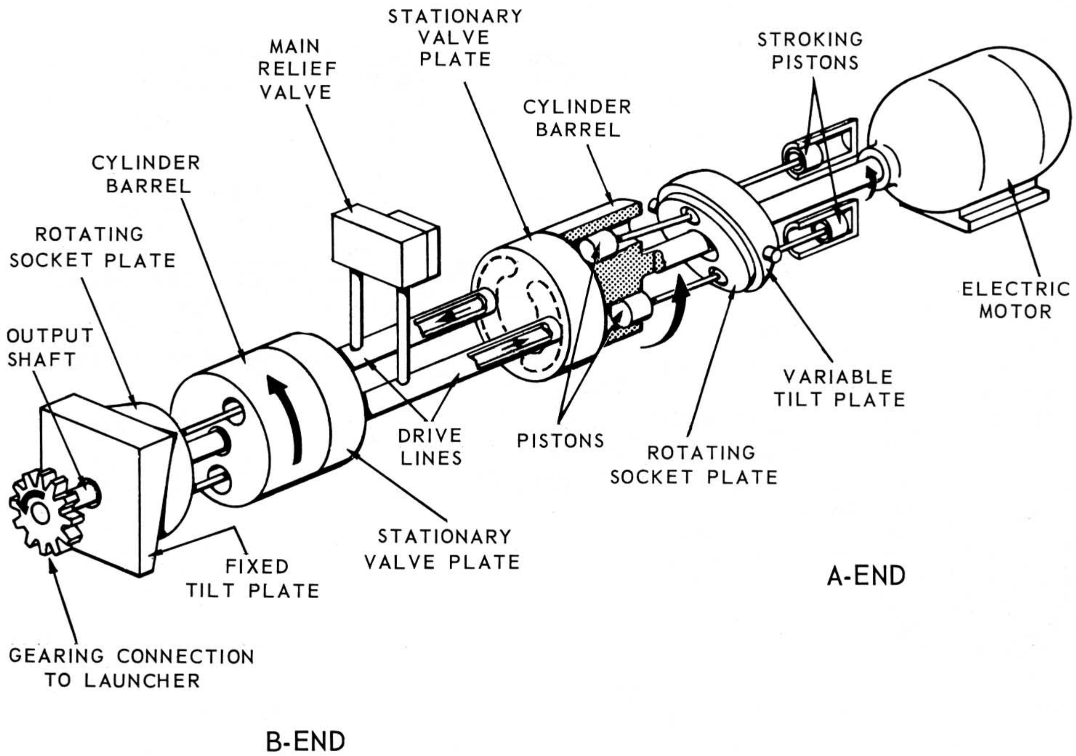
Type-C or CAB (combination A-end and B-end) installation which is most frequently used in launcher train and elevation systems. (See figs. 5-19A and 5-19B for location of train and elevation CAB units in Talos launching system, and fig. 5-26 for a block diagram of the train drive system.)

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.

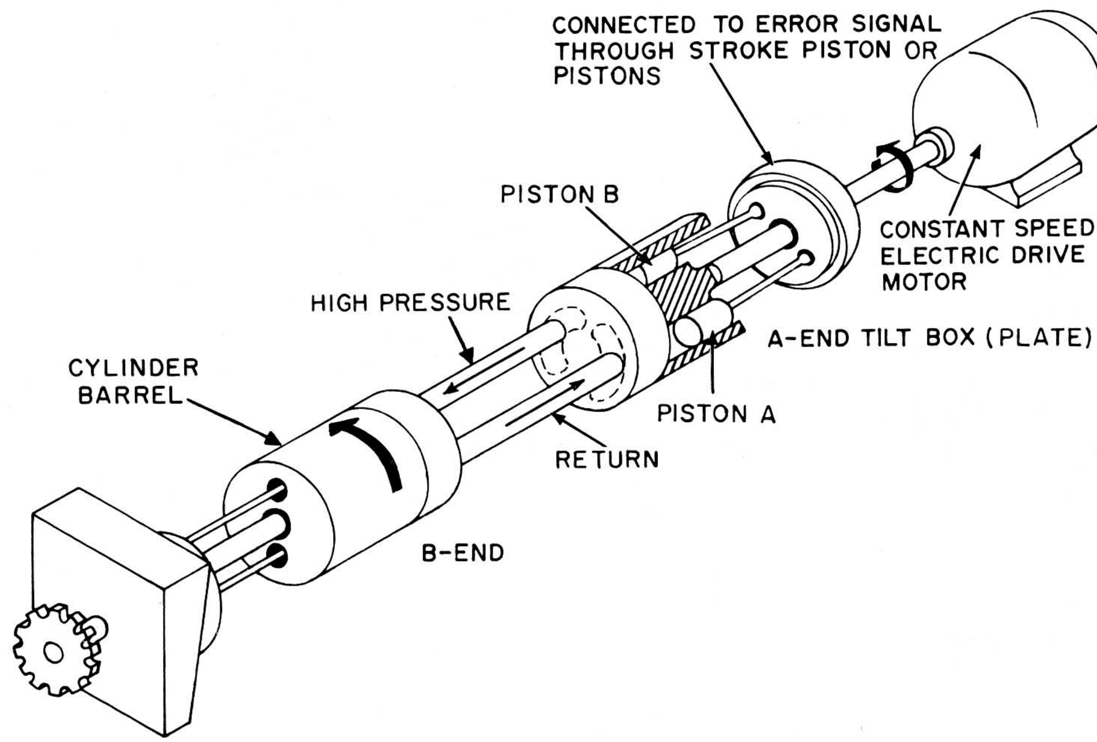
The A-end is constructed somewhat like the B-end, except that the tilt of the socket ring is variable, not fixed. In action it is just the reverse of the B-end. Its input is mechanical and the output is fluid pressure. Very simply, it operates like this:

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.

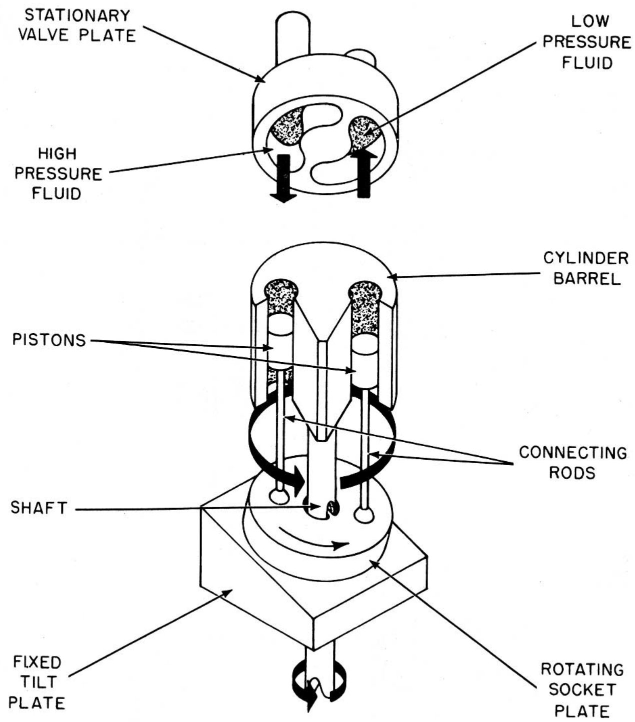
Electrohydraulic Servovalve

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

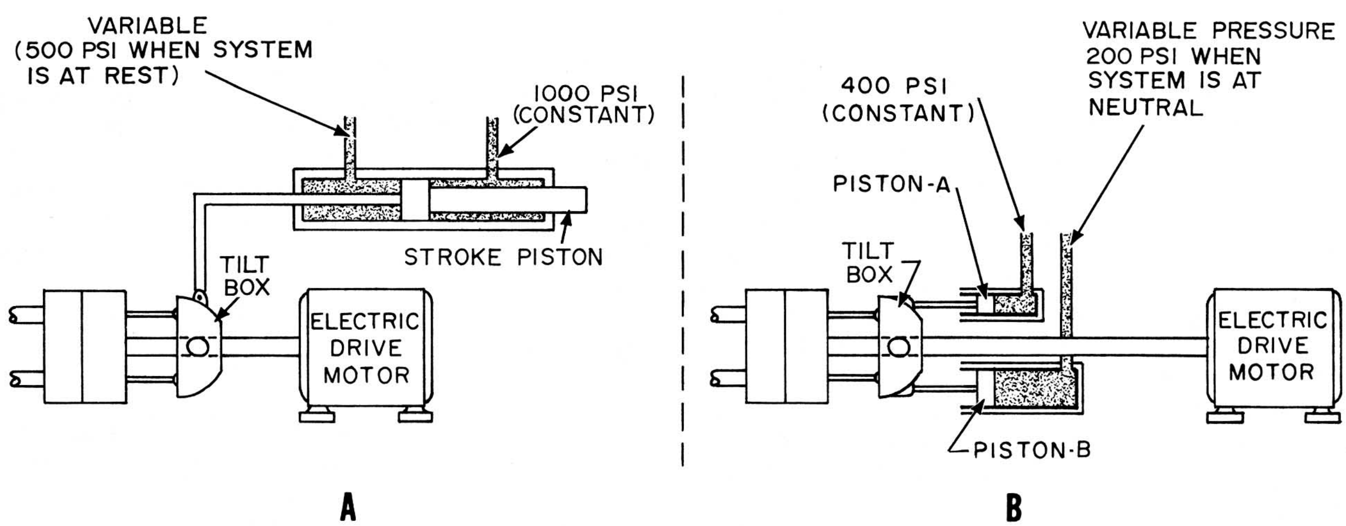
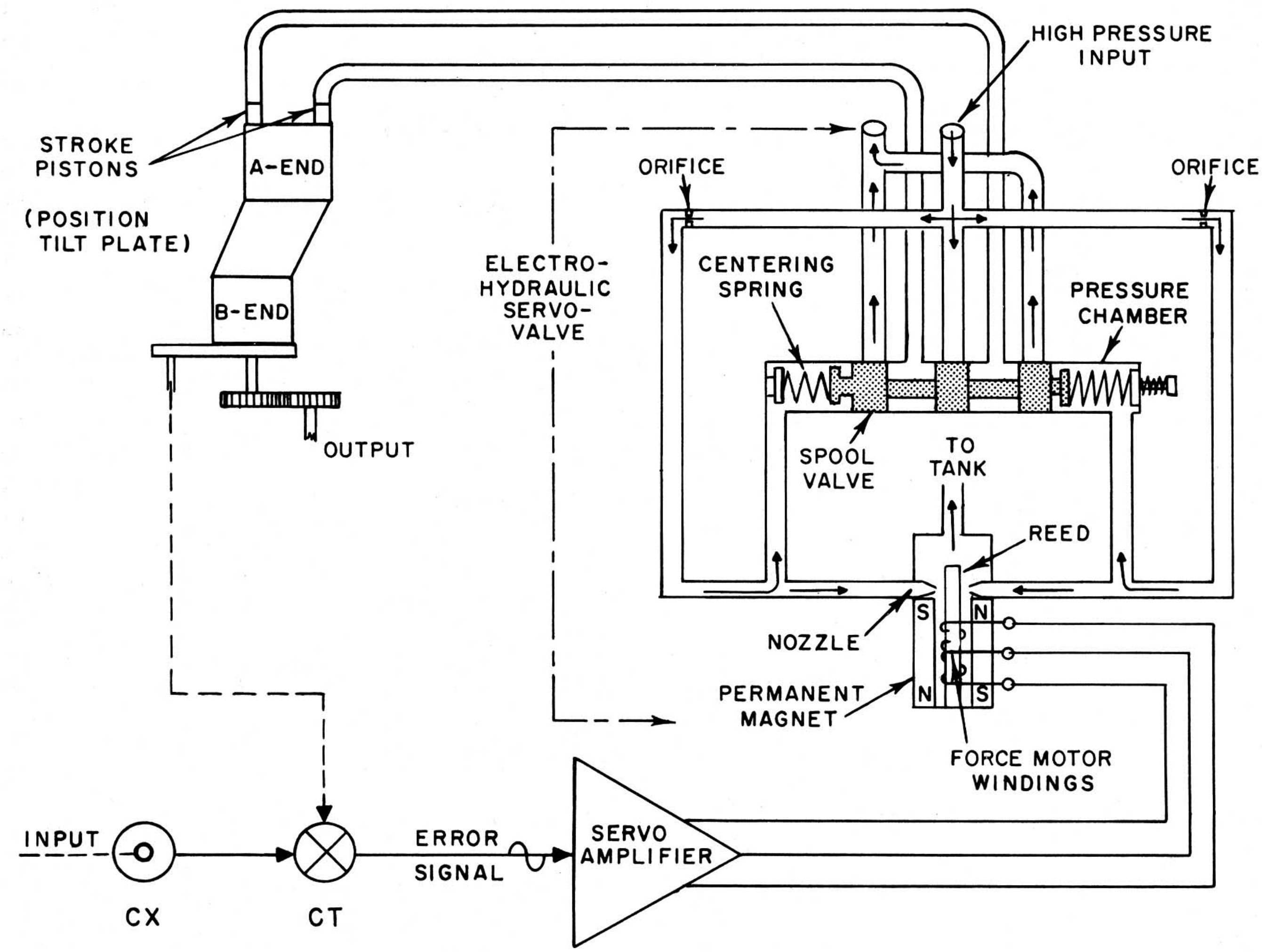


Figure 7-18.— Putting tilt on the A-end: A. Pressure on one piston; B. Pressure applied to two pistons. 83.83



83.84
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

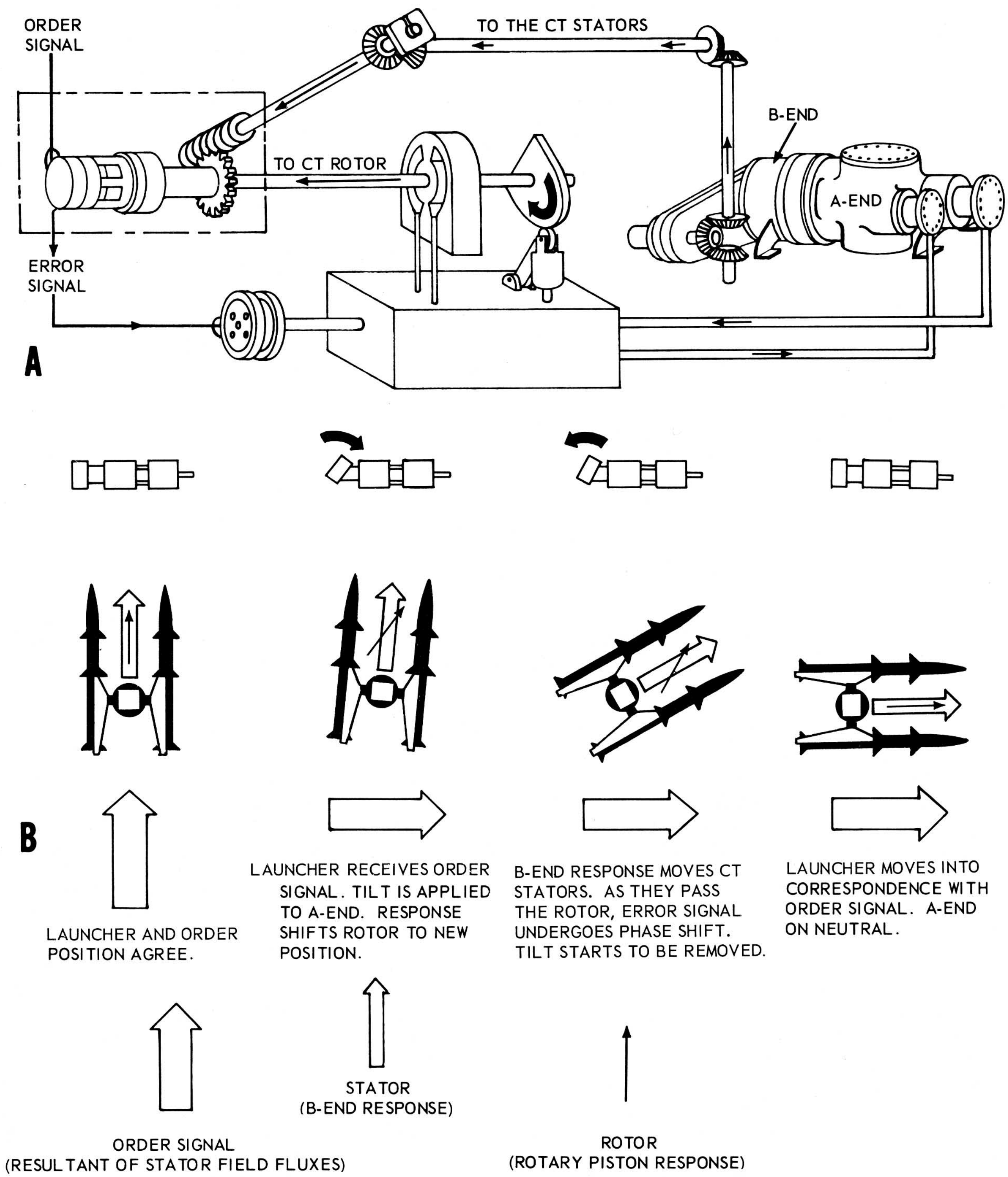


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Figure 7-20. — Reducing hunting and overshooting of power drive servos: A. By using control transformer with a movable stator; B. As launcher synchronizes, CT acts to remove tilt.

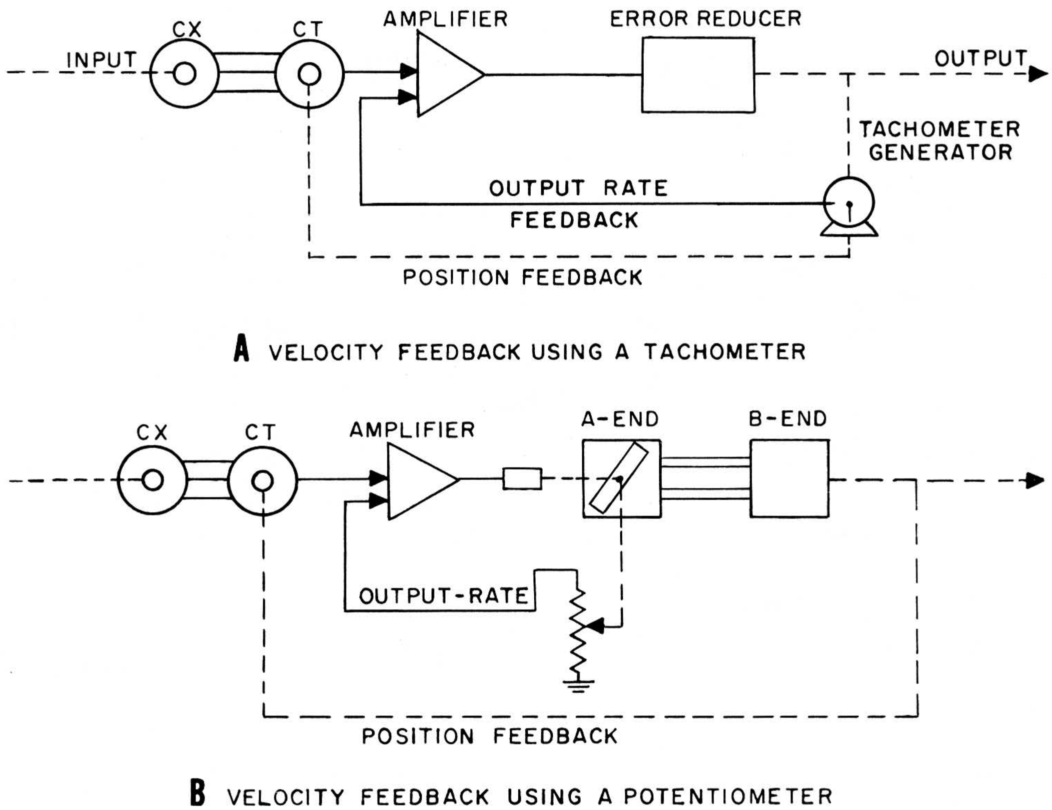


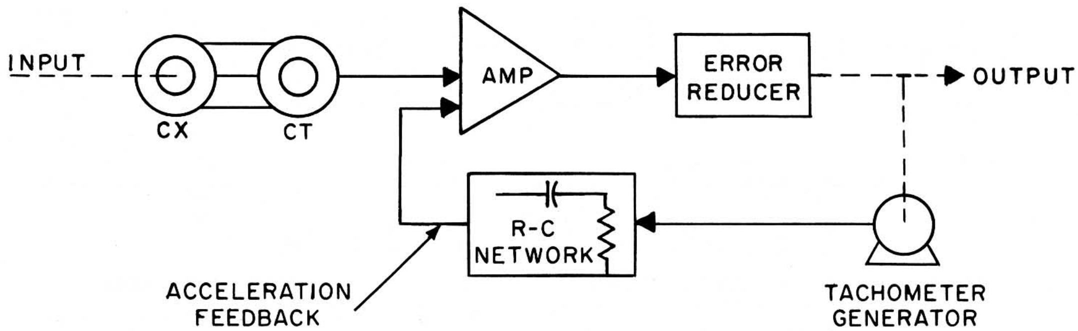
Figure 7-21.— Feedback method to reduce overshooting and hunting: A. Velocity feedback using a tachometer; B. Velocity feedback using a potentiometer. 83.86

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,

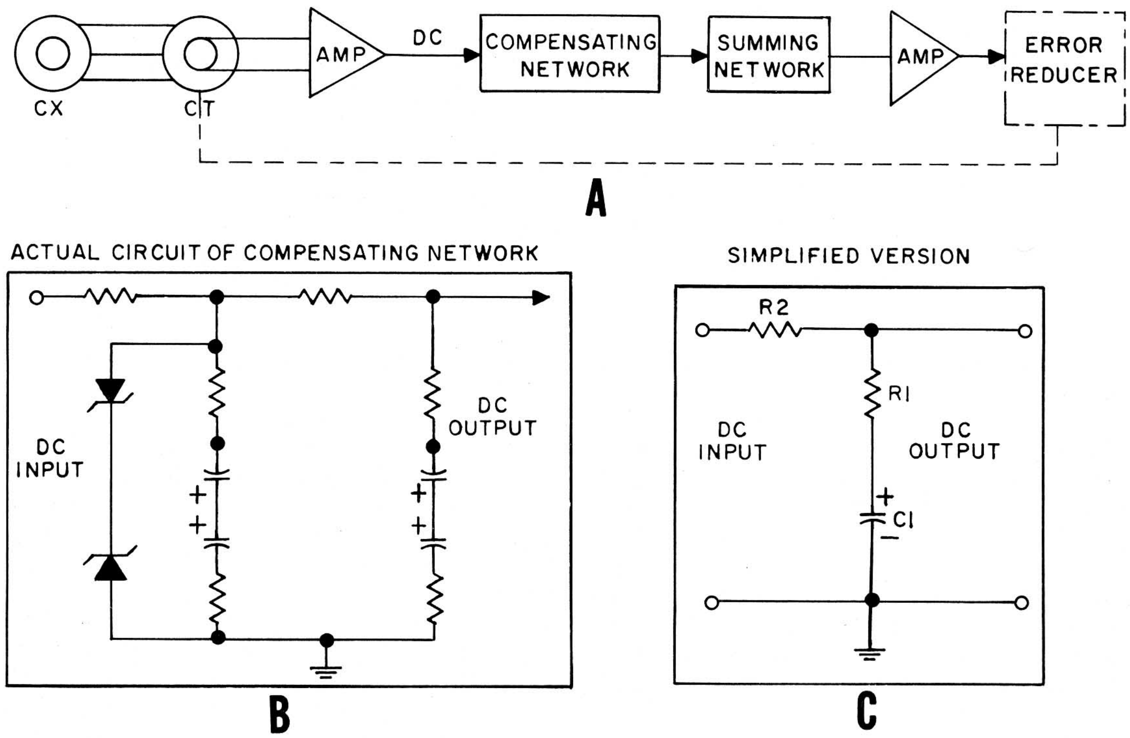


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Figure 7-23. — Integral control: A. Simplified block diagram of power drive servo; B. Integral control circuit of compensating network; C. Simplified circuit of compensating network.

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.