MIL-HDBK-218
1 June 1962

DEPARTMENT
OF THE ARMY
TM 700-5990-1

MILITARY STANDARDIZATION HANDBOOK

APPLICATIONS OF ELECTRICAL RESOLVERS

DEPARTMENT OF DEFENSE
UNITED STATES OF AMERICA

FSC 5990

HEADQUARTERS,
DEPARTMENT OF THE ARMY
WASHINGTON 25, D.C., *17 July 1962*

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MIL-HDBK
Applications of Electrical Resolvers

1. This handbook has been approved by the Department of Defense for use by the Departments of the Army, the Navy, and the Air Force.

2. In accordance with established procedure, the Standardization Division has designated Ordnance Corps, Bureau of Naval Weapons, and Air Research and Development Command, respectively, as Army-Navy-Air Force custodians of this handbook.

3. This handbook is intended as a guide to promote use of standards and standard practices in the application of electrical resolvers by the Departments of the Army, the Navy, and the Air Force.

4. Recommended corrections, additions, or deletions should be addressed to the Standardization Division, Defense Supply Agency, Washington 25, D.C.

FOREWORD

This handbook is intended to help implement the Department of Defense standardization program as it affects precision electrical resolvers. Resolvers, their designations and terminologies, are defined in accordance with military specifications. With eventual compliance by manufacturers to the proposed specifications, this handbook should serve as a guide to the standardization of resolver applications and practices; to this end, the fundamentals and theory of resolvers are briefly reviewed, providing engineers and designers with a convenient reference to the multiple capabilities of the resolver.

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SECTION 1

DESCRIPTION

1.1 Scope of Handbook. This handbook contains reference data concerning the application of precision electrical resolvers and is intended for use by engineers and designers. The physical and electrical characteristics of resolvers are briefly described, and resolver fundamentals are discussed. Performance specifications are defined, but not restricted to particular values. Preferred resolver configurations are discussed with reference to their application in various equipments or systems. A brief description of installation methods is included, based on standard hardware and synchro installation practices.

1.2 Definition of a Resolver. An electrical resolver is a variable transformer whose output is a trigonometric function of its input. It contains a pair of stationary (stator) windings electrically displaced 90 degrees, and a pair of rotating (rotor) windings, also displaced 90 degrees and free to rotate within the stationary windings. Either stator or rotor may be excited, to serve as the primary. While all four windings are not necessarily employed in a particular application, they give the resolver multiple capabilities, in handling various types of input voltage, frequency, and waveform. The secondary or output voltages are trigonometric functions of the primary voltages with a particular transformation ratio determined by the angular displacement of the rotor with respect to the stator.

1.3 Construction of a Resolver.

1.3.1 General. Physically, electrical resolvers are similar to synchros. They are classified according to size (diameter) in the same fashion, and they may be mounted with most standard synchro mounting hardware. Figure 1 shows an assembled electrical resolver, and Figure 2 shows its major components.

1.3.2 Housing. A cylindrical frame with a standardized mounting flange (Figure 1) houses the assembled resolver. External connections can be made to an insulated terminal board on the rear of the housing. Internal connections of the rotor and stator are terminated at the terminal board (Figure 2). Miniature resolvers often have unterminated lead wires brought out through the rear of the resolver, eliminating the need for a terminal block. A reference line is scribed on the face of the housing, for alignment with a similar line on the end of the rotor shaft, to determine coarse electrical zero.

1.3.3 Stator. The stator of the resolver, shown in Figure 2, is a cylindrical structure of slotted laminations on which two coils are wound.

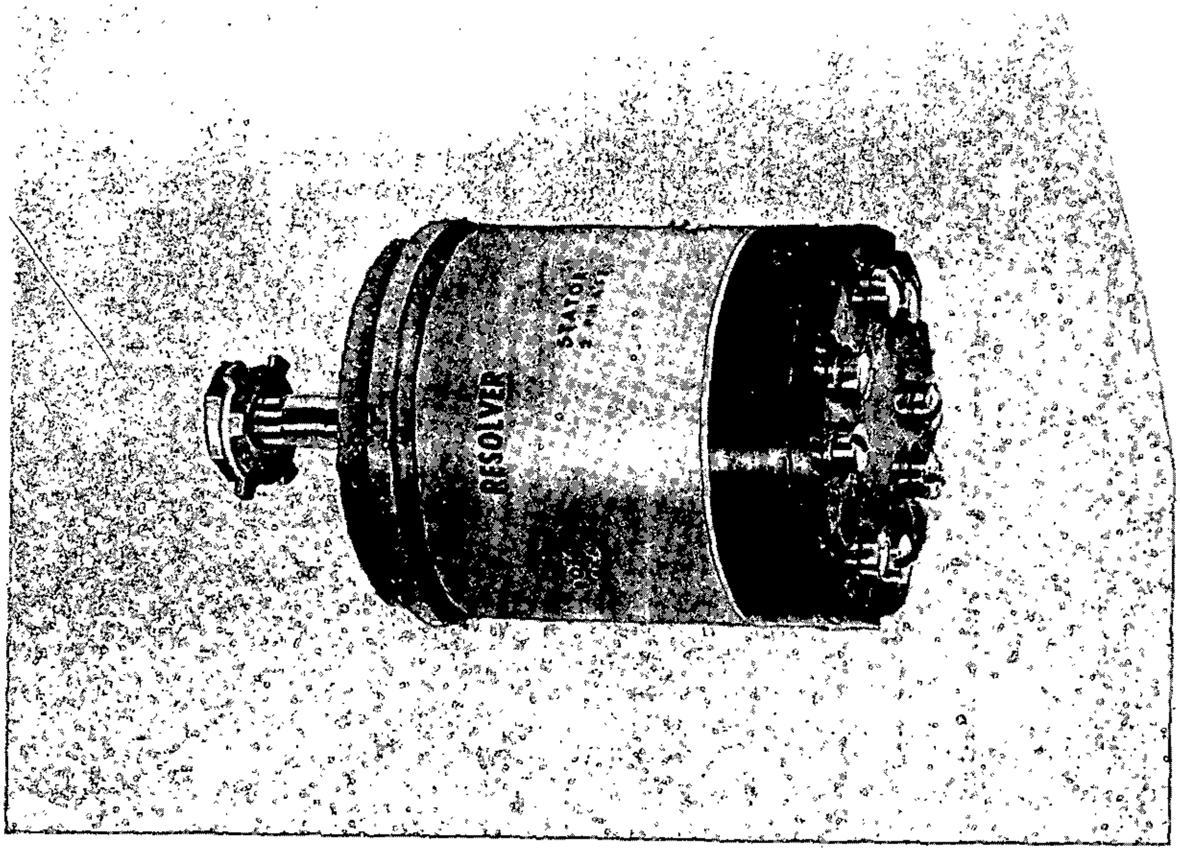


Figure 1. Electrical Resolver, Assembled

These laminations (Figure 3) are stacked so that the slots which are formed are either parallel to the rotor shaft or displaced in such a way that the front end of one slot may be in a straight line with the back end of the preceding slot. The displacement of the slots is called skew, and since the slot pitch is the angular distance between slot centers, the winding is said to be skewed one slot pitch.

1.3.4 Rotor. The rotor of the resolver, shown in Figure 2, is composed of a shaft, laminations, two windings, and slip rings. The laminations of the rotor core (Figure 3) are stacked so that the slot formation differs from that of the stator. If the slots of the stator laminations are skewed one slot pitch, the slots of the rotor laminations are usually parallel to the rotor shaft; conversely, if the stator slots are parallel to the rotor shaft, the rotor slots are usually skewed. The stacked laminations are heated and cemented under pressure and are rigidly mounted on the shaft.

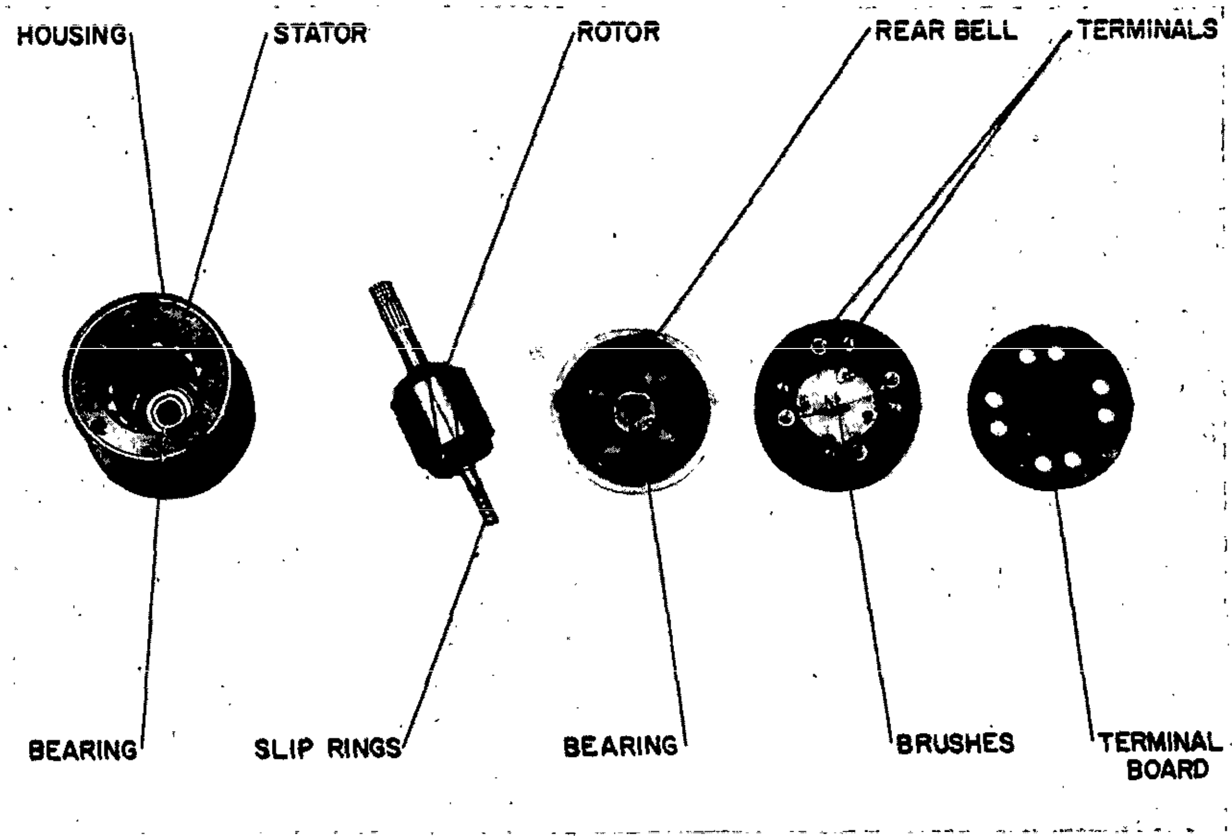


Figure 2. Major Components of an Electrical Resolver

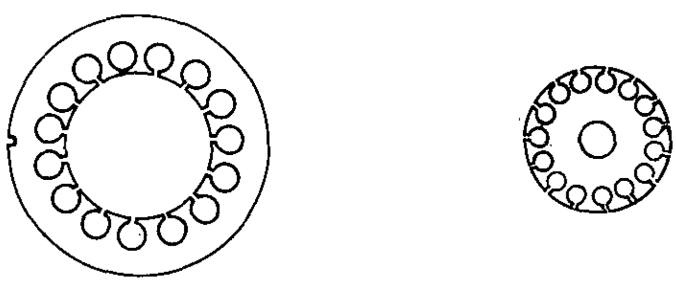


Figure 3. Stator and Rotor Laminations

Slip rings are mounted on the rear of the shaft opposite the mounting flange; insulated from the shaft, they are used to terminate the ends of the coils. Brushes riding on the slip rings (Figure 2) provide electrical continuity during rotation. The other end of the shaft is splined and threaded for connection to dials or gears. An index line is scribed on the exposed end of the shaft for alignment with a similar line on the housing, to determine coarse electrical zero.

1.3.4.1 Ball Bearings. In an assembled resolver, the rotor shaft is mounted on ball bearings located on both ends of the rotor core. Low-friction ball bearings of the radial type are preferred. The balls, retainers, races, and shields preferably are made of corrosion-resistant steel. The ball bearing at the rear of the core is mounted in a bell housing (Figure 2), and the ball bearing at the front of the core is mounted in the main housing which encloses the resolver. C-rings are generally used to secure the ball bearings in the housings.

1.3.4.2 Lubricants. Grease lubricants must conform to Specification MIL-G-3278; oil lubricants must conform to Specification MIL-L-6085.

1.3.5 Distribution of Windings. Stator and rotor laminations are stacked so that the slots formed are either parallel to the rotor shaft or skewed one slot pitch. If the slots of both rotor and stator are skewed or both parallel to the rotor shaft, the resultant flux concentrations of the rotor and stator coils tend to make the rotor slot-lock in certain positions, causing angular errors. Efficiency increases as the number of slots increases.

1.3.6 Compensator Components. Compensator components, which improve the angular accuracy of resolvers, may consist of resistors or additional windings in the stator and rotor winding circuits. Compensator windings are located inside the stator. Compensating resistors may be mounted either inside or outside the resolver housing.

SECTION 2

FUNDAMENTALS

2.1 General. An electrical resolver is similar to a synchro in that it has rotor and stator windings and behaves like a variable transformer. Unlike a synchro, a resolver may employ one stator winding and one rotor winding, one stator winding and two rotor windings, or two stator windings and two rotor windings. Figure 4 shows the schematic diagram for a standardized four-winding resolver. The relationship between the input and output voltages

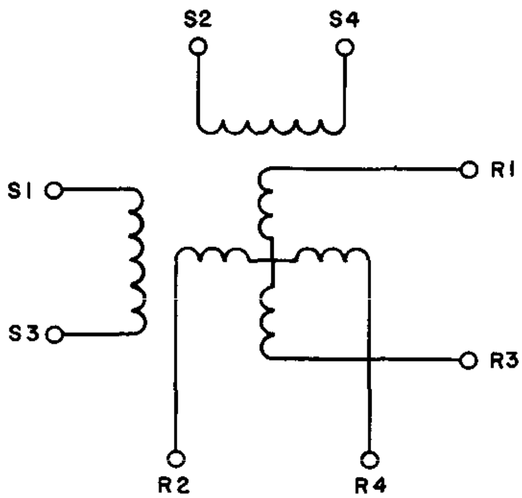
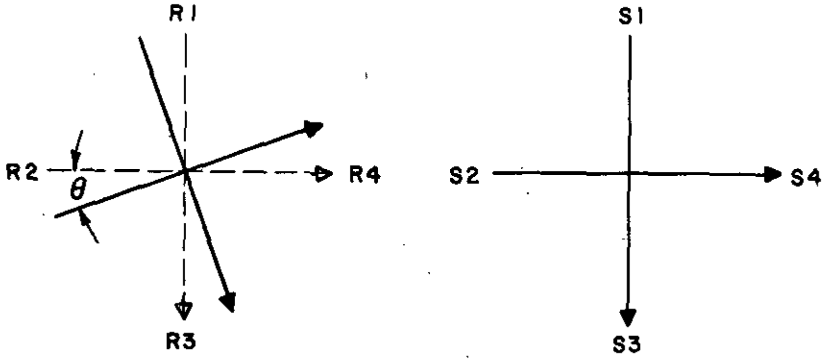


Figure 4. Standardized Four-Winding Resolver, Schematic Diagram

is best described by vector diagrams, as shown in Figure 5. These show the stator and rotor in the resolver zero position (see paragraph 2.3). Angle represents the displacement of the rotor when rotated in the positive or counterclockwise direction (when facing the shaft extension end). Note in the operating equations in Figure 5 that the term for voltage across a winding indicates the two terminals and the polarity or direction. Thus, E(S1-3) is the term for voltage across the stator winding between terminals S1 and S3; the direction of the voltage vector is always written low (S1) to high (S3); if the vector direction is reversed because of rotor displacement, the sign of the term is negative in the equation.

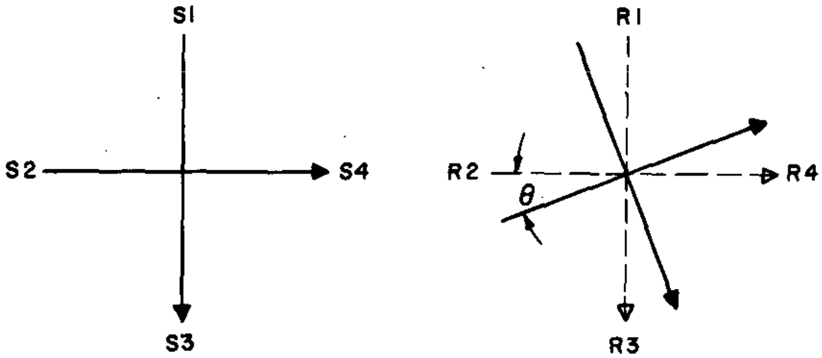
2.2 Resolver Employment. Electrical resolvers operate with one or two electrical inputs and one or two electrical outputs, depending upon whether all windings are used, and whether the stator or rotor windings are connected



$$E_{S1-3} = K(E_{R1-3}\cos\theta - E_{R2-4}\sin\theta)$$

$$E_{S2-4} = K(E_{R2-4}\cos\theta + E_{R1-3}\sin\theta)$$

(A) ROTOR-EXCITED



$$E_{R1-3} = K(E_{S1-3}\cos\theta + E_{S2-4}\sin\theta)$$

$$E_{R2-4} = K(E_{S2-4}\cos\theta - E_{S1-3}\sin\theta)$$

(B) STATOR-EXCITED

Figure 5. Vector Diagrams for Standardized Resolvers

together in series. There is also a mechanical input (or feedback adjustment), through which the rotor is positioned relative to the stator, varying the electromagnetic coupling and the resultant vector magnitudes. By rotating the resolver rotor, a variety of trigonometric functions may be obtained for different vector sums and differences on the output windings. Such an electrical arrangement is ideal for solution of right-triangle relationships, such as sine, cosine, and tangent functions. With perpendicular inputs and outputs, the analogy to Cartesian coordinates is obvious. By applying proportional Cartesian coordinate voltages to the stator windings, the output voltage from one rotor winding in conjunction with the angular displacement of the rotor provides polar coordinate information. Conversely, by applying proportional polar coordinate voltages to the rotor windings and rotating the shaft of the rotor to the proper angular displacement, the output voltages from the stator windings provide Cartesian coordinate information.

2.3 Resolver Zero. The magnitude of the output of a resolver depends upon the orientation of the rotor windings with respect to the stator windings. To express this function as an angular displacement in the positive direction of rotation, resolver zero is required as a reference point. Resolver zero is the condition in which the coupling between one stator winding (S1-3) and one rotor winding (R1-3) maximum, and the coupling between that stator winding (S1-3) and the other rotor winding (R2-4) is minimum.

2.3.1 Rotor-Excited Resolvers. The basic equations for voltage vectors in a rotor-excited resolver are as follows:

$$E_{S1-3} = K\,(E_{R1-3}\cos\theta - E_{R2-4}\sin\theta)$$

$$E_{S2-4} = K\,(E_{R2-4}\cos\theta + E_{R1-3}\sin\theta)$$

where

K = transformation ratio (defined in paragraph 6.9), and

θ = angle of counterclockwise displacement from resolver zero.

Electrical zero for the resolver is so established that, when θ is zero, with rotor winding R1-3 excited and rotor winding R2-4 open, E_{S1-3} will be at a maximum and E_{S2-4} will be zero. If winding R2-4 is excited and R1-3 is open, the outputs will be reversed.

2.3.2 Stator-Excited Resolvers. The basic equations for voltage vectors in a stator-excited resolver are as follows:

$$E_{R1-3} = K\,(E_{S1-3}\cos\theta + E_{S2-4}\sin\theta)$$

$$E_{R2-4} = K\,(E_{S2-4}\cos\theta - E_{S1-3}\sin\theta)$$

with K and θ as defined in 2.3.1. When θ is zero, with stator winding S1-3 excited and stator winding S2-4 open, E_{R1-3} will be at a maximum and E_{R2-4} will be zero. If winding S2-4 is excited and S1-3 is open, the outputs will be reversed.

2.4 Basic Operation.

2.4.1 Two-Winding Resolver. An electrical resolver employing one stator winding and one rotor winding is shown in Figure 6. The windings of the resolver are arranged in the stator and rotor slots in such a manner that the voltage induced in rotor winding R1-R3 is proportional to the cosine of the angle of rotation and the voltage applied to stator winding S1-S3. The relationship between input voltage (E_{S1-3}), output voltage (E_{R1-3}), and shaft angle (θ) is:

$$E_{R1-3} = E_{S1-3} \cos \theta$$

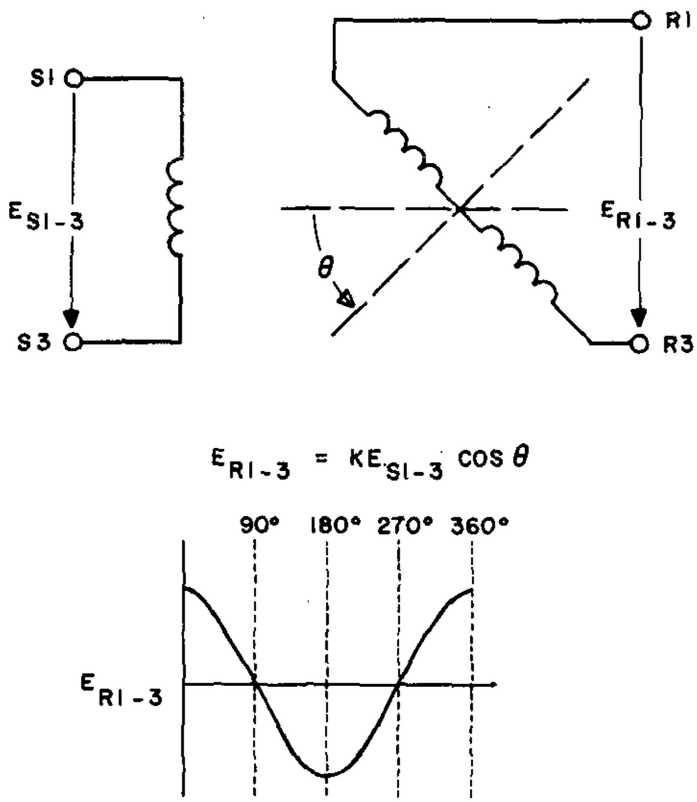


Figure 6. Two-Winding Resolver, Schematic Diagram

2.4.2 Three-Winding Resolver. A slightly more complex resolver is that shown in Figure 7, employing two rotor windings in space quadrature. The voltage induced in rotor winding R1-R3 is proportional to the cosine of the angle of rotation and the voltage applied to stator winding S1-S3. The voltage induced in rotor winding R2-R4 is proportional to the sine of the angle of rotation and the voltage applied to stator winding S1-S3. The relationship between input voltage (E_{S1-3}), output voltages (E_{R1-3} and E_{R2-4}), and shaft angle (θ) is:

$$E_{R1-3} = E_{S1-3} \cos \theta$$

$$E_{R2-4} = E_{S1-3} \sin \theta$$

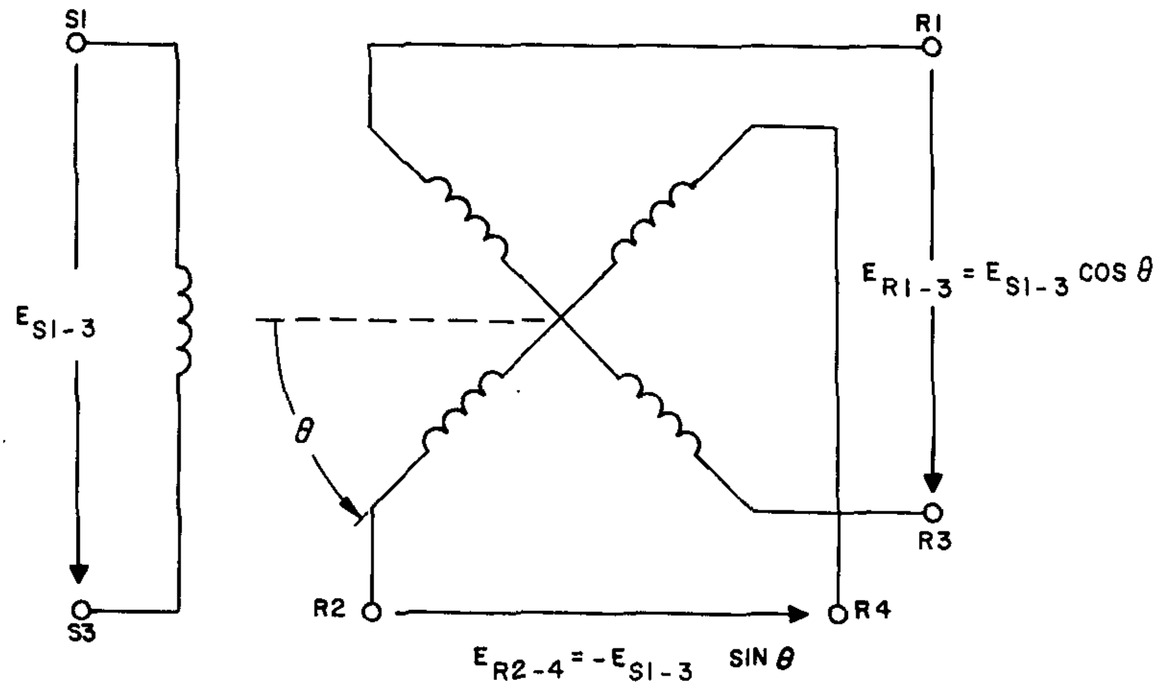


Figure 7. Three-Winding Resolver, Schematic Diagram

2.4.3 Four-Winding Resolver. The most commonly used resolver is that shown in Figure 8; it employs two rotor windings in space quadrature and two stator windings at right angles to each other. This permits complex computations of both sine and cosine functions, provided that two inputs are used. For a stator-excited operation, the following relationship exists between the input voltages (E_{S1-3} and E_{S2-4}), output voltages (E_{R1-3} and E_{R2-4}), and angle of rotation (θ):

$$E_{R1-3} = K\,(E_{S1-3}\cos\theta + E_{S2-4}\sin\theta)$$

$$E_{R2-4} = K\,(E_{S2-4}\cos\theta - E_{S1-3}\sin\theta)$$

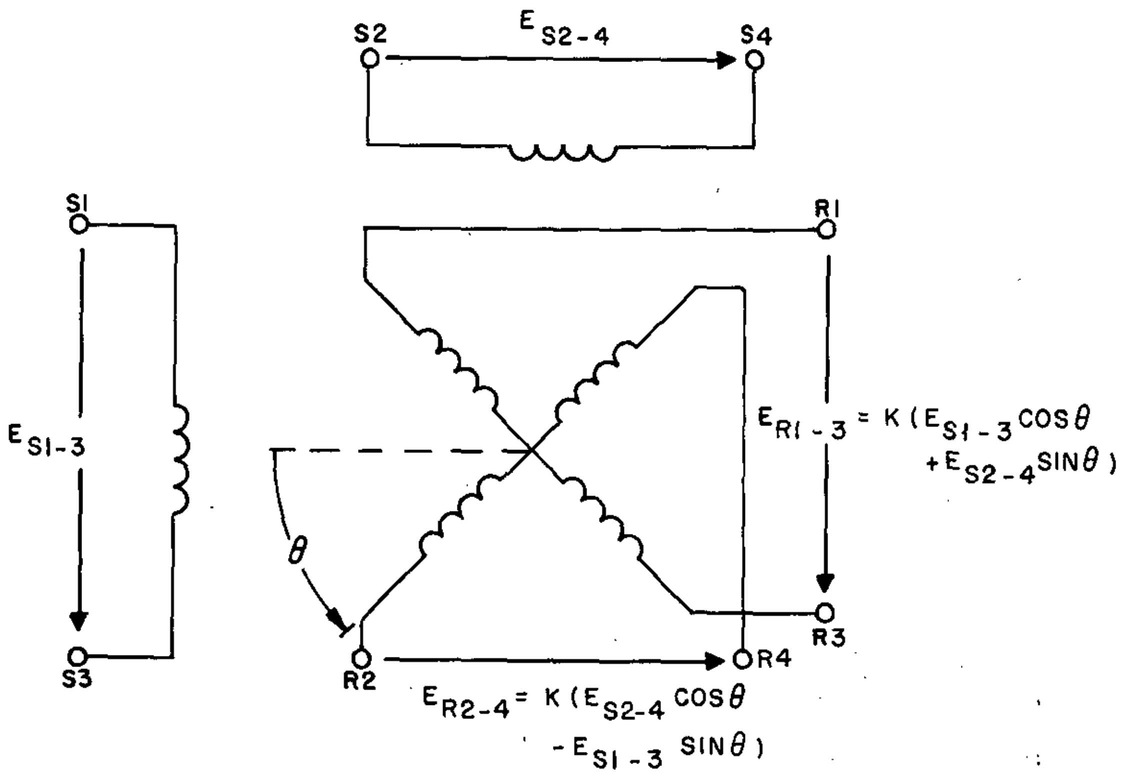


Figure 8. Four-Winding Resolver, Schematic Diagram

SECTION 3

THEORY OF OPERATION

3.1 General. The output of a resolver is determined by the input voltages applied to the primary windings and the position of the rotor with respect to the stator. Currents flowing in the primary windings set up magnetic fields that are perpendicular to each other. The resultant magnetic field produced by the combined primary currents is the vector sum of the separate magnetic fields. This resultant field may be designated by a vector having a magnitude proportional to the instantaneous magnitudes of the primary currents and a direction determined from the arc tangent of the ratio of the two primary currents. The voltage induced in each secondary winding is proportional to the component of the resultant vector that lies in a plane perpendicular to the plane of the secondary winding.

3.2 Resolver Equivalent Circuit. Figure 9 shows the equivalent circuit for a resolver using only one stator winding (S1-S3) and one rotor winding (R1-R3). It is similar to a transformer in that it has low core losses and high leakage inductance. Resistors R1 and R2 represent the d-c resistance of the stator and rotor windings respectively. When an alternating voltage is applied to the input (stator) winding, a magnetic flux is generated in the core. The greater part of this flux is present in the stator and is represented by L1. L2 represents the leakage inductance of the rotor. L3 represents the inductance caused by the magnetic flux that links the stator with the rotor. Eddy currents and magnetic hysteresis account for the energy lost in maintaining flux in the core. This loss is represented by an equivalent shunt resistance, R3. C1 represents an approximation of the distributed capacitance in the stator.

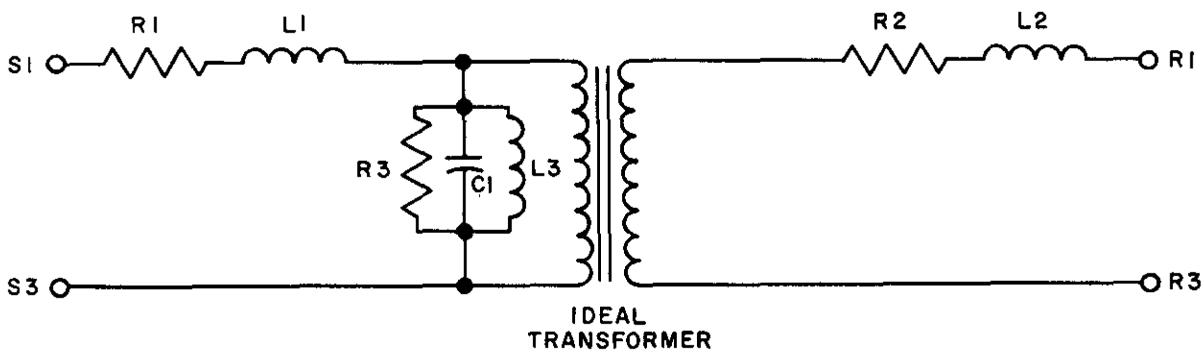


Figure 9. Standard Resolver Equivalent Circuit

3.3 Principal Types of Inputs.

3.3.1 Resolver Used for Data Transmission. The principal type of input applied to the primary winding (stator or rotor) of a data transmission resolver is a sinusoidal input at either 60 cps or 400 cps. The use of a single operating frequency makes the frequency response relatively unimportant and permits fairly accurate temperature and load compensation.

3.3.2 Resolver Used as a Computing Device. The principal types of inputs applied to the primary windings (stator or rotor) of a computing resolver are as follows: sine-wave voltages in phase, sine-wave voltages shifted 90 degrees apart, sawtooth voltages, and square-wave voltages. Although other types of inputs can be used, the above inputs are the most common.

3.3.2.1 Sine-Wave Voltages in Phase. When two sine-wave voltages of the same electrical phase are applied to the input windings of a resolver, the output voltages remain fixed in electrical phase shift and their magnitudes vary in accordance with the equations given in 2.3.1 and 2.3.2.

3.3.2.2 Sine-Wave Voltages Shifted 90 Degrees. When two sine-wave voltages, shifted 90 degrees apart, are applied to the input windings of a resolver, the amplitude of the output voltages remains constant, but the phase of the voltages varies continuously with changes in the angular position of the rotor. The phase shift between the two output voltages remains fixed at 90 degrees.

3.3.2.3 Square-Wave Voltages. When two square-wave voltages that are either in phase or shifted 90 degrees apart are applied to the input windings of a resolver, the output voltages can be determined in the same manner as the sine-wave voltages discussed in 3.3.2.1 and 3.3.2.2.

3.3.2.4 Sawtooth Voltages. When two sawtooth voltages are applied to the input windings of a resolver, the output voltages vary in magnitude as sine and cosine functions of the rotor angle position and the input voltage magnitudes. These outputs are especially suitable in radar sweep applications.

3.4 Stator and Rotor Resistance. The d-c resistances of the stator and rotor differ from the a-c values depending upon the amplitude and frequency of the currents. These resistances vary appreciably with temperature. For example, if the d-c resistance of one of the windings, either stator or rotor, is 125 ohms at room temperature (25° C), the resistance at 100° C is 170 ohms. This change is due to the change in the resistance of the copper wire with temperature and is approximately 0.4 percent per degree centigrade.

3.5 Resolver Error.

3.5.1 Function Error. When the resolver stator winding is excited, the rotor output voltage varies sinusoidally with the angular position of the rotor. Any deviation from this sinusoidal relationship constitutes the function error of the resoler. The major internal source of this error are the imperfections inherent in the resolver mechanical parts which case small distortions of the magnetic fields. This error is expressed as a percentage of the maximum output amplitude, and may be stated mathematically as follows:

$$\text{Error} = \frac{E\,\theta}{E(\theta = 90°)} - \sin\theta$$

where $E\,\theta$ = RMS value of the fundamental component of output voltage at rotor angle θ, and

$E(\theta = 90°)$ = RMS value of the fundamental component of output at $\theta = 90°$.

The difference, when multiplied by 100, expresses function error in percentage of the output at $\theta = 90°$. For example, a resolver having a functional error of ±0.03 percent and a maximum output voltage of 20 volts develops an output voltage that deviates no more than ±0.006 volt from any point on an ideal sine or cosine curve. A typical function error curve is shown in Figure 10.

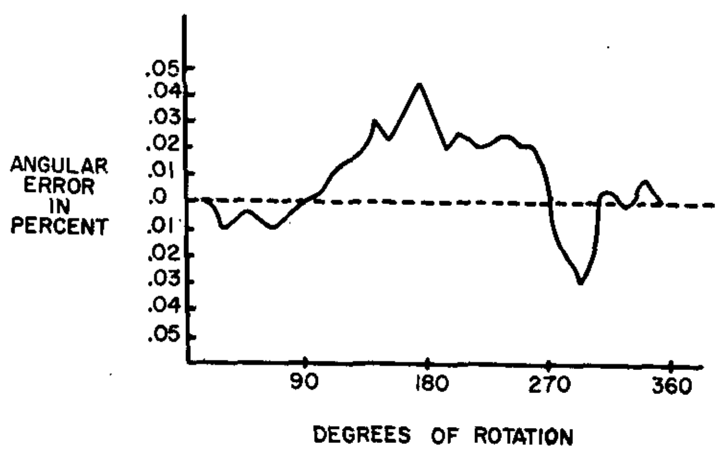


Figure 10. Typical Angular Error in Resolver Shaft Rotation

3.5.2 Interaxis Error. Theoretically, in a four-winding resolver one rotor winding develops a null at exactly 90 mechanical degrees of shaft rotation from the position where the other winding develops a null. In actual practice this is not the case because the perpendicularity of the windings is not perfect and a small error exists. The interaxis error is inserted in the ideal operating equations to indicate the effect of this error as follows:

$$E_{R2-4} = K\,(E_{S2-4} \sin(\theta + \Delta\theta)$$
$$- E_{S1-3} \cos(\theta + \Delta\theta))$$

Therefore, the interaxis error shifts the output of E_{R2-4} 90 degrees plus $\Delta\theta$ E_{R1-3} and E_{R1-3} remains unchanged.

3.5.3 Proportional Voltage Error. A proportional voltage error is encountered in a resolver that is used for data transmission rather than as a computing device. This error is the deviation of the mechanical shaft angle from an ideal angular position required to generate an ideal sine and cosine function. For data transmission, one input winding is generally excited and the error is measured in minutes of arc. A comparison between a resolver used for data transmission and a synchro used for data transmission indicates that the resolver operates with greater accuracy. For example, the most accurate synchro transmitters have errors in the order of 6 to 8 minutes of arc while data transmitter resolvers have errors of less than one minute.

3.6 Rotor Electrical Balance. In some resolver applications, the output voltages of both rotor windings must be nearly equal. This balance is usually achieved in the production of a resolver if the manufacturer maintains the rigid standards that result in uniform winding resistances, magnetic characteristics and mechanical parts. Any deviations in these characteristics result in unequal transformation ratios between the rotor and stator windings.

3.7 Winding Compensation. A technique commonly used to improve the accuracy of resolvers is the addition of an auxiliary or compensating winding within the stator slots. This winding is inserted in such a manner that close coupling is obtained between stator and compensating winding. With close coupling the frequency response between stator and compensating windings is broader than that between stator and rotor windings. The voltage induced in the compensating winding is approximately equal to the back emf of the stator winding. This back emf equals the input voltage minus all the series losses. Thus the compensating winding can be used effectively to compensate for the series losses, resistance and inductance, in the stator windings.

3.7.1 Schematic Circuit. Figure 11 illustrates a resolver with a compensated winding connected to an amplifier. The compensating winding voltage is employed as a negative feedback for the amplifier through a summing network. The resistors in the summing network are adjusted to provide unity gain from

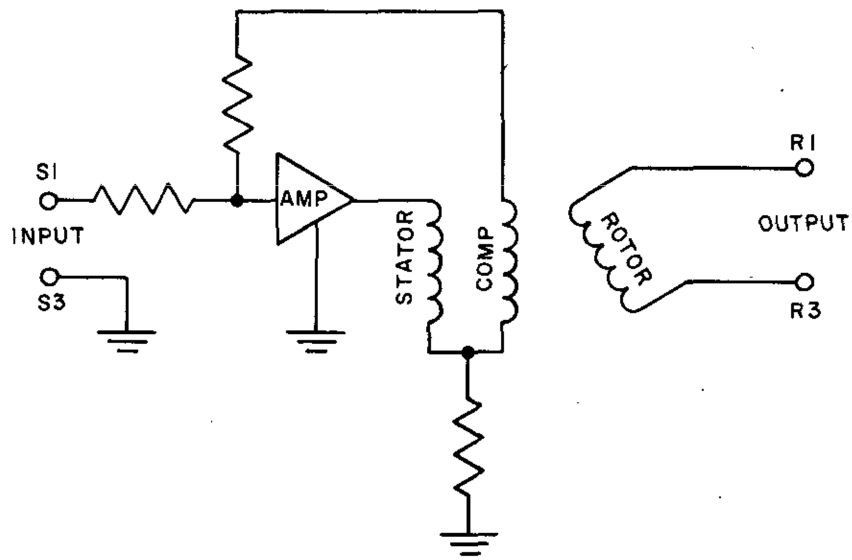


Figure 11. Resolver with Winding-Compensated Stator, Schematic Diagram

the amplifier input to the resolver rotor output. When an input voltage is applied, the amplifier output drives the stator winding until the compensating voltage is equal to the input voltage. As a result, the back emf of the stator is equal to the input voltage regardless of the influences tending to degrade the resolver's accuracy. The rotor output voltage is therefore equal in magnitude and phase to the input voltage.

3.7.2 Equivalent Circuit. An equivalent circuit for a compensated resolver, having a stator winding, a compensating winding, and a rotor winding, is shown in Figure 12. It should be noted that this equivalent circuit contains all the characteristics of the circuit for a noncompensated resolver and also includes the compensating inductance L3, resistance R4, and compensating transformer. Capacitor C1 signifies the distributed capacitance of the compensating winding. Resistor R4 represents the d-c resistance of the compensating winding. Inductor L3 represents the leakage inductance of the compensating winding.

3.7.3 Phase Relations. The leakage inductance of the rotor is smaller than that of the compensating winding. This difference in inductance introduces a slight phase shift between the two windings. This phase shift can be neglected in some applications; however, in critical resolver operation, it can be compensated for by use of a resistor-capacitor network.

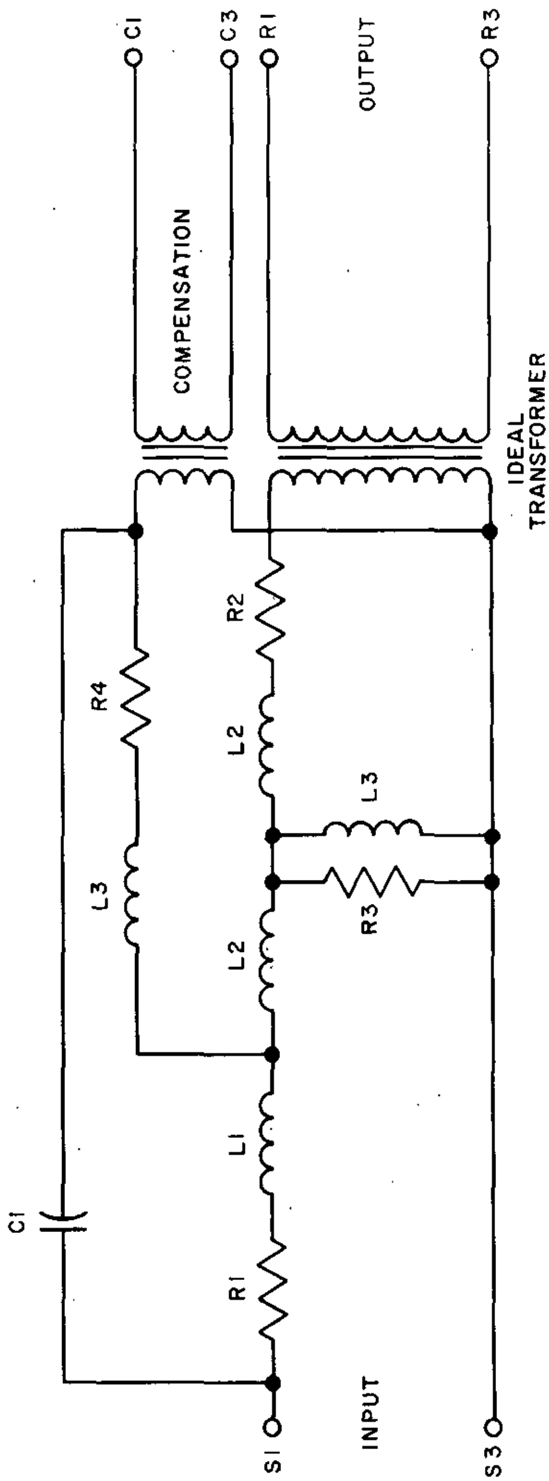


Figure 12. Equivalent Circuit for Resolver with Compensating Winding

3.8 Considerations of Resolver Loading. When considering the proper loading for a resolver, reference should be made to the equivalent circuit. In this way, the loading may be calculated through a few basic computations o the circuit parameters. For most calculations, the shunt inductance and the iron loss may be neglected. The output impedance of the resolver depends mainly on the leakage reactance and the stator and rotor copper losses. Consideration must also be given to the variations of copper losses due to temperature and the variations of leakage reactance with rotor position. In cases where both stator windings are excited, source impedance must be considered. If only one stator is used, the other stator should be shorted.

3.8.1 Resistive and Capacitive Loading. When only resistive loading is used, the output voltage drops and the phase lags. When only capacitive loading is used, the voltage increases and the phase leads. In both cases, however, the variations in output voltages and phase may be easily calculated

3.9 Effect of Temperature. Temperature variations affect the operating characteristics of a resolver whereas the other environmental characteristics affect the life and durability of the unit. Temperature variations cause a change in the value of winding resistance and inductance. These parameter changes cause variations in the transformation ratio and phase shift which can be calculated from the parameter values shown in the equivalent circuit. In an unloaded resolver, the temperature variations are due mainly to the copper losses in the stator windings.

3.10 Windings Without Compensation.

3.10.1 Phase Shift Due to Temperature Variation. In a noncompensated resolver, temperature changes affect the phase shift between input and output more directly than the amplitude. Assuming a no-load condition, this phase shift results primarily from the copper losses in the stator windings. Therefore, the phase shift will have the same coefficient as the temperature coefficient of the copper losses, which is approximately 0.4 percent per degree centigrade. For example, when a resolver has a net phase shift of 1.6°, a change in temperature of 30°C will produce an additional phase shift of approximately 0.2°; that is,

$$1.6 \times 30 \times 0.004 = 0.192^\circ.$$

3.10.2 Transformation Ratio Due to Temperature Variation. The transformation ratio is also varied by temperature changes in a noncompensated resolver. This variation is due to the copper losses of the stator windings and is approximately proportional to the cosine of the phase shift. In the example of the phase shift discussed in 3.10.1, the phase shift was given as 0.192°. Therefore, the amplitude variation due to this phase variation between input and output is equal to the cosine of 0.192°, or, the cosine of 1.6° minus the cosine of 1.792° which is 0.02 percent.

3.11 Transformation Ratio. The transformation ratio of a resolver is the ratio of the output voltage to the input voltage at maximum coupling between the rotor and the stator. This ratio can be determined by a direct measurement of the input and output voltages, but a more accurate determination can be made by placing the resolver in a test circuit (Figure 13) and computing the ratio of certain known impedance values in the output circuit (refer to paragraph 3.17.2).

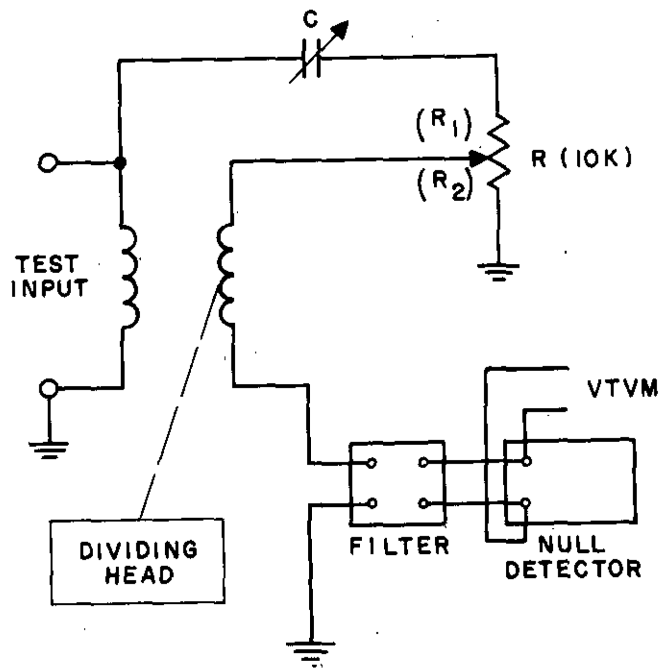


Figure 13. Test Circuit for Measuring Transformation Ratio, Function Error, Null Voltage, and Phase Shift

3.12 Temperature Compensation.

3.12.1 Current Feedback. To decrease the effects of temperature variations, a current feedback loop is used in the amplifier drive stage of a resolver circuit. In this loop, a resistor develops the necessary feedback current. If temperature compensation is to be obtained, the resistor should have a temperature coefficient equivalent to that of the copper wire used in the stator winding. Effectively, this feedback current produces a negative output resistance which counteracts the resistive variations of the resolver that occur during temperature changes.

3.12.2 Effect of Loading. When a resolver is loaded with a finite resistance, i.e., from 100,000 ohms to 1 megohm, the effect of this loading must be considered on the temperature characteristics of the unit. Referring to the equivalent circuit for a noncompensated resolver shown in Figure 9, the copper resistance and the load resistance act as a voltage divider network. Since the copper resistance is a function of temperature variations, the loss in the divider varies with the temperature coefficient of copper. This loss can be readily calculated from the values of the resistances and the temperature coefficient of copper which is 0.4 percent per degree centigrade.

3.13 Frequency Response. Resolvers operate on carrier frequencies such as 60 and 400 cycles per second when used for data transmission. When resolvers are used as computing devices the operating frequencies are considerably higher (10 kilocycles or greater). Therefore, computing resolvers should have a frequency response flat up to 10 kilocycles or greater, depending on the intended application.

3.13.1 Stator-to-Rotor Response. The frequency response curve for a typical resolver is shown in Figure 14. This response curve is similar to that for a transformer which has a high leakage reactance. At low-excitation frequencies, the resolver output amplitude decreases because of the d-c resistance of the stator winding and the magnetizing inductance caused by the magnetic flux linking the stator and rotor windings. At this point the response is 3 decibels down. As the excitation frequencies increase, the

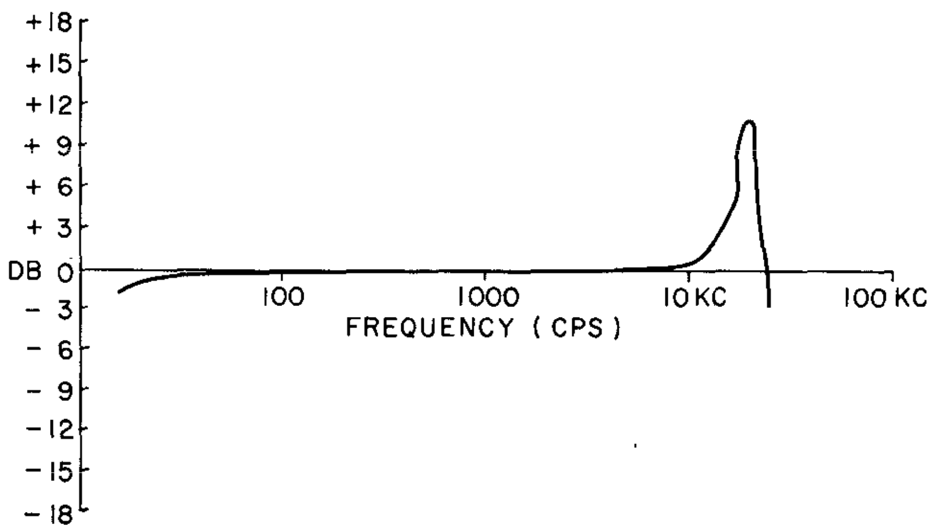


Figure 14. Typical Resolver Frequency Response

output voltage amplitude increases to a constant value for a wide frequency range. At some higher frequency, the distributed capacitance resonates with the stator leakage inductance to give a peak in the response. This occurs at about 30 kilocycles in the curve and may result in a response rise of as much as 10 to 15 decibels. When the resolver is used with inputs consisting of irregular waves, the peaking of the response results in ringing. To compensate for this condition, a damping resistor is generally used across the rotor to increase the resonating frequency.

3.13.2 Stator-to-Compensator Response. In the compensating type of resolver, the response for the stator-to-compensator windings is similar to that described in 3.13.1, except at very high frequencies. The leakage inductance of the compensator winding is lower than that of the rotor, resulting in a much higher frequency response. In some resolver units, it is desirable to have a flat response between stator and compensator windings to well over 100 kilocycles. To obtain this response in resolvers with a 1:1 ratio between stator and compensator windings, corresponding terminals of these windings should be operated at equal a-c potentials. This method of operation minimizes the capacity effects between windings and results in a peaking effect beyond 100 kilocycles.

3.13.3 Carrier Operations with Winding Compensation. Normally, the phase and amplitude response of resolvers with compensator windings is virtually independent of frequency, provided the frequency variation does not exceed approximately ±10 percent. In cases where the frequency variation does exceed ±10 percent, the phase variation is approximately ±1 to ±2 minutes, and the amplitude variation is only about 0.01 percent. These slight changes in amplitude and phase result primarily from the similarity between the frequency responses of the rotor and compensator windings.

3.13.4 Carrier Operations Without Winding Compensation. For carrier frequency operation at 60 or 400 cycles per second, the performance of resolvers without compensator windings can be determined from the equivalent schematic diagram. The phase varies approximately inversely with frequency. For example, if the frequency varies 10 percent above the carrier frequency, the phase also varies 10 percent, but in the opposite direction. The amplitude variations are proportional to the cosine of the resolver phase shift. Therefore, it follows that resolver units that are characterized by extremely low phase shift have negligible amplitude variations.

3.14 Null Voltage. When the position of the rotor of a resolver is fixed so that minimum coupling is obtained between rotor and stator windings, a residual voltage exists at the resolver output. This output is proportional to the input and is caused by the eddy currents and core saturations in the stator and rotor windings. To ensure that this residual or null voltage is kept at a minimum, the laminations are insulated before they are stacked.

3.15 Harmonic Distortion. Even under ideal operating conditions, resolvers generate some harmonics because of the nonlinear characteristics of magnetic materials. In most resolvers, this distortion of the input waveform is about 0.1 percent or less of the input voltage. This distortion is usually in the order of the third harmonic of the carrier frequency. Only when d-c inputs are used in the windings is there second harmonic distortion.

3.16 Effects of Direct Current. Direct current has a negligible effect on the operating characteristics of resolvers, provided the current does not exceed the peak stator current of the unit. As mentioned previously, the use of direct current results in the introduction of second harmonic distortion; however, this distortion usually does not exceed 0.1 percent of the input voltage.

3.17 Testing Procedures.

3.17.1 General. Since a resolver is a precision instrument, extreme care must be exercised in testing these units. In order to perform the measurements in these tests, it is necessary to have test equipment of a greater accuracy than the unit under test. The usual measurements include function error, null voltage, transformation ratio, phase shift, and frequency response.

3.17.1.1 Mechanical Positioning of Rotor. Before attempting to perform the various resolver tests, a mechanical means must be devised for rotating the rotor. A precision dividing head is usually used for this purpose. This head, which is equipped with a fixture for supporting the case of the resolver, positions the rotor with an accuracy of as great as ±2 seconds, although ±30 seconds is a more typical case. Also the coupling between the divider head and the shaft of the resolver does not substantially load the bearings.

3.17.1.2 Test Circuit. Figure 13 shows a test circuit for the measurement of such resolver parameters as transformation ratio, phase shift and function error. A precision dividing head is coupled to the shaft of the rotor. Standard test voltages are applied to one stator winding, and output voltages are measured on one rotor winding. The filter in the output circuit is designed to pass only the frequency of the test or input voltage, eliminating harmonics. The variable capacitor and the voltage-dividing resistor may be decade-box units, for quick determination of impedance values.

3.17.2 Transformation Ratio. The test circuit in Figure 13 is suitable for measuring transformation ratio when it is less than 1:1. With the scale of the dividing head aligned with the electrical zero position of the rotor, rotate the dividing head 90°, for maximum coupling of the stator and rotor windings. Adjust the voltage divider for maximum output (on the VTVM). Adjust C for minimum null, so that the voltage across the divider is in phase with the resolver output. The transformation ratio (TR) can then be obtained directly by comparing the output reading (on the VTVM) with the known input voltage. A more accurate figure can be obtained by computing the ratio of impedances in the divider network. Thus,

$$TR = \frac{R_2}{Z}$$

For a resolver with a transformation ratio equal to or greater than 1:1, a measuring device which indicates or compares the rms voltage of the fundamental frequency, and which does not alter the open circuit secondary voltage by more than 0.1 percent, must be used.

3.17.3 Function Error. Function error is the deviation of the resolver output voltage from true sinusoidal correspondence with the theoretical value of output voltage. It can be determined in terms of transformation ratio by measuring the ratio, as in paragraph 3.17.2, for various increments of rotation (usually a minimum of every five degrees over an 180-degree arc). Thus, with TR_1 the known transformation ratio at maximum coupling, and TR_n the ratio at the angle (θ) where error is being measured, the function error, in percent, may be computed as follows:

$$Error = \frac{(\sin\theta \, TR_1 - TR_n)}{TR_1} \times 100\%$$

3.17.4 Null Voltage. Both fundamental and total null voltages may be measured directly, using the test circuit shown in Figure 13. With the specified test voltage applied to the input, adjust C and R_2 until a minimum indication is obtained on the null detector. This is the fundamental component of the null voltage. At this same position, read the total null voltage with the VTVM connected to the input side of the filter.

3.17.5 Phase Shift. Phase shift can be computed as a function of the impedance values in the test circuit shown in Figure 13. With the rotor positioned for maximum coupling, set the voltage-dividing resistors and adjust C for a minimum null (in-phase voltage). The angle of phase shift, θ , is then as follows:

$$\theta = \tan^{-1} \frac{X_c}{R}$$

3.17.6 Frequency Response. In order to measure the frequency response of a resolver, the rotor windings should be unloaded. The response should be measured from the electrical null of one rotor winding while the other rotor is at a maximum coupling position with the stator. A voltmeter must be used with an appropriate filter so that it responds only to voltages of the fundamental frequency of the input. An oscilloscope should be used to measure the large amplitude and phase shift variations as the frequency is varied. The complete frequency response can be derived from the Lissajous figure on the oscilloscope.

SECTION 4

APPLICATIONS

4.1 General. Resolvers are used extensively in automatic control systems, analog computers, angle data transmission systems, and plan position indicating radar systems. They are employed as phase shifters and data transmission devices, and can also be used to resolve problems in trigonometry.

4.2 Typical Systems.

4.2.1 Automatic Control Systems. The simplest application of resolvers is found in automatic control systems. These systems use the resolver to perform sine and cosine computations, as well as vector additions.

4.2.1.1 Sine Computation. A voltage representing the hypotenuse of a right triangle is applied to one stator winding, and the rotor is positioned to the angle θ as shown in Figure 15. The outputs of the rotor windings represent the coordinates of a right triangle. This method of operation is used to convert polar coordinates to rectangular coordinates.

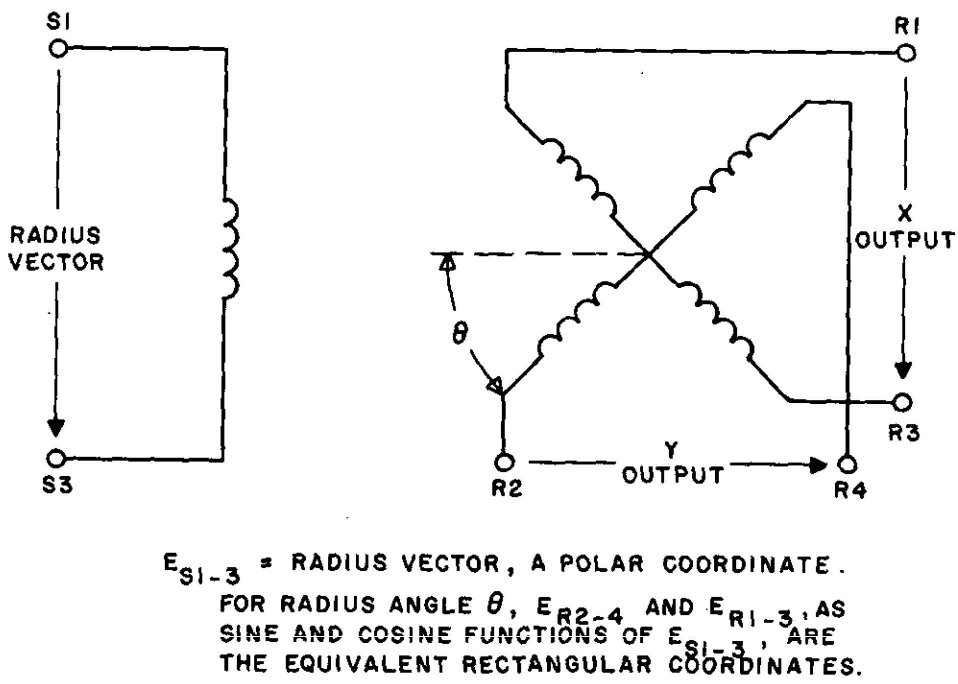


Figure 15. Right-Triangle Computations with a Three-Winding Resolver

4.2.1.2 Conversion of Polar Coordinates. Assume that voltage E_{S1-3} represents one polar coordinate, the radius vector, and is applied to the stator winding of the resolver shown in Figure 15; the rotor is positioned to angle θ , which represents the other polar coordinate. Output voltages E_{R2-4} and E_{R1-3} represent the legs of a right triangle, of which the radius vector is the hypotenuse. Thus, the polar coordinates of a point, P, can be converted to the rectangular coordinates.

4.2.1.3 Vector Addition. A resolver is capable of adding values vectorially. If the two stator windings are excited with voltages corresponding to the coordinates of a right triangle, an output may be produced representing the radius vector and the vector angle. This method of operation is used to convert rectangular coordinates to polar coordinates.

4.2.1.4 Conversion of Rectangular Coordinates. Assume that E_{S1-3} and E_{S2-4} represent rectangular coordinates and are applied to the stator windings of the resolver shown in Figure 16. The servo loop connected to one rotor winding positions the rotor to an angle θ ,

$$\theta = \tan^{-1} \frac{E_{S1-3}}{E_{S2-4}}$$

such that one output, E_{R2-4}, is zero. That is,

$$E_{R2-4} = E_{S2-4} \cos\theta - E_{S1-3} \sin\theta = 0.$$

The other output, E_{R1-3}, being 90 degrees away, will be at a maximum.

Expressed vectorially, the output

$$E_{R1-3} = E_{S1-3} \cos\theta + E_{S2-4} \sin\theta$$

becomes

$$E_{R1-3} = \sqrt{(E_{S1-3})^2 + (E_{S2-4})^2}$$

which is the radius vector, or equivalent polar coordinate. θ , of course, is the radius angle, or vector angle.

4.2.2 Analog Computers. Resolvers are used in computer systems for reciprocal operations and for the rotation of rectangular coordinates.

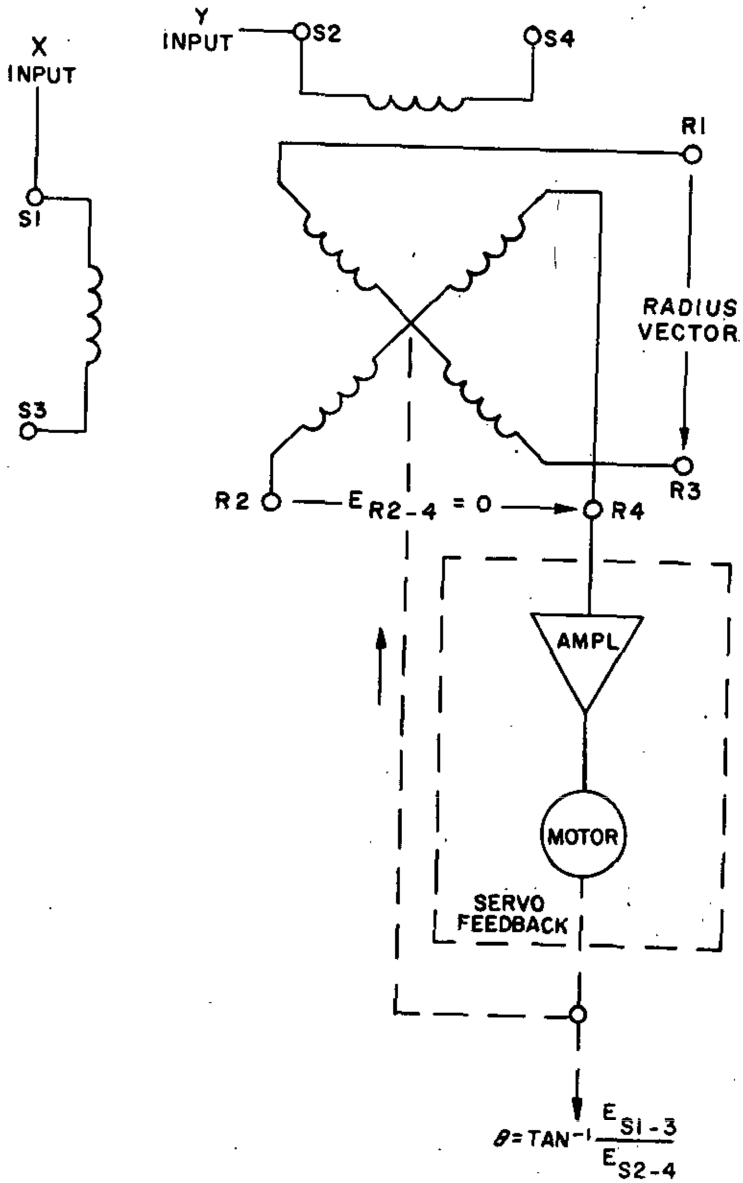


Figure 16. Vector Addition and Coordinate Conversion with a Four-Winding Resolver

4.2.2.1 Reciprocal Operation. In the reciprocal operation shown in Figure 17, one output voltage, E_{R1-3}, is fed back through the high-gain amplifier. The angle of the rotor (θ) is limited to produce the negative feedback voltage ($E_{R1-3} = -E_1$). The gain of the feedback loop is designed to vary as the cosine of θ. Therefore, the gain of the closed loop varies as the secant of θ, which is the reciprocal of the cosine of θ. The other rotor output becomes equal to the tangent of θ ($\frac{\text{sine } \theta}{\text{cosine } \theta}$). This method of division obviates the need for a servo loop. Special consideration must be given to the amplifier, since it must be capable of remaining stable over a wide range of loop-gain values.

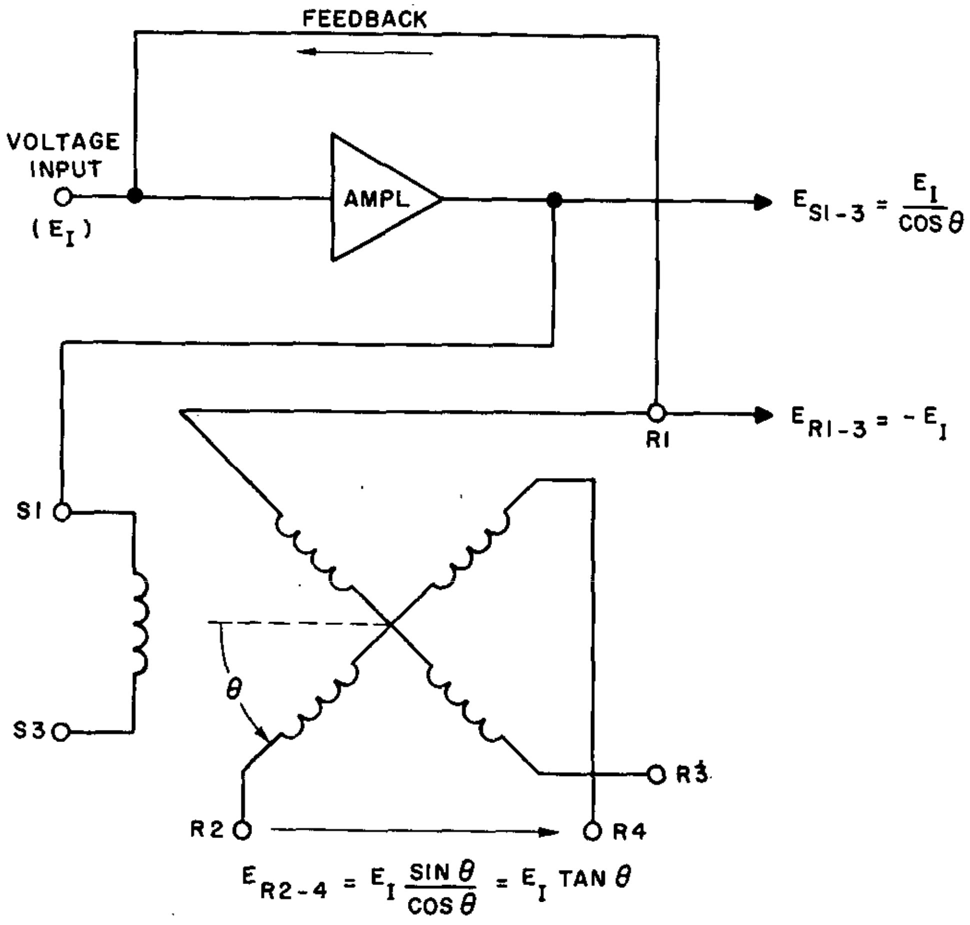
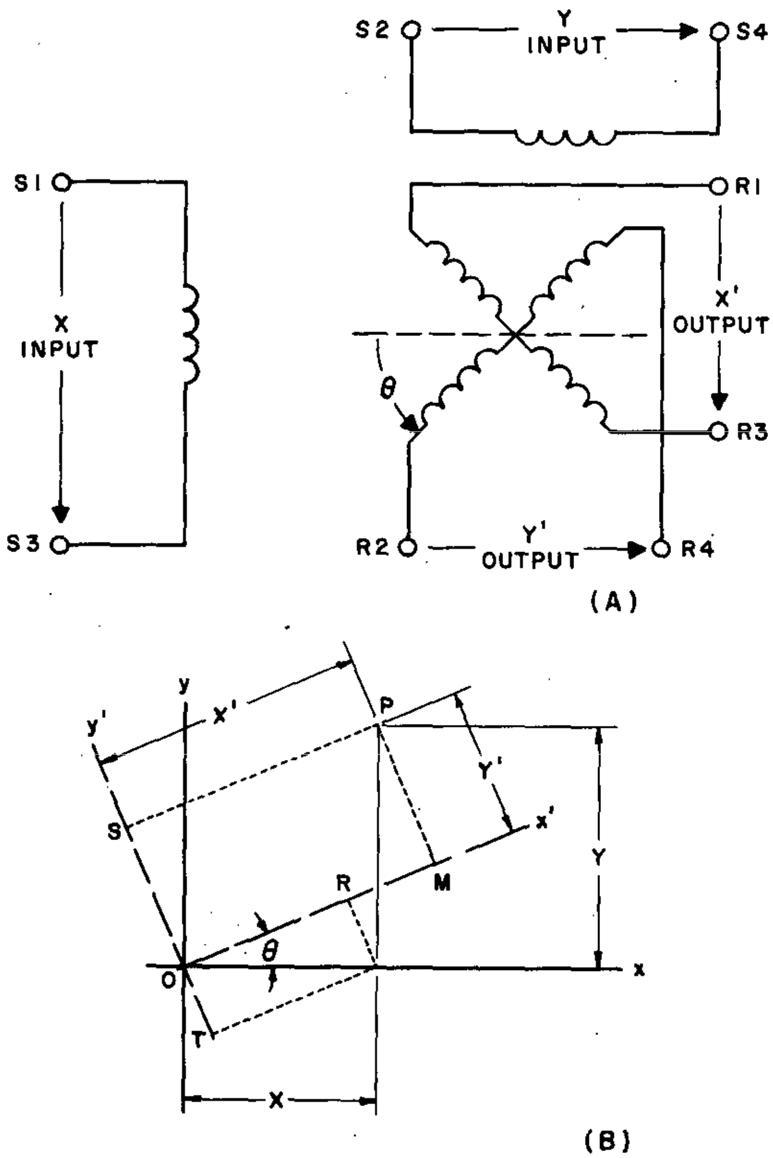


Figure 17. Reciprocal Functions with a Three-Winding Resolver

4.2.2.2 Rotation of Rectangular Coordinates. A four-winding resolver may be used for the rotation of rectangular coordinates. As shown in Figure 18(A), with input voltages on the stator windings corresponding to X and Y coordinates of a point, P, the output voltages from the rotor windings will correspond to X' and Y' coordinates, where the coordinate axes have been rotated through an angle θ . This relationship can be seen in Figure 18(B).



$$X' = OR + RM$$

$$\left(\frac{OR}{X} = \cos\theta\right)\left(\frac{RM}{Y} = \sin\theta\right)$$

$$X' = X\cos\theta + Y\sin\theta$$

$$Y' = ST - OT$$

$$\left(\frac{ST}{Y} = \cos\theta\right)\left(\frac{OT}{X} = \sin\theta\right)$$

$$Y' = Y\cos\theta - X\sin\theta$$

Figure 18. Rotation of Rectangular Coordinates

With angle θ representing the displacement of the rotor from resolver zero, the resulting equations of rotation are the same as those for a standard four-winding resolver (paragraph 2.4.3). Actually, the input voltages on the stator windings form a resultant flux vector whose position, determined by the arc-tangent of Y/X, is independent of the angular position of the rotor. And the rotor windings will at all times develop voltages which are proportional to the sine or cosine of the angle the rotor makes with the flux vector.

4.2.3 <u>Data Transmission</u>. In data transmission applications, more than one resolver must be used, as shown in Figure 19. One of the primary windings

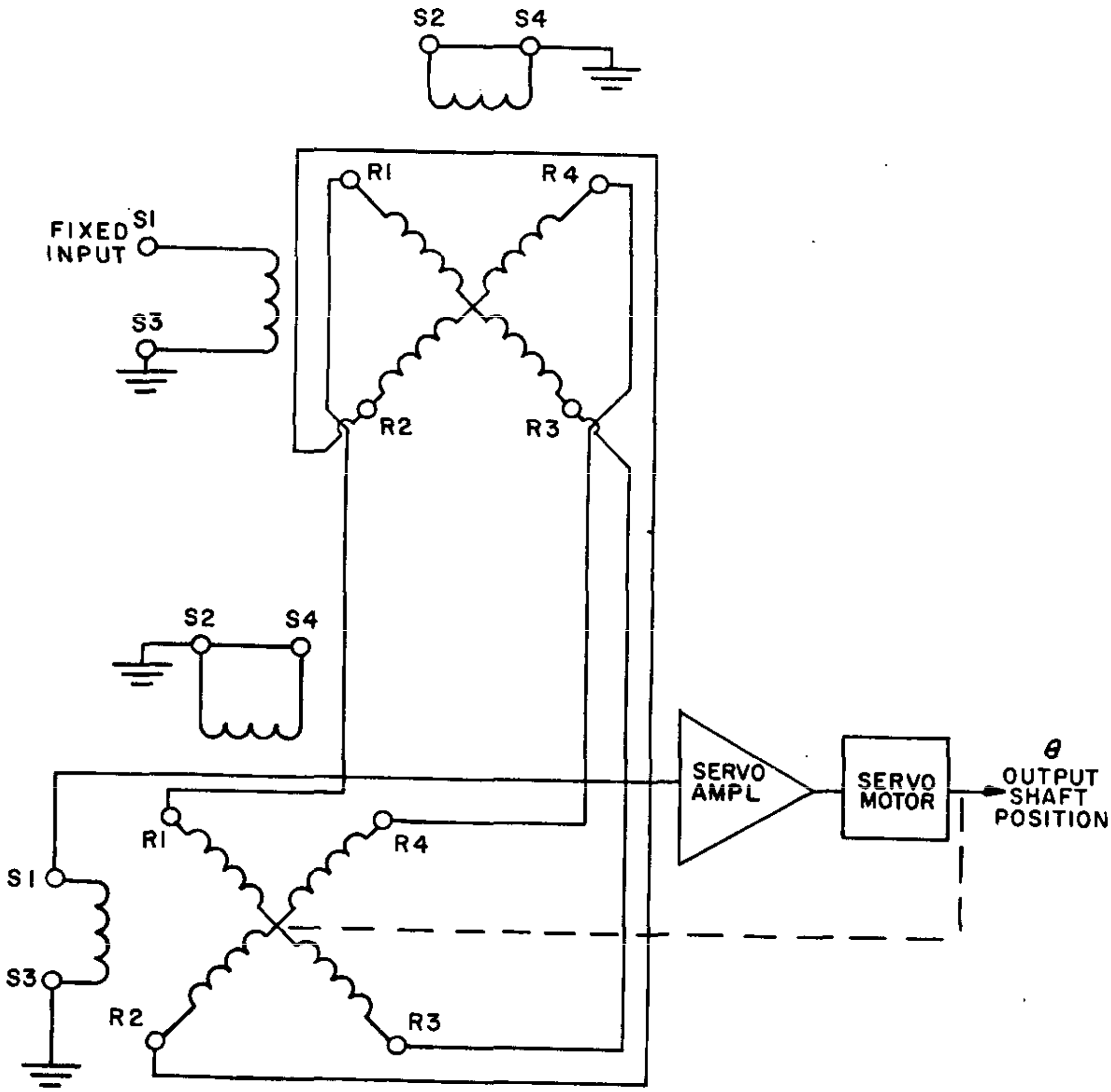
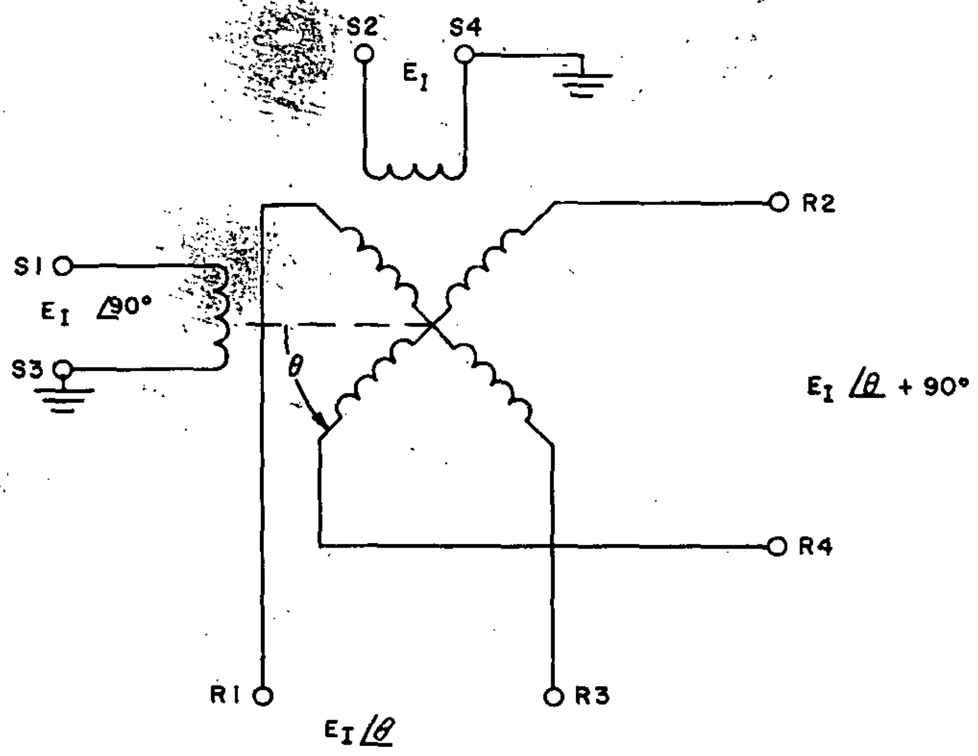


Figure 19. Data Transmission

of the first resolver is supplied with a fixed excitation voltage; the other winding is not excited. The shaft may be at any angle. The outputs appearing across both secondary windings are rectangular coordinates. These outputs are supplied to the secondary windings of the second resolver for conversion to the original polar coordinates. The servo-driven shaft of the second resolver repeats the rotor angle of the first resolver.

4.2.4 Phase Shifters. Figure 20 illustrates one of the many possible arrangements of phase shifter circuits. When the primary windings are excited by two voltages of equal amplitude but 90 degrees apart, the output voltages remain constant in amplitude but vary in phase, depending upon the angular position of the rotor. The output voltages, like the input voltages, are 90 degrees apart. Isolation amplifiers or resistive loading in the output are often necessary to ensure the desired degree of precision in phase shifting.



$$E_{S1-3} = E_{S2-4} = E_I$$

$$E_{R1-3} = E_{R2-4} = E_I$$

Figure 20. Phase Shifting with a Four-Winding Resolve

4.2.5 Radar Sweep Resolution. Wideband resolvers are used to resolve radar range sweeps in plan position indicators. Additional information can be presented on a plan position indicator through multiplexing techniques with resolvers used in place of field coils. The response of a typical wideband resolver is shown in Figure 21. The usable high frequency extends to approximately 100 kilocycles. By using the compensating winding, the usable low frequency is limited only by the maximum current rating of the resolver and external circuit parameters. Figure 22 shows a typical application of a wideband resolver for radar sweep resolution. The rotor of the resolver is connected, through gears, to the radar antenna and a sawtooth voltage, E_{S1-3}, is applied to the stator. When the antenna is positioned at 0 degree, the rotor is at resolver zero and the output sawtooth voltages, E_{R1-3} and E_{R2-4}, applied to the horizontal and vertical deflection plates of the display indicator, are maximum and minimum respectively. As the antenna rotates in a counterclockwise direction, E_{R1-3} decreases in amplitude while E_{R2-4}, increases. This causes the radar sweep to move accordingly. When the rotor angle (θ) equals 45 degrees with respect to resolver zero, the output sawtooth voltages are equal in amplitude and the sweep on the indicator has rotated 45 degrees from its original position. When θ equals 90 degrees with respect to resolver zero, E_{R1-3} is minimum and E_{R2-4} is maximum. The radar sweep now indicates 90 degrees with respect to its original position. Following this procedure, the amplitude of the output voltages will vary as the sine and cosine function of the rotor angle causing the sweep to rotate 360 degrees for each revolution of the antenna.

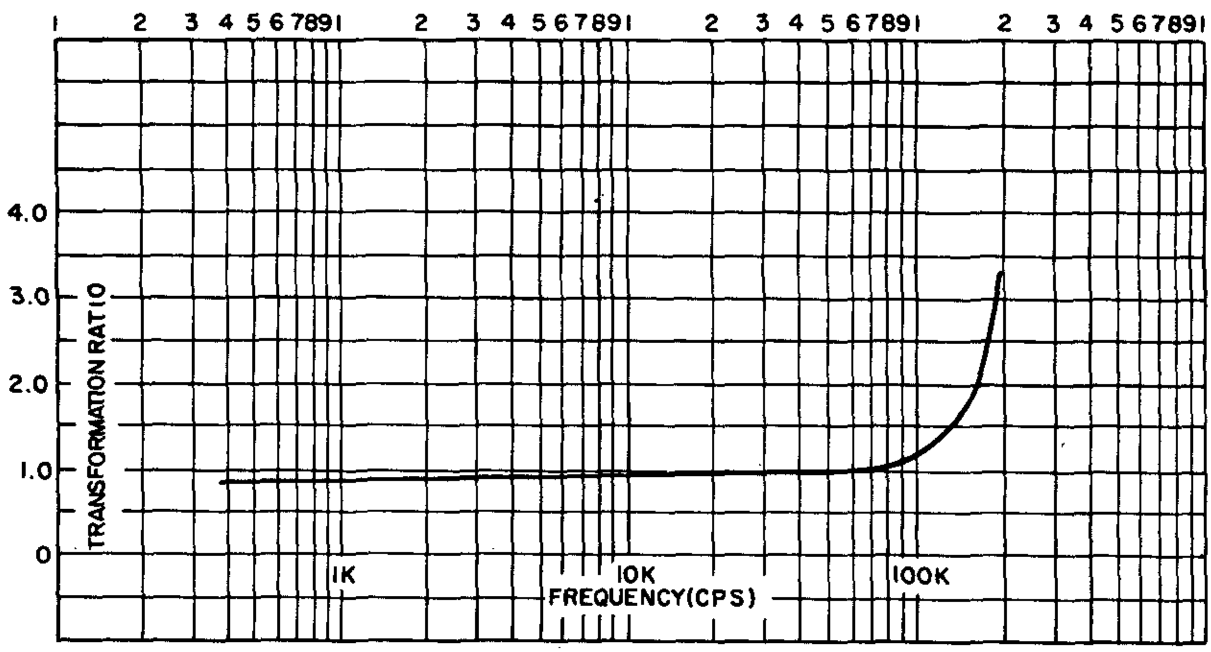


Figure 21. Frequency Response for a Wideband Resolver

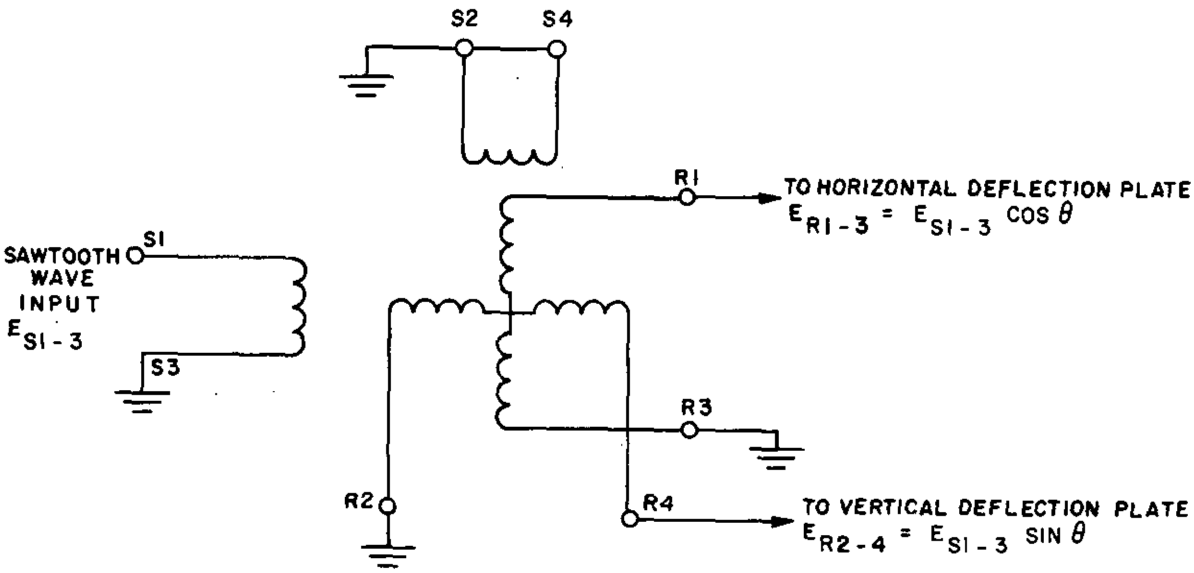


Figure 22. Radar Range Sweep Resolution with a Four-Winding Resolver

SECTION 5

TYPICAL ELECTRICAL RESOLVERS

5.1 General. This section describes the function of some typical electrical resolvers in relation to the systems in which they are employed. The following resolver connections are discussed in subsequent paragraphs: a resolver with two excited stator windings connected in series and two rotor windings connected in series; a resolver with two excited rotor windings connected in series and two stator windings; a resolver with one excited stator winding, one shorted stator winding, a compensating resistor, and two rotor windings; a resolver with two excited stator windings, two compensating windings, and two rotor windings; a resolver with two excited stator windings, two compensating resistors, and two rotor windings; and a resolver with two excited stator windings and two rotor windings.

5.2 Resolver with Two Excited Stator Windings Connected in Series and Two Rotor Windings Connected in Series. The wiring connection for this type of resolver is shown in Figure 23.

5.2.1 Function. The function of the resolver connection illustrated in Figure 23 is to provide a variable amount of time-phase shift. The output voltage of the resolver is a direct function of the shaft position. Therefore, the output may be shifted with respect to the input by simply rotating the resolver shaft.

5.2.2 Systems in Which Employed. Representative systems in which this type of resolver is used include short range navigation (SHORAN) and radar ranging equipments. In the SHORAN system a crystal-controlled oscillator generates a standard frequency of 186 kilocycles, from which three timing signals are derived. The periods of these signals correspond to SHORAN distances of 1 mile (93 kilocycles), 10 miles (9.3 kilocycles), and 100 miles (0.93 kilocycles). The timing signals are generated by three resolvers functioning as phase shifters. These three resolvers comprise a set and are linked together in 10-to-1 ratios. Each output from the resolvers is variable in phase corresponding to the angular shift of the resolver rotor shaft. In the radar ranging system, the resolver is used to vary the phase of a fixed-phase input as a function of range. The fixed-phase input is applied to the stator windings. The rotor is mechanically connected to a range driver unit which rotates the rotor shaft at a speed corresponding to a particular range. The output taken across the rotor is phase-shifted in accordance with the angular position of the rotor. The phase shift between input and output, therefore, is a function of range.

5.3 Resolver with Two Excited Rotor Windings Connected in Series and Two Stator Windings. The wiring connection for this type resolver is shown in Figure 24.

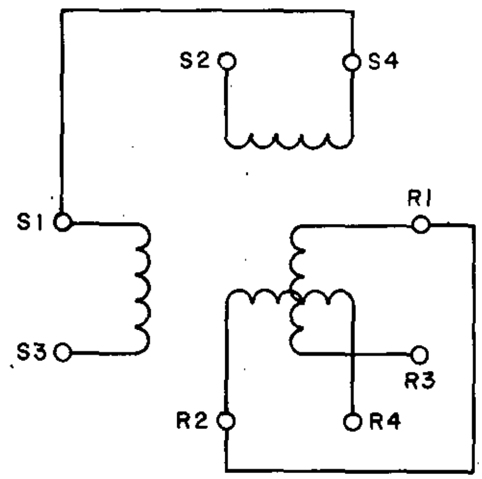


Figure 23. Resolver with Two Excited Stator Windings Connected in Series and Two Rotor Windings Connected in Series

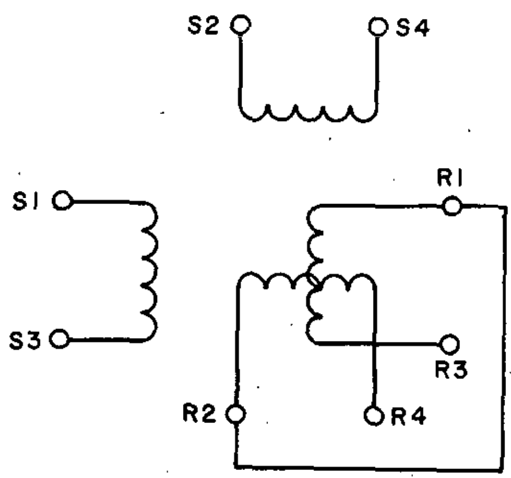


Figure 24. Resolver with Two Excited Rotor Windings Connected in Series and Two Stator Windings

5.3.1 Function. The function of the resolver connection illustrated in Figure 24 is to convert rectangular coordinates to polar coordinates. Also, by short circuiting one of the rotor windings, the resolver may be used to convert polar coordinates to rectangular coordinates.

5.3.2 Systems in Which Employed. Many aircraft, space vehicles, and naval vessels require information generated in one coordinate system to be transformed into another coordinate system. A representative system employing this resolver is the control system used in precision bombing. A polar axis bombsight is mounted in an aircraft so that the polar axis is vertical when the plane is in level flight. The sight acquires a point in space by means of an azimuth rotation, A (Figure 25), about the polar axis and then by an elevation rotation, E, about an axis perpendicular to the polar axis. The elevation axis is carried around by the polar axis. The problem is to maintain the sighting line on a target when the aircraft yaws, pitches, or rolls. It is assumed that yaw is always measured about an axis parallel to the bombsight polar axis, and any yaw indication is fed directly into the azimuth servo. A pitch and roll gyro measures the roll angle, R, about the aircraft's longitudinal axis and the pitch angle, P, about a horizontal transverse axis. This is equivalent to stating that the pitch and roll gyro is oriented so that roll is measured about the pitch line. The known position of the target in a vertical space frame as measured from the aircraft position is specified by coordinates X, Y, and Z. With pitch angle P and roll angle R known, the problem is to find sighting angles A and E of the sight. Figure 25 illustrates the instrumentation. The known vertical space frame coordinates X, Y, and Z are fed into the resolvers P and R. This transforms the data to coordinates of the target as measured in the aircraft coordinate system. This new set of data is available as the output of the P and R resolver chain. If this new data is fed to the sighting-angle resolver chain (A and E), it is then possible to position these resolvers, as shown in Figure 25, so that the line of sight points to the target. Note that the slant range is one of the outputs.

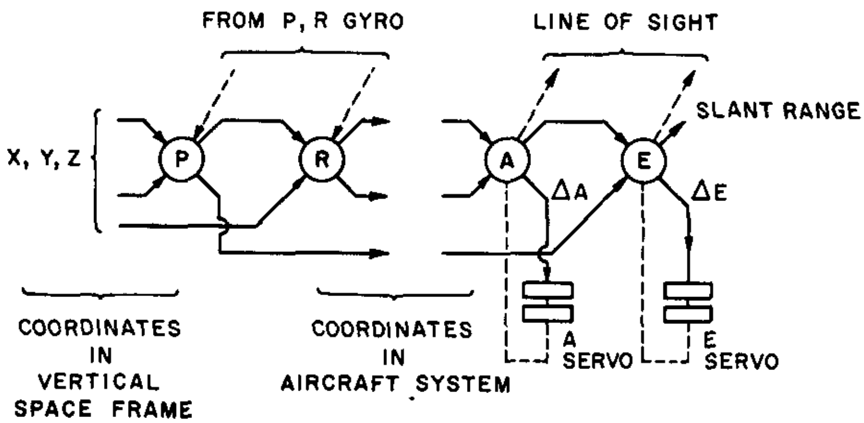


Figure 25. Representative Control System for Precision Bombing

5.4 Resolver with One Excited Stator Winding, One Shorted Stator Winding, a Compensating Resistor, and Two Rotor Windings. The wiring connection for this type of resolver is shown in figure 26.

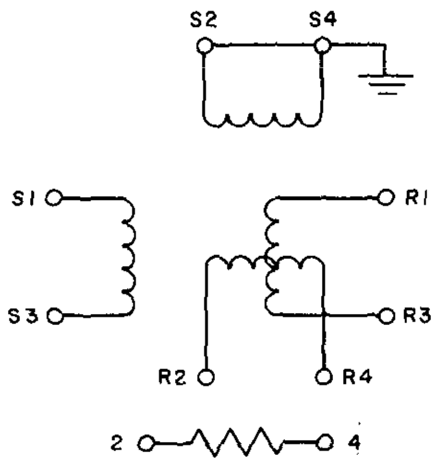


Figure 26. Resolver with One Excited Stator Winding, One Shorted Stator Winding, a Compensating Resistor, and Two Rotor Windings

5.4.1 Function. The resolver illustrated in Figure 26 can be used in the following applications: angle computation, sine and cosine computation, reciprocal operations, and radar sweep resolution.

5.4.2 Systems in Which Employed. This resolver is used in computing equipment resolving right triangular solutions and in radar systems for the resolution of radar sweep voltages. It is especially suitable in providing a rotating radial trace on a plan position indicator. In this application, the rotor shaft is mechanically connected to the radar antenna. A range sweep voltage is applied to the stator. The output from the rotor winding is applied to the deflection plates of the PPI cathode-ray tube, producing a radial trace synchronized with the antenna. The compensating resistor in this application ensures linearity of the radar sweeps.

5.5 Resolver with Two Excited Stator Windings and Two Rotor Windings. The wiring connection for this type of resolver is shown in Figure 27.

5.5.1 Function. The resolver illustrated in Figure 27 can be used in the transmission of angular data and in vector addition and subtraction. It can also be used to provide a radial sweep on a plan position indicator, synchronized with a rotating antenna.

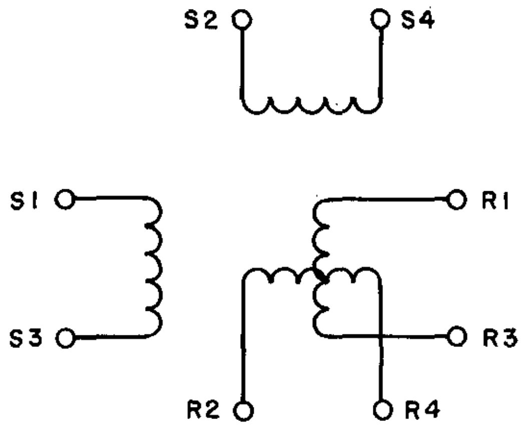


Figure 27. Resolver with Two Excited Stator Windings and Two Rotor Windings

5.5.2 Systems in Which Employed. This type of resolver is used exclusively in antiaircraft fire control systems for producing azimuth marks and a radial sweep on the radar plan-position indicators. Resolvers also are used to add and subtract angles electrically and transmit angular information between remote points. The operation of resolvers used to produce a radial sweep on the plan-position indicator is similar to the operations of the basic resolver system discussed in paragraph 5.4.2. When resolvers are used for data transmission, one primary winding of one resolver is excited. The two outputs from this resolver are used to excite the primaries and drive the shaft of the second resolver (with a servo) so that it repeats the shaft angle of the first.

5.6 Resolver with Two Excited Stator Winding, Two Compensating Windings, and Two Rotor Windings. The wiring connection for this type of resolver is shown in figure 28.

5.6.1 Function. The functions of this type of resolver are similar to those of the resolver with two excited stator windings and two rotor windings. The two compensating windings make this type of resolver especially suitable in applications where resolver performance is susceptible to environmental variations and load and source impedance variations.

5.6.2 Systems in Which Employed. Refer to paragraph 5.5.2 for a discussion of a representative system in which this type of resolver is used.

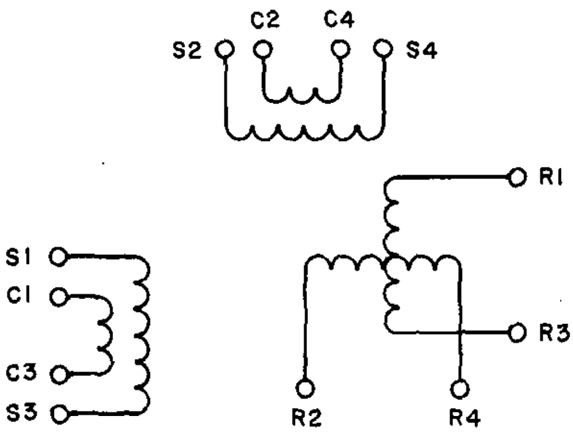


Figure 28. Resolver with Two Excited Stator Windings, Two Compensating Windings, and Two Rotor Windings

5.7 Resolver with Two Excited Stator Windings, Two Compensating Resistors, and Two Rotor Windings. The wiring connection for this type of resolver is shown in Figure 29.

5.7.1 Function. The functions of this type resolver are similar to the functions of the resolver with two excited stator windings and two rotor windings. The two compensating resistors make this a temperature-compensated resolver. The effects of wide temperature variations are minimized because the coefficient of the resistors is equivalent to the coefficient of the copper used in the rotor and stator windings.

5.7.2 Systems in Which Employed. A representative system in which this type of resolver is used is discussed in paragraph 5.5.2.

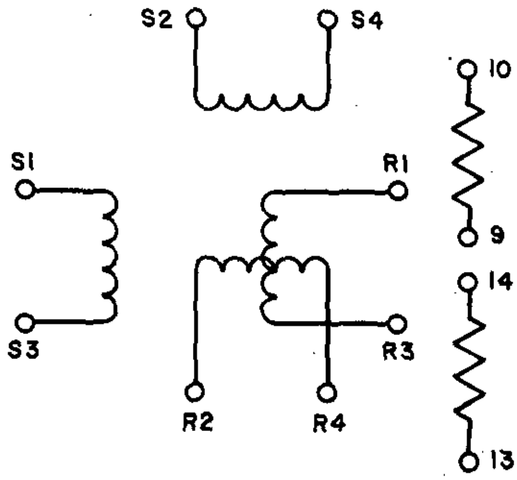


Figure 29. Resolver with Two Excited Stator Windings, Two Compensating Resistors, and Two Rotor Windings

SECTION 6

PERFORMANCE SPECIFICATIONS

6.1 General. General specifications cover performance requirements common to all types of resolvers. Detail specifications invoke the general specification and complete the definition of individual resolver types by stating parameter magnitudes, special requirements and exceptions to the general specification. The performance specifications defined in this section are applicable to all types of resolvers.

6.2 Classification. Resolvers are classified according to size, input impedance, type of compensation, and excitation frequency. A typical reference designation is resolver, type 23R32N4a. These digits and letters classify the resolver as follows.

6.2.1 Size. The first two digits (23) give the maximum diameter of the housing, in tenths of an inch.

6.2.2 Function. All resolvers take the designation "R"

6.2.3 Input Impedance. The next two digits (32) designate the nominal impedance of the input coil, in hundreds of ohms.

6.2.4 Type of Compensation. The letter (N) designates a resolver with no compensation. Other code letters used are "R" for resistor compensated, "W" for winding compensated, and "B" for both resistor and winding compensated.

6.2.5 Excitation Frequency. The next digit (4) gives the frequency of the excitation voltage, 400 cycles per second (cps). Other standard frequency designations are 6 (60 cps), 8 (800 cps), 10 (1000 cps), 100 (10,000 cps), and 200 (20,000 cps).

6.2.6 Modification. The final, lower-case letter (a) indicates that the resolver is the unmodified original issue. The first modification of this type will take the designation "b," the second "c," etc.

6.2.7 Other Designation. If the resolver has a fixed rated input voltage other than 115 volts, the reference designation will be prefixed by the applicable voltage rating.

6.3 Mode of Excitation. The mode of excitation indicates whether the stator or rotor winding is energized. The energized winding is always considered the primary winding of the resolver.

6.4 Direction of Rotation. The positive direction of rotation in standard resolvers is counterclockwise (facing the shaft extension end of the resolver).

6.5 Input Voltage. A resolver must operate satisfactorily over the range of input voltages required by the applicable detail specification. This range of inputs includes the maximum, minimum, and test voltages. The test voltage is the input voltage at which a resolver must meet all of the test requirements of the applicable detailed specification.

6.6 Input Current. The input current of a resolver is the current drawn by the primary windings when the specified test voltage is applied to the primary windings with the secondary windings open-circuited. The input current value is specified by the applicable detail specification and must be measured with a milliammeter having an accuracy of at least one percent.

6.7 Input Power. The input power of a resolver is the power consumed in the primary windings when the specified test voltage is applied to the primary windings with the secondary windings open-circuited. The input power value is specified by the applicable detail specification.

6.8 D-C Resistance. The d-c resistance of the input and output windings and the compensating resistors and windings of a resolver must correspond to the values specified by the applicable detail specification.

6.9 Transformation Ratio. The transformation ratio, designated as K, is the ratio of the fundamental component of the no-load output voltage, at maximum coupling, to the input voltage. The nominal value of the transformation ratio is obtained at the test voltage and is specified by the applicable detail specification.

6.9.1 Equality of the Transformation Ratio. Equality of the transformation ratio refers to the variation of the transformation ratio for all the possible combinations of stator and rotor windings. These variations must not exceed the value specified by the applicable detail specification.

6.10 Nominal Phase Shift. Nominal phase shift is the time-phase angle by which the secondary (output) voltage differs from the primary (excitation) voltage. The nominal phase shift value is specified by the applicable detail specification.

6.10.1 Phase Shift Variation Caused by Rotation or Voltage Variation. Variations of phase shift may occur as a function of the rotor angle or input voltage variations. Such variations must not exceed the value specified by the applicable detail specification.

6.11 Interaxis Error. Interaxis error is the angular deviation of the null positions from space quadrature of all rotor, stator, and rotor-stator winding combinations. When tested as described herein, the interaxis error must not exceed the value specified by the applicable detail specification. To test the resolver, it is mounted in an angular accuracy test stand, which can position the rotor within 15 seconds of arc. The resolver is energized with the specified test voltage, and in the sequence indicated in Table I. At each position in Table I, fine angular adjustment is made to obtain minimum output. The algebraic difference of these angles at positions 1 and 3, 2 and 4, 5 and 7, and 6 and 8 is the interaxis error of the rotor. The algebraic difference of these angles at positions 1 and 7, 2 and 8, 3 and 6, and 4 and 5 is the interaxis error of the stators. The algebraic difference of these angles at positions 1 and 5, 3 and 7, 2 and 6, and 4 and 8 is the interaxis error of the resolver.

Table I. Interaxis Error Test

Null Position	Null Angle	Excitation Winding	Shorted Winding	Output Winding
1	0	S1-S3	S2-S4	R1-R3
2	180	S1-S3	S2-S4	R1-R3
3	90	S1-S3	S2-S4	R2-R4
4	270	S1-S3	S2-S4	R2-R4
5	0	S2-S4	S1-S3	R2-R4
6	180	S2-S4	S1-S3	R2-R4
7	90	S2-S4	S1-S3	R1-R3
8	270	S2-S4	S1-S3	R1-R3

6.12 Fundamental Null Voltage. The fundamental null voltage is the minimum secondary voltage of the excitation frequency, without harmonics, obtained for the null angles indicated in Table I. The fundamental null voltage is specified by the applicable detail specification.

6.13 Total Null Voltage. The total null voltage is the minimum secondary voltage, including harmonics, obtained for the null angles listed in 6.11. The total null voltage is specified by the applicable detail specification.

6.14 Function Error. Function error refers to the deviation of the actual output voltage from the theoretical sinusoidal output voltage expressed as a percentage of the maximum output. The error is normally tested at 5-degree intervals, between 0 and 180 degrees.

6-15 Voltage Zero Shift Null Spacing. After zeroing the resolver, the input voltage must be varied from maximum to test to one-half test to minimum. Variation of the angular deviation from resolver zero is specified by the applicable detail specification.

6.16 Frequency Zero Shift of Null Spacing. After zeroing the resolver, the frequency must be varied from 5 percent above to 5 percent below the rated value. Variation of the angular deviation from resolver zero is specified by the applicable detail specification.

6.17 Friction Torque. Friction torque, measured in ounce-inches, refers to the amount of rotational force required to overcome friction. Friction torque is determined by measuring the rotational force required to rotate the stator housing about the rotor (with the resolver in a horizontal position) at -55°C, 22°C, 75°C, and 85°C. The stator must be rotated at least two times in both a clockwise and counterclockwise direction at a rate of four to six revolutions per minute. The friction torque value is specified by the applicable detail specification.

6.18 Brush Contact Resistance. The resistance developed between the brushes and collector rings of the rotor shaft. To measure this resistance, a Wheatstone bridge, or another suitable measuring device, is connected across rotor terminals R1-3 and R2-4. The shaft is then rotated through a complete revolution at the rate required by the applicable detail specification and the change in resistance noted. This resistance change should not exceed that allowed by the specification.

6.19 Temperature Rise. Temperature rise is the increase of the internal temperature of a resolver above the ambient temperature due to dissipation of the energizing power. The rate of temperature rise is specified by the applicable detail specification.

6.20 Endurance. Resolvers are subjected to 1200 hours of rotation (1150 ± 50 rpm) in various attitudes and at various temperatures as a test of endurance. During this test, they must operate satisfactorily, with the specified test voltage applied, as follows:

Temperature	Time	Attitude
-25°C (-15°F)	62 to 64 hours	Shaft horizontal
85°C (185°F)	23 to 25 hours	Shaft end up, 90°
	23 to 25 hours	Shaft end up, 45°
	23 to 25 hours	Shaft end down, 45°
	23 to 25 hours	Shaft end down, 90°
Ambient	1036 to 1044 hours	Shaft horizontal.

6.21 Weight. Weight represents the overall weight of the resolver and is expressed in ounces.

6.22 Insulation Resistance. The insulation resistance is determined using a megohm bridge with 400 volts d-c applied between the windings and the case. A minimum of 10 megohms is required between any winding and the case.

SECTION 7

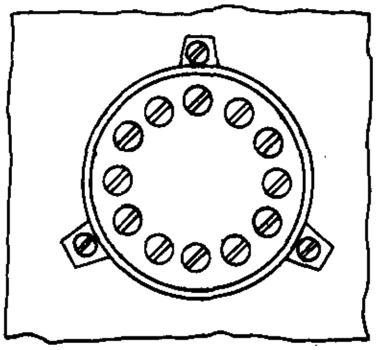
INSTALLATION

7.1 General. Installation of electrical resolvers involves three discrete operations -- mounting the resolver in a chassis or on a panel, making mechanical connection to the rotor shaft, and making electrical connection to the stator and rotor windings. Mounting by clamp assemblies is possible; however, in many cases, various types of adapters must be used. The type of installation depends upon the particular need for zero adjustment and upon accessibility, that is, whether it is more convenient to fasten the resolver from the shaft end or the terminal end. Electrical connections are readily accomplished, whether the resolver uses screw-type terminals, connector pins, or lead wires.

7.2 Precautions. Resolvers are designed to withstand shock, vibration, and a wide range of atmospheric conditions without loss of accuracy. However, errors may be introduced as a result of faulty installation. Established mounting practices, when followed, help to provide high standards of resolver performance. Special care must be exercised when installing the smaller resolvers, such as size 8 or 11. Accuracy of performance tends to decrease with size. This is because the larger resolvers, with greater mechanical rigidity and closer relative tolerances, will be less sensitive to variations in operating conditions.

7.3 Direct Mounting From Terminal Board End. Figure 30 shows a resolver mounted directly on a panel from the terminal board end. It is fastened to the panel with three clamp assemblies (see Figure 36) spaced 120 degrees apart about the resolver housing. (This method is used when no angular adjustment is required.) The shaft end of the resolver is first inserted in the hole in the panel, so that it is flush at point B. One end of each mounting clamp is placed against the rim of the housing, at point A. Each clamp assembly is then secured to the panel with a captive screw, which is inserted in a pretapped hole in the panel.

7.4 Mounting From Shaft End, Using Adapter Assembly. Figure 31 shows a resolver mounted on a panel from the shaft end, using an adapter assembly (Figure 38) and three clamp assemblies. The shaft end of the resolver is passed through the hole in the panel. The adapter assembly is aligned with the four tapped holes in the shaft end and secured with four mounting screws. The resolver is then withdrawn until the adapter is flush with the panel. One end of each mounting clamp is placed against the flange of the adapter assembly. Each clamp assembly is then attached to the panel with a captive screw, which is inserted in a pretapped hole in the panel. Before the screws are tightened, a straight pinion wrench may be used to rotate the adapter assembly for angular adjustment. When the resolver is aligned, the three screws in the clamp assemblies are tightened, securing the resolver at this angular position.



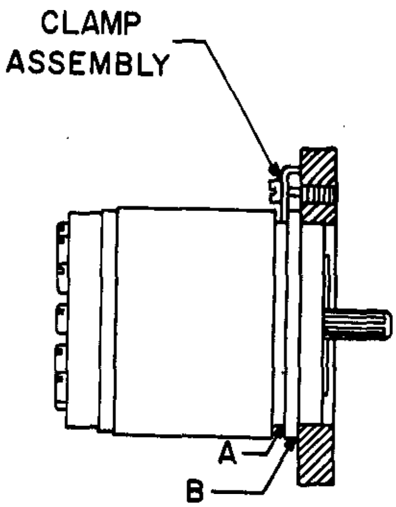
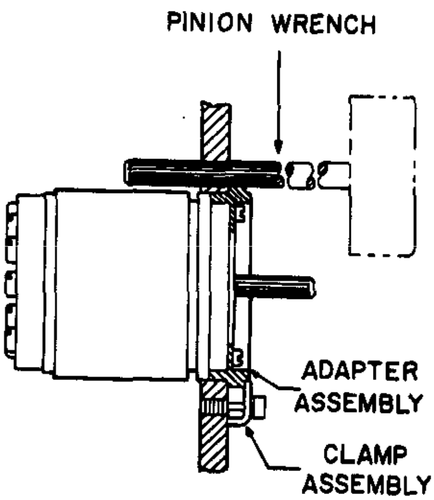


Figure 30. Resolver Mounted Directly from Terminal Board End



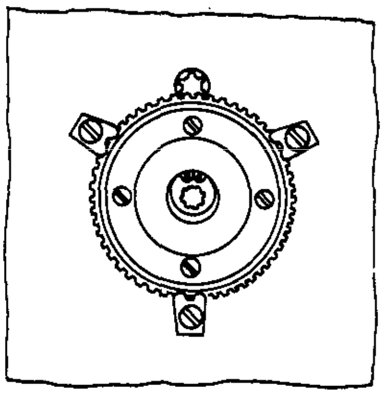


Figure 31. Resolver Mounted with Adapter Assembly from Shaft End

7.5 Mounting From Terminal Board End, Using Adapter Assembly. Figure 32 shows a resolver mounted on a panel from the terminal board end, using an adapter assembly (Figure 38) and three clamp assemblies. The adapter assembly is aligned with the four tapped holes in the shaft end of the resolver and secured with four mounting screws. The adapter assembly is then inserted into the hole in the panel until its flange is flush with the panel. One end of each mounting clamp is placed against the rim of the adapter assembly. Each clamp assembly is then attached to the panel with a captive screw, which is inserted in a pretapped hole in the panel, but not tightened. A straight pinion wrench may be used for angular adjustment of the resolver. When the resolver is aligned, the three screws in the clamp assemblies are tightened, securing the resolver at this angular position.

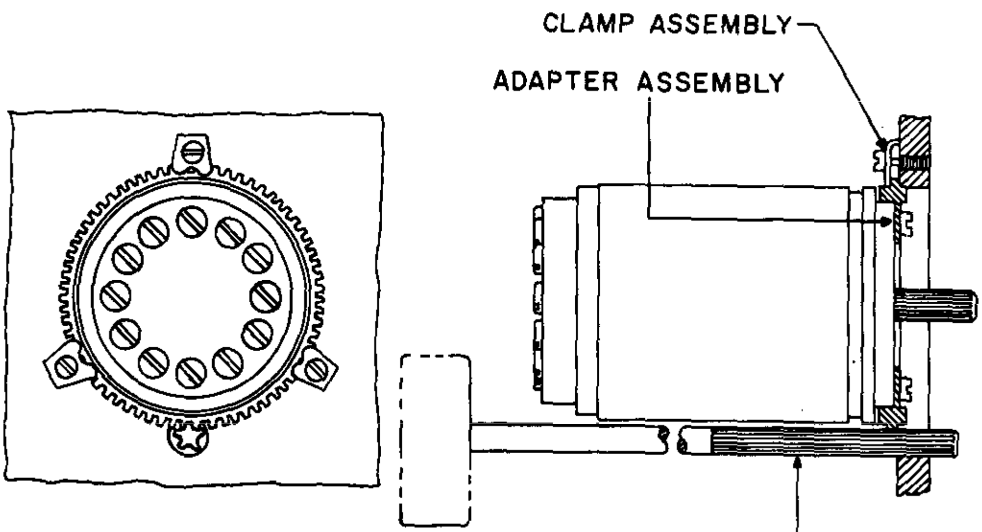


Figure 32. Resolver Mounted with Adapter Assembly from Terminal Board End

7.6 Mounting From Shaft End, Using Adjustable Clamping Disk Assembly. Figure 33 shows a resolver mounted on a panel from the shaft end, using an adjustable clamping disk assembly (Figure 37). The shaft end of the resolver is passed through the hole in the panel until the flange of the housing is flush with the panel. The clamping disk assembly is aligned with the four tapped holes in the shaft end. Four mounting screws are inserted through the holes, but not tightened, so that the assembly is flush with the shaft end of the resolver and the panel. A straight pinion wrench is then used for angular adjustment of the resolver. When the resolver is aligned, the four mounting screws are tightened, securing the resolver at this angular position.

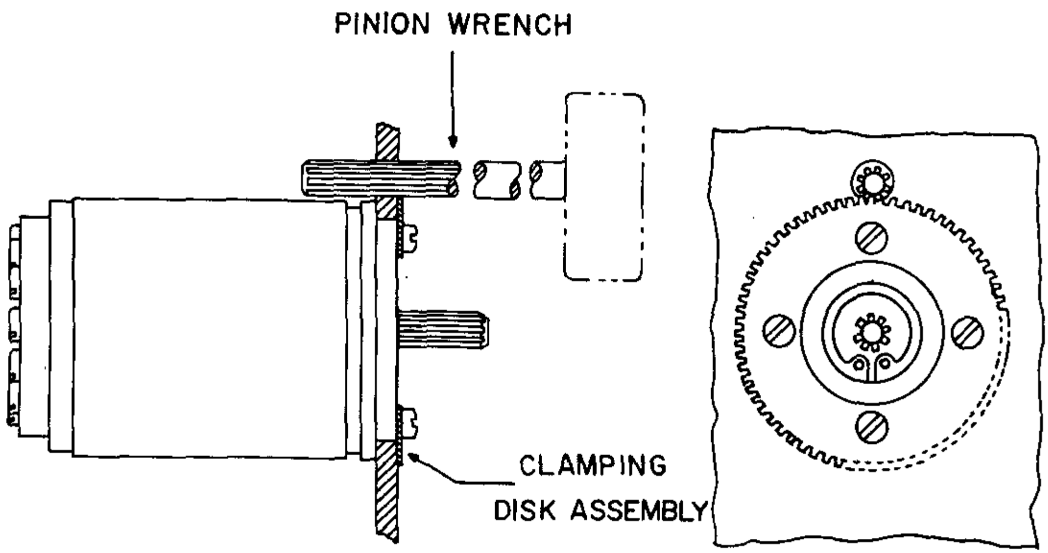


Figure 33. Resolver Mounted with Clamping Disk from Shaft End

7.7 Mounting From Terminal Board End, Using Zeroing Ring. Figure 34 shows a resolver mounted on a panel from the terminal board end, using a zeroing ring (Figure 39) and three clamp assemblies. The zeroing ring is slipped over the shaft end of the resolver so that the tongue of the ring fits into the slot of the resolver flange. The shaft end of the resolver is then inserted in the hole in the panel until the ring is flush with the panel. One end of each mounting clamp is then placed against the flange of the resolver housing. Each clamp assembly is attached to the panel with a captive screw, which is inserted in a pretapped hole in the panel, but not tightened. A 90-degree pinion wrench is used for angular adjustment of the resolver. (Note that straight and 90-degree wrenches are actually interchangeable, depending upon accessibility; the 90-degree wrench is used here for illustration only.) When the resolver is aligned, the three screws in the clamp assemblies are tightened, securing the resolver at this angular position.

7.8 Mounting a Gear on a Resolver Shaft. Figure 35 shows how a gear is mounted on a resolver shaft by means of a drive washer and drive nut, placed on the resolver shaft. The drive washer is next placed on the shaft so that its drive nut is screwed tightly against the drive washer, which is deformed into the spline shaft, eliminating backlash. Figure 41 illustrates the use of the socket wrench to prevent the resolver shaft from turning during assembly. After the nut is tight, tabs on the washer are bent over the nut to secure it. This same procedure is followed when mounting an adjustable dial.

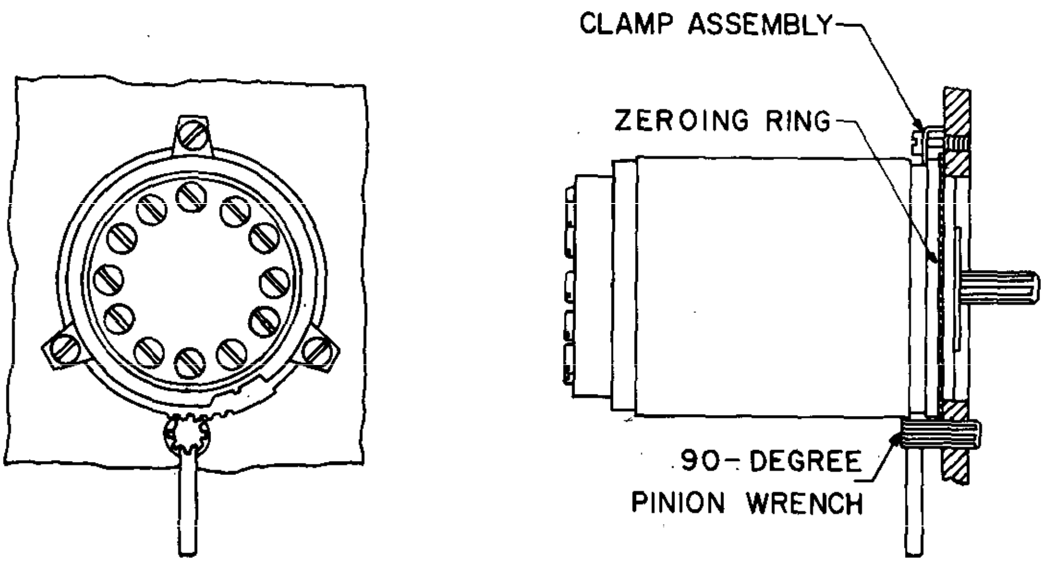


Figure 34. Resolver Mounted with Zeroing Ring from Terminal Board End

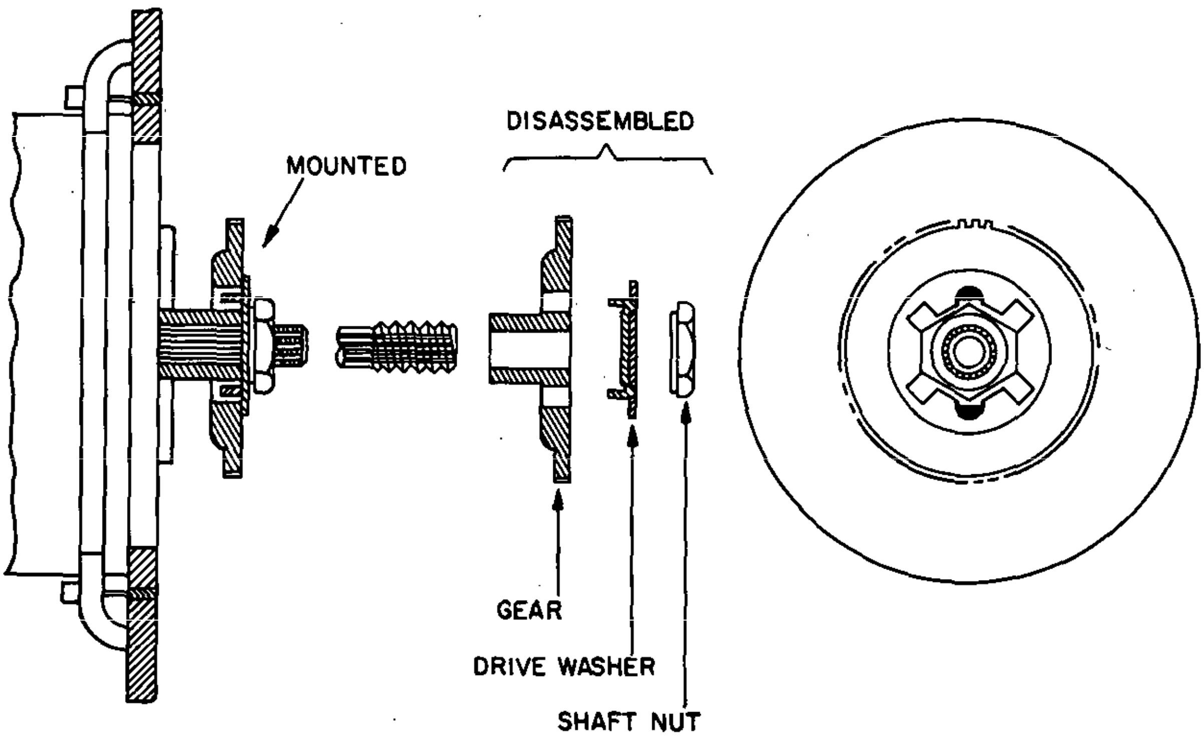


Figure 35. Mounting of a Gear on Resolver Shaft with Adapter

7.9 Electrical Connection. Provision is made for external electrical connections at the end opposite the shaft extension. Internal stator and rotor windings are brought out either to screw-type terminals or connector pins, or as unterminated lead wires. When lead wires are employed, they are color coded in accordance with the listing in Table II. Interconnection with screw-type terminals is direct. For resolvers with connector pins, the leads from the chassis terminal board are first attached to a resolver connector, and then the connector is attached directly to the terminal pins of the resolver.

Table II. Lead Wire Color Code

Rotor		Stator		Compensator	
Terminal	Color	Terminal	Color	Terminal	Color
R1	Red-white tracer	S1	Red	C1	Red-green tracer
R2	Yellow-white tracer	S2	Yellow	C2	Yellow-green tracer
R3	Black-white tracer	S3	Black	C3	Black-green tracer
R4	Blue-white tracer	S4	Blue	C4	Blue-green tracer

Note: When sleeving is used, a red sleeve is used for rotor leads, and a black sleeve is used for stator leads.

SECTION 8

PREFERRED OR STANDARD HARDWARE

8.1 General. Several items of hardware have been developed to facilitate resolver mounting and the attaching of gears or dials to resolver shafts. These hardware items are described in this section. Some of the items are stock material, and others are standard items that are not carried in stock.

8.2 Clamping Assembly. The clamping assembly (Figure 36) consists of a captive screw, lockwasher, and clamp. Three clamping assemblies, displaced from each other 120 degrees about the housing, may be used to mount a resolver directly, or they may be used in conjunction with the adapter assembly or zeroing ring.

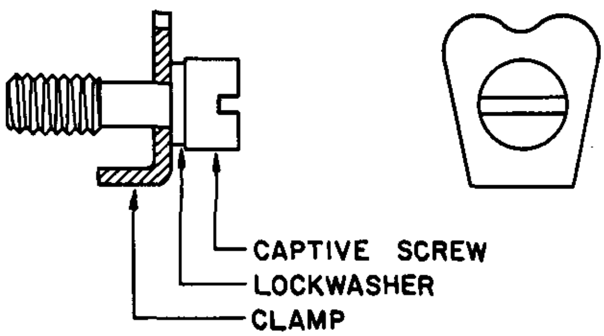


Figure 36. Clamp Assemblies

8.3 Clamping Disk Assembly. The clamping disk assembly (Figure 37) consists of a clamping disk, four captive screws, and four lockwashers. This assembly secures the resolver against the chassis and is made for use on all standard resolvers. The four screws fit into threaded holes on the shaft end of the resolver.

8.4 Geared-Tooth Adapter. The geared-tooth adapter assembly (Figure 38) consists of an adapter plus four captive screws and lockwashers. This assembly is used on resolvers of all sizes. The four screws fit into the four tapped holes on the shaft end of the resolver. When a geared-tooth adapter assembly is used, the resolver is secured to the chassis by three clamping assemblies.

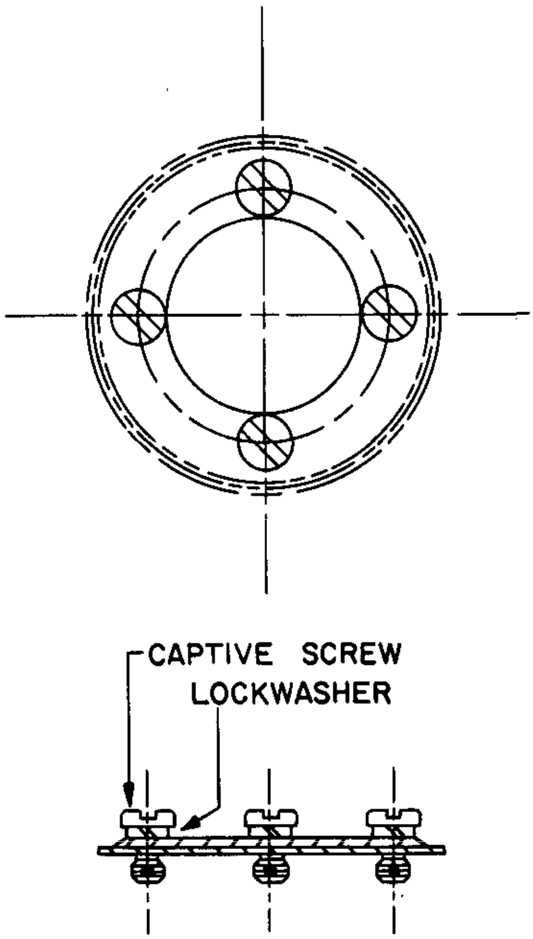


Figure 37. Adjustable Disk Assembly

8.5 Zeroing Ring. The zeroing ring (Figure 39) is a flat-spring steel ring having one sector with 6 to 20 gear teeth. Adjacent to the gear sector is a tongue which fits into a slot in the resolver housing and prevents the ring from turning around the resolver. When a zeroing ring is used, the resolver is secured to the chassis by three clamping assemblies. Zeroing rings are made to fit resolvers of all sizes.

8.6 Pinion Wrenches. When resolvers are mounted using an adapter assembly, clamping disk assembly, or zeroing ring, it is possible to adjust the resolver physically for electrical zero with either a straight or a 90-degree pinion wrench. These wrenches are shown in Figure 40. The chassis on which the resolver is mounted must be provided with a hole located

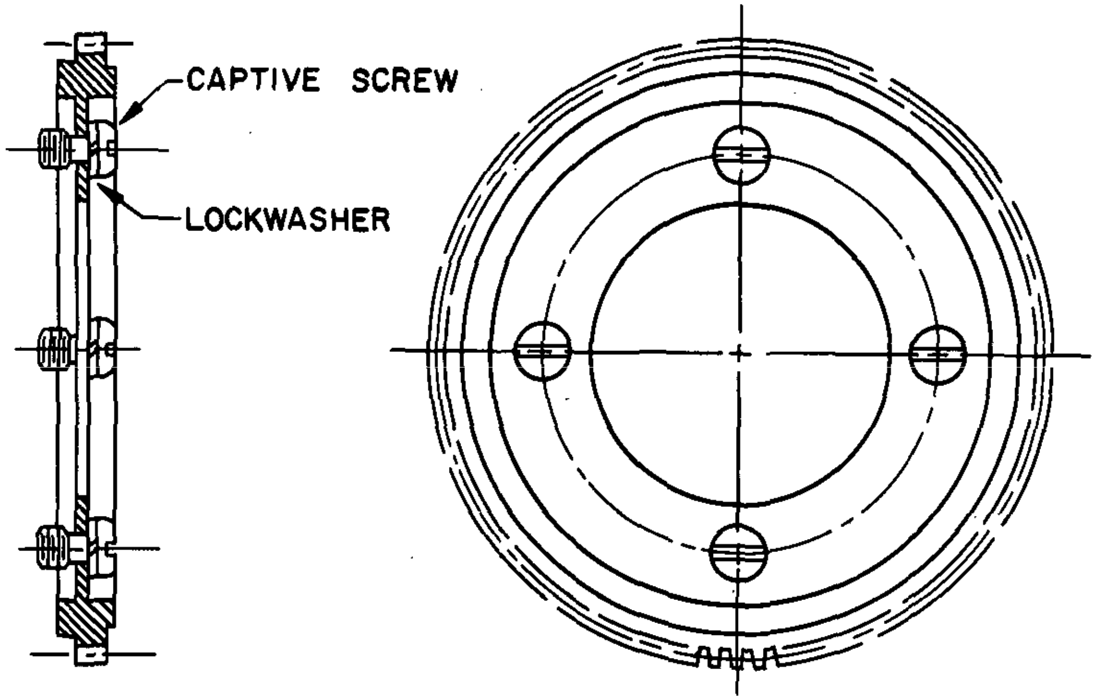


Figure 38. Geared-Tooth Adapter

so that when the pinion wrench is inserted in the hole, the teeth on the wrench engage the teeth in the assembly attached to the resolver. When the clamping arrangement is loosened, the resolver may be accurately adjusted for electrical zero.

8.7 Socket Wrench. The socket wrench shown in Figure 41 holds the splined shaft by means of an internally splined socket while the shaft nut is tightened with the outer socket. Socket wrenches are not available for all shafts.

8.8 Shaft Nut. Gears or dials are usually mounted on the shaft of a resolver, and the shaft nut and the drive washer (see 8.9) are used to hold them in place. These items are shown in Figure 42. Shaft nuts are made for resolver shafts of all sizes.

8.9 Drive Washer. When a dial or a gear is mounted on a resolver shaft, there must be no backlash between the shaft and the dial or gear. Drive washers are splined to fit the shaft, and are shaped so that when the shaft nut is tightened, the teeth will dig into the shaft. Two tapered drive dogs, shown in Figure 42, engage holes or slots in the dial or gear being mounted. The maximum width of the drive dog exceeds the hole diameter or slot width; when the shaft nut is tightened, the tapered drive dogs are wedged tightly into the holes or slots. The oversize drive dogs and splined center assure antibacklash mounting. For locking the shaft nut, tabs are provided which may be bent around the nut.

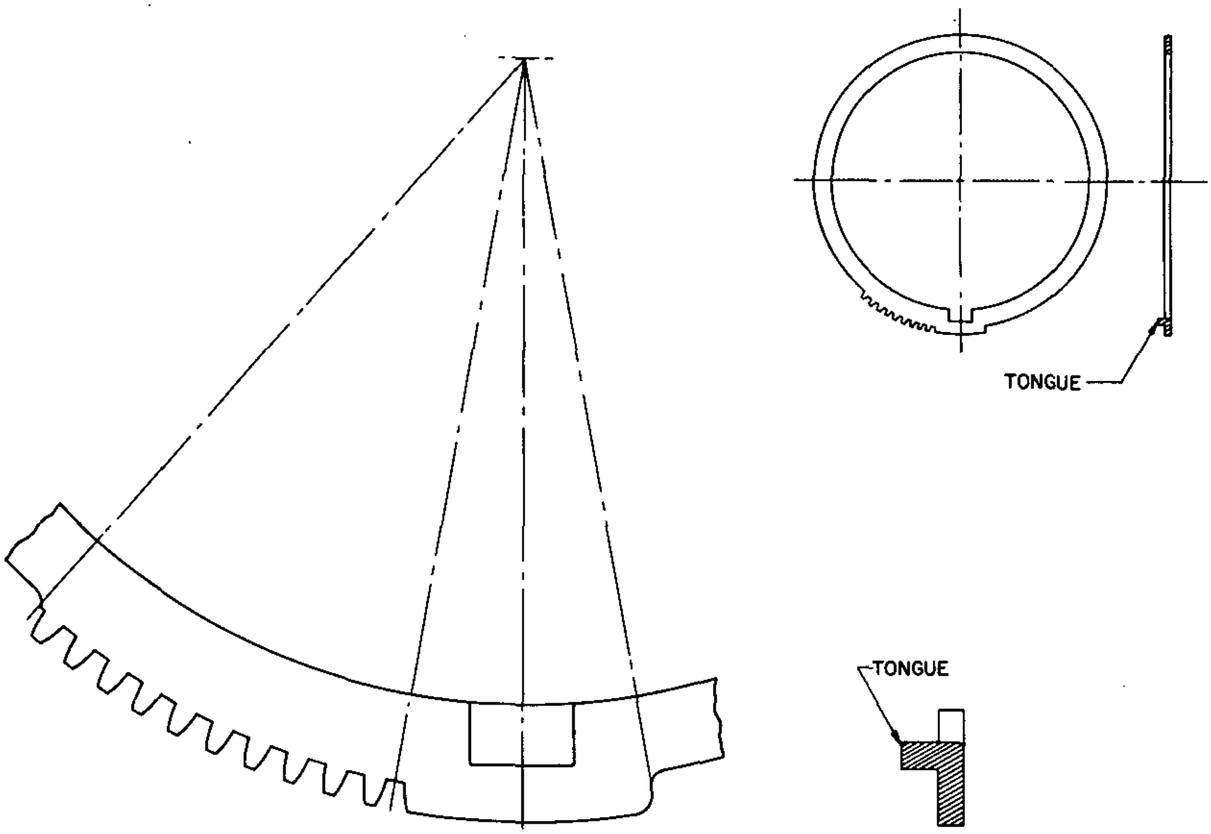


Figure 39. Zeroing Ring

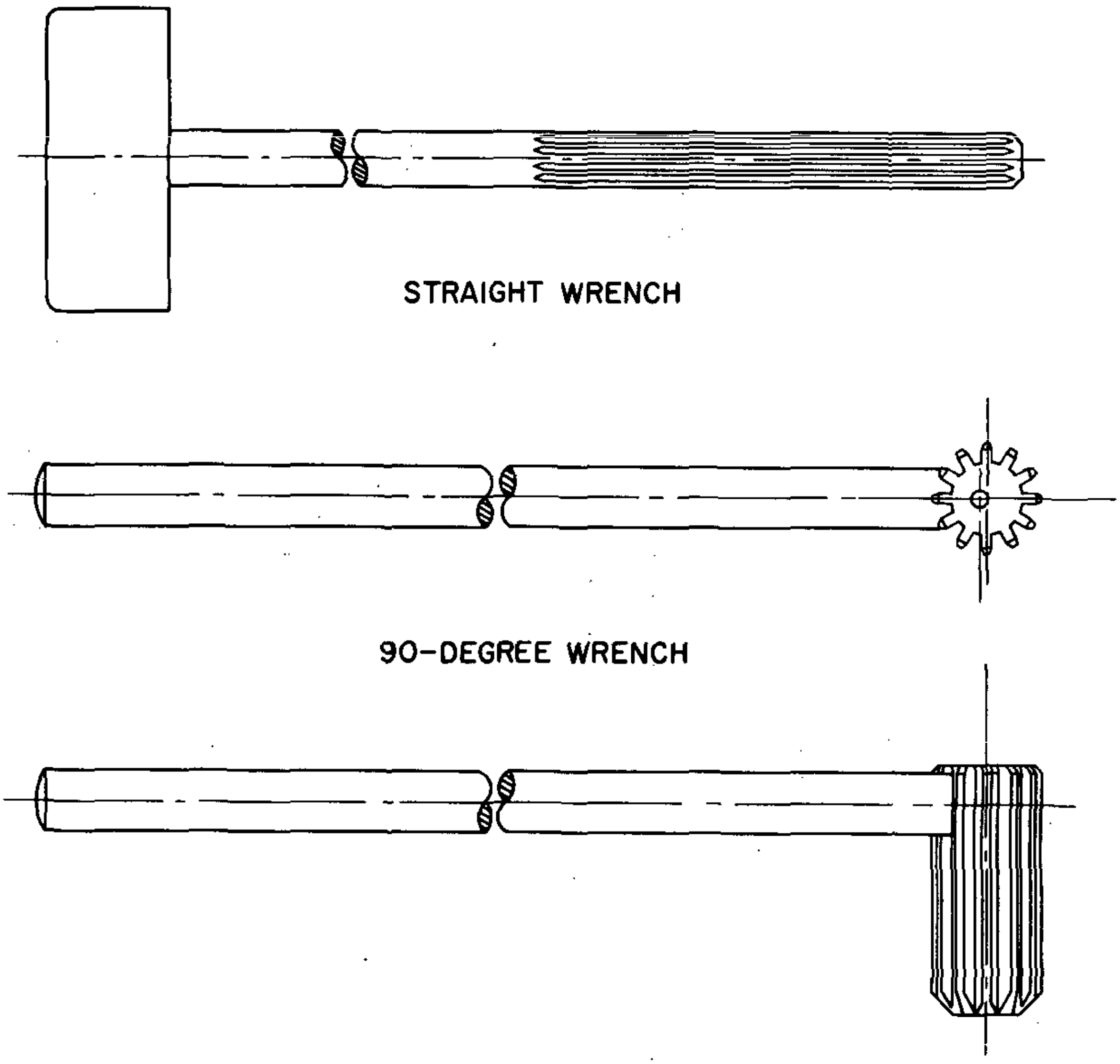


Figure 40. Pinion Wrenches

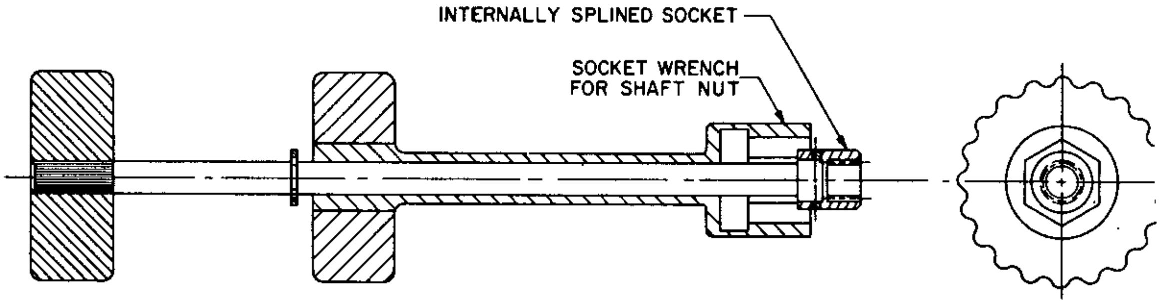


Figure 41. Socket Wrench

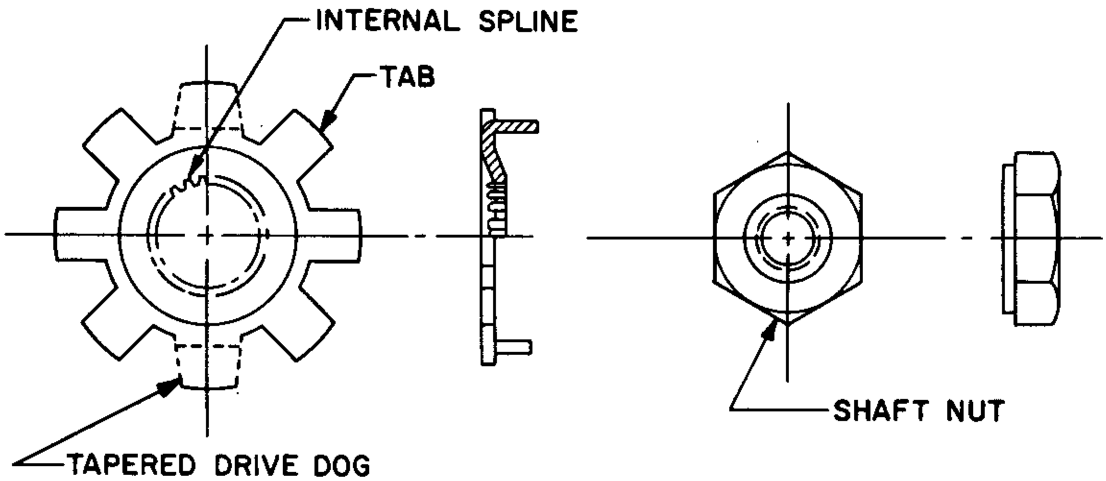


Figure 42. Shaft Hardware

GLOSSARY

CARRIER FREQUENCY	The frequency of the excitation voltage applied to the primary winding.
COMPENSATOR WINDING	An additional winding inserted within the stator slots of the resolver. This winding is stationary with respect to the resolver case and is used to correct the transformation ratio for various errors occurring during resolver operation.
DIRECTION OF ROTATION	Clockwise or counterclockwise rotation, determined when facing the shaft extension end of the resolver.
FUNCTION ERROR	The deviation of the output voltages of a resolver from the defining equations, designated as a percentage of the maximum value of the ideal sinusoidal function.
INEQUALITY OF TRANSFORMATION RATIOS	The variation of transformation ratios of the two rotor windings with respect to the same stator winding.
MAXIMUM COUPLING POSITION	The position of 90 mechanical degrees from a position of minimum coupling between rotor and stator windings.
MINIMUM COUPLING POSITION	The position of the rotor winding where minimum voltage is induced between stator and rotor windings.
MODE OF EXCITATION	The method of energizing the resolver, i.e., either the stator or rotor winding is energized.
NULL ANGLE	That angular position of the rotor at which the fundamental frequency component of each secondary output voltage is a minimum when one primary winding is excited and the other is shorted.
PEAK STATOR CURRENT	The maximum current rating of a resolver stator winding.

PEAKING FREQUENCY — That frequency at which the rotor response peaks because the distributed capacitance in the rotor resonates with the leakage inductance.

PHASE REFERENCE VOLTAGE — The fundamental component of the secondary voltage at the first position of maximum coupling, when the resolver rotor is turned in a positive direction from resolver zero.

PHASE SHIFT — The electrical angle by which the output voltage differs from the input voltage.

PRIMARY WINDING — The winding that receives the energizing power.

ROTOR ANGLE — The angular displacement of the resolver rotor about the rotor's axis from the resolver zero position, measured as an increasing positive angle in the counterclockwise direction.

ROTOR WINDING — The winding that rotates with respect to the resolver case.

SECONDARY WINDING — The winding from which the transformed voltage is taken.

STATOR WINDING — The winding that is stationary with respect to the resolver case.

TEST VOLTAGE — The input voltage at which the resolver will meet all the test requirements.

TRANSFORMATION RATIO — The ratio of the magnitude of the output voltage, at 90 degrees from resolver zero, to the magnitude of the input voltage.

WINDING DESIGNATIONS — The terminal designation (S, R, or C, for stator, rotor, or compensator) followed by an even or odd number, that is,
S1 - S3 for one stator winding
S2 - S4 for the opposite stator winding
R1 - R3 for one rotor winding
R2 - R4 for the opposite rotor winding

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