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ELECTRICAL COMPUTING RESOLVERS

LIST OF FIGURES

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INTRODUCTION

Electrical computing resolvers are important elements in analogue computation and coordinate transformation. It is the purpose of this document to define and detail those computing resolver properties which the designer needs to know for proper system application and which the inspection group needs to measure to assure quality.

1. SCOPE

1.1 This document covers resolvers which are used to perform coordinate transformations as well as sine and cosine computations. It includes both the categories of compensated and uncompensated resolvers which perform these functions. Linear resolvers are also included because of their similarity to resolvers.

1.2 Definitions

1.2.1 Electrical Computing Resolver - An electromagnetic device having primary and secondary windings so oriented that the voltages on the secondaries are sine and cosine functions of the angular position of the rotor with respect to the stator, multiplied by linear functions of the voltages applied to the primaries. The device is used for the computation of sine and cosine functions and for coordinate transformations.

1.2.1.1 Resistor Compensated Resolver - A resolver which contains one or more resistors having external termination intended for connection to an amplifier to bring the transformation ratio or phase shift of the resolver amplifier combination within close limits, or internal elements which compensate for changes in resolver characteristics with variation in temperature or other conditions.

1.2.1.2 Winding Compensated Resolver - A resolver which contains one or more windings magnetically coupled to the primary, with external terminations for providing a feedback voltage to a booster amplifier which energizes the primary. This design usually provides close control on transformation ratio and phase shift, and reduces effects of changes in temperature, frequency, applied voltage, or impedance loading to very low levels.

1.2.2 Linear Resolver - A linear resolver converts a mechanical input, rotor position, into an electrical output which is a linear function of rotor position over a specified angular travel. For purposes of this document the linear resolver will be considered as a special resolver.

1.2.3 Definitions of Terms

1.2.3.1 Rotor Angle - The rotor angle of a resolver is the angular displacement of the rotor from the electrical zero position. Rotation in a counter-clockwise direction facing the shaft extension end is to be considered a positive angular increase. When two shaft extensions exist, the one opposite the lead or terminal end will be used for this definition.

1.2.3.2 Windings

1.2.3.2.1 Primary Windings - A primary winding is one which receives energizing power.

1.2.3.2.2 Secondary Winding - A secondary winding is one from which an output is taken.

1.2.3.2.3 Compensator Winding - A compensator winding is an additional winding which provides a feedback voltage to adjust transformation ratio, phase shift, or loading effects.

1.2.3.3 Terminal or Lead Wire Identification - The following terminal designations shall be used:

Connection

Stator Windings		Rotor Windings	
Terminal	Color	Terminal	Color
S1	Red	R1	Red*
S3	Blk	R3	Blk*
S2	Yel	R2	Yel*
S4	Blu	R4	Blu*

Compensator Windings

Terminal	Color	Compensating Resistor
C1	Red**	1
C3	Blk**	3
C2	Yel**	2
C4	Blu**	4

*White Tracer **Green Tracer

Terminal designations or colors are such that stator and compensator winding terminals with like numbers have like polarity.

1.2.3.4 Phase Shift

1.2.3.4.1 Phase Shift - The time phase of the voltage at the computing resolver secondary with respect to the energizing voltage is the phase shift. The phase shift is measured in degrees and minutes with the rotor at maximum coupling.

1.2.3.4.2 Phase Shift Variation - The change in numerical value of phase shift relative to ambient temperature, input voltage level, excitation frequency, or shaft position should be expressed as a percentage relative to the value of phase shift at maximum coupling under specified excitation voltage, specified excitation frequency, and specified temperature.

1.2.3.5 Voltage Identification

1.2.3.5.1 In-Phase Voltage - An in-phase voltage is of the same time phase as the resolver output of fundamental frequency at maximum coupling.

1.2.3.5.2 Quadrature Voltage - A quadrature voltage differs by 90 deg time phase from the resolver output of fundamental frequency at maximum coupling.

1.2.3.5.3 E (R_{13}) is the fundamental in-phase voltage between rotor terminals R1 and R3.

E (S_{13}) is the fundamental in-phase voltage between stator terminals S1 and S3.

Other voltages are similarly defined.

1.2.3.5.4 The sequence of the terms within the parenthesis indicate the sense of the voltage vector.

1.2.3.6 Voltage Position

1.2.3.6.1 Minimum Voltage (Null) Position - A position of the rotor at which the secondary voltage of fundamental frequency, that is in time phase with the secondary voltage at maximum coupling, is zero (0).

1.2.3.6.2 Maximum Coupling Position - A position of the rotor at which the secondary voltage of fundamental frequency that is in time phase with the secondary voltage is a maximum.

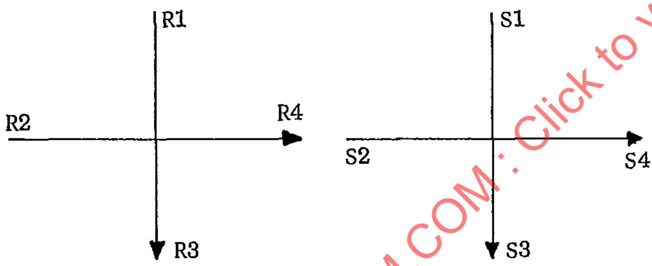
1.2.3.7 Null Voltage

1.2.3.7.1 Fundamental Null - Fundamental null, obtained at the minimum voltage positions, is the fundamental component of the residual voltage when the in-phase voltage is zero. This residual voltage consists entirely of quadrature voltage.

1.2.3.7.2 Total Null - When the fundamental in-phase output voltage obtained at the minimum voltage positions is zero, the residual voltage measured with a vacuum tube voltmeter indicating the average value of the voltage wave in terms of the rms value of an equivalent sine wave, is termed the total null. It includes harmonics and fundamental quadrature voltages.

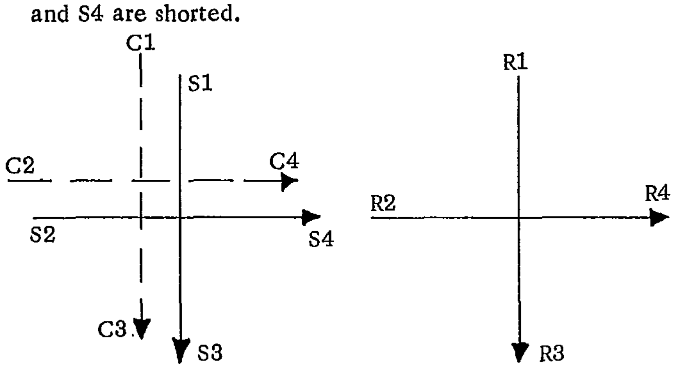
1.2.3.8 Electrical Zero

1.2.3.8.1 Rotor Excited Resolvers - That minimum voltage position of the secondary circuit S2-S4 from which a small counter-clockwise deflection of the rotor will induce a voltage E (S24) approximately in phase with E (R_{13}), when the unit is excited with rated voltage between terminals R1 and R3, and terminals R2 and R4 are shorted.



ROTOR EXCITED - STANDARD POLARITY AND ELECTRICAL ZERO POSITION

1.2.3.8.2 Stator Excited Resolvers - That minimum voltage position of the secondary circuit R2-R4 from which a small counter clockwise deflection of the rotor will induce a voltage E (R_{24}) approximately 180 deg out of phase with E (S_{13}), when the unit is excited with rated voltage between terminals S1 and S3, and terminals S2 and S4 are shorted.



STATOR EXCITED - STANDARD POLARITY AND ELECTRICAL ZERO POSITION

1.2.3.8.3 Linear Resolver - That position of the rotor for which the output windings experience minimum coupling.

1.2.3.9 Electrical Angle

1.2.3.9.1 Resolver, Rotor Excited - The electrical angle is the angle "a" displaced in a positive direction from electrical zero which satisfies the relative magnitudes and polarities of the secondary voltages in accordance with the following equations:

$$E\,(S_{13}) = N\,[E\,(R_{13}) \cos a \;- E\,(R_{24}) \sin a]$$

$$E\,(S_{24}) = N\,[E\,(R_{24}) \cos a \;+ E\,(R_{13}) \sin a]$$

Where: N is the ratio between the maximum fundamental rms, voltage between two secondary terminals (S1 and S3 or S2 and S4), with the other two terminals open, and the primary voltage applied between two primary terminals (R1 and R3 or R2 and R4).

1.2.3.9.2 Resolver, Stator Excited - The electrical angle is the angle "a" displaced in a positive direction from electrical zero which satisfies the relative magnitude and polarities of the secondary voltages in accordance with the following equations:

$$E\,(R_{13}) = N\,[E\,(S_{13}) \cos a \;+ E\,(S_{24}) \sin a]$$

$$E\,(R_{24}) = N\,[E\,(S_{24}) \cos a \;- E\,(S_{13}) \sin a]$$

Where: N is the ratio between the maximum rms, voltage between two secondary terminals (R1 and R3 or R2 and R4), with the other two terminals open, and the primary voltage applied between two primary terminals (S1 and S3 or S2 and S4).

1.2.3.9.3 Linear Resolver - The electrical angle "a" is the rotor position which satisfies the relative magnitude and polarities of the secondary voltages of a linear resolver in accordance with the following equation:

$$E(S2S4) = KaE(R1R3)$$

Lead Wire Identification

Rotor		Stator	
Terminal	Color	Terminal	Color
R1	Red, White tracer	S2	Yel
R3	Blk, White tracer	S4	Blu

1.2.3.10 Transformation Ratio

1.2.3.10.1 Transformation Ratio - The ratio of the no-load maximum fundamental secondary voltage to the fundamental supply voltage applied to the primary.

1.2.3.10.2 Transformation Ratio Unbalance - Transformation ratio unbalance is found by noting the maximum difference in the numerical value of transformation ratio of each output winding as each input winding is excited. This maximum difference expressed as a percentage of the nominal transformation ratio will be used to express transformation ratio unbalance.

1.2.3.10.3 Transformation Ratio Variation - The change in a numerical value of any particular transformation ratio relative to ambient temperature, input voltage level, or excitation frequency, should be expressed as a transformation ratio difference relative to the value of transformation ratio under nominal excitation voltage, nominal excitation frequency, and a specified temperature.

1.2.3.10.4 Voltage Gradient - The output voltage expressed as a function of input angle over the specified linear range - for example, volts per degree.

1.2.3.11 Errors

1.2.3.11.1 Null Spacing Errors - Null spacing error is the deviation expressed in angular units from 180 deg between the two minimum voltage positions of an output winding.

1.2.3.11.2 Interaxis Error - Interaxis error in a resolver is the angular deviation of the null positions for all rotor stator winding combinations from space quadrature.

1.2.3.11.3 Resolver Function Error - Function error is the difference between the actual fundamental in-phase output voltage and the theoretical voltage at any rotor displacement expressed as a percentage of the actual fundamental voltage at +90 deg from the minimum voltage position of the winding under test. The theoretical voltage shall coincide with the actual voltage at both the minimum voltage position and at +90 deg from that position.

1.2.3.11.4 Linear Resolver Functional Error - The functional error of a linear resolver at any rotor position within the specified limits, is the difference between the in-phase component of the output of the secondary winding and the theoretical output voltage. It is expressed as percent linearity. The theoretical output voltage is a straight line passing through zero having a slope equal to the voltage gradient.

1.2.3.11.4.1 Linearity - The ideal in-phase output voltage will be zero at linear resolver zero (EZ) by definition. The term linearity as used in this document will be zero based linearity (See Fig. 1). The tolerance on linearity is expressed in percent of rated output voltage.

$$\% \text{ linearity} = \frac{E_x - \frac{\theta_x}{\theta_{cal}} E_{cal}}{\frac{\theta\ max}{\theta\ cal} E_{cal}} \times 100$$

E_x = inphase output voltage at any angle θ_x

1.2.3.11.4.2 Calibration Angle - A preselected shaft position in the positive quadrant (between 0 and 90 deg shaft rotation, counter-clockwise facing the shaft extension end). A straight line drawn through the calibration angle and electrical zero, terminating at the positive and negative rated excursion angles, represents the ideal output voltage of the linear resolver. Because of the tolerance on transformation ratio, each linear resolver will not necessarily have zero error at the calibration angle.

1.2.3.12 Units - Unless otherwise specified the units for angles are degrees, minutes, and seconds. Potential is volts rms. Impedance is ohms. Current is amperes rms. Temperature is degrees Celsius.

2. CHARACTERISTICS

2.1 Physical

2.1.1 Envelope dimensions (See Figs. 2, 3 and 4)

2.1.2 Leadwire identification (See par. 1.2.3.3 and 1.2.3.9.3)

2.1.3 Terminal identification (See par. 1.2.3.3 and 1.2.3.9.3)

2.2 Electrical

2.2.1 Standard Test Conditions - Whenever the atmosphere and power conditions for a particular test are not definitely specified, it is understood that the test is to be made at the following standard conditions:

Temperature:	25 ± 5 C
Pressure:	30 in Hg nominal
Humidity:	75% max
Source Voltage:	Nominal ± 1%
Source Frequency:	Nominal ± 1%
Source Sinusoidal Waveform:	Less than 1% total harmonic content

2.2.2 Electrical Zero - Measurements of all angular displacements of the rotors of units should be referred to a standard position which will be designated as zero as defined in paragraph 1.2.3.8.

2.2.2.1 Rotor Excited Resolvers - The approximate electrical zero of a rotor excited resolver shall be determined by connecting the primary and secondary as shown in Fig. 5A. The resolver shaft shall be rotated to a position that produces the smallest reading in the VTVM. The electrical zero position shall then be accurately determined as follows: Without rotating resolver shaft, connect the resolver as shown in Fig. 5B. Rotate resolver shaft through the smaller angle that will provide a zero in-phase reading on the null meter. That position is the electrical zero position.

2.2.2.2 Stator Excited Resolvers - The approximate electrical zero of a stator excited resolver should be determined by connecting the primary and secondary as shown in Fig. 6A. The resolver shaft should be rotated to the position that produces the smallest reading in the VTVM. The electrical zero position should then be accurately determined as follows: Without rotating resolver shaft, connect the resolver as shown in Fig. 6B. Rotate resolver shaft through the smaller angle that will provide a zero in-phase reading on the null meter. That position is the electrical zero position.

2.2.2.3 Linear Resolvers - The approximate electrical zero of a rotor excited linear resolver should be determined by connecting the primary and secondary as shown in Fig. 5A except that S_2S_4 should be at maximum coupling. The linear resolver shaft should be rotated to a position that produces the smallest reading in the VTVM. The electrical zero position should then be accurately determined as follows. Rotate the linear resolver shaft 90 deg in the positive direction (counter-clockwise facing the shaft extension end). Connect the null meter across S_2S_4 as shown in Fig. 5B. Rotate the linear resolver shaft through the smaller angle that will provide a zero in-phase reading on the null meter. That position is the electrical zero position. On stator excited linear resolvers, energize S_2S_4 and use the same procedure measuring the null on R_1R_3.

2.2.3 Nulls - Refer to Fig. 5B and Table A1 for rotor excited resolvers or Fig. 6B and Table A2 for stator excited resolvers. With the unit at electrical zero as defined in paragraph 2.2.2 above, the resolver shaft is rotated to the successive null positions. Each null position should be the position where the fundamental in-phase component of the output voltage is zero. Read the fundamental null and total null at this position.

2.2.4 Null Spacing - Refer to Table A1 for rotor excited resolvers or Table A2 for stator excited resolvers. The null spacing for each stator-rotor pair is the deviation from 180 deg of the difference between each of the two positions for that particular stator-rotor pair.

2.2.5 Linear Resolver Null - Total and fundamental nulls are measured at electrical zero using the circuit of Fig. 5B.

2.2.6 Perpendicularity

2.2.6.1 Rotor Perpendicularity - Refer to Table B1 for rotor excited resolvers or Table B2 for stator excited resolvers. The rotor perpendicularity is the deviation from 90 deg of the difference between the two null positions occurring with one stator and the two rotor windings.

2.2.6.2 Stator Perpendicularity - Refer to Table C1 for rotor excited resolvers or Table C2 for stator excited resolvers. The stator perpendicularity is the deviation from 90 deg of the difference between the two null positions occurring with one rotor winding and the two stator windings.

2.2.7 Transformation Ratio

2.2.7.1 Rotor Excited Resolvers

2.2.7.1.1 Stator to Rotor - Es/Er - Refer to Table D1 and Fig. 7A. The ratio divider and phase shifter are adjusted until a null is obtained on the null detector. The transformation ratio is the ratio divider reading corrected for any change in voltage through the phase shifter.

2.2.7.2 Stator Excited Resolvers

2.2.7.2.1 Rotor to Stator - Er/Es - Refer to Table D2 and Fig. 7B. The ratio divider and phase shifter are adjusted until a null is obtained on the null detector. The transformation ratio is the voltage divider reading corrected for any change in voltage through the phase shifter.

2.2.7.2.2 Compensator to Stator - Ec/Es - Refer to Table D3 and Fig. 7C. The ratio divider and phase shifter are adjusted until a null is obtained on the null detector. The transformation ratio is the ratio divider reading corrected for any change in voltage through the phase shifter.

2.2.7.2.3 Rotor to Compensator - Er/Ec - Refer to Table D4. The two transformation ratios are computed as follows:

$$\frac{E_{r13}}{E_{c13}} = \frac{E_{r13}/E_{s13}}{E_{c13}/E_{s13}}$$

$$\frac{E_{r24}}{E_{c24}} = \frac{E_{r24}/E_{s24}}{E_{c24}/E_{s24}}$$

2.2.7.3 Linear Resolver - Transformation ratio as previously defined is not measured for linear resolvers. Instead, the output voltage is measured at the calibration angle with the rated load on the secondary. This measurement is expressed in volts per degree and is the voltage gradient. The ideal voltage gradient occurs when the output voltage at the calibration angle equals the ideal output voltage.

2.2.7.4 Transformation Ratio and Phase Shift - Transformation ratio and shift measurements should be made with the resolver mounted in the angular index stand (paragraph 4.2.3) and excited with rated voltage and frequency from a power source as described under standard conditions. The measurement should be made at the first position of maximum coupling as the rotor is turned in a counterclockwise direction from electrical zero.

2.2.7.4.1 The ratio and phase measuring circuit may be of the type shown in Fig. 7A, 7B, and 7C.

a) The null detector should be of the type described in paragraph 4.2.1.
b) The resistive and capacitive elements should have an accuracy of at least 0.1%.

2.2.7.5 Equality of Transformation Ratio

2.2.7.5.1 Rotor Excited Resolvers

2.2.7.5.1.1 Rotor to Stator - Refer to Table E1. The transformation ratio balance is the difference between the two transformation ratios associated with one rotor winding and two stator windings.

2.2.7.5.2 Stator Excited Resolvers

2.2.7.5.2.1 Stator to Rotor - Refer to Table E2. The transformation ratio balance is the difference between the two transformation ratios associated with one stator winding and the two rotor windings.

2.2.7.5.2.2 Stator to Compensator - Refer to Table D3. The transformation ratio balance is the difference between the transformation ratios associated with the two stator windings and their corresponding compensator windings.

2.2.7.5.3 Primary Balance

2.2.7.5.3.1 Rotor Excited Resolvers - Refer to

Table F1. The primary balance is the difference between the two transformation ratios associated with the two rotor windings and one stator winding.

2.2.7.5.3.2 Stator Excited Resolvers - Refer to Table F2. The primary balance is the difference between the two transformation ratios associated with the two stator windings and one rotor winding.

2.2.8 Phase Shift

2.2.8.1 Rotor Excited Resolvers

2.2.8.1.1 Stator to Rotor - Refer to Table D1 and Fig. 7A. The ratio divider and phase shifter are adjusted until a null is obtained on the null detector as in paragraph 2.2.7.1.1. The phase shift is obtained from the indication of the calibrated phase shifter.

2.2.8.2 Stator Excited Resolvers

2.2.8.2.1 Rotor to Stator - Refer to Table D2 and Fig. 7B. The ratio divider and phase shifter are adjusted until a null is obtained on the null detector as in paragraph 2.2.7.2.1. The phase shift is obtained from the indication of the calibrated phase shifter.

2.2.8.2.2 Compensator to Stator - Refer to Table D3 and Fig. 7C. The ratio divider and phase shifter are adjusted until a null is obtained on the null detector as in paragraph 2.2.7.2.2. The phase shift is obtained from the indicator of this calibrated phase shifter.

2.2.8.2.3 Rotor to Compensator - Refer to Table D4. The two phase shifts are computed as follows:

The phase shift between E_{r13} and $E_{c13} = \phi_1 - \phi_2$.

The phase shift between E_{r24} and $E_{c24} = \phi_3 - \phi_4$.

2.2.9 Function Error

2.2.9.1 Rotor Excited - Refer to Fig. 8A and Table G1. Establish the electrical zero position as indicated in paragraph 2.2.2.1. Rotate the resolver shaft to the mechanical 90 deg position. Adjust the phase shifter and ratio divider until a null is attained on the null detector. For ease of computing function error, an external normalizing circuit may be used to calibrate the ratio divider to unity at this 90 deg position. At any position through the range as indicated on Table G1, the ratio divider is adjusted for a null. Function error is then computed as follows:

$$\text{Function Error (\%)} \quad \frac{100\,[\text{ratio divider reading at angle } \phi - \text{Sin } \phi \text{ (ratio divider reading at } \phi = 90 \text{ deg)}]}{\text{ratio divider reading at } \phi = 90 \text{ deg}}$$

When the windings are switched as indicated in Table G1, a new null position shall be at approximately 0 degrees. Rotate the resolver shaft to the mechanical 270 deg position established from this null position. Adjust the phase shifter, ratio divider, and if applicable, the normalizing circuit until a null is attained on the null detector. Proceed to determine function error for this second set of windings as indicated in Table G1 using the following relationship:

$$\text{Function Error (\%)} \quad \frac{100\,[\text{ratio divider reading at angle } \phi - \text{Sin } \phi \text{ (ratio divider reading at } \phi = 270 \text{ deg)}]}{\text{ratio divider reading at angle } \phi = 270 \text{ deg}}$$

2.2.9.2 Stator Excited - Refer to Fig. 8A and Table G2. Establish the electric zero position as indicated in paragraph 2.2.2.2. Rotate the resolver shaft to the mechanical 90 deg position. Adjust the phase shifter and ratio divider until a null is attained on the null detector. For ease of computing function error, an external normalizing circuit may be used to calibrate the ratio divider to unity at the 90 deg position. At any position through the range indicated in Table G2, the ratio divider is adjusted for a null. Function error is then computed as follows:

$$\text{Function Error (\%)} \quad \frac{100\,[\text{ratio divider reading at angle } \phi - \text{Sin } \phi \text{ (ratio divider reading at } \phi = 90 \text{ deg)}]}{\text{ratio divider reading at angle } \phi = 90 \text{ deg}}$$

When the second set of windings is switched as indicated in Table G2 a new null position should be established at approximately 0 degrees. Rotate the resolver shaft to the mechanical 270 deg position from this null. Adjust the phase shifter, ratio divider, and if applicable, the normalizing circuit until a null is attained on the null detector. Proceed to determine function error for this second set of windings as indicated in Table G2 using the following relationship:

$$\text{Function Error (\%)} \quad \frac{100\,[\text{ratio divider reading at angle } \phi - \text{Sin } \phi \text{ (ratio divider reading at } \phi = 270 \text{ deg)}]}{\text{ratio divider reading at angle } \phi = 270 \text{ deg}}$$

2.2.9.3 Functional Error Measurements - Functional error measurements should be made with the resolver mounted in the angular index stand (paragraph 4.2.3) and excited with rated voltage and frequency from a power source as described under standard conditions. The measurements shall be made in 5 deg increments from 0 to 180 degrees.

2.2.9.3.1 The error test may be accomplished by using the circuit as shown in Fig. 8A.

2.2.9.3.1.1 The "readout" transformer should have an accuracy of at least 10 times that of the unit error under test.

2.2.9.3.1.2 The null meter should be of the type described in paragraph 4.2.1.

2.2.9.4 Linear Resolver Linearity Tests - Refer to Fig. 8B. The setting of the voltage divider is a direct function of the output voltage across the load. Establish the voltage divider setting for the calibration angle position, then divide that setting by the number of test points to be measured. Five deg test increments are recommended. Set the unit at electrical zero. Rotate the unit to the first test point. Set the voltage divider to the first position. If a null does not appear on the null detector, the voltage divider is adjusted and the difference between the ideal setting and the actual setting is recorded. This is the linearity error. This process is repeated for each test position.

2.2.10 Impedance - Impedance measurements should be made under standard conditions with the resolvers set at electrical zero as described in Fig. 9.

2.2.11 Hi Pot and Insulation

2.2.11.1 High Potential Test - Test winding should be at ambient temperature (25 ± 5 C). Each unit should be tested for electrical breakdown of insulation and at rated test voltage of 60 hertz. Test voltage should have the amplitude and should be applied at the location and for the duration specified below. The minimum source impedance of the Hi Pot voltage supply should be 100,000 ohms. A voltmeter should be connected across the location to indicate the voltage applied.

2.2.11.1.1 Amplitude

2.2.11.1.1.1 500 v rms if windings are rated 60 v rms or less.

2.2.11.1.1.2 1000 v rms if winding is rated above 60 v rms.

2.2.11.1.1.3 500 v between insulated halves of windings.

2.2.11.1.2 Location

2.2.11.1.2.1 From windings to frame and between winding.

2.2.11.1.3 Duration

2.2.11.1.3.1 Increase test voltage gradually to maximum rms value at rate not exceeding 75 v per second.

2.2.11.1.3.2 Hold test voltage at maximum rms value for 60 ± 5 seconds.

2.2.11.1.3.3 Decrease test voltage gradually to zero amplitude at rate not exceeding 75 v per second.

2.2.11.1.4 Failure - A leakage current in excess of 1 milli-ampere should be considered a failure except for special windings which must be individually evaluated.

Initial High Potential Tests by qualifying agency should be performed at voltage indicated. Subsequent High Potential Tests should be performed at voltages not in excess of 80% of these values.

2.2.11.2 Insulation Resistance Test - Test windings should be at ambient temperature (25 ± 5 C). The resistance measured at 500 v max, d-c between separate windings and from windings to frame should not be less than 100 megohms. The test should be performed after the high potential test.

2.2.12 D-C Resistance Test - The d-c resistance test should be measured at 25 C. Detail requirements should be called out by the individual requirements.

2.2.13 Frequency Response

2.2.13.1 The resolver should be tested for frequency response over a sufficiently wide frequency range by exciting the input winding at test voltage from a variable frequency source. The variable frequency source should have a waveform with a distortion less than 1%.

2.2.13.2 With the output voltage set at maximum coupling for a given pair of windings and with the resolver housing grounded, measure the db change in the output voltage over the specified frequency spectrum. The test voltage and frequency will be used as the reference point for all measurements.

2.2.13.3 The low corner frequency is that frequency at which the output voltage is down 3 dB from the reference value and at a phase shift of 45 deg with respect to the input voltage.

2.2.13.4 The mid-range frequency is that frequency range over which the output voltage does not vary by more than ±0.5 db from the reference value.

2.2.13.5 Peak or resonant frequency is that frequency at which the output voltage reaches a maximum value.

2.3 Environmental Conditions - The intent of this section is to assure that the resolvers covered by this document will function during and after being subjected to various specified test environments.

The units should not sustain any type of destructive deterioration as a result of environmental testing. Any resolver covered under this document shall be capable of successfully undergoing all of the following tests, except the Endurance Test which applies to units not previously exposed to environmental testing.

2.3.1 Temperature

2.3.1.1 Low Temperature - The resolver shall be mounted in a test fixture suitable for measuring functional accuracy in a temperature controlled chamber. The resolver shall be positioned at electrical zero at standard conditions and then de-energized.

The unit should be maintained at -65°C ± 5°C for a 12 hr period. At the end of this period the chamber temperature should be increased to -54°C ± 5°C. With the unit energized with the rated test voltage and frequency, the chamber temperature should be maintained for a 3 hr period. At the end of this period and while maintaining the chamber temperature, the functional error of the resolver should be checked. The error should not exceed the specified maximum value. The resolver should then be set at its new electrical zero and the nulls and zero shift should be no greater than the specified maximum values. After the completion of this test, the unit should meet the performance requirements of section 2.2 at standard conditions.

2.3.1.2 High Temperature - The resolver should be mounted in a test fixture suitable for measuring functional accuracy in a temperature controlled chamber. The resolver should be positioned at electrical zero at standard conditions and then de-energized. The chamber temperature should be raised to and maintained at 135 ± 5 C for a 3 hr period. At the end of this period the chamber temperature should be reduced to 85 ± 5 C. With unit energized with rated test voltage and frequency, the chamber temperature should be maintained for a period of 3 hr. At the end of this period and while maintaining the chamber temperature, the functional error of the resolver should be no greater than the specified maximum value. The resolver should then be set at its new electrical zero and the null voltage and electrical zero shift should be no greater than the specified maximum values. After completion of this test, the unit should meet the performance requirements of Section 2.2 at standard conditions.

2.3.1.3 Thermal Shock - The resolver should be placed unenergized within a test chamber whose internal temperature is maintained at -65 ± 5 C. After 3 hr of exposure in and within one minute of removal from this chamber, the unit should be transferred to a chamber whose temperature is being maintained at 135 ± 5 C.

Final unit exposure at 135 C should be 3 hr and will constitute the end of one cycle. The complete cycle should be repeated three more times for a total of four cycles.

At the completion of this test the unit should meet the performance requirements of Section 2.2 at standard conditions.

2.3.2 Temperature - Altitude - The resolver should function between sea level and 100,000 ft altitude and throughout an ambient temperature range of -54 C to +85 C.

2.3.2.1 Altitude - Low Temperature - The resolver should be placed in a temperature chamber at atmospheric pressure and the chamber temperature reduced to -54 ± 5 C. With the resolver energized, at its rated voltage and frequency, the conditions should be maintained for a period of at least 3 hr. At the end of this period, and while maintaining temperature, the internal pressure of the chamber should be reduced to simulate an altitude of 100,000 ft and held for an additional hr. There should be no evidence of interruption of the output voltage throughout the test. After the completion of this test, the unit should meet dielectric and insulation tests, as specified for standard conditions.

2.3.2.2 Altitude - High Temperature - The resolver should be placed in a temperature chamber at atmospheric pressure and the chamber temperature raised to 85 ± 5 C. With the unit energized at its rated voltage and frequency, the condition should be maintained for a period of at least 3 hr.

At the end of this period, and while maintaining temperature, the internal pressure of the chamber should be reduced to simulate an altitude of 100,000 ft and held for an additional hr. There should be no evidence of interruption of the output voltage throughout the test.

After the completion of this test, the unit should meet the dielectric, and insulation tests as specified for standard conditions.

2.3.3 Humidity

2.3.3.1 The resolver to be tested should be placed unenergized in a test chamber and the temperature raised at a uniform rate from room temperature (20 C to 38 C) to 71 ± 5 C during a 2 hr period. The temperature of 71 ± 5 C should be maintained during the next 6 hr period. During the following 16 hr period, the temperature in this chamber must drop at a uniform rate to room temperature (20 C to 38 C). This will constitute one cycle. Throughout the cycle the relative humidity should be maintained at 95% ± 5%. The cycle should be repeated ten times (240 hr). Distilled or demineralized water having a ph value of between 6.5 and 7.5 at 25 C should be used to obtain the desired humidity. The condensate from the walls of the chamber should not be permitted to drip directly on resolver under test. The air velocity in the test chamber should not exceed 150 ft per minute. After this exposure the resolver under test should be dried for a period of 24 hr at ambient temperature (20 C to 38 C). At the conclusion of this period the unit should function and meet the requirements of paragraph 2.2.

2.3.4 Vibration

2.3.4.1 The resolver should be rigidly mounted using the normal mounting surfaces. A d-c current, not to exceed .010 amperes, should be applied to the two rotor circuits connected in series. One side of the circuit should be grounded to the case. (The resolver current should be monitored using an oscilloscope or any other suitable device. There should be no indication of opening or shorting of the rotor circuit during vibration).

2.3.4.2 Resonant vibration frequency sweep survey should be conducted along each of the three mutually perpendicular axes throughout a range of 10 to 2000 Hz in 15 minute cycles. The survey should be at either a maximum acceleration of 15 g ± 10% or a double amplitude of .06 in. ± 10%, whichever is the lower value. All measurements should be made at the resolver.

(Critical resonant frequency is defined as that frequency at which any point on the resolver is observed to have a maximum amplitude of twice that of the support point.)

2.3.4.2.1 The resolver shall be vibrated at any indicated resonant frequency determined in the preceding test, for a period of 60 minutes. If more than one resonant point is found along any of the three mutual perpendicular axes, the test may be conducted at the most severe resonant point, or the period may be divided among all the resonant points. The choice should be determined by the selection of the method which is considered most likely to produce unit failure. In no instance should the resolver be vibrated at any resonant mode for a period of less than 30 minutes.

2.3.4.2.2 When critical resonant frequencies are not apparent within the specified frequency range, the resolver under test should be vibrated at a frequency between 400 and 500 Hz along the three mutually perpendicular axes for a period of 60 minutes for each axis.

2.3.4.3 Upon the completion of vibration testing the unit should meet all the requirements of Section 2.2 and there should be no loosening or breakage of parts. The end play and radial play of the shaft should be as specified.

2.3.5 Shock

2.3.5.1 The resolver should be connected to the test equipment by its normal means of mounting. The resolver should be subjected to four blows, applied along each of the three major axes of the resolver, two in each direction for a total of 12 blows. Each blow should be a half a sine pulse having an amplitude of 50 g ± 10% and a duration of 11 milliseconds ± 10%.

2.3.5.2 Upon the completion of this test, the resolver should function and meet the performance requirements of Section 2.2. There should be no loosening or breakage of parts. The end play and radial play of the resolver shaft should be as specified.

2.3.6 Endurance

2.3.6.1 The resolvers covered by this document should, after being subjected to the following tests, sustain no damage which could in any manner prevent the unit from meeting all the electrical and mechanical requirements as specified.

2.3.6.2 The resolver, at ambient temperature, should be given an endurance test of 1200 ± 10 hr at 1150 ± 50 rpm while energized with its rated voltage and frequency. The 1200 hr should be divided as specified below. The clockwise and counterclockwise time may be divided in segments of convenience. The rotor shaft should be mechanically rotated in any manner which does not apply an axial load to the rotor.

1. Shaft vertical, upward - 50 hr
2. Shaft inclined 45°, upward - 50 hr
3. Shaft inclined 45°, downward - 50 hr
4. Shaft vertical, downward - 50 hr
*5. Shaft horizontal - 1,000 hr

*50% of time to be CW: 50% of time to be CCW.

At the conclusion of this test, the resolver should fulfill all specified requirements of this document with the exception of friction torque. The allowable friction torque should be increased 50% at the conclusion of this test.

3. QUALITY ASSURANCE

3.1 Classification of Tests — Symbol

(a) Performance
(b) Qualification
  1. Design Assurance (C)
  2. Environmental
    a. Non-Destructive (E)
    b. Destructive (D)

3.1.1 Performance Tests - Tests performed on each unit, using production test equipment, to determine whether expected normal manufacturing variations are exceeded.

3.1.2 Qualification Tests - Measurements which provide type approval for the component in terms of its conformance to intended requirements (design assurance) and/or in terms of its capability to meet and survive various environmental conditions.

3.1.2.1 Design Assurance Tests - Qualification tests which measure, using laboratory methods and equipment, all characteristics other than environmental capabilities.

3.1.2.2 Environmental Tests - Qualification tests which measure the unit's reaction to temperature, pressure, vibration, shock, etc.

3.1.2.2.1 Non-Destructive Tests - Those tests which cause no damage or deterioration which could shorten life or permanently impair performance.

3.1.2.2.2 Destructive Tests - Qualification tests which could cause damage or deterioration that would shorten life or permanently impair performance. After having been subjected to these tests, a unit could not reasonably be expected to have the same life as a unit not so subjected.

3.1.3 Index of Tests Required

3.1.3.1 Qualification Tests for Qualification Approval

TEST	PARAGRAPH	CLASSIFICATION
Physical	2.1	C
Nulls	2.2.3	C
Null Spacing	2.2.4	C
Linear Resolver Nulls Only	2.2.5	C
Perpendicularity	2.2.6	C
T. R.	2.2.7	C
Phase Shift	2.2.8	C
Function Error	2.2.9	C
Impedance	2.2.10	C
Hi Pot & Insul. Rest.	2.2.11	C
Low Temperature	2.3.1.1	E
High Temperature	2.3.1.2	E
Thermal Shock	2.3.1.3	D

Alt. Low Temperature	2.3.2.1	E
Alt. High Temperature	2.3.2.2	E
Humidity	2.3.3	D
Vibration	2.3.4	D
Shock	2.3.5	D
Endurance	2.3.6	D

3.1.3.2 Performance Tests for Production Acceptance

TEST	PARAGRAPH
Physical	2.1
Hi Potential	2.2.11
Insulation Resistance	2.2.11
Functional Error	2.2.9
Nulls	2.2.3
Null Spacing	2.2.4
Nulls - Linear Resolver	2.2.5
Perpendicularity	2.2.6
Transformation Ratio	2.2.7
Phase Shift	2.2.8

4. APPENDIX

4.1 This appendix describes the recommended test equipment which is required to perform the tests as listed in Section 2.2, Electrical Characteristics.

4.2 Equipment

4.2.1 Phase-Sensitive Null Meter - The PSNM should be a phase-sensitive null meter capable of indicating 0.2 minute of arc displacement of the resolver under test from the null position and having an impedance not less than that of a 500,000 ohm resistance shunted by a capacity of 30 pF. The phase-sensitive null meter shall be capable of discrimination against a value of quadrature of 0.2% of the maximum output voltage of the resolver under test and against a value of total harmonic content of 1% of the maximum output voltage of the resolver under test, such that the combined quadrature and harmonic voltages produce a meter indication less than that produced by a 0.2 minute of arc displacement of the rotor from null position.

4.2.2 Voltmeter

4.2.2.1 Voltage Readings or Total Null Measurements - The voltage measuring devices should indicate the average value of the voltage wave in terms of the rms value of an equivalent sine wave, and should have an input impedance of at least 500,000 ohms shunted by a capacity of 30 pF. Fundamental and total null voltages should be measured at specified test voltage.

4.2.2.2 Fundamental Null Measurement - A frequency-sensitive voltmeter should be used which has a fundamental frequency filter with a change of output voltage not to exceed ± 0.5% for change of ±1% in excitation frequency. The output voltage shall also be at least minus 30 dB at half and twice rated frequency. The meter shall be properly compensated for the insertion loss of the filter. Turn the resolver rotor until a minimum voltage is obtained on the frequency-sensitive voltmeter.

4.2.3 Angular Index Divider - The mechanical index divider for positioning the resolver to the required angles shall have an accuracy of at least 15 seconds of arc.

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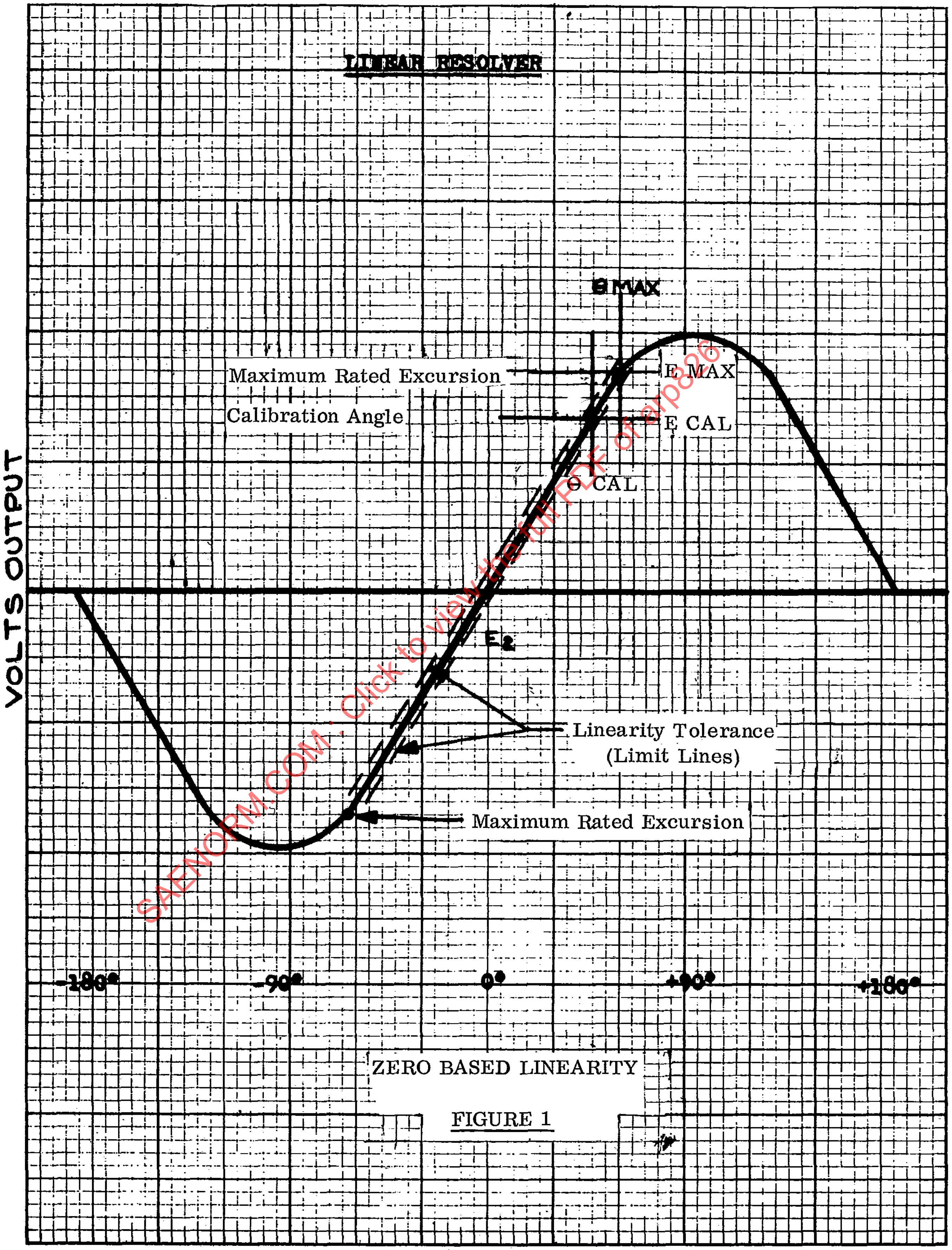
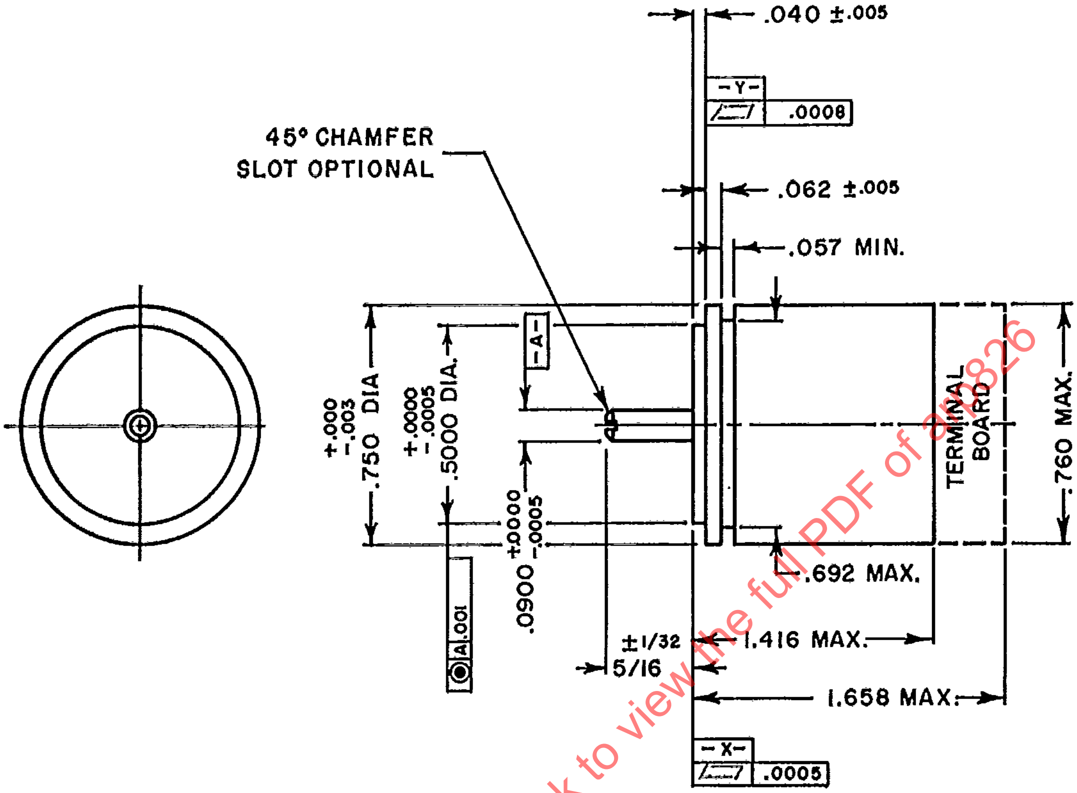
COMMITTEE A-2, AEROSPACE ELECTRICAL & ELECTRONIC EQUIPMENT



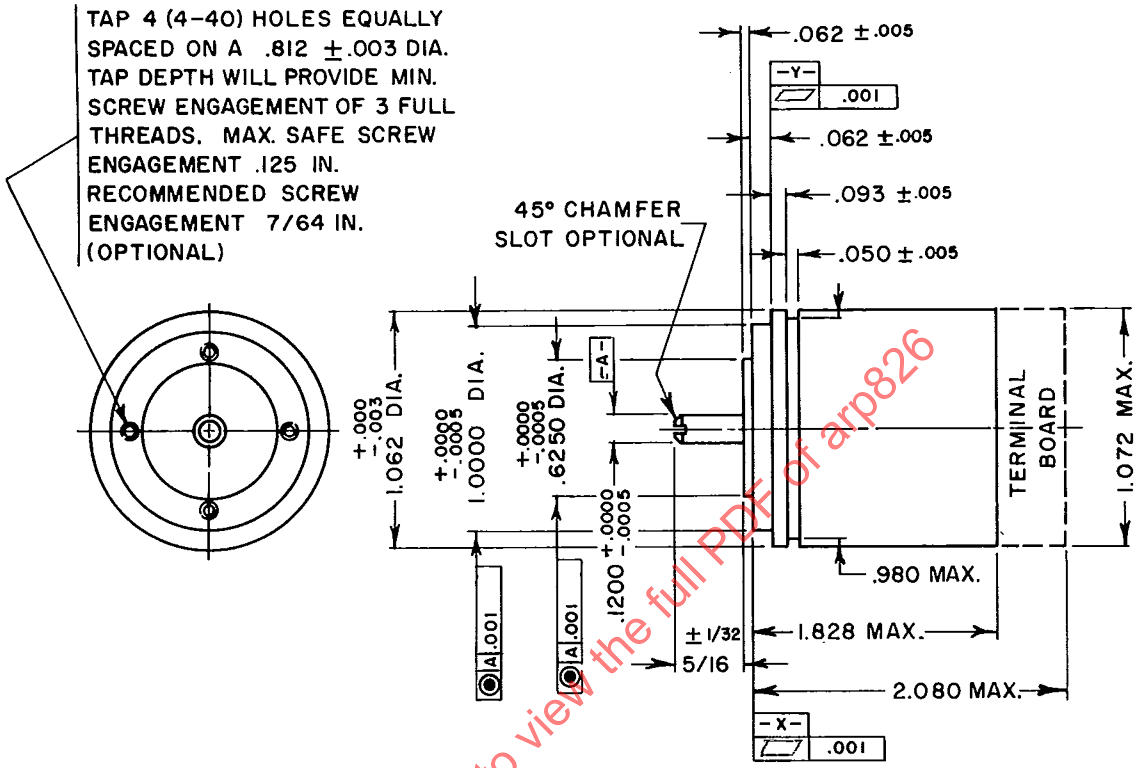
ZERO BASED LINEARITY

FIGURE 1



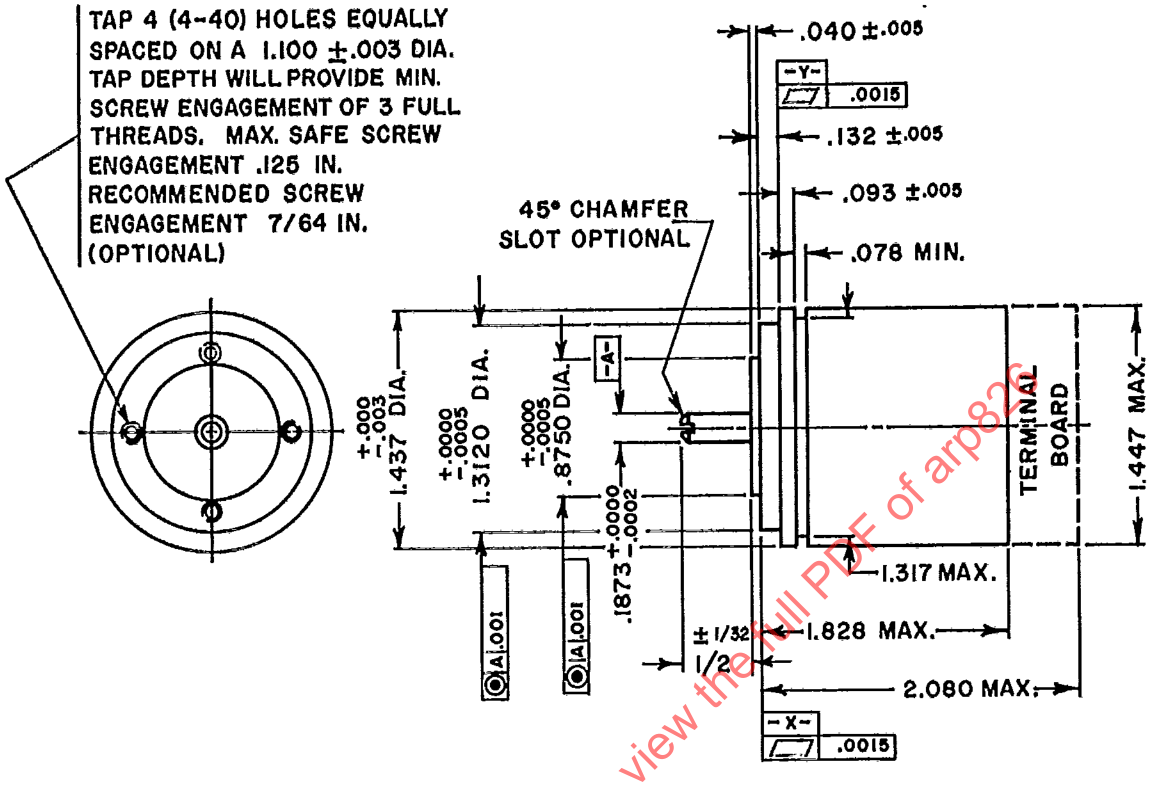
1. RUNOUT MEASURED 1/8" FROM END OF SHAFT WILL NOT EXCEED .001" FULL INDICATOR READING.
2. SURFACES "X" AND "Y" PERPENDICULAR TO CENTER OF ROTATION OF SHAFT WITHIN .001 IN./IN. OF DIA. MEASURED 1/16" FROM OUTSIDE EDGE OF SURFACE.
3. SURFACE "Y" IS RECOMMENDED MTG. SURFACE.
4. RADIAL PLAY OF SHAFT MEASURED WITH 4 OZ. GAUGE LOAD 1/8" FROM FRONT OF HOUSING .001" MAX.
5. END PLAY WITH 4 OZ. GAUGE LOAD .0002" MIN. TO .0015" MAX.
6. FRICTION 3 GM CM AT ROOM TEMPERATURE AND 5 X AT EXTREME TEMPERATURES.

FIGURE 2 - SIZE 8 ENVELOPE



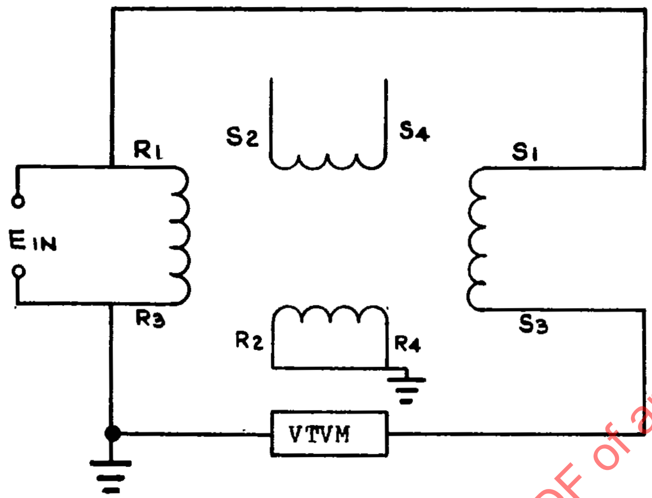
1. RUNOUT MEASURED 1/8" FROM END OF SHAFT WILL NOT EXCEED .001" FULL INDICATOR READING.
2. SURFACES "X" AND "Y" PERPENDICULAR TO CENTER OF ROTATION OF SHAFT WITHIN .001 IN./IN. OF DIA. MEASURED 1/16" FROM OUTSIDE EDGE OF SURFACE.
3. SURFACE "Y" IS RECOMMENDED MTG. SURFACE.
4. RADIAL PLAY OF SHAFT MEASURED WITH 4 OZ. GAUGE LOAD 1/8" FROM FRONT OF HOUSING .0010" MAX.
5. END PLAY WITH 4 OZ. GAUGE LOAD .0002" MIN. TO .0015" MAX.
6. FRICTION 5 GM CM AT ROOM TEMPERATURE AND 5 X AT EXTREME TEMPERATURES.

FIGURE 3 - SIZE 11 ENVELOPE

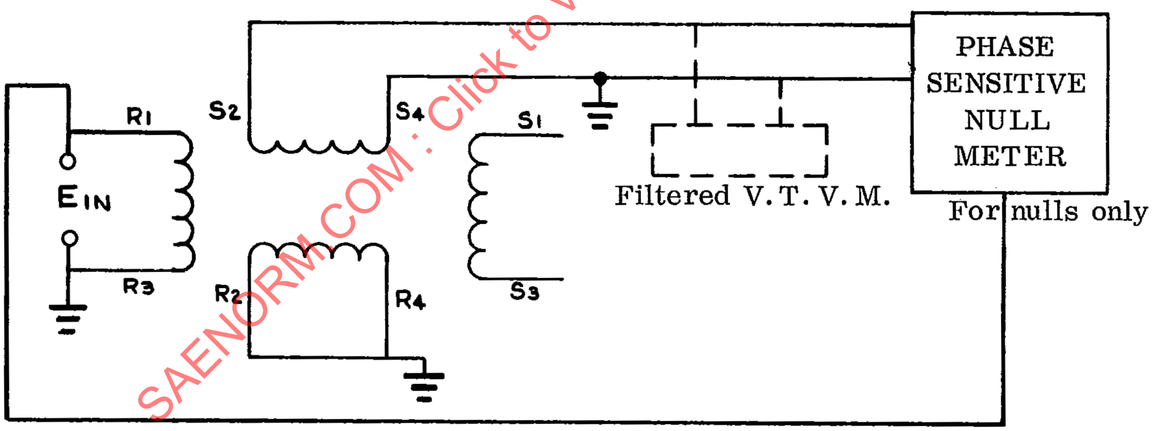


1. RUNOUT MEASURED 1/8" FROM END OF SHAFT WILL NOT EXCEED .001" FULL INDICATOR READING.
2. SURFACES "X" AND "Y" PERPENDICULAR TO CENTER OF ROTATION OF SHAFT WITHIN .001 IN./IN. OF DIA. MEASURED 1/16" FROM OUTSIDE EDGE OF SURFACE.
3. SURFACE "Y" IS RECOMMENDED MTG. SURFACE.
4. RADIAL PLAY OF SHAFT MEASURED WITH 4 OZ. GAUGE LOAD 1/8" FROM FRONT OF HOUSING .0005" MAX.
5. END PLAY WITH 4 OZ. GAUGE LOAD .0002" MIN. TO .0015" MAX.
6. FRICTION 5 GM CM AT ROOM TEMPERATURE AND 5X AT EXTREME TEMPERATURES.

FIGURE 4 - SIZE 15 ENVELOPE

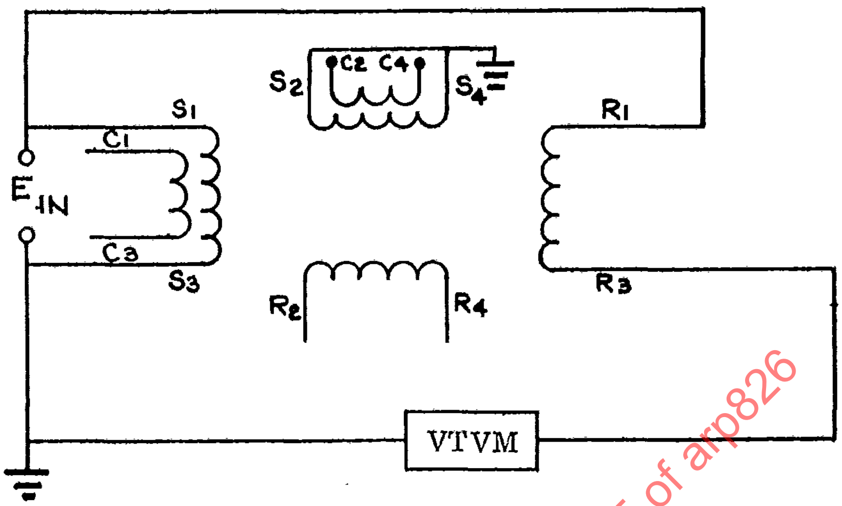


A Approximate Electrical Zero - Rotor excited resolvers.

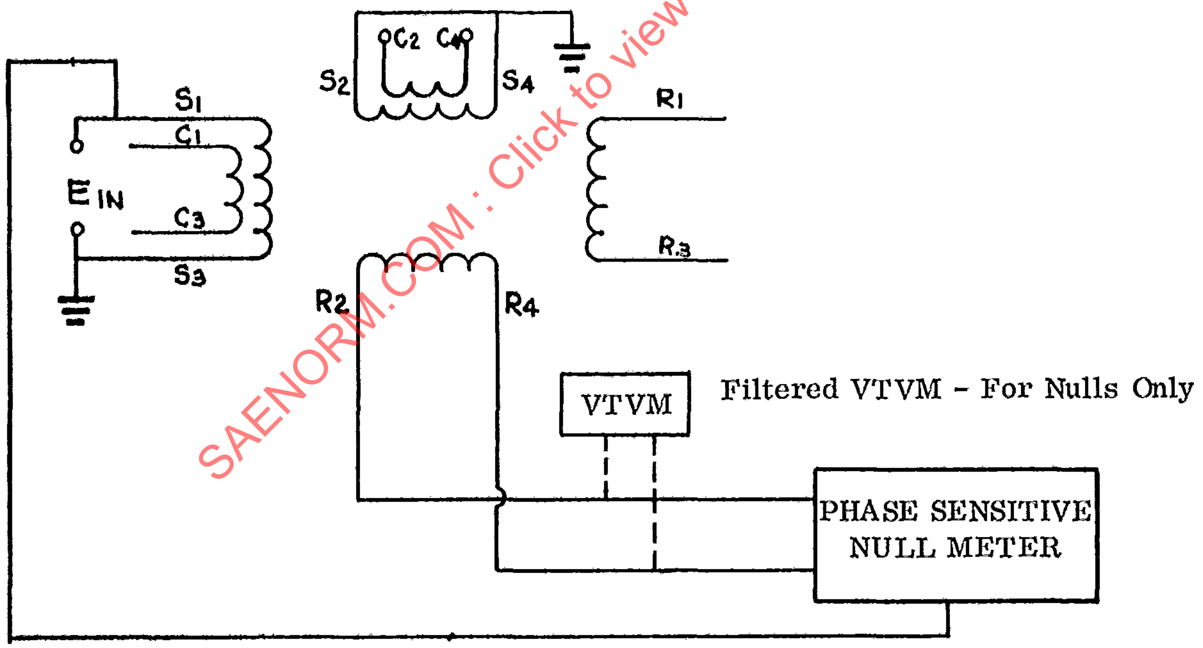


B Electrical Zero Rotor excited Resolvers

FIGURE 5 - ELECTRICAL ZERO TEST CIRCUIT ROTOR PRIMARY



A Approximate Electrical Zero - Stator Excited Resolvers.



B Electrical Zero Stator Excited Resolvers

FIGURE 6 - ELECTRICAL ZERO TEST CIRCUIT STATOR PRIMARY

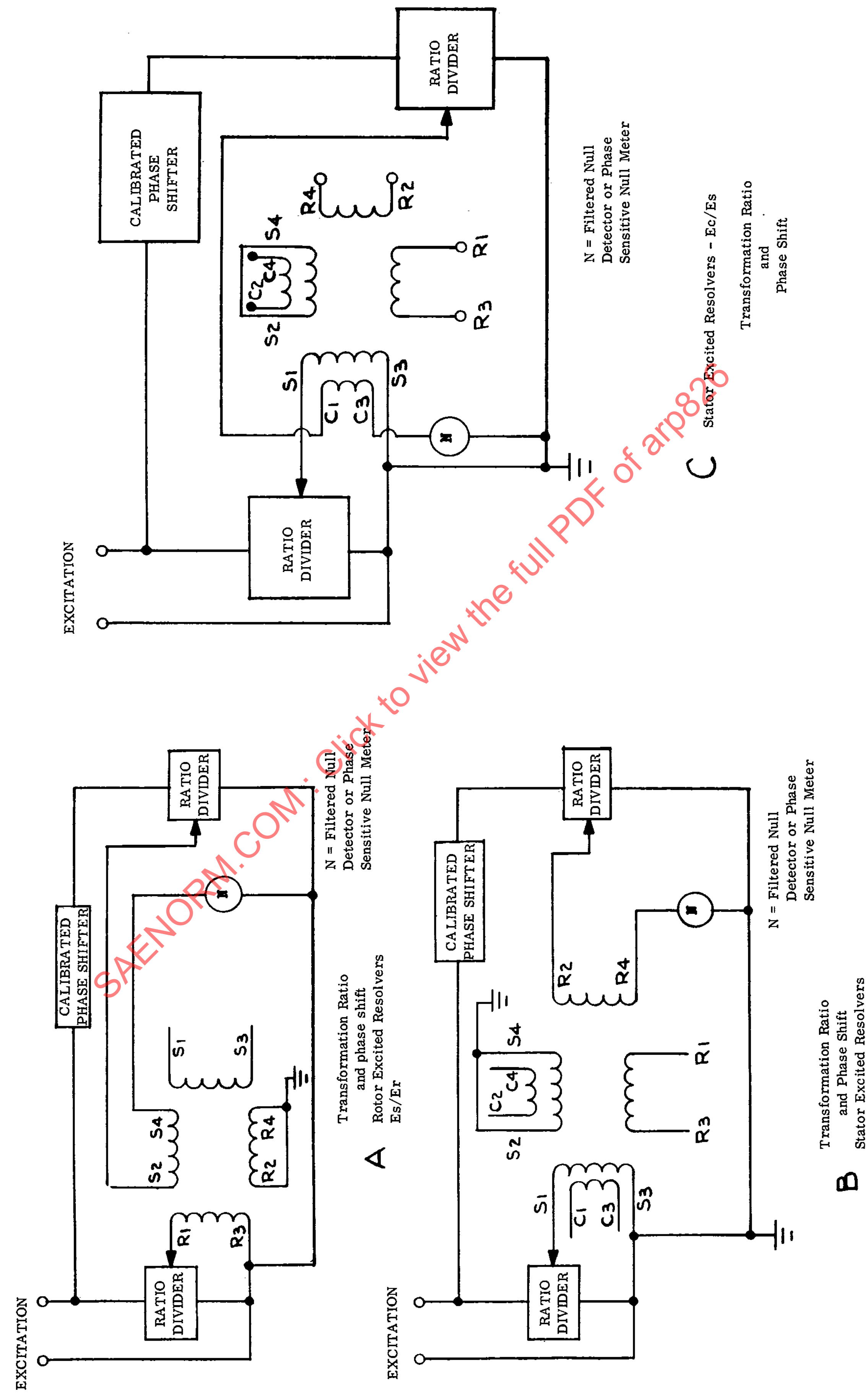


FIGURE 7 - TRANSFORMATION RATIO and PHASE SHIFT TEST CIRCUIT