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SYNCHRO CONVENTIONS

All schematics are shown at electrical zero when facing shaft extension (end opposite lead exit or terminals).

TRANSMITTERS (CG)

have a single phase salient pole rotor mechanically positioned with respect to a symmetrical 3-phase stator.

Low impedance and relatively high power capabilities characterize Torque Transmitters used to drive synchro Receivers or combinations of Differentials and Control Transformers.

Control Transmitters use less exciting current and they are most frequently connected to a Control Transformer or, less often, to a Differential and a C.T. in series.

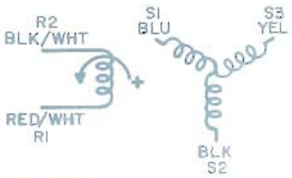
(See diagram below)

RECEIVERS (CR)

have a line excited salient pole rotor free to turn within a 3-phase stator electrically connected to the corresponding stator leads of the driving Torque Transmitter.

Receivers feature free end-play (.002-.005″) and an internal means of damping the rotor's tendency to oscillate or even spin when subjected to transients.

Despite high torque gradients the equilibrium position of Receiver rotors is a torqueless one and the electrical accuracy is obscured by the friction of bearings and brushes.



Rotor as Primary

$E(S13)=N[E(R21)\sin a]$

$E(S32)=N[E(R21)\sin(a+120^\circ)]$

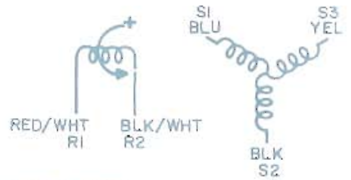
$E(S21)=N[E(R21)\sin(a+240^\circ)]$

CONTROL TRANSFORMERS (CT)

have 3-phase stators of medium to high impedance which are excited by other synchros, Transmitters or Differentials, establishing electrically a directional field whose heading or angle is detected by the proper null output of the single phase winding on a cylindrical rotor.

Of course cylindricalness and perfect symmetry are essential to minimize or avoid distortions of the stator established directional field, i.e., C. T. calibration error.

C.T.'s with their impedances and cylindrical rotors should not generally be used as Transmitters to other C.T.'s without wider tolerances on system accuracy, null levels, and phase shift variations than that obtainable in Transmitter-C.T. systems.



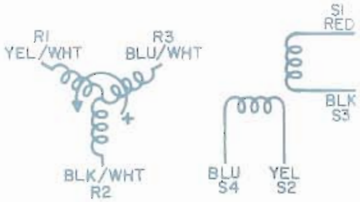
Stator as Primary

$E(R12)=N[E(S13)\sin(a+120^\circ)-E(S32)\sin a]$

$E(S13)+E(S32)+E(S21)=0$

DIFFERENTIAL RESOLVERS (CDS)

have a three-phase cylindrical rotor and a two-phase stator. The construction is the inverse of our transolver and its uses are the same—it can be used either as a CG or a CT with no loss in accuracy. The advantage of the differential resolver over the transolver lies in the fact that the outputs are not picked off of slip rings, thus reducing noise and making four-wire outputs less costly.



Size 10 lead units only, rotor color coding:
RI=BLU/WHT; R2=BLK/WHT; R3=YEL/WHT.

Rotor as Primary

$E(S13)=N[-E(R13)\cos(a+240^\circ)+E(R32)\cos a]$

$E(S42)=N[-E(R13)\sin(a+240^\circ)+E(R32)\sin a]$

$E(R13)+E(R32)+E(R21)=0$

Stator as Primary

$E(R13)=N[E(S31)\sin a+E(S42)\cos a]$

$E(R32)=N[E(S31)\sin(a+240^\circ)+E(S42)\cos(a+240^\circ)]$

$E(R21)=N[E(S31)\sin(a+120^\circ)+E(S42)\cos(a+120^\circ)]$

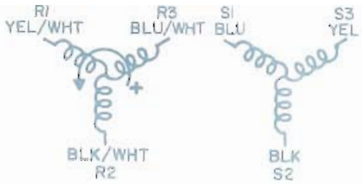
DIFFERENTIALS (CD)

are the synchro analog of their mechanical namesake. 400 cycle airborne units consist of 3-phase stators and 3-phase cylindrical rotors.

In servo control systems, the stator primary is excited by the stator voltages of a Transmitter and the rotor leads are wired to those of another stator, most often those of a C.T. and occasionally another Differential in a synchro chain.

Sometimes a Differential is used to provide a pointer-dial readout of two Transmitters between which it is connected. In this mode it is subject to the end-play and friction factors of Receivers.

Differentials must be double-tested for electrical accuracy. The stator calibration error is that observed by locking the differential rotor and looking at the rotor output relative to an electrically rotating stator input; and the rotor calibration is the output error in minutes as a function of different rotor positions.



Size 10 lead units only, rotor color coding
RI=BLU/WHT; R2=BLK/WHT; R3=YEL/WHT.

Stator as Primary

$E(R13)=N[E(S13)\sin(a+120^\circ)-E(S32)\sin a]$

$E(R32)=N[E(S13)\sin a-E(S32)\sin(a+240^\circ)]$

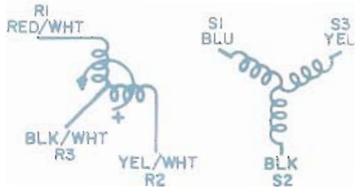
$E(R21)=N[E(S13)\sin(a+240^\circ)-E(S32)\sin(a+120^\circ)]$

$E(S13)+E(S32)+E(S21)=0$

TRANSOLVERS (CSD)

have a two-phase cylindrical rotor mechanically positioned within a three-phase stator.

The two-phase rotor enables this device to be used as either a transmitter or a control transformer with no degradation of accuracy or nulls. For use as a transmitter, one rotor phase is excited; the other is shorted to ground, providing quadrature suppression and producing, in effect, a salient-pole rotor. For use as a CT, the stator is excited from another three-wire device (CG or CD) and the output is obtained from one rotor phase. The second rotor phase is then symmetrically loaded to avoid unbalances.



Rotor as Primary

$$E(S13) = N[E(R13)\sin a - E(R23)\cos a]$$

$$E(S32) = N[E(R13)\sin(a + 120^\circ) - E(R23)\cos(a + 120^\circ)]$$

$$E(S21) = N[E(R13)\sin(a + 240^\circ) - E(R23)\cos(a + 240^\circ)]$$

Stator as Primary

$$E(R13) = N[-E(S13)\cos(a + 120^\circ) + E(S32)\cos a]$$

$$E(R23) = N[-E(S13)\sin(a + 120^\circ) + E(S32)\sin a]$$

$$E(S13) + E(S32) + E(S21) = 0$$

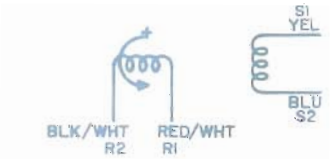
Note: This type unit is also available with a four-wire rotor excitation; Transolver (CZD). Substitute (R24) for (R23) in the above equation; R4 = BLU/WHT.

LINEAR TRANSFORMERS (LT)
(Induction Potentiometers)

have a single phase salient pole rotor primary winding and a single phase non-sinusoidally wound stator secondary.

Being transformers, the windings are electrically isolated and the resolution is practically unlimited. Since the range of travel and the desired sensitivity varies widely in different applications, best results are obtained by advising Clifton's Engineering Department of these factors along with any secondary load information available.

The popularity of Linear Transformers is due to their temperature coefficients being the same as the resolvers with which they are most often used.



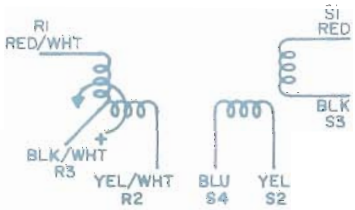
Rotor as Primary

$$E(S12) = N[E(R12)\,a]$$

ELECTRICAL RESOLVERS (CS)

in the synchro family, is the name given to units used for vector addition and also to resolve a vector representing voltage into its orthogonal components. The classic application is to solve the unknowns of a right triangle.

As a vector adder, single frequency, sinusoidal voltages are applied, generally, to the 2-phase windings of the stator establishing a resultant field within which a 2-phase servo rotated rotor is turned to produce a null on one winding. The output of the other rotor winding represents the magnitude of the resultant, and the physical rotor angle is the direction. In the tables, 2Φ-2Φ units have CS or CZ type number prefixes.



Rotor as Primary

$$E(S13) = N[E(R13)\cos a + E(R23)\sin a]$$

$$E(S24) = N[E(R23)\cos a - E(R13)\sin a]$$

Stator as Primary

$$E(R13) = N[E(S13)\cos a - E(S24)\sin a]$$

$$E(R23) = N[E(S24)\cos a + E(S13)\sin a]$$

Note: This type unit is also available with a four-wire rotor excitation; Computing Resolvers (CZ). Substitute (R24) for (R23) in the above equation; R4 = BLU/WHT.

PHASE SHIFTERS (PS)

generically are resolver type synchros specially manufactured and tested for calibration error as phase shifters, the error being the plus or minus difference in degrees between the time phase of the output and the mechanical input angle setting of the rotor.

In some models, single frequency two phase excitation is applied to the two space phase windings of either the rotor or the stator, thereby establishing a circular, rotating field.

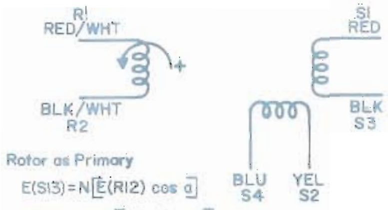
Another phase shifting principle is employed in those instances where only single phase excitation exists for the primary winding. In this instance, the two orthogonal secondary windings are connected in series with a resistor and a capacitor of equal impedance. The time phase measured between the input voltage and that appearing at the junction of R and C will correspond in degrees to the rotor angle measured from "zero" or the exact in-phase heading.

For schematic diagram and phasing equation, see applicable Resolver.

VECTOR RESOLVERS (CV-CW)
(Sine-Cosine Generators)

If the application only requires the resolution of a vector into its components then a 1Φ-2Φ unit suffices. If the output windings terminate in high impedances, the rotor may be of dumbbell (salient pole) variety like the units listed in the following pages with a CV prefix.

Cylindrical, single phase rotor windings, marked in the tables by a CW prefix to the type number, are employed where the impedances of the input and output circuits are not so favorable.



Rotor as Primary

$$E(S13) = N[E(R12)\cos a]$$

$$E(S24) = -N[E(R12)\sin a]$$

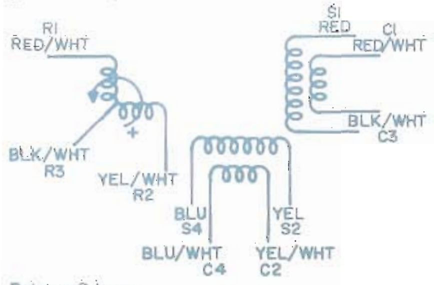
Stator as Primary

$$E(R12) = N[E(S13)\cos a - E(S24)\sin a]$$

COMPENSATED RESOLVERS (CY)

made with feedback or compensation windings in the stator that parallels the regular two stator phases are marked in the tables by a CY prefix to the type number.

Where very exacting performance requirements justify the complexity of feedback amplifiers or driver amplifiers (sometimes simply called "booster amplifiers") featuring a very low output impedance into the resolver, the feedback winding will extend the range, especially at the low end, over which the output will be a trigonometrically faithful function of the input amplitudes.



Rotor as Primary

$$E(S13) = N[E(R13)\cos a + E(R23)\sin a]$$

$$E(C13) = N[E(R13)\cos a + E(R23)\sin a]$$

$$E(S24) = N[E(R23)\cos - E(R13)\sin a]$$

$$E(C24) = N[E(R23)\cos - E(R13)\sin a]$$

Stator as Primary

$$E(R13) = N[E(S13)\cos a - E(S24)\sin a]$$

$$E(R23) = N[E(S24)\cos a + E(S13)\sin a]$$

Note: This type unit is also available with a four-wire rotor excitation; (CQ). Substitute (R24) for (R23) in the above equation; R4 = BLU/WHT.

The preceding phasing equations are for Standard Clifton Units, and derivations are based on ARP-461B conventions. Many other phasing combinations are available upon request.

TYPE NUMBER INFORMATION

In general, CLIFTON part numbers specify the following information:

TGH-11-E-4/□□□□

- MECHANICAL CONFIGURATION AND FUNCTION OF UNIT (TGH)
- FRAME SIZE (11)
- SHAFT CONFIGURATION (E)
- ELECTRICAL CHARACTERISTICS (4)
- ELECTRICAL AND MECHANICAL MODIFICATIONS TO BASIC UNIT (□□□□)

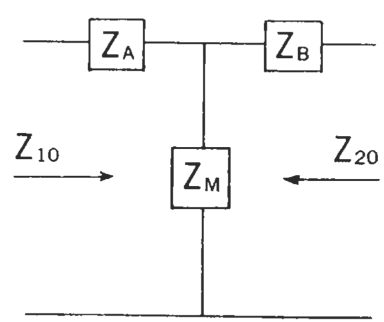
EQUIVALENT "T" NETWORKS

The loading effect of synchro systems and loads may be calculated by treating each synchro as an equivalent T network and then solving for the chain.

The formulas are based on line to line impedances and since Z_{so} for a three phase winding is measured between two leads tied together and the third lead, the correction factor of 4/3 must be used. This correction factor must also be used on Z_{ro} and Z_{rss} for differentials. Line to line voltages should be used.

T—Equivalent calculations are valid only for a synchro positioned at maximum coupling.

"T" NETWORK FORMULA



$Z_{10} = Z_{ro}$ (4/3 Z_{ro} for differentials)

$Z_{20} = 4/3\ Z_{so}$ (Z_{so} for resolvers)

$Z_M = \sqrt{Z_{20}(Z_{10} - Z_{rss})}$ (use 4/3 Z_{rss} for differentials)

$Z_A = Z_{10} - Z_M$

$Z_B = Z_{20} - Z_M$

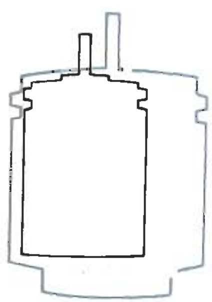
TOLERANCES

Unless otherwise stated, the tolerances on the electrical parameters for Clifton synchros at 25°C shall be as follows:

Input Voltage	±1%
Input Frequency	±2%
Input Current	±10%
Input Power	±20%
Output Voltage or TR	±3%
Phase Shift	±20% or ±1°*
Null Voltage	
26 volt synchros	30 mv. max.
115 volt synchros	100 mv. max.
Resolvers	1 mv./volt of input
Impedances	
Open Circuit	R: ±15% or ±2 ohms*
	X: ±10% or ±2 ohms*
Short Circuit	R: ±15% or ±2 ohms*
	X: ±15% or ±2 ohms*
D.C. Resistances	±10%

Note: Null voltage is not measured on receivers.

*(whichever is larger)



All electrical parameters are for reference only and are subject to change without notice.

ENVIRONMENTAL REQUIREMENTS

The following list contains many environmental service conditions to which our standard synchros have successfully demonstrated conformance. It is by no means all-inclusive, nor is it indicative of the ultimate limits of which our units are capable. Rather it is meant as a guide in establishing specifications for synchros which must withstand environmental extremes during their operating life. Detailed particulars may be obtained by contacting Sales or CLIFTON's Engineering Department.

Vibration: MIL-STD-202E, Method 204C, Cond. B
MIL-S-20708C, Paragraph 3.9.6

Shock: MIL-STD-202E, Method 213B, Cond. A
MIL-S-20708C, Paragraph 3.9.7.1 (low-impact)

Altitude: MIL-STD-202E, Method 105C, Cond. A, B, C, or F

Humidity: MIL-STD-202E, Method 103B, Cond. A or B; Method 106D
MIL-S-20708C, Paragraph 3.9.3
MIL-STD-810B, Method 507, Procedure I

Ambient Temperature: MIL-S-20708C, Paragraph 3.9.1
MIL-STD-810B, Methods 501 and 502

Thermal Shock: MIL-STD-202E, Method 107D, Cond. A or B

Explosion: MIL-STD-202E, Method 109B

Salt Spray: MIL-S-20708C, Paragraph 3.9.4

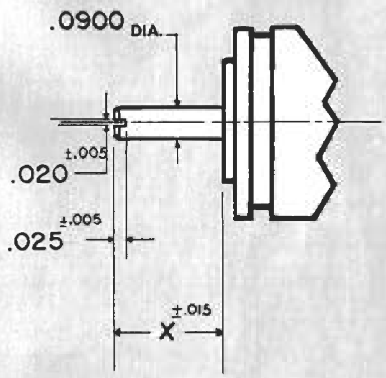
Fungus Resistance: MIL-STD-810B, Method 508

Endurance: MIL-S-20708C, Paragraph 3.9.8
2000 hours minimum at 100 rpm

SYNCHRO SHAFTS

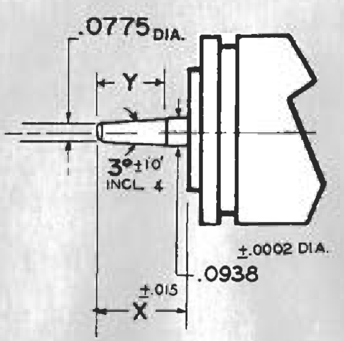
SIZE 8

STRAIGHT SHAFTS



SHAFT TYPE	LENGTH X
A	.332
B	.200
C	.285
E	.437
F	.500
K	.250
L	.375

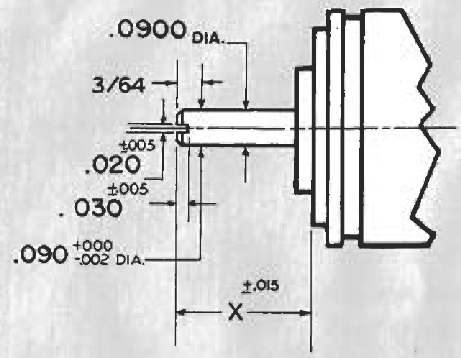
TAPERED SHAFTS



SHAFT TYPE	LENGTH X	LENGTH Y
D	.187	.194 REF.
H	.332	.194 REF.

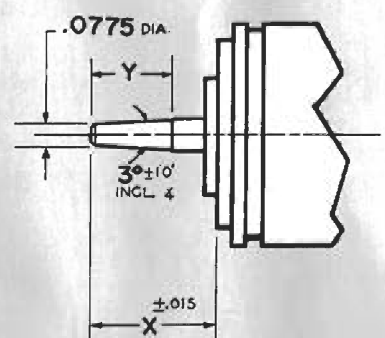
SIZE 10

STRAIGHT SHAFTS



SHAFT TYPE	LENGTH X
A	.375
B	.250
M	.418
N	.293
V	.750
W	.475

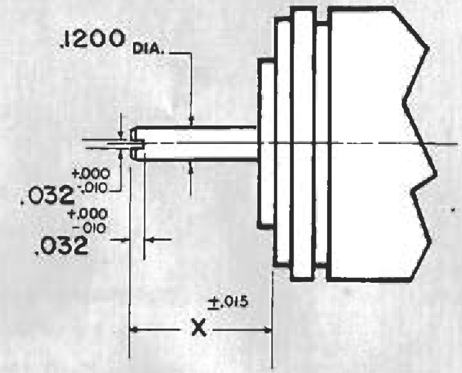
TAPERED SHAFTS



SHAFT TYPE	LENGTH X	LENGTH Y
D	.230	.194 REF.
E	.288	.194 REF.

SIZE 11

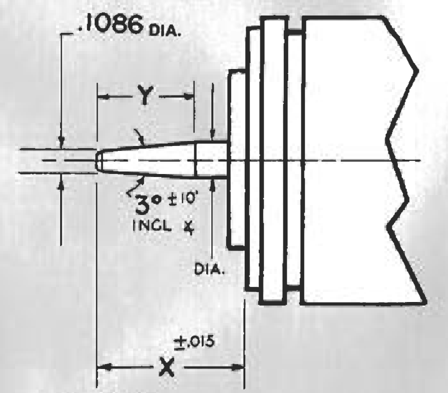
STRAIGHT SHAFTS



SHAFT TYPE	LENGTH X
A	.187
B	.218
C	.312
D	.250
E	.375
F	.562
G	.437
H	.500

Shaft type letter applies to "T" and "E" units only.

TAPERED SHAFTS

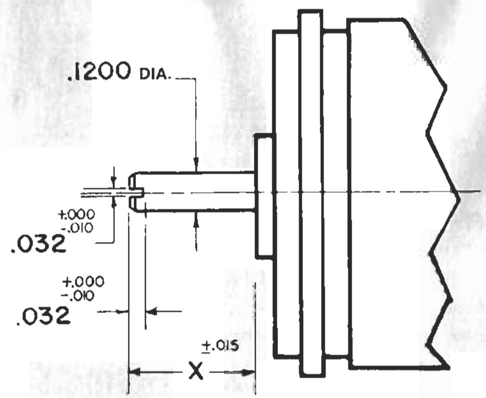


SHAFT TYPE	LENGTH X	LENGTH Y
AV	.218	.217 REF.

Shaft type letter applies to "T" and "E" units only.

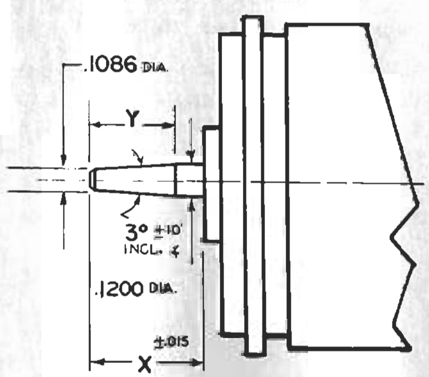
SIZE 15

STRAIGHT SHAFTS



SHAFT TYPE	LENGTH X
A	.437
B	.250
D	.500
F	.375

TAPERED SHAFTS



SHAFT TYPE	LENGTH X	LENGTH Y
C	.218	.217 REF.

SYNCHRO STANDARD SHAFT DIAMETERS

SIZE	FRONT EXTENSION		REAR EXTENSION		NOTES
	STANDARD DIA.	MAXIMUM DIA.	STANDARD DIA.	MAXIMUM DIA.	
8	.0900 .1200	.1248	.0900	.1200	1 thru 4
10	.0900	.0935	.0900	.0935	1 thru 4
11	.1200	.1248 .1875	.0900	.1200	1 thru 5
15	.1200	.1248 .1875	.0900	.1200	1 thru 5

GENERAL NOTES

1. Normal tolerance on a shaft diameter is $^{+.0000}_{-.0005}$. Tolerances as low as $^{+.0000}_{-.0002}$ available on request.
2. Normal tolerance on a front shaft extension is ± .015. Tolerances down to ± .010 can be held at a slight extra charge. On a rear shaft extension, the tolerance is ± .015 referenced from either the bearing boss or the mounting face. Due to tolerance build-up within the unit, shaft extensions from the rear of the synchro can be given for reference only.
3. The maximum diameters listed in the table above are those that can be supplied without an internal redesign.
4. All shafts are made of #416 stainless steel, Cond. H. per QQ-S-764. Rockwell hardness: C26 Min.
5. The .1875 maximum diameter is available only in non-standard housing configurations.
6. Mounting holes are available upon request.

The above information is meant as a general guide to shaft configurations. In addition to the straight and tapered shafts, Clifton has supplied shafts with splines, threads, tapped holes, radial holes, axial holes, flats, and grooves. If you have a special synchro shaft requirement, Clifton stands ready to satisfy your needs.

SYNCHRO APPLICATION DATA

As a circuit element, the synchro is essentially a variable-coupling transformer; the magnitude of the magnetic coupling between the primary and secondary, and hence the magnitude of the output voltage, varies according to the position of the rotatable element. In function, the synchro is an electro-mechanical transducer. A mechanical input, such as a shaft rotation, is converted to a unique set of output voltages; or a set of input voltages is used to turn a synchro rotor to a desired position.

Synchros can be classified in two overlapping groups: torque synchros and control synchros.

Torque synchros include transmitters (CG), differentials (CD) and receivers (CR).

Control synchros include transmitters (CG), differentials (CD), control transformers (CT), resolvers (CS), linear transformers (LT), and the two hybrid units—transolvers (CSD), and differential resolvers (CDS).

TRANSMITTER

The synchro transmitter (CG) consists of a single-phase, salient-pole (dumbbell-shaped) rotor and a three-phase, Y-connected stator.* The primary or input winding is usually the rotor; the stator is usually the secondary or output element. The rotor is excited through a pair of slip rings with an AC voltage. The field produced by this voltage induces a voltage into each of the stator phases. The magnitude of the induced phase-voltage depends on the angle between the rotor field and the resultant axis of the coils forming that stator phase. Since the axes of the three stator phases are 120° apart, the magnitudes of the stator output voltages can be written as:

$$V_{S1\text{-}3} = k\, V_{R2\text{-}1} \sin \theta$$
$$V_{S3\text{-}2} = k\, V_{R2\text{-}1} \sin (\theta + 120)$$
$$V_{S2\text{-}1} = k\, V_{R2\text{-}1} \sin (\theta + 240)$$

*In this discussion, the use of the word "phase" will always indicate a space-phase relationship, unless a time-phase relationship is specifically called out.

where k is the maximum coupling transformation ratio (TR), which is further defined as $TR = \frac{V_{out}\,(max.)}{V_{in}}$ and is a scalar quantity.
θ is the rotor position angle.
$V_{S1\text{-}3}$ is the voltage from the S1 terminal to the S3 terminal, and all other voltages are similarly defined here and throughout this discussion.

These stator voltages are all either approximately in time-phase or approximately 180° out of time-phase with the applied voltage. The amount by which the output voltages differ from an exact 0° or 180° time-phase relationship with the input voltage is known as the synchro (time) phase shift. For a synchro operated at 400 Hz working into an open circuit, the output voltage will always lead the input voltage by a few degrees (8° to 20° for small sizes; 2° to 8° for larger sizes).

From the above transmitter equations it can be readily be seen that nowhere over the entire 360° rotation of the rotor will the same set of stator voltages appear. The transmitter thus supplies information about the rotor position angle as a set of three output voltages. To make use of this information, however, it is necessary to find an instrument which will measure the magnitude of these voltages, examine their time-phase relationships and return them to their original form—a shaft position. Such an instrument is the synchro receiver (CR). These two units—the transmitter and the receiver—form the most basic synchro system.

RECEIVER

In construction, the receiver is electrically identical to the transmitter. The output voltages vary with rotor position in the identical manner as that given for the transmitter. In use, the receiver is connected back-to-back with a transmitter; i.e., like-numbered terminals are connected together (See Figure 1) and the rotors are excited

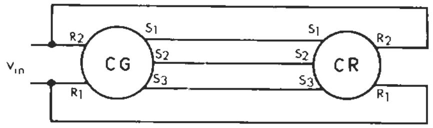


FIGURE 1

in parallel. At the instant the system is energized, if the rotors of each unit are not at the exact same angle relative to the stator phases, voltage differences exist across each pair of stator windings causing current to flow in both stators. This stator current produces a torque on each rotor.

Since the CG rotor is constrained from turning, the resultant torque acts on the CR rotor in such a direction as to align itself with the transmitter. When alignment occurs, the voltages at each stator terminal are equal and opposite, and no current flows. Perfect synchronization is never achieved in practice because of the internal friction (due to bearings and brushes) of the receiver. To minimize this error, the receiver is designed to have a maximum starting friction of 2700 mg-mm.

Turning the transmitter rotor from the equilibrium position will again exert a force on the receiver rotor. As soon as this developed force exceeds the internal friction of the receiver, the CR will track the CG to its new position. The torque developed on the receiver shaft is proportional to the angle between the two rotors and is usually expressed in mg-mm/deg. Methods for measuring the torque produced by a transmitter-receiver pair are to be found in Society of Automotive Engineers Specification ARP-461B.

Receivers are so constructed as to minimize oscillation and overshoot or spinning when the rotor is turning to a new position. The time required for the rotor to reach and stabilize at its new rest position is called the damping or synchronizing time. This time varies with the size of the receiver, the inertia of the load, and the system torque. By special receiver construction, the damping time can be reduced if system considerations so warrant.

The CG-CR system is used to transmit angular information from one point to another without mechanical linkages. The standard transmission accuracy for such a system is 30 arc minutes. The information can be sent to more than one location by paralleling more than one receiver across the transmitter. The more receivers used, however; the less accurate the system; and the larger the power draw from the source.

DIFFERENTIAL

A third type of synchro may be added to our basic torque system—the differential (CD). The differential stator is three-phase, Y-connected, and is usually the primary element; the rotor is cylindrical and is also wound with three Y-connected phases. The output voltages of the CD depend not only on the input voltages but also on the rotor shaft position. As shown in Figure 2 the differential stator is normally excited from a transmitter stator, and the differential rotor is connected to the receiver stator. The output voltages of the differential are dependent now on both the transmitter rotor position (θ_{CG}) and its own rotor position (θ_{CD}). The receiver rotor will seek a position (θ_{CR}) which is either the sum or difference of the transmitter and differential rotor angles ($\theta_{CR} = \theta_{CG} \pm \theta_{CD}$), depending on how the CG and CD stators are interconnected.

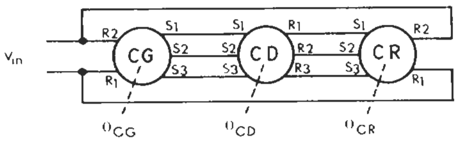


FIGURE 2

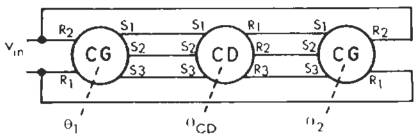


FIGURE 3

The differential may also be energized between two transmitters as shown in Figure 3. In this system, each transmitter is turned to its desired angle, and the differential rotor is forced to assume a position which is either the sum or the difference of the angles between the transmitter rotors ($\theta_{CD} = \theta_1 \pm \theta_2$). In this application, the differential is sometimes called a differential receiver and is especially constructed so as to have an extremely low starting friction (5000 mg-mm) to minimize system errors. An accuracy of 1° is standard.

All synchro systems are subject to one serious drawback; torque levels typically run around 3000 mg-mm per degree of receiver displacement. This is sufficient to turn a dial or a pointer but nothing larger without increasing system errors. When large torques are required, synchros are used to control other devices which will provide these torques. An integral part of these control systems is the synchro control transformer. (CT).

CONTROL TRANSFORMER

The CT consists of a three-phase, Y-connected stator and a single-phase drum (cylindrical) rotor. In normal usage, the stator is the primary element, the rotor is the secondary, and the unit is connected as shown in Figure 4. From the schematic of Figure 4, it can be seen that the transmitter sets up a voltage field in the CT stator whose direction is exactly that of the transmitters and whose magnitude is directly proportional. As the transmitter rotor turns with the CT rotor stationary, the magnitude of the CT stator field remains constant, and its direction exactly matches that of the transmitter. The field cutting across the CT rotor induces a voltage in the rotor. The magnitude of this voltage depends on the sine of the angle between the axis of the rotor winding and the stator flux vector; the time phase of the CT output voltage is either approximately in time-phase or 180° out of time-phase with the exciting voltage on the transmitter rotor. Since the angle of the CT stator flux field depends upon the transmitter rotor angle, the CT output voltage can be used to obtain information about the transmitter rotor angle.

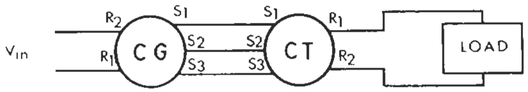


FIGURE 4

The basic CG-CT control system is shown in Figure 5.

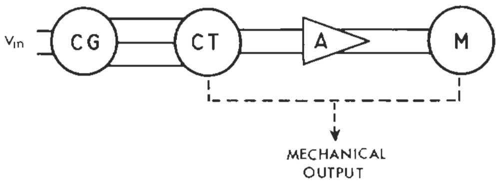


FIGURE 5

If the CT rotor angle is not the same as that of the transmitter, a voltage proportional to the sine of the angular difference appears on the CT rotor. This voltage is impressed across the input of a servo amplifier, which, in turn, is connected to the control phase of a servo motor. The motor, which is geared back to the CT rotor shaft, will turn in such a direction so as to oppose the voltage causing its motion. It will rotate until the CT rotor is at the same angle as the CG rotor; at this position, the CT output voltage is theoretically zero and motion will cease. By additional gearing, the servo motor provides a mechanical output for other useful work to be done. This synchro system, which develops no torque of its own, acts as the control device which moves high torque loads. The accuracy of the entire system depends on synchro error, amplifier gain, servo response, and gearing errors. Using standard components, the synchro system error is usually specified as 10 arc minutes maximum; by selecting synchros or by trimming, this error can be reduced well below the given figure. If multispeed pancake synchros are used, accuracies measured in seconds of arc are standard.

In some systems a control transformer is made to act, through switching circuits, as both a transmitter and a CT. This practice is not recommended. Because of its impedance levels and its cylindrical, distributed-winding rotor, the CT can never act as a transmitter without causing degradation in system accuracy and system null voltage. Whenever a synchro must serve as both a CG and a CT, we recommend the use of a transolver (CSD).

TRANSOLVER; DIFFERENTIAL RESOLVER

The transolver is essentially a control transformer with a second rotor winding wound in space quadrature to the main winding. When used as a CT, the transolver's second rotor winding is dummy-loaded symmetrically with the main winding to avoid unbalances. When using the transolver as a transmitter, the unused rotor winding is shorted to ground, thus providing electrical saliency and permitting the transolver to operate as a transmitter without introducing additional errors. The differential resolver (CDS) is the inverse of the transolver; i.e., the rotor is the three-phase element, the stator is two-phase. In function, the transolver and differential resolver are identical. The advantage of the differential resolver over the transolver lies in those applications where four-wire outputs are desired; it is more economical to bring out four stator leads than to provide four rotor slip rings and four sets of brushes. Both the transolver and the differential resolver find considerable usage in systems where it is desirable to convert three-wire data into four-wire data. These units form the bridge between the three-phase devices—transmitters, receivers, differentials, and control transformers—and the two-phase units or resolvers.

RESOLVER

The resolver (CS) consists of a cylindrical rotor with two phases wound in space quadrature and a stator also with two quadrature phases. In standard resolvers (CS), the ends of the rotor phases are internally connected and brought out with a common lead; a resolver with all four rotor leads brought out separately is designated by CZ. The classical function of a resolver, as the name implies, is to resolve a vector into its components. Energizing one phase of the input element—either rotor or stator—with a voltage V induces a voltage into one output winding whose magnitude varies according to the sine of the rotor position angle θ. The other output winding, being in space quadrature to the first, must then have an induced voltage whose magnitude varies as $\sin(90-\theta)$ or $\cos\theta$. The two outputs are thus $V \sin\theta$ and $V \cos\theta$ (assuming a unity transformation ratio), which are the components of the input vector V.

A resolver which is specifically meant to separate a vector into its components is the vector resolver (CV or CW). This unit type differs from the standard resolver in that the rotor is wound with only one phase.

The vector resolution function is reversible in that if two voltages, X and Y, representing vector components are applied to the inputs of the resolver, the corresponding polar coordinates (R,θ) can be obtained. Since the two inputs are in quadrature, applying voltages X and Y to these inputs will set up a resultant field whose magnitude is $\sqrt{X^2 + Y^2}$ or R. If one output phase is connected through an amplifier to a servo motor which is geared back to the resolver shaft, the voltage on the other output will be proportional to R, and the rotor position angle will indicate θ $(\tan^{-1} Y/X)$.

Exciting one input of a resolver with voltage A produces outputs of $A \sin\theta$ and $A \cos\theta$; exciting the other input with voltage B produces outputs of $B \sin(\theta + 90)$ or $B \cos\theta$ and $B \cos(\theta + 90)$ or $-B \sin\theta$. Energizing both windings at once then gives two outputs Y and X whose magnitudes are of the form:

$$\mathbf{Y = A \sin\theta + B \cos\theta}$$
$$\mathbf{X = A \cos\theta - B \sin\theta}$$

From analytic geometry, these two equations represent a transformation of axes by rotation without translation; Y and X are the new components obtained by rotating A and B through the angle θ. Resolvers then find usage wherever transformation of coordinates from one system to another is desired. Spacecraft and aircraft often require the craft's pitch, roll, and yaw to be transformed back to earth references. One resolver is needed to provide two-axis transformation; three resolvers, to provide three-axis transformation.

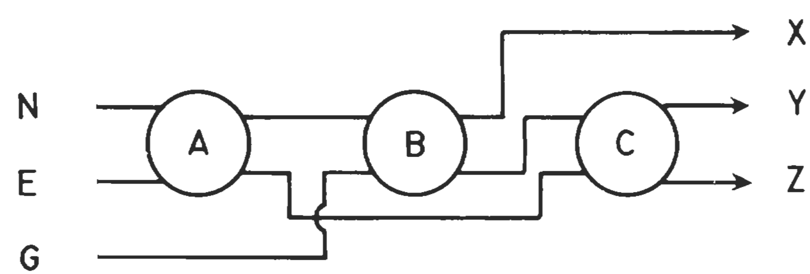


FIGURE 6

Figure 6 schematically represents the interconnections of three resolvers necessary to transform from inertial platform coordinates (N,E,G) to an airborne vehicle's coordinates (X,Y,Z). This resolver chain essentially solves the matrix equation:

$$\begin{bmatrix} X \\ Y \\ Z \end{bmatrix} = \begin{bmatrix} 1 & 0 & 0 \\ 0 & \cos C & \sin C \\ 0 & -\sin C & \cos C \end{bmatrix} \begin{bmatrix} \cos B & 0 & \sin B \\ 0 & 1 & 0 \\ -\sin B & 0 & \cos B \end{bmatrix} \begin{bmatrix} \cos A & \sin A & 0 \\ -\sin A & \cos A & 0 \\ 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} N \\ E \\ G \end{bmatrix}$$

Resolver chains are commonly used to solve trigonometric problems of varying degrees of complexity. Our computing resolver amplifier chain is a combination of Clifton precision computing resolvers and amplifiers. The resolvers in this application are specially designed to work with a buffer, booster, or feedback amplifier; and they are known as feedback or compensated resolvers (CQ or CY). The rotor of a compensated resolver is identical to that of a standard resolver; the stator however, has two additional sets of coils, called the compensator or feedback winding. The compensator winding is laid in the same slots as the stator winding. Practically all the flux generated by the stator exciting current links all the turns of the compensator, so that the compensator output is essentially equal to the input voltage, and is naturally constant with rotor position. The time phase shift of the rotor output voltage of the compensator voltage is identical with the time phase shift of the rotor output voltage, since both voltages were induced by the stator flux field. Because of the resolver's construction, any change in the stator flux due to temperature or voltage, immediately produces a change in the compensator voltage. The negative feedback through the amplifier restores the stator field to its original conditions. A resolver-amplifier pair is thus basically error-free, with respect to resolver chain performance, over a wide range of environmental conditions.

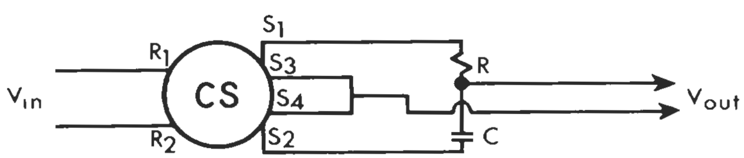


FIGURE 7

Resolvers also are used in time-phase-shifting applications. A typical connection for a resolver phase shifter is shown in Figure 7. The resistance R is chosen to match the reactance of the capacitor C at the operating frequency, and both R and X_C are substantially higher than the resolver output short circuit impedance. Under proper operating conditions, the phase shifter output is:

$$\text{Vout} = \text{k Vin} \angle \theta$$

Note that the output voltage is constant with rotor position, but the time phase shift in electrical degrees between the output and the input is equal to the rotor position angle in mechanical degrees. Using a balanced R-C network and a stable frequency source, standard resolvers can be used as phase shifters with an accuracy of $\pm 1/4°$ or better.

Resolvers are also used in control systems exactly like those described for three-phase units. In such applications, the units are sometimes referred to as resolver transmitters, resolver differentials, and resolver control transformers. Their construction is identical to standard resolvers with the exception of the resolver differential, which should have four-wire input and four-wire output. Data transmission by resolvers is usually to be preferred over three-phase transmission, as resolvers are usually more accurate than their three-phase counterparts.

LINEAR TRANSFORMER

In many resolver circuits involving vector resolution, the input voltage to the resolver is taken from the output of a linear transformer (LT). The linear transformer consists of a one-phase, salient-pole rotor and a single-phase stator. Unlike all other synchros where the output voltage is proportional to the sine of the rotor position angle, the LT is so constructed that the output voltage is directly proportional to the angle itself. In equation form:

$$\text{Vout} = \text{k}\,\Theta \qquad (-50° < \Theta < 50°)$$

The angular band over which the output equation remains valid is known as the excursion range. Beyond the excursion range, the plot of output voltage against rotor position tends toward a sinusoid. The LT acts as a circuit replacement for a potentiometer with the chief advantages of low starting friction and infinite resolution over the excursion range. Because of construction similarities, the LT also matches the performance of resolvers over environmental service conditions.

ACCURACY

Of all synchro parameters, accuracy is probably the most important. The synchro is meant to give unique information about the rotor position angle as a set of output voltages. Synchro error is thus defined as the electrical angle, as indicated by the output voltages, minus the rotor position angle. Calibration is the process of determining the error at specified angular intervals for the full 360° rotor travel. The calibration starts at a reference point, called electrical zero (EZ) and defined as a rotor position angle of 0°. The electrical zero point is defined differently for each synchro type, but it always is a rotor position where a specified output winding has minimum voltage induced in it with a specified input winding energized with rated voltage and frequency. The EZ positions for the various unit types are shown elsewhere in this catalog. During calibration, the units are held and precisely positioned in a Clifton Index Stand. The Index Stand provides a mechanical position accurate within ten (10) arc seconds. The calibration itself is in accordance with the proportional voltage methods of military specifications MIL-S-20708C and MIL-R-23417.

Synchro accuracy is of necessity a function of the electrical balance of the windings comprising the input and output phases.

Total turns, pitch factors, distribution factors, insertion patterns, winding integrity—all must be in accordance with design requirements if the synchro is to calibrate within specification limits. Surpassing the electrical problems, however, are the mechanical ones. Accuracy is to a great extent dependent on mechanical perfection. To obtain proper accuracy, it is extremely important to control eccentricities of the air gap surfaces with respect to the mounting surfaces, roundness of the air gap surfaces, mechanical parallelism and perpendicularity, and the radial and axial position of the rotor inside the stator. Clifton's long experience in recognizing and combatting these problems insures you of accurate, repeatable synchros.

Component accuracy itself, however, is only one part of system accuracy. When units are cascaded in a synchro chain, unbalances in time phase shift, transformation ratio, and impedance may far outweigh inherent unit accuracy in determining system error. A resolver with a five (5) minutes maximum error cannot exhibit that accuracy when working into unbalanced loads. Severe impedance mismatches may cause sufficient distortion of the voltage waveforms with subsequent loss of accuracy. Our Synchro Engineering Department stands ready to help you with recommendations for proper synchro usage in your applications.

NULL VOLTAGE

Theoretically, when a coil is exactly parallel to the direction of a flux field—such as at electrical zero—no flux lines link the turns of this coil and the voltage induced in it is exactly zero. At any minimum-coupling position, however, there is always some residual voltage. This voltage is called the null voltage.

The null is composed of a fundamental component, which is in time quadrature with the exciting voltage (the in-time phase component is always forced to zero), and odd harmonics. The fundamental component is due mainly to winding imperfections and magnetic circuit distortions; the harmonics, to non-sinusoidal distribution of the air gap flux.

Nulls are measured in accordance with the phase-sensitive voltmeter method of MIL-S-20708C at each synchro minimum-coupling point. Because of symmetry, each output winding has two null points, 180° apart, for each input winding. A transmitter has six null points; a resolver, eight; and a differential, eighteen.

Low synchro nulls are essential to proper system performance. Clifton currently specifies that the maximum null voltage shall not exceed 0.1% of the applied voltage.

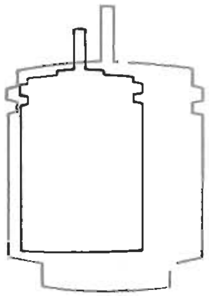
OTHER ELECTRICAL PARAMETERS

The remaining electrical tests—transformation ratio, phase shift, DC resistance, input current and power, impedances—are performed in accordance with applicable industry and military specifications. Nominal values, including tolerances, for a wide variety of Clifton units are to found elsewhere in the catalog. Technical information on other units or on parameters not specified in the catalog may be obtained by contacting the Synchro Engineering Department or our nearest Sales office.

MECHANICAL PARAMETERS

In addition to checking mounting dimensions, Clifton Final Test checks each synchro for conformance to our shaft end play, shaft radial play, and starting friction requirements. Shaft end play is the total axial motion of the shaft when an eight-ounce reversing load is applied along the shaft axis. Shaft radial play is the total side-to-side motion of the shaft measured as close to the bearing as possible, when a four-ounce reversing load is applied radially to the shaft within ¼ inch of the bearing. Starting friction is the torque necessary to overcome the internal friction of the bearings and brushes and to commence shaft rotation.

Because of the important relationship between accuracy and shaft end play and shaft radial play, these parameters are controlled as rigidly as possible. If end play and radial play are too loose, higher errors and non-repeatability of the calibration pattern result; if they are too tight, performance over environmental service conditions may suffer. Friction, except in receivers, is relatively unimportant. We currently specify four (4) gram-centimeter maximum friction; this has been found to be an optimum level for operation in both normal and extreme temperature ambients. On units where lower friction limits are a system requirement, however, Clifton will work with our customers to establish these limits consistent with the end requirement and with good design practices.



BRUSHLESS SYNCHROS

For synchro applications where conventional commutation—slip rings and brushes—is either undesirable or unwanted, Clifton has developed several varieties of brushless synchros, for both full rotation and limited rotation.

ELECTROMAGNETIC TYPE

In the electromagnetic brushless synchro, energy is transferred from the rotor by means of a circular transformer mounted at the rear of the unit. There are no physical connections to the rotor; hence, the life of the unit is solely limited by the life of the bearings. Tens of thousands of hours of operational life at high rotational speeds are easily achievable with this type of unit. The major disadvantage of the electromagnetic brushless synchro is that the dual magnetic structures—synchro and transformer—do not allow the duplication in this design of standard synchro parameters. In general, when compared with a standard unit, the brushless synchro will have higher power consumption, lower impedance angle, higher phase shift and lower unit torque gradient. This can be a problem if the intent is to replace a synchro in an existing system; in new applications, the variations in unit performance can be allowed for. Closer conformance to existing synchros can be achieved with additional unit length; in any case, multi-phase rotors require additional length.

HAIRSPRING TYPE

Limited rotation units are made with spirally wound conductors used to pick off information from the rotor. These hairspring conductors allow a rotation of as much as ±165° from the electrical zero position. The units are normally supplied with a mechanical stop to prevent damage to the hairsprings due to excessive shaft rotation. The addition of the stop normally engenders extra length.

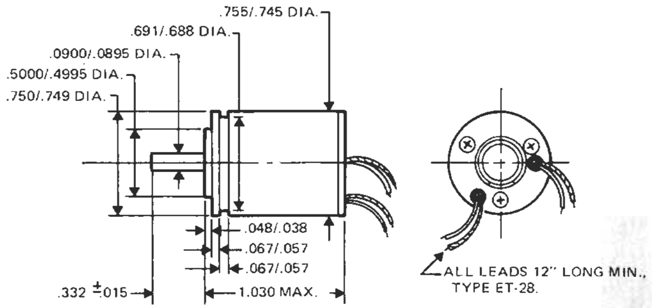
The advantage of a hairspring synchro over an electromagnetic brushless is that any standard synchro can be manufactured in a hairspring design with no change in electrical parameters. If the application permits limited rotation, a hairspring unit can replace the conventional unit already in the system with no effect on system performance except for the benefits attendant on the elimination of sliding contacts. Properly-designed hairsprings, such as ours, will perform millions of operations without failure.

To discuss the possibility of the use of either type of brushless unit in your application, contact your Local Clifton Sales Office.

SYNCHRO BRUSHLESS DC REPEATER*

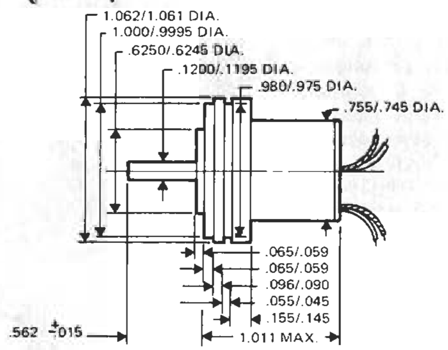
SIZE 8

ACTUAL SIZE
WEIGHT: Al: 36.9 gms/1.3 oz
SS: 45.4 gms/1.6 oz
DIAMETER: .750 inches



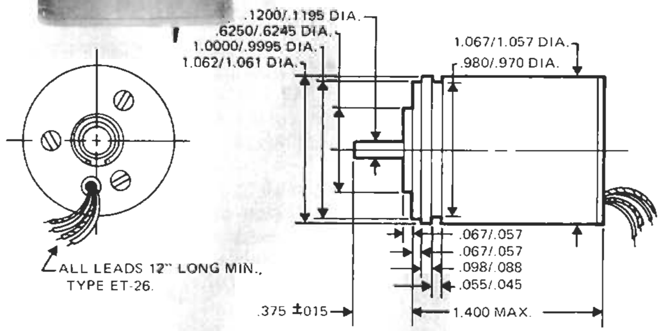
SIZE 8

WITH SIZE 11 FLANGE
ACTUAL SIZE
WEIGHT: Al: 42.5 gms/1.5 oz
SS: 51 gms/1.8 oz



SIZE 11

ACTUAL SIZE
WEIGHT: Al: 85 gms/3.0 oz
SS: 113.4 gms/4.0 oz
DIAMETER: 1.062 inches

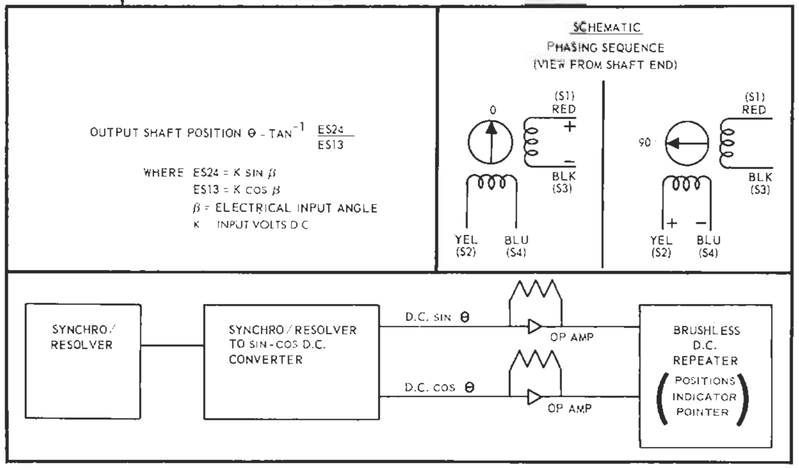


SIZE 8

CLIFTON TYPE	Input Voltage (DC)	Input Current/ Phase (Amps)	Input Power/ Phase (Watts)	Stator Resistance/ Phase (Ohms)	Max. Static Receiver Error (Deg. Spread)	Unit Torque Gradient (mg-mm/deg.)	NOTES
08-PCR-1A	3	0.146	0.437	20.5	1	1200	1
08-PCR-2A	10	0.200	2.000	50	1	2250	1
08-PCR-3A	5	0.050	0.250	100	1	750	1
SIZE 11							
11-PTR-7E	10	0.172	1.724	58	1	4500	2
11-PTR-8E	3	0.136	0.409	22	1	2500	2
11-PTR-9E	10	0.141	1.408	71	1	6200	2
11-PTR-10E	10	0.056	0.556	180	1	2500	2
11-PTR-11E	10	0.172	1.724	58	1	6200	2

Electrical characteristics are specified as nominal values at 25°C.

NOTES:
1. Rotor moment of inertia = 0.5 gm - cm² Ref.
2. Rotor moment of inertia = 1.9 gm - cm² Ref.
* May be used as brushless tachometer.



MECHANICAL CHARACTERISTICS

High Pot	
Windings to Ground	550 Volts, 60Hz
Between Windings	250 Volts, 60Hz
Operating Temp. Range	−40°C to +100°C
Shaft Radial Play (4 oz. load)	0.001 Max.
Shaft End Play (8 oz. load)	0.002-0.005
Shaft End Run-out	0.001 Max.