

SYNCHROS – Simple and Accurate

What are they?

Synchros and Synchro Resolvers form a group of transducing elements using an electromechanical scheme. In its basic form synchros are specially wound rotary transformers with the stator windings typically fixed. These transducer devices played a large role in the Air Forces and Navy's during WWII and proved their value enormously. They're two most common uses are for shaft angle measurement or to position a system or dial in a servo loop system. The mechanical input or shaft rotation is converted to a unique set of output voltages or when driving a receiver a set of input voltages is used to turn the rotor to the desired position. Internally most all synchros are similar in construction, having a rotor with one or three windings (depending on type) capable of revolving inside a fixed stator assembly. These synchro stator voltages are expressed in the following form as shown in MIL-S-20708:

$$\begin{aligned}E_{s3-s1} &= N E_{r1-r2} \sin \omega t \sin \theta \\E_{s2-s3} &= N E_{r1-r2} \sin \omega t \sin (\theta+120) \\E_{s1-s2} &= N E_{r1-r2} \sin \omega t \sin (\theta+240)\end{aligned}$$

Where N is the transformation ratio of the synchro and θ is positive for a CCW rotation from electrical zero as viewed from the shafts end.

This results in an absolute analog angle that accurately reflects the rotor position and at no point through the shafts complete rotation is the same. As shown in the relationships above the induced phase voltage will depend on the shaft angle. The primary winding is usually the rotor and the stator is the secondary or output winding. The rotor shaft angle is expressed in degrees and with more resolution as minutes (1/60 of a degree) and seconds (1/3600 of a degree). The typical synchro accuracy is 6' (6 arc minutes) however some synchro accuracies can be as high as 30" (30 arc seconds). This resolution is used when measuring in a rotational plane as evidenced here. The synchro construction is such that the three-stator windings (S1, S2, S3) are separated each by 120 degrees in a wye fashion. In physical form these synchros resemble small AC/DC motors.

Conventions

The control synchros include the transmitter (CG), control transformers (CT), differentials (CD) resolvers (CS), transolvers (CSD), and differential resolvers. In respect to the transmitter it consists of a single-phase, salient-pole rotor and a three phase, wye connected stator (the word "phase" here indicates a space phase relationship). The primary or input winding is usually the rotor (R1, R2) and the stator (S1, S2, S3) is usually the secondary or output element. The synchro resolver (CS) consists of a cylindrical rotor with two phases wound in space quadrature and a stator also with two quadrature phases. In this standard resolver, the rotor phases are internally connected and brought out to a common lead. In the case where all four leads are brought out separately the designation is CZ. The similar fashion the resolver rotor leads are designated R1 and R2 with the four stator leads designated S1, S2, S3, and S4. The avionics industry has also assigned other designators to these windings and most commonly they are; A, B and C for the rotor, with C being the common rotor connection. The four stator leads are commonly assigned D, E, F, and G. The original equipment manufacturers may vary the designations depending on how they are used in their equipment.

Voltage Categories

Synchros predominately fall into three voltage/frequency categories as listed here,

- (1) 115-volt r.m.s. 60hz reference excitation with a 90-volt r.m.s. line to line signal voltage.
- (2) 115-volt r.m.s. 400hz reference excitation with a 90-volt r.m.s. line to line signal voltage.
- (3) 26-volt r.m.s. 400hz reference excitation with an 11.8-volt r.m.s. line to line signal voltage.

The most prevalent excitation voltage used in the aviation synchro community is 26vrms/400hz with a smaller percentage using 115vrms/400hz. The excitation frequency plays importance in the physical size of the synchro and a size 11 (1.1in diameter) is again the common size in the aviation community. The Navy and their shipboard systems typically use a reference excitation of 115vrms/60hz or 115vrms/400hz, this results in a larger frame size of either 18 (1.8in diameter) or 23 (2.3in diameter).

Synchro Nulling

The synchro null is composed of both a fundamental component in time quadrature with the reference excitation and odd harmonics. The fundamental results from magnetic distortions and the odd harmonics imperfect distribution of the air gap flux. The method of nulling is described in MIL-S-20708C for synchros and MIL-S-20708E for synchro resolvers using a phase sensitive voltmeter. Each winding of the device has two null points and a typical synchro resolver operated at 26vrms/400hz can be specified as having a maximum null of 20-30mv or .1% of the reference excitation. These low synchro null voltages are critical for maintaining proper system performance.

Accuracy Defined

The error in angle is defined as the difference between the true physical positions of the synchro shaft and the angle as defined by the stator voltages at its output (CX or transmitter). In a synchro receiver (CT) the angular error is defined as the angular amount required that the rotor has to be moved from the angular positions as defined by the stator voltages in order to produce a minimum output. The leading manufacturers will specify a maximum allowable error in the form of arc-minutes ($1/60^\circ$) or even more accurately in arc-seconds ($1/3600^\circ$) for a particular device. In the family of transducer types the rotary inductosyn is typically most accurate.

Pointing Fundamentals

The following discussion relates to a torque transmitter (CG) and a torque receiver (CR) with their stators wired in parallel and the same excitation applied to both units rotors. The field produced by the input voltage induces a voltage into each of the transmitters stator phases. These stator voltages are either approximately in time-phase or approximately 180 degrees out-of-time-phase with the applied voltage. The synchro inherently has some phase shift so the output voltages will differ some from the exact 0 or 180 degree relationship with the input voltage. In a synchro operated at 400hz (no load) the output voltage will

lead the input by several degrees. At the instant the excitation is applied to this loop the rotors of each unit are not at the same phase angle therefore voltage differences exist across each pair of stator windings and causing current to flow in both stators. This then results in a torque on each rotor. Since the synchro transmitter (CG) rotor is fixed and can't rotate the resulting torque then acts on the synchro receiver (CR) rotor in the proper direction to align itself with the transmitter. When alignment occurs the voltage at each stator is equal and opposite and current flow ceases. A subsequent further rotation of the transmitter rotor will re-exert a force on the receiver's rotor with the torque proportional to the angle developed between the two rotors. The response time of the receiver's rotor to re-align itself is referred to as the synchronizing time. Multiple receivers can be wired in parallel to the transmitter but the downside of this scheme is reduced accuracy.

Resolver Fundamentals

The Synchro Resolver (CS) is a form of synchro in which the windings on the stator and rotor are displaced mechanically at 90° to each other instead of the 120° as in the case of synchros. The resolver thus employs the use of the sinusoidal relationship between the rotor shaft angle and the output voltage. The resolvers utilize the same standard frame sizes as the synchro. Internally the resolvers come in many forms of winding configurations and transformation ratios. The simplest resolver employs a single rotor winding and two stator windings at 90 degrees to each other. The frame or outward appearance of the resolver is similar to that of the synchro. In developing the resolver voltage relationships we can look at the following;

Lets assume the rotor is excited by an AC reference voltage:

$$A \sin w t$$

This yields voltages appearing on the stator terminals that are:

$$S1 \text{ to } S3 = V \sin w t \sin q$$

$$S4 \text{ to } S2 = V \sin w t \cos q$$

Where the resolver shaft angle is shown as q and the carrier (reference) frequency is shown as w .

The resolver is another form of angular transducer which can be used in applications which require performance of trigonometric computations, conversion between rectangular and polar coordinates and transmission and reception of angular position data by one or more rotor shafts. The resolver is described in MIL-S-20708E and MIL-S-23417. The expressions above show that the output voltages will vary as a function of the Sine and Cosine of the shaft angle. Some current applications are: target acquisition, gun trunnions, FLIR systems, Radar and missile seekers. In general resolvers can have leading phase shifts between 0 and 20°. Resolvers also can be used in time phase shifting applications with great accuracy. In these applications the output voltage remains constant with rotor position, but the time phase shift in electrical degrees between the input and output is equal to the rotor position angle in mechanical degrees. In using a balanced R-C network across the stator windings you can obtain accuracies of +/- 1/4 of a degree. This technique is used in the aviation community in the VHF Navigation systems Omni Bearing Selector (OBS) to establish the desired radial the pilot wants to fly. This application of the resolver represents its classic function, as the name implies and that is to resolve a vector into its individual components.

It is interesting to note here that the resolver as it applies to aircraft instruments is zeroed at 300° on the azimuth card of either the standard OBS indicator or the Horizontal Situation Indicator (HSI). This alignment procedure is documented in RTCA/DO-62. In practice several compensation circuits can be configured around a 400hz resolver to allow operation at 30hz with minimal phase shift error. In a higher degree of complexity three resolvers can be wired together to transform the inertial platform coordinates (N, E, G) to their airborne coordinates (X, Y, Z).

Still Today

Synchros and Synchro Resolvers still to this day play a very important part in today's motion and position sensing applications. On board ships for example a multitude of information is acquired; engine data, heading, roll angle, pitch angle, speed, radar, longitude and latitude can all be interfaced into a common node or control point for the required processing and or digitizing. Robotics also employs many uses for synchros and synchro resolvers for positioning of their extremities. Still today, the electromechanical aviation instruments almost without exception employ some form of synchro for providing attitude, azimuth position or some form of displacement or position feedback. The resolver still provides a simple yet necessary interface between the pilot and his navigation equipment. The evolution of the "Glass" cockpit and the solid-state transducers has reduced the requirement for these synchros, to be sure. Even as we see this trend however, there is still the need to synthesize these signal formats to provide that much needed bridge between the old and the new technologies. Synchros and Synchro Resolvers regardless of application must be properly aligned. The alignment of these synchros is performed easily with an Angle Position Indicator which measures the phase relationship of the stator voltages and displays the shaft angle in digital form. Tech-Aid Products manufactures a line of both portable and panel mount Angle Position Indicators that serve this need well and will allow any Avionics or Instrument shop to perform proper alignment of these synchros.

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