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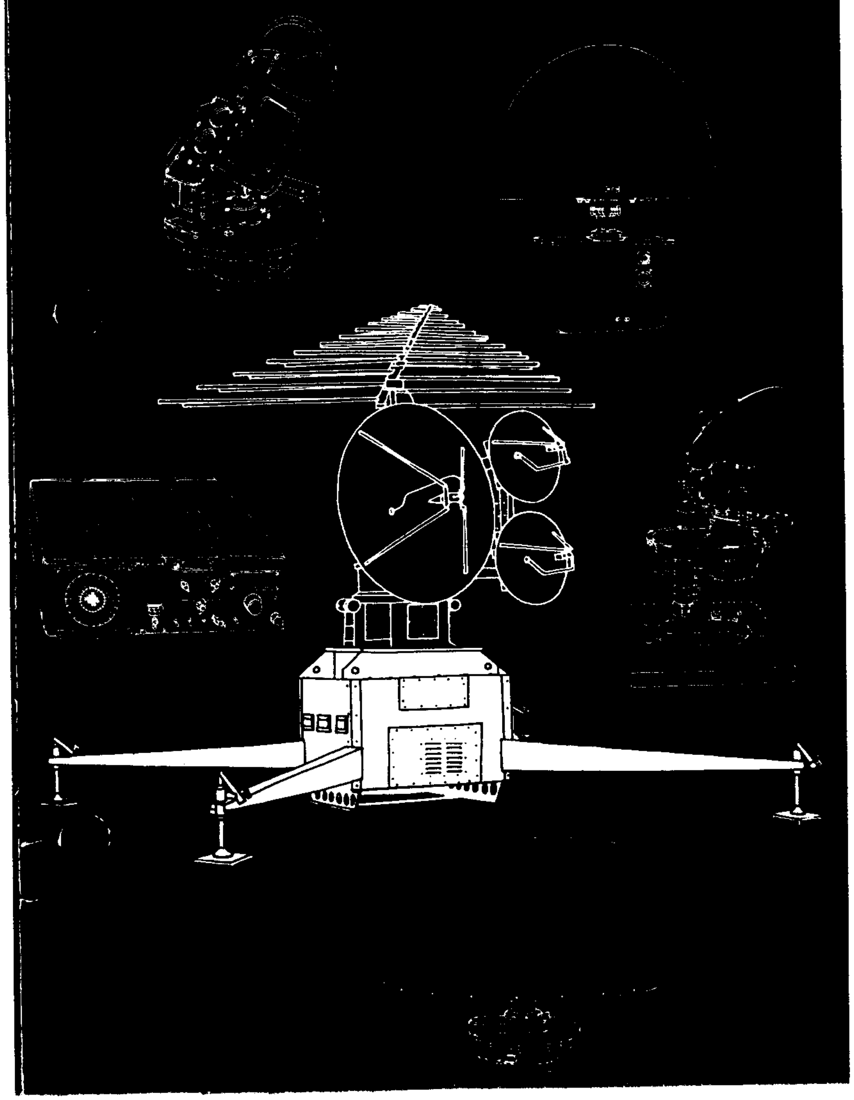
Antenna Pedestals for Microwave Recon Systems



Antenna Pedestals for Microwave Reconnaissance Systems

Advances made in electronically rotatable array antennas for direction-finding and directional-type antenna systems indicate that in the future, these types of rotation and positioning devices may replace electro-mechanical rotating and pointing devices. However, from a standpoint of antenna gain, accuracy, simplicity and, therefore, cost, reflector-type antennas, mounted atop servo motor-driven antenna pedestals will continue to be used on most standard reconnaissance systems. Advances made in servo motors, which have resulted in increased torque from lower power and lighter weight pedestals, along with advances in servo control systems brought about by recent developments in solid-state, digital and analog devices will serve to extend the application of motor-driven antenna positioners for reconnaissance applications. Motor-driven pedestals are used on three basic types of receiving antenna systems. Direction-finding (DF) antenna systems are used to locate and identify a moving emitter, and generally consist of a small, narrow-beam antenna, rapidly rotated on a fast moving pedestal. Reconnaissance systems of this type are frequently mounted aboard aircraft or mobile ground and shipboard platforms. Directional type of EW systems are used to locate and intercept less mobile emitters and are usually stationary-mounted in an area of signal activity. However, for increased utility, the directional system is usually designed for portability, to be moved about to wherever signals of interest may be generated, and may be ship-mounted or mobile ground-mounted. Tracking-type EW receiving antenna positioners are used to track an emitter which, in most cases, is an orbiting satellite. These systems usually feature large, heavy duty, highly accurate pedestals which precisely track the orbiter with a large aperture high-gain antenna. This discussion is limited to DF and directional antenna pedestals, which have distinct differences in requirements from tracking systems.

Special Requirements for Pedestals for Reconnaissance Systems

As already stated, the mission of the EW reconnaissance system is to locate, sort and identify emitters of RF signals of interest for analysis, cataloging and, in some cases, for countermeasures determination. Based on these mission requirements, the components of a reconnaissance receiving system must meet several implied mechanical requirements.

Mobility and/or Portability

Most of the time the emitted information to be gathered is of a tactical nature; therefore, to effectively track a tactical emitter, the receiving system itself must have nearly the portability or mobility of the emitter. This implies that the system is either mounted aboard a movable or moving platform (aircraft, surface or submersible vessel, or land vehicle) or transported to, assembled and disassembled at a remote site within range of the emitter. Portability, then, implies that the system be rugged enough to withstand the rigors of being mounted to any number of mobile platforms for transportation and utilization or deployment.

Mobility and portability also mean that the system must be lightweight. In many cases, the primary mission of the mobile platform may not be reconnaissance, and because the platform is mobile, it is very likely payload-limited. This is especially true in the case of airborne systems, and to a lesser extent in shipboard systems where extra ballast may be required for a mast-mounted system, and in mobile land-based systems where axle loads are limited. In addition, installation and assembly is always facilitated by a lighter-weight system. This is especially true when assembly must be accomplished at a remote site where personnel and lifting/erecting devices are limited.

Small size is a desired requirement for a reconnaissance system in all cases also. Again, this is especially true for airborne equipment where space is always limited and because profile drag on exposed surfaces (e.g., a radome protecting the antenna and pedestal) must be minimized.

Accuracy

Generally, pointing-accuracy for a reconnaissance system is specified at the overall system level and is based on several factors including, antenna beamwidth, control-system (electronics) error and pedestal mechanical inaccuracies. For the most part, reconnaissance systems utilize broadband antennas whose 3-dB beamwidths may vary from 90° at 0.5 GHz to 6° at 18 GHz. Since in most cases a single antenna pedestal is utilized for positioning a system whose coverage is from 0.5 to 18 GHz and higher, the accuracy of the pedestal must be based on the worst-case (narrowest) beamwidth. As a rule of thumb, based on currently achievable electronic control-system error limits (achievable in a practical sense), the combined control-system and drive-system error is 0.1 degrees, with equal variances (±0.05 degrees) due to electrical and mechanical inaccuracies. Electrical inaccuracies of the pedestal are due to synchro winding error, which may range from 7 minutes to 0.5 degrees. This must be added to any errors in analog-to-digital conversion of servo information and in indicating devices of the control system. Mechanical errors of the pedestal are associated with gearing of the synchro (position feedback information to the controller) and drive-system backlash. Naturally, mechanical errors of the reconnaissance pedestal must be minimized because of both the direct and indirect (control electronics) affect on accuracy. On the other hand, for a pedestal used to position only a low-frequency broad beamwidth antenna system, the mechanical and electrical inaccuracies of any properly designed system are almost inconsequential when compared to the pointing errors introduced by, say, a beamwidth of 90 degrees.

Reliability

As mentioned previously, many times reconnaissance is the secondary mission of the platform used to transport the receiver system. Regardless of its secondary importance, the reconnaissance system's reliability must not jeopardize the carrying out of the primary mission assigned to the platform. An example of this would be a mechanical or electrical failure of the pedestal that would perpetrate a primary mission failure due to say, electrical overload, excessive EMI/RFI, explosion caused by sparking in proximity to fumes from evaporating fuel and others. Sometimes, through post-mission intelligence, the gathering of reconnaissance information occurs as the planned witnessing of an event, such as tactical maneuvers or fly-over by a tracked emitter. This makes system reliability during the event a must. Although through the recording of intercepted data, it is possible to give analysts additional chances to disseminate the received information, all components of the receiver system must be functioning, including the antenna system, for an intercept to occur. In some cases in which the reconnaissance gear is transported along as secondary-mission equipment, the operator's time allocated for performing secondary-mission duties is limited. Therefore, these requirements may be relaxed, and commercial design standards may be substituted for the more stringent MIL Spec variety.

Cost Factors

Because of the special nature of the utility of reconnaissance systems, the ratio of cost to overall use is quite high. Though not always assigned to a "one-shot" mission, it is apparent that once the reconnaissance information regarding a particular emitter or class of emitters is gathered, repetitiveness, except in the case of communications surveillance, may not be required. Although most of the equipment of the reconnaissance system is usable in a general sense, such as RF receivers and analysis gear, generally the antenna and, therefore, the pedestals are of such a specific nature that the cost of utilization is high, and applicability to other usage may be unlikely. In the case of the pedestal, if the design is based on the special requirements listed above, the range of applications may be extended. In any case, careful thought must be given by the pedestal designer to include versatility, while maintaining low production costs in the pedestal design. This may influence the designer to forego some manufacturing processes associated with high start-up costs for tooling for a short production run. A modular design, in which a family of products with various capabilities is manufacturable from a set of dash-numbered drawings helps to lower design costs while increasing the number of pedestal applications possible. An example of modular design for a pedestal for a elevation-over-azimuth directional system would be one which would utilize the same drive system on both elevation and azimuth axis and similar bearings and gears. Versatility, along with portability and mobility is a byword for pedestal design.

Pedestals for DF Antenna Systems

When used in conjunction with a high-sensitivity superheterodyne receiver, the direction-finding antenna system is the prime means of accurately locating emitters and determining the direction of arrival (DOA) or angle of arrival (AOA) of the incoming signal. A typical block diagram of an EW reconnaissance system utilizing a DF antenna is shown in Figure 1. Briefly, the system functions as follows: The DF antenna, mounted within a protective shroud atop the pedestal is rotated continuously in azimuth, or, if a general direction of signal is expected, is scanned about a vector in the expected direction. For a favorable probability of intercept, the rotational speed of the DF antenna is between 60 and 200 rpm [1]. The operator controls the antenna rotational rate, scan rate and pointing by means of a control and display unit which is switchable to accommodate all of these functions as well as having a storage-type CRT display of a received emitter-signal pattern. Increasing the rotational rate increases the rate at which the composite image of the signal pattern is formed. Video output from the superheterodyne receivers is used to provide this signal information. When enough rotations or DF "cuts" have been taken to accurately determine the emitter's angle of arrival, the operator may point the DF antenna directly at the emitter for further signal processing, such as determining pulse width (PW), pulse repetition interval (PRI) and other desired data. As pointed out in the beginning, this type of operation is usually carried out on board an EW aircraft, or other mobile platform. If this procedure is done at several known locations of the aircraft, the emitter's location may be pinpointed.

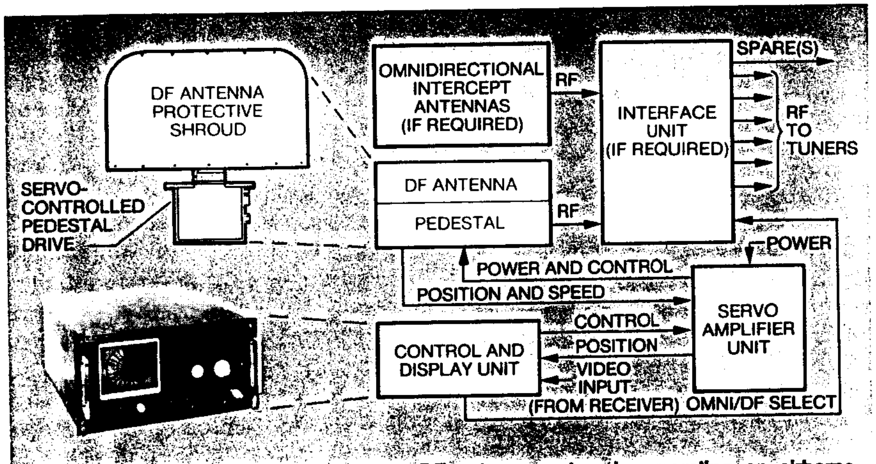


Figure 1. A block diagram of a rotary DF antenna system incorporating an airborne operator's rotary DF equipment.

The DF antenna is a narrow-beam, high-gain device. Positional accuracy is a prerequisite for maximizing the performance of this type of antenna. Therefore, the positioning error associated with the drive system of the pedestal turntable and feedback information device (synchro or encoder) must be minimized along with the error in translating and displaying the position data at the controller. From a hardware standpoint, the pedestal should have little or no gearing backlash associated with either the driving and positioning of the antenna, or the subsequent feedback of position data. Backlash is a chronic problem for the servo engineer; therefore, a system which has a minimum of backlash will be the easiest to control. The pedestal should be lightweight and rugged to withstand the inflight vibration associated with all aircraft. Since rotational rates are higher, induced noise from pedestal operation may be objectional; therefore, the design should be one which minimizes structural-borne noise. The unit should have good reliability, with maintenance functions minimized and made easier to be accomplished at established intervals. The drive motor should have sufficient torque for steering any cataloged antenna, and the bearings should have sufficient load-carrying capacity for long life. The unit should be dustproof, humidity resistant and, depending upon application, may be explosion-proof.

Design Considerations for the DF Pedestal

The drive motor selected for the DF pedestal is one of the most important considerations in pedestal design. Several candidates may be considered for driving the DF pedestal: AC synchronous, stepper motors and various DC motors. The basic requirements for the DF pedestal application, however, include: high torque for starting and reversing the load; good efficiency for power-limited applications; small size; no "cogging" at low speed, therefore, good variable speed control; and long life. On the basis of these requirements, it is easy to rule out the stepper motor and AC synchronous devices as having the fewest number of qualifying features. Stepper motors have little to offer in the way of high starting torque, and speed control requires a more complicated and less reliable set of electronics. Stepper motors are also prone to EMI problems associated with high-frequency pulsing. AC devices have rather undesirable starting torque characteristics, even for capacitor-start types, which are the best of the lot, and good speed control of a synchronous motor is difficult to attain. In addition, both the stepper and AC motor are not energy-efficient. The so-called DC torque motor, therefore, most nearly satisfies all of the requirements for DF pedestal motive power. It attains its greatest torque at starting speed for good starting and reversing. Its speed is variable and easy to control. It can be rotated at low speed without cogging, and, although its continuous-use period is limited to its brush life, for most applications, its mean time between failures (MTBF) is more than adequate. It is available in a frameless, componentized form, making it ideal for incorporation into the pedestal-drive system. And, most importantly, it can be used in a direct-drive type of application, in which no other drive train components (i.e., gears, belts or pulleys) are required. Another feature which makes the DC torque motor ideal for pedestal applications is that the unit is available with a large internal diameter (ID). This is very advantageous for high-frequency DF antenna applications in which a "splash plate" or reflector rotates about one of several fixed-in-place waveguide antenna feeds, which must be located coaxially within the ID of the motor bore.

There is also a new candidate in the way of DC servo motors now available on the market. This is the brushless DC servo motor. Switching of poles is done by solid-state electronics, and an entire switching circuit along with digital encoder for position information may be packaged within the confines of the motor frame. However, torque sizes currently available are limited and the units are not available in component form. All have small diameter, solid-shaft mounted armatures, ruling out the possibility of direct-drive type of application. Figure 2 shows a typical frameless DC torque motor. Figure 3 shows how the large through-bore of the torque motor is used to accommodate stationary waveguide-type feed, rotating reflector-type antennas for DF applications.

Courtesy of Inland Motor Specialty Products Division
Radford, Virginia

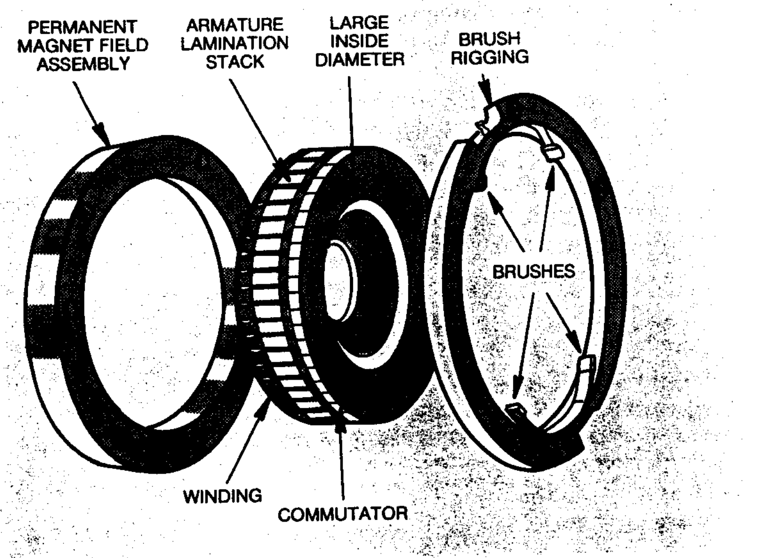


Figure 2. Details of a torque motor, showing hole for hollow-drive shaft mounting.

Drive Types

Three typical drive systems are shown in Figures 4A, 4B and 4C. Even though the DC torque motor represents the best prime mover for the DF pedestal, and is very adaptable to direct drive (no gear or belt reduction), the use of a speed-reducer drive system has some merits which must be considered in the design of the pedestal drive system. The use of a speed-reducing arrangement allows a lower torque-rated drive motor to be used because of the linear increase in output torque available from a given torque motor. Another advantage of speed reducers is that the majority of the frictional torque losses are on the "other side" of the drive ratio, where their effects are minimal in affecting an increase in servo response dead band. However, the advantages of increased torque by speed reduction is offset by a lack of coupling stiffness caused due to the greater number of moving parts subject to backlash and wear. In the case of a gear reducer, noise is increased and a lubrication system of some type is required. Belt-type reducers employing timing belts and sprockets are sometimes used, which provide speed reduction without gear noise and lubrication; however, the disadvantages include: Belt replacement due to wear and age; large volume for packaging and temperature variations of the belt, which affect servo performance. The efficiency of gear drives is usually better than 97%. For belts, this number will be much lower due to the higher friction inherent in a belt drive.

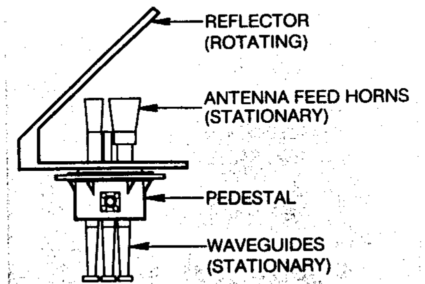


Figure 3. A pedestal with a large thru bore is used to rotate a reflector about stationary feeds in a wideband, circularly polarized antenna system.

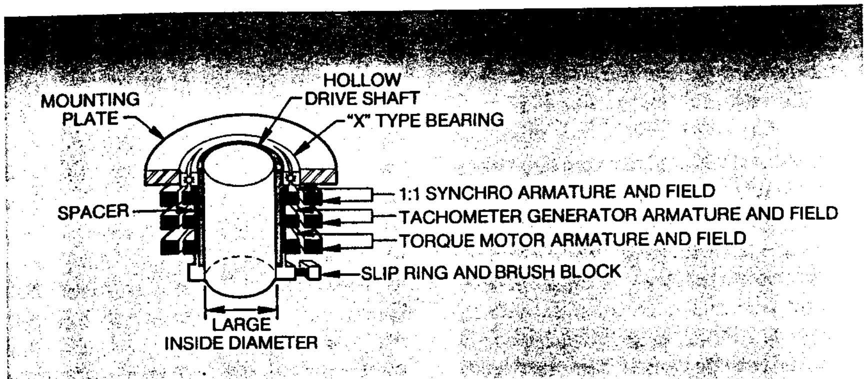
Advantages of the Direct Drive

The advantages of the direct drive, including those already mentioned are, first of all, a very high coupling stiffness. The direct drive motor is attached directly to the load itself; therefore, no gears, no backlash errors. High coupling stiffness results in high mechanical resonance frequency, which results in high servo stiffness.

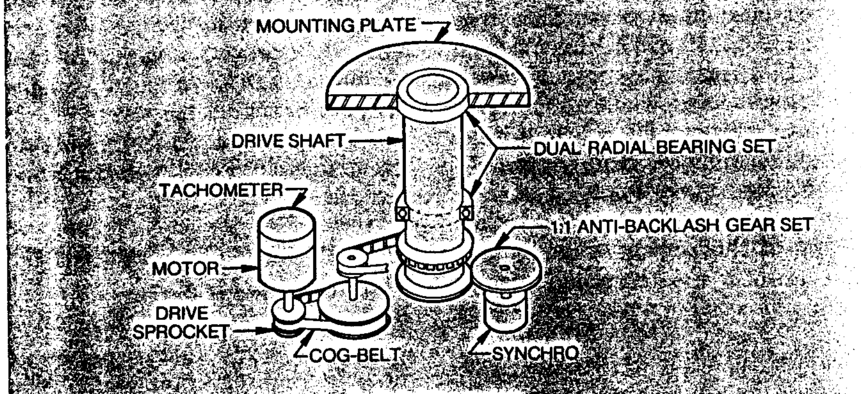
The direct-drive motor also provides the highest practical torque-to-inertia ratio where it counts, at the load shaft. A gear train decreases the torque-to-inertia ratio by a multiple equal to the gear-train ratio, resulting in poorer acceleration capability.

Torque motors mounted for direct-drive can take advantge of their low self-inductance due to the large number of poles and high-level magnetic saturation of the armature core, which allows torque to be developed at a high rate.

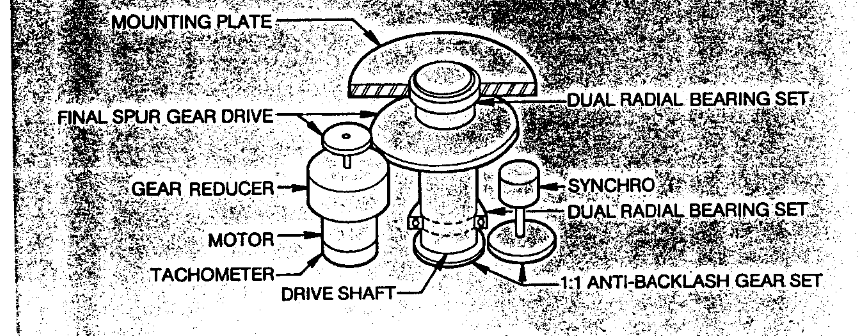
There is no dead zone due to backlash



A. Direct drive system with coaxially stacked components.



B. Belt drive system.



C. Gear drive system.

Figure 4. Three types of drive systems for DF antenna pedestals.

with a direct-drive system. Positional accuracy is limited only by the error-detecting transducer system, either synchro or encoder.

The frameless torque motor is designed-in as an integral part of the equipment, thus saving weight and space of the conventional motor frame or housing. In addition, the "pancake" configuration type of construction has the best form factor for pedestal applications. The motor can be fitted into minimum space around the drive shaft, and other pancake-type components of the servo system, tachometer generator and synchro, can be conveniently stacked in a simple packing arrangement. Figure 5 shows the W-J EP30-02 pedestal, which has all the advantages of direct-drive design.

Bearing Arrangement

Support for the rotating elements of the DF pedestal must be provided by a bearing arrangement which is suitable to the task. In pedestals which use speed reducers, the bearing set is usually a duplex-type arrangement in which the antenna is mounted to a hollow spindle which is seated in the bore of each of the two bearings, as shown in Figures 4B and 4C. The bearings used in such an arrangement are the radial-ball type, which must also be selected on the basis of their thrust-load capability, since due to the mass of the antenna, the thrust direction presents the worst-case load criteria. The advantages of the duplex-bearing arrangement are low friction and high over-turning moment capability, depending on spacing. Although bearings of this type are, by nature, relatively inexpensive, the necessary machining (line-boring) required to accommodate them is more complicated. In addition, the use of a duplex-type of bearing arrangement accounts for an undesirable form factor for the pedestal by reason of the necessary increase in vertical height. Most importantly, the main disadvantage of the double radial bearing set-up is the limitations imposed on the use of a direct-drive system of rotation. Radial bearings lack the necessary large ID (except in the case of extra large, heavy models) to accommodate the hollow drive shaft of the typical direct-drive torque motor. This limits the pedestal's capability to adapt to axial mounting of feeds for "splash plate" type of antennas. Most of the disadvantages of the duplex-radial bearing arrangement may be eliminated by using a single, large bore, X-type ball bearing. A typical arrangement using an X-type turntable bearing is shown in Figure 4A. X-type bearings provide a means for supporting combined thrust, overturning moment and radial loads by a single bearing. A cross section of the X-bearing and how combined dynamic loads are supported is shown in Figure 6. The advantages of the single turntable bearing over the duplex type are several. First, the single X-bearing is lighter than the double radial. Less space is required, and the large-bore turntable bearing lends itself ideally to stacking along with the frameless direct-drive torque motor. The single bearing arrangement results in the most simple arrangement possible for moving parts. Machining costs are lowered somewhat because line-boring is eliminated. There

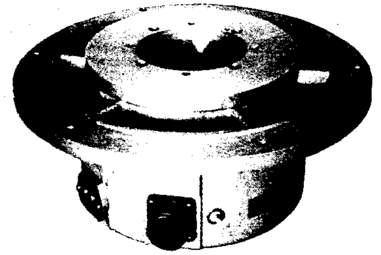
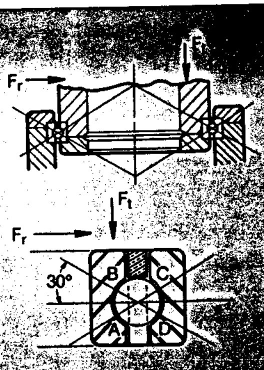


Figure 5. The W-J DF antenna pedestal EP30-2.

are two slight disadvantages in the single-bearing arrangement. Frictional torques at start up are a little greater due to the additional number of balls included in the bearing for support. This may serve to increase servo system dead band, in the direct-drive case, but this may be compensated for in the selection of the torque motor. There may also be a slightly higher inertia for the turntable bearing due to the greater distance of the rotating bearing mass from the axis of rotation. When used in conjunction with a flange type of arrangement of mounting for the pedestal, the single-bearing arrangement provides the most direct path for rotational and thrust forces on the bearing to the pedestal mount itself. Unlike the double bearing set-up, there is no need for additional structure to bridge the region from the bearing to the mounting flange.

Mounting Considerations

The pedestal should be designed such that, as mentioned in the preceeding section, a short direct-load path is set up from the antenna to the pedestal mount. In addition, if possible, the plane formed by the mounting surface of the pedestal should coincide with the center of gravity of the combined antenna/pedestal assembly. For mobile platforms this is very important, as the platform or vehicle to which the pedestal is mounted usually imposes vibration inputs to the pedestal. If the center of gravity of the assembly is nearly at the vertical location of the mounting flange, the so-called rocking mode of vibration, which is set up by lateral accelerations and is the most destructive, is eliminated. This is shown in Figure 7A. If at all possible, base mounting as shown in Figure 7B should be avoided. Figure 7A also shows a mounting arrangement in which the pedestal may also be mounted internally or externally, by virtue of the double mounting surface provided.



In the Type-X bearing, the groove in each race has two radii whose centers are offset from the plane of the ball centers. The latter construction gives the Type-X bearing its unique "Gothic Arch" configuration, making possible four contact points between a ball and the raceways.

A force in the thrust direction from top to bottom applied to the inner race is passed from the race to the ball at point B. It is then transmitted through the ball to point D, where it passes into the outer race and support structure. The line of action BD forms a nominal 30° angle with the radial centerline of the bearing. Because of the elastic deformation of the ball and the race grooves along the load transmission line, the ball load is relieved at points A and C, permitting smooth rotation around an axis perpendicular to line BD. Likewise, with a thrust force applied to the inner race from bottom to top, a similar transmission occurs between points A and C.

A moment or overturning load is similar to two thrust loads acting in opposite directions at diametrically opposite sides of the bearing. With a moment load, the loading on one side of the bearing will pass from point B to D, relieving points A and C.

Directly across the bearing, the load passes from point C to point A, relieving points B and D.

A radial load is resisted equally across the lines of contact CA and BD. Under combined loading, the resistance is along both lines of contact with the magnitude of each reaction dependent upon the relationship of the individual loads.

By its ability to resist radial, thrust, and moment loads in any combination, the Type-X bearing is often able to replace two bearings — a pair of angular contact ball bearings, a pair of tapered roller bearings, or a combination of thrust and radial bearings, either ball or roller.

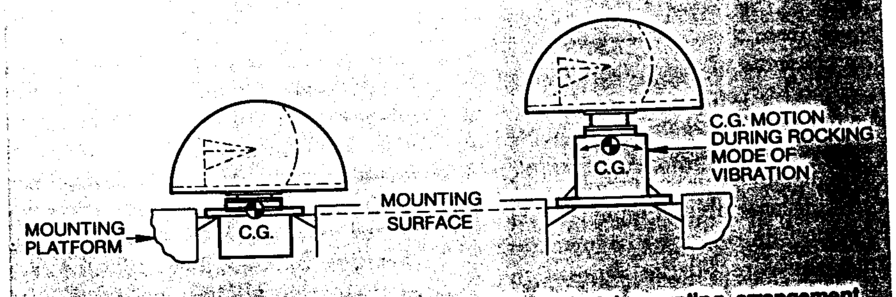
Figure 6. How a single X-type bearing supports thrust, radial and moment loads.

Position and Velocity Component Coupling and Selection

The pedestal must be equipped with a means of providing error signals with regard to both velocity and position to the controller. Typically, either a synchro or an encoder is required for position data, and a tachometer generator is used to provide velocity feedback. The coupling of these components to the rotating element is another important factor to be considered in the pedestal design, but the mechanical effects of the mounting are additionally important to the controller design. Just as in the case of the drive system, backlash must be minimized or eliminated, if possible, in order to minimize servo system dead band and improve stability. Again, the direct-drive system is the best means of accomplishing minimum error in feedback information. To some extent, anti-backlash gearing arrangements are successful in providing servo system rigidity, and are generally less expensive than a direct drive, frameless synchro or encoder. The disadvantages of transducer gearing includes more moving parts subject to wear, greater inertia, and more complexity with more packaging volume required. Figure 4 shows both a geared transducer arrangement and the direct drive set-up.

Antenna Mounting to the Pedestal

The mounting of the antenna to the



A. Pedestal/antenna center of gravity in-line with mounting plane allows only translational vibration modes.

B. Pedestal mounting arrangement which permits additional rocking mode of vibration.

Figure 7. How pedestal mounting affects vibration modes.

pedestal should be a simple operation, as this must be carried out many times in unfavorable conditions in the field. In some cases, such as aircraft applications, the rear side (side furthest from the antenna) of the pedestal is difficult to access. The best mounting arrangement in most cases is a flange on the antenna which mates to the turntable flange of the pedestal. The flange interface must be equipped with alignment features, such as pins or keys. In some cases, a V-type clamp, similar to a Marmon clamp, is used to decrease the overall height of the antenna above the turntable, since less space is required for assembly. This shortens the distance between the antenna center-of-mass and the bearings, and results in lower bearing loads and, therefore, longer service life.

Slip-Ring Considerations

In many cases, the antenna being rotated by the pedestal is actually a switchable assembly composed of several units which, through coupling, comprise a wide-band system. In addition, the feeds of the units may have both horizontal and vertical polarization. Both of these functions, band selection and polarization require electromagnetic RF switches, and the voltage required for switching requires the need for slip-ring and brush-block arrangements in the pedestal, in order to send power from the stationary to the rotating elements of the system. Slip rings are another coaxial type of device, and for the direct-drive pedestal are readily adapted to the same stacking arrangement as for other components of the pedestal assembly. Figure 4A shows how the slip ring may be incorporated into the direct-drive pedestal as a clamp which holds the coaxial component stack together.

EMI Factors

The main disadvantage associated with the use of commutated devices in conjunction with high sensitivity EW reconnaissance systems is the emission of electromagnetic interferences (EMI) or radio frequency interference (RFI), synonomous terms describing the generation of unwanted emissions by the making and breaking of the commutated circuit at the interface of the brushes and commutator. Not only is EMI undesirable in the case of internal receiver-system noise affecting intercept performance, but, in many cases, the entire reconnaissance mission may be placed in jeopardy if the level of EMI is sufficient to reveal the position and intent of the receiver system. The EMI generated by the brushes of the DC servo motor and slip rings of the pedestal must not be allowed to escape the confines of the pedestal housing. Sealing of metal-to-metal surfaces must be done with sufficiently close spacing of fasteners to prevent emission of both primary and higher harmonics of the EMI. Where required, conductive gasket materials may be used to provide increased sealing. In addition, "spikes" of noise present on the tachometer generator voltages and back emf of the motor may be isolated within the pedestal through the placement of filters in the lines directly adjacent to the inside of the connector bulkhead. The synchro lines may be protected from EMI by using twisted, shielded pairs of conductors, thus assuring that the position information is "clean." The whole concept of DC commutated devices may be changed as a result of recent advancements in so-called "brushless" DC motors. New units have appeared on the market which employ electronic commutation and have very low associated EMI. In one design, switching of poles of the motor is accomplished by rotor position sensing through the use of LED's and photo transistors. As the reliability of these types of motors develops, some replacement of mechanical commutated types may be seen, especially where EMI is critical. One of the other advantages of these devices is that the tachometer circuitry and switching circuitry may be mounted within the case of the motor.

Pedestals for Directional Antenna Systems

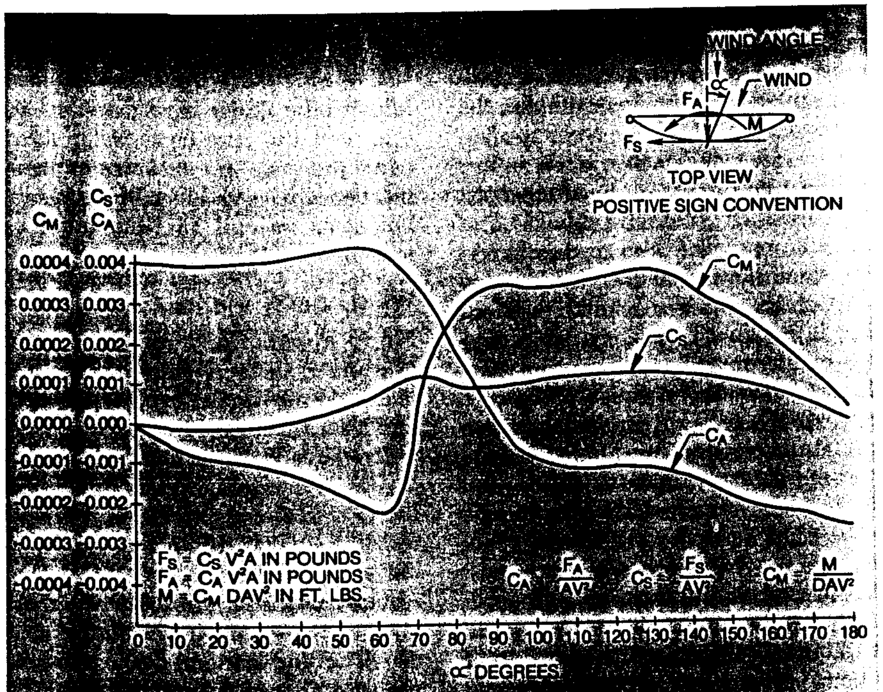
When used in conjunction with EW reconnaissance systems, directional antennas perform a similar function with regard to receiving and locating an emitter, as their smaller, faster-rotating DF counterparts. The chore of positioning a more massive, larger-aperature antenna however, imposes a slightly different set of requirements for the pedestal. Being able to accommodate larger mass and inertia loads immediately suggests a heavier-duty machine. In addition, exposed (no radome) operation also requires steering against wind and ice loads. Dual axis or elevation-over-azimuth positioning is required in many cases where the emitter must be tracked other than in the horizontal direction. Generally speaking, accuracy requirements are similar to that for DF antenna pedestals; however, due to the inertia loads usually involved, lower rotational rates must be used, which, due to gearing, will require anti-backlash measures to ensure pointing accuracy and good servo performance. Since the system will, in all likelyhood, require portability, transportation "g" loads must be considered. Mechanical and electrical limit stops must be incorporated where the amount of rotation about an axis must be controlled. In many cases, sensitivity requirements dictate that preamplifiers and other parts of the receiver system must be mounted on the rotating portion of the pedestal. This requires that sufficient volume in the pedestal be allowed for slip rings, rotary joints, cable wraps or twist capsules to transport power or signals from rotating to stationary points on the pedestal. The majority of mounting is external to a radome; therefore, the pedestal must be rain and drip-proof, dust-proof and corrosion resistant. For remote operation, it is sometimes better to mount elements of the servo amplifier within the pedestal. This may mean that auxiliary cooling must be provided for the additional power dissipation within the pedestal. Accessories such as stowlocks and handcranks are more often than not a requirement to facilitate set up of the system.

Design Considerations

Most of the design considerations included in the requirements for directional pedestals are the same as those mentioned previously for DF pedestals, but some special subjects must be mentioned.

Wind Loads

Many applications for directional antenna systems require that the system be located in an exposed location, and likewise, in many cases, the use of a protective radome must be omitted due to performance (gain and sensitivity) or cost considerations. For this reason, an understanding of wind loading and its effect on pedestal design requirements is required. There is more to be considered than the simple case of overturning moment due to dynamic pressure caused by wind impinging upon the superstructure of an antenna and its support. As the antenna is positioned against the wind, side forces cause torques which must be overcome by the drive system and supported by the turntable bearing system. Seldom are antenna configurations alike, and to get real information as to the effect of wind loading would require wind tunnel tests of a model of each type. Such tests have been carried out for the parabolic reflector family of antennas. Figure 8 shows a graph of wind loads versus wind angle for parabolic reflectors, taken from wind tunnel tests of the basic configuration. The results are plotted in terms of wind angle versus force and moment coefficients, and represent the ideal case, that of a simple geometric configuration. In the real situation, support structure for the antenna feed and pedestal mount would have an unknown effect on these data; however, for the most part, these curves represent the worst case effects of wind loading. Note that in the same manner as nozzle forces act upon the surface of the stationary vane, the effects of dynamic pressure on the parabolic reflector may be resolved into two force components and one moment, all taken at the vertex of the parabola. Since in most cases it is not possible to mount the vertex at the center of rotation of the pedestal, each component must be considered as a separate effect, depending on the actual location of the reflector with respect to the center of rotation. As one might expect, the forces and moment about the reflector are cyclic with respect to negative and positive direction, as defined in the figure. In the actual case, the reflector vertex will be offset from the center of rotation by some distance, i.e., as shown in the figure for geometry. This will cause the side and axial components, F_s and F_a to have an additional effect upon total moment about the pedestal axis. The sum of the moments, $F_s \times e\cos\theta + F_a \times e\sin\theta + M$ is equal to the torque which must be output at the turntable of the pedestal for operation under wind conditions. For an elevation pedestal drive system, the added effect of the gravity load of the antenna and radial ice, if icing is to be considered, must also be summed in the above relation.



Wind effects can be separated into two force components and a twisting moment as shown in upper right of Figure 8. The axial force, F_A, acts along the axis of the antenna, the side force, F_S, acts perpendicular to the axis of the antenna with its line of action passing through the vertex of the paraboloid. The twisting moment, M, is a couple which acts in the horizontal plane (the plane of the wind).

The magnitude of F_A, F_S and M depends on the dynamic pressure of the wind, the projected frontal area of the antenna, and the aerodynamic characteristics of the antenna body. The aerodynamic characteristics vary with wind angle. It is therefore convenient to express the variation of F_A, F_S and M in terms of the following coefficients: $F_S = C_S V^2 A$, in pounds; $F_A = C_A V^2 A$, in pounds; $M = C_M DAV^2$, in Ft. lbs.

Figure 8. Wind forces on parabolic reflector antennas.

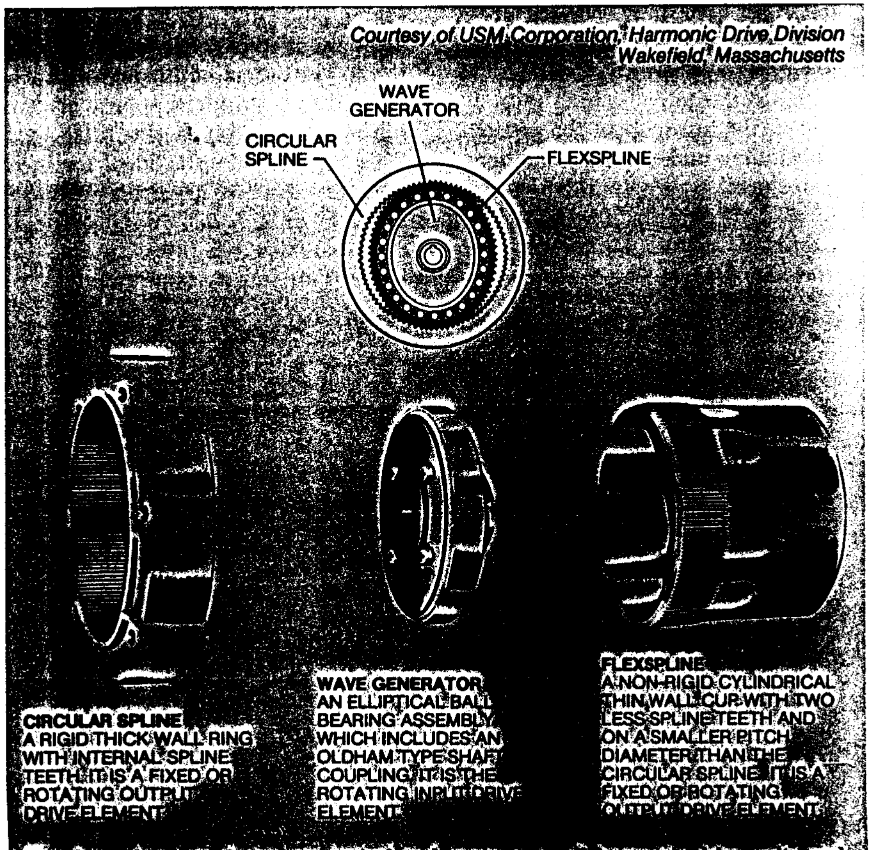
To achieve higher speed reduction and low backlash in a lightweight package, aerospace designers have "rediscovered" a drive system that has been in use for many years, but until recently has enjoyed little recognition for its merits. This is the so-called harmonic drive. A sketch of the harmonic drive is shown in Figure 9. Briefly, the device works as follows: The input rotation is given to a rotating component called a wave generator, which is a sort of oval-shaped hub with a ball bearing and race system which accommodates the shape of the oval hub. The wave generator is inserted into a flexible cup-shaped part equipped with a set of drive teeth on the outside lip of the cup. The cup is inserted, in turn, into the stator of the drive system, which appears as an internal tooth gear with provision for fastening the stator to a rigid mount. The stator has several more teeth than the cup. When assembled, the teeth of the cup engage about half of the teeth of the stator. As the wave generator is rotated, the cup is constantly flexed and rotated as different sets of teeth engage each other. The result is a high amount of speed reduction with only three moving parts. Standard reductions are from 80 to 200 to 1 for a harmonic drive. The large number of teeth engaged allow the unit to accommodate high torque loads without "ratcheting." There is very little backlash, per se, due to the kind of pre-loading taking place, and again, because of the large number of teeth engaged at all times. The output of the device may be coupled to a standard spur gear drive pinion for driving a turntable gear. This type of set-up is ideal for incorporation into a pedestal for EW reconnaissance where, to mention again, the requirements for lightweight and high performance are mandatory.

Mounting

Just as in the DF pedestal, consideration must be given to a short path from the loaded portion (turntable) of the pedestal through its supporting bearings to the pedestal mounts. Compliance is a term generally reserved for defining the axial stiffness of a pedestal. The units for compliance are radians per foot-pound. In other words, with the input or rotor shaft locked, for a certain amount of torque about the turntable axis, there must be a corresponding amount of angular displacement. What is desired is a very low compliance or, conversely, a very high spring rate. Not only does compliance take into account the stiffness of the drive train but also the stiffness of the structure of both rotating and stationary parts; therefore, the need for rigid housing to transfer the bearing loads to the mounts without distortion. Generally speaking, a single turntable bearing is much more effective in providing for low structural compliance than any type of duplex-bearing (two in-line bearings) arrangement. Manufacturers of good, rigid pedestals, without exception utilize the single turntable bearing arrangement over any other bearing setup. As a side note, in order to facilitate adapting designs, manufacturers of these bearing components are able to provide the bearing with the inner race fitted with internal gear teeth for easier drive line hook-up to a drive pinion. X-type turntable bearings, as mentioned in the DF pedestal discussion, may be used effectively to support thrust, overturning moment, and radial loads in a lightweight configuration.

Drive System

Rotational rates for directional antenna systems is in the low rpm range, from stall to 2½ rpm or slightly higher. This means that a DC servo motor which has been properly selected to operate satisfactorily at a constant velocity and torque, without cooling at, say, 2000 to 2500 rpm, must be geared down by a ratio of 800 to 1000 to 1. The selected speed reducer, whether it be spur gear, worm gear or any other type, must be able to achieve this ratio with a minimum of backlash. Backlash specifications are usually less than 0.100 degrees, with one major pedestal manufacturer quoting 0.05 degrees on all standard pedestals. To provide this type of minimum backlash, a spur gear system must be assembled with most gear engagements preloaded. This means that the gears are, in effect, compressed together such that the only differential motion between them, other than the driving of one by another, is due to the elastic properties of the materials. The price paid for achieving that low backlash in such a manner is extra weight.



Courtesy of USM Corporation, Harmonic Drive Division
Wakefield, Massachusetts

The three elements shown are typical and common to all harmonic drive units and function in the following manner:

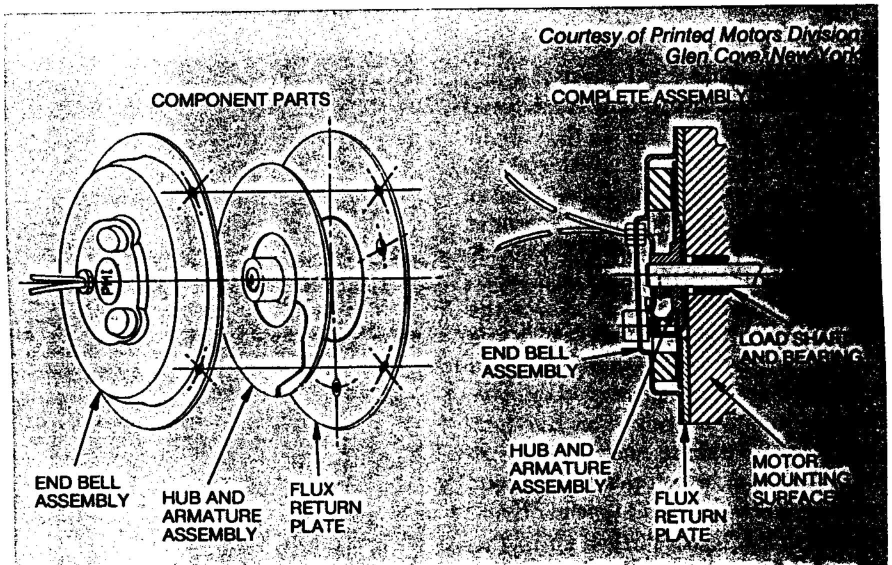
The flexspline assumes an elliptical shape upon insertion of the wave generator into the bore. The resultant spline pitch diameter at the major axis becomes the same as the circular spline. The flexspline teeth thus engage with the circular spline teeth at two points 180° apart to form a positive gear mesh.

One CW input revolution of the wave generator produces one CW revolution of the flexspline elliptical shape, causing a continuous tooth-to-tooth rolling mesh at the two points of engagement. The resultant rotation of the flexspline proper, relative to a fixed circular spline is two teeth in a CCW direction or a reduction ratio equal to one-half the number of teeth on the output element.

Figure 9. The harmonic drive and how it works.

Drive Motors

The advantages of the DC servo motor have already been outlined in the previous DF section, as were also the advantages of the frameless, pancake type motor. A different type of pancake type motor, shown in Figure 10, provides many great advantages when coupled to the harmonic drive or another pedestal-drive system. The unit illustrated is a so-called ironless armature unit, which has a pancake-shaped rotor manufactured much in the form of a disc-shaped printed circuit. This unit is capable of developing amazingly high torques for its size and weight. It has low inertia, low EMI, and is available in component form, thereby providing for integral packaging of the speed reducer and motor. One feature of this unit is its rated "pulse torque." This is a characteristic normally not established for any other DC servo motor. Pulse torque is the rated torque which the unit will deliver for a short duty cycle. Typically, these pancake armature motors will deliver more than ten times their rated static torque for a short duty cycle, say about 5%. This is ideal for servo type motor devices,



Courtesy of Printed Motors Division
Glen Cove, New York

Figure 10. The printed circuit or ironless armature pancake DC motor is lighter, has less inertia and greater torque than other DC motors.

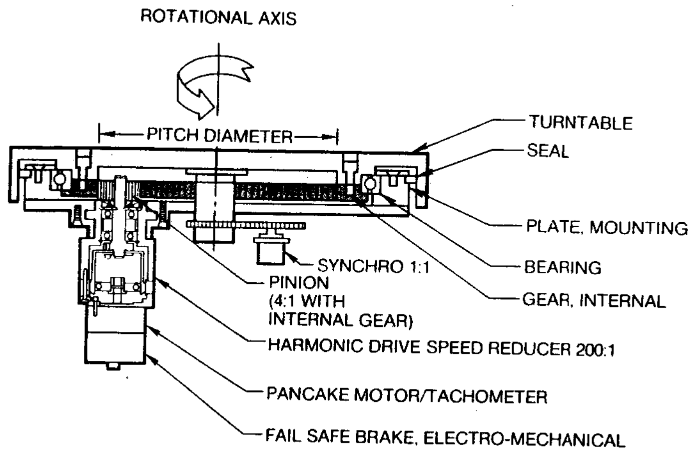


Figure 11. The W-J EP40 pedestal drive module.

especially for a pedestal, which is being scanned (rotated back and forth over an included angle) or intermittently started and stopped under a high load. These units are available in motor/tachometer versions too, which make it the ideal prime mover for a servo controlled system.

Brakes

Fail-safe braking for the pedestal is a desirable feature, especially for exposed mounting. Fail-safe braking (brakes are electro-mechanically activated when no current is applied) assures better servo performance for stopping and assures that the drive system will not be back-driven by an overhanging load when the unit is at rest. This allows the pedestal drive motor to "rest," with less heat dissipated in the standby mode when positioning against wind or overturning moment loads. For the harmonic drive, braking must be done at the motor shaft, which causes no major problem. For a spur gear type of drive, mounting the brake further up in the drive train helps lessen the amount of directly coupled inertia; however, a large capacity brake must be used.

The W-J EP40 pedestal drive module shown in Figure 11 represents a successful attempt to combine all of the preferred design aspects for a directional antenna pedestal into a single unit. The actual pedestal, shown mounted to a housing appears in Figure 12.

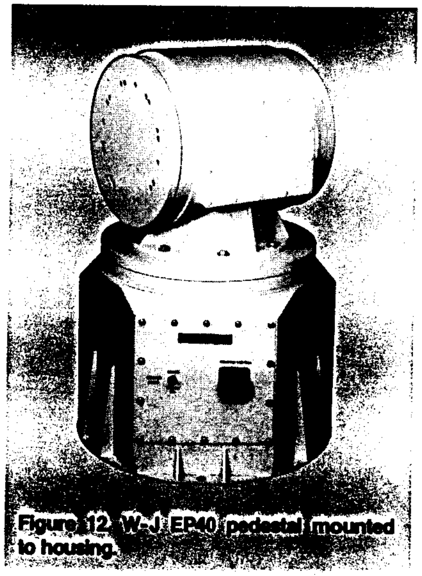


Figure 12. W-J EP40 pedestal mounted to housing.

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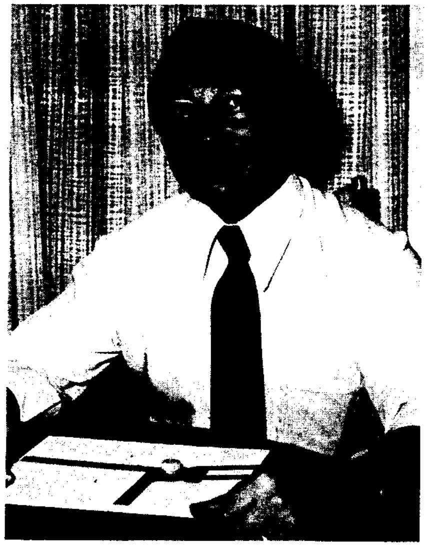

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