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SPACE STATION ROTARY JOINT MECHANISMS

Glen W. Driskill*

This paper describes the mechanism which will be used on the Space Station to position the solar arrays and radiator panels for sun pointing and sun avoidance, respectively. The unique design features will be demonstrated on advanced development models of two of the joints being fabricated under contract to NASA-MSFC.

INTRODUCTION

The Space Station, to be placed in low Earth orbit in the early 1990s presents some new challenges for rotary joint drive mechanisms, power transfer and fluid transfer, because of the large size, long life, and EVA maintenance requirements. Other requirements include high structural stiffness to avoid low frequency structural modes and trouble-free, autonomous operation. Existing technologies have been adapted from other applications to fit these new demands. Table I lists the presently defined requirements for the Advanced Development Project units.

ROTARY JOINT TYPES

There are three different rotary joint types on the Space Station structure (Refer to Figure 1); The solar alpha joint, which allows the boom supporting the solar collectors to track the sun at orbital rate, 2) the solar beta joint, which allows the solar collectors to be individually rotated to track orbital declination and seasonal variations, and 3) the radiator panel joint orientated in the alpha axis, but with tracking to avoid the sun. Of the three joints, the solar array alpha joint is the most challenging because of the size, the requirement to maintain the structural stiffness of the truss across the joint, and the requirement to transfer greater than 100 kW of power across the rotary interface.

The solar alpha joint requirements for the reference (IOC) configuration for the Space Station called for a size and stiffness compatible with a 2.7-m (9-ft) truss. These requirements led to an optimized design based on stiffness/weight trade-offs which utilize a 2.7-m (108-in.) wire race bearing and a shell structure from the square truss to the bearing. Power transfer in each alpha joint will be one half of the total station power and will be handled by the continuous rotation roll-ring assembly developed by Sperry. The joint will be driven by a dual-redundant drive assembly, which uses a direct-drive brushless dc motor with a pinion gear engaging a ring gear incorporated in the inner race of the wire race bearing. Figure 2 shows the alpha joint cross section.

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*Sperry Corporation, Aerospace & Marine Group, Space Systems Division, Phoenix, Arizona.

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Table 1. Key Requirements for Rotary Joints

Characteristic	Requirement
Stiffness	No reduction across joint.
Redundancy	Fail-safe, redundancy, as required, to meet 20-year life.
Rate/Position	Both sides of joint; position sensor accuracy of 1 percent, rate sensor accuracy of 3 percent.
Output Torque	54.2 N.m (40 ft-lb), minimum, solar alpha; 27.1 N.m (20 ft-lb), minimum, other joints.
Range	Continuous on solar alpha; 270 degrees on other joints.
Power Transfer	100 kW, minimum at 120 V dc across solar alpha
Fluid Transfer	Ammonia; three 1.3-cm (1/2-in.) lines, three 0.65-cm (1/4-in.) lines.
Life/Maintenance	20-year life; EVA replaceable.

In the solar beta axis, the joints will interface with the deployable solar panels and will use a 91-cm (36-in.) wire race bearing. Here the power transfer requirement will be one fourth of the solar alpha joint. Since this joint only tracks the orbital inclination and seasonal variation, it does not require full rotation and, therefore, power transfer can be by roll ring or wind-up cable. Present thinking tends toward a roll-ring assembly.

The radiator panel joint can be made full rotation since it also tracks orbital rate or it can be limited rotation with rewind on the dark side of the orbit. Full rotation requires a rotary fluid coupling joint, which is more complicated than a hose wind-up used for limited rotation. The mechanical part of the joint is the same as the solar beta joint and uses the same drive assembly as all the joints. Figure 3 shows an outside view of the joint.

DESIGN DESCRIPTIONS

Drive/Engagement Module

The drive assembly design, which is used on all of the joints, consists of a brushless dc motor, commutation resolver, multispeed/single-speed position resolver, pinion gear and follower bearing (See Figure 4). The drive assembly is mounted on a pivoting arm into an orbital replaceable module, which also contains the mechanism to engage or disengage the drive pinion to

the ring gear on the wire race bearings. A follower bearing adjacent to the pinion gear rolls on a follower surface, machined accurately relative to the pitch diameter of the ring gear. Complete mechanical redundancy is achieved by incrementing the drive/engagement module axially so that one of the two drive assemblies per joint engages one row of teeth on the ring gear and the other engages the second row of teeth.

The drive motor is a 16-pole, permanent magnet, two-phase motor that is continuously commutated from a 16-pole resolver. Use of continuous versus discrete commutation by an optical or hall-effect switch provides a high efficiency and a lower ripple torque. The paired motor and commutation resolver are coupled through a pulse-width-modulated signal with a voltage (torque) amplitude proportional to the excitation level to the resolver.

A combination single-speed/multispeed resolver is incorporated in the drive assembly. The single-speed resolver provides position information for the joint but, because of the gear ratio, it must be processed to obtain output angle. A power-down will cause loss of absolute alpha position information, but the absolute angular position can be established from the resolver on the outboard side of the joint. The absolute position resolver is located in the power/signal module. Rate information is derived from the multispeed resolver using a tracking converter.

The pinion bearing used in the drive assembly is a preloaded pair of thin section bearings. These bearings and the follower bearing are the only bearings that are constantly loaded when the drive assembly is being used since they must counter the engagement spring force. The engagement force must be high enough to withstand the gear separation forces which result if the output is locked and full stall torque is applied to the motor. If sufficient engagement force is not applied, the pinion gear teeth will ratchet over the ring gear teeth and possibly result in damage.

Engagement and disengagement of the drive pinion is provided by an eccentric arm driven by a gear train motor. Switches are incorporated to indicate engagement, disengagement or transition in between. The engage/disengage motor will be used only a few times in the 20-year life and does not have to be high quality.

Orbital change out of the module or manual operation of the drive motor and the engage/disengage motor can be performed EVA. Any drive/engagement module can be used in any joint without complicated change-out procedures or realignment. The drive/engagement module can be changed out by releasing three quick-release, hold-down devices and two electrical connectors.

WIRE RACE BEARINGS

The 2.7-m (108-in.) and 91-cm (36-in.) bearings used in all the joints will be "wire race" type, which uses aluminum for the structural members and stainless-steel raceways and rollers at the wear interfaces. Thermal expansion differential effects between the steel and aluminum members are

minimized by making the raceways noncontinuous within the aluminum main structure. The use of an all-steel bearing would not avoid a thermal expansion problem since it must be mated with an aluminum or graphite epoxy transition structure. There are three vendors who supply the wire race-type bearing in addition to more conventional bearings. Current applications for bearings of this size include heavy machininery, gun turrets and other heavily loaded turntable-type applications. In the Space Station application, the design driver, at least for the 2.7-m (108-in.) bearing, will be moment stiffness. Load capacity and fatigue life will be much higher than required. Life is predicted to be 100-plus years and the probability of success for 20 years is 0.999995 due to the low operating stresses.

The ring gear and follower surface are incorporated into the design of the inner race of the bearing (see Figure 4). Specific data on long term use of a large aluminum gear in space is not available, but Sperry has run accelerated life tests in vacuum on steel gear sets which used 45.7-cm (18-in.) gear and a follower bearing to control backlash, and GSFC has run aluminum gear tests in vacuum (Reference 1). The normal use of these types of bearings with gears is in severe load situations. Life is not expected to be a problem, based on the related data available, but cannot be shown by a specific AGMA analysis.

Other types of bearings and bearing arrangements were investigated but did not meet key requirements of being weight-efficient, simple to apply, or of having ease of orbital change-out.

INTERFACE STRUCTURE

Several key configuration types and iterations within the type categories were investigated by Rockwell International under subcontract to Sperry for the Rotary Joint Advanced Development Project. The basic requirement was to interface with the 2.7-m (9-ft) square box truss (in the IOC configuration) through the bearing without a loss in structural stiffness. Trade-offs were made for weight, stiffness, and cost to fabricate. Configurations considered included truss, box, monocoque and a ring and shell type. The truss type had the disadvantage of asymmetric load transfer to the bearing; the box type was heavy; the monocoque was a good option but is complex to build. A simple, weight-efficient, and easy-to-fabricate type is the ring and shell type (Figure 5). The interface structure will consist of two identical welded and/or riveted main elements consisting of a square bulkhead plate to interface with the box truss, a ring (or cylinder) to transfer torque, and uniform loads to the bearing and the four corner shells to distribute the corner loads uniformly to the ring. A closeout ring mates with this structure and the bearing races.

Rockwell International also investigated a range of bearing sizes to determine the optimum bearing diameter. The 2.7-m (108-in.) bearing was the best, based on direct-load path considerations, but a bearing down to 80 percent of the truss size was found to be workable. Material trade-offs were made, with the result that aluminum was determined to be cheapest to

fabricate, but graphite epoxy was the lightest. It is not within the budget of the Advanced Development Project to develop the graphite epoxy structure.

POWER TRANSFER

Power transfer across the solar alpha joint, which is one half of the total station supply, will utilize a roll-ring transfer device (References 2 and 3). This device, when compared to rotary transformer types, is much lighter, requires no heat dissipation device, and can transmit ac or dc power. When compared to conventional slip-ring devices, it exhibits comparatively little debris generation because of rolling versus sliding contact and hence does not have a life limited by wear or debris accumulation. An eight-ring model of the roll ring has been in test at LeRC for almost a year with accelerated life tests at 100 KW of power and equivalent to several Space Station lifetimes. The roll-ring assembly, to be supplied in the Advanced Development Project solar alpha joint, will be a 12-ring model with greater than 100 kW capacity at 120 V dc. The power capacity of the roll-ring unit is a function of the voltage and, perhaps, frequency which is yet to be evaluated at LeRC. Further details of the roll-ring unit will not be described here because the data is readily available in other papers (References 2 and 3). Reference 3 contains LeRC test data up to October 1985.

A position resolver will be incorporated in the Power/Signal Module to provide absolute angular alpha-angle position of the solar arrays. The sensor used will be a single-speed resolver, accurate to 3 minutes of arc, which was developed for, and is used in, single-axis control moment gyroscopes for gimbal angle sensing. Also incorporated in the module is a signal-level roll-ring assembly with 30 signal circuits.

The Power/Signal Module is an orbital replaceable unit with quick-release fasteners for the power leads and the structural assembly. A ribbed diaphram-type structure supports the module to the stationary and rotary parts of the bearing. The coupling misalignments of the rotating part of the module are accommodated by a two-axis leaf spring type of coupling.

FLUID TRANSFER

Transfer of fluid in the Advanced Development Project radiator joint is simplified by making it limited rotation with programmed rewind on the dark side of the orbit. There are advantages to a continuous rotation joint, but also disadvantages in mechanical complexity and reliability. LaRC is presently testing a continuous rotation joint and JSC has issued a subcontract for another development source. The limited rotation joint, which will be demonstrated on the contract, is the least mechanically complicated but, if used on the Space Station, would cause a large disturbance to the station once each orbit when the radiators are stopped, rewound, and then restarted.

The fluid line scheme chosen over several alternatives is a four-turn wrap around the radiator boom with a 38.1-cm (15-in.) pitch. To accommodate

a 270-degree total travel, a significant fluid line pitch diameter change occurs during rotation. The greater the number of turns, the lower the diameter change, but beyond four turns for this excursion angle, the trade-offs are less than optimum. No specific data exists relative to ammonia permeability through the walls of flexible hoses since most conventional ammonia applications are in rigid-pipe ground applications (ice plants). Ammonia offers the highest liquid/vapor latent heat values of available refrigerants, which is why it was chosen for Space Station application. Two types of flexible lines are being considered for the limited-angle fluid transfer: 1) Teflon®-lined, steel-braided hydraulic hose, and 2) convoluted stainless-steel tubing, which can also be supplied with a steel-braid outer wrap. Teflon-lined, braided hose has advantages in weight, coiling behavior and availability, but the hose manufacturers and Teflon manufacturer (DuPont) do not have permeability (leakage) values for Teflon. They do concur that it has the best chance, among all plastics, of doing the job. Stainless-steel or convoluted-type bellows are compatible with ammonia and would have the best chance for zero leakage, initially, but long-term fatigue effects are yet to be evaluated and the coiling behavior is yet to be addressed. Hose change out on orbit will be facilitated by a low-pressure, drop-ball cock valve on each side of the hose joints and a quick disconnect at each end. The valves will prevent any significant amount of ammonia venting during the change-out process.

DRIVE/CONTROL ELECTRONICS

Each joint in the Space Station will operate autonomously and will have built-in health monitoring, but fault signals, which may require switch-over to redundant devices, will be processed through the main computer. Autonomous operation will be accomplished with a microprocessor-based control system that will interface with the main computer. Each joint will have a controller, which will communicate with the central computer, control the engage/disengage mechanism for the dual-redundant torquer module, and interface with the dual-redundant drive electronics. In the Advanced Development Project, a minicomputer, with a printer, display screen and an instruction keyboard, will substitute for the flight model embedded microprocessor unit. Electronic boxes (one interface and two redundant drive) with the same part number can be used on all joints, but some joints may require algorithm and compensation filter changes directed from the central computer. Figure 6 is a diagram representation of the solar alpha joint.

The drive electronics will excite the torque motor from a pulse-width-modulated bridge with the amplitude of the continuous commutation signals proportional to the excitation level of the commutation resolver. This scheme is extensively used by Sperry in CMGs and RWAs because of simplicity of design and low torque ripple considerations. A digital commutation and control approach will be considered for the flight configuration to be more compatible with microprocessor-based electronics if increased torque ripple can be tolerated.

SPECIAL CONSIDERATIONS

There are peculiarities in the Space Station application, as in all space hardware, but the added considerations are on-orbit change-out of components for long-term use of the station, on-orbit maintenance, and the enormity of the structure.

Temperature effects on the rotary joint mechanisms appear to be a manageable problem according to predictions from the Rockwell thermal analysis. The combination of multilayer insulation, high thermal capacitance and good internal thermal paths serves to minimize temperature swings and thermal gradients. Absolute temperature changes of less than 11°C (20°F) are predicted for orbital and seasonal variations. These variations are easily accommodated in the thermal design of the drive mechanisms and the follower bearing concept for backlash control. Temperature gradients between the outer ring and inner ring of the joint bearing can cause preload changes which could result in drag torque problems or loss of stiffness in the extreme cases. With a 279.75 kg (7500-1b) preload on the alpha joint bearing, it would take an 4.4°C (8°F) differential inner/outer ring gradient to go to zero preload or double preload. The Rockwell prediction is for a 2.2°C (4°F) worst-case differential. If the predicted gradients are shown to be greater than 2.2°C (4°F) in later analyses, the preload can be increased and/or heater control can be provided to reduce the gradient.

On orbit change-out of boxes, drive/engagement modules, power/signal modules and fluid hoses is accommodated in the design. Change-out of joint bearings has been rejected in favor of total structural joint change-out due to considerations of total EVA time. Bearing health can be monitored by drag torque, temperature, and stiffness (by observing structural frequencies). Signs of deterioration would allow time to schedule transportation of a replacement joint in a future shuttle flight. Spares for the boxes and drive/engagement module could be stored on orbit because of the small size and common utilization on all twelve joints.

REFERENCES

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2. Porter,Ryan, "Rotating Electrical Transfer Device," Nineteenth Aerospace Mechanism Conference, May 1985.

3. Jacobson, Peter, "Advanced Space Power Transfer Device," EASCON 85 Eighteenth Annual Conference, October 1985.
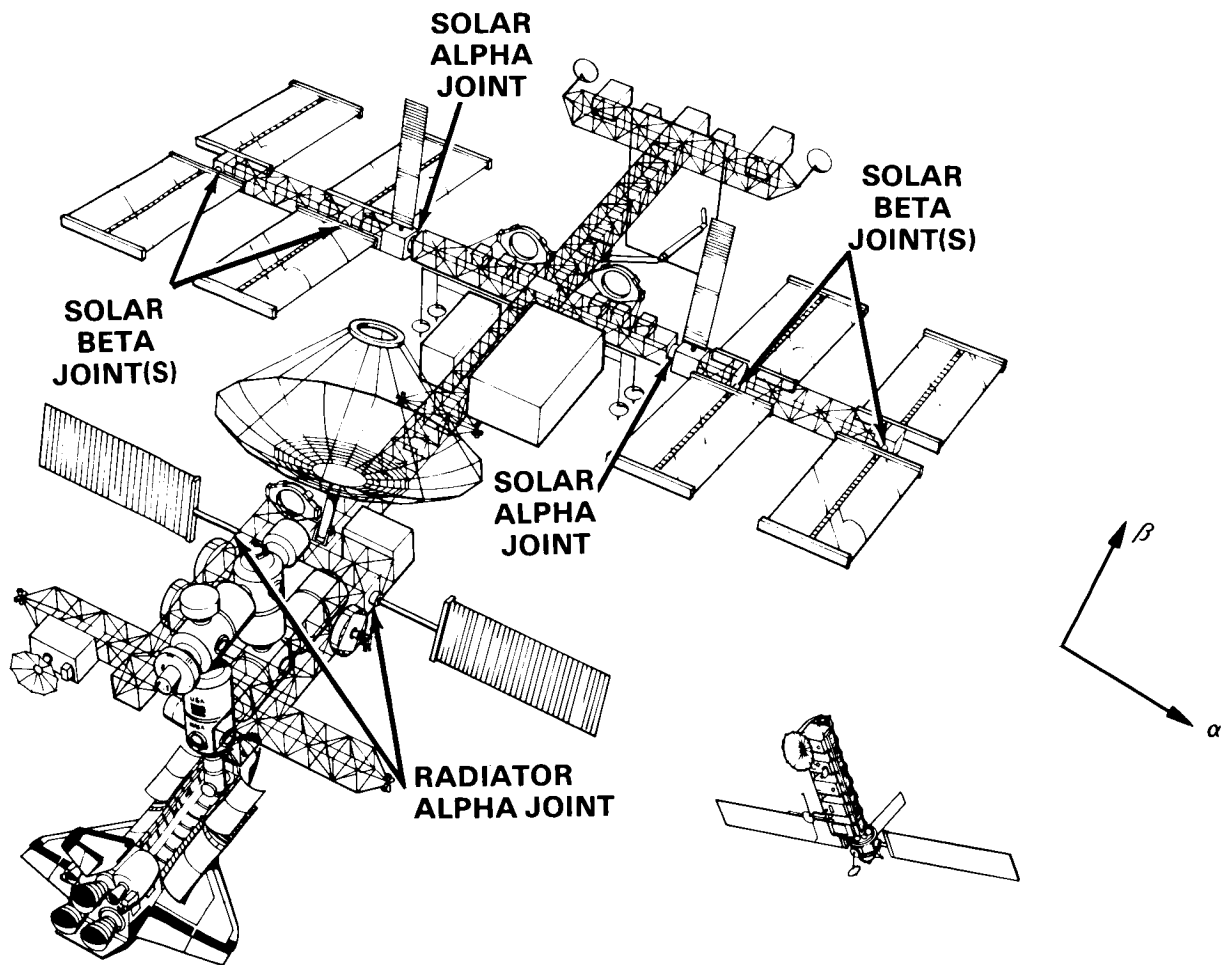
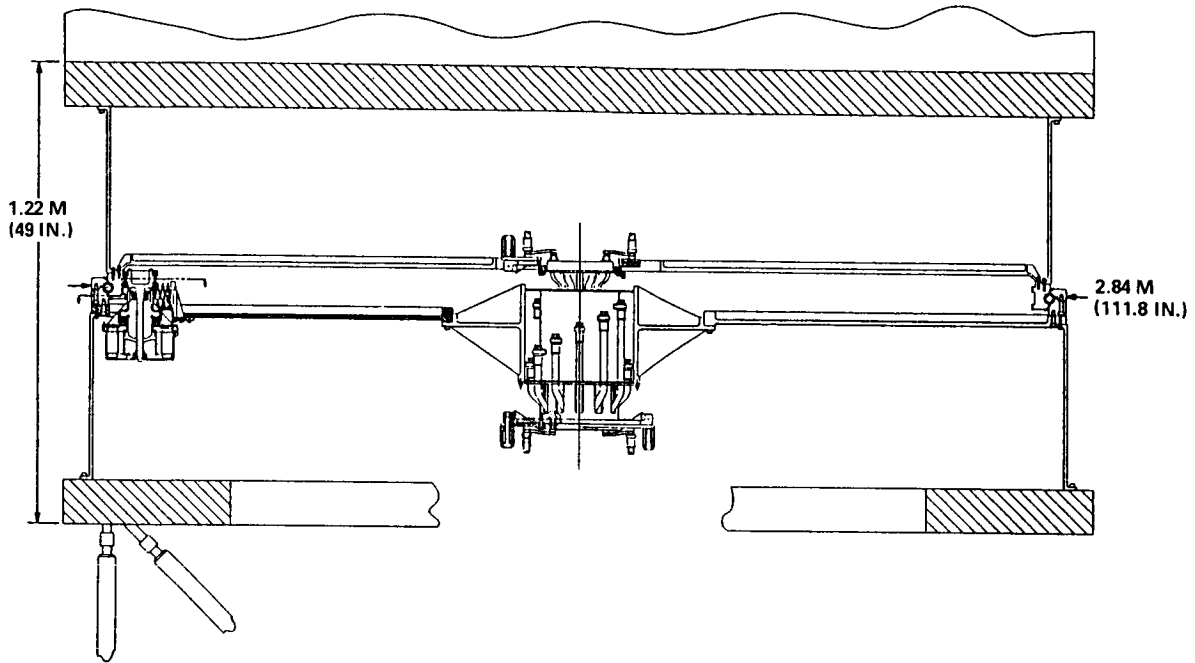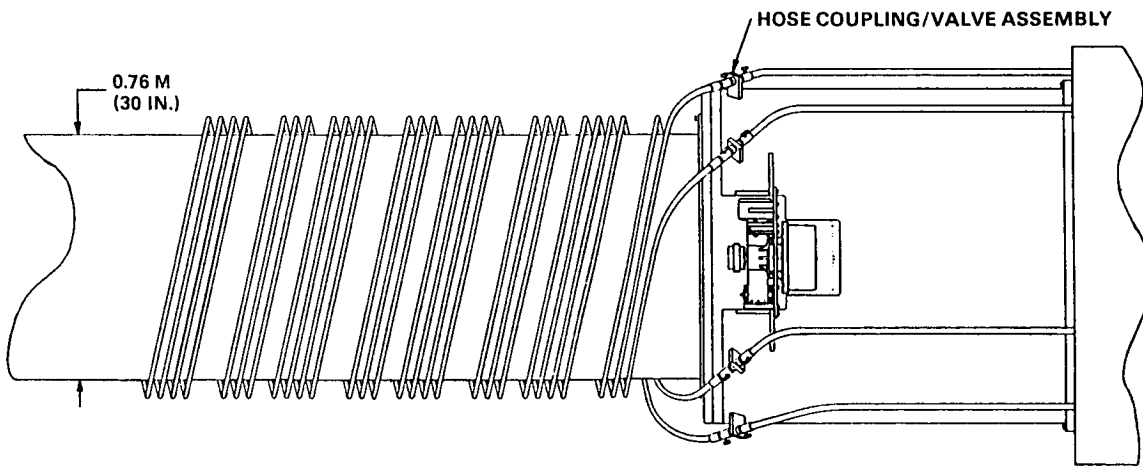Figure 1. - Space station reference configuration.

Figure 2. - Solar alpha joint.

0.76 M
(30 IN.)

HOSE COUPLING/VALVE ASSEMBLY
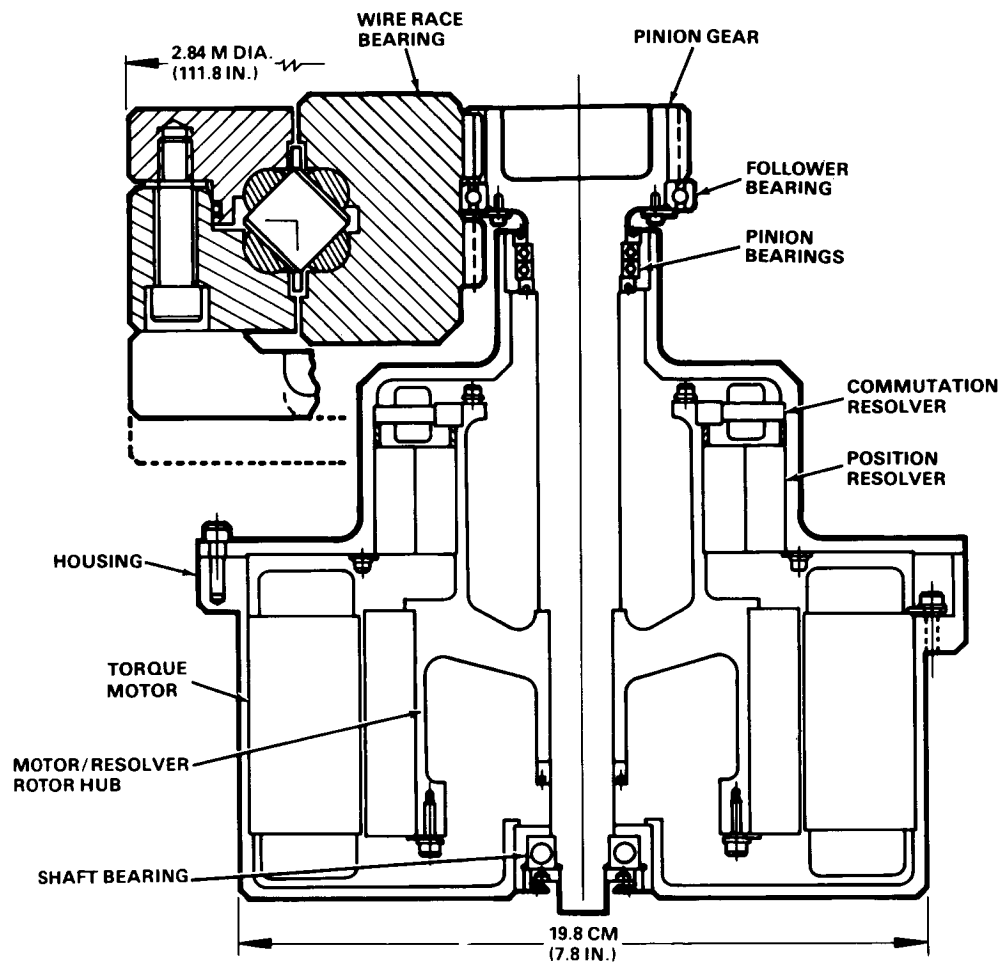
Figure 3. - Radiator alpha joint.
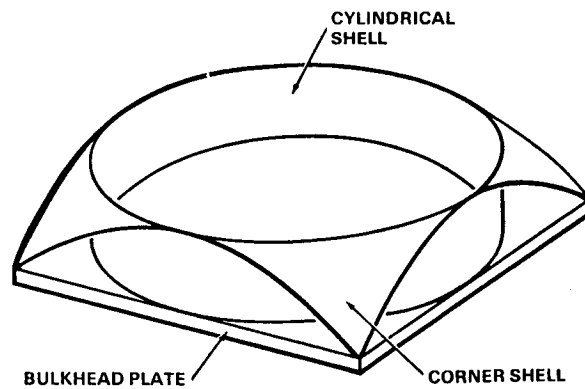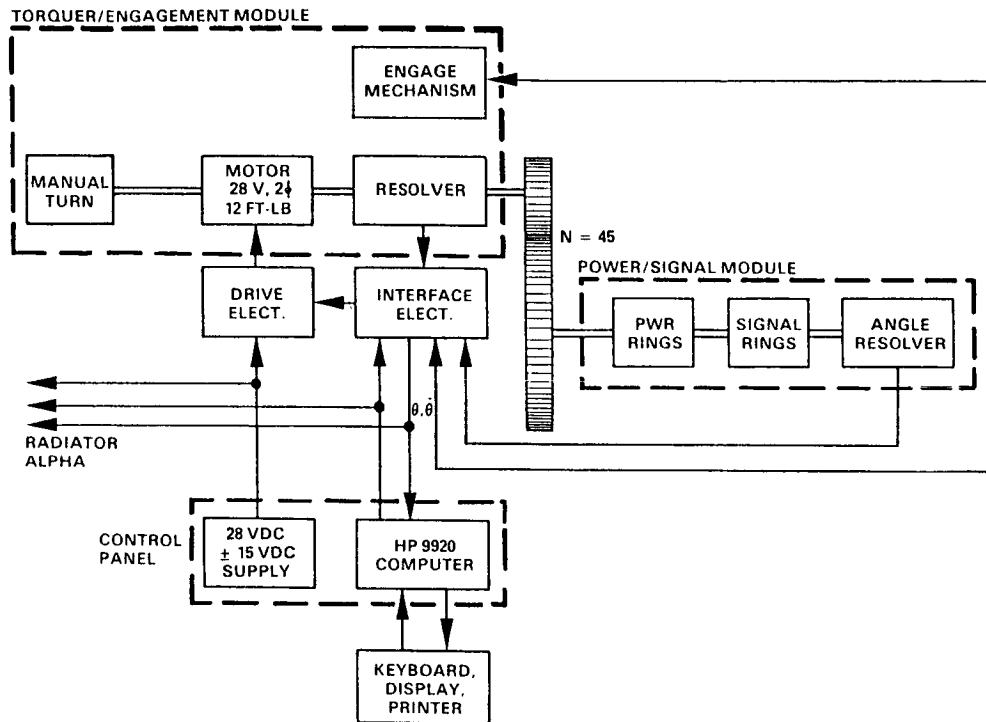
Figure 4. - Drive assembly.

Figure 5. - Alpha joint transition structure.

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Figure 6. - Solar alpha joint.