DESIGN OF A 7kW POWER TRANSFER SOLAR ARRAY DRIVE MECHANISM

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ABSTRACT

With the availability of the Shuttle and the European launcher, Ariane, there will be a continuing trend towards large payload satellite missions requiring high-power, high-inertia, flexible solar arrays. The need arises for a solar array drive with a large power transfer capability which can rotate these solar arrays without disturbing the satellite body pointing. This paper describes the modular design of such a Solar Array Drive Mechanism (SADM) which is capable of transferring 7kW of power or more. Total design flexibility has been achieved, enabling different spacecraft power requirements to be accommodated within the SADM design.

INTRODUCTION

Since the early 1970's, British Aerospace (BAe), Space and Communications Division, has designed and manufactured Solar Array Drives (SAD) for flight applications. In 1978, the Bearing and Power Transfer Assembly (BAPTA) was qualified for and successfully flown on the Orbital Test Satellite (OTS) for the European Space Agency (ESA). To the present day, suitably modified versions of the BAPTA are being used on a number of European spacecraft including MARECS, ECS, EXOSAT and currently, TELECOM 1, due to be launched in 1983. The BAPTA was also successfully used on the Indian national spacecraft APPLE.

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The BAPTA, shown in Figure 1, was evolved to orientate medium power (~ 0.5kW) and medium size (~ 5kgm^2) rigid panel solar arrays at geosynchronous orbit rate. Communication spacecraft of the near future, such as those used for direct television broadcasting with European coverage, will require high-inertia (~ 100-2000kgm^2), flexible solar arrays providing up to 10kW of power. The operational requirements imposed on the solar array drive by these high-power arrays have necessitated a redesign of BAe's present BAPTA concept.

BAe was awarded a contract in 1978, funded under the Advanced Supporting Technology Programme (ASTP) and coordinated by ESA. This contract was for a design study for an Advanced Solar Array Drive Subsystem (ASADS). The prime objectives were to identify the requirements for and to design an ASADS which would meet the varying needs of different spacecraft applications with a special emphasis on telecommunications. To achieve this, potential satellite market requirements over the next 10 to 15 years were reviewed, together with the types of solar array available to meet the associated higher power levels. It was concluded that an array drive with a power transfer capability of 7kW was required. Several design concepts were evolved, enabling a design trade-off study to be completed. This resulted in a preferred mechanical configuration for the Solar Array Drive Mechanism (SADM) described in this paper.

Design flexibility was a principal objective in designing the SADM in order to satisfy the requirement of being able to meet various spacecraft needs, especially in the area of power transfer. This was achieved by adopting a modular design approach whereby subassembly modules or components can be removed from the mechanical assembly and modified to suit a customer's particular requirements without impacting on the remainder of the mechanism. In meeting its performance objectives, the SADM employs several novel design techniques in the areas of power transfer, bearing support, drive redundancy and pyro/signal transfer.

MECHANICAL CONFIGURATION

The mechanical configuration for the SADM is shown in Figure 2. It consists of four prime modules; namely:

- power slip ring unit
- bearing support unit
- drive actuator unit
- pyro/signal slip ring unit

The power slip ring unit, shown in Figure 3, provides the means of transferring the solar-generated electrical power from the rotating solar array into the stationary spacecraft body. The unit consists of two pancake-type slip ring discs mounted on a titanium array drive shaft. Each disc is double sided with 13 concentric slip rings per side. Two triangular brush block assemblies, mounted diametrically opposite each other, are positioned on each face of the two discs. Each brush block provides 4 contacts on each slip ring by having 13 brushes per side in a leading and trailing 'V' configuration relative to the rotation of the slip ring discs. The brush blocks are mounted on stiffened aluminium diaphragms which act as heat collectors for the power dissipated in the unit. Each slip ring circuit is current rated at 8A for operating voltages up to 100V. The brush contacts are sized on the basis that any three of the four contacts shall be capable of carrying this current should a brush circuit fail.

It was evident during the design evaluation that the large number of slip rings required to meet the 7kW power transfer requirement would be a design driver. Volume constraints, thermal performance, and compatibility with the modular design approach were also important considerations. For these reasons, a pancake-type unit was preferred to the cylindrical-drum-type assembly used on the BAe BAPTA. The pancake-type unit provides an axially compact assembly whose large surface area, provided by each face of the slip ring discs, helps radiate the heat dissipated when carrying high currents, thereby preventing excessive component temperatures within the unit. For the SADM, heat dissipation is minimised by oversizing the brush contacts to carry a larger current than the design requirement. This provides a degree of redundancy in that a single brush failure will not impair the performance of the unit; and, since a larger contact area is required for the higher current rating, the brush contact resistance will be proportionally lower. High friction torque and brush wear are inherent disadvantages with the pancake-type unit due to the increasing radius of contact with each concentric slip ring. The materials selected for the slip rings and brushes will directly influence these parameters.

For this reason, the first choice of materials are those currently developed in Europe and space proven on the BAe BAPTA programmes; i.e., gold-plated copper slip rings contacted by silver-molydisulphide-copper brushes. From test data accrued by BAe, the performance of the SADM using this combination of materials could be readily predicted. The estimated wear on the outermost brush, having the greatest rubbed distance, is on the order of 0.06mm, assuming a 10-year, low-Earth-orbit mission. This will result in little variation in friction torque(~1.5Nm) and contact resistance (~3-10 milliohms) since the brush contact pressure will effectively remain constant at 345kN/m^2. Recent investigations with this combination of materials have revealed the presence of a high-resistant (~90 milliohms) silver-sulphide film on the surface of the gold slip rings. This phenomena appears to be associated with long storage times in air, following running-in and performance testing. Subsequent operation in vacuum appeared to remove the film after several revolutions. For the SADM, with its high current levels, this film would have a significant impact on power dissipation within the unit, increasing the level by a factor of up to 30 times the predicted norm of 2.3W.

This problem may be alleviated using a novel design approach whereby the dry-lubricated, composite silver-molydisulphide-copper brushes are replaced by multi-filament gold wire brushes running in 'U' shaped, gold-plated-copper slip rings. No additional lubricants are used and therefore contamination from oils or from chemical reactions does not occur. In the USA, Polyscientific has carried out extensive research and development into this technique and has demonstrated that, by selecting the correct combination of gold alloys for the brushes and slip rings, a vacuum performance comparable to that of the composite brush design can be achieved. Proprietary test data has revealed that as a result of the low filament contact pressures inherent in the design, extremely low contact wear rates can be achieved. Tests carried out on a brush contact configuration similar to that of the SADM have resulted in over 1.5 billion inches of ring travel under ambient conditions. The multi-filament contact with the slip ring surface provides an extremely low contact resistance (~ 3 milliohms) due to a greater number of asperity contacts; and, since each filament is effectively a wire conductor, a much improved current density (~ 31 X 10^6 A/m^2 in air) can also be achieved. The modular constuction used in the slip ring unit allows either or both slip ring designs to be incorporated in the SADM.

The bearing support unit, shown in Figure 4, provides the major structural element within the SADM, enabling array launch and deployment loads to be transmitted through to the spacecraft structure. The unit consists of a beryllium drive shaft supported on two rigidly preloaded, lead lubricated, angular contact bearings. The bearings are mounted in a beryllium housing which is precision located in an aluminium baseplate. The baseplate provides the basic structure on which all the modular assemblies and other components are mounted.

Rigidly preloaded bearings are very sensitive to thermal gradients across the bearing assembly. Differential expansion within the bearing preload system will result in high bearing loads and friction torques. These effects can be desensitised by using a soft preload system employing springs to absorb the differential movements without causing significant changes in preload and bearing friction. However an off-loading mechanism is required to protect the soft preload system during launch. A considerable mass saving can therefore be made by using a rigid preload method. For the SADM, the bearings are sized to withstand directly the worst-case loads expected during launch (~3000N, 450Nm). Thermal compensation is achieved by using aluminium alloy spacers within the rigid preload system. Detailed bearing analyses performed by the European Space Tribology Laboratory (ESTL) in the UK have found that this choice of spacer material used in conjunction with the steel bearings and beryllium housing/shaft permit temperature differentials of up to 100°C to exist without exceeding the static capacity of the bearings. The maximum predicted temperature differential for the SADM is 20°C.

For low speed applications, good, reliable boundary lubricants must be used to prevent metal contact between the bearing raceway and balls.

This is achieved by using a dry-film lubricant method which has been developed in Europe by ESTL (Reference 1). The process involves ion plating a lead film on the ball bearing raceways to a thickness of 0.2-0.5 microns. Over one million hours' worth of operational test data has been gathered on this process, which has been shown to produce an adherent, good-quality, low-friction lead film with low wear rates. From test data contained in Ref. 1., bearings of approximately BAPTA size (42mm outside diameter, 20mm inner diameter) were rotated in a vacuum at 100-200 rpm for over 2 million revolutions, with an average torque of 0.002Nm. This technique is currently used on all BAe BAPTA programmes with flight experience having been gained with the successful launches of OTS, MARECS and APPLE. This process has also been selected for use on the SPOT, SAD and GIOTTO despin mechanism.

The torque required to rotate the solar array is provided by the drive actuator unit. This unit consists of two main drive stepper motors fixed to a pivoted rocker arm. The rocker arm is connected to an eccentric cam by a hinged rod. The cam is driven by a third stepper motor. The output shaft of each main drive motor terminates in a drive pinion. Either drive pinion, may be brought into mesh with a 30-to-1 main ring gear which is keyed onto the main drive shaft of the bearing support unit. Gear engagement is achieved by slightly rotating the rocker arm using the eccentric cam drive motor. The eccentricity on the cam is sufficient to fully engage one drive pinion, whilst simultaneously disengaging the other. When driving the ring gear, the engaged pinion will exert a radial force on the rocker arm, tending to separate the two gears and backdrive the cam. This is prevented by locating the cam in an over-centre condition such that this separating force will always tend to lock the cam against mechanical end stops as shown in Figure 5.

Mechanical drive redundancy was introduced as a requirement to prevent a single-point failure occurring in the drive system as a result of a tribological breakdown of the gears. Test data for the gear materials used on the SADM, i.e., nitrided nitralloy steel and 440C steel with ion-plated lead, has shown that a gear life of over 50 times that required has been achieved (1.7 million revolutions for a low-Earth-orbit mission) using gears with diametral pitches identical to those on the mechanism (Reference 2).

Control analyses performed for a solar array drive rotating a high-inertia, flexible solar array have shown that a stepped drive system can give an acceptable performance providing the torque impulse applied to the array is sufficiently small. If not, the step motion of the drive is likely to excite the arrays, resulting in unacceptable disturbance torques being applied to the spacecraft body with an associated loss in pointing capability. For the SADM the torque impulse is minimised by reducing the time over which the torque (~15Nm maximum) is applied. This enables a healthy torque margin (~5) to be maintained over the estimated worst-case friction levels. The time period over which the torque is applied will be a function of the motor step size since the output speed is required to be constant.

Therefore the torque impulse per step may be significantly reduced by stepping through smaller angles. This is achieved on the SADM by electronically sub-dividing the basic motor step into smaller mini-steps of 0.06°. The resulting impulse bit has been demonstrated analytically not to disturb the satellite when rotating the arrays at geosynchronous rates and during transition to faster sun acquisition speeds.

The SADM is required to provide a number of slip rings for transferring pyrotechnic firing currents, motor drive currents and control signals to and from the solar arrays. Safety requirements dictated that the slip rings carrying the pyrotechnic firing currents should be totally electrically isolated from the remainder of the slip rings. This was to prevent premature firing of a pyrotechnic device due to electromagnetically induced currents in the pyrotechnic firing circuits.

A novel design solution for this pyro/signal slip ring unit was found for the SADM. The unit is a self-contained assembly consisting of two miniature cylindrical slip ring assemblies concentrically mounted within the main shaft of the bearing support unit. The innermost assembly provides 20 gold-plated slip rings which are contacted tangentially by gold fibre brushes similar to those previously discussed for the power slip ring unit. This assembly provides the pyrotechnic slip ring circuits and therefore is contained within a metallic shield to isolate it from the outermost slip ring assembly. The outermost assembly provides a total of 50 slip rings, identical to those of the inner assembly. These slip rings provide the control and array monitoring functions. Dry-lubricated bearings are used to support the slip ring assemblies within the unit.

Polyscientific has demonstrated lives in excess of 20 million inches of ring travel in a vacuum ($\sim 10^{-8}$ torr) using a 0.5-inch-diameter cylindrical slip ring unit with unlubricated tangential fibre brushes.

The mechanical configuration for the SADM has been evolved to meet the foreseen requirements of large power spacecraft. Its key features may be summarised as follows:

- compact mechanical design
- full mechanical and electrical redundancy
- simple operation
- high reliability
- design flexibility to meet varying system requirements

FUTURE DEVELOPMENTS

At the time of writing, an engineering model SADM is being manufactured and assembled. This unit will undergo functional and environmental testing to qualification levels. This will be followed by a thermal vacuum test and an accelerated life test, designed to simulate a 10-year operational life. The SADM will undergo a strip examination following the life test.

A derivative of the SADM has been successfully bid for use on the European Large Satellite (L-SAT) programme. For this satellite a reduced mass version of the mechanism will be flown, whereby the two main drive motors will be fixed in constant mesh with the ring gear. This approach deletes the need for the redundant actuator mechanism and can be readily achieved without significantly impacting on the remainder of SADM assembly. For L-SAT 1, only a single power slip ring disc is required, further illustrating the flexibility of the SADM design.

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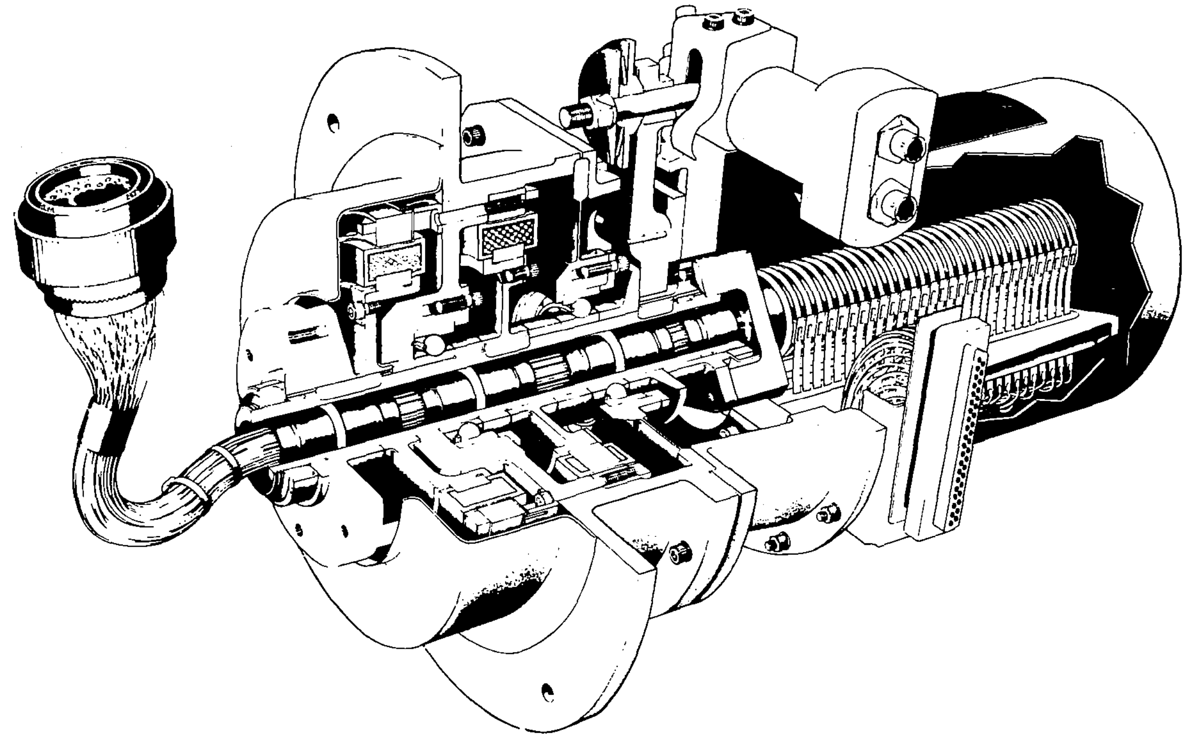
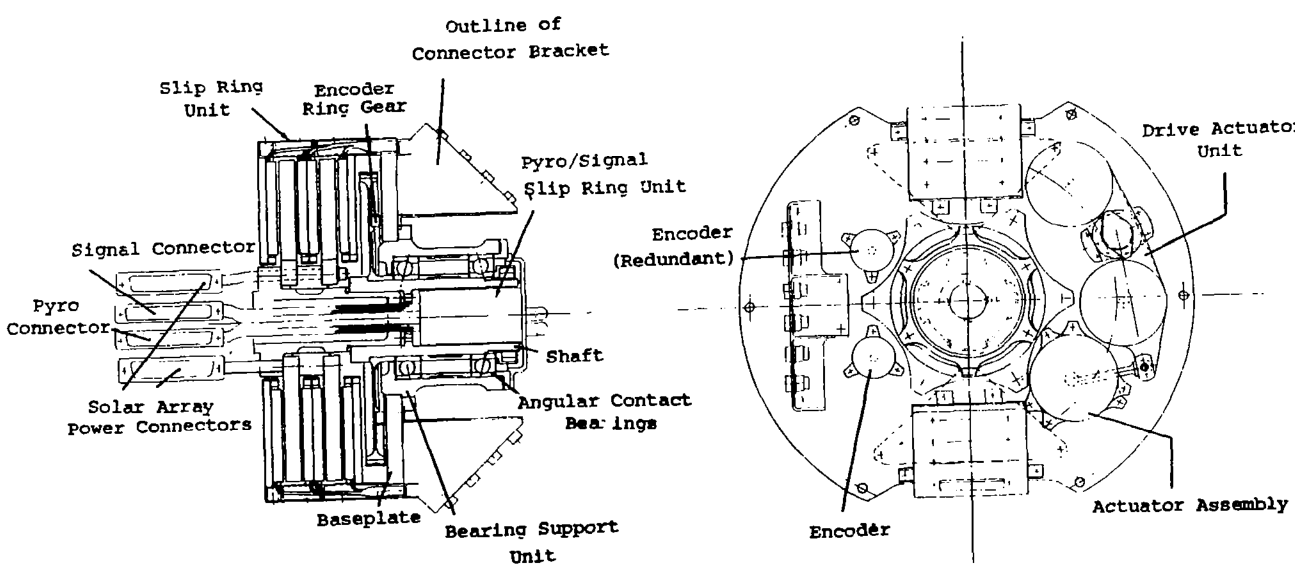
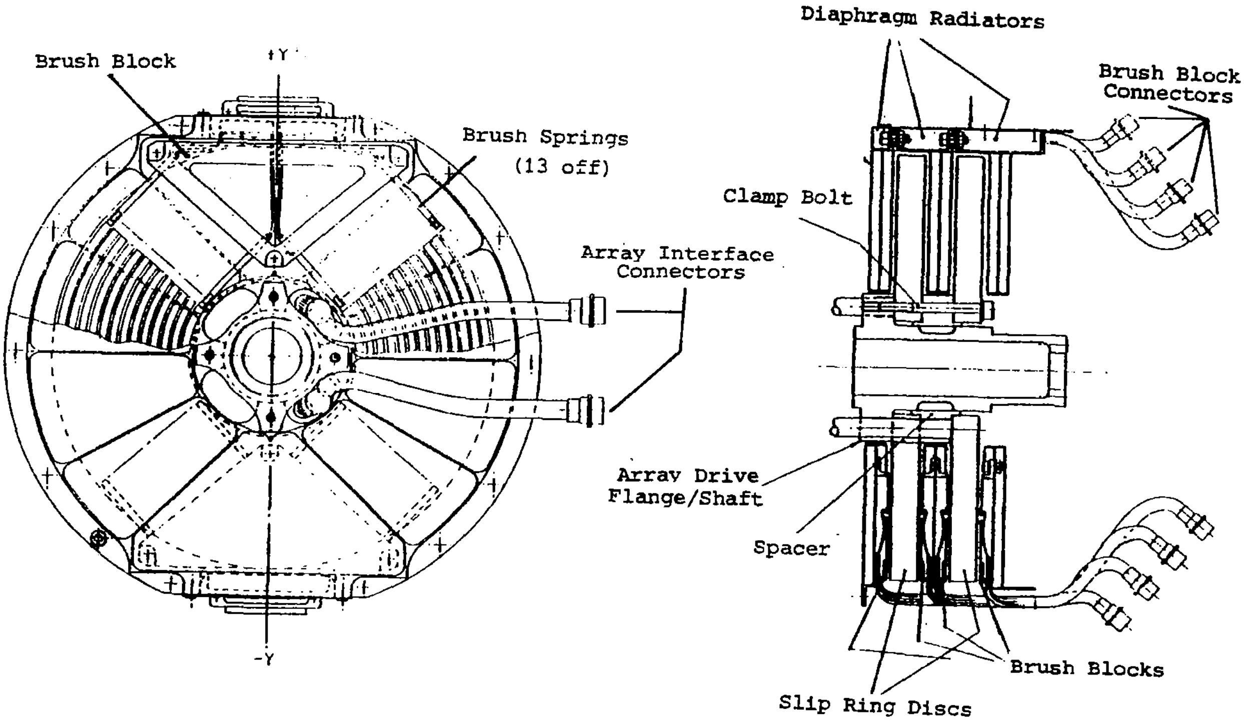


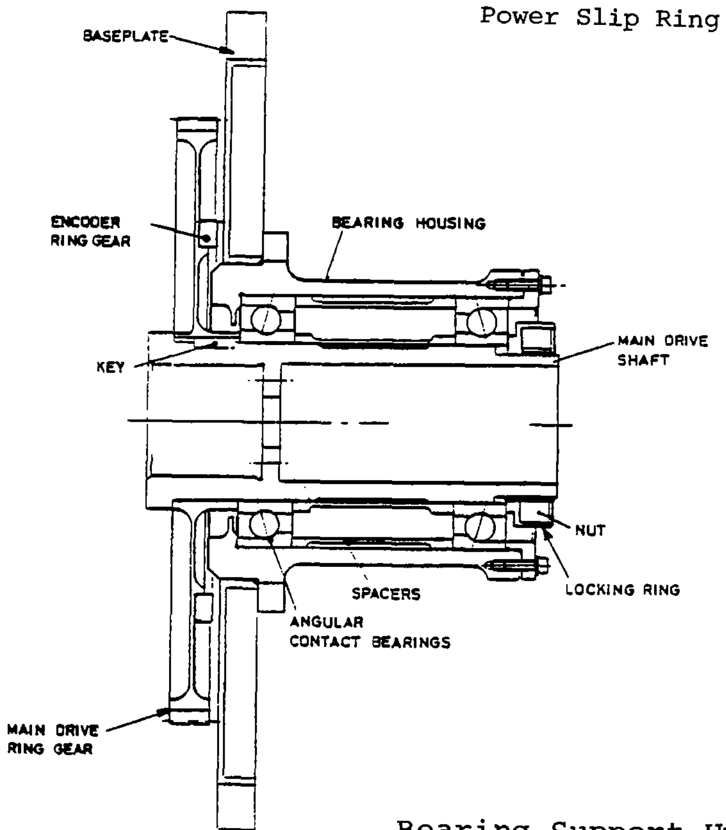
Bearing and Power Transfer Assembly (BAPTA) Fig. 1



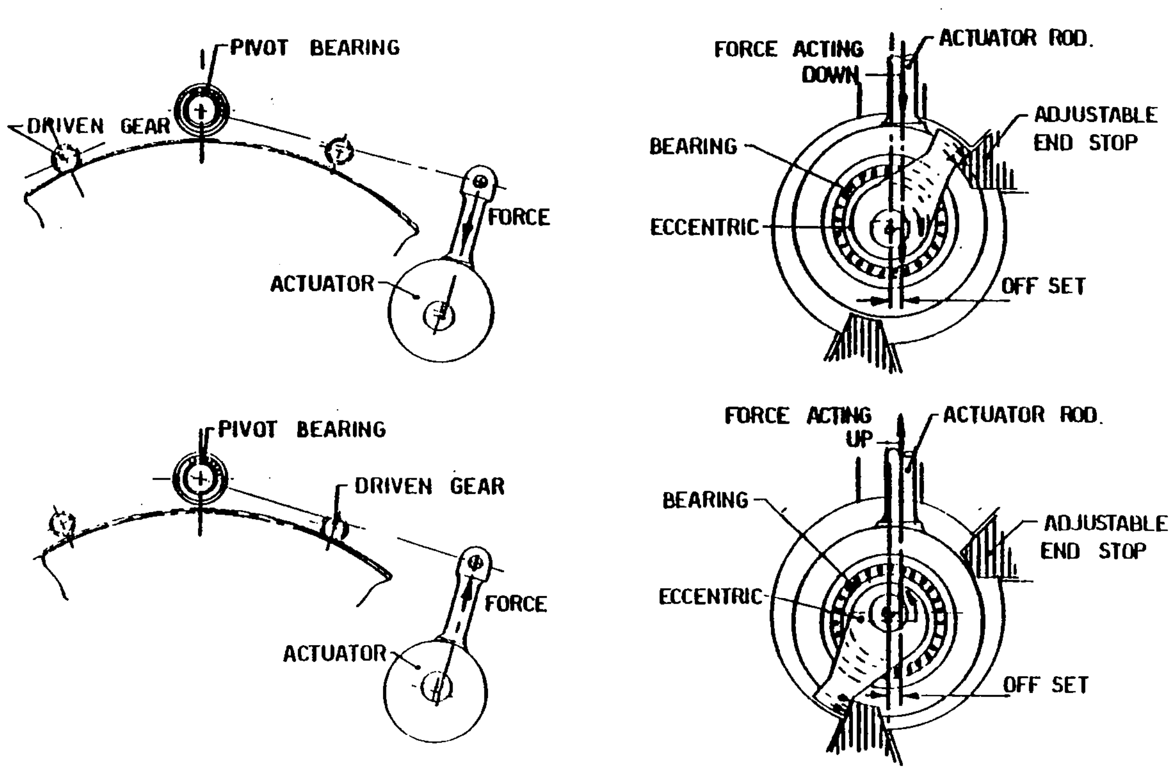
Solar Array Drive Mechanism (SADM) Fig. 2



Power Slip Ring Unit Fig. 3



Bearing Support Unit Fig. 4



Eccentric Cam Engagement Mechanism Fig. 5

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15. Supplementary Notes

16. Abstract

The proceedings of the 16th Aerospace Mechanisms Symposium held at the John F. Kennedy Space Center on May 13-14, 1982, are reported in this NASA Conference Publication. Technological areas covered include design of unique ground support equipment, orbiter specialized hardware, payload deployment and positioning. Devices used in space operations are also described.

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