N79-19015

Paper No. 4

DEVELOPMENT OF A FERROMAGNETIC ROTARY VACUUM SEALED SPACECRAFT SPIN FIXTURE

M. B. Levine, *Hughes Aircraft Company, El Segundo, California*

ABSTRACT

The Hughes Aircraft Company Space Simulation Laboratory has conducted a number of successful spacecraft tests on an environmental spin fixture which utilizes a ferrofluidic rotary vacuum seal. The 27cm (10.5 inch) diameter fixture drive shaft supports and spins Hughes Communications Satellites during flight acceptance testing in a thermal vacuum chamber. The drive shaft rotary seal serves to maintain the canned drive system electro-mechanical components at ambient pressure within the space simulator. The ferromagnetic fluid seal was chosen over conventional mechanical sealing devices for its zero-leakage, zero-wear, and minimum friction drag characteristics, as well as its high reliability potential.

INTRODUCTION

A new environmental spin fixture was designed and fabricated by the Hughes Aircraft Company Space Simulation Laboratory for flight acceptance tests of Hughes Communications Satellites. The fixture incorporates a ferromagnetic fluid vacuum shaft seal to sustain an ambient pressure environment within the spin fixture drive housing during thermal vacuum testing in a space chamber. The hermetically sealed drive housing approach was chosen to preclude significant development effort on a non-vacuum compatible direct drive motor and tachometer feedback servo-loop, necessary to meet spin fixture speed stability requirements imposed by spacecraft antenna pointing specifications. The seal is the most critical component in the entire drive housing pressurized system and its low friction drag characteristics help to achieve a fixture speed stability performance level of less than ±.03% speed variation (long and short term).

A description of the spin fixture is provided, along with a summary of seal development problems.

SPACECRAFT DESCRIPTION

The spin fixture was designed to satisfy thermal vacuum acceptance test criteria of two commercial communications satellite programs. Fixture completion was scheduled to support the initial phases of the Intelsat IVA Communications Satellite Program, which consists of a substantial number of flight spacecraft constructed for Intelsat by an international team headed by Hughes Aircraft Company. These spacecraft will be used for global communications coverage. The second program, which started soon after Intelsat, and currently shares fixturing, is the Comstar Program which provides U. S. domestic communications satellite coverage. Both spacecraft families utilize the same basic bus design, with significant differences in their communications systems.

The spacecraft are spin stabilized synchronous orbit vehicles which are maintained on station at the synchronous altitude of 41,300 km (22,300 miles). The basic bus or spinning section contains the solar panel, power distribution, and station keeping propulsion system. The despun electronics section which contains the antenna array and communication equipment is despun by means of a bearing and power transfer assembly (BAPTA) which provides the electro-mechanical interface between the two sections.

FIXTURE DESCRIPTION

The fixture (figures 1 and 5) consists of a drive system module supported by a base frame which transfers the load path to the chamber endbell hardpoints. LN_2 shrouds are incorporated above the fixture base frame to prevent thermal interaction between the spacecraft and the fixture where the fixture structure shadows the chamber or endbell cold walls.

A heat post, which consists of an array of tubular quartz-envelope tungsten filament IR lamps, provides thermal boundary control of the spacecraft rotor. The heat post is oriented parallel to the vertical spin axis at the circumference of the spacecraft and provides an intense thermal energy source which is integrated over the spacecraft as the spacecraft spins past it. A small heat post is mounted under the spacecraft to illuminate the aft thermal barrier.

A spotlight array consisting of a number of quartz-iodide spotlights is mounted above the spacecraft to the chamber hardpoints. This array provides thermal conditioning of the forward sunshield and despun antenna array.

A spoked wheel interface adapter is mounted on the vertically oriented fixture drive shaft to support the spacecraft and provide boundary thermal conditioning at the separation plane. The spoked configuration provides for radiant heat transfer between the spacecraft and the LN_2 cooled fixture shrouds mounted behind the interface adapter. The interface adapter incorporates a shear pin clutch and slip ring cable quick-disconnect. The shear pin clutch provides for a free-wheeling coastdown of the spacecraft in the unlikely event of fixture bearing failure, and the quick-disconnect prevents test cables between the spacecraft and the fixture slipring assembly from wrapping up and damaging the spacecraft in the event the safety clutch is activated.

DRIVE SYSTEM & SHAFT SEAL DESCRIPTION

The concept of a hermetically sealed drive system evolved out of the speed stability requirements imposed by spacecraft antenna pointing criteria. Minimum jitter and wow requirements dictated use of a DC motor and tachometer feedback system (in lieu of an AC motor) with the drive motor mounted directly on the spin fixture drive shaft to preclude instabilities introduced by a coupling or gear train.

Anticipated arcing problems with high power density DC motor brushes in vacuum, indicated the potential for a rigorous development program in this area. As a number of small ferrofluidic seals had been successfully run by the design team, it was decided to enclose the motor/tachometer system and explore the feasibility of developing a large seal for the fixture (structural and dynamic loads as well as geometry constraints required a shaft diameter of approximately 27cm or 10.5 inches) while proceeding with a parallel investigation of conventional mechanical sealing devices. An optimistic response by the ferromagnetic seal manufacturer was evaluated, and design was initiated.

A cross section of the drive system is shown in figure 2. The ferromagnetic seal assembly which consists of upper and lower pole blocks separated by an array of permanent magnets enclosed within a seal housing, is located at the upper surface of the drive system enclosure. Clearance between the pole block I.D. and the drive shaft was held to nominally 0.127mm (.005 inches) radial (.010 inches diametrical) to prevent shaft/seal contact under normal operating conditions while minimizing the ferrofluid gap. This seal gap is a very critical parameter as performance of the seal (ability to maintain zero leakage across a finite pressure differential) is a function of magnetic strength which is inversely proportional to gap width for any specific seal geometry.

The drive shaft is supported by two angular contact roller bearings which are preloaded to provide for differential thermal expansion. The drive motor and tachometer rotors are installed directly on the drive shaft to eliminate speed stability perturbations due to mechanical play in the system.

A slip ring assembly is installed inside the hollow drive shaft to provide the electrical interface between the rotating sections of the spin fixture and spacecraft, and the ground support equipment.

SEAL DIFFERENTIAL PUMPING & DRIVE SYSTEM COOLING

Development testing of the prototype seal assembly indicated an operational performance capability well in excess of 414 kPa (60 psi) differential pressure across the seal, thereby providing a 400% safety margin. However, as the spin fixture delivery schedule precluded adequate development and life testing of the prototype geometry, or cataloging of degradation characteristics of the ferrofluid used, a conservative approach which applied a differential pumping scheme was incorporated into the drive system (figure 3).

The pumping system was designed to provide a dual function:

a. Differentially pump and regulate the seal cavity (between upper and lower pole blocks) to a nominal half-atmosphere.

b. Evacuate the drive housing in the event of a significant leak across the seal.

Guard pumping of the seal cavity to 48 kPa (7 psia) provided additional safety margin by reducing the Δp across each pole block, as well as offering the capability of pumping against any potential nominal real or virtual leak within the seal assembly.

Evacuation of the drive housing would be implemented if a large leak prevented seal cavity vacuum from being maintained by the guard pump. This mode would constitute a test abort condition as it was anticipated that the non-space-qualified motor, tachometer and slip ring components would malfunction fairly rapidly in a vacuum environment, although it was anticipated they would operate during the time required for chamber warmup and abort operations.

A cooling system was provided for circulating filtered ambient air through the drive system, after thermal analysis indicated a potential heating problem if the drive housing were isolated and simply provided with radiation and interface conduction cooling. Air was chosen in lieu of a GN_2 purge to provide the water vapor necessary for motor, tachometer, and slip ring brush lubrication. A centrifugal blower system was utilized which would maintain a slightly negative pressure within the drive housing for added seal safety, thereby precluding an overpressure potential inherent in a forced air cooling system. Isolation valves and the logic to isolate the housing and shut the blower were provided to allow evacuation of the housing if a large seal leak were to develop. This abort mode logic was initially implemented as an automatic function, however, as confidence in seal reliability increased, the automatic feature was disarmed. Subsequent empirical data obsoleted the need for supplementary cooling, as drive system operating temperatures hardly varied from ambient during either LN_2 cold wall or ambient temperature vacuum test phases, although minimal heating of the drive housing was required during LN_2 cold wall test phases (silicone rubber resistance heater strips bonded to the external surfaces of the housing assembly as shown in figure 6).

SEAL DEVELOPMENT

The ferrofluidic seal is a non-contacting rotary seal which captures magnetic ferrofluid sealant in the gap between the rotary and stationary members. Simple permanent magnets provide the magnetic flux required to retain the fluid which is typically a colloidal suspension of magnetic particles in a low vapor pressure vacuum compatible oil. Figure 4 shows a cross section of the seal assembly, and the details of the geometry of the pole block focussing structure consisting of a series of labrynth type seal stages.

Contact of the shaft and the fragile focussing structure is prevented by stringent runout requirements. However, if large shaft deflections were to occur due to lateral seismic loads, the seal housing would prevent damage to the pole block by laterally restraining the shaft.

An Ester base ferrofluid was originally chosen for its high gauss magnetic saturation capabilities, however, hydrolytic stability characteristics provided the forcing function for a change to a Diester base fluid. Hydroscopic tendencies of the Ester base fluid resulted in an extreme increase of viscosity after the seal had been stored and operated for a period of time in a laboratory ambient environment. Observation of this phenomenon resulted in a series of experiments on the Ester base fluid to determine if the thickening was a result of loss of volatiles due to evaporation, or indeed caused by contact with the water vapor in the air. These experiments proved conclusively that relative humidity and not evaporation was the culprit, with samples exposed to high humidity thickening virtually to the point of solidification.

Subsequent experiments with the Diester base fluid indicated no degradation in either sealing or physical characteristics after significant periods of exposure to high humidity environments, and the change over to Diester was accomplished post-haste. No observable degradation of viscosity or sealing characteristics has been noted for the Diester exposed to humidity for over a year.

Seal assembly and disassembly procedures are critical due to the high magnetic forces generated by the large complement of permanent magnets and the fragile nature of the pole block focussing structure. A fairly stiff and close tolerance mechanical restraint must be used to maintain concentricity of the shaft to seal interfaces to preclude seal stage damage during assembly operation.

A number of precautionary measures and suggestions are delineated below:

1. Do not expose seal fluids to solvents or lubricants.

2. If seal components or shafts have been in contact with silicone fluids and these fluids have not been completely removed, a slight degradation in sealing potential will occur.

3. Heat in excess of 93°C (200°F) will cause deterioration of the seal fluid.

4. A smooth matte finish is preferred over highly polished or rough surface finishes for the shaft.

5. The stages that comprise the focussing structure are fragile. Extreme caution should be used when assembling the seal so as to not cause damage to these stages.

6. A clean area that is void of ferris particulate matter should be used for assembly and testing.

7. Spare seal fluid should be stored at room temperature in a sealed container preferably away from strong magnetic sources.

8. Field strength of magnets should be established and verified prior to each assembly phase.

9. Seal integrity can be monitored during storage periods by evacuating and isolating the seal cavity and periodically comparing the vacuum gage reading.

10. Ultimate seal pressure capabilities can be empirically determined by cavity pressurization, however, fluid blowout can contaminate equipment unless precautions are taken to contain the effluent.

11. Diester base fluids are superior to Ester base fluids if the fluid surface is exposed to an ambient (relative humidity) environment.

12. Ferrofluid surfaces external to the evacuated cavity can be stored in a dry environment to preclude hydrolytic degradation by bagging with desiccant or a GN_2 purge.

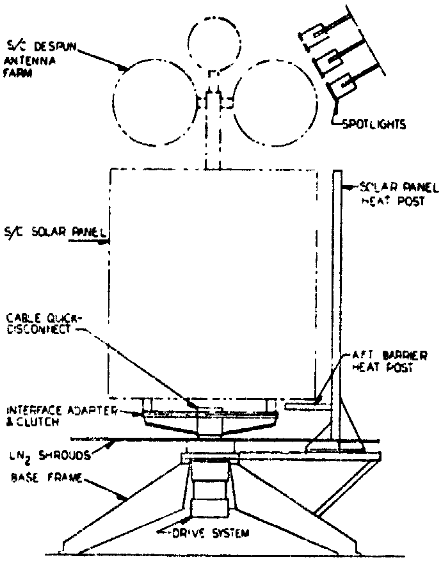
CONCLUSION

The ferrofluidic sealed spin fixture drive has performed successfully during a number of spacecraft thermal vacuum acceptance tests at operational speeds of approximately 60 RPM. Thermal vacuum tests for another program were also successfully conducted at operational speeds of up to 120 RPM with short duration excursions above 300 RPM.

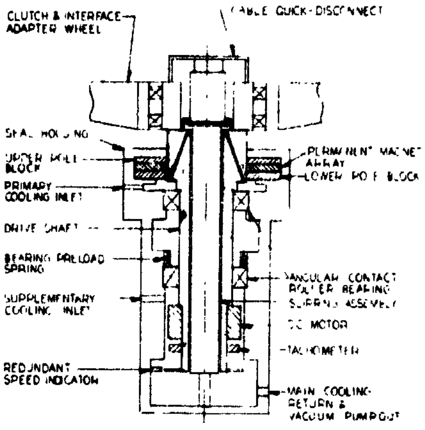
Excellent performance of the fixture drive system relative to speed stability and reliability resulted in a second identical spin fixture drive system, being constructed for another program. The only change incorporated in the second system was simplification of the plumbing and controls brought about by deletion of the unnecessary cooling system.

NOTE

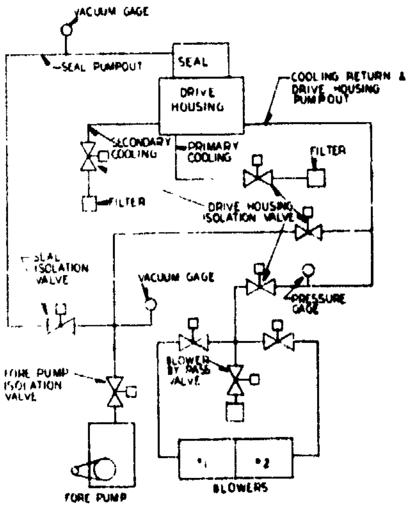
This paper is based, in part, on work performed under the sponsorship of the International Telecommunications Satellite Organization (Intelsat). Any views expressed are not necessarily those of Intelsat.



SPIN FIXTURE
FIGURE 1

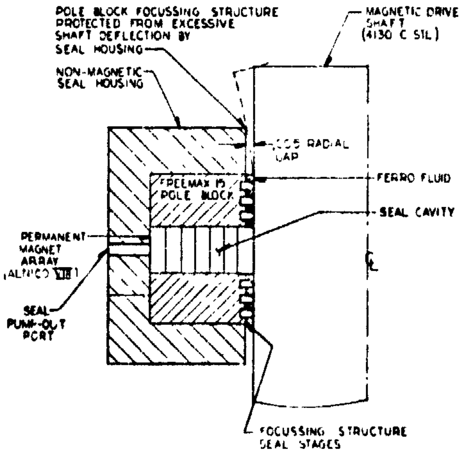


DRIVE SYSTEM
FIGURE 2



DRIVE SYSTEM VACUUM
& COOLING SYSTEM SCHEMATIC

FIGURE 3



FERROFLUIDIC SEAL INSTALLATION

FIGURE 4

**ORIGINAL PAGE IS
OF POOR QUALITY**

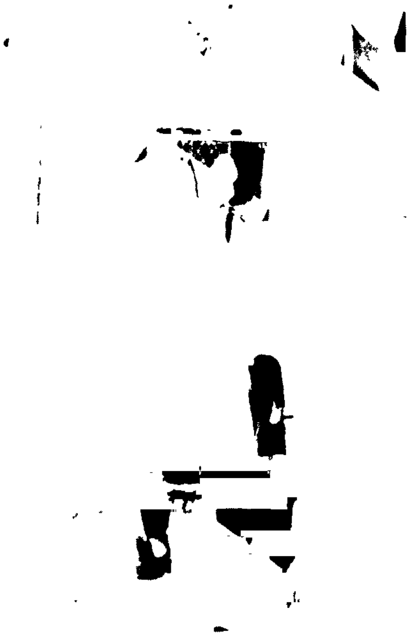


FIG 5.-INTELSAT IV A SPACECRAFT INSTALLED ON THE SPIN FIXTURE

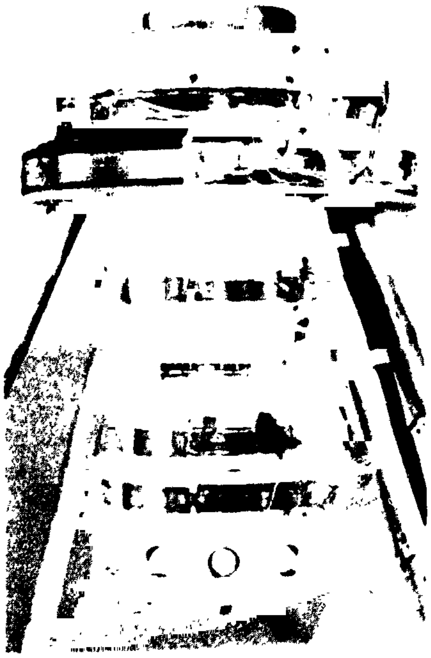


FIG 6.-DRIVE SYSTEM INSTALLED ON A MAINTENANCE STAND

Paper No. 5

SURVIVABILITY TESTING AND ENVIRONMENTAL SIMULATION FOR MATERIALS DEPLOYED AT GEOSYNCHRONOUS ORBIT

V. J. Belanger, A. E. Eagles, *General Electric Company*

ABSTRACT

Synchronous altitude satellites have been observed to exhibit anomalous behavior not noted in sub-synchronous spacecraft. These anomalies have included logic upsets, gradual temperature increases due to degradation of thermal control surfaces, communications, interference and in at least one case, catastrophic power system failure. Studies have been conducted to resolve these anomalies and high correlations were found between anomalous events and high magnetic indices during the hours between midnight and 6 a.m. spacecraft local time.

These correlations indicate the problem is related to some geophysical phenomena that results in electrical discharges in the vicinity of or on spacecraft structural surfaces. It is now generally accepted that this phenomena is the occurrence of a solar magnetic substorm when the spacecraft is in the plasma sheath, a vast region of space extending from the side of the Earth opposite the Sun. This can result in a nonuniform distribution of surface charge on the spacecraft.

In order to study these effects and meet survivability requirements for spacecraft operating in these regions of space, facilities have been developed to simulate the plasma charging environment found at synchronous altitudes. Capabilities and limitations of these facilities are discussed and the effects of basic materials parameters such as surface and bulk resistivity, dielectric constant, dielectric strength, secondary emission and photoemission and the equilibrium state of materials exposed to the environment are also considered. More sophisticated characterizations such as electron bombardment induced conductivity (EBIC) and the related phenomena of secondary emission conductivity (SEC) are also discussed to show how these properties may be used to improve environmental survivability of spacecraft.

Discussions include considerations for the design of future simulation facilities which will improve the reliability of behavior predictions for spacecraft surface materials proposed for application at geosynchronous orbit.