CURRENT AND FUTURE DEVELOPMENT OF THE ANNULAR SUSPENSION AND POINTING SYSTEM

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ABSTRACT

The Annular Suspension and Pointing System (ASPS) is a prototype space payload pointing and isolation mount, designed and built for NASA Langley Research Center (LaRC) by Sperry Flight Systems (subsequently Honeywell Satellite Systems). Over the recent decade, magnetic suspension technology has continued to advance, notably in the area of control system design, such that performance improvements from an ASPS-like design are likely to be acheivable. In addition, new applications for magnetic suspensions are being investigated, where the existing ASPS hardware can provide a useful technology demonstration tool. In this paper, the existing ASPS design and hardware will first be described in detail. Next, some of the potential applications currently of interest will be discussed. Finally, the hardware developments completed, underway, or planned will be reviewed.

INTRODUCTION

The Annular Suspension and Pointing System (ASPS) is a high-accuracy space payload pointing and isolation mount. A prototype system was designed and built for NASA Langley Research Center (LaRC) by Sperry Flight Systems (subsequently Honeywell Satellite Systems) during the latter part of the 1970's, with delivery to NASA in 1983. Shifting priorities at NASA and subsequent difficulties with the Shuttle program resulted in cessation of effort on the ASPS program. Continuing advances in magnetic suspension technology and continuing requirements for high-accuracy pointing and vibration isolation have resulted in renewed interest in the ASPS concept. In addition, new applications for magnetic suspensions are being investigated, where the ASPS hardware could provide a useful technology demonstration tool. Comprehensive descriptions of the ASPS hardware can be found in References 1-6. Summaries of ASPS and other related projects are given in References 7-9.

HARDWARE DESCRIPTION

The two major subassemblies of ASPS are a two-axis, large-angle mechanical gimbal, and a six degree-of-freedom magnetically suspended fine pointing and vibration isolation assembly, both illustrated in Figure 1. The mechanical gimbal system has been referred to as the Advanced Gimbal System (AGS) and the magnetic assembly as the ASPS Vernier System (AVS). Early in 1993, the ASPS Vernier System hardware was loaned to Old Dominion University and a recommissioning effort started. The AGS has been in use at the NASA Marshall Spaceflight Center. Only the AVS assembly is of interest in this paper.

The magnetic assembly, shown in Figure 2 and 3, consists of a large nickel-iron rotor, approximately

0.65 meters diameter and of L-shaped cross-section, suspended by five Magnetic Bearing Actuators (MBA's). Three MBA's act on the radial flange, parallel to the axis of the rotor, and two act on the cylindrical rim, in the radial direction. The design air-gaps were approximately ± 7.5 mm at all stations. These five MBA's control all three translations as well as two rotations, about the two axes in the plane of the rotor. The orientation of the rotor about its own axis is controlled using a linear induction motor acting on the rim. Air-gaps at all MBA's are measured using Kaman 6400-series inductive proximity sensors.

The original design payload was 600 kg, with payload moment of inertia perpendicular to the rotor axis of up to 500 kg-m^2. Both these values were raised in later design revisions [6]. The important specifications of the AVS are summarized in Table 1.

Table 1 - Original AVS Specifications

Pointing Axes	
Angular range	$\pm$ 0.75 deg
Pointing accuracy	$\pm$ 0.1 arc sec
Pointing stability	$\pm$ 0.01 arc sec
Bandwidth	1.0 Hz
Payload mass	up to 600 kg
Payload inertia	up to 500 kg-m^2
C.G. offset	up to 1.5 m

Roll Axis	
Angular range	Unlimited
Pointing accuracy	$\pm$ 1.0 arc sec
Pointing stability	same
Bandwidth	1.0 Hz
Payload inertia	up to 100 kg-m^2

APPLICATIONS

Fine Pointing and Isolation

The original fine pointing application is still of interest. The design performance goal corresponds to roughly 0.025 meter jitter at ground level from a 500 km (270 nautical mile) orbit. This level of performance was validated by laboratory testing of the AVS. Stability of this order tends to be limited as much by sensor and actuator noise as it is by controller performance. Therefore, conversion of the control system to digital form, permitting the implementation of more sophisticated algorithms would not be likely to result in a dramatic gain in absolute performance. Perhaps the most important opportunity, however, would be the ability to incorporate adaptive elements, such that the highest level of performance could be maintained over long time periods, even with hardware degradation and payload mass or inertia changes. Such changes might occur with deployment of solar arrays or instrument packages, or with the consumption of fuel or cryogenic fluids.

Solar Array Rotary Joint

One possible new application for a magnetic suspension of this general configuration is the attachment of solar panels on a space station. This corresponds to the "Alpha" joint on the Space Station Freedom (and the current International Space Station design), illustrated in Figure 3. The rotary joint could perform pointing of the arrays about one axis as well as isolate the station from array vibration. Existing mechanical bearing designs are difficult to lubricate in the space environment, offer no significant vibration isolation and would be difficult to repair or service in orbit. The AVS represents a candidate configuration for this application and will be used in a combined experimental and theoretical study. The concept is to employ the five magnetic bearings to support the rotor, to which the solar arrays would be mounted, with vibration isolation naturally provided by choice of control algorithm. The major pointing axis would be about the axis of the assembly, as shown in Figure 4, such that the rim-mounted linear induction motor could provide the torques required to maintain the desired orientation and rate of rotation. These required torques are, of course, quite small. Power transfer from the solar arrays could be accomplished with a non-contacting axial transformer. A transformer of this type was studied in the ASPS program and a preliminary design completed [10]. It was concluded that high efficiencies and power ratings could be acheived with this type of design. The only major difference for the new application would be the reversal of the direction of power transfer, since the ASPS design was intended to transfer power up to the rotor-mounted payload, rather than down from the payload, the solar arrays in this case, to the base.

HARDWARE UPGRADES

Axial Magnetic Bearing Assemblies

The original design could not be operated in a 1-g environment, since the MBA's were sized for on-orbit control forces, rather than suspension of the payload and rotor deadweight. During ground tests, a gravity offload system (a rather elaborate counterbalance arrangement [4,5]) was used. Rather than rely on the counterbalance system in the early phases of system recommissioning, it was decided to investigate the possibility of reducing the air-gaps at the three axial MBA's so as to raise the vertical force capability to the appropriate level. The original bearing design was double-acting, with bias current linearization, as shown in Figure 5. If the bearings are to be operated with a large steady-state force, the operating strategy requires modification. Typically, the top side of the bearing alone could be activated, with the bottom unused. Linearization can be carried out, if required, by input signal conditioning. This choice is illustrated in Figure 6.

The weight of the rotor is 212 N. An allowance of 70.6 N (30% of the rotor weight) was made for a top plate, payload and instrumentation. Therefore each axial MBA has to create a steady-state force of around 92 N. A further factor of 1.5 was used to set a design target for control force capability at 138 N (each station). It should be noted that the original design maximum force at each station was only 34 N (each station).

Two options are available for increasing the force capability of this type of MBA, increase the operating current or reduce the air-gap (or both). The maximum steady-state current for the bearings in the original design was, of course, equal to the bias current, i.e. 0.57 A. The design maximum current was around 1.5 A. It was experimentally determined that the MBA's could be operated (in an air environment) at the design maximum current for unlimited periods, without overheating. By classical magnetic circuit analysis, a design was developed where the air-gaps of the three axial MBA's would be reduced to roughly half their original value, then each MBA could be operated at well below the maximum tolerable steady-state current. The reduced air-gap was achieved by fabrication of new pole-pieces for the existing MBA's.

Control System

The original control system was all-analog, and included local linearization and control of each MBA, illustrated in Figure 7, as well as global control of payload position and orientation, illustrated in Figure 8. Several coordinate transformation (decoupling) stages were required to properly transition between bearing station displacements and forces, rotor position and orientation, and payload centered coordinates. Several feedforward loops were employed for various linearization and compensation tasks.

The entire controller, as well as some additional compensation functions previously built in to power amplifier hardware, will be replaced by a digital controller. The controller is based on a 486-class PC with standard commercial data acquisition boards. At the time of writing, individual MBA's have been made operational with simple local PD controllers [11]. Difficulties with some of the power amplifier hardware has so far prevented full (5-component) suspension.

CONCLUDING REMARKS

The ASPS Vernier System is in the process of being recommissioned and modified in order to facilitate future studies of payload pointing and vibration isolation, as well as a potential application for solar array attachment to a space station. Replacement of further controller functions and completion of the digital controller are the next major steps in this project.

ACKNOWLEDGEMENTS

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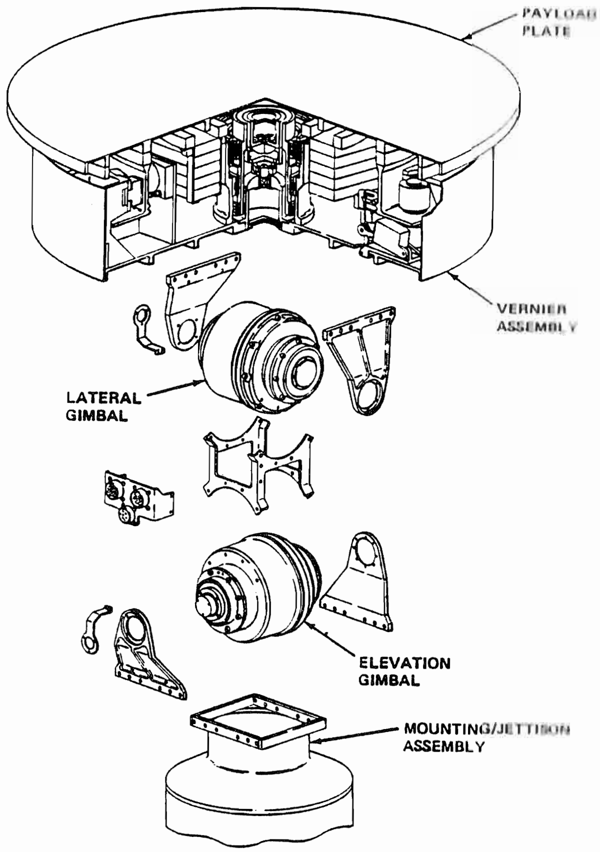


Figure 1 - The Annular Suspension and Pointing System (ASPS)

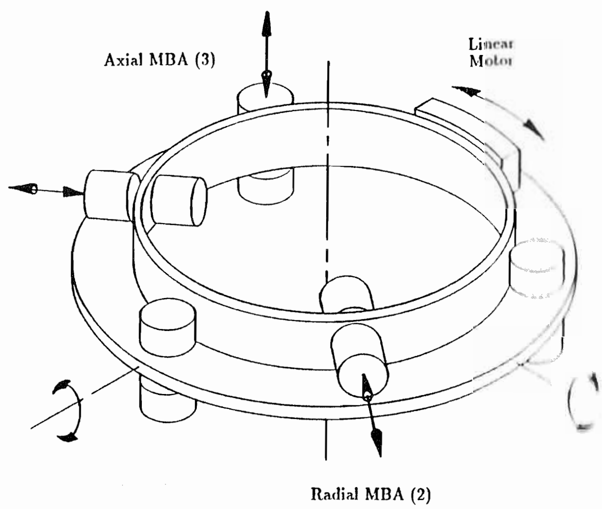


Figure 2 - Schematic Diagram of the AVS Magnetic Configuration

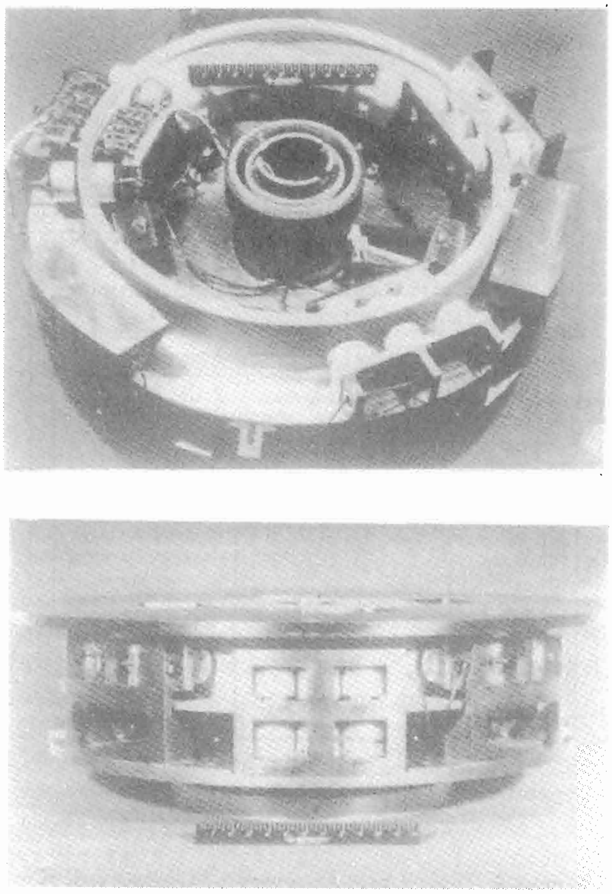


Figure 3 - The AVS Magnetic Assembly

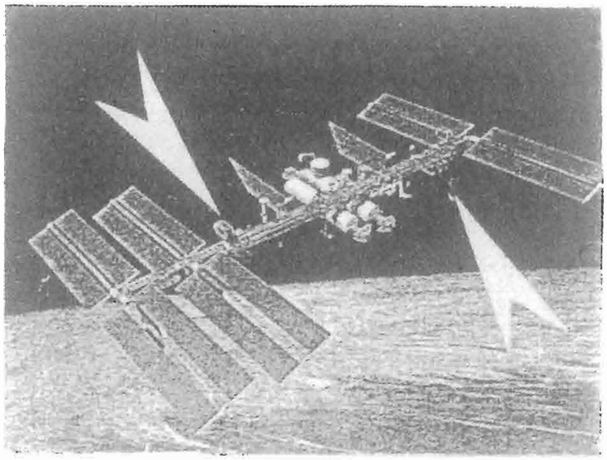


Figure 4 - Space Station Freedom
(showing Alpha joint locations)

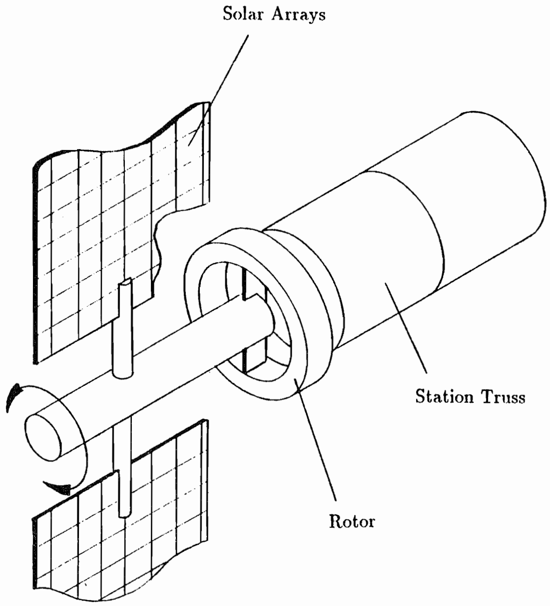
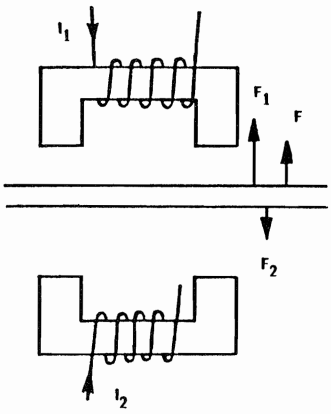


Figure 5 - Solar Array Rotary Joint Application



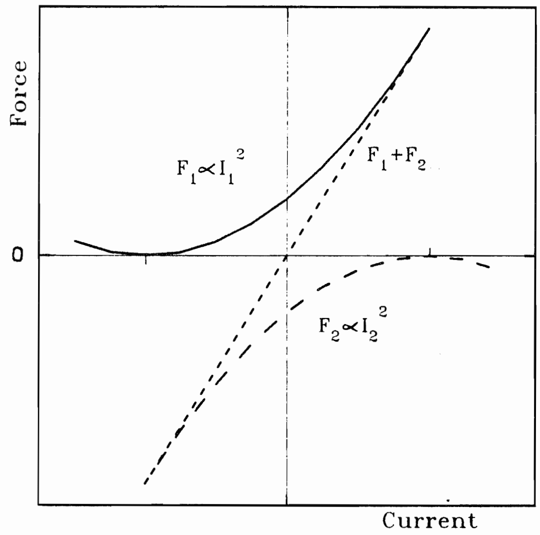


Figure 6 - Bias Current Linearization

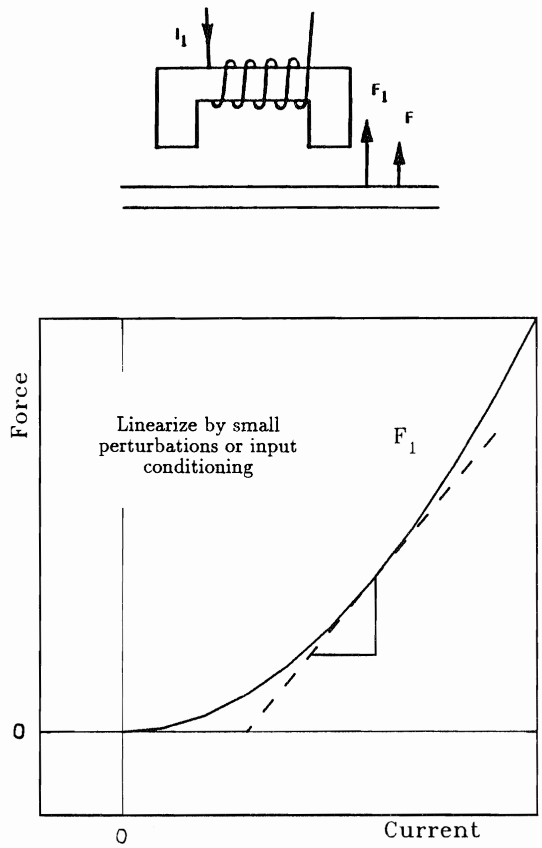


Figure 7 - Alternative Operational Scheme

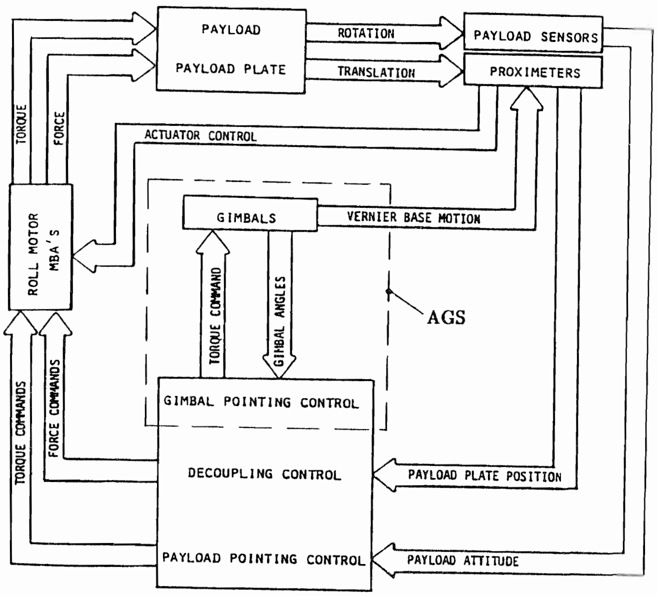


Figure 9 - Schematic Diagram of Global ASPS Controller

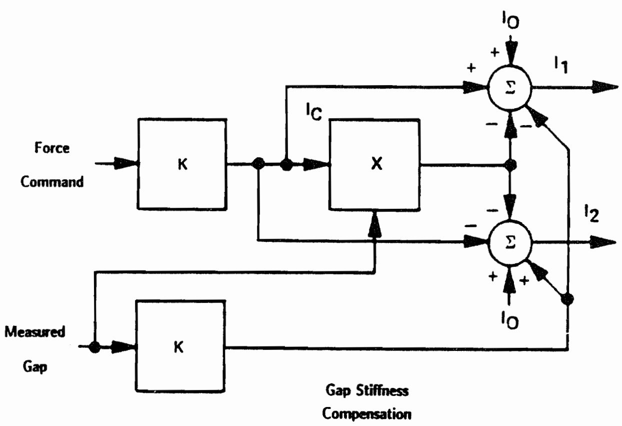


Figure 8 - Schematic Diagram of Existing MBA Local Controller