ENVIRONMENTAL EFFECTS ON THE DYNAMICS AND CONTROL OF AN ORBITING LARGE FLEXIBLE ANTENNA SYSTEM

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ENVIRONMENTAL EFFECTS ON THE DYNAMICS AND CONTROL OF AN ORBITING LARGE FLEXIBLE ANTENNA SYSTEM*

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Large flexible orbiting systems have been proposed for possible use in communications, electronic orbital based mail systems, detection of earth resources, and in solar energy collection. The size and low weight to area ratio of such systems dictate that system flexibility is now the main consideration in the dynamics and control problem as contrasted with the inherently rigid nature of earlier spacecraft systems. For such large flexible systems both orientation and shape control will often be required. In order to meet the stringent pointing and shape control requirements of some of the proposed systems the effects of the environmental disturbances on the dynamics of such structures need to be considered. The purpose of the present paper is to consider the shape and orientation control of the proposed Hoop/Column antenna system[1] in the presence of the environmental disturbances.

The Hoop/Column antenna system is one of the configurations under consideration for use in the future multi-beam Land Mobile Satellite System[1], designed to provided point to point communications for 250,000 subscribers across the U.S. in the mid 1990's.

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The system is based on a large geosynchronous relay antenna and a number of mobile, Earth-based receivers. In order to achieve the required RF performance a pointing accuracy of $\pm$ (0.03 - 0.10) degree RMS and a surface (antenna) accuracy of 12 mm RMS will be required.

The Hoop/Column antenna system[2], depicted in Fig. 1, in deployed configuration, contains the deployable (telescoping) mast system connected to the hoop by support cables under tension. The hoop contains 48 rigid sections, to be deployed by motor drive units. The desired shape of the RF reflective mesh is produced by a secondary drawing surface using surface control cables. The reflective mesh is connected to the hoop by quartz or graphite stringers. At one end of the mast the electronic feed assemblies are positioned, whereas at the other end are the principal solar arrays connected to the main bus based control.

The controllability and the control law synthesis based on a finite element model of the Hoop/Column antenna system was considered previously, neglecting the environmental effects.[3] Graph theoretic techniques were employed to analyze the controllability of the system for possible proposed actuator arrangements (Fig. 2) which included torquers and point actuators along the mast and nearby feed assembly, and a single actuator placed on the hoop assembly. After establishing controllability for a given combination of the number and location of the actuators, the synthesis of control laws was based on an application of the linear regulator theory and also pole placement techniques.

In the present work, the linear regulator theory is used again to obtain orientation and shape control of the orbiting antenna system considering the environmental effects. The major disturbances considered are: (i) due to the solar radiation pressure on the vibrating antenna structure, (ii) the solar heating effect and, (iii) the gravity-gradient torques.

The effect of solar radiation pressure on the dynamics of an orbiting flexible beam was analyzed previously[4] by using the force and moment expressions developed by Karymov.[5] The work was later extended to consider the dynamics of an orbiting flexible square plate under the solar radiation pressure disturbance.[6] It was shown that the principal effect of the solar radiation pressure on the vibrating beams and plates was to induce oscillations in the rigid rotational modes. The solar radiation pressure disturbance model for the antenna system is now developed by considering the antenna to be mainly composed of a flexible beam (the mast) and the two rectangular solar panels, as flexible thin plates. The force and moment expressions for the solar radiation pressure acting on the mast are evaluated numerically by considering the mode shapes of the mast. The mode shapes and the frequencies of the solar panels which are connected to the mast are evaluated first using a finite element program. The mode shapes of the solar panels are then used to develop the solar radiation force and moment expressions, numerically. The effects of the solar radiation pressure resulting from the rest of the sturctural elements such as the mesh and its supporting structure are considered to be negligible, based on the extremely small projected areas involved.

Another important source of disturbance arises from the temperature gradient induced in the structure due to solar heating. Expressions for deflections induced in thin beams and plates (Fig. 3) resulting from solar radiation heating are developed. Then mathematical models for the moments resulting from the solar radiation pressure interacting with the thermally deflected beams and plates are also derived. After incorporating these expressions in the models for the uncontrolled and the controlled dynamics of the beams and the plates, it was shown that the effect of solar radiation pressure on the thermally deflected structures is larger than the effect of solar radiation pressure on the vibrating structures. The results of Ref. 6 are now applied to the Hoop/Column antenna, assuming a nominal maximum thermal deflection of 1m in 100m length of mast and 0.03 meters in 3m long solar panels.

The finite element model of the antenna system considered here does not include the gravity effects of the structure in the orbit. Therefore, the stabilizing gravity-gradient torques are modelled here as an external disturbance. The effect of the solar radiation pressure interacting with the vibrating as well as thermally deformed structure together with the gravity-gradient torques are incorporated into the finite element model of the antenna system.

A finite element model of the Hoop/Column antenna system which includes all six rigid modes and seven flexible modes is considered. Only seven actuators are selected (Nos. 1,5,6,8-11) so that the resulting closed-loop control system would have time constants of the order of 1000 secs.

With this choice of time constants, the environmental disturbance effects on the transient responses of the antenna system can be visualized more distinctly. The optimal feedback gain values are obtained using a split weighting fuction for the matrices Q = 1000 I (except Q(4) = Q(5)= Q(6)= 1.0) and R = 100 I contained in a quadratic cost functional. The controlled transient response of the antenna system in the pitch, roll and yaw rotational modes are shown in Fig. 4., with and without the effect of the environmental disturbances. The effect of disturbance is more pronounced in the roll mode than in the pitch and yaw modes. A steady state biased error of 0.001 radians is seen in all three modes which is recognized as due to the interaction of solar radiation pressure on the thermally deflected structure. The effects of the disturbances on the flexible modes of the system are found to be less than 1 percent of the peak flexural amplitudes. The maximum control force required in actuator No. 6 increased from $1x10^{-4}$ lb_f to $3x10^{-4}$ lb_f as a result of the disturbances induced in the model. The total control effort required in the absence of the disturbances was about 1 lb_f-sec. The control effort is increased to 400 lb_f-secs in 4000 secs, when the environmental disturbance effects were induced in the dynamic model of the system.

In conclusion, the environmental disturbances predominantly affect only the rigid modes of the system. The effect of solar radiation pressure interacting with the vibrating structure is seen to be much smaller than the solar radiation pressure acting on the thermally deformed structure. In order to reduce the control effort to maintain the shape and orientation, the thermal deformations will have to be minimized in the preliminary design of the system.

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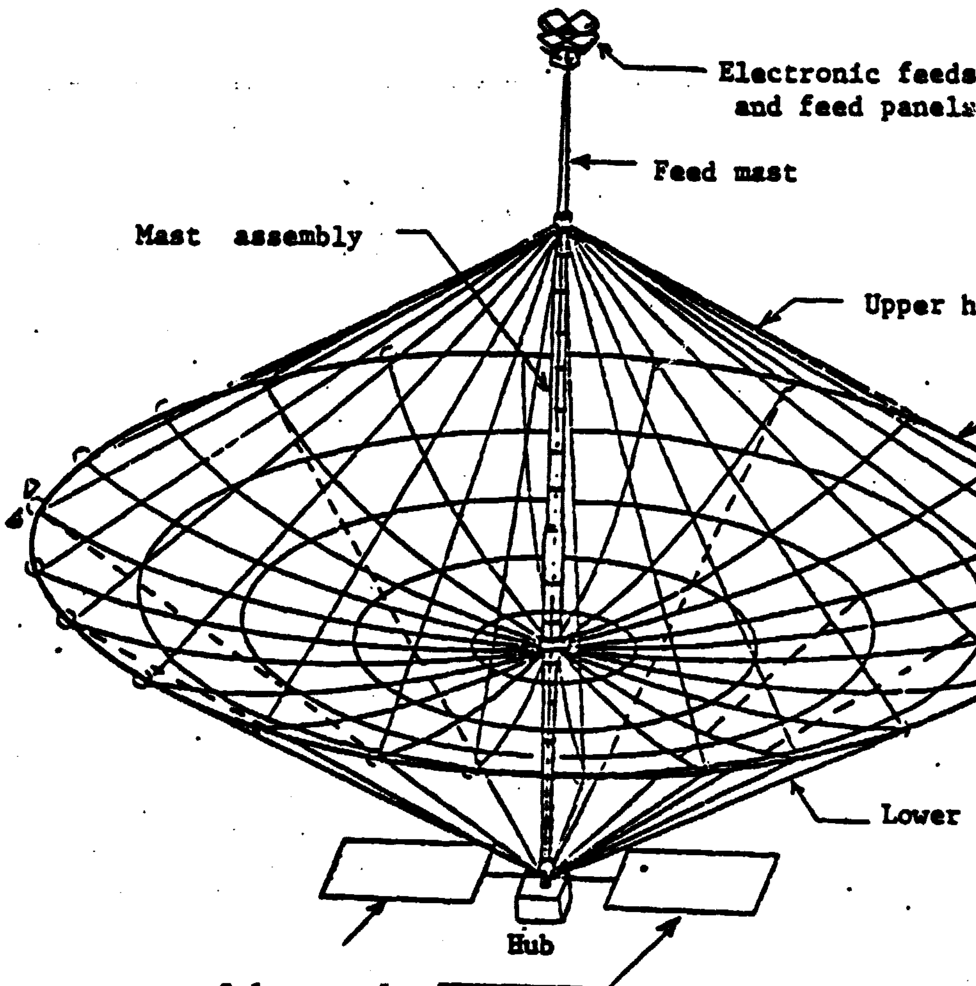

Fig. 1 The Hoop/Column Antenna System

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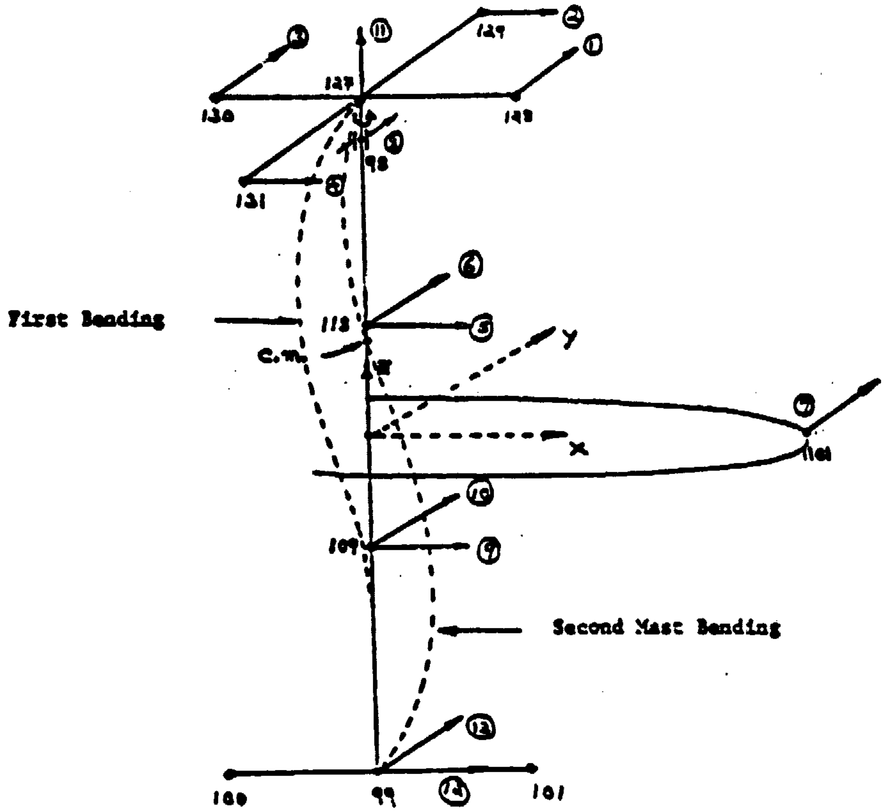

Fig. 2. Proposed arrangement of actuators Hoop/Column system.
(uncircled numbers identify grid points from finite element analysis)

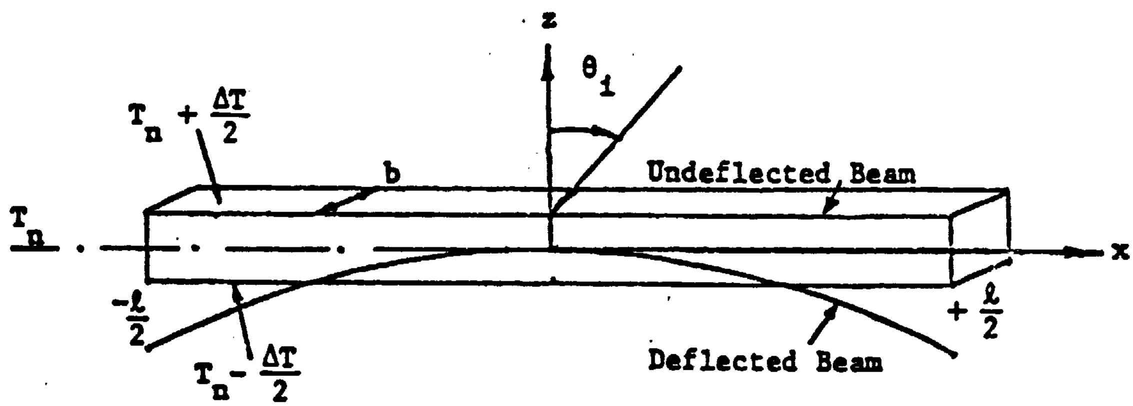

Fig. .3. Beam Bending Due to Solar Radiation Heating

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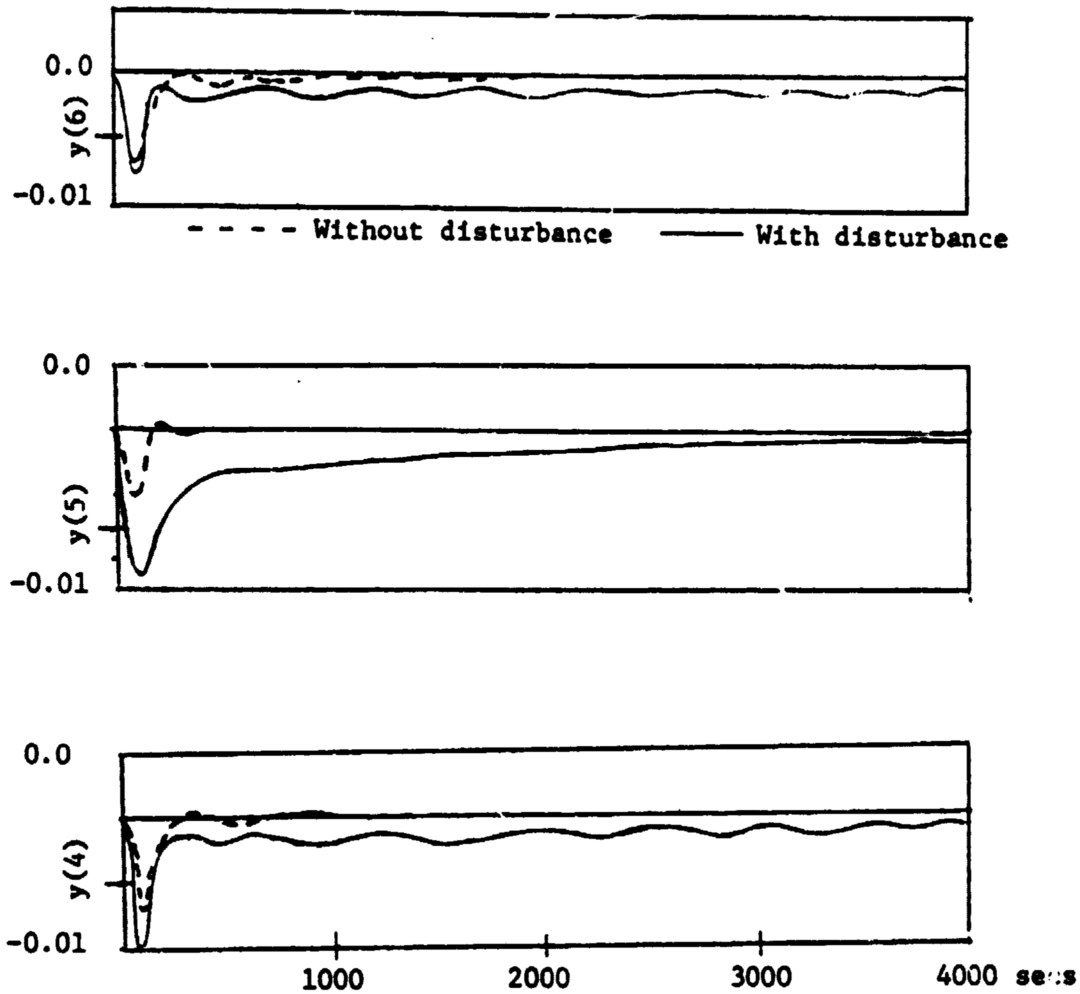

I.C.'s: y(1) = y(2) = ... = y(6) = 0.0

y(7) = y(8) = ... = y(13) = 0.01

Q = 1000I, R = 100I, Except Q(4) = Q(5) = Q(6) = 1.0

Fig. 4. Controlled Transient Response of the Hoop/Column Antenna System. Control Based on LQG.