CONTROLS FOR SPACE STRUCTURES

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Assembly and operation of large space structures (LSS) in orbit will require robot-assisted docking and berthing of partially-assembled structures. These operations require new solutions to the problems of controls. This is true because of large transient and persistent disturbances, controller-structure interaction with unmodeled modes, poorly known structure parameters, slow actuator/sensor dynamical behavior, and excitation of nonlinear structure vibrations during control and assembly.

For on-orbit assembly, controllers must start with finite element models of LSS and adapt on line to the best operating points, without compromising stability. This is not easy to do, since there are often unmodeled dynamic interactions between the controller and the structure. The indirect adaptive controllers are based on parameter estimation. Due to the large number of modes in LSS, this approach leads to very high-order control schemes with consequent poor stability and performance. In contrast, direct model reference adaptive controllers operate to force the LSS to track the desirable behavior of a chosen model.

These schemes produce simple control algorithms which are easy to implement on line. One problem with their use for LSS has been that the model must be the same dimension as the LSS—i.e., quite large. We have developed a control theory based on the command generator tracker (CGT) ideas of Sobel, Mabins, Kaufman and Wen, Balas to obtain very low-order models based on adaptive algorithms. Closed-loop stability for both finite element models and distributed parameter models of LSS has been proved. In addition, successful numerical simulations on several LSS databases have been obtained. An adaptive controller based on our theory has also been implemented on a flexible robotic manipulator at Martin Mariettta Astronautics.

We have developed computation schemes for controller-structure interaction with unmodeled modes, the residual mode filters or RMF. At present, we have modified the RMF theory to compensate slow actuator/sensor dynamics. We are in the process of applying these new ideas to LSS simulations to demonstrate the ease with which we can incorporate slow actuator/ sensor effects into our design. We have also shown that residual mode filter compensation can be modified for small nonlinearities to produce exponentially stable closed-loop control.

Accommodation for transient disturbances can be handled with the usual feedback design techniques. Persistent disturbances, however, require modification of the controller algorithms. We have developed a theory for disturbance-accommodating controllers based on reduced-order models of structures, and have obtained stability results for these controllers in closed-loop with large-scale finite element models of structures.

Flexible
Structure

U reference

actuators

Modeled modes

sensors

Y

U

Residual modes

U reference

R.O.M.
based
controller

- Develop a R.O.M. controller, designed for performance.

- Dimension of the controller << dimension of the structure.

BUT

- Energy is pumped into all modes by the R.O.M. controller.

- Some residual modes may be driven unstable; this is known as Controller / Structure Interaction (C.S.I.)

Flexible
Structure

U reference

actuators

Modeled modes

sensors

Y

U

Stable
Residual modes

Unstable
Residual modes

U reference

R.O.M.
based
controller

+

U

y_Q

-

Residual Mode
Filter

- Develop R.M.F. as a bank of parallel second-order filters; one filter for each unstable residual mode.

- R.M.F. interrupts the control loop around all unstable residual modes; R.O.M control input is screened.

- R.M.F. compensates for C.S.I. , insuring system stability.

Fig 4.1   Comparison of two methodologies for flexible structure control
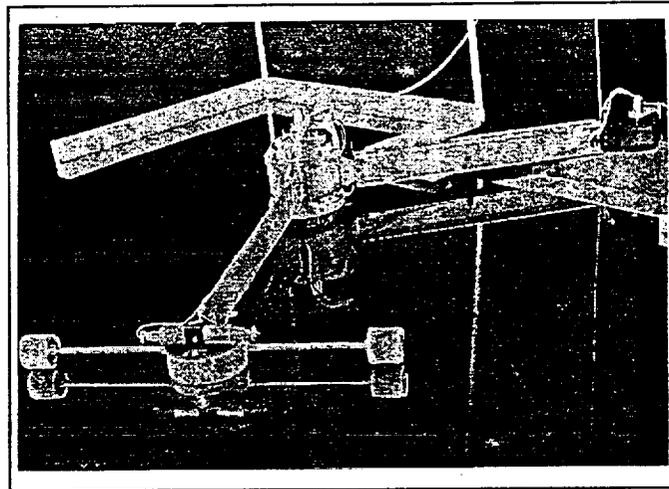
Fig 4.2   Flexible robot manipulator at Martin Marietta
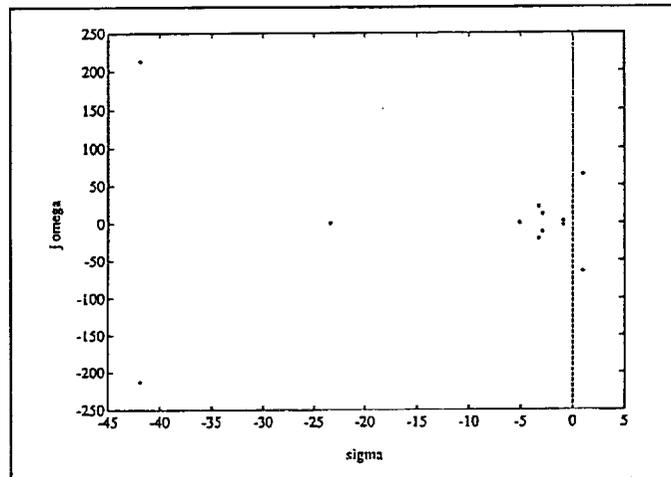
Fig 4.3   Closed loop poles without CSI compensation
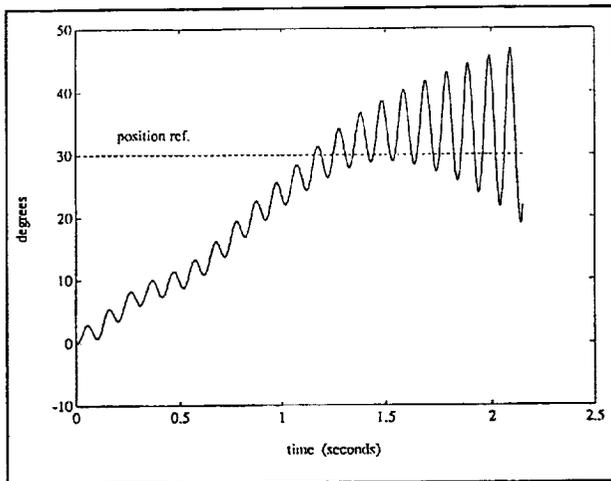
Fig 4.4   Hub position without CSI compensation
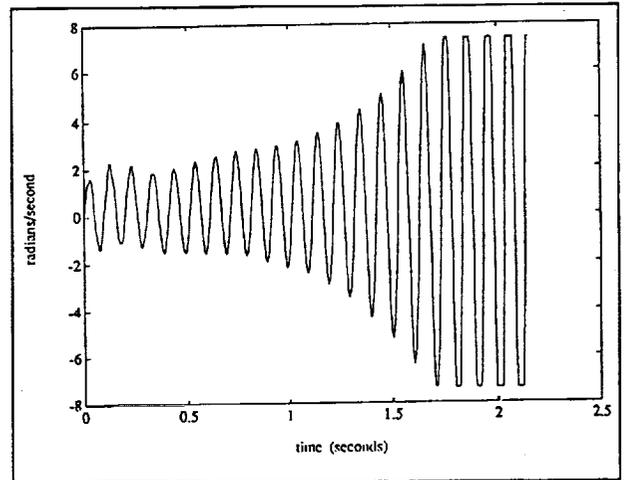
Fig 4.5   Hub velocity without CSI compensation
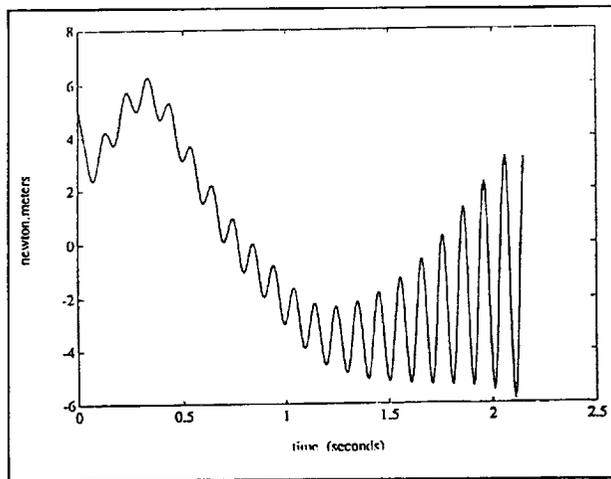
Fig 4.6   Control command without CSI compensation
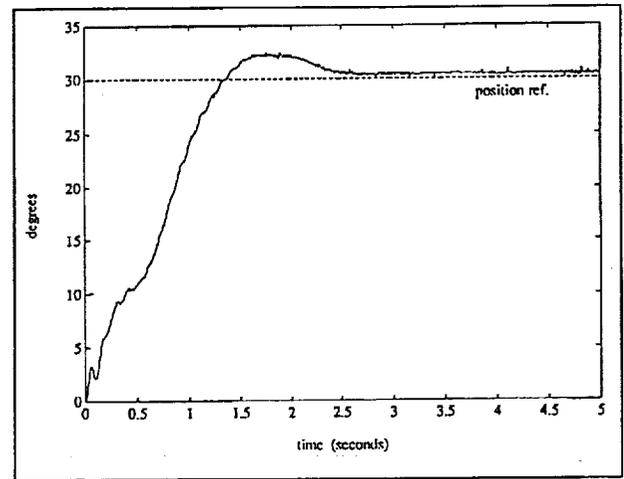
Fig 4.7   Hub position with CSI compensation
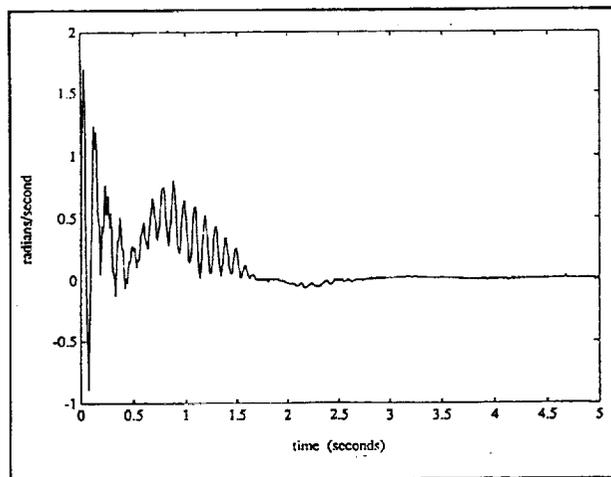
Fig 4.8   Hub velocity with CSI compensation
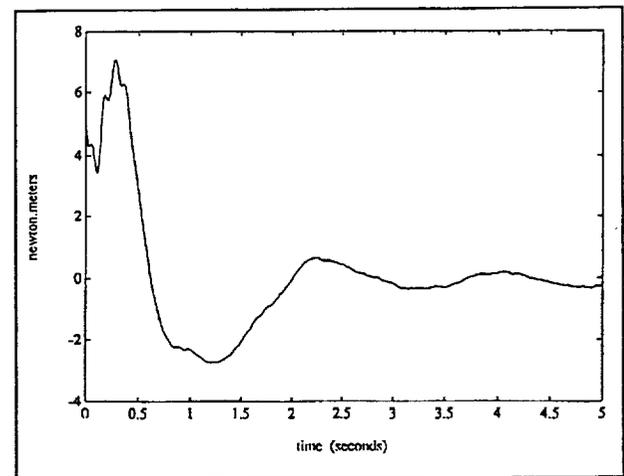
Fig 4.9   Control command with CSI compensation

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