OPTIMUM DAMPER LOCATIONS FOR A FREE-FREE BEAM

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RESEARCH ISSUES IN STRUCTURAL DYNAMICS AND CONTROL OF LARGE SPACE STRUCTURES

An in-house research team has been formed to address some key issues in the dynamics and control of large space structures. Contracts and grants are used to supplement the in-house research effort.

One technical issue under research is structural modeling of large space structures. One difficulty is the large number of degrees of freedom and how to reduce the equations of motion to a manageable size. One promising technique for achieving this appears to be the continuum approach. System identification techniques will have to be developed so that space borne structures may be analyzed and characterized.

The placement of actuators and sensors in optimal locations is of technical interest. The most effective locations for achieving a certain control objective must be identified. The issue of colocated versus noncolocated sensors and actuators should be investigated in terms of performance and stability.

Another issue is adaptive/learning control systems for large space structures. Some classes of structures such as deployable and erectable structures may require control at an intermediate stage before the final configuration is achieved. To control these systems an algorithm which can identify the pertinent dynamics in real time will be needed.

- MODELING AND IDENTIFICATION PROCEDURES FOR DYNAMIC ANALYSIS AND CONTROL
- OPTIMUM ACTUATOR AND SENSOR PLACEMENT AND DESIGN
- DISTRIBUTED SENSING AND ACTUATION VERSUS COLOCATED SENSING AND ACTUATION
- ADAPTIVE/LEARNING CONTROL SYSTEMS FOR STRUCTURAL SYSTEMS
- REDUNDANT MANAGEMENT TECHNIQUES FOR STRUCTURAL SYSTEMS

Figure 1

OPTIMUM DAMPER LOCATIONS FOR A FREE-FREE BEAM

The objectives of this research are to identify optimum locations for sensors and actuators on large space structures. If it is assumed that large platforms and antennae will have many potential actuator/sensor locations, we may logically ask "Where should actuators and sensors be placed?" Not only should the optimum placement be determined, but also the dynamic characteristics of actuators may also be necessary.

OBJECTIVES

- DEVELOP ALGORITHMS TO OPTIMALLY LOCATE AND DESIGN DAMPERS FOR LARGE SPACE STRUCTURES
- DETERMINE REQUIREMENTS FOR DISTRIBUTED SENSING AND ACTUATION (AS OPPOSED TO COLOCATED SENSOR AND ACTUATOR) IN CONTROL OF STRUCTURAL SYSTEMS

APPROACH

- USE MATHEMATICAL PROGRAMMING TO SOLVE FOR OPTIMUM DAMPING RATE AND LOCATION.
- CONSIDER ACTUATOR DYNAMICS TO SOLVE FOR OPTIMUM ACTUATOR MASS.

Figure 2

DAMPING CHARACTERISTICS OF A FREE-FREE BEAM

To get an understanding of the behavior of large space structures, we first look at the damping characteristics of a uniform beam. A dash pot is located at one end of a free-free beam. This is an ideal dash pot which is characterized by a damping rate, C, and no other dynamic characteristics. In figure 3 it is seen that for small values of C (<.005), the damping ratio, ζ , and damping rate are linearily related. This is denoted as perturbation theory. As the damping rate is increased, the damping ratio reaches a peak value and then decreases. The peak value of the damping ratio is about 0.2 for the first flexible mode. Suppose a design problem were stated which required that the first mode have a damping ratio greater than 0.2. This requirement may be a result of mission performance specifications. To achieve more than the 0.2 damping ratio in the first mode, one or more dash pots are required. Since the design problem being addressed here is one in which the damping ratio is prescribed for each mode to be damped, the damping rate of the dash pots is determined.

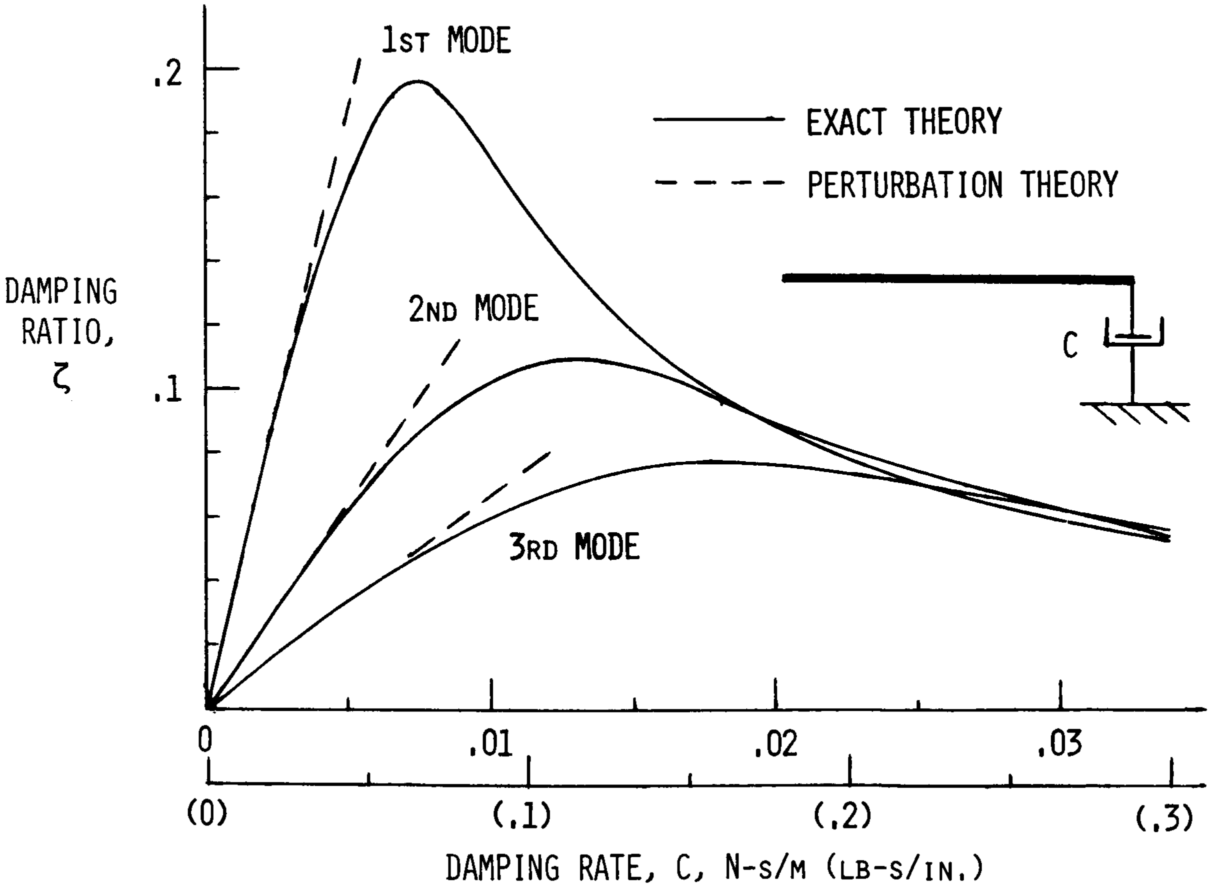


Figure 3

DAMPING CHARACTERISTICS OF A CLAMPED-FREE BEAM

The results are essentially the same as for the free-free beam in figure 3.

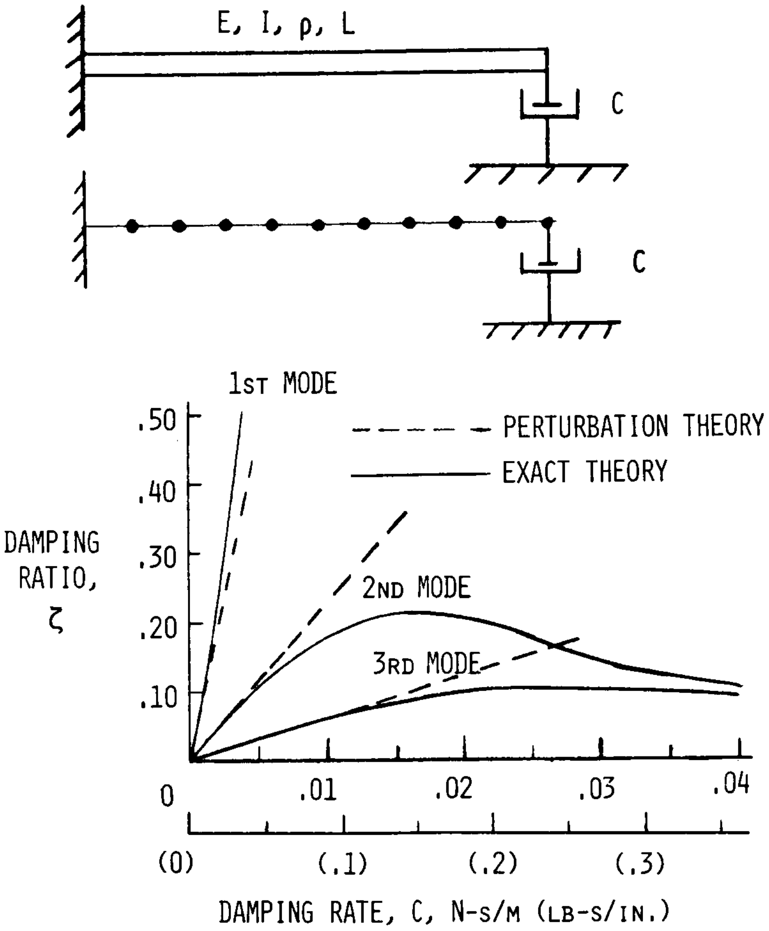


Figure 4

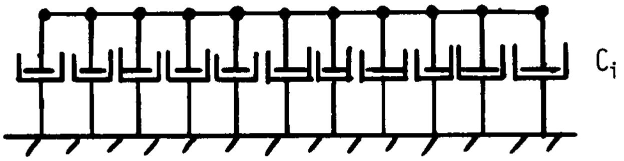
NONLINEAR OPTIMIZATION PROBLEM

A design problem is posed which states that given the prescribed modal damping ratio for N modes, what are the optimum damping locations and sizes? The design problem is now cast as a nonlinear optimization problem. Since it is not known where the dash pots should be located on a structure, the initial step is to put a dash pot at every location of the beam. The objective function is to minimize the total dissipative effort. The constraints are that the actual computed modal damping ratios must be greater than or equal to the prescribed value. Another constraint is that the damping rate must be positive. This guarantees stability.

O FOR PRESCRIBED MODAL DAMPING RATIO IN N MODES, WHAT ARE THE BEST DAMPING SIZES AND LOCATIONS?

O OBJECTIVE

MINIMIZE TOTAL DISSIPATION $\quad \text{MIN} \sum_i C_i$



O CONSTRAINTS

(COMPUTED MODAL DAMPING RATIO)$_j$ $\geq$ (DESIGN VALUE)$_j$

C_i MUST BE POSITIVE

Figure 5

OPTIMUM DAMPING LOCATIONS AND SIZES FOR A FREE-FREE BEAM

Some results are presented in figure 6 for a free-free beam. The design problem consisted of prescribing a modal damping ratio of 0.5 in N modes. The results are shown for N = 1, 2, 3, 4. The results are also split between symmetric solutions and nonsymmetric solutions. The symmetric solutions are obtained by minimizing the total dissipation while imposing symmetry in the solution. The horizontal lines represent the length of the beam. The vertical lines are proportional to the magnitude of the damping rate at the location shown on the beam axis. The nonsymmetric solution is obtained by removing the symmetry requirement and the smallest damper location. Thus, nonsymmetric solutions will have no more than one fewer dampers than the symmetric case. In some cases the objective function for the nonsymmetric solution is less than that for the symmetric case.

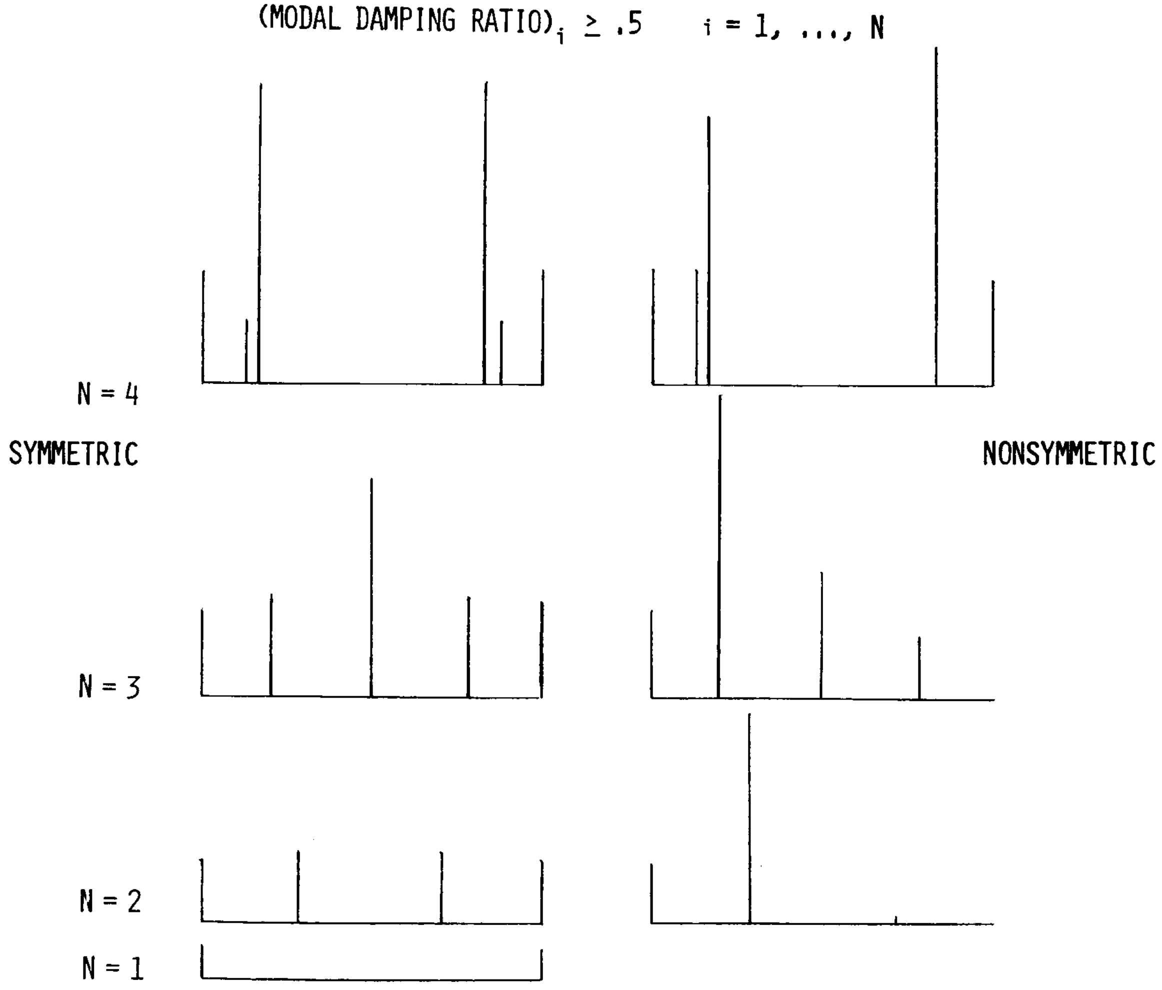


Figure 6

OPTIMUM DAMPER LOCATIONS AND SIZE FOR A CLAMPED-FREE BEAM

The results shown in figure 7 are similar to those in figure 6.

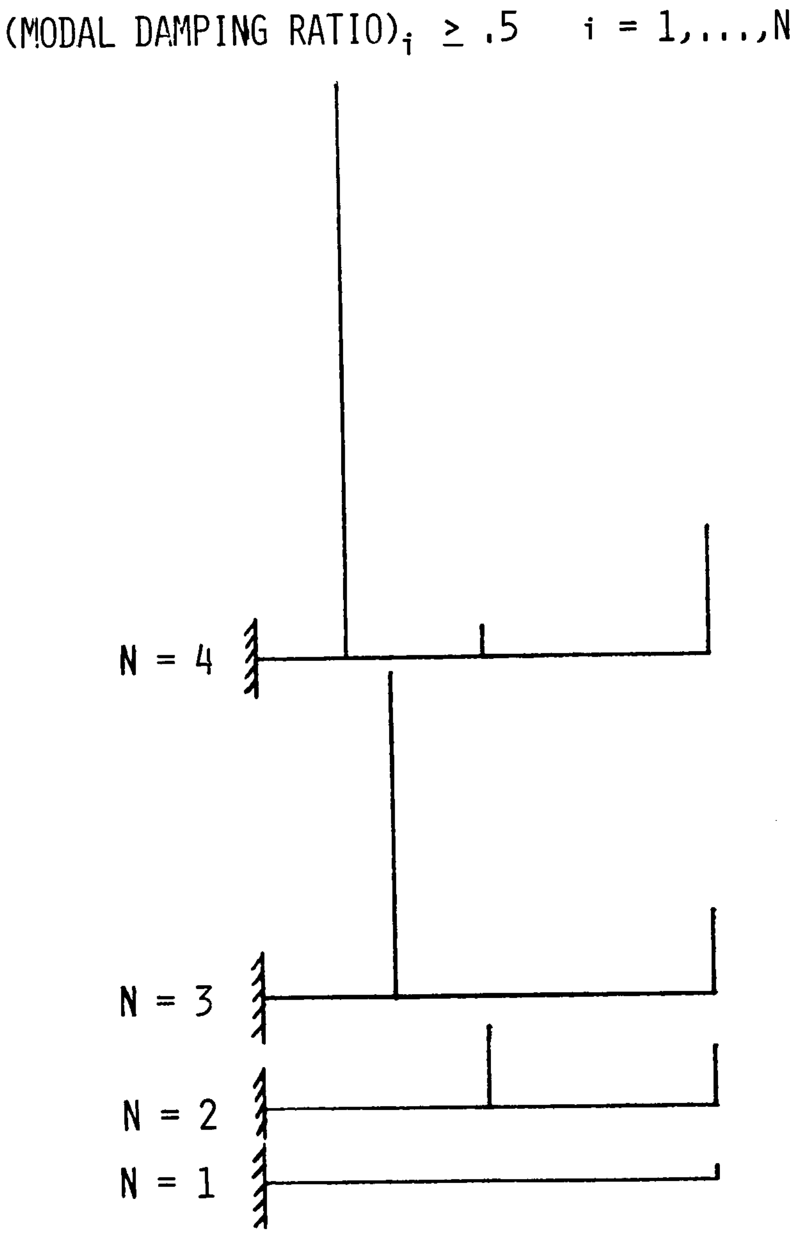


Figure 7

FUTURE RESEARCH

The future research thrusts will involve the addition of actuator dynamics to the structural dynamic models. This will allow the mass and stiffness as well as the damping rate of the damper to be design variables. Thus this will be the actuator design phase.

Next, a 2-dimensional structural model which has a higher modal density will be developed.

0 NONCOLOCATED SENSORS AND ACTUATORS

0 ADDITION OF ACTUATOR DYNAMICS

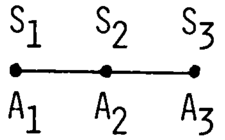
0 2-DIMENSIONAL STRUCTURAL MODEL

Figure 8

NONCOLOCATED SENSORS AND ACTUATORS

One possible configuration of sensors and actuators is shown by the damping matrix. As seen by the matrix, each sensor "talks" to each actuator which gives rise to the fully populated matrix. This is in contrast to colocation which would give a diagonal matrix. By enforcing the three inequalities, stability will be guaranteed a priori.

o ONE POSSIBLE CONFIGURATION



S = VELOCITY SENSOR
A = FORCE ACTUATOR

DAMPING MATRIX

$$\begin{bmatrix} A_1 \\ A_2 \\ A_3 \end{bmatrix} = \begin{bmatrix} C_{11} & -C_{12} & -C_{13} \\ -C_{12} & C_{22} & -C_{23} \\ -C_{13} & -C_{23} & C_{33} \end{bmatrix} \begin{bmatrix} S_1 \\ S_2 \\ S_3 \end{bmatrix}$$

FOR A STABLE SYSTEM

$$C_{11} - C_{12} - C_{13} > 0$$

$$-C_{12} + C_{22} - C_{23} > 0$$

$$-C_{13} - C_{23} + C_{33} > 0$$

Figure 9

LaRC FLEXIBLE BEAM EXPERIMENT

To verify some of the optimization results and other control algorithms, a flexible beam experiment has been initiated at LaRC. In figure 10, the flexible beam experiment consists of a 3.66 m (12 ft) long aluminum beam with a 4.76 mm (3.16 in.) by 15 cm (6 in.) cross section. The beam is suspended by two small flexible cables so that free-free end conditions are approximated. Located in front of the beam are four electromagnetic shakers (actuators) which can be repositioned along the beam by sliding them along the platform which supports them. The console on the left contains the power amplifiers for the shakers.

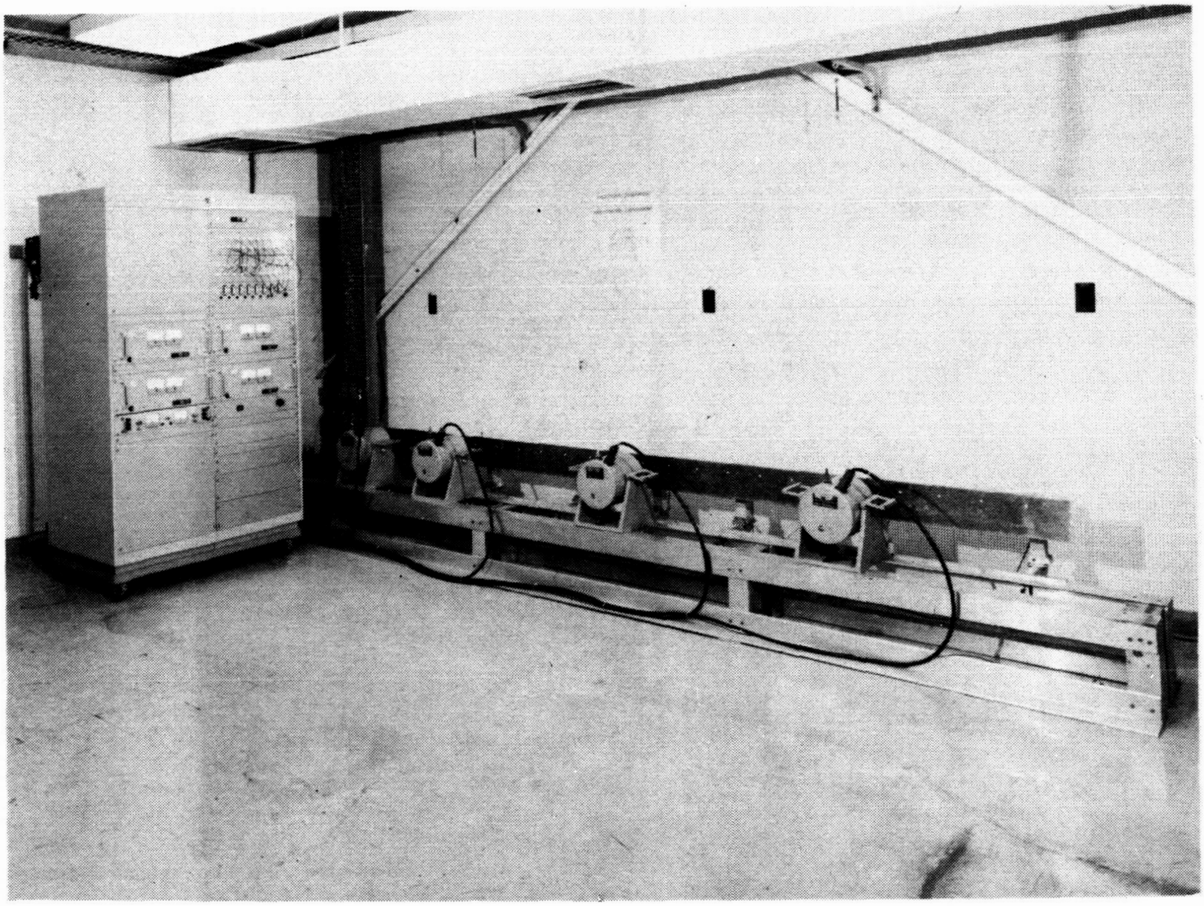


Figure 10

Figure 11 shows another picture of the experimental setup. On one side of the beam the four shakers are located and on the other side of the beam there are nine noncontacting displacement probes. With the experiment being tied in with the CDC Cyber 175 computer, real-time calculations may be made. For example, the output of the displacement probes can be made available to the computer. Using state estimation, the velocity at the shaker locations can be approximated. Knowing the damping rate or gain from the optimization program and the velocity, the desired force output of the shakers can be calculated.

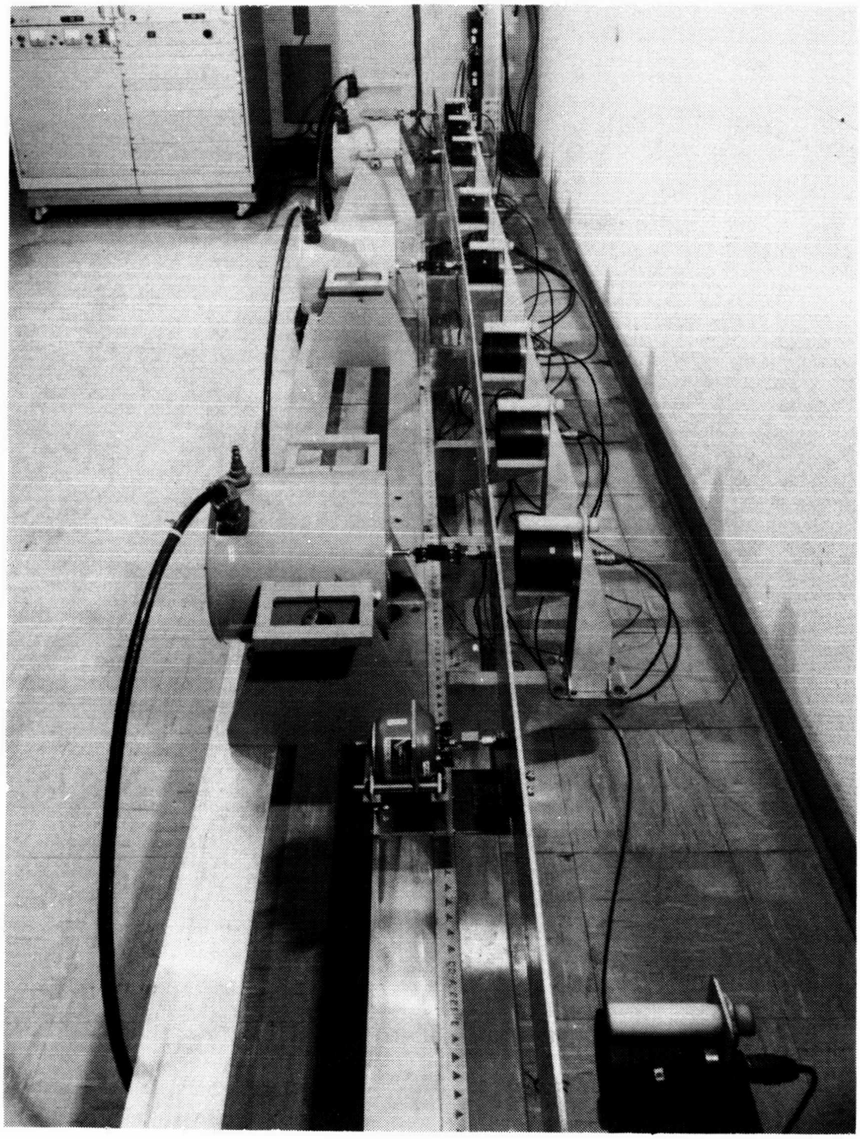


Figure 11