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ACTUATOR PARTICIPATION IN A BENDING MODE IDENTIFICATION SYSTEM

By Zack Thompson and Perry Davis
Astrionics Laboratory

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16. ABSTRACT

A hydraulic actuator designed for a thrust vector control system used as a shaker for a vehicle to determine the bending mode frequencies is described. The actuator is used as the prime mover and the frequency sensor for the flexible vehicle in a test tower. Advantages in using the actuator piston position with respect to a commanded position to obtain the bending mode frequencies are shown.

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APPROVAL

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The information in this report has been reviewed for security classification. Review of any information concerning Department of Defense or Atomic Energy Commission programs has been made by the MSFC Security Classification Officer. This report, in its entirety, has been determined to be unclassified.

This document has also been reviewed and approved for technical accuracy.

Melvin S. Brooks

MELVIN BROOKS
Chief, Guidance and Control Systems Division

J L Mack

J. L. MACK
Chief, Systems Division

F. B. Moore

F. B. MOORE
Director, Astrionics Laboratory

MSFC—RSA, Ala

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DEFINITION OF SYMBOLS

Symbol	Definition	Units
$K_a G_1$	amplifier transfer function	mA/deg
$K_v G_2$	servovalve and actuator transfer function	deg/mA
G_3	notch and shaping network	deg/deg
G_4	load transfer function	deg/deg
F_o	open loop transfer function	deg/deg
ΔI	differential valve current	mA
ϵ	error signal	deg
β, β_p	piston ideal position and piston position unloaded, respectively	deg
β_p	actuator piston position	deg
β_e	engine position	deg
β_c	input command	deg
β_f	feedback signal	deg
S	Laplace operator	1/S
f	frequency	Hz
K_p	pressure feedback gain	$(M^5/S)/N$
H_1	feedback gain	

DEFINITION OF SYMBOLS (Concluded)

Symbol	Definition	Units
K_1	$\frac{K_1 K_0}{K_1 + K_0}$	N/M
A	piston area	M^2

TECHNICAL MEMORANDUM X-64689

ACTUATOR PARTICIPATION IN A BENDING MODE IDENTIFICATION SYSTEM

INTRODUCTION

To design filters for the body bending frequencies of a flexible body vehicle, it is first necessary to determine the bending frequencies and their influence on vehicle stability. An analytical derivation is made to get the first approximation of the frequencies, then elaborate testing is conducted to verify the derived information. The vehicle or stage is suspended in the test tower by long cables arranged to permit free vibration (Fig. 1). To obtain frequency response information, the vehicle is then vibrated by connecting a large shaker to the aft part of the vehicle and sensing the motion of the vehicle at various points.

A thrust vector control system is capable of generating the forces necessary for shaking the vehicle. The bending mode frequencies can be determined from the actuator piston position.

To control the angular position of the engine, a servosystem that will attenuate the commands to the dynamic load in the vicinity of the load resonant frequency must be used. The desired servo would filter out the load resonant frequency and give the proper attenuation in the neighborhood of that frequency. A block diagram of a system of this nature is shown in Figure 2.

The transfer functions are as follows:

$$K_a G_1 = \frac{909}{\left[\dfrac{S^2}{(300)^2} + \dfrac{2(0.7)S}{300} + 1\right]}$$

$$K_v G_2 = \frac{2.49}{S\left(\dfrac{S}{377} + 1\right)}$$

$$G_3 = \frac{\left(\frac{S^2}{\omega_n^2} + \frac{2\zeta}{\omega_n} S + 1\right)}{\left[\frac{S^2}{(70.37)^2} + \frac{2(0.416)S}{(70.57)} + 1\right]}$$

$$G_4 = \frac{1}{\left(\frac{S^2}{\omega_n^2} + \frac{2\zeta}{\omega_n} S + 1\right)}$$

An amplitude ratio frequency response of the system with the notch filter is shown in Figure 3. This system contains the dynamics of the load, the driving amplifier, the actuator, the servovalve, and the necessary dynamics to give the proper response.

In a multiengine control system, it is desirable from a hardware viewpoint to design one servoloop that can be interchangeable from engine to engine. Because of the tolerance used in manufacturing the stage structure, the engine, and the actuators, it is difficult to predict exactly what the resonant frequency of the load will be. It is desirable to have a system that would track the resonant frequency of the load and adjust the servosystem notch so that it would always be set at the proper frequency.

The closed-loop transfer function of the actuation system contains a numerator term that is exactly equal to the denominator in the transfer function of the load. The numerator term exists because the hydraulic fluid is compressible and the degree of compression is a function of the load acceleration, or force on the piston. The overall transfer function is a product of the servoloop and the load transfer functions. The development of this follows.

Since

$$\frac{\beta_p}{\beta_c} = \frac{F_o}{1 + F_o}$$

where

$$F_o = \frac{22.64\left(\frac{S^2}{\omega_n^{\ 2}} + \frac{2\zeta}{\omega_n} S + 1\right)}{S\left(\frac{S}{377} + 1\right)\left[\frac{S^2}{(300)^2} + \frac{2(0.7)}{300} S + 1\right]\left[\frac{S^2}{(70.57)^2} + \frac{2(0.416)}{(70.57)} S + 1\right]},$$

$$G_4 = \frac{1}{\left(\frac{S^2}{\omega_n^{\ 2}} + \frac{2\zeta}{\omega_n} S + 1\right)}$$

$$\frac{\beta_p}{\beta_c} = \frac{22.64\left(\frac{S^2}{\omega_n^{\ 2}} + \frac{2\zeta}{\omega_n} S + 1\right)}{S\left(\frac{S}{377} + 1\right)\left[\frac{S^2}{(300)^2} + \frac{2(0.7)}{300} S + 1\right]\left[\frac{S^2}{(70.57)^2} + \frac{2(0.416)}{70.57} S + 1\right] + 22.64\left(\frac{S^2}{\omega_n^{\ 2}} + \frac{2\zeta}{\omega_n} S + 1\right)}$$

The parameters of the load can be changed at random to produce any natural frequency, and the notch filter will always be at the proper frequency.

$$\frac{\beta_e}{\beta_c} = \left(\frac{F_o}{1 + F_o}\right)(G_4)$$

$$\frac{\beta_e}{\beta_c} = \left\{\frac{22.64\left(\frac{S^2}{\omega_n^{\ 2}} + \frac{2\zeta}{\omega_n} S + 1\right)}{S\left(\frac{S}{377} + 1\right)\left[\frac{S^2}{(300)^2} + \frac{2(0.7)}{300} S + 1\right]\left[\frac{S^2}{(70.57)^2} + \frac{2(0.416)}{70.57} S + 1\right] + 22.64\left(\frac{S^2}{\omega_n^{\ 2}} + \frac{2\zeta}{\omega_n} S + 1\right)}\right\}\left[\frac{1}{\left(\frac{S^2}{\omega_n^{\ 2}} + \frac{2\zeta}{\omega_n} S + 1\right)}\right]$$

A representation of the traveling notch is shown in Figures 4 and 5. The natural frequency of the dynamic load was the only parameter varied.

To obtain tracking and the proper amount of attenuation for a dynamic load, it is necessary for the actuator piston position (β_p) to be a function of engine acceleration. This is how the transfer function β_p/β_i is obtained. The traveling notch and associated shaping networks are mechanical components and are installed within the actuator body.

BENDING MODE IDENTIFICATION

It has been established that the actuator will produce a notch at the resonant frequency of the load and that the notch will follow changes to the resonant frequency. To evaluate the actuation system to see if it would also produce a notch for loads that have more than one resonant frequency, the lumped parameter model in Figure 6 was used. The following equations must be solved simultaneously to obtain a load to the actuator.

$$F = K_0 (\beta - \beta_p)$$

$$0 = -K_0 \beta + (K_1 + K_0) \beta_p - K_1 \beta_1$$

$$0 = -K_1 \beta_p + (K_2 + K_1 + M_1 S^2) \beta_1 - K_2 \beta_2$$

$$0 = -K_2 \beta_1 + (K_2 + K_3 + M_2 S^2) \beta_2 - K_3 \beta_3$$

$$0 = -K_3 \beta_2 + (K_3 + M_3 S^2) \beta_3$$

A block diagram of these equations and the actuator dynamics is shown in Figure 7.

A frequency response of this system β_p / β_c is shown in Figure 8.

These frequencies and the lumped parameters were not intended to simulate any particular vehicle bending frequencies. This simulation does illustrate how an actuator can be used to shake a test vehicle and use the actuator piston position to determine the bending frequencies. The piston position potentiometer voltage can be of any magnitude necessary to achieve desired resolution and sensitivity.

The same conventional sensors presently used on this type of test may be used.

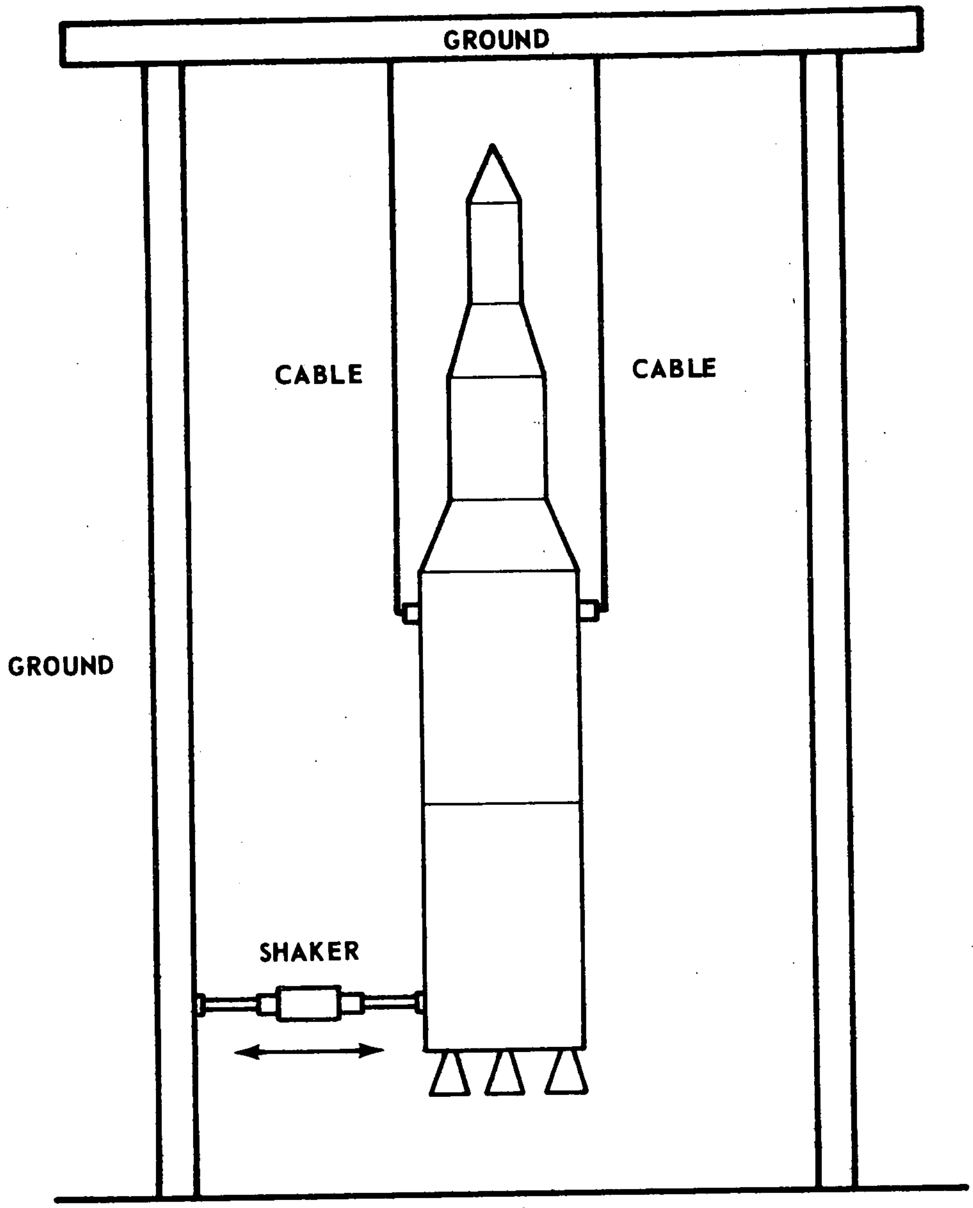

Figure 1. Vehicle and actuator test schematic.

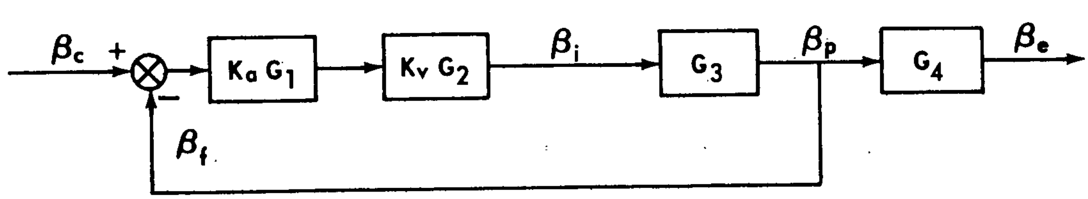

Figure 2. Actuator and load block diagram.

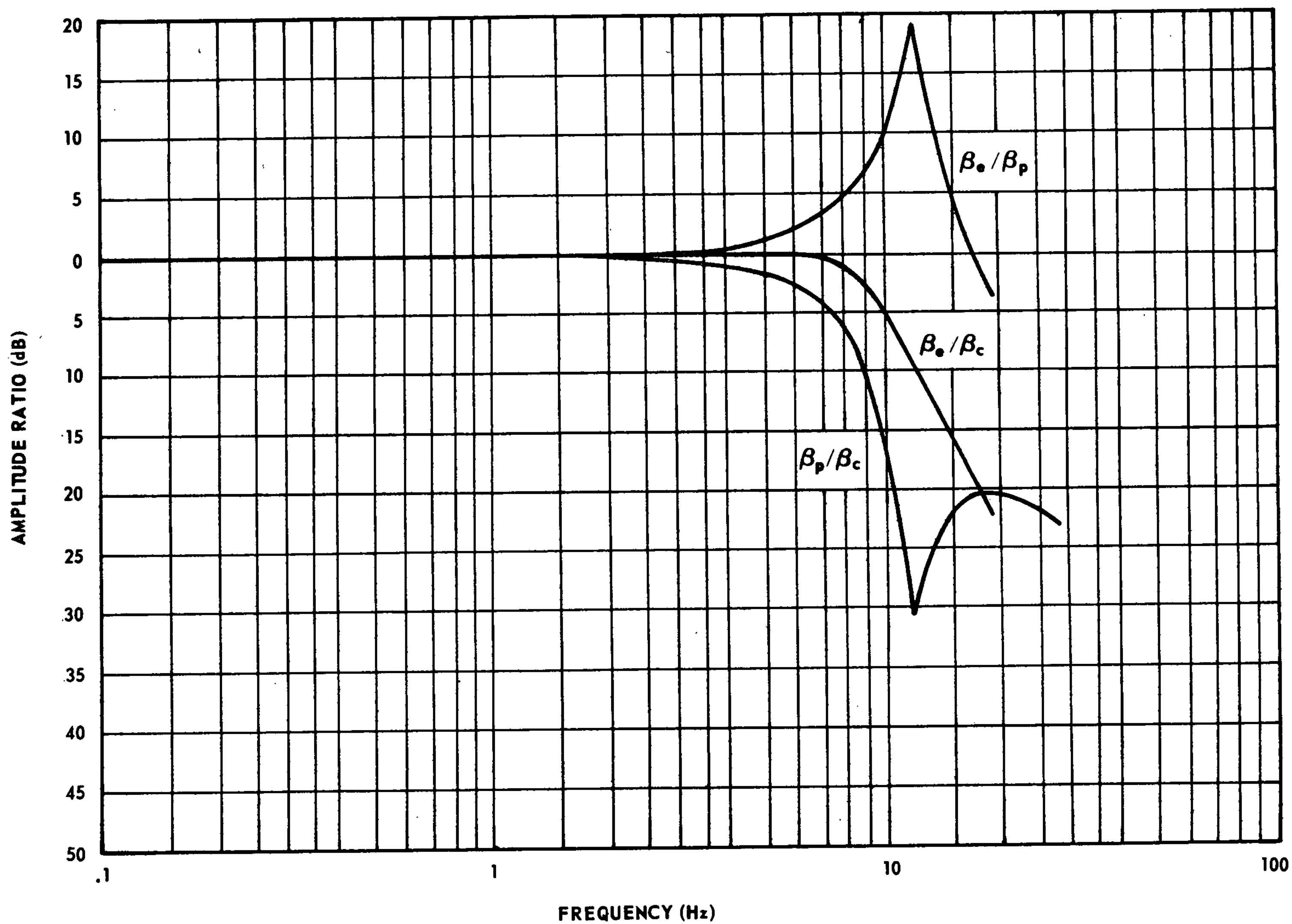

Figure 3. Amplitude curves for transfer functions.

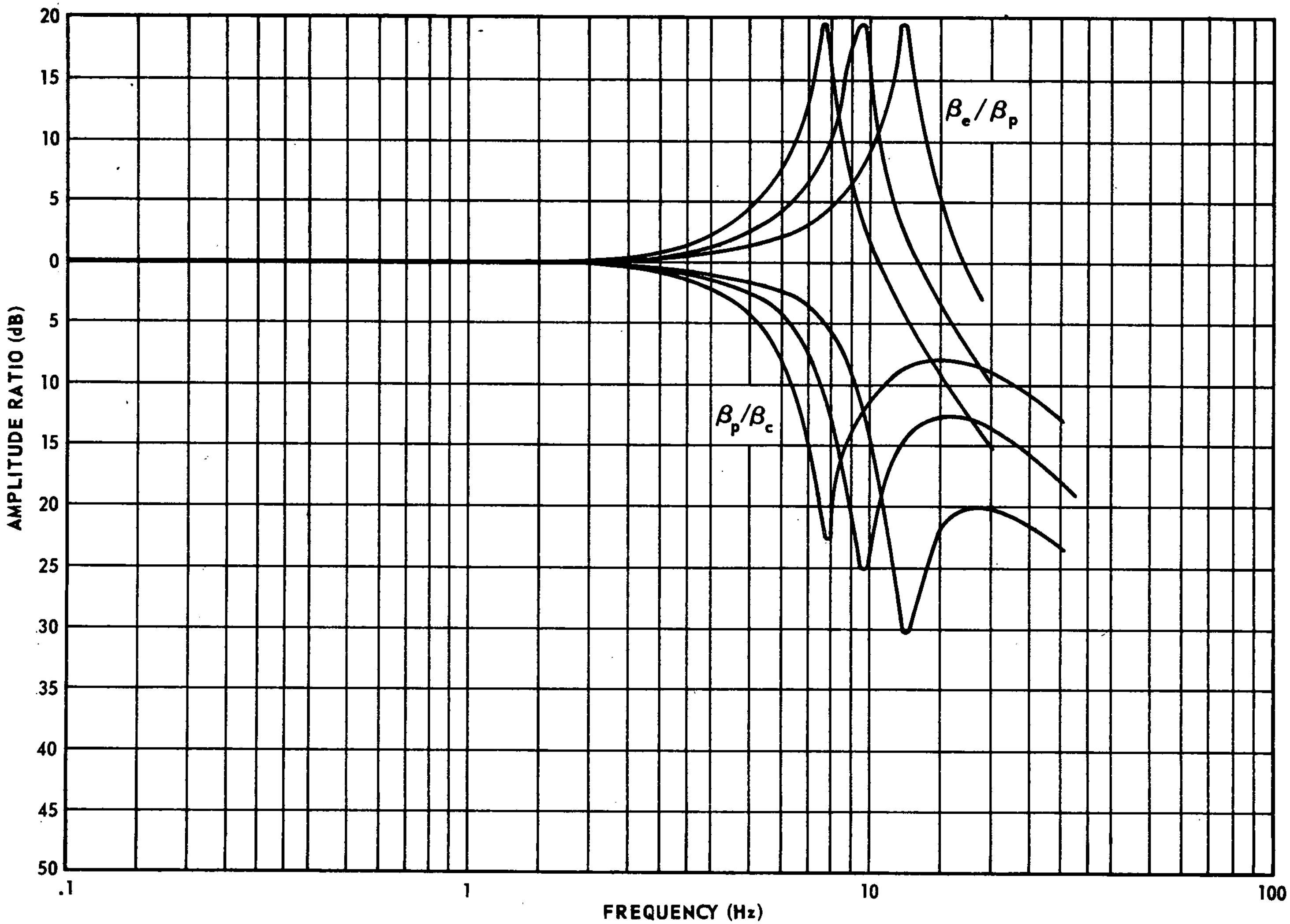

Figure 4. Change in amplitude curves for load changes.

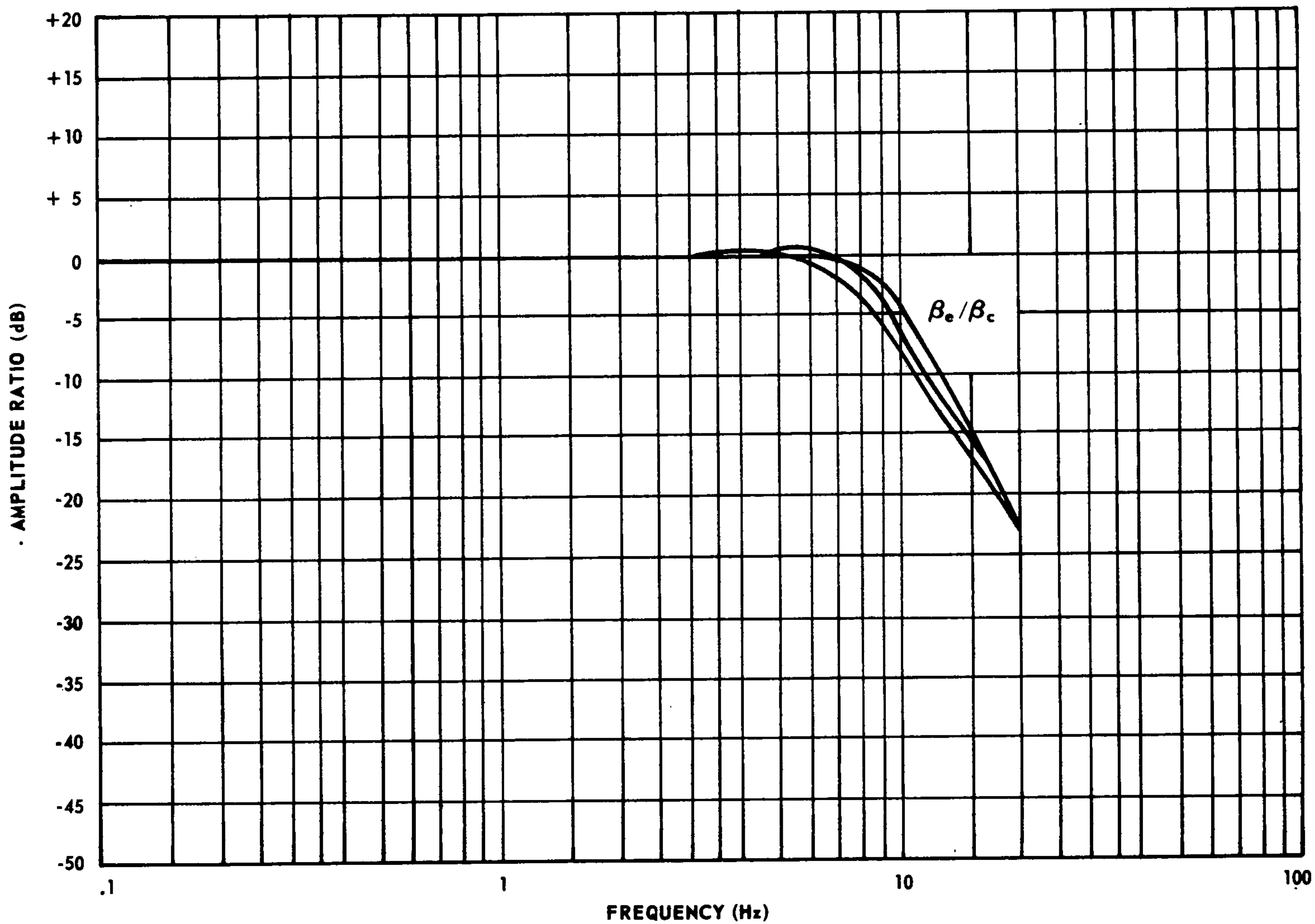

Figure 5. Overall amplitude curves for load changes.

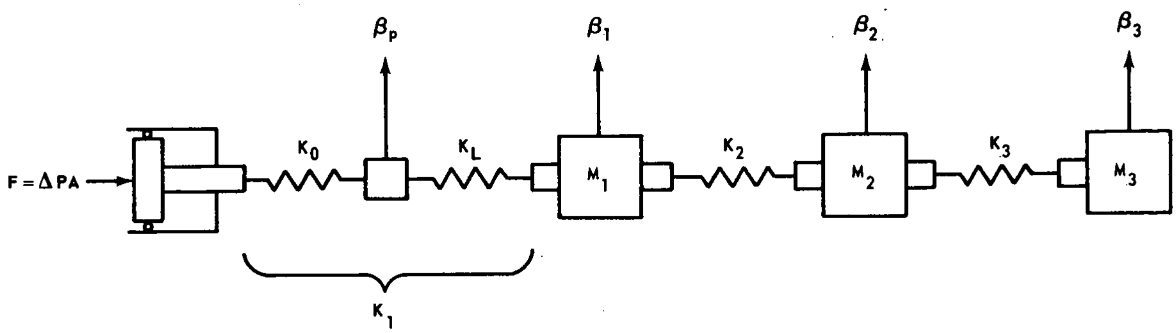

Figure 6. Lumped parameter model.

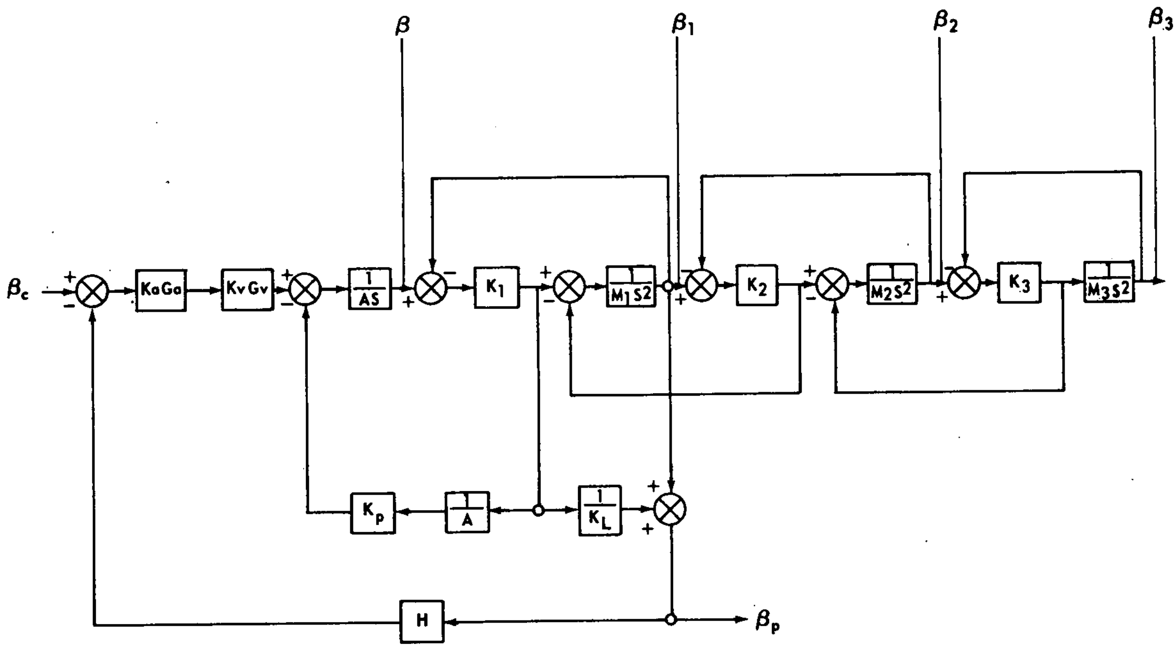

Figure 7. Actuator and load dynamics.

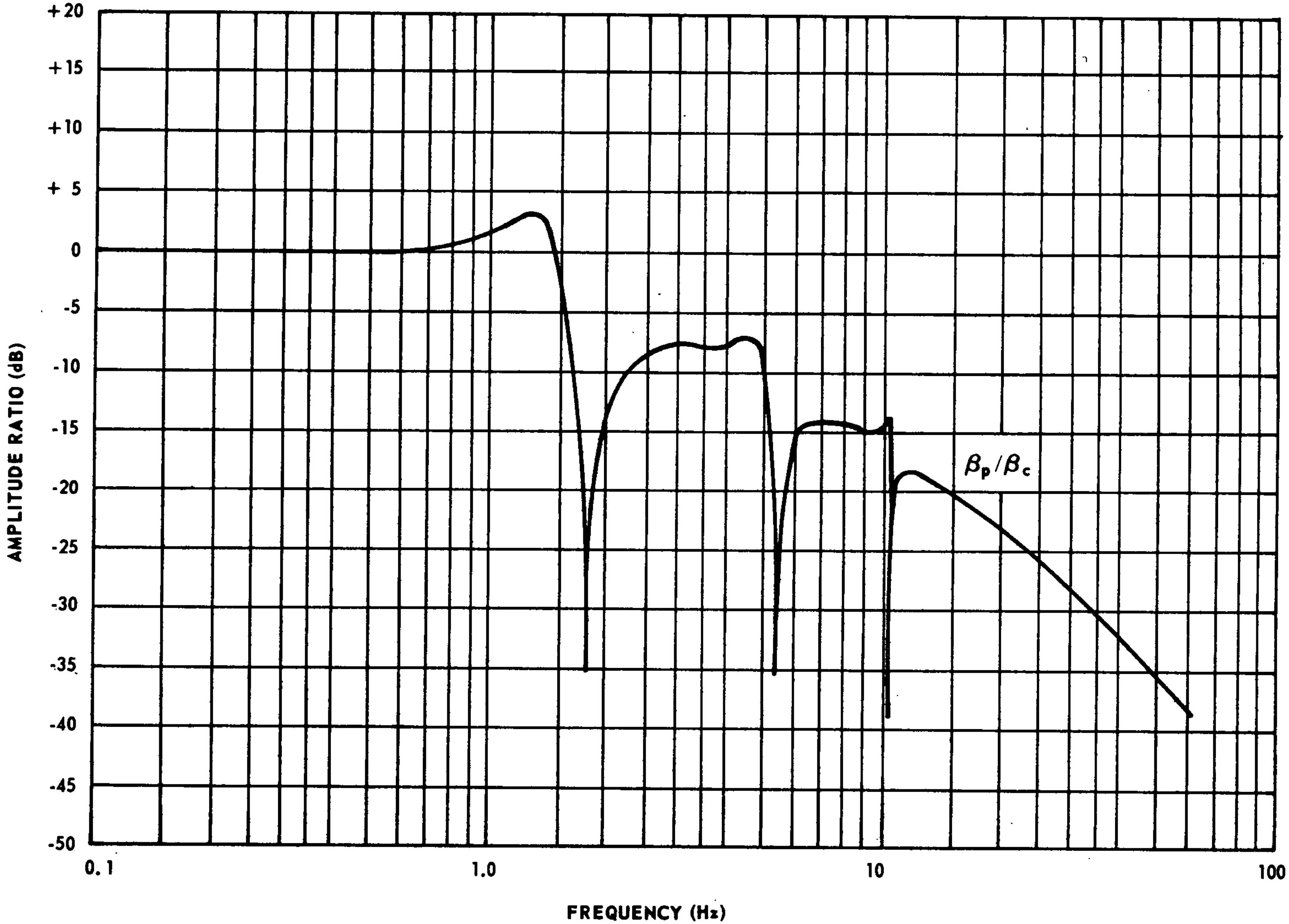

Figure 8. Piston position with respect to piston command with multiple resonant load.