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A PRELIMINARY INVESTIGATION OF THE DYNAMIC FORCE-CALIBRATION OF A MAGNETIC SUSPENSION AND BALANCE SYSTEM

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A Preliminary Investigation of the Dynamic Force-Calibration of a Magnetic Suspension and Balance System

by

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Abstract

The aerodynamic forces and moments acting upon a magnetically suspended wind tunnel model are derived from calibrations of suspension electro-magnet currents against known forces. As an alternative to the conventional calibration method of applying steady forces to the model, this report outlines early experiences with dynamic calibration, that is a calibration obtained by oscillating a model in suspension and deriving a force/current relationship from its inertia force and the unsteady components of currents. Advantages of dynamic calibration are speed and simplicity. The two methods of calibration applied to one force component show good agreement.

1. Introduction

The ten-electromagnet array of the magnetic suspension and balance system (MSBS) is shown on Figure 1 together with the wind direction and the normal position of a model relative to them. The electromagnets suspend the model by supporting its weight and resisting the aerodynamic force. The MSBS may be used as a balance by calibrating electromagnet currents against known steady forces mechanically applied to the model in a separate test. This calibration method is accurate, but slow and inconvenient because usually it must be carried out inside the test section. Calibrations are further extended because they are usually functions of model position and must therefore be carried out over the range of attitudes expected in a wind tunnel test.

One of the inherent advantages which the MSBS has over the conventional mechanical supports for models, the ability to quickly and easily move a model, allows the exploitation of a new method of calibration, that is calibrating its inertia force against an unsteady component of current. In principle the model can be accelerated in any mode of motion while monitoring the accelerations and appropriate currents, perhaps allowing very rapid complete calibration by simultaneously exciting accelerations in six degrees of freedom while gradually moving the model through the required ranges of attitude.

This is a report on a preliminary investigation of the principle. The object of the work was to compare the two methods of calibration applied to just one force component, lift, with the model in one attitude. The model was aligned with the wind axis as shown on Figure 1. The lift force convention is positive upwards, requiring a magnetic downforce in the Z direction indicated on Figure 1.

The conventional static calibration was made by hanging a range of weights from the magnetically suspended model. While only negative lift forces are simulated in this way, calibrations are very linear and can be expected to apply over wide positive and negative ranges of force.

For the corresponding dynamic calibration the model was oscillated sinusoidally in a vertical heaving motion in the Z-direction with the model's axis remaining horizontal. Positive and negative inertia forces are generated, of magnitudes depending on mass, frequency and amplitude of motion. Amplitude of motion must be small if calibration is strongly affected by model position.

2. The Model

This comprised a permanent magnet core 5/8" diameter and 5" long, of Alnico V material. The core as encased in a Lexan shell having the approximate contours of the 7-caliber AN spinner. The maximum diameter of the shell was .875 inches, and the total weight of the model (core plus shell) was 181.81 gm. For these tests it was suspended with its axis horizontal.

3. Static Calibration

Weights (in approximate 10 gram increments) were hung below the centre-of-gravity of the model while it was magnetically suspended, up to a maximum added weight of 131 grams. Therefore during calibration the suspended weight increased by a maximum of about 72%. This force, acting vertically downwards in the direction of arrow Z on Figure 1, is resisted by fields produced by the electro-magnets above and below the model numbered 1-4 on the figure. The vertical magnetic force is produced by electromagnet 1 repelling the forward end of the model with the same force as electromagnet 2 attracts the same end, while 3 and 4 act similarly in unison. Asymmetry in the model, or in its position in the wind direction relative to these electromagnets, would normally be expected to have the effect of producing unequal currents: the currents in 1 and 2 not equalling those in 3 and 4. However in this case the static calibration showed very nearly equal increments in current with applied force for all four electromagnets. The static calibration constant, that is the current change in the electromagnets per unit change of force, was 0.03451 amps/gram.

4. Dynamic Calibration

This calibration is the ratio of the AC component of current (in electromagnets 1-4) to the inertia force of the model. The same currents are being used to actively control the motion of the model and inevitably contain a residue of noise, but the AC component which is exciting the fundamental sinusoidal mode of model motion can be extracted using simple methods once it climbs sufficiently far out of the noise. All parameters, that is current levels and model position, were sampled 400 times per second, digitised and recorded as required. An example of oscillation signals is shown on Figure 2(a) as the average variation of current from its mean value and the vertical (heave) position of the model. Each spot corresponds to a digitised sample. It can be seen that some averaging method should lead to a particularly good value for the amplitude of motion because the waveform is almost pure, and a fairly good value for current amplitude. The current excursion is proportional to the inertia force and therefore to the maximum acceleration of the model, in this case 0.324g. With reduction of acceleration the motion signal remains good but the relative quality of the current signal deteriorates as shown in the example on Figure 2(b), which was taken at the same frequency of oscillation but at about one-quarter of the motion amplitude and peak inertia force. Undoubtedly there are methods which can analyse such waveforms particularly when long time-samples are available, but in this case it is not necessary to cope with them, merely to avoid the circumstances leading to unacceptable distortion, that is low inertia force or acceleration. It was decided to use the larger signals typified by Figure 2(a), and to average the excursions of current and model position over complete cycles, leading in each case to values for the amplitudes. Frequencies were chosen such that 256 samples (an arbitrary number) spanned complete cycles of oscillation. For example at the fixed sampling rate of 400 per second, the averaging of 256 samples of a 6.25 Hz wave covers just 4 cycles.

The question had to be addressed of the minimum peak model acceleration suitable for this simple method of analysis. Tests were carried out over a small range of frequency and wide range of amplitude to determine where the effects of noise began to introduce spurious calibrations. The data is shown on Figure 3 which is a plot of the force calibration normalised with respect to the value obtained at the higher levels of maximum acceleration. Evidently with frequency/amplitude combinations giving low values of maximum model acceleration the noise, which is predominantly on the current signal, indicates a high current/force calibration. Examination of these results suggests that for this MSBS and its associated systems a maximum model acceleration of at least 0.1 g is required during a sinusoidal oscillation for simple averaging of current and model excursions to lead to reliable calibrations.

Dynamic calibration data for one frequency of oscillation of the model is given on Figure 4 as a function of amplitude of oscillation. The dynamic calibration data points are close to the static calibration value, but consistently higher. The group taken at maximum model accelerations above 0.1 g are on the average 1.4% above the static value for the calibration constant.

A similar set of dynamic calibration data is shown on Figure 5 where the principal variable is frequency of oscillation. Amplitude is roughly constant and maximum model accelerations were all above 0.1 g. The average dynamic calibration data is again above the static by about the same amount. No explanation for the difference is yet available.

5. Discussion

Both methods of calibration rely on precision in the measurement of weights and currents, while dynamic calibration also relies on the additional measurement of model position from which inertia force is derived. However it can be argued that precision in the measurement of the latter is already a requirement in wind tunnel testing. The two methods of calibration and the applications of the data depend on measurements of similar physical properties varying through similar ranges and could therefore be expected to not only agree but to be equally precise. In this preliminary investigation they differed by less than 2%. The dynamic method proved to be much quicker, as expected, and also simpler to apply.

Efforts to improve the precision of new calibration methods continue, and to extend application of the method initially to other force and moment components and then to the simultaneous calibration of several components.

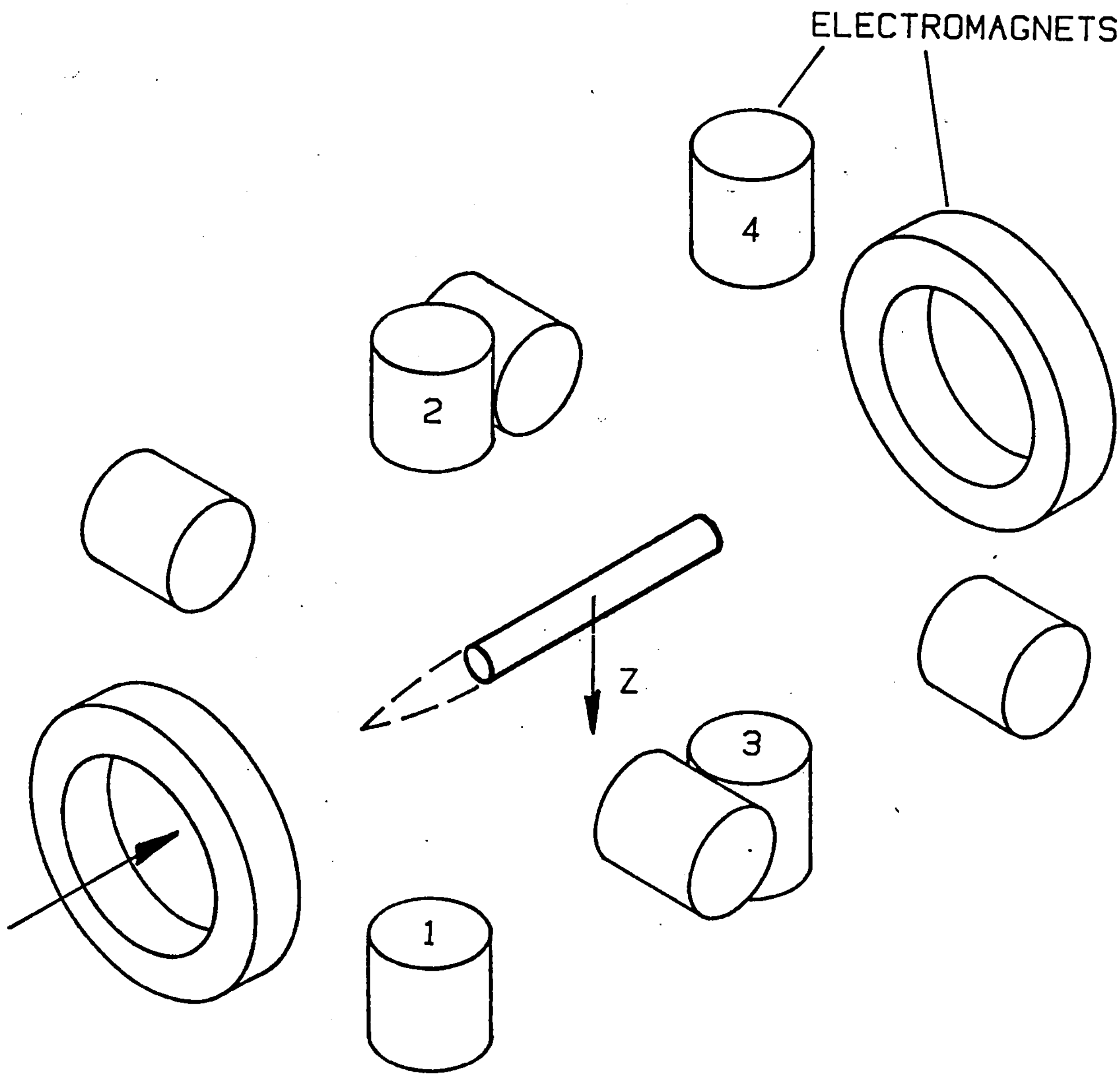

FIGURE 1. SOUTHAMPTON UNIVERSITY MAGNETIC SUSPENSION AND BALANCE SYSTEM FOR WIND TUNNEL MODELS. ELECTROMAGNET CONFIGURATION AND MODEL.

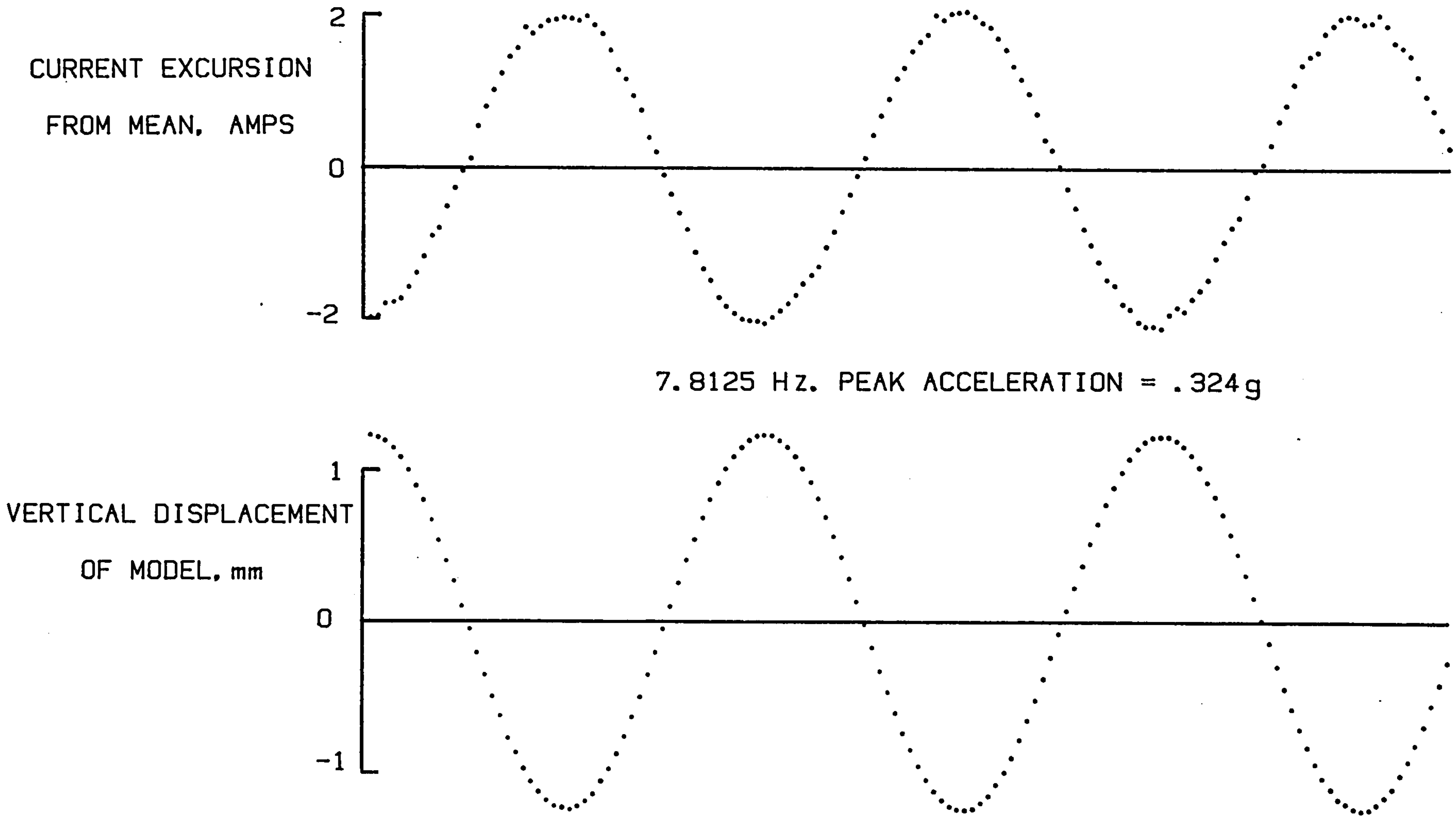

FIGURE 2(a). LIFT CURRENT AND MOTION WAVEFORMS FOR MAGNETICALLY SUSPENDED MODEL OSCILLATED IN VERTICAL HEAVE

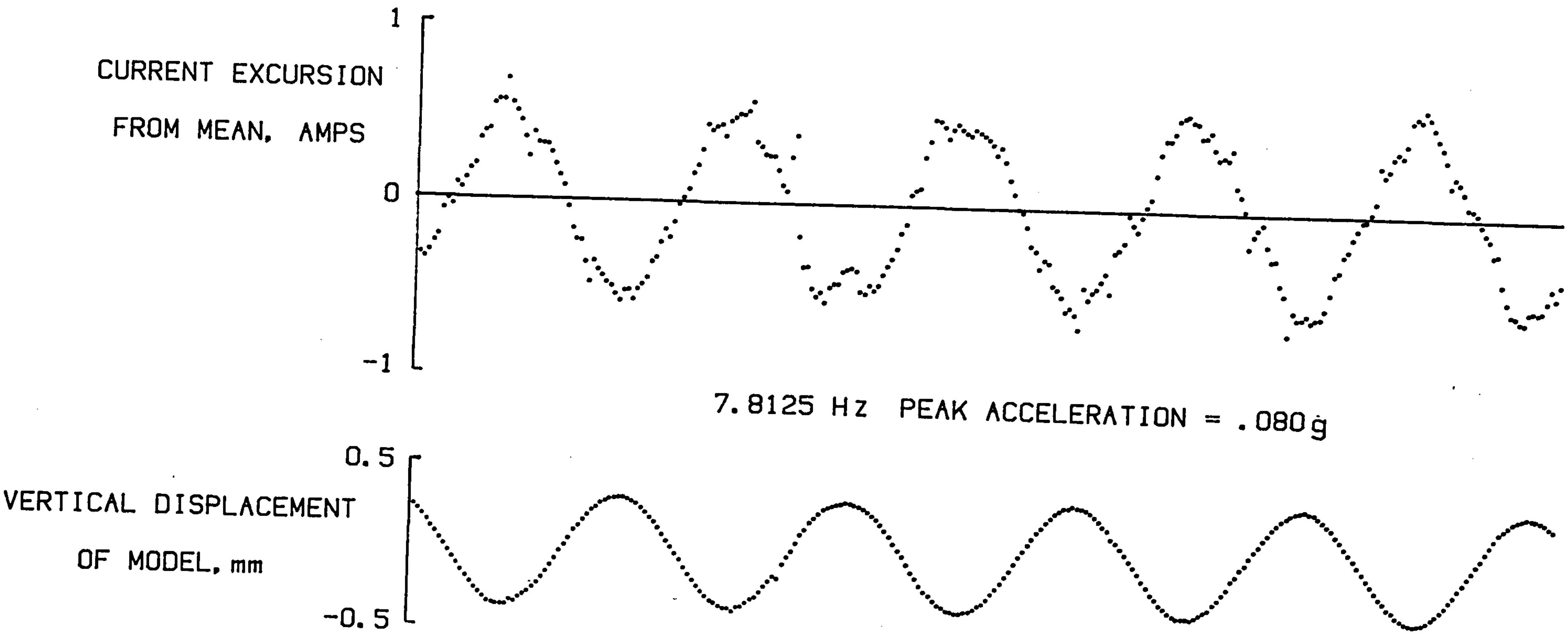

FIGURE 2(b). LIFT CURRENT AND MOTION WAVEFORMS FOR MAGNETICALLY SUSPENDED MODEL OSCILLATED IN VERTICAL HEAVE

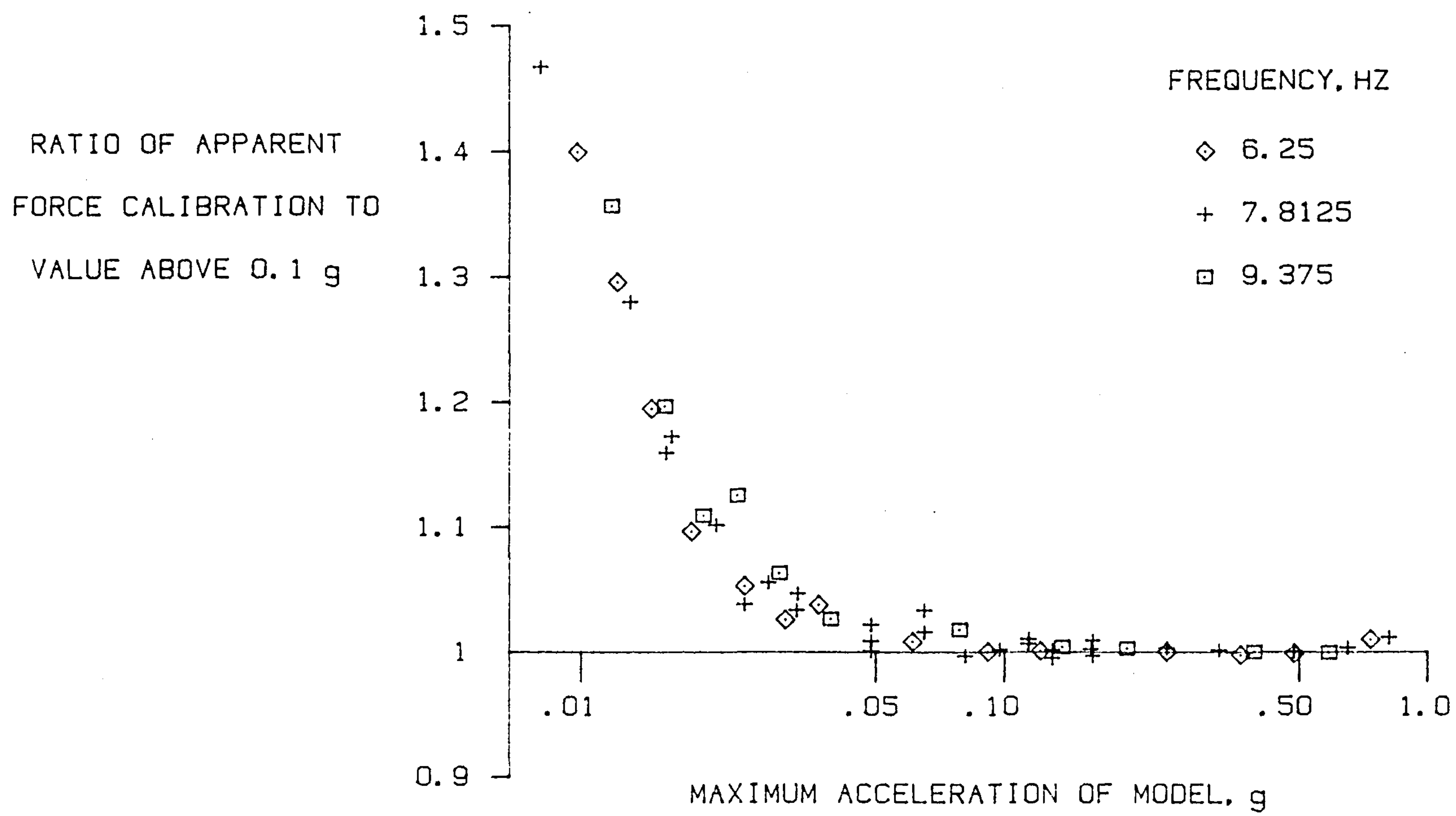

FIGURE 3. DYNAMIC CALIBRATION OF MAGNETICALLY SUSPENDED MODEL:

EFFECT OF MODEL ACCELERATION ON APPARENT CURRENT/FORCE CALIBRATION

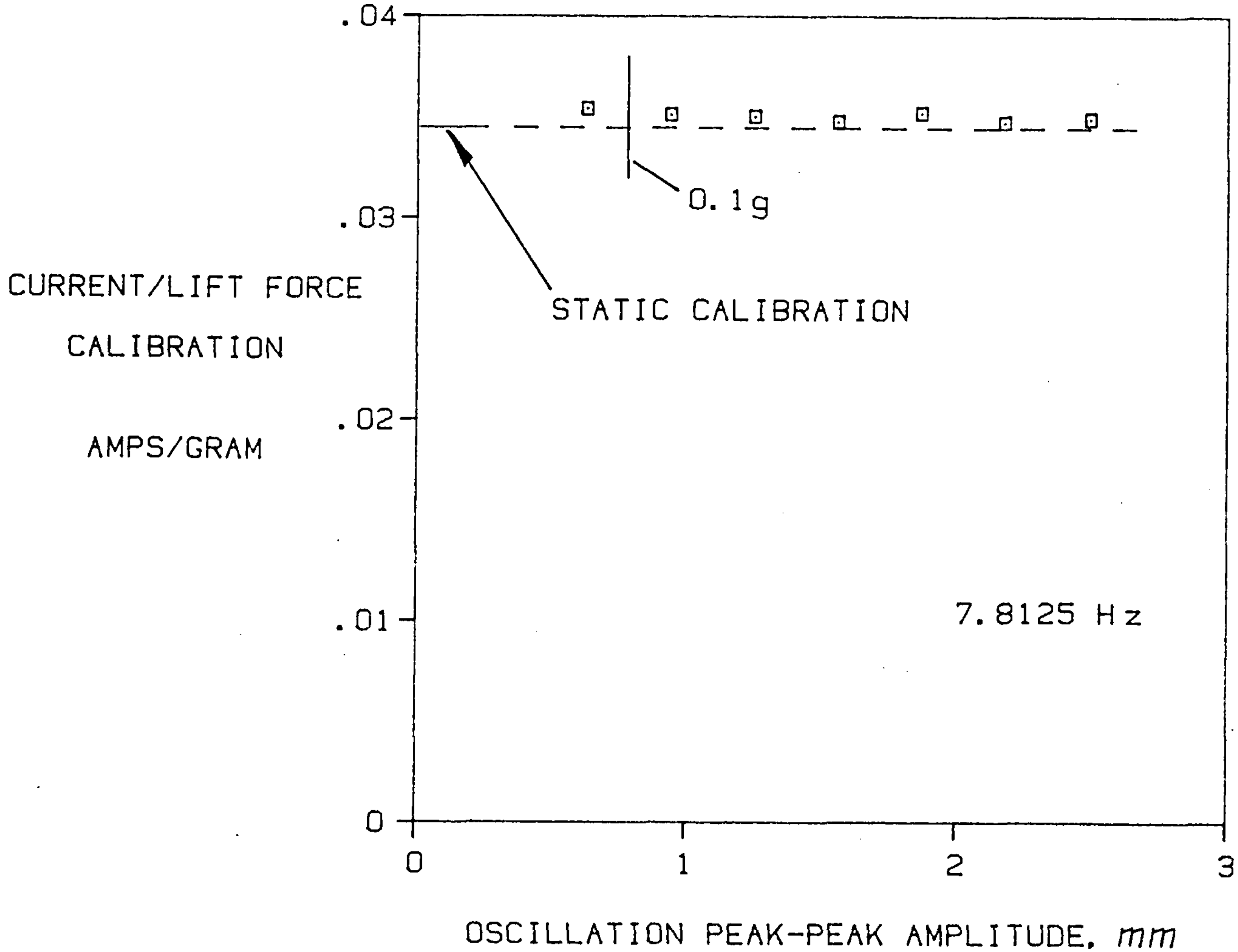

FIGURE 4. DYNAMIC CALIBRATION OF MAGNETICALLY SUSPENDED MODEL OVER BAND OF OSCILLATION AMPLITUDE

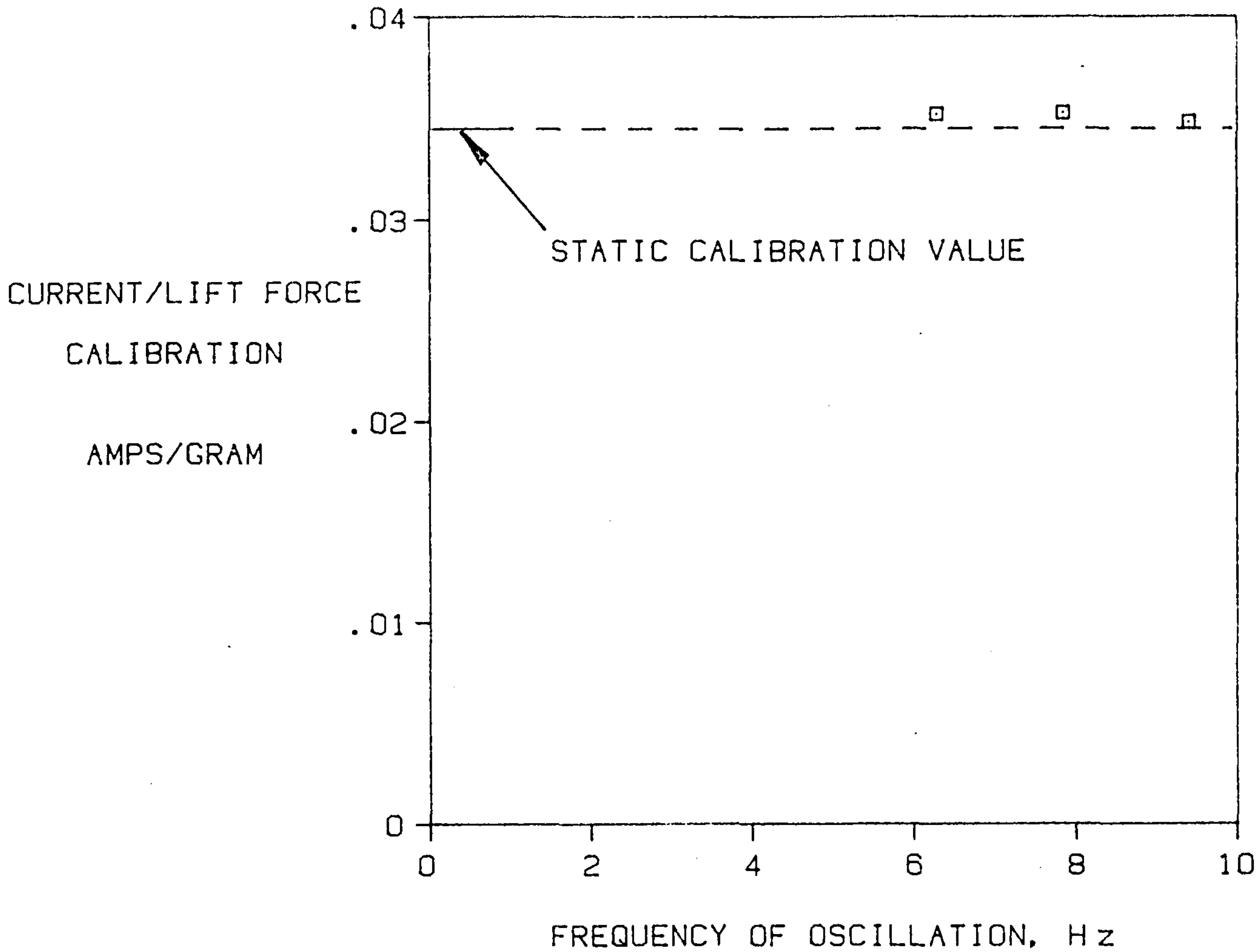

FIGURE 5. DYNAMIC CALIBRATION OF MAGNETICALLY SUSPENDED MODEL OVER BAND OF OSCILLATION FREQUENCY.

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