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The Response of Vibration Mounts Subjected to Biharmonic Vibration

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RESPONSE OF VIBRATION MOUNTS · ADAMS

THE RESPONSE OF VIBRATION MOUNTS SUBJECTED TO BIHARMONIC VIBRATION

By

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INTRODUCTION

ORIGIN OF THE PROBLEM

Existing specifications used in vibration testing are based on envelopes of many points of fixed frequency and vibration amplitude measured at specific points in aircraft. In addition these specifications are to some extent written to be compatible with the two common types of vibration test machines, the reaction or constant-displacement type and the electromagnetic or constant-acceleration type. Thus the "envelope" of the measured vibration amplitudes is drawn in such a manner as to have a constant displacement from 3 to 60 cycles per second, the range of the reaction type of vibration test machine, and a constant acceleration from 60 cycles per second and higher, the range of the electromagnetic type of vibration test machine. The total time of testing required by this type of specification may amount to as long as 3 hours, inasmuch as continuous cycling between the lower and upper frequency limits at a slow rate or vibration at the resonant frequency of the component is specified.

Obviously, missile components designed for flights in the order of minutes will be unnecessarily penalized by tests which are longer than this duration. Increasing the cycling rate does not adequately solve this problem, since adequate time must be provided at each frequency for the resonant amplitude to increase to a maximum in the vibrating system. The ideal test requirements would be to subject the component under consideration to an exact reproduction of the flight vibratory conditions. Considerable work has been done by various missile manufacturers along this line. Specifically, the vibration environment has been recorded on magnetic tape, and then this tape has been used to drive an electromagnetic

vibration exciter. Thus, depending upon the fidelity of the reproduction, the component's performance may be examined under the flight vibratory conditions. These tests have been used as proof tests of component performance only, with very little emphasis on the comparison of the theoretical and measured response of the vibration isolated systems. The design of vibration-isolating or shock-absorbing systems, however, is made primarily on the basis of the performance of the systems when subjected to simple vibration over a wide frequency range. The problem is then to predict the vibration response characteristics of the vibration isolated system when subjected to complex vibration composed of many frequencies.

PURPOSE OF INVESTIGATION

The purpose of this investigation was to confirm the principle of superposition for a linear system when excited by periodic motion composed of two frequencies and to determine if the behavior of two types of commercial vibration mounts when subjected to this same type of excitation was predictable from simple vibration amplification data.

ORGANIZATION OF THE INVESTIGATION

The major phases of this investigation were first the determination of the amplification curves of the linear-spring system and the vibration-mount system when subjected to simple harmonic motion, and second the determination of the response of both the linear-spring system and the vibration-mount system to biharmonic vibration, periodic motion of two harmonic frequencies.

Selection of the method and equipment used for this investigation was made with the primary idea of achieving a system which would be both accurate

and easily operable. Conversion of the vibration amplitudes into voltages to permit accurate, continuous recording was the method selected. The best available instrument for conversion of mechanical vibration into voltages is the accelerometer. The electrical output of an accelerometer is proportional to its acceleration, whereas, amplification curves are generally determined at constant input vibration displacement. Acceleration is the second derivitive of displacement with respect to time.[1] Hence, the voltage proportional to the vibration acceleration was electrically double integrated for displacement throughout the investigation. Since the vibration exciter used was necessarily of the electrodynamic type, which has the characteristic of an essentially constant-acceleration output with varying frequency, a constant amplitude would be difficult to maintain without a displacement signal. Optical measurement of the amplitude is not only extremely tedious but would be of dubious value for the part of the investigation which involved biharmonic vibration.

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[1]Thomson, W. T., Mechanical Vibrations, McGraw-Hill, New York, 1947, p. 5.

PRELIMINARY INVESTIGATION

LITERATURE SURVEY

A search of published technical literature was made, and no previous work of this type was found. The "Industrial Arts Index" for the years 1940 through 1954 was thoroughly searched for published articles describing work of this type. In addition the "Shock and Vibration Bulletins" for the 22 Shock and Vibration Symposiums held under the auspices of the Department of Defense were reviewed without results.

PRESENT WORK ELSEWHERE

Known work elsewhere centers on the development of electromagnetic-vibration systems which will allow the use of a magnetic tape or a "white" noise generator and tuneable filters for an input. These systems have been used mostly for exploratory design approval on electronic components. Various missile contractors have reported the use of such systems in classified publications, but the only published application of such systems seems to be on performance tests of components.

THEORY

Referring to Fig. 1, the equation of motion of this simple system may be written as:

$$m\ddot{y} = -k(y-x) - b(\dot{y}-\dot{x}). \qquad (1)$$

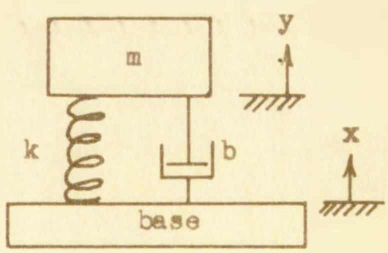

FIGURE 1. SIMPLE SYSTEM

In equation (1) one dot indicates the first derivitive with respect to time, two dots indicates the second derivitive with respect to time and

m = the mass,

b = the damping coefficient,

k = the spring constant,

x = displacement of the base,

y = displacement of the mass.

Assuming the motion of the base to be harmonic and equal to

$$x = X \sin\omega t \tag{2}$$

where X = the maximum displacement,

ω = the circular frequency,

then

$$\dot{x} = X\,\omega \cos\omega t. \tag{3}$$

The equation of motion becomes

$$m\ddot{y} + b\dot{y} + ky = +b\omega X\cos\omega t + kX\sin\omega t \tag{4}$$

which reduces to

$$m\ddot{y} + b\dot{y} + ky = X\sqrt{k^2 + b^2\omega^2}\,\sin(\omega t + \tau) \tag{5}$$

where $\tau = \tan^{-1}\dfrac{b\omega}{k}$.

The solution of this equation is

$$y = \frac{X\sqrt{k^2 + b^2\omega^2}}{\sqrt{(k-m\omega^2)^2 + \omega^2 b^2}}\,\sin(\omega t - \alpha) \tag{6}$$

where

$$\alpha = \tan^{-1}\frac{bm\omega^3}{k^2 - mk\omega^2 + b^2\omega^2}. \tag{7}$$

The maximum value of y without regard to time is

$$y = \frac{X\sqrt{(k^2+b^2\omega^2)}}{\sqrt{(k-m\omega^2)^2 + \omega^2 b^2}} \tag{8}$$

and since

$\omega_n = \sqrt{k/m}$ = natural frequency of undamped vibration,

$r = b/b_c$ = damping factor,

where $b_c = 2m\omega_n$ = critical damping coefficient

then

$$y = \frac{X\sqrt{1+(2r\ \omega/\omega n)^2}}{\sqrt{[1-(\omega/\omega_n)^2]^2 + (2r\ \omega/\omega_n)^2}}. \qquad (9)$$

The amplification of the system is then

$$\frac{y}{x} = \frac{\sqrt{1 + (2r\ \omega/\omega n)^2}}{\sqrt{[1 - (\omega/\omega_n)^2]^2 + (2r\ \omega/\omega_n)^2}}. \qquad (10)$$

The curve for y/x for r = 0.15 is shown in Fig. 2.

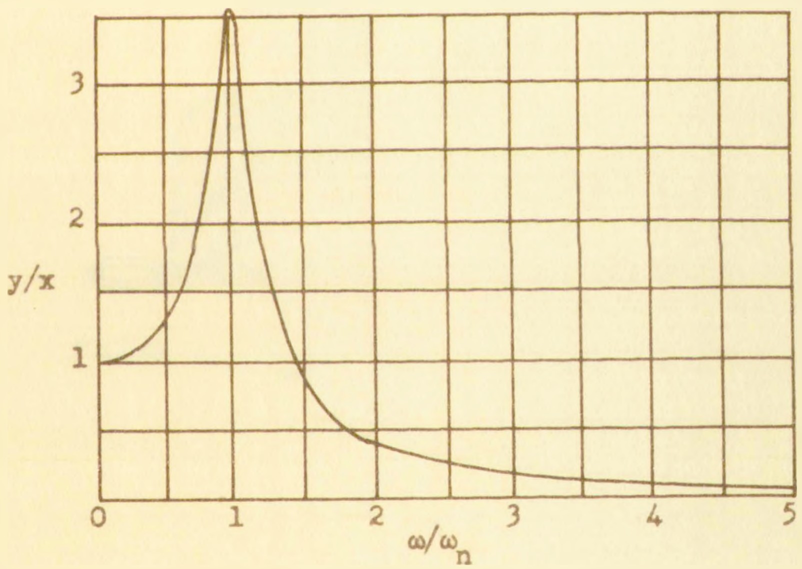

FIGURE 2. AMPLIFICATION CURVE

PRELIMINARY ANALYSIS AND DESIGN

TEST SPECIMEN

The limitations of the vibration exciter dictated that the test specimen weigh less than 10 pounds, and that the natural frequency of the system must be in the range of 40 to 200 cycles per second.

The vibration mounts selected were in the highest load capacity commonly used for electronic apparatus. The particular vibration mounts used in this investigation were Barry type 990-30 and Barry type 780-35G. See Figs. 3 and 4.

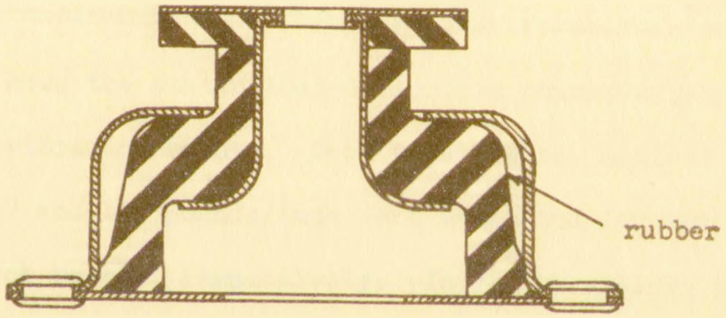

FIGURE 3. BARRY TYPE 990-30 VIBRATION MOUNT

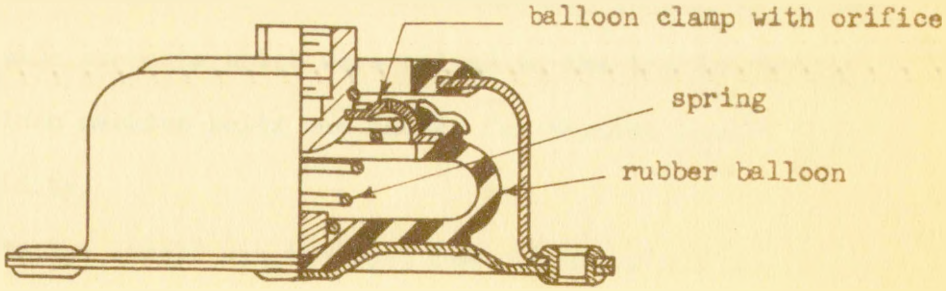

FIGURE 4. BARRY TYPE 780-35G VIBRATION MOUNT

Manufacturer's specifications and pertinent dimensions are listed in table 1.

TABLE 1. VIBRATION-MOUNT DATA

	Barry type 990-30	Barry type 780-35G
Load range, lbs	20-30	22-35
Maximum allowable travel, in.	5/16	1/4
Spring element	rubber	helical conical spring
Damping element	hysterisis of rubber	air flow through orifice

Figure 5 shows the static load-deflection characteristics of the 990-30 and 780-35G vibration mounts. From this figure, nominal static spring constants of 187 and 147 pounds/inch were estimated for the 990-30 and 780-35G vibration mounts, respectively. These two nominal static spring constants were estimated in the region of the neutral point which was the point to which the mounts were deflected when assembled in the framework.

Utilizing these nominal static spring constants, an aluminum test mass of one pound weight was designed. A magnesium framework consisting of a base plate built especially to fit the vibration shaker top, a top plate, and four side supports which were bolted to the top and bottom plates with 1/4 inch machine bolts was chosen for maximum operating convenience and rigidity.

The spring design itself was the most restricted, since the spring constant must be approximately the same as those for the isolators, and

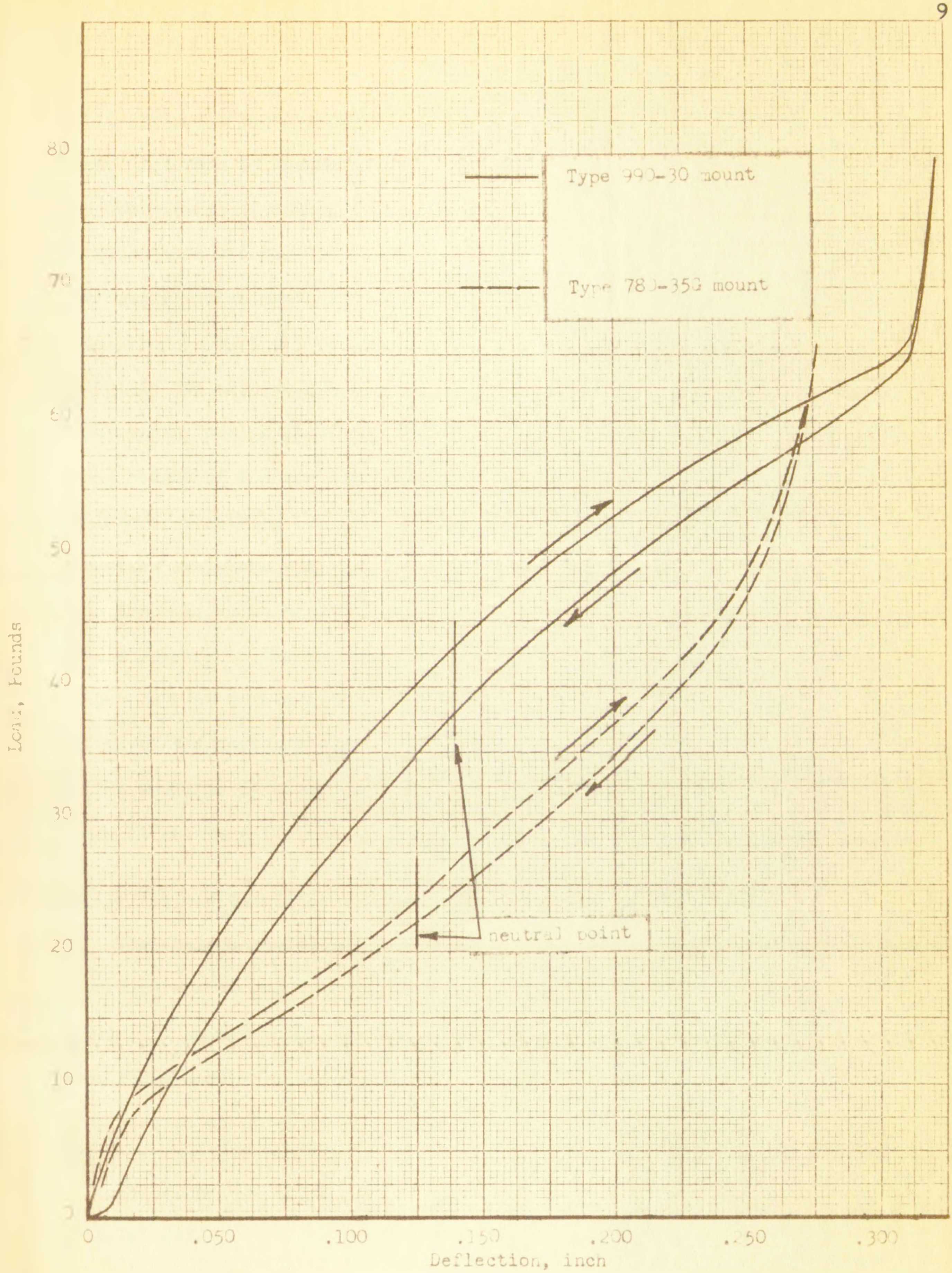

FIGURE 5. STATIC LOAD DEFLECTION CHARACTERISTICS OF VIBRATION MOUNTS

total spring deflection and free height the same as those for the isolators. In order to insure as nearly linear spring as possible throughout the whole range of spring travel, a tension-compression spring with threaded ends was selected. A total spring weight of 0.3 or 0.4 pound per spring was assumed on the basis that about 1/3 of the spring can be considered as part of the mass element[2] and that the ratio of the spring weight to the mass weight should not be more than 1/4. Although the final spring design yielded a sufficiently high spring constant, the total height of the springs were approximately 1/2 inch longer than the isolators; requiring two sets of side supports, one short set for the vibration isolators and one long set for the spring. Although the long side supports could have been used for the isolators by placing appropriate spacers in the system, it was imperative that the overall system height be kept to a minimum in order to reduce any possibility of a rocking motion of the test specimen and vibration-exciter spider. Any rocking motion would be particularly harmful to the 780-35C vibration-mount system since it has very low side stability.

AMPLIFYING, INTEGRATING, AND RECORDING SYSTEM

The obvious choice of components for the amplifying, integrating, and recording system was a readily available system such as the Consolidated linear and integrating amplifiers and recording oscillograph. Since these amplifiers were only single integrating, cascading of two amplifiers was necessary to obtain a double-integrated signal. This system, which employed

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[2]Wahl, A. M., Mechanical Springs, Penton Publishing Co., Cleveland, 1944, p. 233.

conventional RC integrating circuits, proved too insensitive and was discarded.

Other RC integrating systems with various types of amplifiers were tried but also proved too insensitive.[3]

The integrating system which was finally adopted utilizes the capabilities of high-gain DC amplifiers, as adders, inverters, or integrators, depending upon the selection of the input and feedback components used.

A preamplifier stage was placed before the integrating system and a variable gain power amplifier after the integrating system so that galvanometers of a recording oscillograph could be used. Initial tests of this system revealed an excessively high noise level which was reduced by supplying the filaments of all tubes in the amplifying and integrating stages with battery voltage.

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[3]DenHartog, J. P., Mechanical Vibrations, McGraw-Hill, New York, 1947, p. 86.

DESCRIPTION OF INVESTIGATION

APPARATUS

An overall view of the apparatus is shown in Fig. 6.

Vibration Generator

The vibration generator used was the Westinghouse Type HI Vibration Fatigue Equipment. This equipment consists of an audio oscillator, an audio amplifier and a vibration exciter. The vibration exciter consists essentially of a coil placed in a uniform magnetic field. This coil is fastened rigidly to a drive rod which is attached to the mechanical system to be vibrated. When alternating current is passed through the drive coil, an alternating force is applied to the coil and hence to the drive rod. The spring suspension of the drive rod is such that the maximum amplitude of vibration is one-sixteenth of an inch from the position of the coil at rest.

The audio oscillator determines the frequency and amplitude of vibration of the vibration exciter. The biharmonic excitation was obtained by placing two audio oscillators in series.

Test Specimen

The test specimen consists of a rigid framework which supports either two springs or two vibration isolators in series which in turn support a mass containing an accelerometer. See Figs. 7, 8, and 9. An accelerometer-mounting position is provided on the base of this framework, which in turn is bolted to the vibration exciter drive rod.

The accelerometers were Glennite Type A-403 self-generating type. These accelerometers utilize a compressionally sensitive piezo-electric

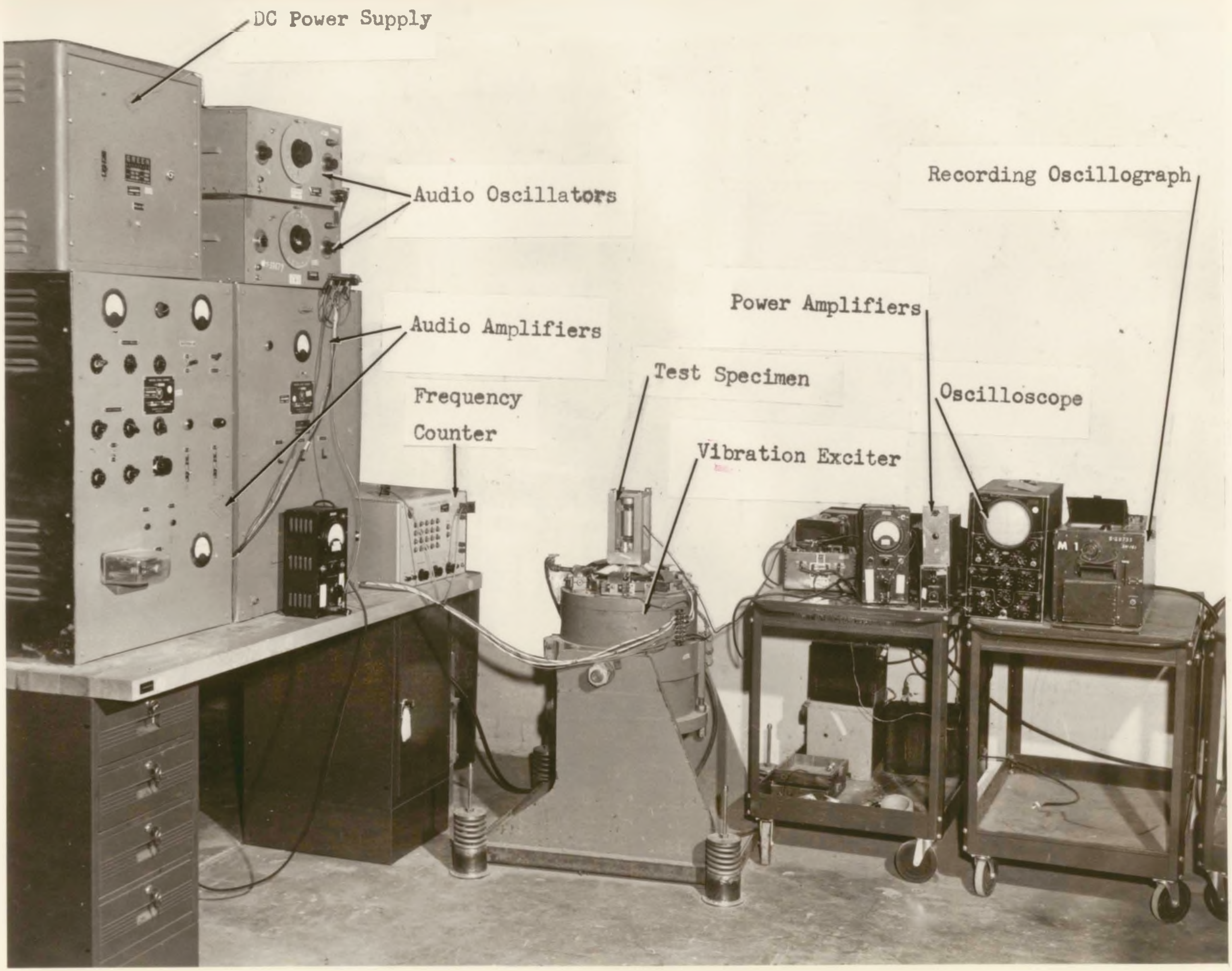

FIGURE 6. GENERAL VIEW OF APPARATUS

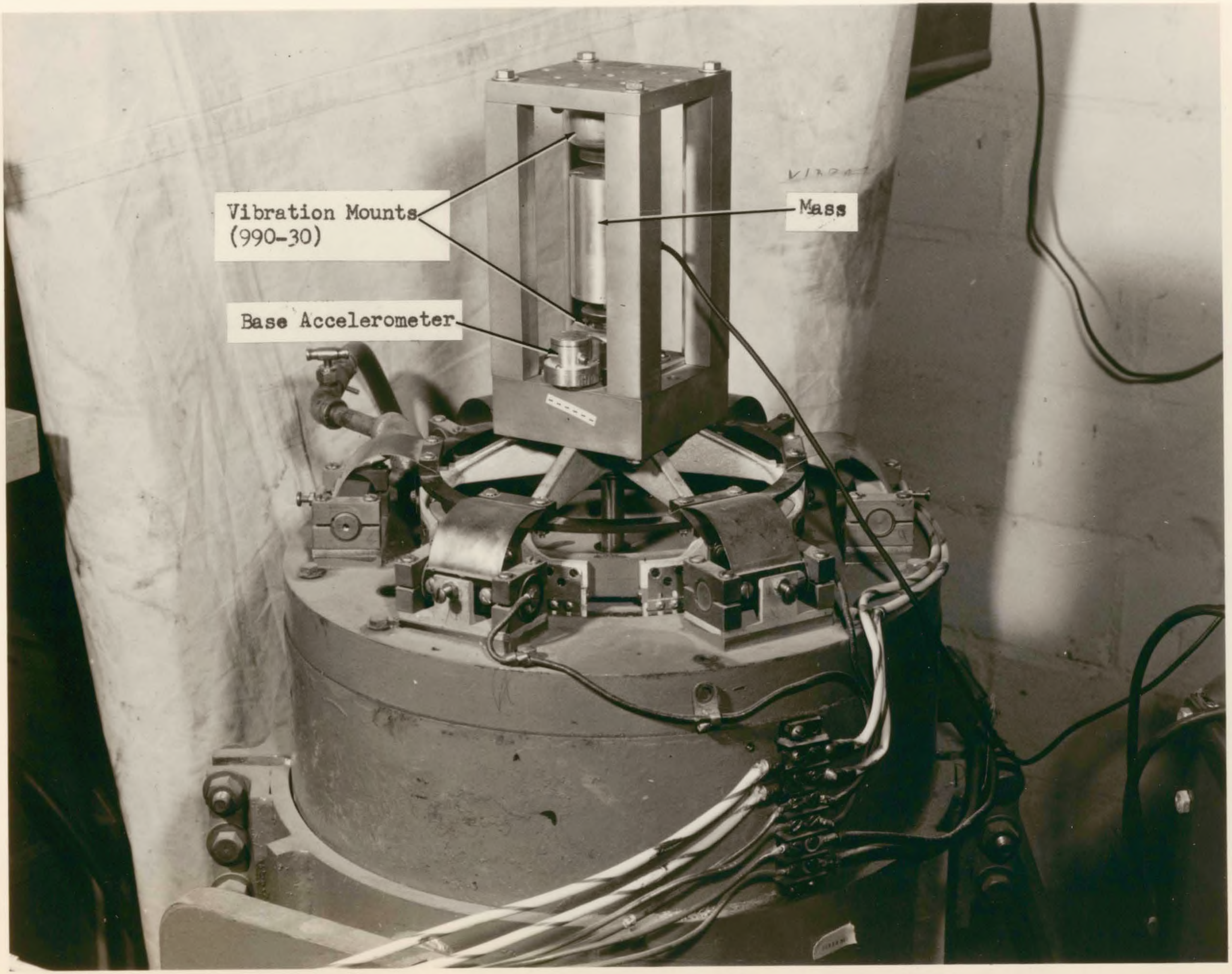

FIGURE 7. TEST SPECIMEN MOUNTED ON VIBRATION EXCITER

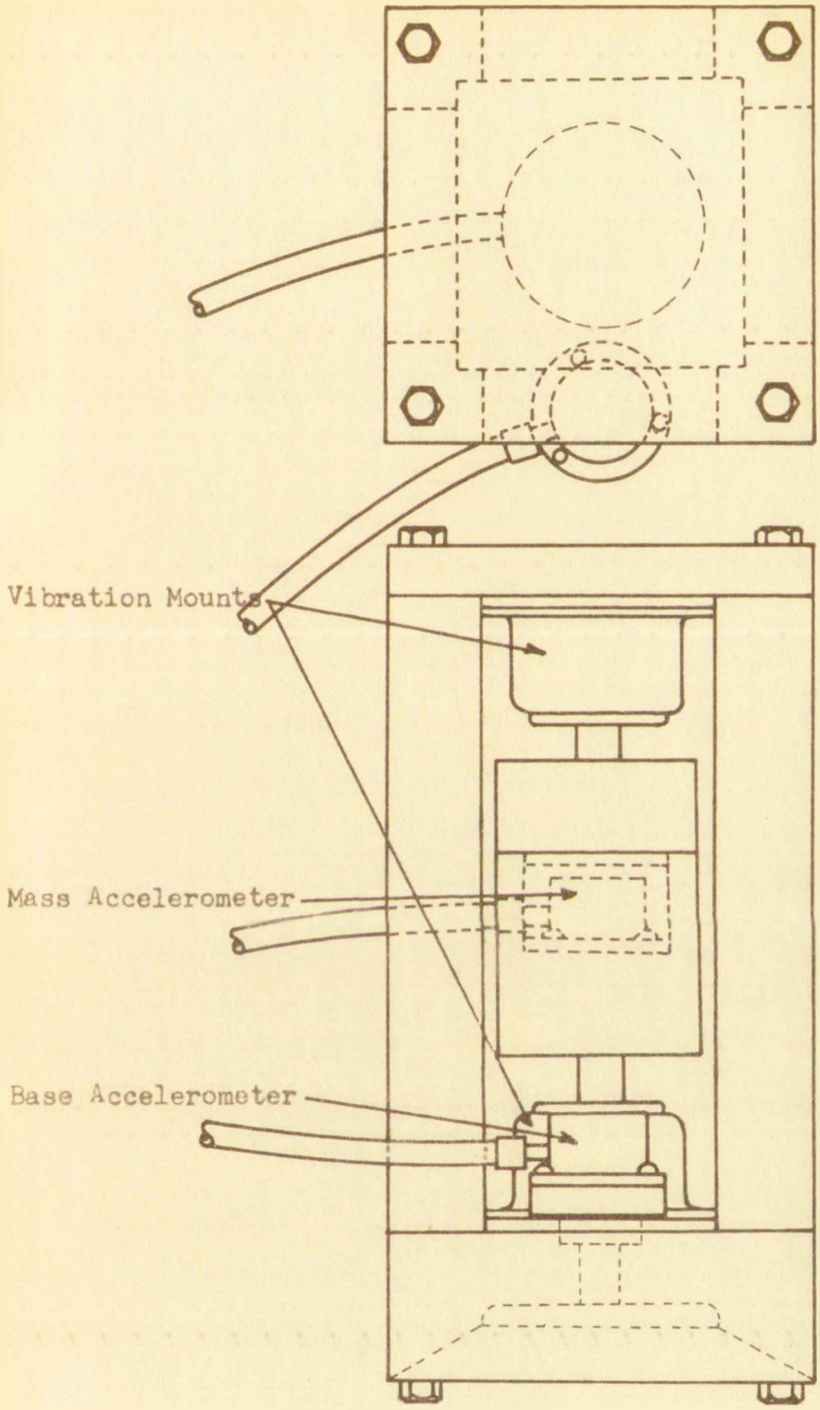

FIGURE 9. TEST SPECIMEN WITH VIBRATION MOUNTS

system wherein a small weight rides freely against two barium titanate sensitive elements. The movement of these piezo-electric elements against the inertia of the weight produces the compression force from which the voltage output is generated.

Amplifying, Integrating, and Recording System

Figure 10 is a block diagram of the amplifying, integrating, and recording system.

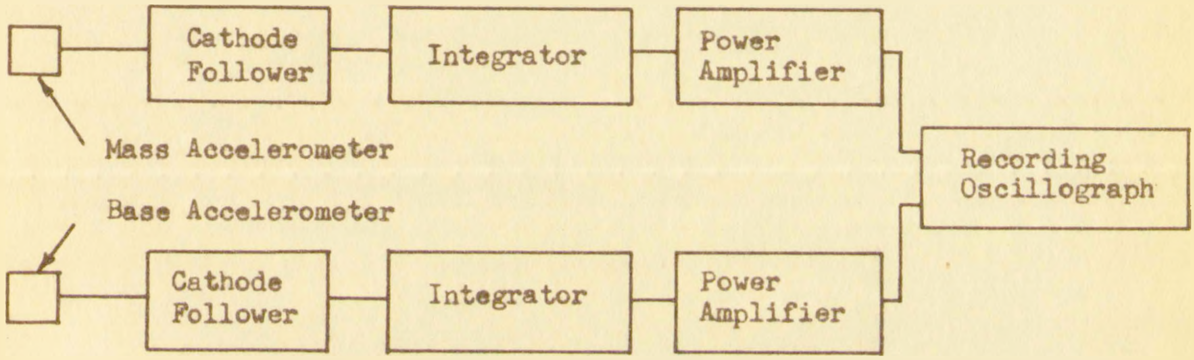

FIGURE 10. BLOCK DIAGRAM OF AMPLIFYING, INTEGRATING, AND RECORDING SYSTEM

A Glennite Model F406 cathode follower provides a suitable impedance matching circuit with unity gain to allow the voltage generated by the high-impedance accelerometers to be fed into the low-impedance double-integrating system without the loss of low-frequency capabilities.

The system utilized for the double integration of the accelerometer signals was an operational analogue of the simple system of Fig. 1. An operational analogue consists of a number of separate elements, each of which simulates a certain mathematical operation.[4] These separate

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[4]McMaster, R. C., Merrill, R. L., and List, B. H., "Analogous Systems in Engineering Design", Product Engineering, January 1953, p. 191.

elements are arranged so that the equations describing the performance of this operational analogue are of the same form as those of the simple system of equation 1.

The elements used in the operational analogue were high-gain DC "operational" amplifiers. These operational amplifiers can be utilized as sign changers, scale changers, integrators, or adders, depending upon the choice of input and feedback components. The basic equation for the output voltage of a high-gain direct-current feed-back amplifier with an odd number of stages shown in Fig. 11 is

$$e_2 = - \frac{Z_f}{Z_i} e_1 . \qquad (11)$$

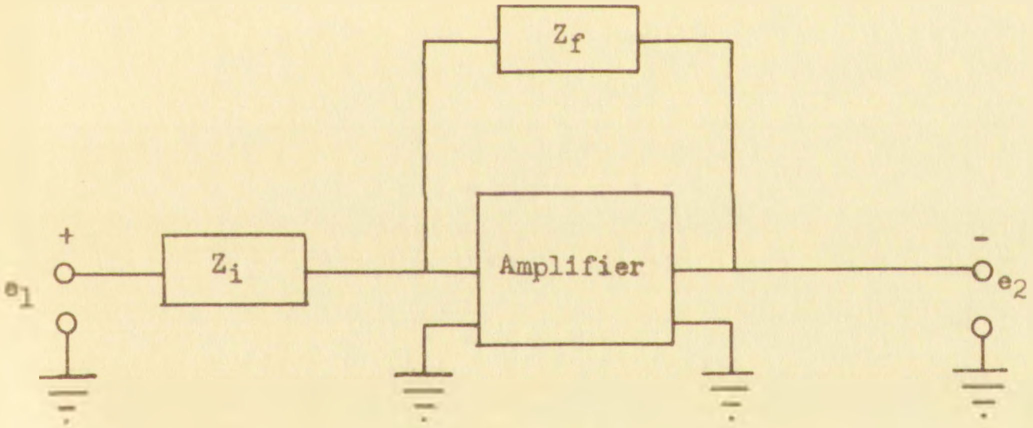

FIGURE 11. BLOCK DIAGRAM OF AMPLIFIER

If the impedences Z_f and Z_i are purely resistive as in Fig. 12 the equation of the output voltage is

$$e_2 = - \frac{R_f}{R_i} e_1 . \qquad (12)$$

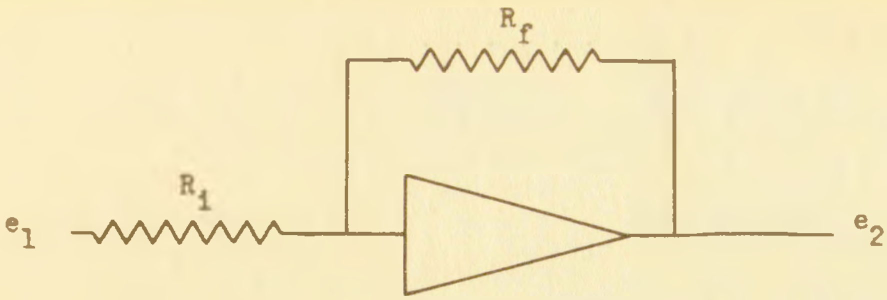

FIGURE 12. SCHEMATIC DIAGRAM OF OPERATIONAL AMPLIFIER

Thus an operational amplifier as shown in Fig. 12 may be used either as a sign changer ($R_i = R_f$) or as a sign and scale changer ($R_i \neq R_f$). If the Z_f is a pure capacitance and Z_i is purely resistive as shown in Fig. 13 the equation of the output voltage is

$$e_2 = - \frac{1}{(R_i C_f)} \int e_1 dt. \qquad (13)$$

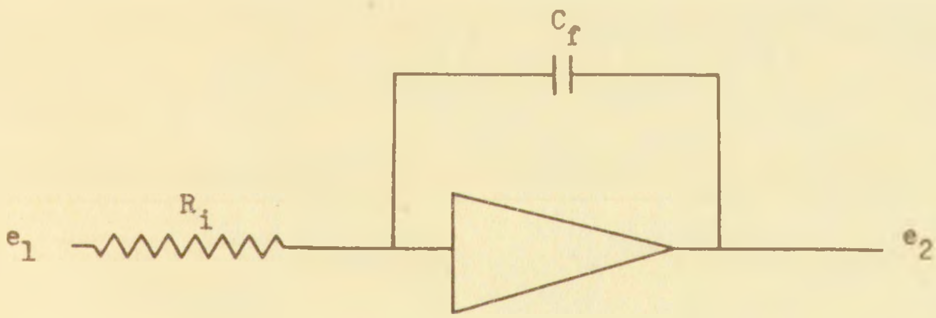

FIGURE 13. SCHEMATIC DIAGRAM OF INTEGRATING OPERATIONAL AMPLIFIER

The final operation of importance to this problem is that of addition. It can be shown that if three inputs are connected to an operational amplifier

through input resistors as in Fig. 14 that the output voltage is

$$e_2 = -\left(\frac{R_f}{R_1} e_1 + \frac{R_f}{R_3} e_3 + \frac{R_f}{R_4} e_4\right). \qquad (14)$$

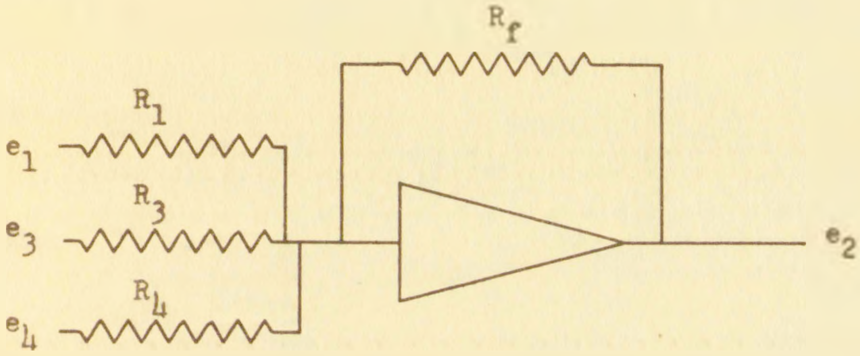

FIGURE 14. SCHEMATIC DIAGRAM OF ADDING OPERATIONAL AMPLIFIER

Referring back to equation (1) and letting

$$z = y - x,$$

$$\dot{z} = \dot{y} - \dot{x},$$

$$\ddot{z} = \ddot{y} - \ddot{x},$$

then

$$m\ddot{z} + b\dot{z} + kz = -m\ddot{x}. \qquad (15)$$

Differentiating equation (3)

$$\ddot{x} = -X\omega^2 \sin\omega t \qquad (16)$$

then

$$m\ddot{z} + b\dot{z} + kz = mX\omega^2 \sin\omega t. \qquad (17)$$

The solution of this equation is

$$z = \frac{m\omega^2 X}{\sqrt{(k-m\omega^2)^2 + \omega^2 b^2}} \sin(\omega t - \phi) \qquad (18)$$

where

$$\phi = \tan^{-1} \frac{b\omega}{k - m\omega^2}$$

and the maximum value of z/x without respect to time is

$$\frac{z}{x} = \frac{(\omega/\omega_n)^2}{\sqrt{[1-(\omega/\omega_n)^2]^2 + (2r\ \omega/\omega_n)^2}}. \qquad (19)$$

It is apparent that if ω/ω_n were large and r small, z/x would approach unity or z would approach x numerically.

Rearranging equation (15)

$$-\ddot{z} = (b/m)\dot{z} + (k/m)z + \ddot{x} \qquad (20)$$

or in electrical terms

$$-e_1 = 1/(R_1C_1) \int e_1 dt + 1/(R_1C_1)\ 1/(R_2C_2) \iint e_1 dt dt + e_4. \qquad (21)$$

The schematic diagram of the operational analogue utilized for double integration of the accelerometer voltage is shown in Fig. 15.

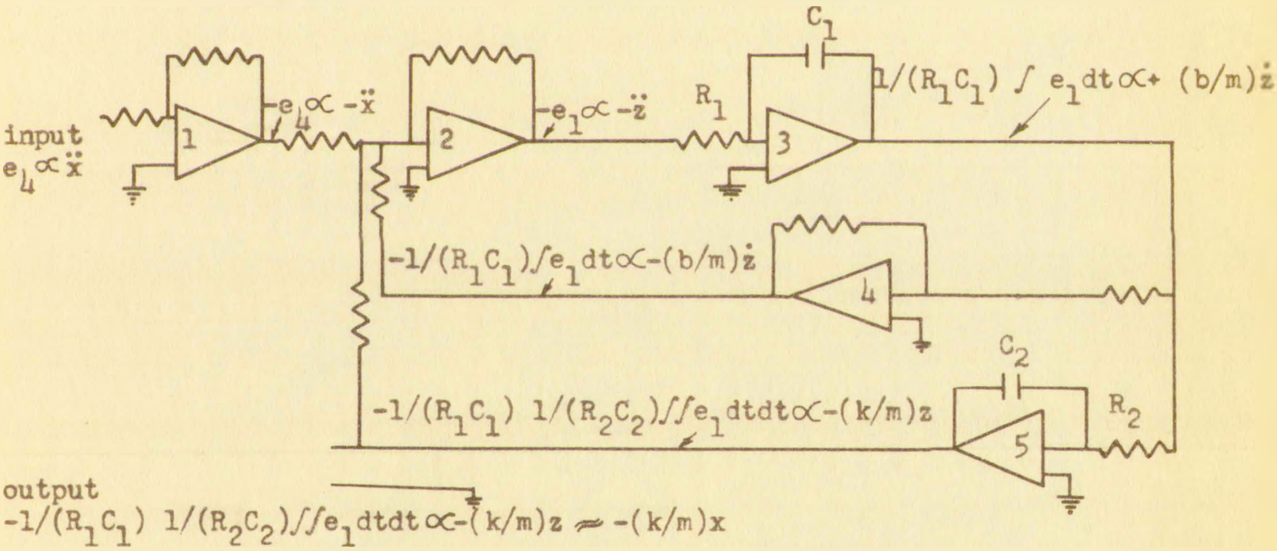

FIGURE 15. SCHEMATIC DIAGRAM OF THE OPERATIONAL ANALOGUE

The operation of this operational analogue can best be explained in the following manner: Assume that a voltage $-e_1$ proportional to $-\ddot{z}$ exists at the output of operational amplifier number 2 as indicated in Fig. 15. Operational amplifier No. 3 integrates voltage as a function of time and changes its sign; hence, the voltage output $1/(R_1C_1) \int e_1 dt$ is proportional

and the maximum value of [illegible] occurs for [illegible]

$$[illegible]$$

It is apparent that if [illegible] were large and [illegible] small, [illegible] would approach [illegible] of a small number [illegible] logarithmically.

Rearranging equation (15)

$$[illegible]$$

in logarithmic terms

$$[illegible]$$

The schematic diagram of the operational [illegible] for [illegible] generation of the [illegible] transfer voltage is shown in Fig. 15.

FIGURE 15. SCHEMATIC DIAGRAM OF THE OPERATIONAL [illegible]

The operation of this operational [illegible] may best be explained by the following sequence. Assume that a voltage [illegible] proportional to [illegible] at the output of operational amplifier number [illegible] Operational amplifier No. [illegible] integrates [illegible] voltage [illegible] phase, [illegible]

to $+(b/m)\dot{z}$. Amplifier No. 4 changes the sign of the voltage so its output is $-1/(R_1C_1) \int e_1 dt$ proportional to $-(b/m)\dot{z}$. Amplifier No. 5 integrates and changes the sign of the output voltage of amplifier No. 3 so its output $-1/(R_1C_1)\ 1/(R_2C_2) \iint e_1 dtdt$ is proportional to $-(k/m)z$. Thus, the inputs to amplifier No. 2 are $-e_4$ proportional to $-\ddot{x}$ from amplifier No. 1, $-1/(R_1C_1) \int e_1 dt$ proportional to $-(b/m)\dot{z}$ from amplifier No. 4, $-1/(R_1C_1)\ 1/(R_2C_2) \iint e_1 dtdt$ proportional to $-(k/m)z$ from amplifier No. 5. Amplifier No. 2, being an adder and sign changer gives an output voltage proportional to $1/(R_1C_1) \int e_1 dt + 1/(R_1C_1)\ 1/(R_2C_2) \iint e_1 dtdt + e_4 = -e_1$. Thus checking our original assumption that a voltage $-e_1$ proportional to $-\ddot{z}$ exists at the output of amplifier No. 2.

Amplifier No. 1 provides a single stage of amplification variable in steps of 50 and 100 for the base accelerometer voltage and in steps of 10, 25, 50, and 100 for the mass accelerometer voltage.

The DC amplifiers were Model K2-W from Geo. A. Philbrick Researches, Inc. modified so that the filaments supply was a battery to decrease the noise level.

The output voltage from the integrators was amplified by two Hathaway MRC-15 AC amplifiers. These current amplifiers were necessary to provide adequate power to drive the galvanometers in the Miller Model H Recording oscillograph used to record the data. The amplifier of the mass accelerometer voltage was modified by installation of an additional input attenuator to provide attenuation steps as follows: 1.5, 2, 3, 5, 7, 10, 15, 20, 30, 50, 70, 100, 150, 200, 300, 500, 700, and 1000.

PROCEDURE

A number of accelerometers were checked until two accelerometers were

found with approximately the same sensitivity. The selected accelerometers were then calibrated over the frequency range from 20 to 200 cycles per second to confirm linearity in the intended operating range and to obtain a conversion factor between the accelerometer output voltage and input acceleration. Calibration was accomplished on a standard calibration setup consisting of an electromagnetic shaker MB Model C11 and power supply. A standardized velocity coil on the armature of the shaker is used to set the acceleration level at each particular frequency. The accelerometer output is then read on a Ballentine electronic voltmeter.

The comparative performance of the two calibrated accelerometers was later checked with the test specimen itself by replacing one of the spring elements or vibration mounts with a solid bolt. This calibration proved that the two accelerometers and associated cathode followers and integrators had equal and linear frequency responses within three per cent for the vibration mount test specimen. The same type calibration of the spring test specimen resulted in a factor of 1.041 for base accelerometer integrator voltages and linear frequency response within three per cent.

Both channels of the integrator itself were checked for proper operation in the final setup by adjusting the integrator input voltage at each frequency until the integrator output voltage was a predetermined constant value. A subsequent plot of integrator input voltage versus frequency confirmed integrator performance within 2,8 per cent over the desired frequency range of 30 to 200 cycles per second. In addition, a function generator was utilized to provide square and triangular input waveforms of varying frequency. Visual observation of the input and output waveforms on a

cathode-ray oscilloscope also confirmed satisfactory performance.[5]

The actual gain of the integrator preamplifier stage from calibration is shown in Table 2.

TABLE 2. CALIBRATED INTEGRATOR PREAMPLIFIER GAIN

Nominal	Calibrated Actual
Mass Integrator Channel	
100	100.000
50	46.233
25	24.667
10	10.000
1	1.000
Base Integrator Channel	
100	100.00
50	50.00

The additional attenuator in the mass accelerometer voltage power amplifier was calibrated and all steps were found to be exactly as rated except the lower four attenuation steps, which had the calibrated values listed in Table 3.

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[5]Thomson, W. T., Mechanical Vibrations, McGraw-Hill, New York, 1947 p. 98.

TABLE 3. CALIBRATED ATTENUATOR VALUES FOR MASS POWER AMPLIFIER

Rated	Calibrated
1.5	1.858
2	2.194
3	3.116
5	5.168

Simple Vibration Tests

The audio-oscillator voltage was adjusted so that the base amplitude as indicated by the output of the base accelerometer voltage integrator as indicated on the voltmeter was the desired value for a particular test. The frequency setting of the audio oscillator was adjusted to such a point that the output of the mass accelerometer voltage integrator was equal to the output of the base accelerometer voltage integrator as indicated by equal voltmeter readings. The attenuators on the AC amplifiers were set at their lowest value and the gain control of the amplifiers adjusted until the galvanometer deflections appeared equal. A recording was made. This record provided the amplifier gain ratio for a particular test, since the amplifier gain controls were not changed from this setting. The voltmeter and counter readings were recorded.

At each frequency after the audio oscillator had been set for the desired frequency and base accelerometer voltage integrator output, the attenuator on the mass AC amplifier was adjusted to produce a galvanometer deflection of approximately one inch. All voltmeter and frequency counter readings and attenuator settings were recorded, and an oscillograph recording

was made.

The change from one frequency to the next was made while holding the base accelerometer voltage integrator output as constant as possible.

Biharmonic Vibration Tests

The biharmonic vibration tests were conducted essentially the same as the simple vibration tests, so that the only procedure peculiar to them will be detailed in this section.

Since with the series arrangement of the audio oscillators there was no point at which the voltage of the individual frequencies could be measured, a special procedure was necessary. Each audio oscillator was set on the desired frequency. The first oscillator output was turned up until the base-analogue voltage was the desired value. The second oscillator output was then shorted, and the voltage output of the first audio oscillator was read. This procedure was repeated in order to set the output level of the second oscillator. With these two voltage readings, the two oscillators can be set with the other one shorted. Then with all shorts removed, the combined audio oscillator output is used to drive the vibration generator. Since there is no phase control between the two frequencies, a very slight change in frequency will produce a slowly shifting phase angle. The continuous recording will then contain a full range of phase-angle variation.

RECORD ANALYSIS AND CALCULATION

Simple Vibration Tests

Peak-to-peak measurements were made on 5 or 10 successive peaks to obtain an accurate average of the oscillogram trace amplitude. The amplification was then calculated as follows:

$$\frac{y}{x} = \frac{Tm}{Tb} \frac{Am}{Ams} \frac{Abs}{Ab} GcCs \qquad (22)$$

where Tm = oscillogram trace amplitude for mass,

Tb = oscillogram trace amplitude for base,

Am = power amplifier attenuator setting for mass,

Ams = power amplifier standard attenuator setting for mass,

Ab = power amplifier attenuator setting for base,

Abs = power amplifier standard attenuator setting for base,

Gc = power amplifier gain correction factor,

Cs = spring system calibration factor.

Record No. 252 made with the spring system was taken with the base and mass integrator voltages equal; hence, the ratio of base oscillogram trace amplitude to mass oscillogram trace amplitude will provide a correction factor applicable to the mass oscillogram trace amplitude measurements of records No. 253 through 263.

$$\text{Power amplifier gain correction factor} = \frac{763.1}{799.6} = .9543$$

for run No. 253 then

$$\frac{y}{x} = \frac{(1132.2)}{(968.2)} \frac{(3)}{(3)} \frac{(1)}{(1)} (.9543) (1.041) = 1.46.$$

Biharmonic Vibration Tests

Initial runs at the biharmonic excitation composed of 50 cps and 100 cps harmonics were made without an adequate system for control of the relative amplitude of the two frequencies. Determination of the relative amplitudes was made from the record of the base integrator output as follows:

Comparison of the records with various synthesized 50 cps 100 cps composite curves indicated that two suitable curves to analyze were the ones that corresponded to the equations

$$X = A\sin \omega t + B \sin 2 (\omega t + 45^{\circ}) \quad (23)$$

and

$$X = A\sin \omega t + B \sin 2\omega t. \quad (24)$$

This synthesized curve and the individual components in the proper phase relationship are shown in Fig. 16.

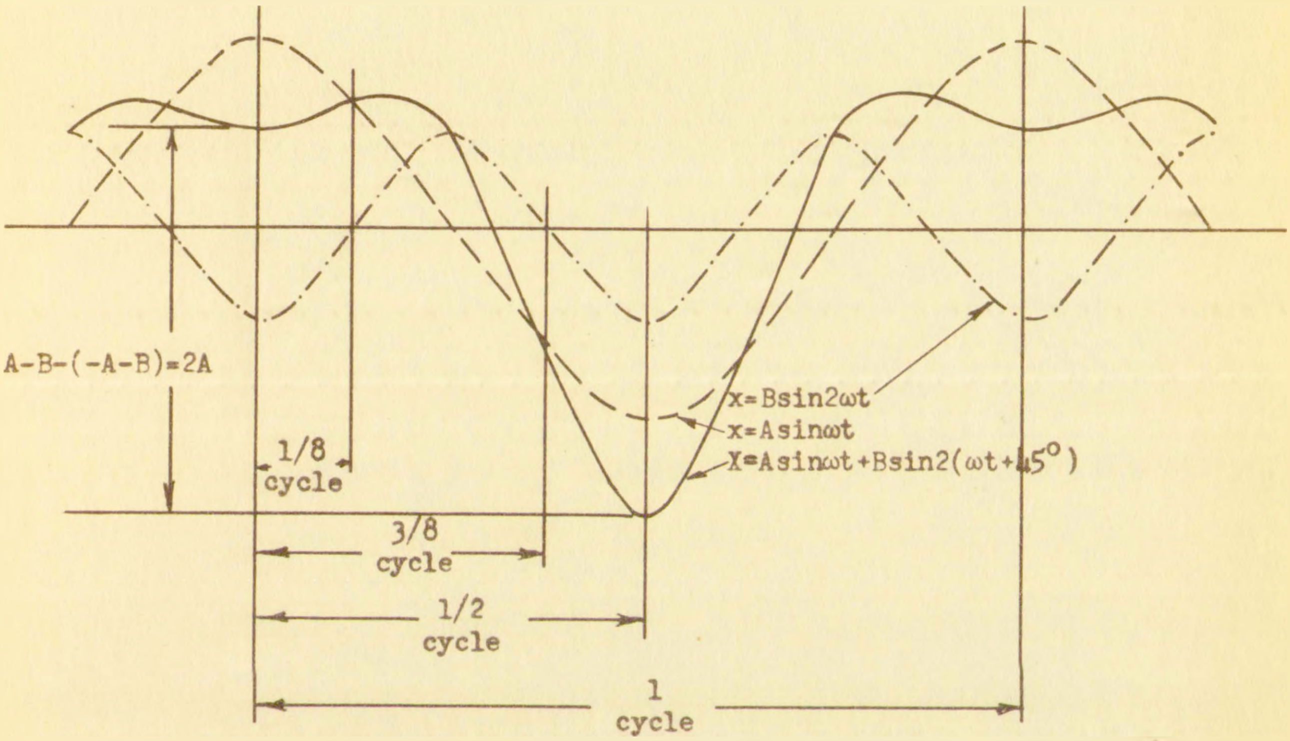

FIGURE 16. 50 CPS 100 CPS COMPOSITE CURVE AND INDIVIDUAL HARMONICS

Examination shows that the distance "2A" can be measured directly, then by laying off .70711A at the 1/8 and 3/8 cycle point the zero axis can be located. Measurement of the "A + B" peak at the 1/2 cycle point then allows calculation of "B".

Once "A" and "B" of the base integrator trace have been determined and multiplied by the appropriate amplifications (1.87 @ 50 cps and 1.20 @ 100 cps) the predicted equation of the mass integrator output trace can be written as:

$$Y = 1.87\ A\ \sin\omega t + 1.20\ B\ \sin 2\ (\omega t + 45^{\circ}). \qquad (25)$$

Examination of the simple vibration records show that negligible phase shift occurs up to 68 cps on the spring system with 180° phase shift above 80 cps. Equation (24) is then solved for the maximum plus and maximum minus values which, when added without regard to sign, gives the predicted double amplitude. The predicted amplification is then the ratio of the predicted mass double amplitude to the measured base double amplitude. Similarly, the measured amplification factor is the ratio of the measured mass double amplitude to the measured base double amplitude.

The second synthesized curve and its individual component in the proper phase relationship are shown in Figure 17.

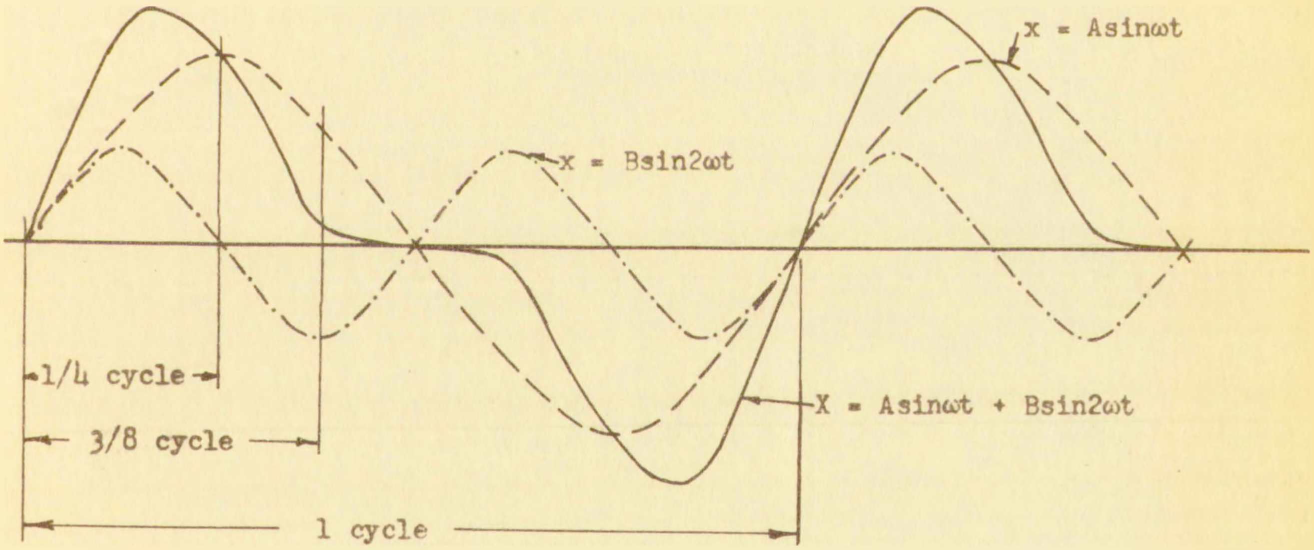

FIGURE 17. 50 CPS 100 CPS COMPOSITE CURVE AND INDIVIDUAL HARMONICS

Determination of the "A" and "B" values from the composite curve was made in the following manner. First, the zero axis was drawn at the point midway between the maximum positive and maximum negative peaks. The zero axis also passes through the inflection points. The trace height at the

1/4 cycle point equals A. The trace height at the 3/8 cycle point equals .70711 A - B; thus, both A and B can be determined.

As in the first example of this frequency combination, the predicted equation of the mass integrator output trace can be written as:

$$Y = 1.87A\sin\omega t + 1.20B\sin 2\omega t. \qquad (26)$$

A similar procedure was used for the record analysis of the 50-cps/150-cps combination for which the equation of the base-analogue trace was determined from the trace itself.

The remainder of the biharmonic vibration records, which involved two frequencies which were 14 cycles per second or less apart were simply measured for peak double amplitudes.

(17) again equals A. The [illegible] variation of [illegible] (17) [illegible] [illegible] [illegible] = [illegible] then, both A and [illegible] can be determined.

As in the first example of this frequency [illegible], the predicted equation of the mean integrative output [illegible] can be written as:

Y = 1.0978[illegible] + 1.[illegible] [illegible]

A similar procedure was used for the [illegible] analysis of [illegible] [illegible] simulation for which the equation of the [illegible] was determined from the [illegible] itself.

The remainder of the homeostatic [illegible] results, which [illegible] the frequencies which were [illegible] per minute in [illegible] computed for each [illegible] oscillation.

RESULTS

SUMMARY

During biharmonic vibration excitation the linear spring mass system behaved according to predictions made from the simple vibration performance of the system shown in Figure 18. Appendix A contains the run data and amplification tables. Table 4 is a resume of the data obtained from the biharmonic vibration excitation of the linear spring mass system. Appendix C contains sample oscillograph records of the biharmonic vibration excitation of the linear spring mass system.

TABLE 4. BIHARMONIC VIBRATION EXCITATION OF THE LINEAR SPRING SYSTEM

Frequency	Cycles/sec.	Frequency ratio		Harmonic amplification		Individual contribution, percent		Phase angle, degrees	Base double amplitude, in.	Biharmonic amplification	
f_1	f_2	f_1/f_n	f_2/f_n	@f_1	@f_2	f_1	f_2			Predicted	Measured
50	60	.685	.825	1.87	2.91	50	50	30	.0047	2.39	2.37
									.0089	2.39	2.50
									.0209	2.39	2.47
68	78	.932	1.07	7.30	7.60	50	50	—	.0201	7.44	7.31
50	100	.685	1.38	1.87	1.20	68.3	31.7	0	.0132	1.67	1.69
								45	.0113	1.67	1.68
50	150	.685	2.05	1.87	.36	76.6	23.4	0	.0162	2.15	2.13
						45.4	54.6		.0084	1.49	1.49

Both of the vibration-isolator systems which exhibited nonlinear characteristics during the harmonic vibration as shown in Figures 19 and 20 proved to have unpredictable amplifications during biharmonic vibration

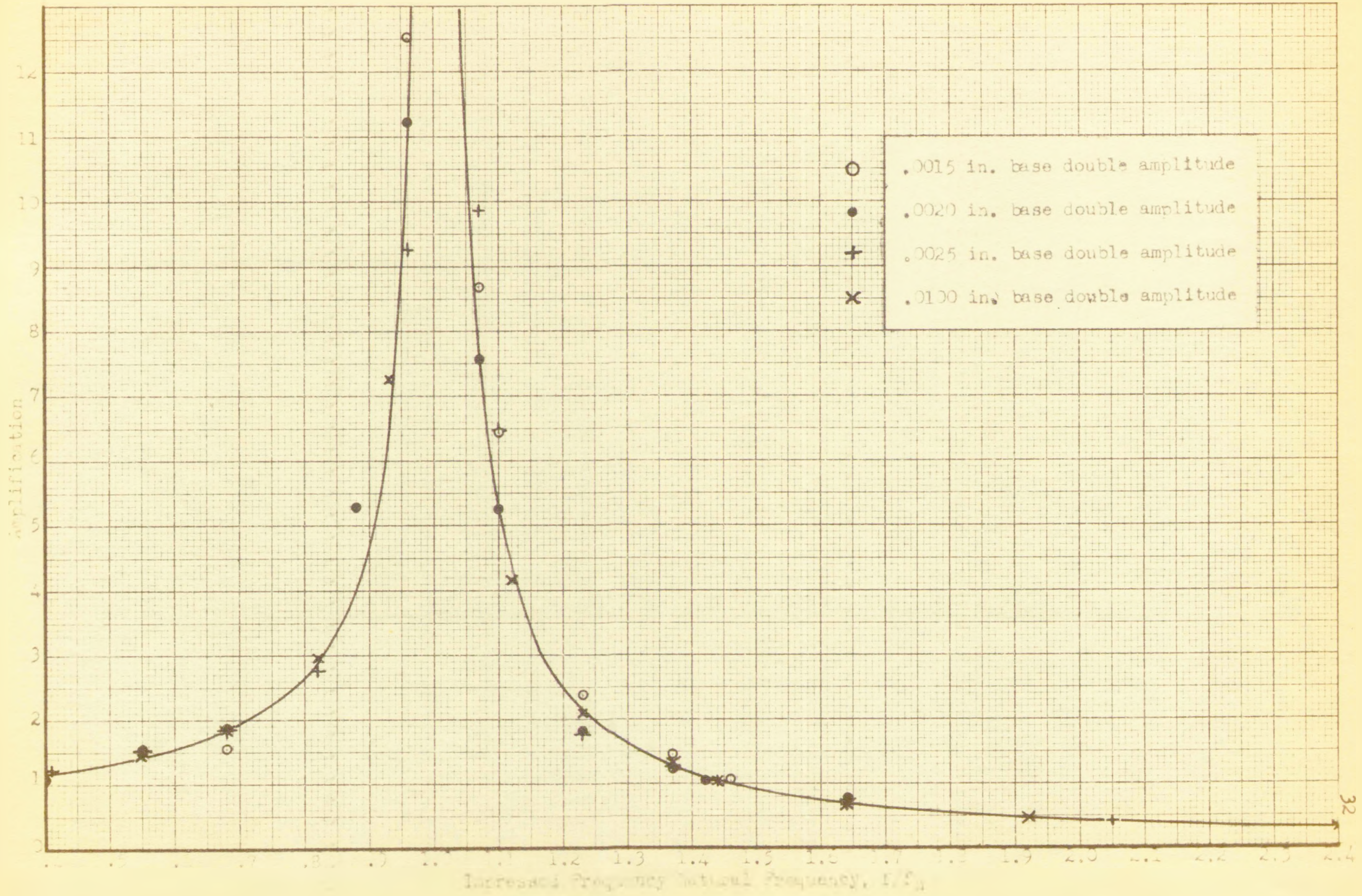

FIGURE 18. AMPLIFICATION CURVE FOR SPRING SYSTEM

excitation. Appendix B contains run data and amplification tables and amplification curves for both vibration-isolator systems. Appendix C contains sample oscillograph records of the biharmonic vibration excitation of the vibration-isolator systems. Tables 5 and 6 are resumes of the data obtained from the biharmonic vibration excitation of the two vibration mount systems.

TABLE 5. BIHARMONIC VIBRATION EXCITATION OF THE TYPE 990-30 VIBRATION MOUNT SYSTEM

Frequency Cycles/sec.		Frequency ratio		Harmonic amplification		Individual contribution, percent		Phase angle, degree	Base double amplitude, in.	Biharmonic amplification	
f_1	f_2	f_1/f_n	f_2/f_n	@f_1	@f_2	f_1	f_2			Predicted	Measured
84	90	1.062	1.138	7.10	4.10	50	50	--	.0049	5.60	5.03
84	90	1.062	1.138	6.00[6] 9.30[8]	3.55[7] 3.10[9]	50	50	--	.0227	4.78 6.20	4.31
84	90	1.062	1.138	9.30[8] 13.60[10]	3.10[9] 3.10[11]	50	50	--	.0324	6.20 8.35	4.88

[6]Amplification for 0.010 inch base double amplitude.

[7]Amplification for 0.010 inch base double amplitude.

[8]Amplification for 0.025 inch base double amplitude.

[9]Amplification for 0.025 inch base double amplitude.

[10]Amplification for 0.035 inch base double amplitude.

[11]Amplification for 0.035 inch base double amplitude.

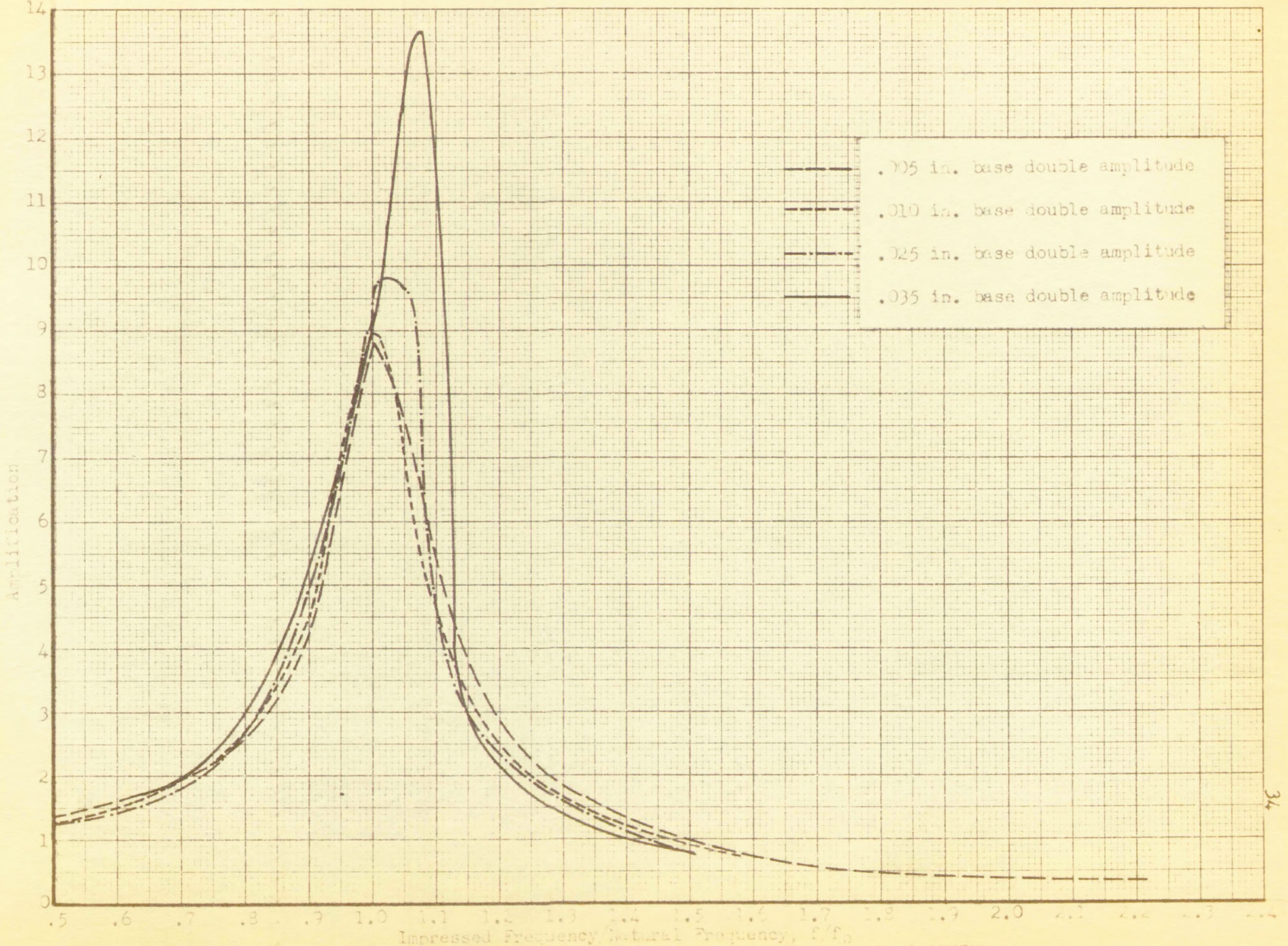

FIGURE 19. AMPLIFICATION CURVES FOR TYPE [illegible] VIBRATION MOUNT SYSTEM

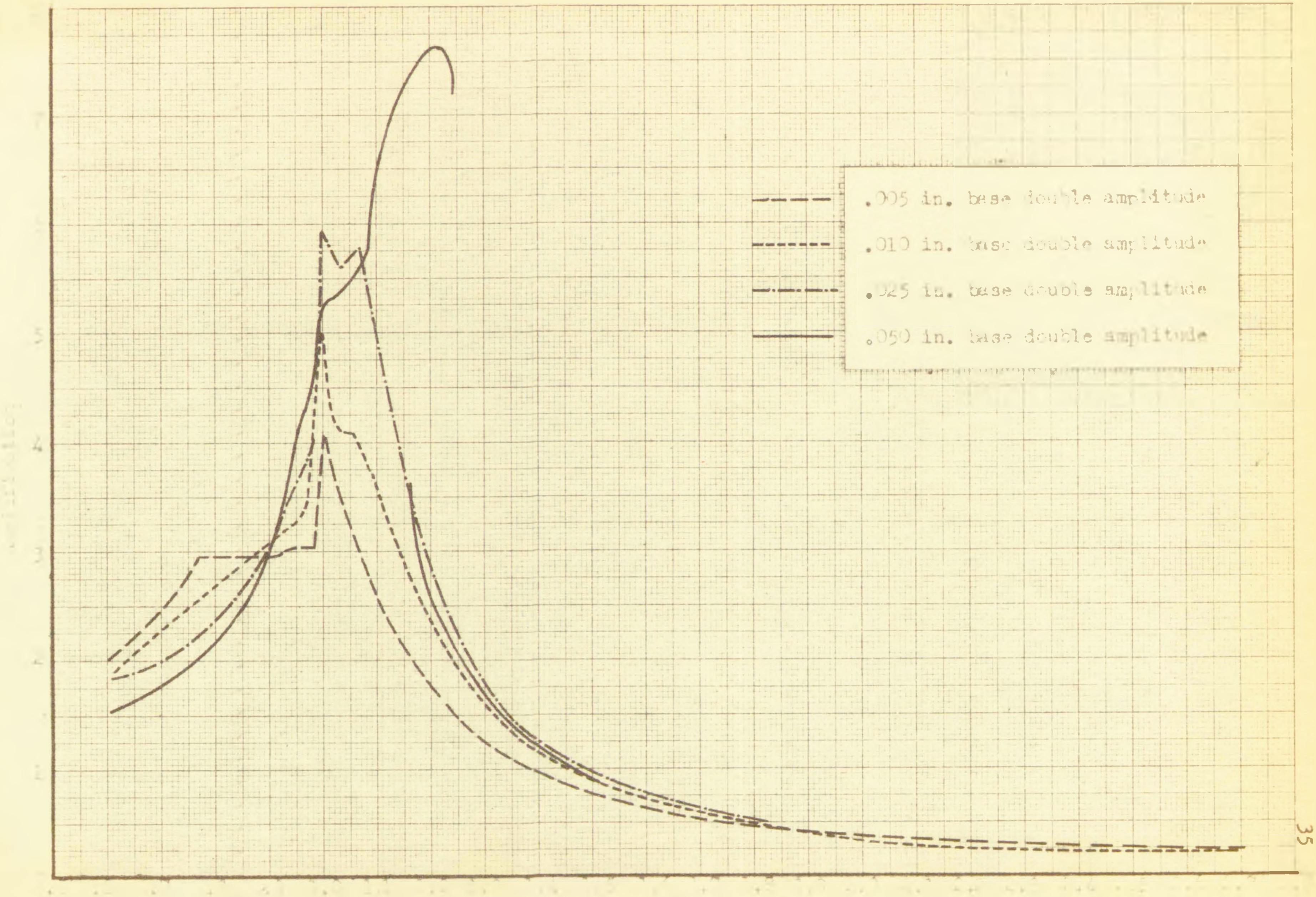
.005 in. base double amplitude
.010 in. base double amplitude
.025 in. base double amplitude
.050 in. base double amplitude

FIGURE 20.

TABLE 6. BIHARMONIC VIBRATION EXCITATION OF THE TYPE 780-35G VIBRATION MOUNT SYSTEM

Frequency Cycles/sec.		Frequency ratio		Harmonic amplification		Individual contribution, percent		Phase angle, degrees	Base double amplitude, in.	Biharmonic amplification	
f_1	f_2	f_1/f_n	f_2/f_n	@f_1	@f_2	f_1	f_2			Predicted	Measured
62	76	.943	1.156	3.06[12] 3.29[14]	2.02[13] 2.80[15]	50	50	--	.0097	2.54 3.05	2.64
62	76	.943	1.156	3.62[16] 3.98[18]	3.60[17] 3.57[19] 7.25[20]	50	50	--	.0499	3.61 3.77 5.61	3.56

[12]Amplification for 0.005 inch base double amplitude.

[13]Amplification for 0.005 inch base double amplitude.

[14]Amplification for 0.010 inch base double amplitude.

[15]Amplification for 0.010 inch base double amplitude.

[16]Amplification for 0.025 inch base double amplitude.

[17]Amplification for 0.025 inch base double amplitude.

[18]Amplification for 0.050 inch base double amplitude.

[19]Amplification for 0.050 inch base double amplitude.

[20]Amplification for 0.050 inch base double amplitude.

DISCUSSION OF RESULTS

The linear spring system gave the same amplification versus frequency curve over a range of base double amplitudes between 0.0015 and 0.0100 inch. Some scatter of the points for Fig. 18 can be attributed to the fact that the frequency counter was not utilized on the lower amplitude runs, hence, the frequency was not known within 0.1 cycle as it was on runs when the frequency counter was used. Although complete phase angle measurements between the base accelerometer integrator output and the mass accelerometer integrator output were not made it was noted that the phase angle changed from 0° to 180° between $f/f_n = .97$ and $f/f_n = 1.04$. Within the accuracy of this work then, the linear spring system behaved according to the theory for a simple system with a very low damping coefficient.

There were, in general, two primary sources of error in this work. First, the non-linearities of the system as a whole. The most serious non-linearity of the system as a whole seemed to result from some peculiar interaction of the test specimen and vibration generator. Second, the inherent errors associated with recording on photographic paper which is wet processed and dried before measurements are possible are generally regarded as being in excess of the three per cent estimated for this investigation. It should be pointed out, however, that all the measurements of the oscillographs were used in the determination of ratios. Thus, shrinkage and other distortion errors should be reduced considerably.

The measured biharmonic amplification of the linear spring system agreed within 4.6 per cent of the predicted biharmonic amplification with most of the measured amplifications being slightly higher than the predicted. The biharmonic amplifications were measured at base double amplitudes between

0.0047 and 0.0209 inch.

The accuracy of the measured biharmonic amplifications is probably somewhat less than that of the simple vibration since measurements were made at only a single point whereas five or ten measurements were made to obtain the simple vibration data.

The Barry type 990-30 vibration mount system gave larger amplifications at the larger base double amplitudes particularly in the region between f/f_n = .95 and f/f_n = 1.15. The amplification curves also revealed an increase in f_n with increasing base double amplitudes. This increase in f_n was particularly noticed at the 0.035 inch base double amplitude which resulted in the vibration mounts deflecting almost to their maximum in both directions at resonance.

Measured biharmonic amplifications were all lower than the most conservative predicted amplifications by 9 to 27 per cent. The most conservative amplifications were calculated from the amplification curves determined at a base double amplitude one-half the base double amplitude of the biharmonic base double amplitude.

The Barry type 780-35G vibration mount system also gave larger amplifications at larger base double amplitudes. Unlike the type 990-30 vibration mounts, the type 780-35G vibration mounts did not give smooth amplification versus f/f_n curves particularly in the region from f/f_n = .75 to 1.05. Only at the maximum base double amplitude of 0.050 inch did the natural frequency shift appreciably. The amplification curve revealed a marked non-linear characteristic which resulted in a discontinuous jump in amplification. This increase in natural frequency and discontinuous jump in an amplification is characteristic of a non-linear system with a

gradually stiffening spring. This apparent stiffening of the spring may be attributable to the additional spring action from the air in the air damping system.

A second set of 780-35G vibration mounts were checked to confirm the irregular amplification curve at lower base double amplitudes. Comparison of Figs. 21 and 22 show the same general type of irregular curve obtained for the two different sets of type 780-35G vibration mounts.

Measured biharmonic amplifications were only about 3.8 per cent lower than the most conservative predicted amplifications. Thus, the biharmonic amplification of the 780-35G vibration mounts can be predicted from the harmonic amplification characteristics for a biharmonic vibration composed of equal amplitude harmonics.

The type 780-35G vibration mounts exhibited higher amplifications than specified in the manufacturer's literature. The manufacturer claims a maximum amplification at resonance of 3.5. This maximum amplification was specified with a vertical resonance of 7 to 9 cycles per second. Since the vertical resonance was approximately 66 cycles per second in this work it may be surmised that the effectiveness of the air damping is decreased at higher frequencies of vibration.

CONCLUSIONS

The amplification of a linear single degree-of-freedom system subjected to biharmonic vibration may be predicted from the simple vibration amplification of the system. The amplification of Barry type 990-30 and 780-35G vibration mount systems subjected to biharmonic vibration cannot be accurately predicted in a similar manner, but predicted amplifications

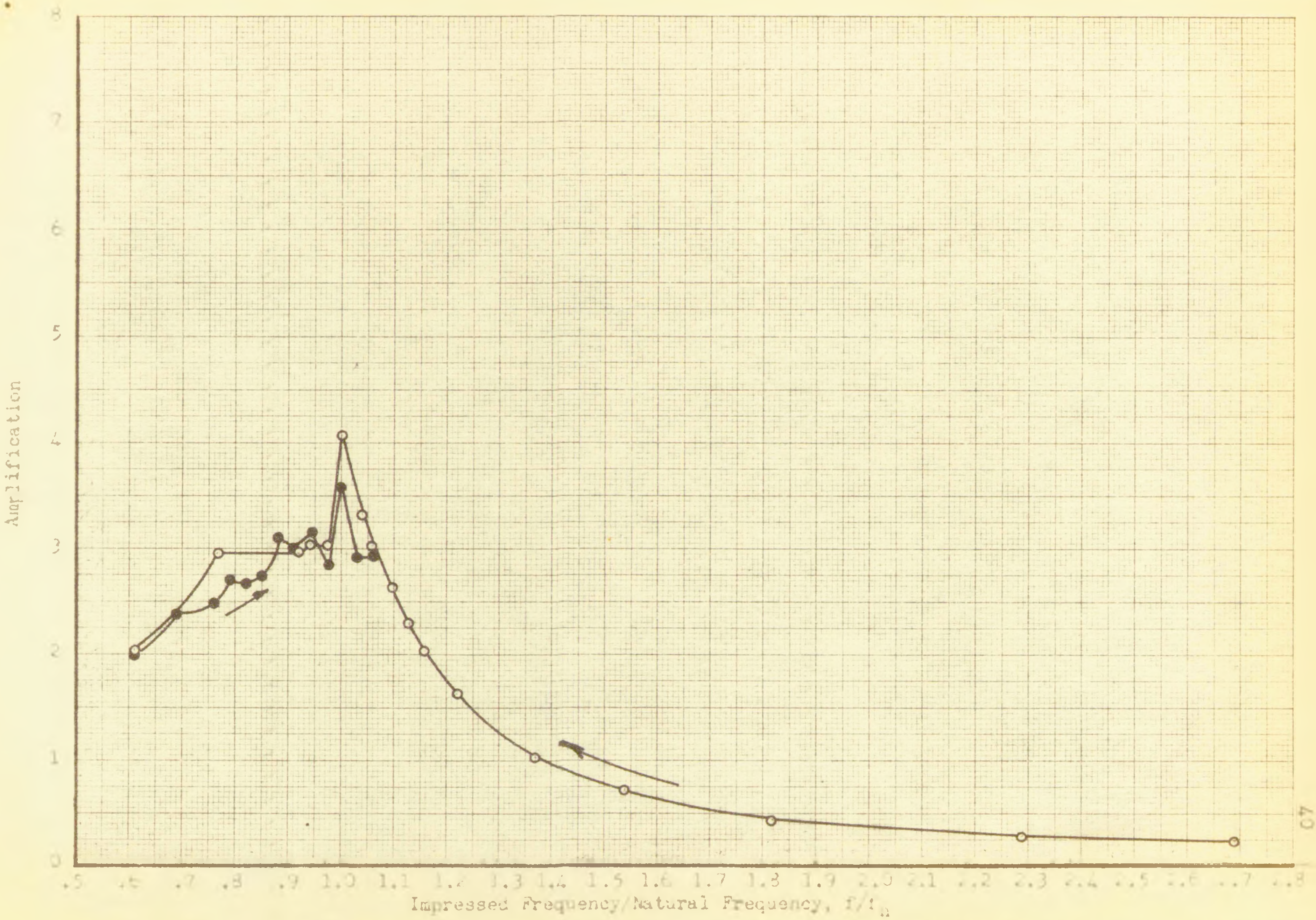

FIGURE 21. AMPLIFICATION CURVES FOR SET NO. 1 TYPE 780-35G VIBRATION MOUNT SYSTEM AT A BASE DOUBLE AMPLITUDE OF .005 IN.

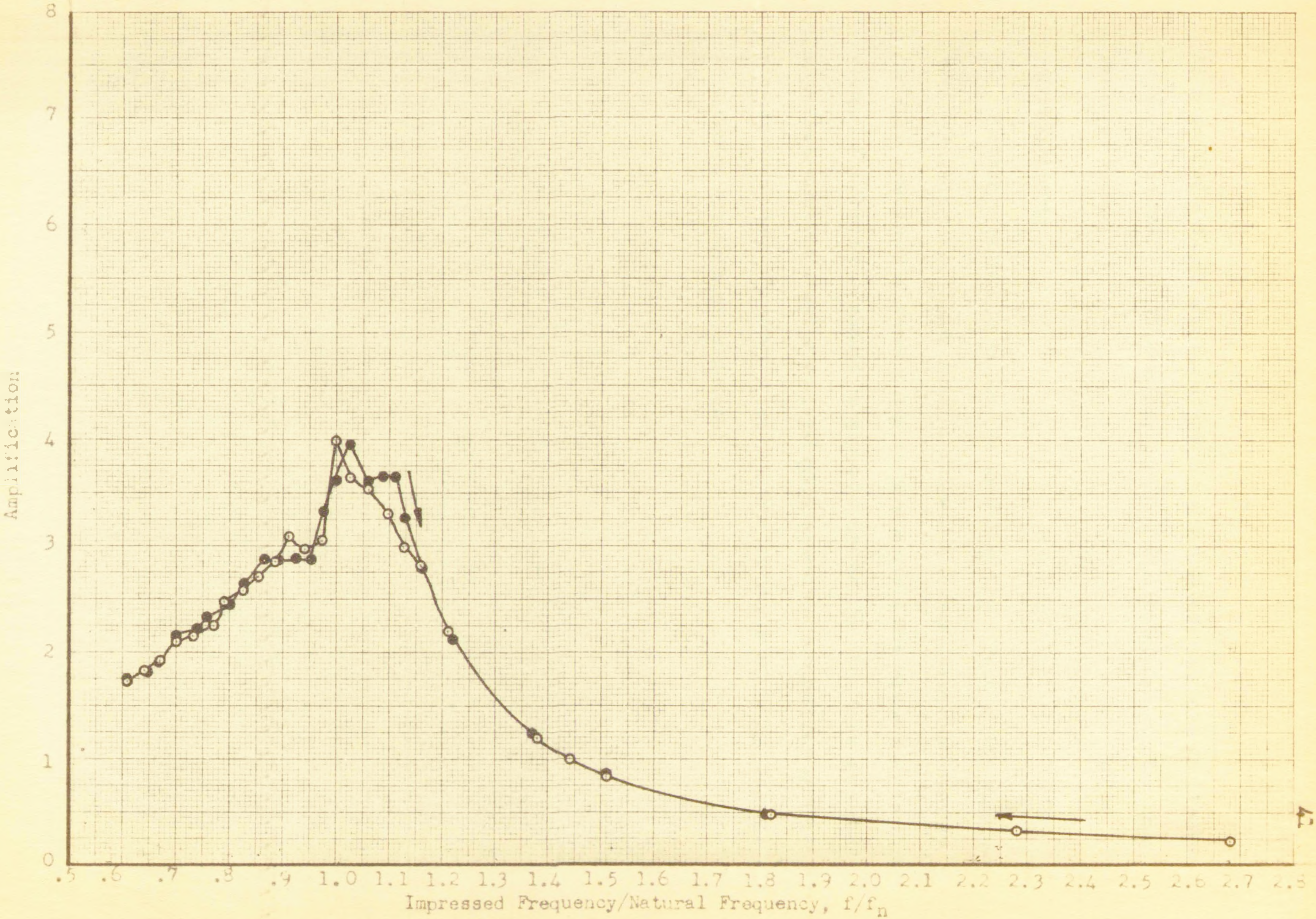

FIGURE 22. AMPLIFICATION CURVES FOR SET NO. 2 TYPE 780-35C VIBRATION MOUNT SYSTEM AT A BASE DOUBLE AMPLITUDE OF .005 IN.

made on the basis of simple vibration amplifications at base amplitudes equal to one-half the biharmonic vibration amplitude were greater than measured values.

RECOMMENDATIONS

Further work should be done to establish the effect of the high natural frequencies on these types of vibration mounts which are normally employed with natural frequencies as much as 1/10 the value used in this study. Consideration should be given to the design of a test specimen such that vibration mounts employed will be acting in parallel so that non-linear spring characteristics will not be distorted as is possible in a series arrangement of mounts.

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APPENDIX A

RUN DATA AND AMPLIFICATIONS FROM THE SIMPLE VIBRATION OF THE SPRING SYSTEM

TABLE 7. RUN DATA AND RECORD MEASUREMENTS OF THE SIMPLE VIBRATION OF THE SPRING SYSTEM

Run Data								Record Measurements	
Frequency cycles/sec.	Integrator voltage		Attenuator setting		Integrator gain		Record number	Average amplitude	
	Base	Mass	Base	Mass	Base	Mass		Base	Mass
106.8	.0030	.0030	1	3	100	100	252	763.1	799.6
100.0	.0030	.0034	1	3	100	100	253	768.2	1132.2
90.0	.0030	.0060	1	7	100	100	254	825.0	879.8
80.0	.0030	.0145	1	15	100	100	255	747.2	1004.4
78.0	.0030	.0200	1	30	100	100	256	781.0	701.0
76.0	.0031	.0350	1	50	100	100	257	800.0	730.2
74.0	.0030	.1050	1	150	100	100	258	748.2	721.4
72.0	.0030	.1000	1	100	100	100	261	775.4	1035.0
70.0	.0030	.0330	1	30	100	100	262	834.4	1089.8
50.0	.0030	.0054	1	5	100	100	263	1061.6	999.0
104.0	.0040	.0040	1	5	100	100	209	972.2	906.6
120.0	.0040	.0025	1	2	100	100	211	928.3	1528.8
100.0	.0040	.0047	1	5	100	100	212	980.0	1065.6
90.0	.0040	.0081	1	10	100	100	213	1152.0	963.4
80.0	.0040	.0200	1	20	100	100	214	971.4	1181.8
78.0	.0040	.0265	1	30	100	100	215	906.4	1059.2
76.0	.0040	.0490	1	70	100	100	216	971.8	846.0
70.0	.0040	.0400	1	50	100	100	221	939.8	946.0
64.0	.0040	.0150	1	20	100	100	222	772.6	943.6
50.0	.0040	.0076	1	10	100	100	223	1012.2	878.2
40.0	.0040	.0052	1	7	100	100	224	896.2	859.8
30.0	.0040	.0040	1	5	100	100	225	922.6	888.6
105.0	.0050	.0050	1	10	100	100	47	1131.3	1220.6
175.0	.0050	.0019	1	10	100	100	49	1143.0	402.3
150.0	.0050	.0022	1	10	100	100	50	1132.6	491.5
120.0	.0050	.0034	1	10	100	100	51	1110.0	789.2

TABLE 7. (Continued)

Run Data								Record Measurements	
Frequency cycles/sec.	Integrator voltage		Attenuator setting		Integrator gain		Record number	Average amplitude	
	Base	Mass	Base	Mass	Base	Mass		Base	Mass
100.0	.0050	.0066	1	10	100	100	53	1139.4	1507.4
90.0	.0050	.0100	1	10	100	100	54	1121.8	2084.3
80.0	.0050	.0280	1	50	100	100	55	1116.3	1503.1
78.0	.0050	.0410	1	150	100	100	57	1079.8	737.1
76.0	.0050	.0750	1	150	100	100	58	1140.2	1564.4
72.0	.0049	.0960	1	300	100	100	64	1172.2	748.3
70.0	.0049	.0470	1	300	100	100	65	1143.3	366.5
60.0	.0050	.0132	1	30	100	100	67	1158.3	1106.2
50.0	.0051	.0088	1	30	100	100	68	1147.1	727.6
40.0	.0050	.0061	1	30	100	100	69	1041.2	546.6
30.0	.0050	.0054	1	30	100	100	70	1078.4	459.1
105.0	.0200	.0200	1/2	10	100	100	308	937.7	979.5
175.0	.0200	.0068	1/2	3	100	100	309	956.7	923.8
140.0	.0200	.0095	1/2	5	100	100	310	944.0	871.6
120.0	.0200	.0135	1/2	7	100	100	311	948.4	945.2
100.0	.0201	.0251	1/2	15	100	100	312	951.8	856.0
90.0	.0200	.0400	1/2	20	100	100	313	954.3	1007.3
82.0	.0200	.0800	1/2	50	100	100	314	967.2	806.2
68.0	.0200	.1320	1/2	70	100	100	315	933.6	970.8
60.0	.0200	.0600	1/2	30	100	100	316	993.2	986.0
50.0	.0200	.0350	1/2	20	100	100	317	923.8	859.4
40.0	.0200	.0270	1/2	20	100	100	318	958.0	688.4

TABLE 8 . AMPLIFICATIONS FROM THE SIMPLE VIBRATION OF THE SPRING SYSTEM

Freq. cps	f/fn	Amplification	Freq. cps	f/fn	Amplification
0.0015 in. Nominal Base Double Amplitude			0.0025 in. Nominal Base Double Amplitude		
106.8	1.46	1.04	105.0	1.44	1.04
100.0	1.37	1.46	175.0	2.40	0.339
90.0	1.23	2.38	150.0	2.05	0.418
80.0	1.10	6.43	120.0	1.64	0.686
78.0	1.07	8.60	100.0	1.37	1.28
76.0	1.04	14.55	90.0	1.23	1.79
74.0	1.01	46.10	80.0	1.10	6.49
72.0	0.99	42.55	78.0	1.07	9.88
70.0	0.96	12.51	76.0	1.04	17.90
50.0	0.68	1.55	72.0	0.99	18.48
			70.0	0.96	9.28
			60.0	0.82	2.76
0.0020 in. Nominal Base Double Amplitude			50.0	0.68	1.84
			40.0	0.55	1.52
			30.0	0.41	1.23
104.0	1.42	1.04	0.0100 in. Nominal Base Double Amplitude		
120.0	1.64	0.78			
100.0	1.37	1.21			
90.0	1.23	1.81	105.0	1.44	1.04
80.0	1.10	5.25	175.0	2.40	0.300
78.0	1.07	7.57	140.0	1.92	0.48
76.0	1.04	13.16	120.0	1.64	0.70
70.0	0.96	11.24	100.0	1.37	1.34
64.0	0.88	5.28	90.0	1.23	2.10
50.0	0.68	1.87	82.0	1.12	4.16
40.0	0.55	1.45	68.0	0.93	7.26
30.0	0.41	1.07	60.0	0.82	2.97
			50.0	0.68	1.85
			40.0	0.55	1.43

APPENDIX B

RUN DATA AND AMPLIFICATIONS FROM THE SIMPLE VIBRATION OF THE VIBRATION MOUNT SYSTEMS

TABLE 9. RUN DATA AND RECORD MEASUREMENTS OF 990-30 VIBRATION MOUNTS SIMPLE VIBRATION

Run Data								Record Measurements	
Frequency cycles/sec.	Integrator voltage		Attenuator setting		Integrator gain		Record number	Average amplitude	
	Base	Mass	Base	Mass	Base	Mass		Base	Mass
115.1	.0200	.0200	1/2	10	100	100	350	833.4	869.6
199.6	.0100	--	1	1.5	100	100	351	818.6	593.5
175.1	.0100	--	1	2	100	100	352	768.3	625.4
119.6	.0100	.0100	1	5	100	100	354	878.4	821.6
99.6	.0100	.0210	1	10	100	100	355	813.6	913.6
90.0	.0100	.0400	1	20	100	100	356	834.8	892.4
85.4	.0100	.0590	1	30	100	100	357	821.6	888.0
83.2	.0100	.0700	1	30	100	100	358	823.8	1071.0
79.8	.0100	.0820	1	50	100	100	359	826.2	745.6
79.1	.0100	.0820	1	50	100	100	360	829.0	758.2
78.1	.0100	.0800	1	50	100	100	361	841.4	713.4
77.1	.0100	.0740	1	30	100	100	362	813.8	1095.0
76.1	.0100	.0670	1	30	100	100	363	806.8	1003.9
72.0	.0100	.0460	1	30	100	100	364	841.6	685.2
69.9	.0100	.0385	1	20	100	100	365	842.0	850.4
60.5	.0100	.0220	1	10	100	100	367	817.2	949.8
50.4	.0100	.0160	1	7	100	100	368	790.8	1008.6
40.2	.0100	.0135	1	5	100	100	369	870.8	1171.8
116.4	.0200	.0200	1/2	10	100	100	370	849.0	898.0
116.4	.0100	.0200	1/2	10	50	100	371	421.4	846.2
198.6	.0100	--	1	2	50	100	372	821.5	983.2
176.6	.0200	--	1/2	3	100	100	373	843.7	875.9
149.8	.0200	--	1/2	5	100	100	374	829.4	792.6
119.4	.0200	.0180	1/2	7	100	100	375	806.8	1057.8
99.5	.0200	.0390	1/2	20	100	100	376	835.4	843.4
89.9	.0200	.0720	1/2	30	100	100	377	829.2	1045.2
85.1	.0200	.1160	1/2	50	100	100	378	850.8	974.4

TABLE 9. (Continued)

Run Data								Record Measurements	
Frequency cycles/sec.	Integrator voltage		Attenuator setting		Integrator gain		Record number	Average amplitude	
	Base	Mass	Base	Mass	Base	Mass		Base	Mass
83.2	.0200	.1390	1/2	70	100	100	379	866.0	841.0
79.7	.0200	.0800	1/2	50	100	50	381	847.2	744.2
78.9	.0200	.0799	1/2	50	100	50	382	843.5	737.2
78.0	.0200	.0800	1/2	50	100	50	383	841.6	715.8
77.0	.0200	.0760	1/2	50	100	50	384	845.8	675.8
76.0	.0200	.0695	1/2	30	100	50	385	826.4	1026.0
72.8	.0200	.1070	1/2	50	100	100	387	8[illegible].0	872.4
69.9	.0200	.0840	1/2	50	100	100	388	846.0	745.0
60.4	.0200	.0450	1/2	20	100	100	389	825.6	1011.8
50.3	.0200	.0320	1/2	15	100	100	390	821.8	936.4
40.3	.0200	.0265	1/2	10	100	100	391	838.0	1090.4
113.4	.0500	.0500	1/4	20	100	100	392	1033.8	1098.0
119.3	.0250	.0415	1/2	20	50	100	393	1036.0	893.4
99.4	.0500	.0410	1/4	20	100	50	395	1051.2	895.2
89.8	.0500	.0790	1/4	50	100	50	396	1045.6	681.0
85.1	.0500	.1510	1/4	70	100	50	397	1041.8	939.4
83.2	.0500	.1300	1/4	50	100	50	399	1026.4	1089.4
79.7	.0500	.1320	1/4	50	100	50	400	1027.0	1117.6
78.9	.0500	.1290	1/4	50	100	50	401	1056.4	1085.9
77.9	.0500	.1220	1/4	50	100	50	402	1043.4	1026.2
77.0	.0500	.1110	1/4	50	100	50	403	1056.2	956.2
76.0	.0500	.1050	1/4	50	100	50	404	1075.0	875.6
71.9	.0500	.0720	1/4	30	100	50	405	1072.2	1042.4
69.9	.0500	.1190	1/4	50	100	50	406	1060.6	997.2
60.4	.0500	.0310	1/4	15	100	25	408	1041.8	851.8
50.4	.0500	.0380	1/4	20	100	50	409	1045.2	828.4
40.2	.0500	.0310	1/4	15	100	50	410	1007.4	878.4
110.4	.0350	.0700	1/4	30	50	100	412	713.4	1014.2
119.0	.0350	.0250	1/4	10	50	50	414	698.4	1092.0
99.4	.0350	.0535	1/4	20	50	50	415	726.8	1171.2

TABLE 9.(Continued)

Run Data									Record Measurements	
Frequency cycles/sec.	Integrator voltage		Attenuator setting		Integrator gain		Record number	Average amplitude		
	Base	Mass	Base	Mass	Base	Mass		Base	Mass	
89.8	.0350	.0560	1/4	30	50	25	427	721.6	810.0	
85.1	.0300	.0840	1/4	50	50	10	429	619.6	728.2	
84.0	.0300	.0820	1/4	50	50	10	430	618.8	721.2	
83.0	.0300	.0790	1/4	50	50	10	431	632.6	696.6	
82.3	.0310	--	1/4	50	50	10	432	656.0	674.2	
81.0	.0325	--	1/4	50	50	10	433	693.0	651.8	
80.0	.0350	.0700	1/4	30	50	10	434	750.8	1028.0	
69.8	.0350	.0340	1/4	20	50	10	435	725.4	733.0	
60.4	.0350	.0180	1/4	7	50	10	436	722.6	1074.2	
50.3	.0350	.0121	1/4	5	50	10	437	724.4	1004.5	

TABLE 10. AMPLIFICATIONS FROM THE SIMPLE VIBRATION OF THE 990-30 VIBRATION MOUNT SYSTEM

Freq. cps	f/fn	Amplification
0.005 in. Nominal Base Double Amplitude		
115.1	1.45	1.00
199.6	2.52	0.26
175.1	2.21	0.34
119.6	1.51	0.93
99.6	1.26	2.15
90.0	1.14	4.10
85.4	1.08	6.21
83.3	1.05	7.47
79.8	1.01	8.65
79.1	1.00	8.76
78.1	0.99	8.12
77.1	0.97	7.74
76.1	0.96	7.15
72.0	0.91	4.50
69.9	0.88	3.87
60.5	0.76	2.23
50.4	0.64	1.71
40.2	0.51	1.33
0.010 in. Nominal Base Double Amplitude		
116.4	1.47	1.00
198.6	2.51	0.13
176.5	2.23	0.31
149.8	1.89	0.47
119.4	1.51	0.87
99.5	1.26	1.91
89.9	1.14	3.57
85.1	1.08	5.41
83.2	1.05	6.43
79.7	1.01	8.98
78.9	1.00	8.93
78.0	0.99	8.68
77.0	0.97	8.17
76.0	0.96	7.61
72.0	0.91	4.83
69.9	0.88	4.16
60.4	0.76	2.32
0.010 in. Nominal Base Double Amplitude (Continued)		
50.3	0.64	1.62
40.3	0.51	1.23
0.025 in. Nominal Base Double Amplitude		
113.4	1.43	1.00
119.3	1.51	0.77
99.4	1.26	1.84
89.8	1.14	3.15
85.1	1.08	6.83
83.2	1.05	9.61
79.7	1.01	9.86
78.9	1.00	9.31
77.9	0.98	8.91
77.0	0.97	8.20
76.0	0.96	7.38
71.9	0.91	5.28
69.9	0.88	4.54
60.4	0.76	2.22
50.4	0.64	1.53
40.2	0.51	1.26
0.035 in. Nominal Base Double Amplitude		
110.4	1.40	1.00
119.0	1.50	0.79
99.4	1.26	1.63
89.8	1.13	3.20
85.1	1.08	13.70
84.0	1.06	13.64
83.0	1.05	12.89
82.3	1.04	12.02
81.0	1.02	11.00
80.0	1.01	9.62
69.8	0.88	4.73
60.4	0.76	2.44
50.3	0.64	1.68

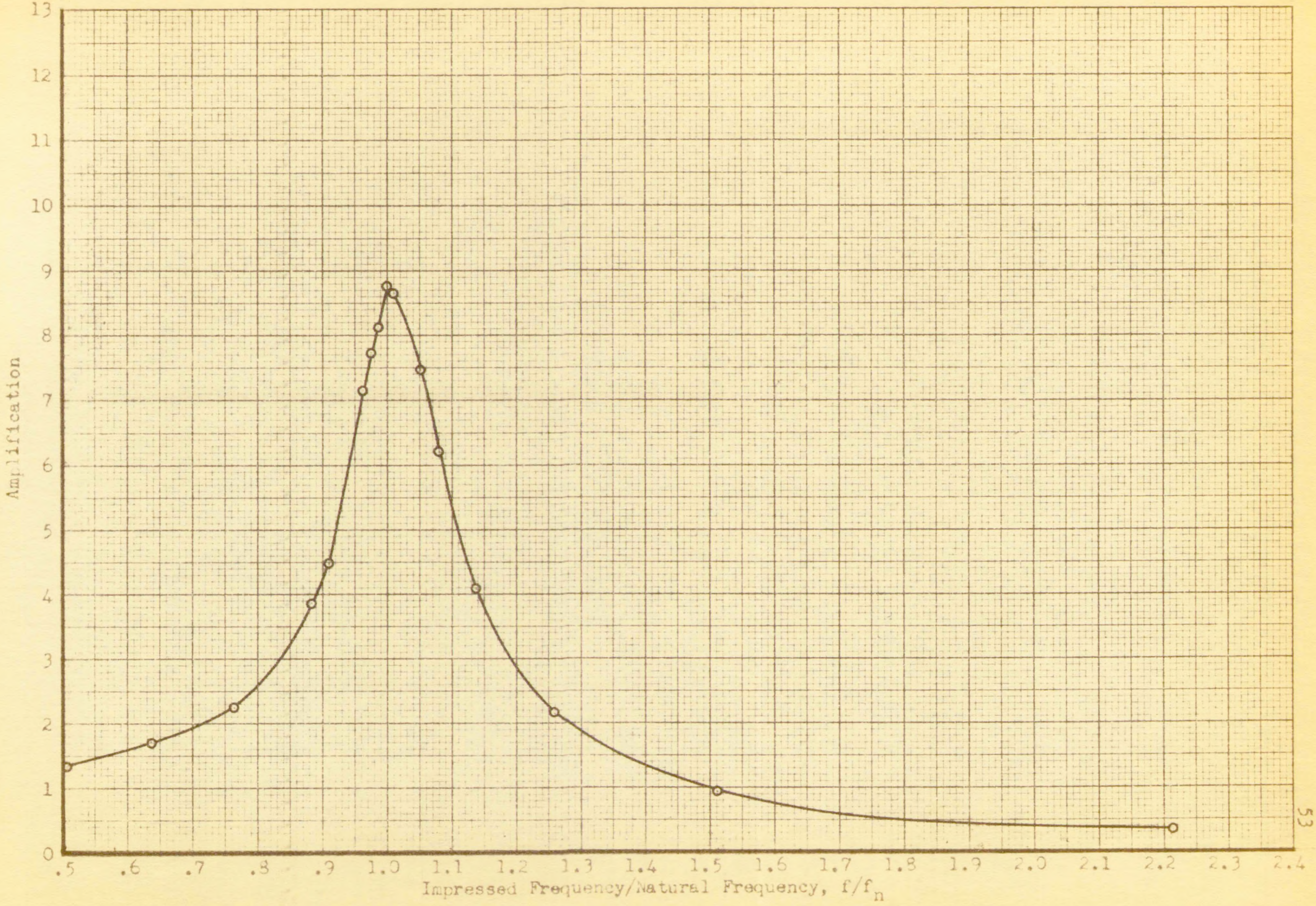

FIGURE 23. AMPLIFICATION CURVE FOR TYPE 990-30 VIBRATION MOUNT SYSTEM AT A BASE DOUBLE AMPLITUDE OF .005 IN.

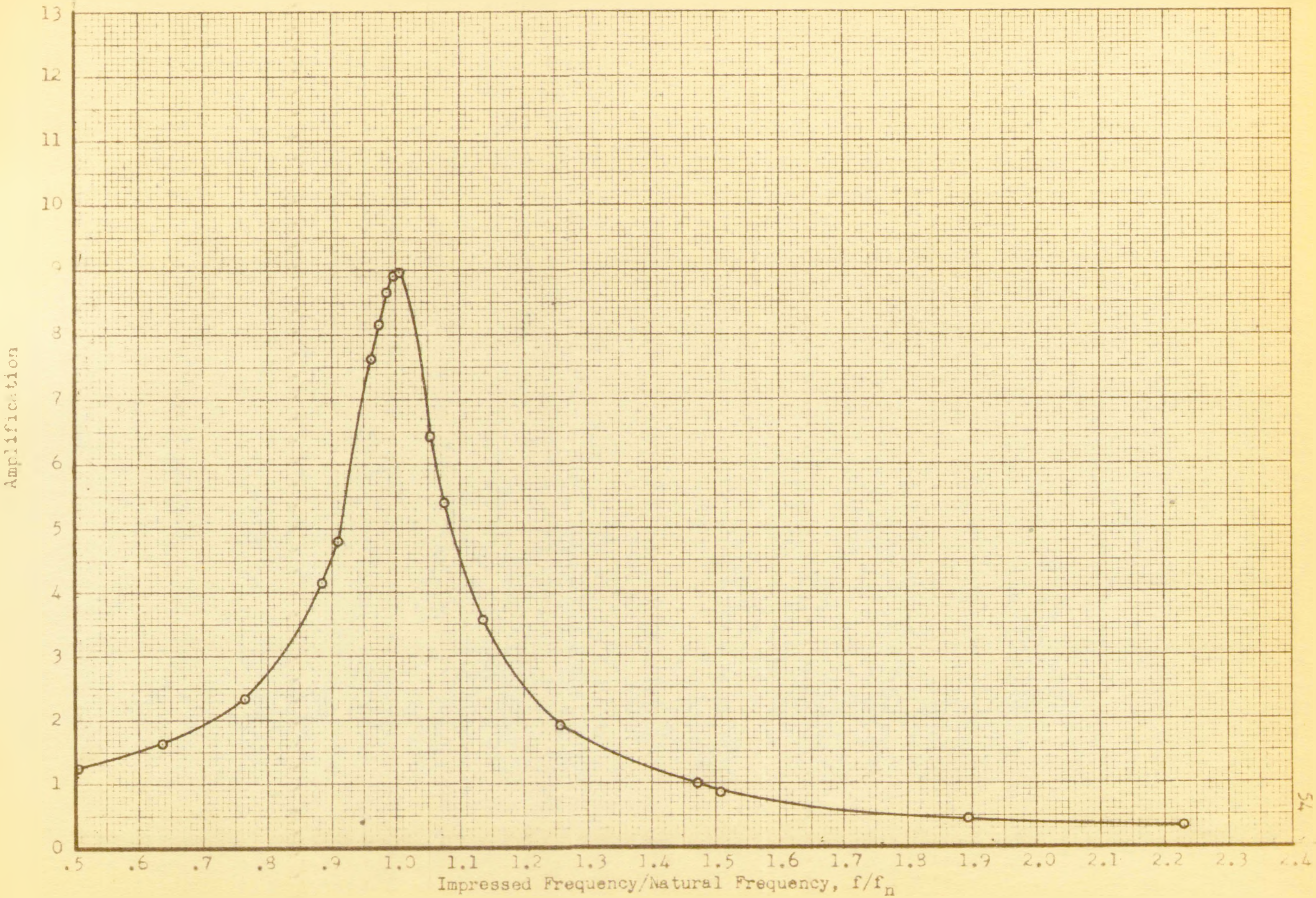

FIGURE [illegible]. AMPLIFICATION CURVE FOR TYPE 990-30 VIBRATION MOUNT SYSTEM AT A BASE DOUBLE AMPLITUDE OF .010 IN.

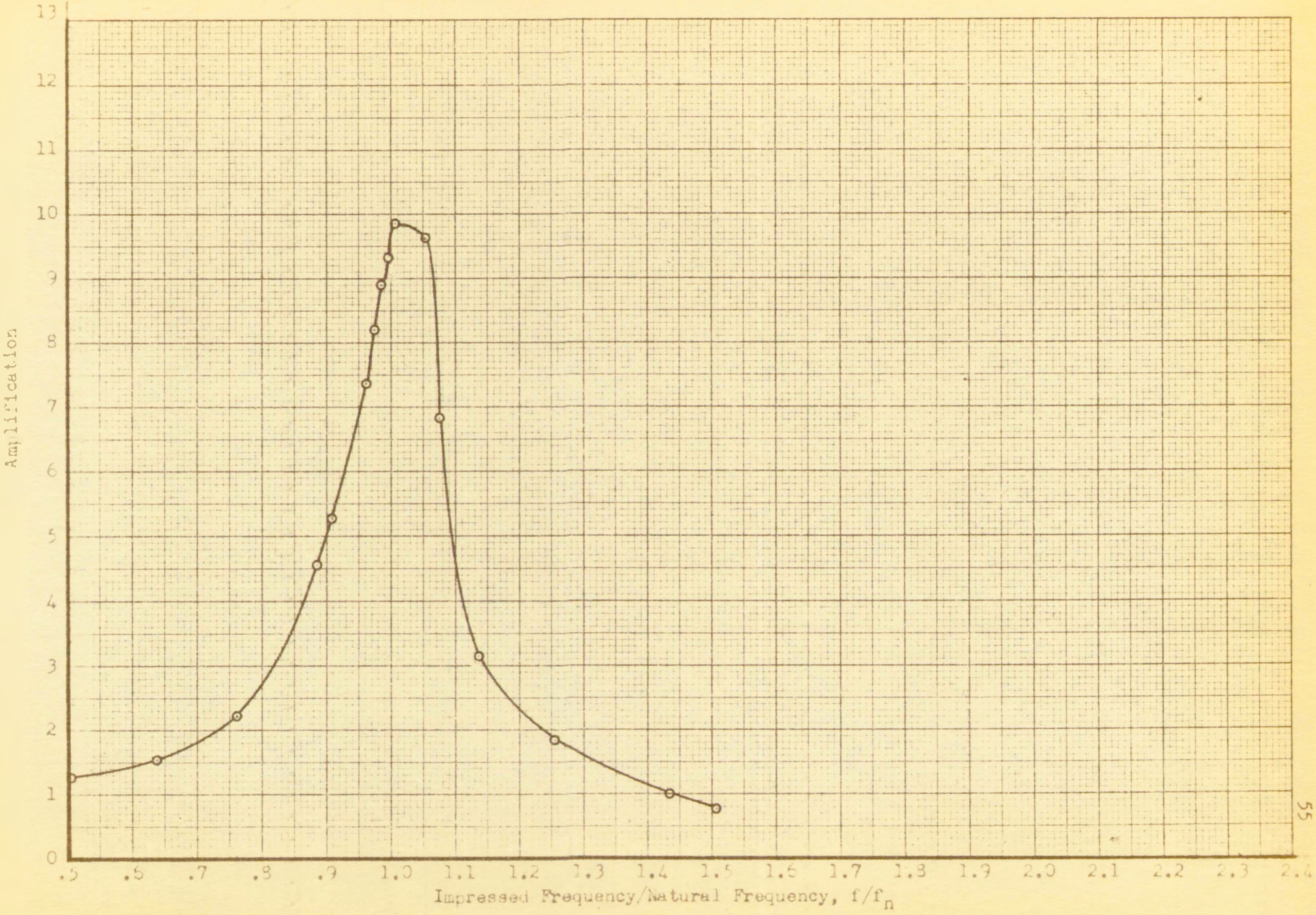

FIGURE 25. AMPLIFICATION CURVE FOR TYPE 990-30 VIBRATION MOUNT SYSTEM AT A BASE DOUBLE AMPLITUDE OF .025 IN.

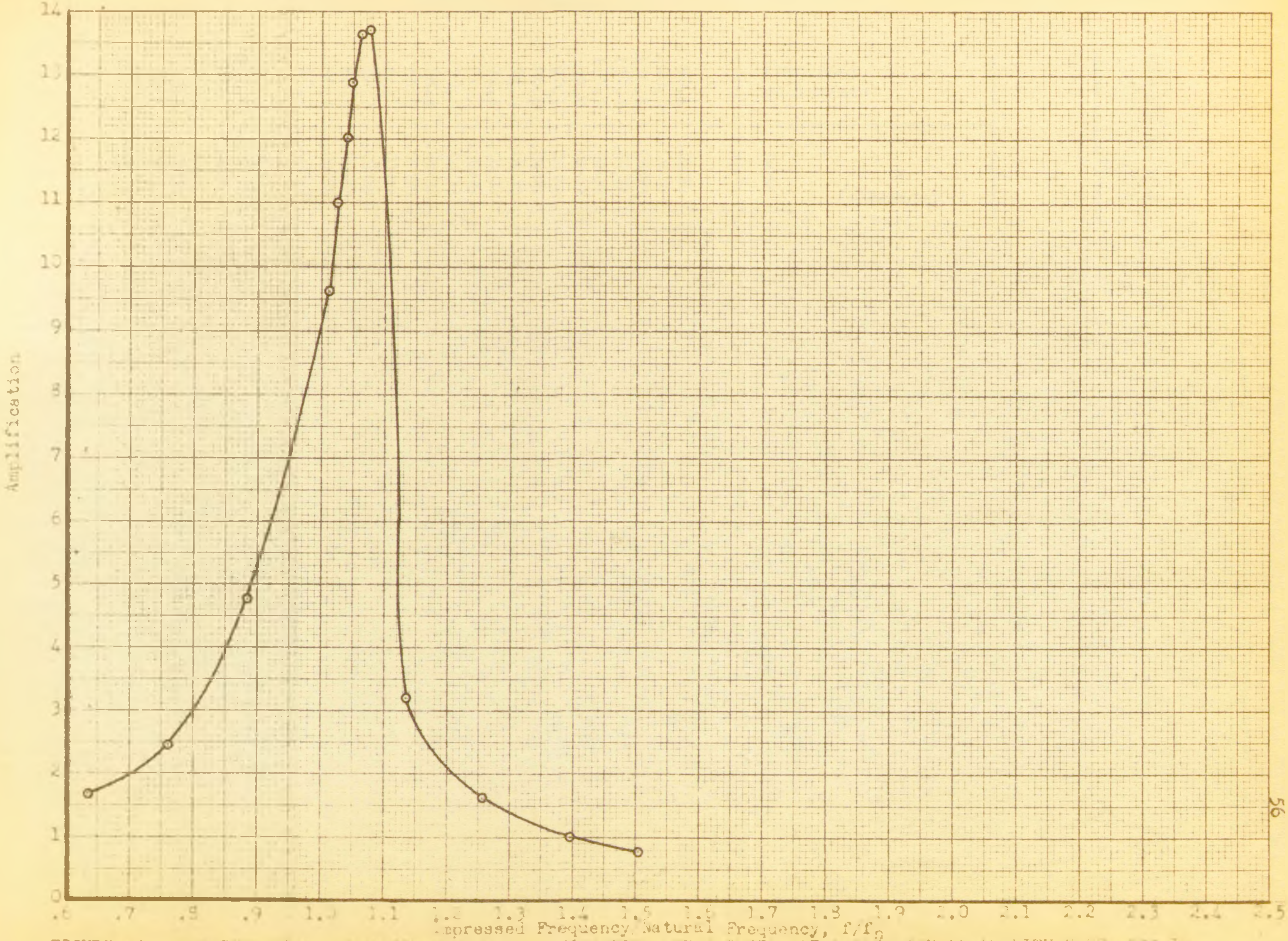

FIGURE 26. AMPLIFICATION CURVE FOR TYPE 990-30 VIBRATION MOUNT SYSTEM AT A BASE DOUBLE AMPLITUDE OF .035 In.

TABLE 11. RUN DATA AND RECORD MEASUREMENTS OF SET NO. 1-780-35G VIBRATION MOUNTS SIMPLE VIBRATION

Run Data								Record Measurements	
Frequency cycles/sec.	Integrator voltage•		Attenuator setting		Integrator gain		Record number	Average amplitude	
	Base	Mass	Base	Mass	Base	Mass		Base	Mass
90.1	.0100	.0100	1	5	100	100	440	881.0	865.4
200.0	.0100	--	1	1.5	100	100	441	821.5	356.2
176.6	.0100	--	1	1.5	100	100	442	793.1	534.2
150.2	.0100	--	1	2	100	100	443	818.0	526.6
119.7	.0100	--	1	2	100	100	444	853.8	874.0
99.8	.0100	.0070	1	3	100	100	445	855.4	1028.2
90.1	.0100	.0100	1	5	100	100	446	811.0	810.4
80.0	.0100	.0155	1	7	100	100	447	832.0	992.4
76.2	.0100	.0195	1	10	100	100	448	843.2	866.2
74.1	.0100	.0215	1	10	100	100	449	820.0	955.0
72.2	.0100	.0260	1	15	100	100	450	848.0	754.4
70.0	.0100	.0288	1	15	100	100	451	850.8	871.0
68.1	.0100	.0300	1	15	100	100	452	795.4	901.2
65.9	.0100	.0380	1	20	100	100	453	861.6	889.4
64.1	.0100	.0298	1	15	100	100	454	851.8	873.8
62.3	.0100	.0260	1	15	100	100	455	804.4	832.2
60.4	.0100	.0280	1	15	100	100	456	860.0	857.2
50.4	.0100	.0275	1	15	100	100	457	836.6	836.6
40.2	.0100	.0190	1	10	100	100	458	819.2	849.6
95.4	.0200	.0200	1/2	10	100	100	459	872.2	887.6
200.0	.0200	--	1	1.5	50	100	460	872.0	752.2
176.4	.0200	--	1/2	2	100	100	461	852.0	862.6
150.0	.0200	--	1/2	2	100	100	462	847.1	856.6
119.6	.0200	.0100	1/2	5	100	100	463	892.6	874.4
99.8	.0200	.0170	1/2	10	100	100	464	861.4	750.8
90.0	.0200	.0247	1/2	15	100	100	465	864.0	742.2
79.9	.0200	.0430	1/2	20	100	100	466	871.6	948.8

TABLE 11.(Continued)

Run Data								Record Measurements	
Frequency cycles/sec.	Integrator voltage		Attenuator setting		Integrator gain		Record number	Average amplitude	
	Base	Mass	Base	Mass	Base	Mass		Base	Mass
75.1	.0200	.0600	1/2	30	100	100	467	869.0	897.0
72.0	.0200	.0720	1/2	50	100	100	468	867.8	651.8
69.9	.0200	.0790	1/2	50	100	100	469	866.8	718.8
68.0	.0200	.0780	1/2	70	100	100	470	847.6	507.0
65.9	.0200	.0960	1/2	50	100	100	471	857.8	864.2
64.1	.0200	.0680	1/2	30	100	100	472	870.6	995.6
62.1	.0200	.0640	1/2	30	100	100	473	866.6	966.4
60.5	.0200	.0600	1/2	30	100	100	474	840.8	888.2
50.4	.0200	.0490	1/2	30	100	100	475	864.4	744.0
40.2	.0200	.0390	1/2	20	100	100	476	883.0	845.6
97.2	.0500	.0500	1/4	30	100	100	478	1058.0	732.2
119.7	.0500	.0260	1/4	10	100	100	479	1045.4	1143.6
99.6	.0500	.0460	1/4	20	100	100	480	1055.2	1021.8
89.9	.0500	.0690	1/4	30	100	100	481	1053.6	1001.0
79.7	.0500	.0600	1/4	30	100	50	483	1061.2	887.2
75.0	.0500	.0900	1/4	50	100	50	484	1053.0	801.6
72.0	.0500	.1200	1/4	70	100	50	485	1055.2	740.4
70.0	.0500	.1350	1/4	70	100	50	486	1061.4	838.2
68.0	.0500	.1310	1/4	70	100	50	487	1060.8	815.2
65.7	.0500	.1400	1/4	70	100	50	488	1055.4	861.4
64.0	.0500	.0880	1/4	50	100	50	489	1073.8	801.8
62.2	.0500	.0800	1/4	50	100	50	490	1036.6	720.6
60.2	.0500	.0740	1/4	30	100	50	491	1058.6	1084.8
50.2	.0500	.0520	1/4	30	100	50	492	1078.2	761.2
40.0	.0500	.0420	1/4	20	100	50	493	1067.8	914.4
96.3	.0500	.0500	1/4	20	50	50	494	1055.4	1108.6
99.4	.0500	.0450	1/4	20	50	50	495	1064.4	1002.6
89.7	.0500	.0685	1/4	30	50	50	496	1057.6	1016.8
79.6	.0500	.0640	1/4	30	50	25	498	1040.6	930.8
79.0	.0500	.0680	1/4	30	50	25	499	1063.8	988.6

TABLE 11.(Continued)

Run Data								Record Measurements	
Frequency cycles/sec.	Integrator voltage		Attenuator setting		Integrator gain		Record number	Average amplitude	
	Base	Mass	Base	Mass	Base	Mass		Base	Mass
78.0	.0500	.0740	1/4	30	50	25	500	1069.0	1076.0
76.9	.0500	.0800	1/4	30	50	25	501	1050.2	1177.6
76.0	.0500	.0940	1/4	50	50	25	502	1051.8	837.4
76.0	.0500	.1950	1/4	100	50	25	503	1076.0	845.0
74.0	.0500	.1900	1/4	100	50	25	504	1087.4	821.8
71.8	.0500	.1620	1/4	70	50	25	505	1077.2	992.4
69.9	.0500	.1570	1/4	70	50	25	506	1064.4	947.6
67.8	.0500	.1500	1/4	70	50	25	507	1059.4	902.6
65.6	.0500	.1480	1/4	70	50	25	508	1068.2	885.6
63.9	.0500	.1200	1/4	50	50	25	509	1064.2	1038.2
62.3	.0500	.1100	1/4	50	50	25	510	1065.8	945.4
60.2	.0500	.0865	1/4	50	50	25	511	1062.0	761.0
50.2	.0500	.0520	1/4	30	50	25	512	1050.2	760.2
40.0	.0500	.0410	1/4	20	50	25	513	1043.6	885.0
92.0	.0100	.0100	1	7	100	100	563	981.8	1106.0
40.1	.0100	.0190	1	15	100	100	564	934.8	980.0
45.1	.0100	.0235	1	20	100	100	565	947.0	883.0
50.1	.0100	.0251	1	30	100	100	566	965.6	628.6
52.1	.0100	.0260	1	30	100	100	567	928.2	659.0
54.1	.0100	.0271	1	30	100	100	568	995.6	696.2
56.1	.0100	.0290	1	30	100	100	569	1007.8	726.6
58.2	.0100	.0300	1	30	100	100	570	933.8	761.0
60.0	.0100	.0325	1	30	100	100	571	1063.6	841.6
62.1	.0100	.0310	1	30	100	100	572	960.8	795.2
64.1	.0100	.0290	1	30	100	100	573	997.0	744.0
65.8	.0100	.0360	1	30	100	100	574	960.0	904.2
67.6	.0100	.0305	1	30	100	100	575	1004.6	771.6
69.6	.0100	.0292	1	30	100	100	576	965.8	744.2
95.7	.0200	.0200	1/2	20	100	100	577	984.6	1028.2
40.1	.0200	.0369	1/2	50	100	100	578	988.8	788.2

TABLE 11.(Continued)

Run Data								Record Measurements	
Frequency cycles/sec.	Integrator voltage		Attenuator setting		Integrator gain		Record number	Average amplitude	
	Base	Mass	Base	Mass	Base	Mass		Base	Mass
45.1	.0200	.0410	1/2	50	100	100	579	980.8	632.2
50.2	.0200	.0400	1/2	50	100	100	580	965.0	935.8
52.2	.0200	.0470	1/2	50	100	100	581	992.4	987.8
54.1	.0200	.0500	1/2	50	100	100	582	958.2	1041.6
56.2	.0200	.0540	1/2	50	100	100	583	953.4	1112.2
58.2	.0200	.0570	1/2	70	100	100	584	992.8	827.2
60.0	.0200	.0600	1/2	70	100	100	585	986.2	885.8
62.2	.0200	.0640	1/2	70	100	100	586	939.6	934.2
64.0	.0200	.0640	1/2	70	100	100	587	943.0	948.4
65.8	.0200	.0850	1/2	100	100	100	588	943.8	877.8
67.7	.0200	.0720	1/2	70	100	100	589	962.2	1039.0
69.4	.0200	.0780	1/2	70	100	100	590	972.8	1149.4
71.4	.0200	.0780	1/2	70	100	100	591	1006.2	1158.8
72.1	.0200	.0740	1/2	70	100	100	592	972.4	1099.8
98.2	.0500	.0500	1/4	7	100	100	594	910.2	893.6
98.3	.0500	.0250	1/4	7	100	50	595	904.8	930.2
40.0	.0500	.0355	1/4	10	100	50	596	911.8	1065.8
45.0	.0500	.0430	1/4	15	100	50	597	896.6	813.4
50.2	.0500	.0460	1/4	15	100	50	598	884.2	909.6
52.1	.0500	.0505	1/4	15	100	50	599	912.6	947.2
54.1	.0500	.0550	1/4	15	100	50	600	904.4	1027.0
56.0	.0500	.0585	1/4	15	100	50	601	899.2	1094.4
58.2	.0500	.0650	1/4	20	100	50	602	911.4	905.2
60.0	.0500	.0700	1/4	20	100	50	603	907.2	990.6
62.0	.0500	.0760	1/4	20	100	50	604	896.2	1060.4
63.9	.0500	.0840	1/4	20	100	50	605	892.0	1174.2
66.0	.0500	.1220	1/4	50	100	50	606	922.2	721.0
67.9	.0500	.1250	1/4	50	100	50	607	914.2	731.0
69.7	.0500	.1320	1/4	50	100	50	608	887.6	763.0
71.4	.0500	.1170	1/4	50	100	50	609	908.2	683.0
72.4	.0500	.1100	1/4	50	100	50	610	894.8	632.8

TABLE 11.(Continued)

Frequency cycles/sec.	Run Data: Integrator voltage		Run Data: Attenuator setting		Run Data: Integrator gain		Record number	Record Measurements: Average amplitude	
	Base	Mass	Base	Mass	Base	Mass		Base	Mass
72.2	.0500	.1120	1/4	50	100	50	614	931.6	653.4
73.8	.0500	.1000	1/4	30	100	50	615	885.0	926.0
75.7	.0500	.0845	1/4	30	100	50	616	894.4	792.8
77.9	.0500	.0710	1/4	20	100	50	617	907.8	994.6
97.4	.0500	--	1/4	15	50	50	618	894.8	900.6
40.0	.0500	--	1/4	20	50	50	619	892.0	1007.6
45.2	.0500	--	1/4	20	50	50	620	899.8	1168.4
50.0	.0500	--	1/4	30	50	50	621	898.2	853.6
52.1	.0500	--	1/4	30	50	50	622	898.6	932.4
54.1	.0500	--	1/4	30	50	50	623	896.8	1001.6
56.0	.0500	--	1/4	30	50	50	624	887.0	1079.8
58.0	.0500	--	1/4	50	50	50	625	874.8	486.2
59.8	.0500	--	1/4	50	50	50	626	898.2	842.0
62.0	.0500	--	1/4	50	50	50	627	891.8	1072.4
63.9	.0500	--	1/4	50	50	50	628	910.6	1208.8
66.1	.0500	.1350	1/4	50	50	25	630	889.0	770.0
67.7	.0500	.1370	1/4	50	50	25	631	889.8	766.8
69.6	.0500	.1420	1/4	50	50	25	632	906.4	816.4
71.3	.0500	.1490	1/4	50	50	25	633	905.8	841.0
73.7	.0490	.1750	1/4	50	50	25	634	898.0	997.2
75.8	.0470	.1780	1/4	50	50	25	635	842.8	1006.2
77.9	.0465	.1790	1/4	50	50	25	636	826.0	1022.0
79.8	.0470	.1800	1/4	50	50	25	637	818.2	1031.8
81.8	.0500	.1820	1/4	50	50	25	638	894.0	1054.2
84.0	.0500	.0470	1/4	15	50	25	639	905.8	896.0

TABLE 12. AMPLIFICATIONS FROM THE SIMPLE VIBRATION OF THE SET NO. 1 780-25G VIBRATION MOUNT SYSTEM

Freq. cps	f/fn	Amplification
0.005 in. Nominal Base Double Amplitude		
90.1	1.37	1.00
200.0	3.04	0.16
176.6	2.69	0.25
150.2	2.29	0.28
119.7	1.82	0.44
99.8	1.52	0.74
90.1	1.37	1.02
80.0	1.22	1.64
76.2	1.16	2.02
74.1	1.13	2.29
72.2	1.10	2.63
70.0	1.06	3.02
68.1	1.04	3.35
65.9	1.00	4.07
64.1	0.98	3.03
62.3	0.95	3.06
60.4	0.92	2.94
50.4	0.77	2.95
40.2	0.61	2.04
0.010 in. Nominal Base Double Amplitude		
95.4	1.45	1.00
200.0	3.04	0.11
176.4	2.68	0.22
150.0	2.28	0.22
119.6	1.82	0.50
99.8	1.52	0.86
90.0	1.37	1.27
79.9	1.22	2.14
75.1	1.14	3.04
72.0	1.09	3.69
69.9	1.06	4.07
68.0	1.03	4.11
65.9	1.00	4.95
64.1	0.98	3.37
62.1	0.94	3.29
60.5	0.12	3.11
0.010 in. Nominal Base Double Amplitude (Continued)		
50.4	0.77	2.54
40.2	0.61	1.88
0.025 in. Nominal Base Double Amplitude		
97.2	1.48	1.00
119.7	1.82	0.53
99.6	1.52	0.93
89.9	1.37	1.37
79.7	1.21	2.61
75.0	1.14	3.97
72.0	1.10	5.12
70.0	1.06	5.76
68.0	1.03	5.60
65.7	1.00	5.95
64.0	0.97	3.89
62.2	0.95	3.62
60.2	0.92	3.20
50.2	0.76	2.21
40.0	0.61	1.78
0.050 in. Nominal Base Double Amplitude		
96.3	1.47	1.00
99.4	1.51	0.90
89.7	1.37	1.37
79.6	1.21	2.41
79.0	1.20	2.50
78.0	1.19	2.71
76.9	1.17	3.02
76.0	1.16	3.57
76.0	1.16	7.05
74.0	1.13	6.77
71.8	1.09	5.79
69.9	1.06	5.59
67.8	1.03	5.35
65.6	1.00	5.21

TABLE 12.(Continued)

Freq. cps	f/fn	Amplification
0.050 in. Nominal Base Double Amplitude (Continued)		
63.9	0.97	4.38
62.3	0.95	3.98
60.2	0.92	3.21
50.2	0.76	1.95
40.0	0.61	1.52
0.005 in. Nominal Base Double Amplitude		
92.0	1.40	1.00
40.1	0.61	1.99
45.1	0.69	2.36
50.1	0.76	2.48
52.1	0.79	2.70
54.1	0.82	2.66
56.1	0.85	2.74
58.2	0.88	3.10
60.0	0.91	3.01
62.1	0.94	3.15
64.1	0.98	2.84
65.8	1.00	3.58
67.6	1.03	2.92
69.6	1.06	2.93
0.010 in. Nominal Base Double Amplitude		
95.7	1.46	1.00
40.1	0.61	1.91
45.1	0.69	2.16
50.2	0.76	2.32
52.2	0.79	2.38
54.1	0.82	2.60
56.2	0.85	2.79
58.2	0.88	2.79
60.0	0.91	3.01
62.2	0.95	3.33
64.0	0.97	3.37
65.8	1.00	4.45
67.7	1.03	3.62

Freq. cps	f/fn	Amplification
0.010 in. Nominal Base Double Amplitude (Continued)		
69.4	1.06	3.96
71.1	1.08	3.86
72.1	1.10	3.79
0.025 in. Nominal Base Double Amplitude		
98.2	1.49	1.00
98.3	1.50	1.00
40.0	0.61	1.62
45.0	0.68	1.89
50.2	0.76	2.14
52.1	0.79	2.16
54.1	0.82	2.37
56.0	0.85	2.54
58.2	0.88	2.76
60.0	0.91	3.03
62.0	0.94	3.29
63.9	0.97	3.66
66.0	1.00	5.43
67.9	1.03	5.55
69.7	1.06	5.97
71.4	1.09	5.22
72.4	1.10	4.91
72.2	1.10	4.87
73.8	1.12	4.36
75.7	1.15	3.69
77.9	1.18	3.05
0.050 in. Nominal Base Double Amplitude		
97.4	1.48	1.00
40.0	0.61	1.50
45.2	0.69	1.72
50.0	0.76	1.81
52.1	0.79	1.97
54.1	0.82	2.12
56.0	0.85	2.31
58.0	0.88	2.58

TABLE 12.(Continued)

Freq. cps	f/fn	Amplification	Freq. cps	f/fn	Amplification
0.050 in. Nominal Base Double Amplitude (Continued)			0.050 in. Nominal Base Double Amplitude (Continued)		
59.8	0.91	3.10	73.7	1.12	6.75
62.0	0.94	3.98	75.8	1.15	7.26
63.9	0.97	4.40	77.9	1.18	7.52
66.1	1.01	5.26	79.8	1.21	7.66
67.7	1.03	5.24	81.8	1.24	7.17
69.6	1.06	5.47	84.0	1.28	1.80
71.3	1.08	5.64			

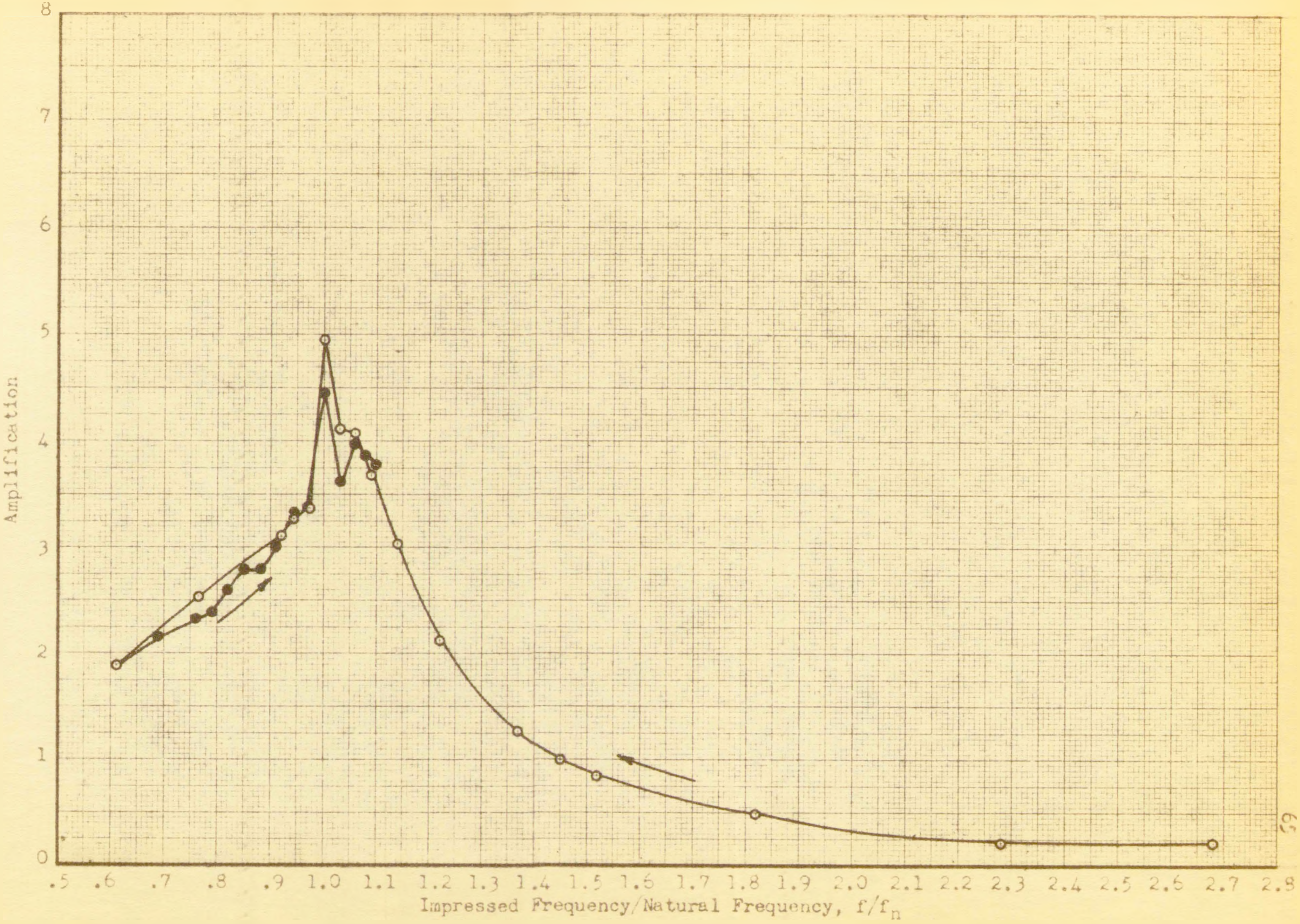

FIGURE 27. AMPLIFICATION CURVES FOR SET NO. 1 TYPE 783-353 VIBRATION MOUNT SYSTEM AT A BASE DOUBLE AMPLITUDE OF .010 IN.

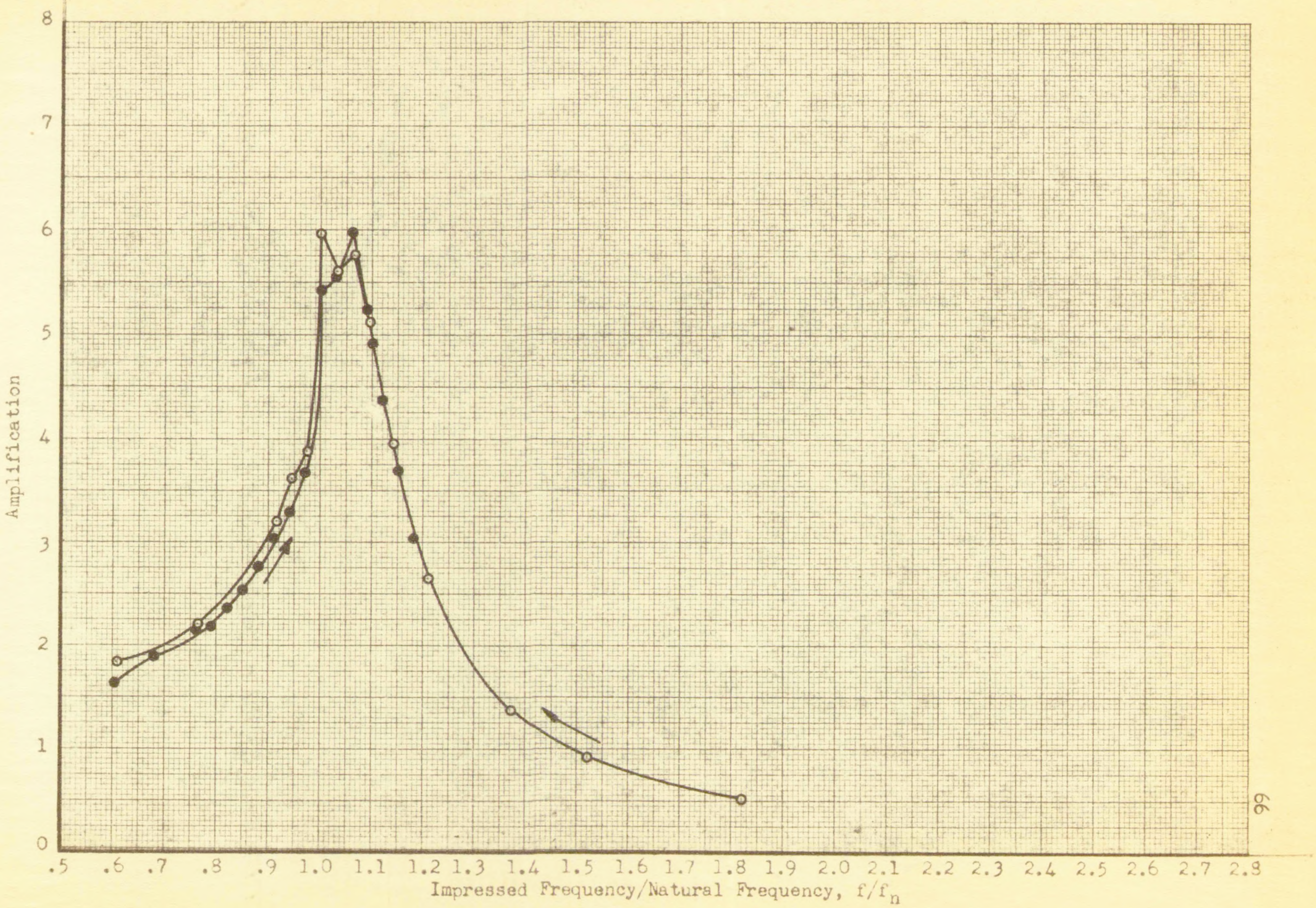

FIGURE 28. AMPLIFICATION CURVES FOR SET NO. 1 TYPE 780-35G VIBRATION MOUNT SYSTEM AT A BASE DOUBLE AMPLITUDE OF .025 IN.

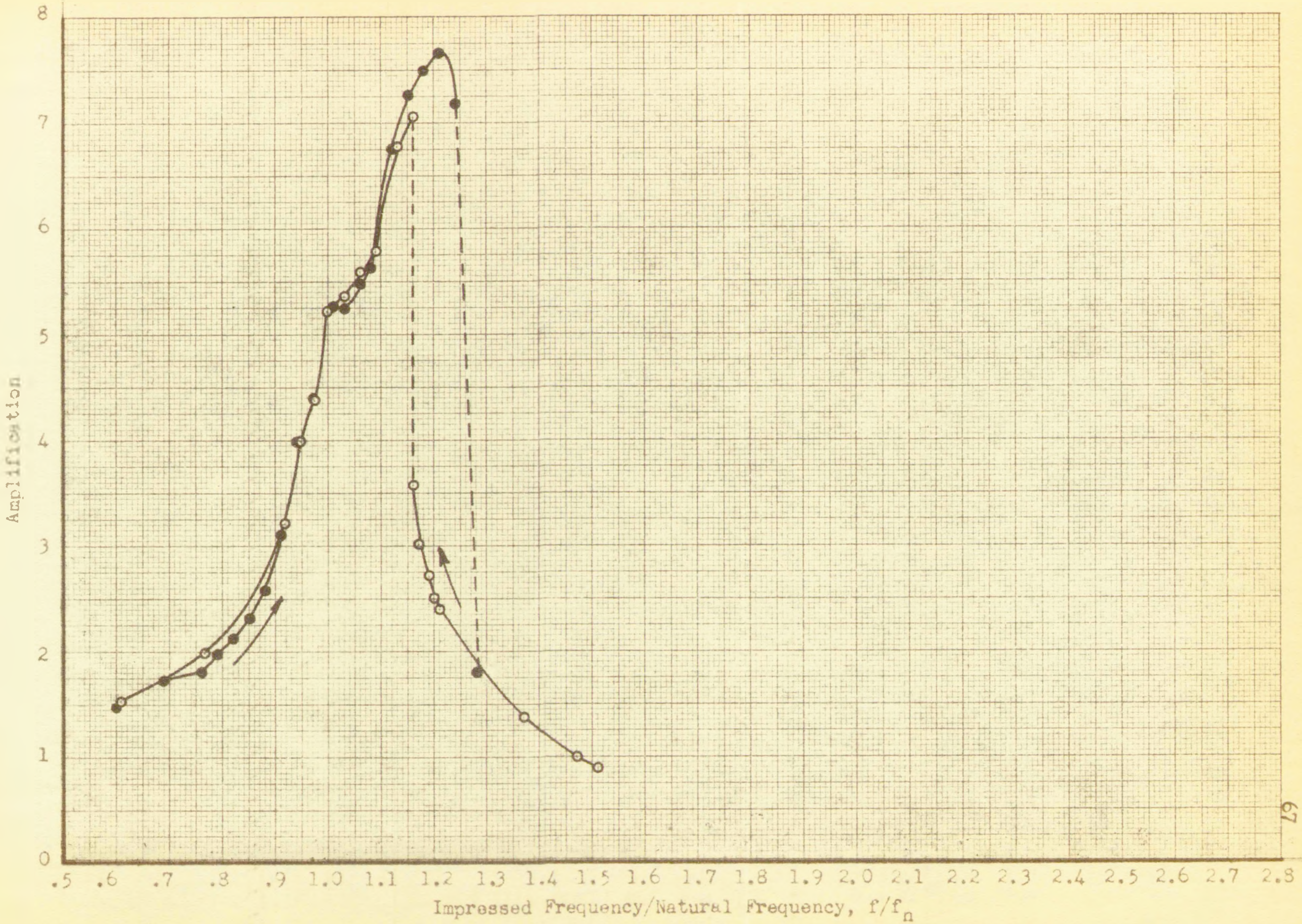

FIGURE 29. AMPLIFICATION CURVES FOR SET NO. 1 TYPE 780-35G VIBRATION MOUNT SYSTEM AT A BASE DOUBLE AMPLITUDE OF .050 IN.

TABLE 13. RUN DATA AND RECORD MEASUREMENTS OF SET NO. 2 780-35C VIBRATION MOUNTS SIMPLE VIBRATION

Run Data								Record Measurements	
Frequency cycles/sec.	Integrator voltage		Attenuator setting		Integrator gain		Record number	Average amplitude	
	Base	Mass	Base	Mass	Base	Mass		Base	Mass
94.6	.0100	--	1	10	100	100	306	150.4	168.0
200.0	.0100	--	1	3	100	100	307	147.6	87.3
176.0	.0100	--	1	3	100	100	308	145.8	113.7
149.8	.0100	--	1	5	100	100	309	142.2	100.0
119.8	.0100	--	1	7	100	100	310	150.0	112.8
99.6	.0100	--	1	10	100	100	311	147.2	137.2
90.6	.0100	--	1	15	100	100	312	147.6	132.0
79.6	.0100	--	1	30	100	100	313	147.0	121.0
76.0	.0100	--	1	30	100	100	314	143.6	151.2
73.9	.0100	--	1	50	100	100	315	150.8	100.6
72.1	.0100	--	1	50	100	100	316	153.4	113.4
69.8	.0100	--	1	50	100	100	317	155.2	122.6
67.5	.0100	--	1	50	100	100	318	148.8	121.2
65.8	.0100	--	1	50	100	100	319	156.8	139.6
64.0	.0100	--	1	50	100	100	320	146.4	99.6
62.0	.0100	--	1	50	100	100	321	1372.0	910.8
60.0	.0100	--	1	50	100	100	322	1244.2	861.4
58.1	.0100	--	1	50	100	100	323	1324.8	844.8
56.0	.0100	--	1	50	100	100	324	1340.6	806.2
54.2	.0100	--	1	30	100	100	325	1312.8	1263.6
51.9	.0100	--	1	30	100	100	326	1264.0	1170.2
50.5	.0100	--	1	30	100	100	327	1315.6	1102.4
48.0	.0100	--	1	30	100	100	328	1280.8	1029.8
46.1	.0100	--	1	30	100	100	330	1290.2	1014.6
44.0	.0100	--	1	30	100	100	331	1291.8	925.0
42.0	.0100	--	1	20	100	100	332	1250.6	1272.2
40.1	.0100	--	1	20	100	100	333	1246.6	1207.2

TABLE 13.(Continued)

Run Data								Record Measurements	
Frequency cycles/sec.	Integrator voltage		Attenuator setting		Integrator gain		Record number	Average amplitude	
	Base	Mass	Base	Mass	Base	Mass		Base	Mass
94.7	.0100	--	1	10	100	100	334	1300.1	1443.9
40.0	.0100	--	1	20	100	100	335	1289.2	1252.0
42.5	.0100	--	1	20	100	100	336	1293.8	1308.0
43.9	.0100	--	1	20	100	100	337	1286.2	1365.6
46.1	.0100	--	1	30	100	100	338	1248.8	999.2
48.6	.0100	--	1	30	100	100	339	1290.2	1036.0
49.8	.0100	--	1	30	100	100	340	1259.2	1082.4
52.6	.0100	--	1	30	100	100	341	1293.2	1175.0
54.4	.0100	--	1	30	100	100	342	146.4	142.2
56.8	.0100	--	1	50	100	100	343	148.4	94.8
58.6	.0100	--	1	50	100	100	344	153.6	98.0
60.7	.0100	--	1	50	100	100	345	155.2	107.0
62.6	.0100	--	1	30	100	100	346	150.4	105.4
64.2	.0100	--	1	50	100	100	347	140.8	103.6
65.7	.0100	--	1	50	100	100	348	152.0	122.2
67.5	.0100	--	1	50	100	100	349	139.6	122.6
69.5	.0100	--	1	50	100	100	350	152.4	122.4
71.5	.0100	--	1	50	100	100	351	148.0	120.0
72.5	.0100	--	1	50	100	100	352	145.8	118.4
74.1	.0100	--	1	50	100	100	353	143.6	104.0
76.4	.0100	--	1	50	100	100	354	150.2	94.2
80.0	.0100	--	1	30	100	100	355	149.2	118.0
90.1	.0100	--	1	15	100	100	356	148.4	136.6
99.2	.0100	--	1	10	100	100	357	146.8	141.0
119.2	.0100	--	1	7	100	100	358	149.0	111.6
149.9	.0100	--	1	3	100	100	359	146.8	159.8
175.6	.0100	--	1	3	100	100	360	152.0	120.7
198.2	.0100	--	1	3	100	100	361	148.2	86.7

TABLE 14. AMPLIFICATIONS FROM THE SIMPLE VIBRATION OF SET NO. 2 780-35G VIBRATION MOUNT SYSTEM

Freq. cps	f/fn	Amplification	Freq. cps	f/fn	Amplification
0.005 in. Nominal Base Double Amplitude			0.005 in. Nominal Base Double Amplitude		
94.6	1.44	1.00	94.7	1.44	1.00
200.0	3.04	0.16	40.0	0.61	1.75
176.0	2.68	0.22	42.5	0.65	1.82
149.8	2.28	0.32	43.9	0.67	1.91
119.8	1.82	0.47	46.1	0.70	2.16
99.6	1.51	0.83	48.6	0.74	2.17
90.6	1.38	1.20	49.8	0.76	2.32
79.6	1.21	2.21	52.6	0.80	2.45
76.0	1.16	2.83	54.4	0.83	2.62
73.9	1.12	2.99	56.8	0.86	2.87
72.1	1.10	3.31	58.6	0.89	2.87
69.8	1.06	3.53	60.7	0.92	2.88
67.5	1.02	3.65	62.6	0.95	2.70
65.8	1.00	3.98	64.2	0.98	3.31
64.0	0.97	3.05	65.7	1.00	3.62
62.0	0.94	2.97	67.5	1.03	3.95
60.0	0.91	3.10	69.5	1.06	3.61
58.1	0.88	2.85	71.5	1.09	3.65
56.0	0.85	2.69	72.5	1.10	3.66
54.2	0.82	2.58	74.1	1.13	3.26
51.9	0.79	2.49	76.4	1.16	2.82
50.5	0.77	2.25	80.0	1.22	2.14
48.0	0.73	2.16	90.1	1.37	1.24
46.1	0.70	2.11	99.2	1.51	0.86
44.0	0.67	1.92	119.2	1.81	0.47
42.0	0.64	1.82	149.9	2.28	0.30
40.1	0.61	1.73	175.6	2.67	0.22
			198.2	3.02	0.16

APPENDIX C

SAMPLE OSCILLOGRAPH RECORDS OF THE BIHARMONIC VIBRATION

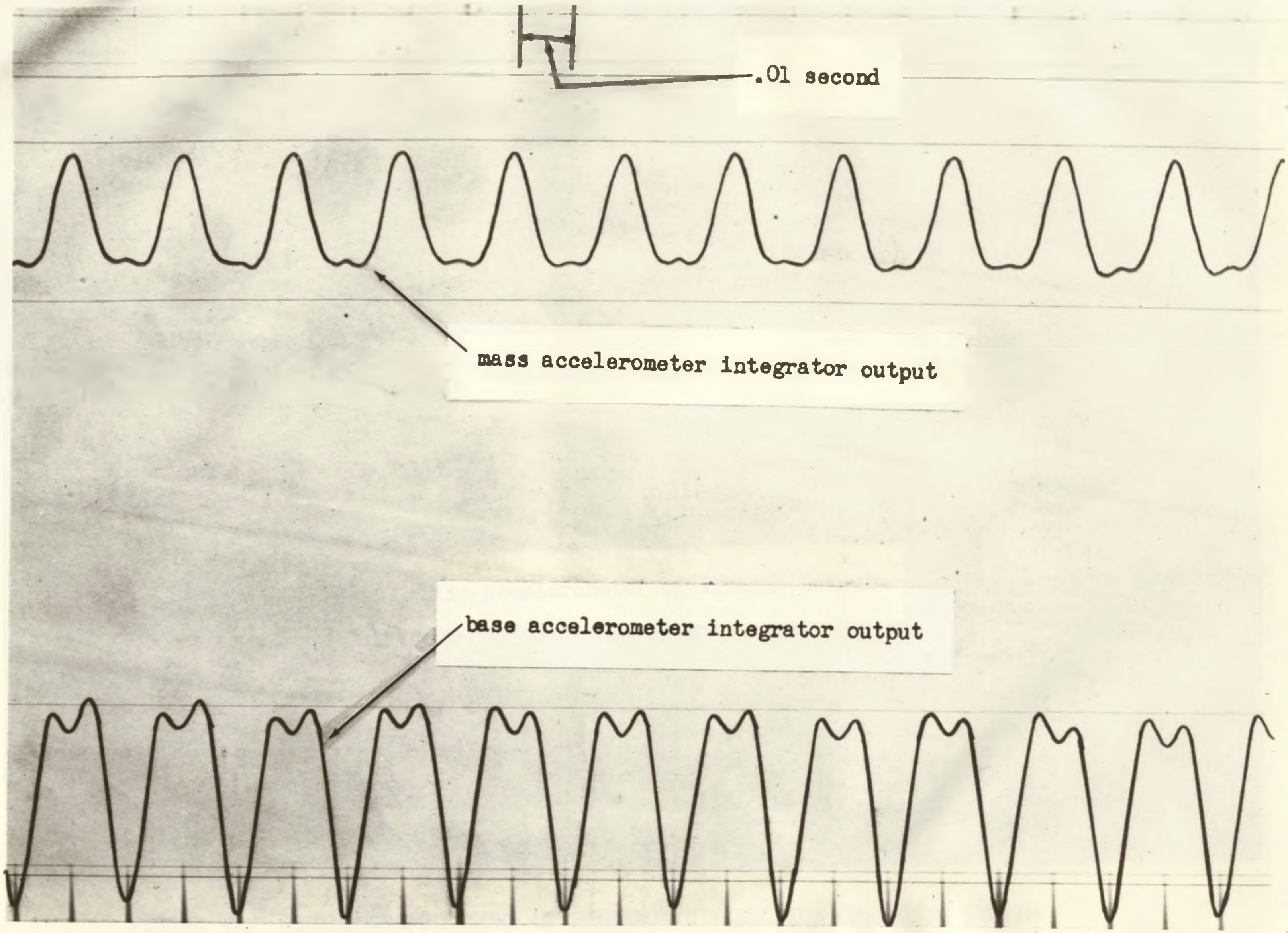

FIGURE 30. OSCILLOGRAPH RECORD OF BIHARMONIC VIBRATION OF SPRING SYSTEM

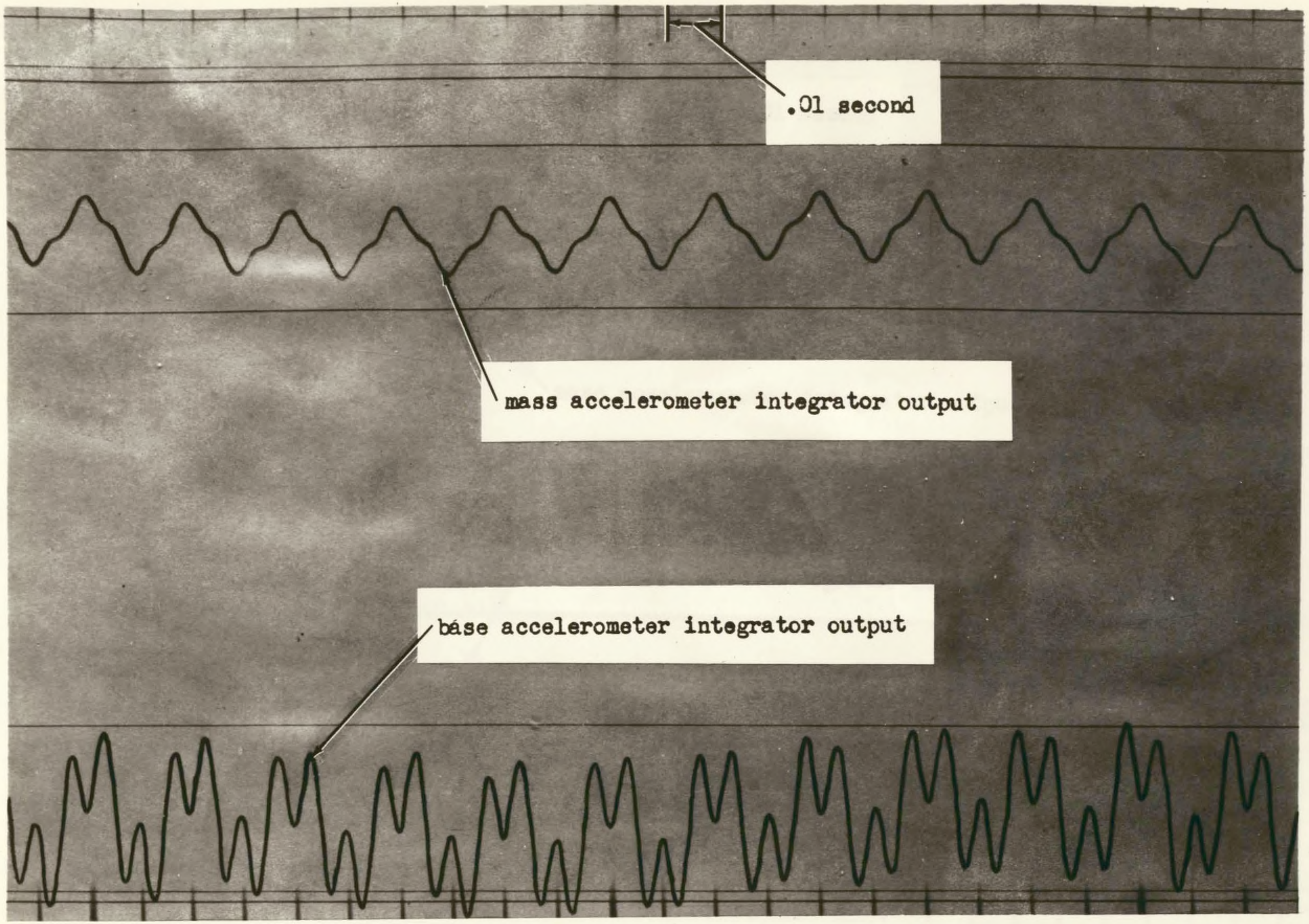

FIGURE 31. OSCILLOGRAPH RECORD OF BIHARMONIC VIBRATION OF SPRING SYSTEM

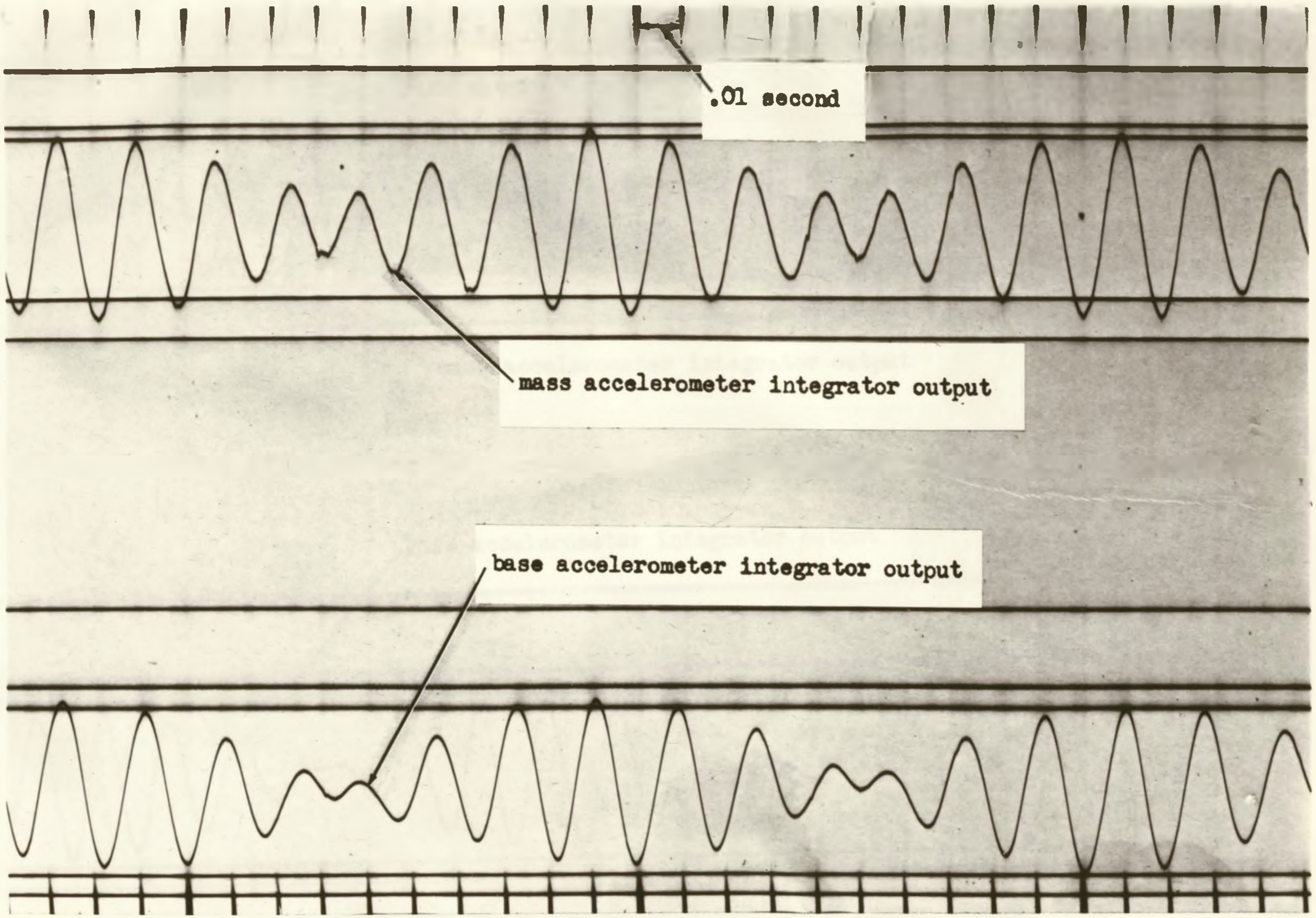

FIGURE 32. OSCILLOGRAPH RECORD OF BIHARMONIC VIBRATION OF SPRING SYSTEM

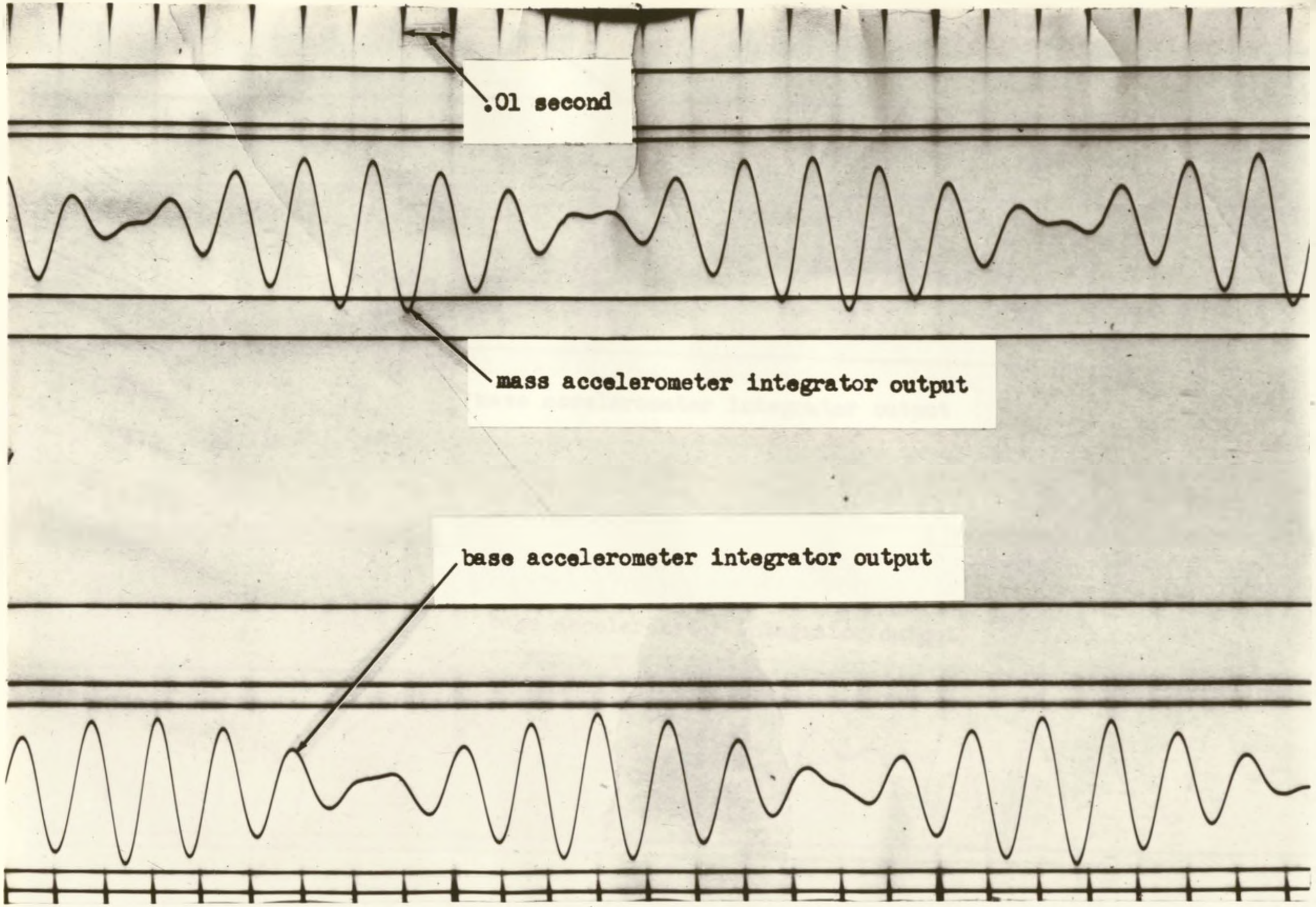

FIGURE 33. OSCILLOGRAPH RECORD OF BIHARMONIC VIBRATION OF SPRING SYSTEM

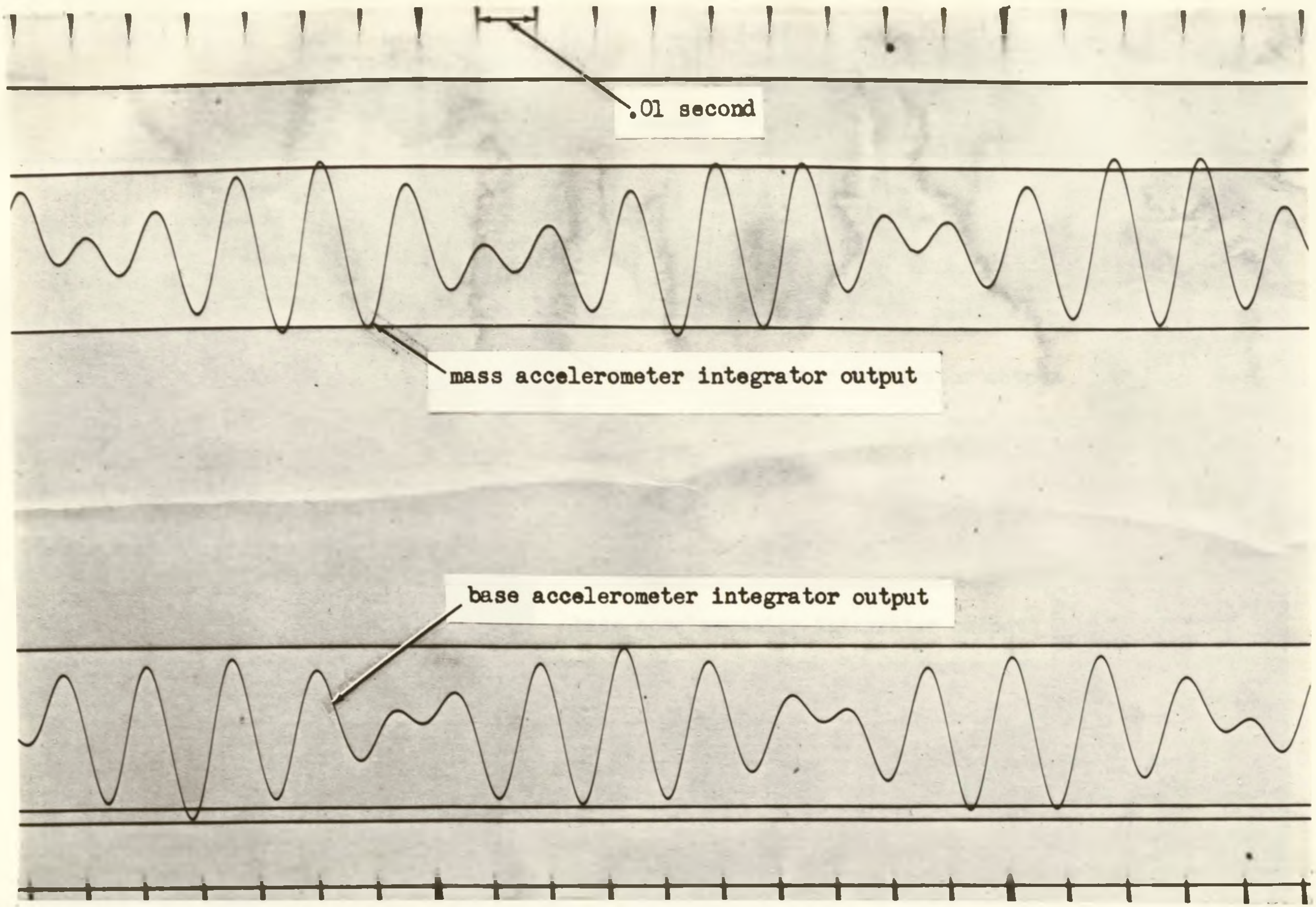

FIGURE 34. OSCILLOGRAPH RECORD OF BIHARMONIC VIBRATION OF VIBRATION MOUNT SYSTEM

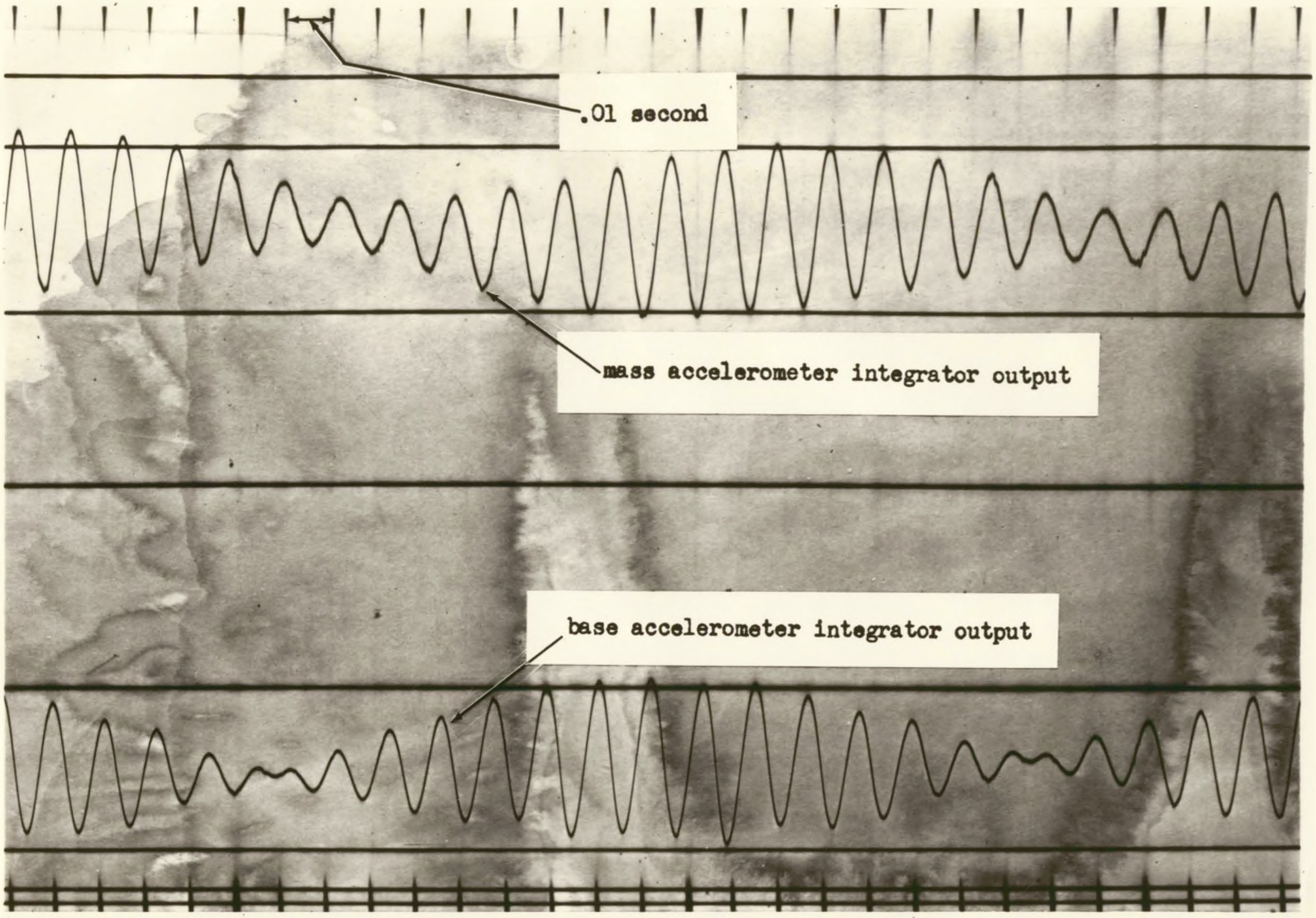

FIGURE 35. OSCILLOGRAPH RECORD OF BIHARMONIC VIBRATION OF VIBRATION MOUNT SYSTEM