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NAVY DEPARTMENT
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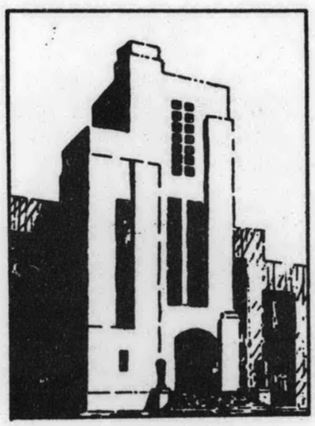
VIBRATION GENERATOR TEST ON THE
USS NORTHAMPTON (ECLC-1)

by

John T. Birmingham



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NS712-100

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ABSTRACT

This report describes a vibration generator test made on the USS NORTHAMPTON (ECLC-1) and compares the experimental results with computed data. These data include the transverse and vertical critical frequencies and normal modes of hull vibration.

INTRODUCTION

In an investigation of the shock and vibration characteristics of the polemast of the USS NORTHAMPTON (ECLC-1)* it was found that the fundamental frequencies of fore-and-aft and transverse vibration of the mast would probably fall within the range of the lower modes of vibration of the hull. So that steps could be taken to correct the possible coincidence of mast and hull frequencies, which would lead to excessive vibration of the mast in service, the David Taylor Model Basin proposed[1]** that the natural frequencies of the hull be determined experimentally. With the approval of the Bureau of Ships[2], vibration generator tests were conducted on the NORTHAMPTON in deep water.

The Taylor Model Basin is also interested in compiling experimental data on the natural frequencies, normal modes, and amplitudes of vibration of ship hulls in general in order to check the validity of theoretical developments in the field of ship vibration.[3] The ultimate object of this program is to permit reliable predictions of the vibration characteristics of a hull in the early stages of design. The data from the NORTHAMPTON thus afforded another opportunity to check the theory. A comparison of these data is presented in this report.

INSTRUMENTATION AND TEST PROCEDURE

The vibration generator test made by the Taylor Model Basin on the USS NORTHAMPTON was conducted in deep water in the Atlantic Ocean off the New England coast in late June 1953. The load conditions for the period of the test were substantially constant.

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* The results of this investigation will be published in a separate TMB report.

** References are listed at the end of this report.

The main characteristics of the ship are as follows:

Length overall on centerline	677 ft 1 3/4 in.
Length between perpendiculars	664 ft 0 in.
Breadth, extreme (outside armor)	70 ft 2 3/4 in.
Depth, main deck to B.L. at centerline	51 ft 2 in.
Displacement	17,000 long tons
Mean draft	22 ft 11 in.

The vibration generator[4] and its controls and the instrumentation used to measure the amplitude and frequency of the vibration were installed at the Boston Naval Shipyard. Figure 1 is a block diagram of the vibration generating and measuring instrumentation. The vibration generator is controlled by the operator at the control console. The frequency of the exciting force can be controlled either manually or automatically. Automatic operation permits a sweep of the desired range of vibration generator frequency at a slow even rate, which can be varied at the discretion of the operator. A slow sweep of the frequency range is desirable in order to permit a build-up in amplitude of the vibration at the resonant frequencies of the hull. The stabilizing voltage fed back from the vibration generator allows smoother operation and assists in holding the vibration generator frequency constant when it is desired to vibrate the hull at some fixed frequency.

The vibration generator was located in Compartment 5-152-0-A between Frames 157 and 158 on the centerline of the ship for the entire test. The range of vertical vibration frequencies excited by the vibration generator was from 40 to 1030 cpm. The transverse range excited was from 40 to 550 cpm. For this installation it was felt that shoring of the deck under the vibration generator was not necessary. The TMB medium vibration generator used on this test was designed to exert maximum alternating forces of 20,000 lb; later it was estimated to be safe up to 30,000 lb. Its practical speed range is from 50 to 1500 rpm.

The six-channel recording system shown in Figure 1 was used to obtain a vibration displacement record of the horizontal and vertical response of the hull for the frequency ranges covered by the vibration generator. The signal generated in the General Radio crystal pickup due to the vibration of the hull was integrated and amplified by the General Radio vibration meter. This amplified signal was carried to the Brush amplifier and recorder through an eight-pair two-conductor shielded cable that extended the full length of the ship. The desired positioning of the vibration measurement pickups along the hull of the ship was facilitated by the many tap-in points available along the length of the signal cable. An intercommunication system was used to maintain contact between the operator of the vibration generator controls at the stern of the ship, the operator of the recording instrumentation at the bow, and the man who positioned the pickups along the main deck.

The location of the vibration generator is shown in Figure 2, which is a profile of the vessel.

TEST RESULTS

Table 1 lists the frequencies of the vertical and transverse modes* obtained from the vibration generator tests on the USS NORTHAMPTON. Definite resonances were not observed above the seventh vertical mode or the fifth transverse mode. This is consistent with the observation, made from tests on other ships,[5,6,7] that the vessel does not act as a beam above a limiting frequency that is, in part, determined by the length-to-breadth ratio of the vessel. The amplitude profiles of the second through the seventh vertical modes are shown in Figure 3. The fundamental vertical mode was excited by sea conditions. The force generated by the vibration generator was not of sufficient magnitude to maintain vibration of the hull at this low frequency. The first five modes of transverse vibration are shown in Figure 4. The amplitude of the exciting force as well as its point of application is indicated on the figures. Figure 5 is a plot of vertical and horizontal vibratory response of the hull at the forward perpendicular over the range of frequencies that includes all the normal modes excited during these tests. At frequencies above the range covered by Figure 5, the amplitude of the vibration measured at the forward perpendicular decreases steadily until it becomes impractical to measure vibration.

An attempt was made to determine the vibratory response of the hull at vibration generator frequencies that extend through the top blade frequency** of the USS NORTHAMPTON. Serious local vibration at the vibration generator location made it unwise to approach the top blade frequency of 1360 cpm. The highest vibration generator frequency attained on the attempt to reach top blade frequency was 1030 cpm.

GENERAL DISCUSSION

In Table 2 the experimentally determined frequencies of the natural modes of vibration are compared with frequencies calculated by means of the electrical analogy described in Reference 3.

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* In the discussion, the term "mode" is to be understood as a normal mode of vibration of the hull.

** Blade frequency is equal to shaft rpm times the number of propeller blades.

TABLE 1

Critical Frequencies of Flexural Hull Vibration Obtained From Vibration Generator Tests

Mode	Critical Hull Frequencies in CPM	
	Vertical Modes	Transverse Modes
1	68	103
2	133	183
3	204	276
4	288	327
5	359	392
6	437	
7	500	

TABLE 2

Comparison of Experimental and Theoretical Resonances

Mode	Resonances of Flexural Hull Vibration in CPM			
	Vertical Modes		Transverse Modes	
	Experimental	Theoretical	Experimental	Theoretical
1	68	64	103	80
2	133	130	181	166
3	204	207	276	277
4	288	283	327	405
5	359	358	392	530
6	437	434		
7	500	500		

Computed and experimental frequencies of the vertical and transverse modes are compared in Table 3 in terms of errors. The errors in the computed values of the frequencies of the vertical modes are less than the average of those obtained for previous ships tested, while the errors for the computed frequencies for the transverse modes are, in general, greater.

To complete the comparison of the experimental data with the results of the electrical-analog calculations on the USS NORTHAMPTON, Figures 6 through 9 are presented. Figures 6 and 7 are the vertical and transverse modes obtained by use of the electrical analog. Figures 8 and 9 show the flexural response of a point on the hull to a constant-amplitude, variable-frequency driving force as determined by electrical analogy. No attempt was made to represent the actual damping in these analog calculations. The resistance in the circuit was only the internal resistance of the elements used, which was known to be small, or in general, comparable with the low damping known to exist in the ship. Only relative values are plotted.

TABLE 3

Errors in Computation of the Frequencies of the Vertical and Transverse Modes of Vibration

Mode	Error-Percent	
	Vertical	Transverse
1	-5.6	-22.0
2	-2.3	- 8.3
3	+1.5	+ 0.4
4	-1.7	+24.0
5	-0.8	+38.0
6	-0.7	
7	0.	

The plus sign indicates that the computed frequency is higher than the experimental frequency.

PERSONNEL

The vibration generator tests were conducted by M. E. Graybill, Q. R. Robinson, B. M. Wigle, J. T. Birmingham, and E. Kapiloff. The analog calculations were made by R. R. Milam and J. T. Birmingham.

The vibration generator test of the hull was run by E. Kapiloff. The project involving the correlation of stress in the mast with vibration of the hull is under the direction of N. H. Jasper.

REFERENCES

1. TMB ltr S87/Vibration of 28 July 1952 to BuShips.

2. BuShips ltr CLC1/S17(371) Ser 371-445 of 22 August 1952 to TMB.

3. McGoldrick, R. T., Gleyzal, A. N., Hess, R. L., and Hess, G. K., Jr., "Recent Developments in the Theory of Ship Vibration," TMB Report 739, February 1951.

4. Berdahl, E. O., "Construction and Operation of the Taylor Model Basin 5000-Pound Vibration Generator," TMB Report 524, April 1944.

5. Jasper, Norman H., "Vibration-Generator Survey of the USS NIAGARA (APA87)," TMB Report 699, December 1948.

6. Kapiloff, Edward, and Birmingham, John T., "A Report on Hull Vibration Measurements Made on the SS BETHLEHEM and Vibration Generator Tests Made on the SS C. A. PAUL and the SS PERE MARQUETTE 21 While in Service on the Great Lakes," TMB Report 848, March 1953.

7. McGoldrick, R. T., "Determination of Hull Critical Frequencies on the Ore Carrier SS E. J. KULAS by Means of a Vibration Generator," TMB Report 762, June 1951.

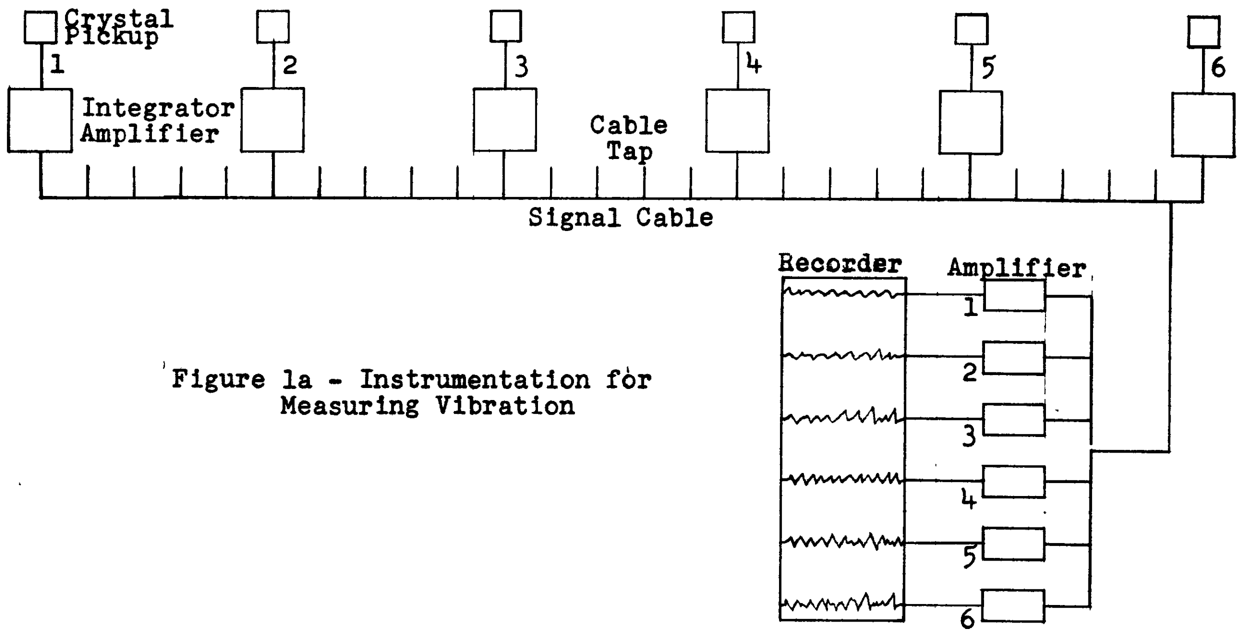

Figure 1a - Instrumentation for Measuring Vibration

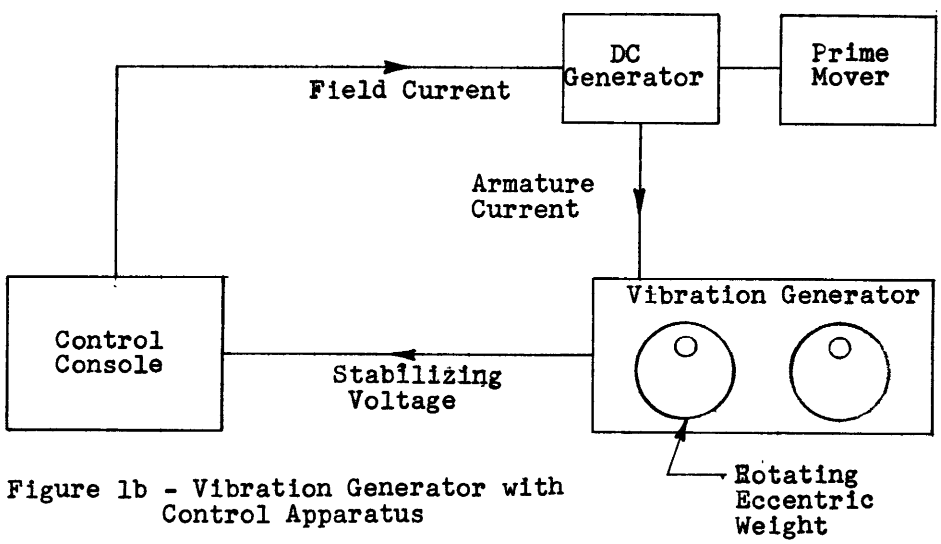

Figure 1b - Vibration Generator with Control Apparatus

Figure 1 - Block Diagram of the Instrumentation for Vibration Generator Tests on the USS NORTHAMPTON (ECLC-1)

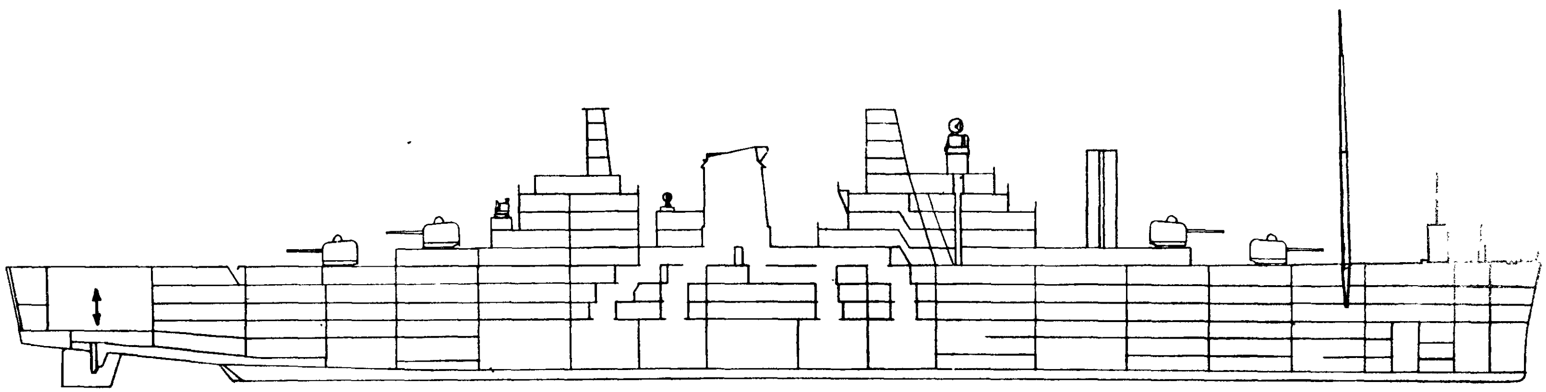

Figure 2 - Profile of USS NORTHAMPTON (ECLC-1)

The arrow shows the location of the vibration generator.

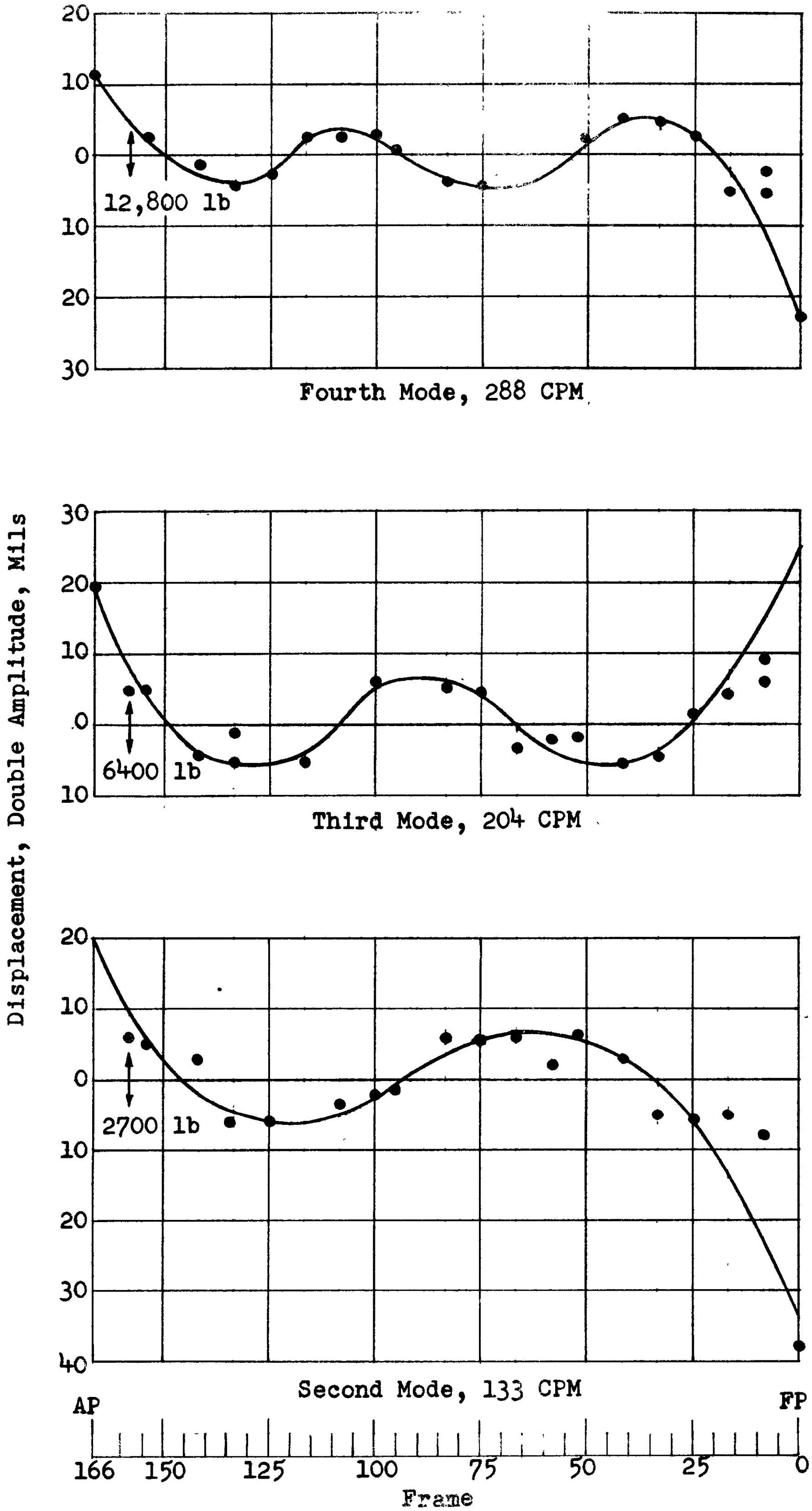
Displacement, Double Amplitude, Mils
12,800 lb
Fourth Mode, 288 CPM
6400 lb
Third Mode, 204 CPM
2700 lb
Second Mode, 133 CPM
AP
FP
166
150
125
100
75
50
25
0
Frame

Figure 3

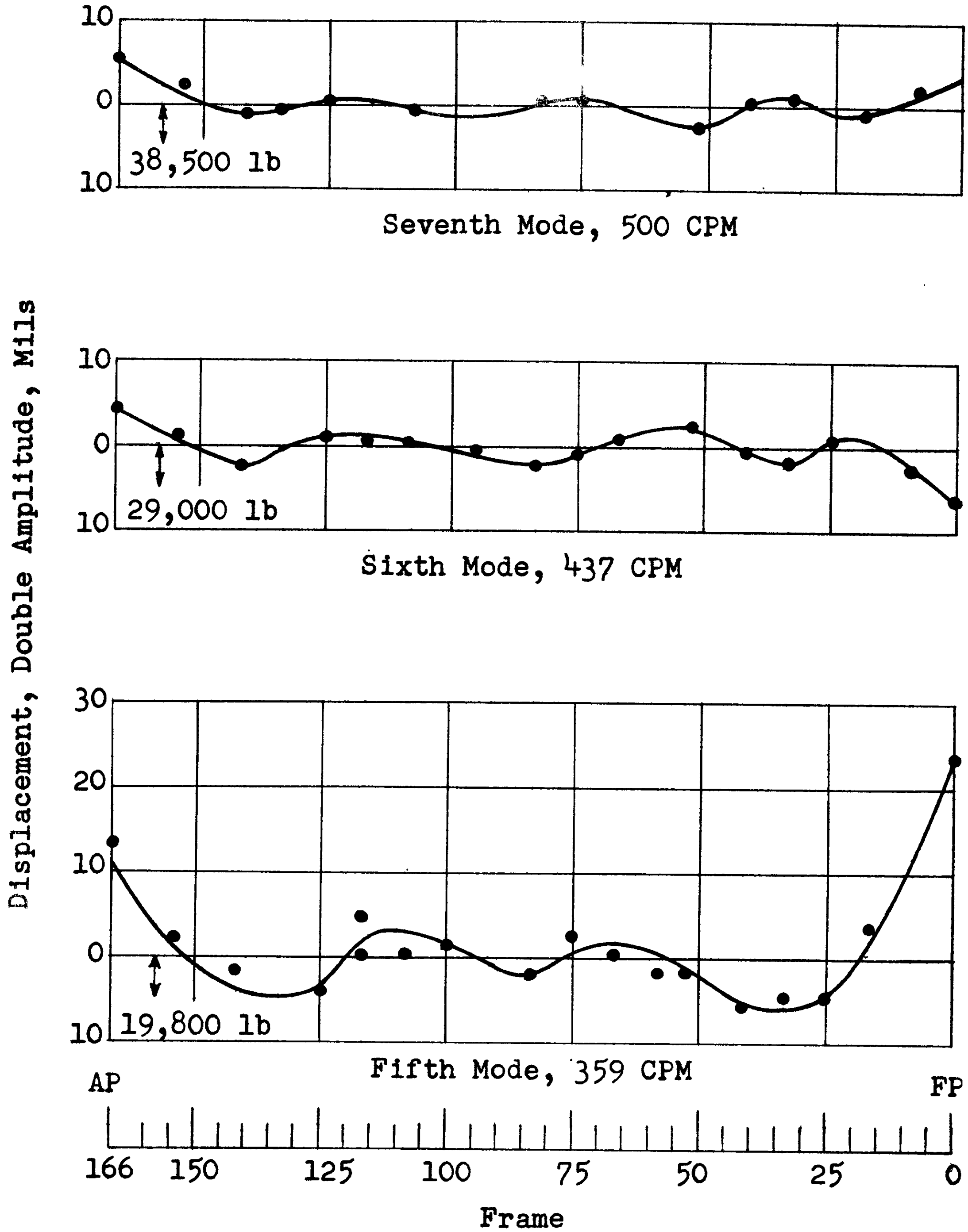

Figure 3 - Normal Modes of Vertical Hull Vibration

The driving forces indicated were applied between Frames 157 and 158. The sixth and seventh modes were actually explored at a reduced eccentricity, and the amplitudes shown were scaled up to those equivalent to an eccentricity of 180 deg.

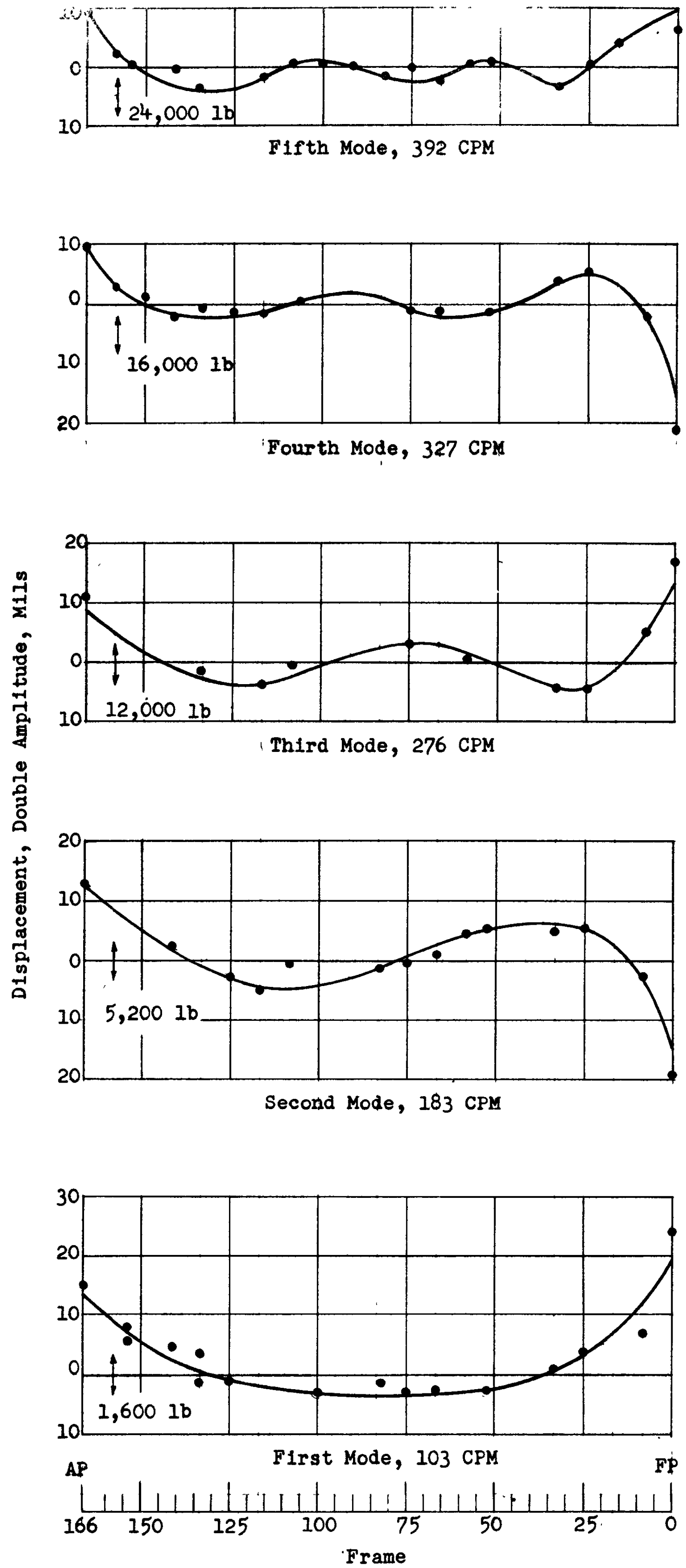

Figure 4 - Normal Modes of Transverse Hull Vibration

The driving forces indicated were applied between Frames 157 and 158.

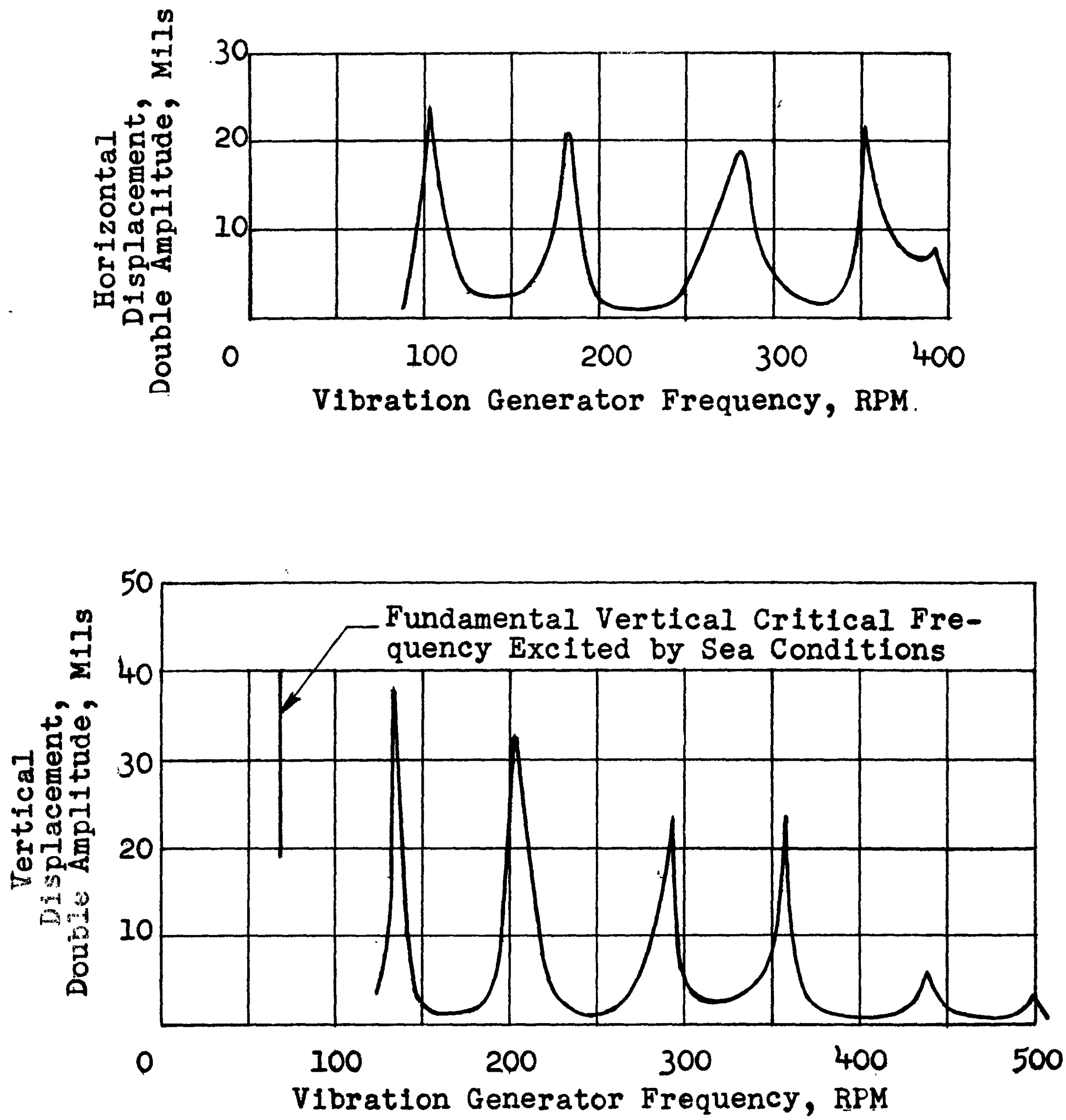

Figure 5 - Vertical and Horizontal Flexural Response of Ship's Hull to Vibration Generator Driving Force

A driving force of 0.116 $(RPM)^2$ lb was applied between Frames 157 and 158. Vibration amplitudes were measured at the forward perpendicular.

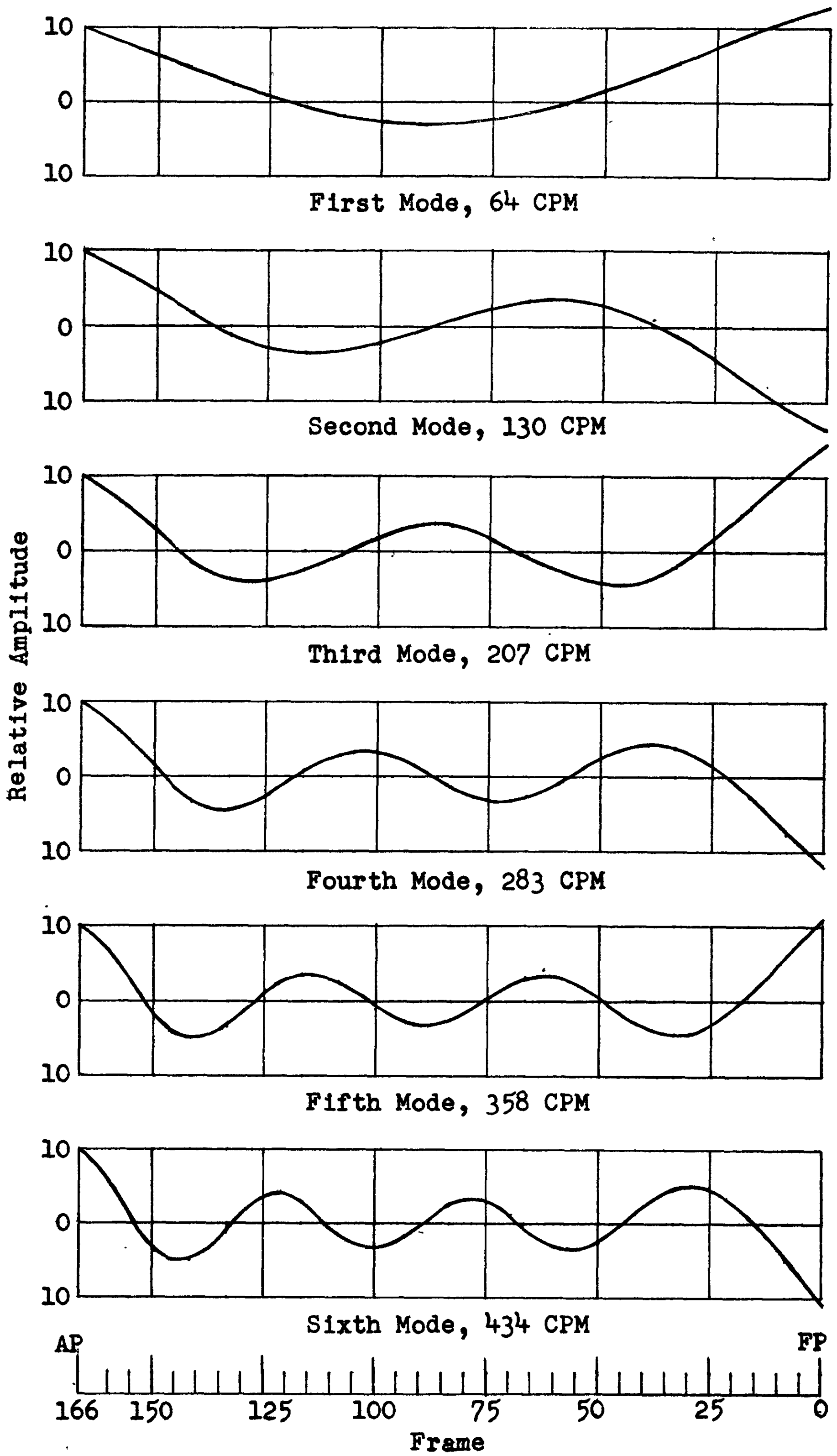

Figure 6 - Normal Modes of Vertical Hull Vibration as Computed by Use of Electrical Analog

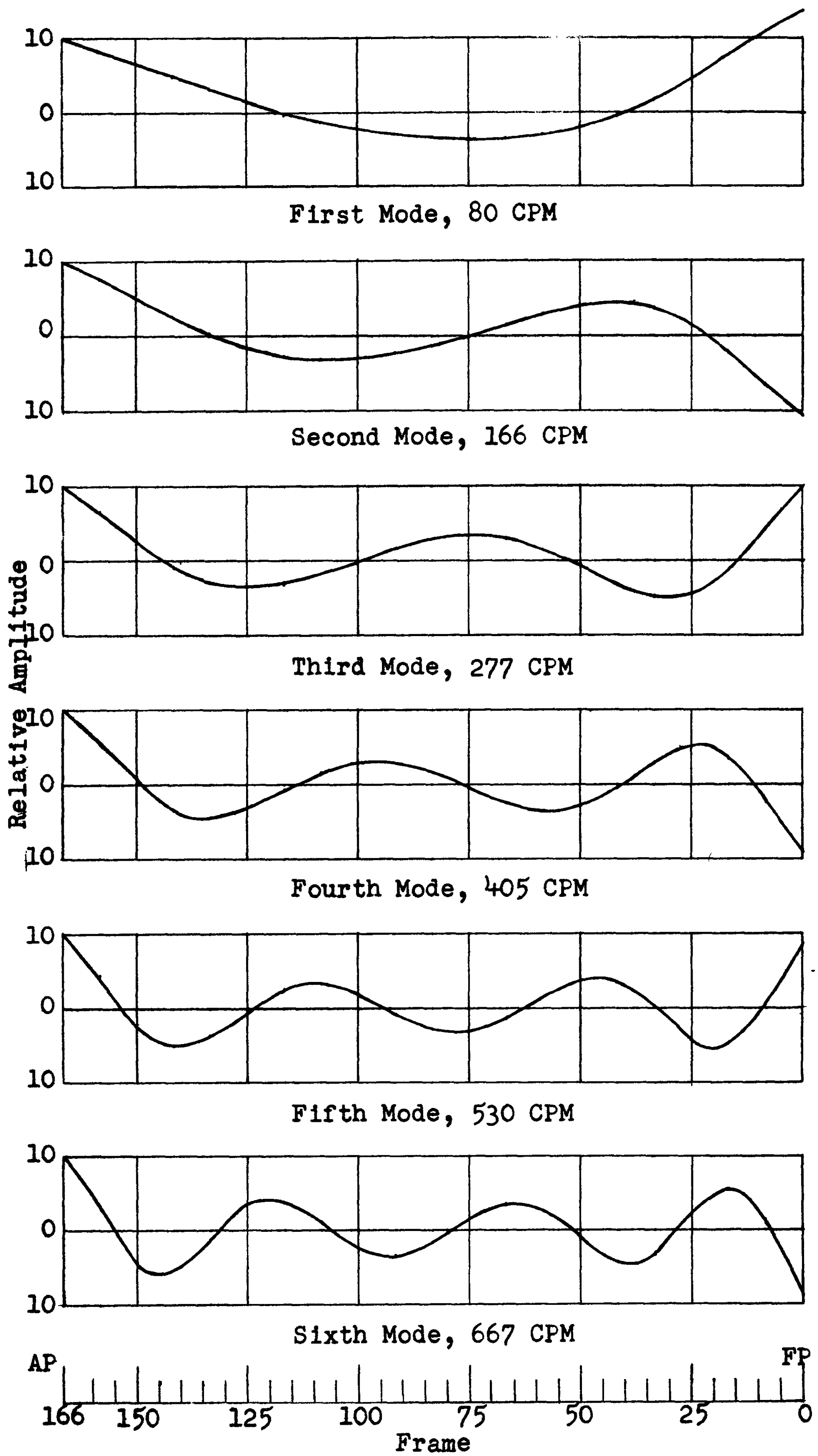

Figure 7 - Normal Modes of Transverse Hull Vibration as Computed by Use of Electrical Analog Computation

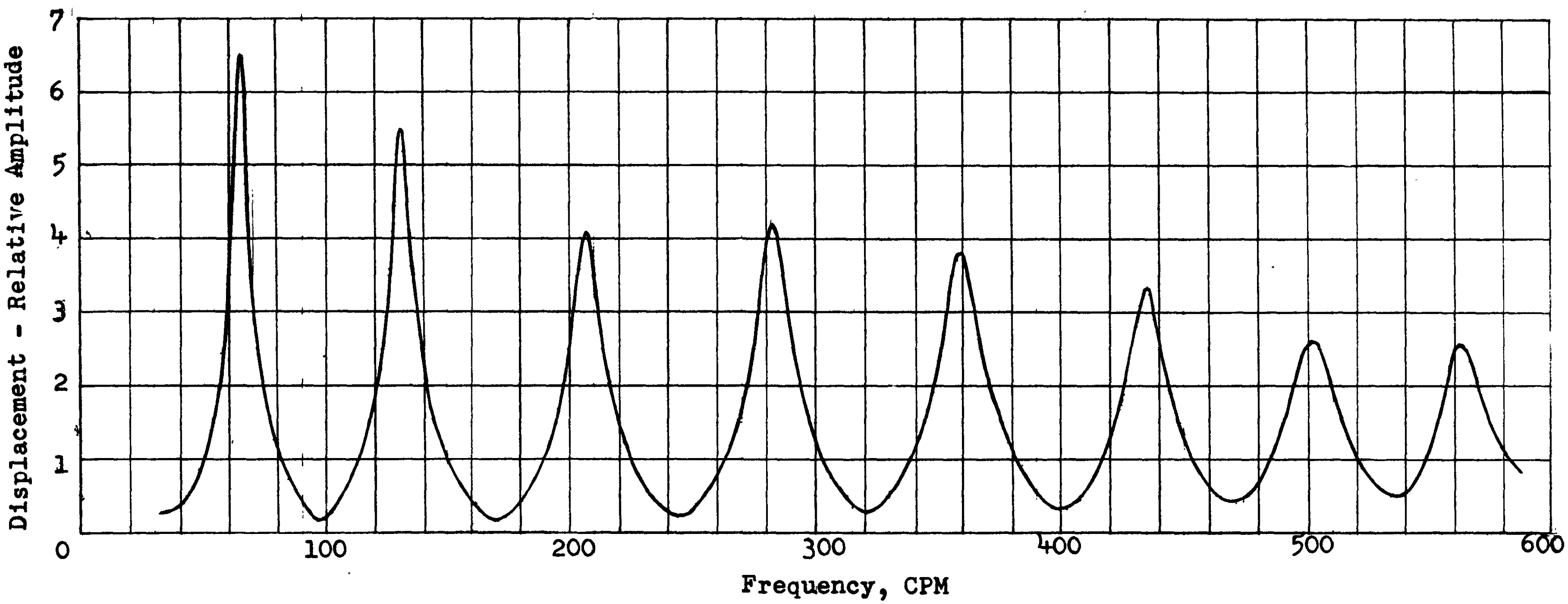

Figure 8 - Vertical Flexural Response of Hull at Forward Perpendicular to a Driving Force of Constant Amplitude and Variable Frequency as Computed by Means of Electrical Analog

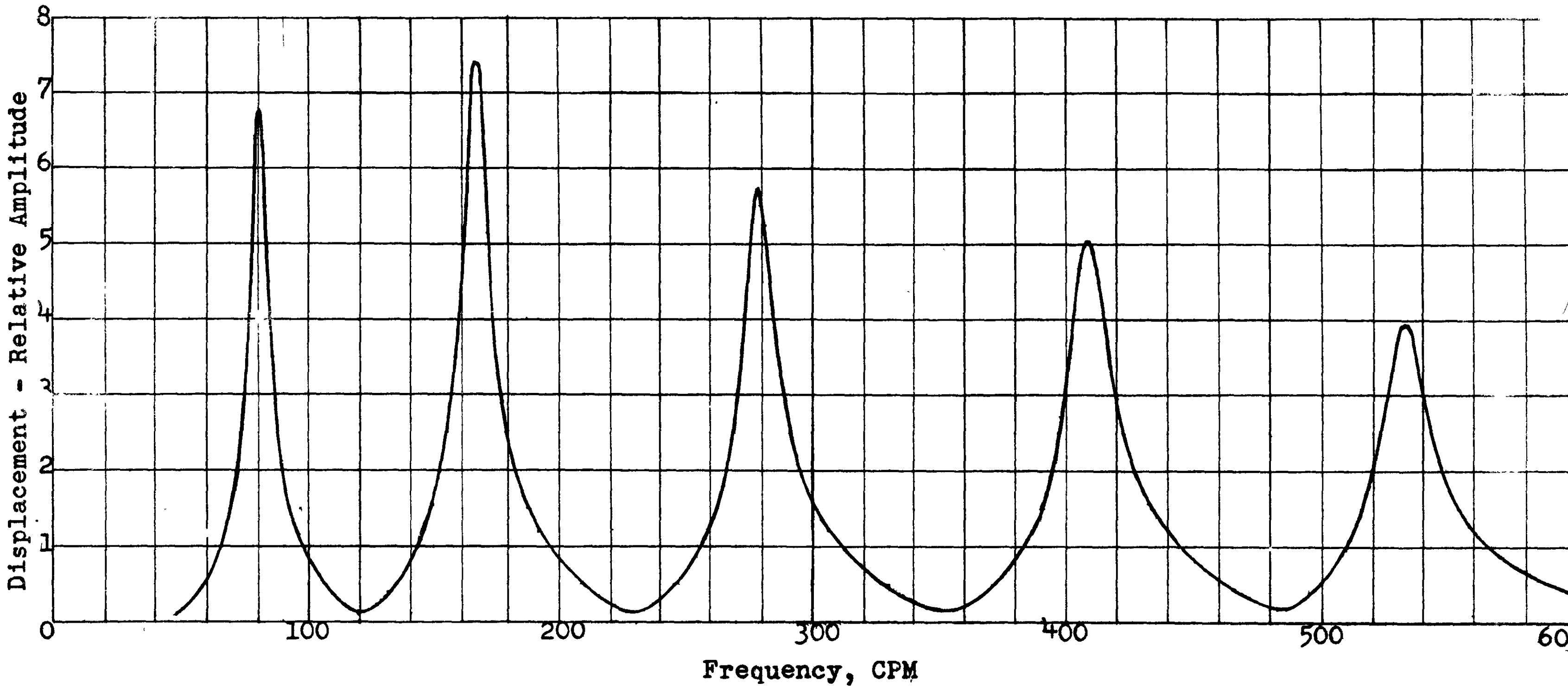

Figure 9 - Horizontal Flexural Response of Hull at Forward Perpendicular to a Driving Force of Constant Amplitude and Variable Frequency as Computed by Means of Electrical Analog

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