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NAVY DEPARTMENT
DAVID TAYLOR MODEL BASIN
WASHINGTON, D.C.

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VIBRATION MEASUREMENTS MADE 18 AUGUST 1947 ON THE USS AMBERJACK (SS522)

by

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U.S. Navy Regulations, 1920, Art. 76(11).

November 1947

Report C-34

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ABSTRACT

Vibration measurements were taken on 18 August 1947 on the USS AMBERJACK (SS522), a submarine of the GUPPY conversion Class, to determine the vibrations of the hull during surfaced and submerged operations in the speed range from 180 to 380 RPM. The vibrations of propeller-blade and shaft-RPM frequency were of low magnitude, indicating well-balanced propellers, correctly aligned propeller shafts, and the existence of very little objectionable hydrodynamic interaction between the propellers and the hull and its appendages.

Comparison of the results of this test with the results of previous tests on the USS ODAX (SS484), which belongs to the same class but which has stabilizing planes mounted close to the propellers, showed that increased vibrations of propeller-blade frequency resulted from hydrodynamic action between the stabilizing planes and the propellers.

INTRODUCTION

On 11 August 1947 the Bureau of Ships requested (1)* the David Taylor Model Basin to measure vibrations on the USS AMBERJACK (SS522).

The primary purpose of this test** was to measure and analyze the vibration characteristics of the USS AMBERJACK (SS522) and to compare its vibration characteristics with those of the USS ODAX (SS484), a ship of the same class which had certain differences in hull appendages.

The AMBERJACK is one of the first submarines of the SS487 Class (GUPPY conversion Class) on which vibration measurements have been made. Ships of this class differ from those of the previous class in having a streamlined hull and modified propulsion machinery for attaining higher speeds, up to 380 shaft RPM surfaced and 330 RPM submerged. In addition, some design plans for this class include the mounting of a stabilizing plane a short distance forward of each propeller. Figure 1 is a photograph of a model submarine of this class without stabilizing planes and Figure 2 shows one with stabilizers installed.

Vibration tests were made on the ODAX, which is also of the SS487 Class (GUPPY conversion Class), during June and July 1947 and were reported previously (3) (4). There were two differences in the hull appendages of the AMBERJACK and the ODAX. First, the ODAX was equipped

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* Numbers in parentheses indicate references on page 13 of this report.

** The research project symbol and number assigned to the test is SRD265, C-175-35, Reference (2).

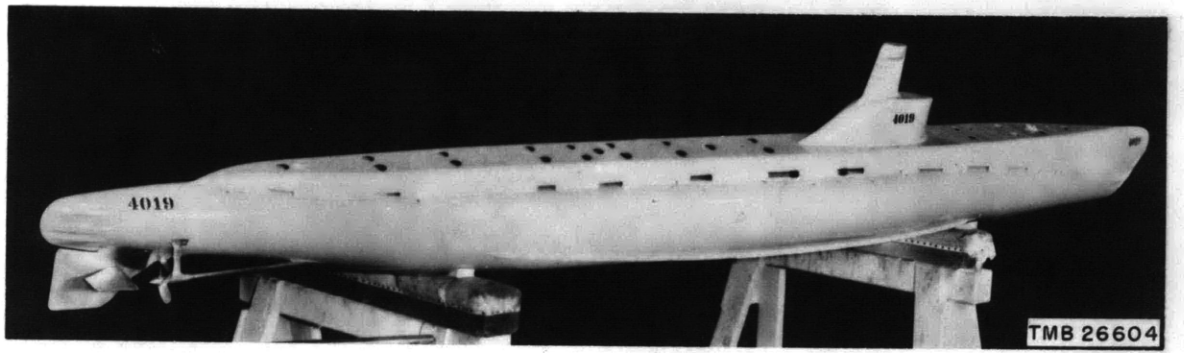

Figure 1 - Model of a Submarine of the SS487 Class without Stabilizing Planes

Figure 2 - Stern of a Model of a Submarine of the SS487 Class with Stabilizing Planes

with two stabilizing planes which extended horizontally beneath the stern section of the ship just forward of the propellers as shown in Figure 2. The AMBERJACK was not equipped with these stabilizing planes. During the first test on the ODAX (3), the stabilizers extended from Frame 113 to Frame 127 1/4 and ended 8 inches forward of the propellers. The location of the frames and other structures of the submarines discussed in this report are shown in Figure 3 which is an outboard elevation of a submarine of the SS487 Class. Hull vibrations of propeller-blade frequencies (three times the shaft RPM) as well as the vibration of Torpedo Tube 7 measured during the ODAX test were believed to be caused by the proximity of the stabilizers to the propellers and it was recommended (3) that the clearance between propellers and stabilizers be increased. The stabilizing planes were then cut back to provide a clearance of 1 foot 8 inches on the outboard side and of 2 feet 8 inches on the inboard side of the propellers (5). A second vibration test was made on the ODAX after these changes were made on the stabilizers. The results of this test indicate that vibrations of the hull and of the torpedo tube at propeller-blade frequency were of smaller amplitude during the later trials of the ODAX.

A second difference between the hulls of the two ships, which undoubtedly was of minor importance as related to the vibration characteristics, was the addition, on the AMBERJACK, of a sheet-metal casing around the snorkel tubes just aft of the conning tower extending from Frame 56 to Frame 62 as shown by the dotted outline on Figure 3. Both ships were equipped with three-bladed propellers.

For the purpose of comparing the vibrations on both vessels the same type of instrumentation was used at the same locations for all three tests.

TEST METHODS AND PROCEDURE

Vibration measurements were made in the after torpedo room on Frame 122, on the ship's centerline in both the vertical and in the transverse directions, using two Consolidated vibration pickups, Type 4-102, feeding through an electrical integrator into a Brush amplifier and oscillograph. The location of the pickups is shown in Figure 3. The two Consolidated vibration pickups used had been calibrated together with their accessory recording instruments to record displacements at frequencies down to 180 CPM. The amplitudes of vibrations at frequencies lower than 180 RPM are estimated to be accurate to within 30 per cent.

Since vibration frequencies of 120 CPM had been recorded on the earlier tests on the ODAX, References (3) and (4), a TMB pallograph, Type V, which had been calibrated to record displacements at frequencies down to 60 CPM was also used to record vertical vibrations. This instrument was located at Frame 120 1/2 on the centerline of the deck plate of the after torpedo room. Measurements were made at these stations during surfaced operation at speeds from 180 to 385 shaft RPM in 20-RPM

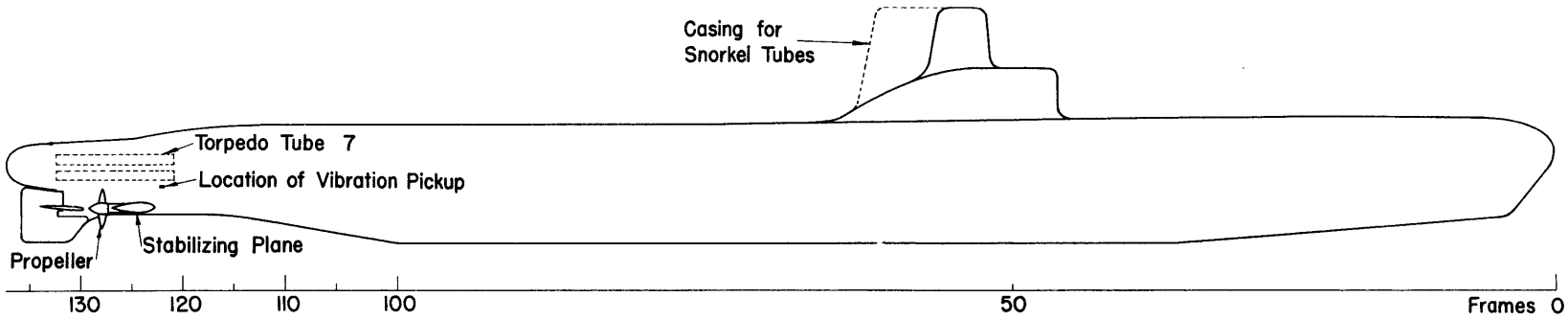

Figure 3 - Outboard Elevation of Submarine of SS487 Class (GUPPY Conversion Class)

intervals, as well as during a crash-back run from full power ahead to full power astern. Measurements were also made at these stations while the ship was cruising submerged at several speeds.

The transverse and vertical vibrations of Torpedo Tube 7 were recorded by means of an Askania vibrograph during surface and submerged operations.

TEST RESULTS

Amplitudes of vertical vibration measured at Frames 122 and 120 1/2 during surfaced operation are plotted against propeller shaft RPM in Figure 4 and similar measurements of transverse vibration are plotted in Figure 5.

The only frequencies of vertical vibration in evidence (see Figure 4) were 120 CPM and from 270 to 300 CPM. The maximum vertical single amplitude* at 120 CPM was about 9 mils. In the range from 270 to 300 CPM, the maximum vertical amplitude was about 3 mils. The transverse vibrations, similarly, were predominantly of these same frequencies, that is, 120 CPM and from 270 to 300 CPM, as plotted in Figure 5. The maximum transverse amplitude at 120 CPM was about 21 mils, whereas in the range from 270 to 300 CPM it was only about 1 mil. Transverse vibration of propeller-blade frequency of very low amplitude, about 0.4 mil, was recorded at speeds from 320 to 385 RPM; see Figure 5.

As noted in the section on "Test Methods and Procedures" the Consolidated vibration pickups and the accessory recording equipment were not calibrated below 180 CPM and therefore the magnification factor of these instruments at 120 CPM was not known accurately. By extrapolating the calibration curve below 180 CPM an approximate magnification factor can be obtained. The accuracy of measurement of amplitude at the 120-CPM frequency is within 30 per cent. The vibration amplitudes as measured with the TMB pallograph from 120 to 300 CPM are of higher accuracy and probably within 10 per cent of the true value. At the three points, 240, 320, and 360 RPM, where vibration amplitudes at the same frequencies were recorded with both instruments, as shown on Figure 4, the vibration amplitudes check fairly well.

Vertical amplitudes of 11 mils at 680 CPM and of 27 mils at 150 CPM, both measured by the Consolidated vibration pickups at Frame 122, were recorded during the crash-back run, surfaced operation.

The ship was operated submerged at only four speeds corresponding to 100, 215, 270, and 330 shaft RPM. Vibration records were obtained at 215, 270, and 330 shaft RPM. The maximum amplitudes recorded at the full power submerged speed, 330 RPM, were smaller than the maximum amplitudes recorded at full power surfaced speed, corresponding to 380 RPM. However, for the same RPM values the vibration amplitudes were greater during the

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* All vibration amplitudes given in this report are single amplitudes of displacement.

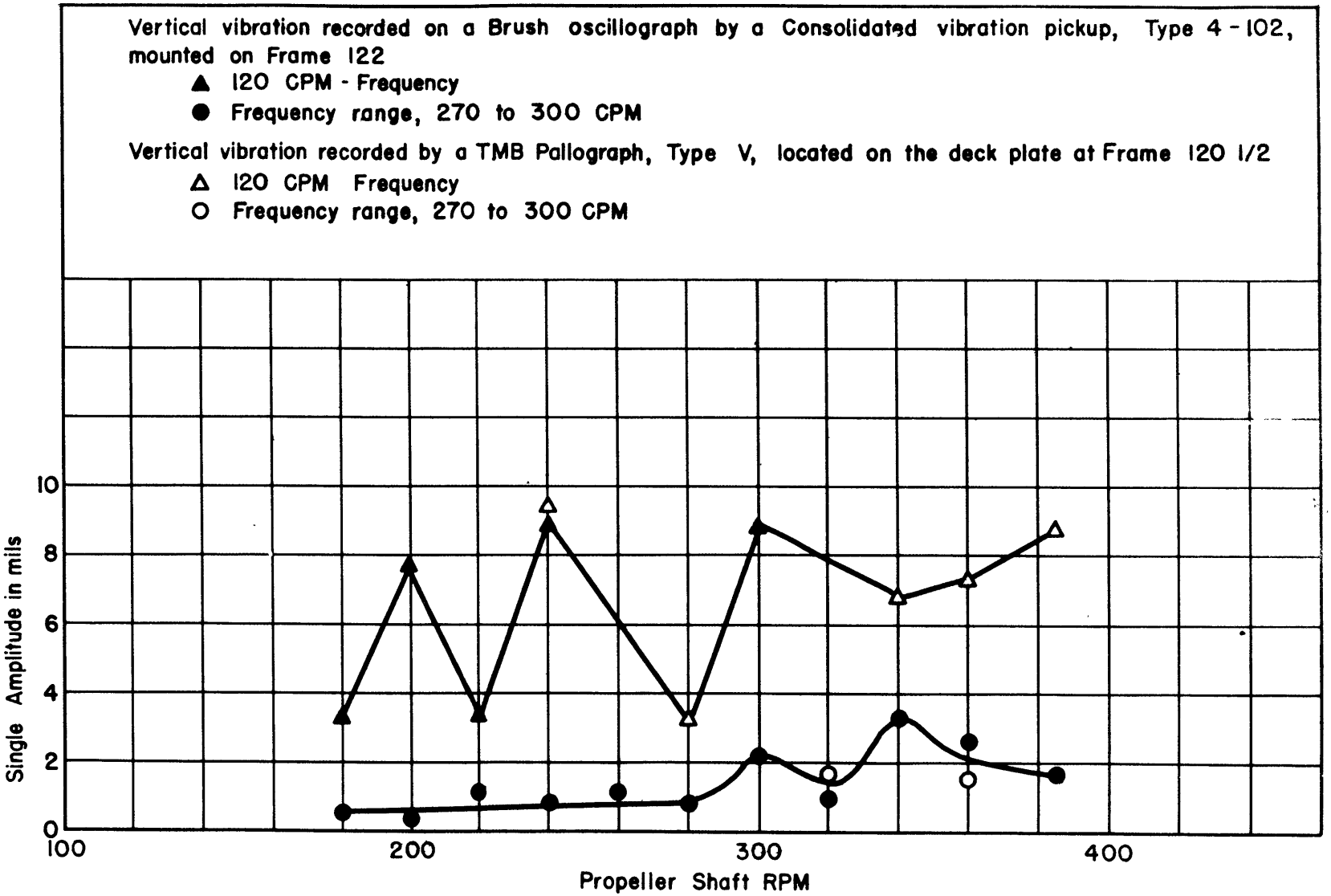

Figure 4 – Amplitudes of Vertical Vibration Measured at Frames 120½ and 122 on the USS AMBERJACK (SS522) during Surfaced Operation

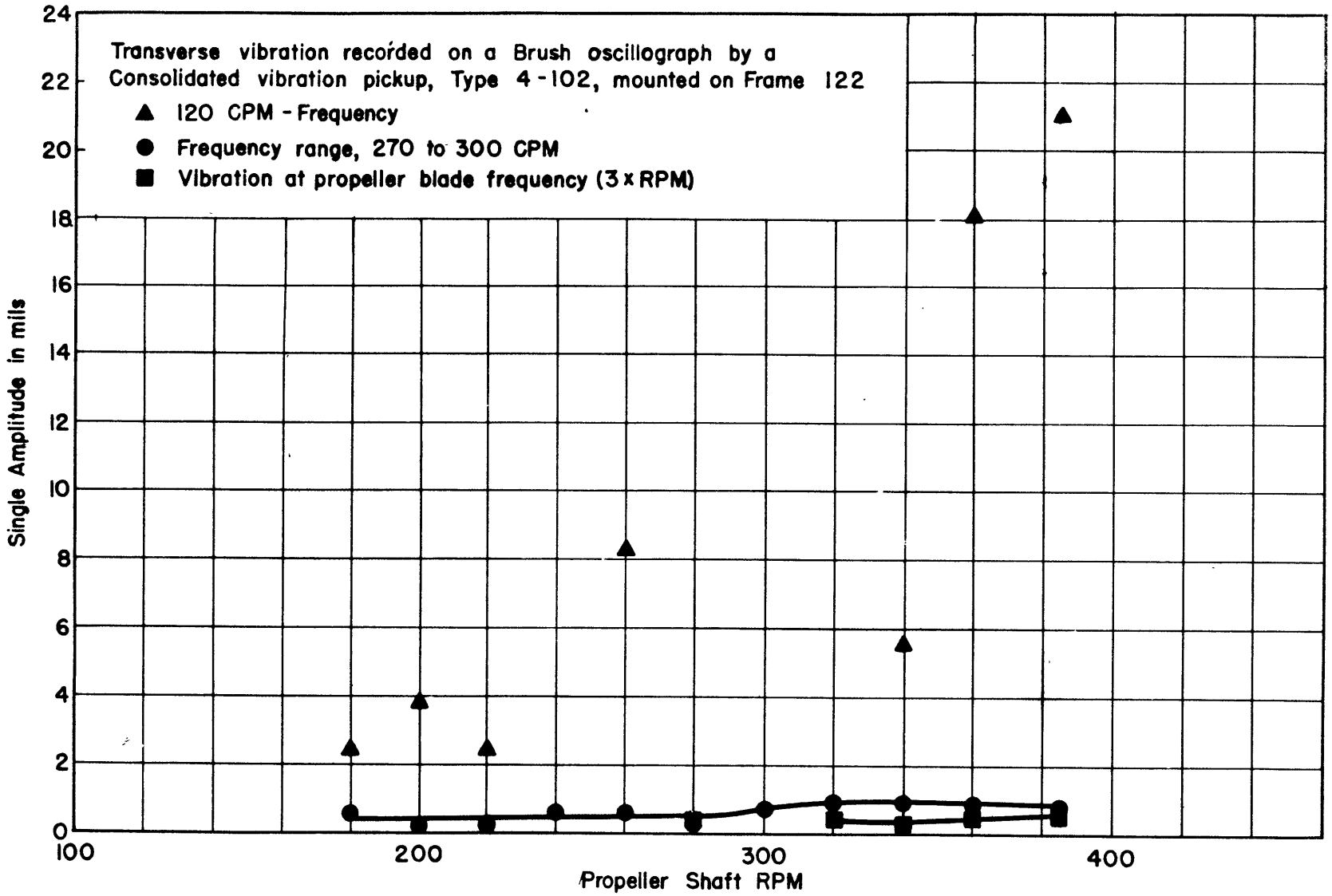

Figure 5 – Amplitudes of Transverse Vibration Measured at Frame 122 on the USS AMBERJACK (SS522) during Surfaced Operation

submerged condition than during the surfaced condition, as shown in Table 1 below, except for the 120-CPM frequency component of the vertical vibration which was greater during the surfaced operation.

TABLE 1

Comparison of Amplitudes and Frequencies, Recorded during Surfaced and Submerged Operation, at Frame 122

Shaft RPM	Surfaced Operation				Submerged Operation			
	Vertical Amplitude mils	CPS	Transverse Amplitude mils	CPS	Vertical Amplitude mils	CPS	Transverse Amplitude mils	CPS
330	2 7.3	270 120	0.4 0.2	270 990	2.3	240	1.4 3.8	270 180
270	0.4 4.7	270 120	0.3	270	1.5 3.2	240 130	3.3 1.5	240 300
215	0.6 6	270 120	0.3	270	2.0	240	0.5	230

The maximum vibration amplitudes of Torpedo Tube 7 were 8.3 mils in the transverse and 0.8 mil in the vertical direction; these values were recorded during full power surfaced operation, corresponding to 385 RPM and 375 RPM of the starboard and port shafts respectively. At other surface speeds the amplitudes of transverse vibration of the torpedo tube were 2.5 mils at 360 RPM and 0.8 mil at 340 RPM. At the maximum submerged speed of 330 RPM, amplitudes of only 0.8 mil and 1.9 mil were measured in the transverse and vertical directions respectively.

DISCUSSION OF RESULTS

The occurrence of two predominant frequencies, one of about 120 CPM and the other between 270 and 300 CPM, throughout the range from 180 to 385 propeller RPM indicates that these frequencies are probably natural frequencies of flexural vibration of the ship's hull. It has previously been observed on two submarines with the same type hull, the USS ODAX (SS484), Reference (3), and the USS RUNNER (SS476), Reference (6), that the natural frequencies of the hull were about 120 CPM for the first mode and about 280 CPM for the second mode of vibration.

It is possible that the vibrations at frequencies between 270 and 300 CPM observed at shaft speeds in the range of 270 to 300 RPM were due to propeller unbalance or shaft misalignment as these frequencies would be approximately the same as the shaft RPM. But in view of the fact that the propellers were balanced and that the propeller shafts

were aligned before the test and since these frequencies persisted over the entire speed range covered, it is more likely that these vibrations are natural flexural vibrations of the hull.

Vibrations of the hull at its natural frequencies are caused by any hydrodynamic force which affects the hull as a whole and are for the most part nonperiodic. The action of waves beating against the hull generates such forces. Reference (3) notes also the possibility that the hydrodynamic action set up by the stabilizing planes on the ODAX (SS484) might result in such forces, causing the hull to vibrate in its natural modes.

Vibrations at propeller-blade frequencies, which for this vessel are equal to three times the propeller shaft RPM's, are caused by the hydrodynamic action originating at each propeller. Blade-frequency forces may be transmitted to the hull through the after bearing or may act directly on the hull in the form of pressure variations. Such frequencies were not recorded except for the vibrations of about 0.4-mil amplitude in the transverse direction between 320 and 385 shaft RPM. Their almost complete absence on the AMBERJACK indicates that the clearance between the propellers and the hull and other underwater appendages of the ship was sufficiently large.

An evaluation of all the previously discussed vibration data obtained on this test indicates that the vibrations caused by the propeller action is of a very low order and also that the addition of the snorkel-tube casing to the superstructure did not result in any undesirable vibration during these trials.

As mentioned in the "Introduction," one of the objectives of this test was to compare the vibration characteristics of this ship with those of the ODAX, to determine, if possible, the effect of the stabilizing planes on the vibration of ships of this type. During the test of 16 June 1947 on the ODAX the stabilizing planes extended to within about 8 inches forward of the propellers and during the test of 11 July 1947 the clearance was increased to about 2 feet 2 inches. The AMBERJACK was not equipped with stabilizing planes. The instrumentation used for all three tests was the same except for the additional use of the TMB pallograph which increased the reliability of the readings of the 120-CPM vibrations taken on the AMBERJACK.

Table 2 tabulates the vibration amplitudes of propeller-blade frequency and of 270 to 300 CPM frequency as measured at Frame 122 during surfaced operation for the three separate tests.

No appreciable vibrations of propeller shaft RPM frequency were found during any of the several tests. This indicates that the shafting and the propellers were well-balanced. The hull vibrations of 270 to 300 CPM frequency show no definite variation in amplitude with change in propeller clearance. It is believed that the vibration of the hull in its

TABLE 2

Comparison of Vibration Amplitudes at Frame 122 Recorded during Surfaced Operation

Frequency CPM	USS ODAX (SS484)								USS AMBERJACK (SS522)			
	Test of 16 June 1947				Test of 11 July 1947				Test of 18 August 1947			
	Vertical Amplitude mils		Transverse Amplitude mils		Vertical Amplitude mils		Transverse Amplitude mils		Vertical Amplitude mils		Transverse Amplitude mils	
	Max.*	Av.**	Max.	Av.	Max.	Av.	Max.	Av.	Max.	Av.	Max.	Av.
Propeller-Blade Frequency	1.5	0.35	1.5	0.6	0.7	0.2	1.0	0.4	0	0	0.5	0.2
270 to 300 CPM, second mode of hull vibration	3.6	1.5	2.2	0.6	3.0	1.2	1.8	0.5	3.0	1.4	0.8	0.6

* The maximum amplitudes occurred at the maximum shaft RPM, which was 360 for the ODAX and 380 for the AMBERJACK.

** This is the average of all measurements.

natural modes is induced, primarily, by action of the sea and that the stabilizers have but little influence on this behavior. The vibration amplitudes of propeller-blade frequency evidence a marked decrease with an increase of the clearance between the stabilizers and the propellers, so that the largest amplitudes were observed during the first test of the ODAX, smaller ones during the second, and the smallest during the AMBERJACK test. It appears probable, on the basis of this behavior pattern, that the vibrations of propeller-blade frequency are due mainly to interaction between the propeller and the stabilizing planes.

The vibration amplitudes measured at Torpedo Tube 7 during the several tests are tabulated in Table 3. These were forced vibrations of propeller-blade frequency and they show the same type of variation as noted previously for the hull vibration at propeller-blade frequency, that is, the amplitudes decrease with an increase between the stabilizer and the propeller. The manner of attaching the torpedo tube to the hull will greatly affect its vibration amplitude and for this reason vibrations of different torpedo tubes cannot readily be compared on the same basis.

CONCLUSIONS

The data indicate that the propellers of the USS AMBERJACK were well-balanced, that the propeller shafts were correctly aligned, and also that little objectionable hydrodynamic interaction occurred between the propellers and the hull and its appendages.

A comparison of the vibration data obtained on this test with those obtained on the two previous tests of the USS ODAX, a submarine of the same class but equipped with stabilizing planes near the propellers, indicates that vibrations of propeller-blade frequency are set up by the hydrodynamic interaction between the propellers and the stabilizing planes and that the amplitudes of the vibrations decrease with increased clearance between the propellers and the stabilizers.

ACKNOWLEDGEMENTS

The vibration tests on the SS487 Class (GUPPY conversion Class) were carried out under the direction of N.H. Jasper. The first test on the USS ODAX (SS484) was made by Mr. Jasper. The second test on the USS ODAX and the test on the USS AMBERJACK (SS522) were conducted by S. Davidson.

TABLE 3

Comparison of Vibration Amplitudes Recorded at Torpedo Tube 7

Measurements were not made for those conditions for which no value is recorded in this table.

	USS ODAX (SS484)				USS AMBERJACK (SS522)			
	Test of 16 June 1947		Test of 11 July 1947		Test of 18 August 1947			
	Transverse Amplitude mils	Shaft RPM	Transverse Amplitude mils	Shaft RPM	Transverse Amplitude mils	Shaft RPM	Vertical Amplitude mils	Shaft RPM
Surfaced	67	360	31 11	360 340	8.3 2.5 0.8	368 360 340	0.8	368
Submerged			5	360	0.8	330	1.9	330
Clearance between propellers and stabilizers.		8 inches	20 inches at outboard edge of stabilizers and 32 inches at inboard edge of stabilizers.		No stabilizers installed.			

REFERENCES

(1) Telephone Conversation of 11 August 1947 between Capt. G.C. Weaver, USN, of BuShips and Capt. R.A. Hinners, USN, of the David Taylor Model Basin, authorizing the vibration tests on the USS AMBERJACK (SS522).

(2) Research Project SRD265,C-172-35 entitled "Motion Analysis of Hulls and Machinery."

(3) "Vibration Measurements on USS ODAX (SS484)," TMB letter report C-S87-19/A11-(1), dated 16 June 1947.

(4) "Vibration Measurements Made 11 July 1947 on the USS ODAX (SS484)," by Samuel Davidson, TMB CONFIDENTIAL Report C-3, August 1947.

(5) TMB Model Drawing Plan 3965A-1 dated 20 August 1947.

(6) "Vibration Measurements on USS RUNNER (SS476)," TMB letter report S87-19/A11-(1), dated 26 February 1947.