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ALTERNATING TORQUE TESTS ON A TURBINE SHAFT U.S. DESTROYER MOFFETT

by

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PERSONNEL

The tests were conducted at sea by Lt. Comdr. A.G. Mumma, USN, W.F. Curtis, and L.E. Wedding, of the David Taylor Model Basin Staff. Lt. D.C. Campbell, USNR, and V.E. Benjamin, also from the David Taylor Model Basin, assisted in installing the gages. Preparations for the sea trials were made with the help of the Navy Yard, Charleston. The report was written by W.F. Curtis.

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ABSTRACT

The alternating component of the torque present in the port low-pressure turbine shaft of the USS MOFFETT was measured by electrical resistance strain gages. The primary purpose of the measurement was to determine whether torsional oscillations of dangerous magnitude existed, and if so, whether or not the oscillations were excited by the propeller and which of the several possible natural frequencies of the system was associated with the maximum amplitude of oscillation. It was found that torsional oscillations were present but were low in magnitude, that these oscillations were excited chiefly by imperfections in the reduction gears, and that maximum amplitude occurred at the lowest, i.e., first order, natural frequency.

INTRODUCTION

The reduction gears of the USS MOFFETT (DD362) and of other vessels of that class were found to be wearing much faster than was reasonably to be expected. The gear manufacturers suggested that this difficulty might be due to torsional oscillations excited by the three-bladed propeller, particularly at the second-order torsional critical speed, which they estimated should occur at about 240 RPM.

By ascertaining the RPM at which high stresses occurred and the frequency of alternations it was possible to determine whether oscillations at the second-order torsional critical speed were responsible for the wearing of the gears. Therefore, in accordance with instructions from the Bureau of Ships (1)* the alternating components of torsional stress present in the port low-pressure turbine shaft of the USS MOFFETT were measured during post-repair trials conducted on 28 October 1942.

TEST APPARATUS

As the turbine shaft did not present enough exposed length for attaching even the very small metalectric gages, it was decided to place these gages on the shaft inside the low-pressure pinion, through which it extended as a quill shaft, keyed to the pinion at its outer end. Advantage was taken of a time when the low-pressure pinion was being renewed to install the gages on the pinion quill shaft.

Strains were measured by electrical resistance or metalectric gages cemented to this shaft, substantially as described in an earlier Taylor Model Basin report (2). Slight departures from the instrumentation and procedure described in that report were adopted on account of special features of this test.

Experience had shown that carbon, metallized graphite, or pure metal brushes on bronze slip rings provided uncertain contact and became too hot when the shafts

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* Numbers in parentheses indicate references on page 9 of this report.

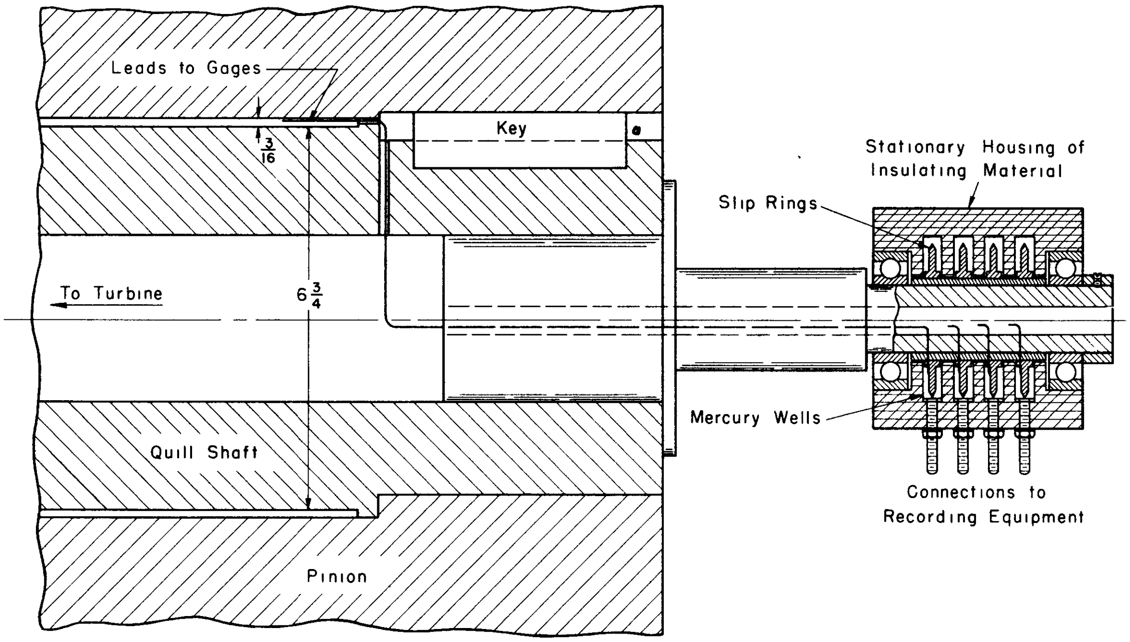

Figure 1 - Schematic Diagram showing Locations of Gage Leads and Slip Rings

The metalectric gages were cemented to the quill shaft about 7 inches to the left of the key.

were turning at speeds as high as those of the low-pressure turbine shaft on the MOFFETT. For these tests, therefore, stainless steel rings dipping into mercury-filled wells were employed to make electrical contact from the recording apparatus to the strain-gage bridge mounted on the shaft. The general arrangement is shown in Figure 1.

Special gages were made up of Number 40 Advance* wire secured to thin paper with bakelite cement. The terminals consisted of Number 28 copper wire soldered to the gage wire; it was found necessary to place an extra insulating thickness of paper under the soldered joint to avoid short-circuiting to the shaft. The gages were cemented to the shaft with bakelite cement. The appropriate electrical connections were made with Number 22 wire insulated with acetate braid, and the whole shaft was wrapped with cotton tape over the gages. The cotton tape was painted with glyptol varnish and the entire assembly was then baked at 175 degrees fahrenheit. This provided excellent electrical insulation and mechanical protection for the gages and the connecting wires.

The shaft diameter at the gage location was 6 3/4 inches and the maximum diameter over the installation was 7 inches ± 1/64 inch, leaving a total diametral clearance of 7/64 inch inside the pinion.

A Dumont Type 208 Oscilloscope and a moving-film camera were used in place of the usual string oscillograph for recording the data.

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* Advance is a trade name for one of the types of resistance wire commonly used for these gages. It contains approximately 60 per cent copper and 40 per cent nickel.

TEST PROCEDURE

Visual observations of torsional stresses were started while the USS MOFFETT was moored and the propeller shaft was being jacked over preparatory to getting underway. Visual observations were continued while the ship was underway proceeding to sea. These maneuvers occupied approximately five hours; propeller shaft speeds during this interval ranged from 80 to 140 RPM. Some records were taken near the end of this period. All shafts were then stopped for a short time to obtain zero readings.

When the ship was again underway records were taken at appropriate intervals while the speed was gradually increased to the maximum obtainable, i.e., 338 RPM. Course and speed were maintained constant while each record was being taken. Speed was maintained at approximately 338 RPM for two hours. At the end of this period, the shafts were again stopped for a zero check, and further records were taken while the ship was slowing down.

TEST RESULTS

The oscillograms shown in Figures 2 to 6 are typical of those obtained in these tests. The results are given in Tables 1 and 2, and are represented graphically in Figures 7, 8, and 9. In most cases, the time taken for 6 cycles of the most obvious oscillatory component is slightly more than the time for 1 propeller revolution. The low-pressure turbine shaft makes 5.72 revolutions per revolution of the propeller shaft. The periodicity apparent on the oscillograms is very close to this value; agreement is not quite exact, probably owing to the difficulty of exactly locating points of equivalent phase on different cycles.

All oscillograms suitable for the purpose were analyzed with a Mader harmonic analyzer. In most cases, two different periods were considered in the analysis of each oscillogram.

It will be noted from Table 2 that the results of the two analyses are in general quite similar; this is because the analyzer is unable to distinguish accurately between two alternations of nearly equal periods. The data obtained from analyzing the "maximum-to-maximum" period were chosen for plotting in Figures 7 and 8, as

TABLE 1

Results of Alternating Torque Tests on Port Low-Pressure Turbine Shaft

Entry	Propeller RPM	Total Alternating Torque, lb-ft. Peak Single Amplitude	Total Alternating Stress, lb/in^2. Peak Single Amplitude
1	50	7050	1460
2	55	15,550	3220
3	60	15,300	3170
4	82	9163	1900
5	90	3412	710
6	100	3191	660
7	110	6211	1285
8	120	10,670	2220
9	130	10,880	2250
10	140	2371	480
11	160	1510	310
12	200	1060	220
13	220	1510	310
14	230*	1520	315
15	240		
16	250		

* Observable torsional oscillations did not occur at speeds in excess of 230 RPM.

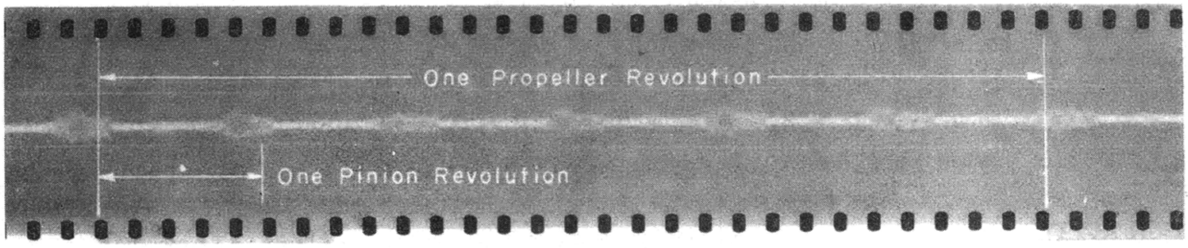

Figure 2 - Oscillogram of Torque on Port Low-Pressure Turbine Shaft
Propeller RPM 60

The trace of the propeller revolution marker is at the bottom of the film strip. The pinion makes 5.72 revolutions for one revolution of the propeller.

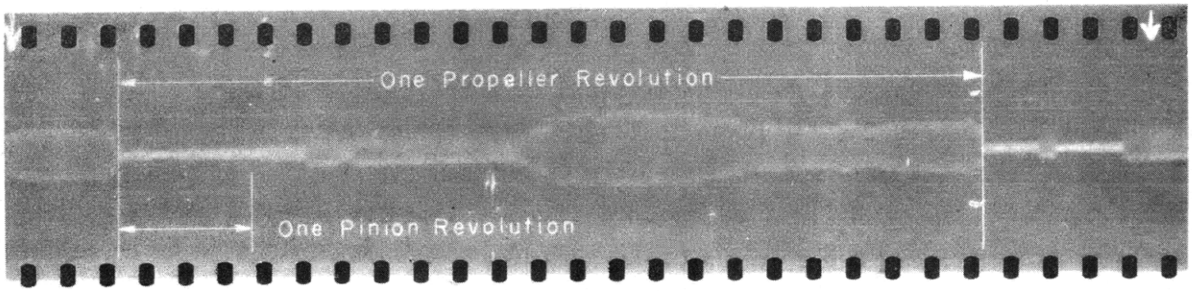

Figure 3 - Oscillogram of Torque on Port Low-Pressure Turbine Shaft
Propeller RPM 82

The propeller revolution marker was not functioning. The period was estimated from the film speed.

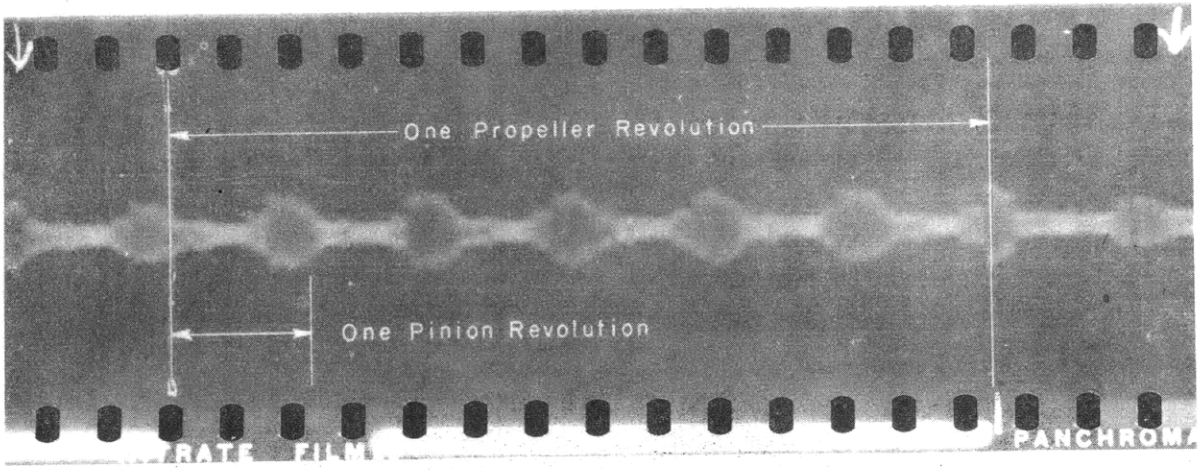

Figure 4 - Oscillogram of Torque on Port Low-Pressure Turbine Shaft
Propeller RPM 130

As gages were supplied with an alternating "carrier" frequency current, torsional oscillations are represented by variations in the width of the central band in all these oscillograms. Individual oscillations of the carrier current are not resolved by the recording process used.

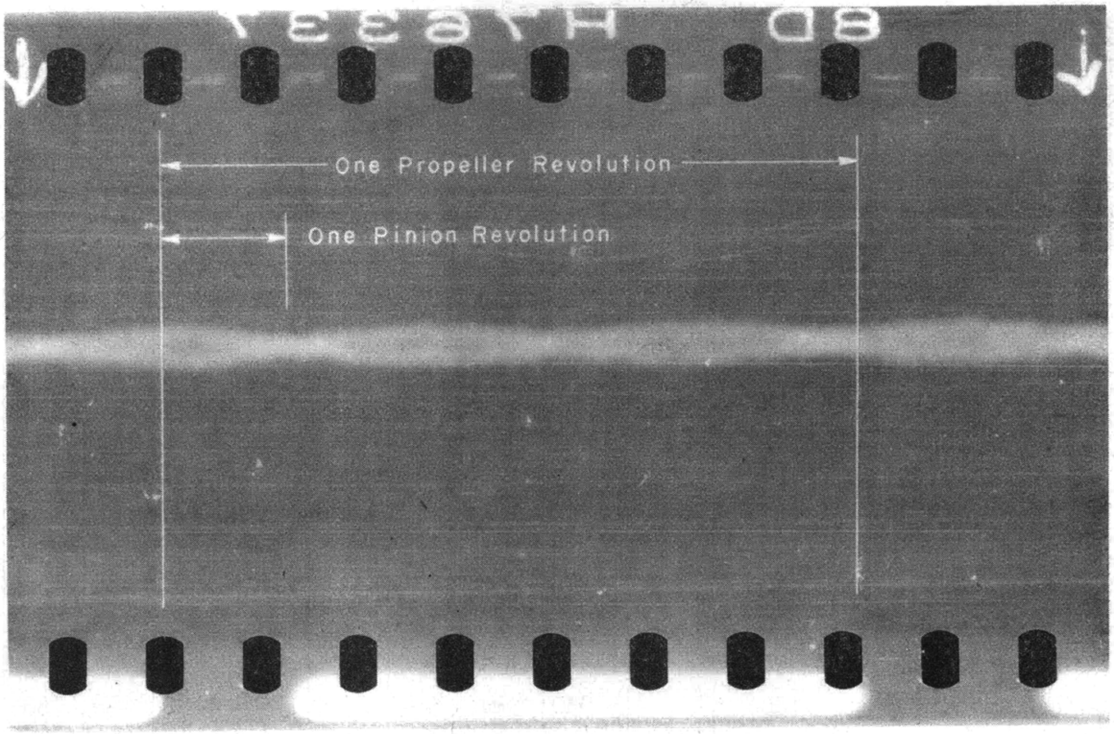

Figure 5 - Oscillogram of Torque on Port Low-Pressure Turbine Shaft
Propeller RPM 230

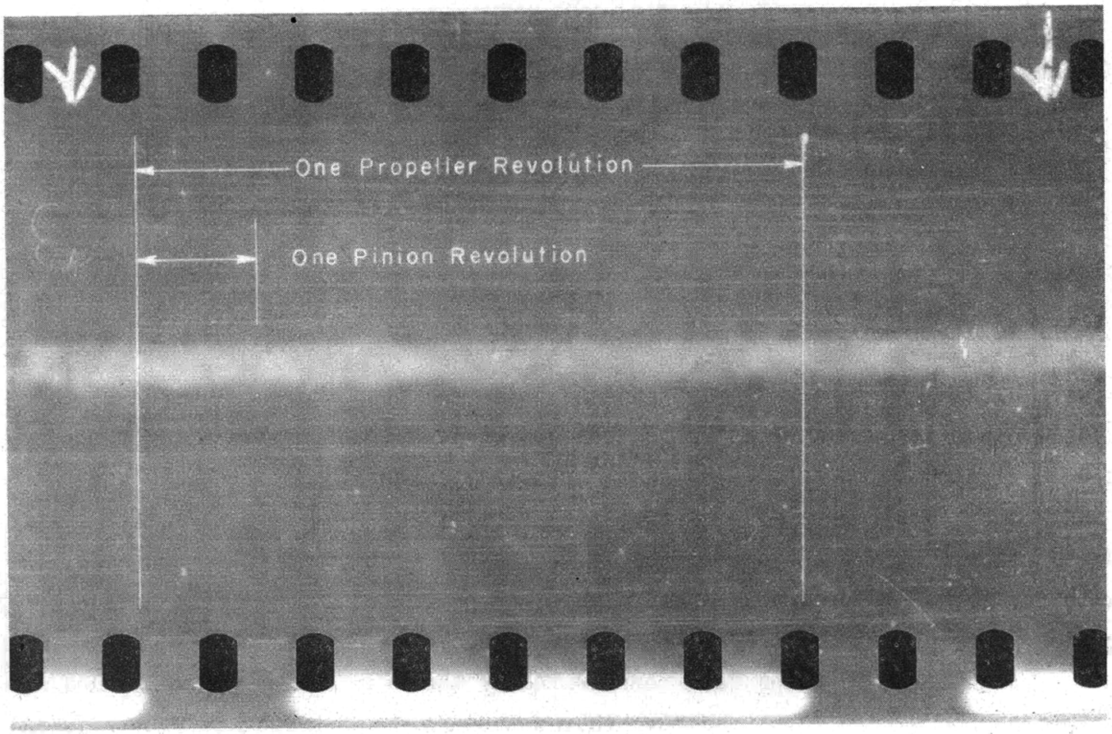

Figure 6 - Oscillogram of Torque on Port Low-Pressure Turbine Shaft
Propeller RPM 250

TABLE 2

Harmonic Analysis of Torsional Oscillations on Port Low-Pressure Turbine Shaft

The magnitude of each component is in pound-feet of alternating torque.

The results given in Columns 1, 2, 4, 6, and 8 were derived by analyzing a period taken from maximum to maximum on the oscillogram. This period has been assumed equal to the period of rotation of the turbine shaft, which it closely approximates. The results given in columns 3, 5, 7, and 9 were derived by using a period equal to one propeller revolution, as indicated by a contactor on the propeller shaft.

Column		1	2	3	4	5	6	7	8	9
Frequency of Component in cycles per propeller shaft rev.		0.958	2.875	3	3.84	4	5.75	6	11.5	12
Cycles per turbine shaft rev.		1/6	1/2	0.521	2/3	0.695	1	1.042	2	2.085
Time of Observation	Prop. RPM									
During speed run	50	obviously negligible	1970	†		†	1820	†	1650	
After speed run	55		1990				8640		8120	
During speed run	60		1230				5810	5580	7130	7300
Before speed run	82	5440	3000	†	540	†	480	†	560	†
During speed run	90	obviously negligible	**	300	**	300	**	1320	**	950
During speed run	100		930	330	550	260	1350	1280	2490	1660
During speed run	110		210	660	4100	720	3670	900	4890	
During speed run	120		2780	1670	750	4520	7060	7700	4200	
During speed run	130		1280	1800	1360	1100	6790	7500	2700	
Before speed run	140		300		320		790			
During speed run	160		**	140	**	860	**	410	**	
During speed run	200		790*	790	610*	610				
During speed run	220		520*	520	550*	550				
During speed run	230		1310		270					

* The period determined by inspection of the vibration record is the same as the period determined by the propeller revolution marker.

** These oscillograms showed no apparent periodicities.

† The propeller revolution marker did not function.

they were considered more reliable than the data from the other analyses. On theoretical grounds, it would seem that components of less than turbine shaft frequency should be related to the propeller shaft frequency rather than to the turbine shaft frequency; exciting forces arising from the propeller or from irregularities in the main reduction gear are the most probable sources of such components. However, the oscillogram for 230 RPM clearly shows a major component of one-half the turbine shaft frequency, not three times propeller shaft frequency.

With respect to the data represented by the rest of the curves marked "one-half turbine shaft frequency" and "two-thirds turbine shaft frequency" there is a reasonable doubt as to whether the chief exciting forces might not be respectively

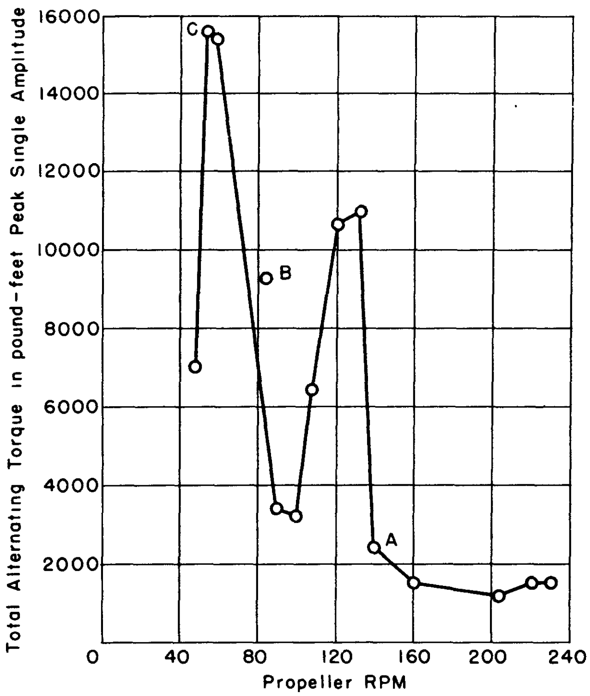

Figure 7 - Total Alternating Torque on Port Low-Pressure Pinion Shaft

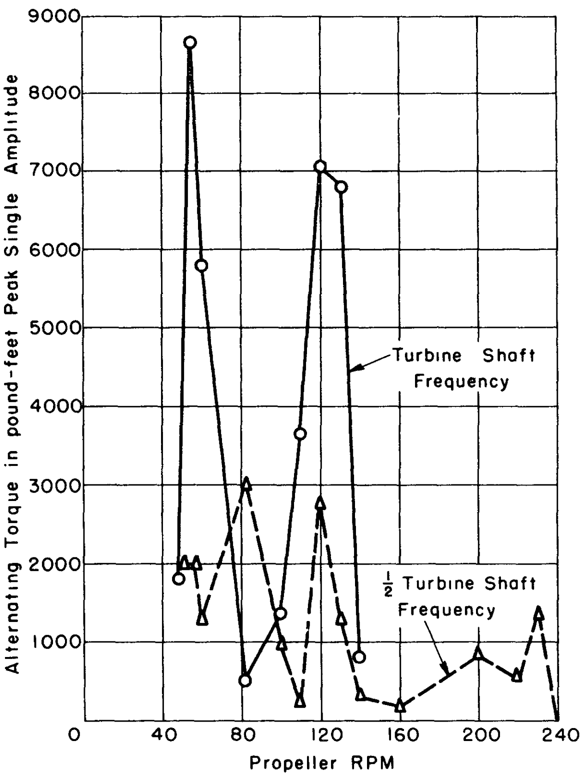

Figure 8 - Harmonic Analysis of Alternating Torque Components of Turbine Shaft Frequency and 1/2 Turbine Shaft Frequency

The latter component might be chiefly due to an exciting force of three times propeller shaft frequency rather than one-half the turbine shaft frequency, these two frequencies being so nearly equal that analysis failed to distinguish between them. The frequency of the chief component of the torsional oscillations due to a three-bladed propeller is three times the propeller shaft frequency. It is therefore certain that the propeller-excited torsional oscillations do not exceed the values given on the curve marked "1/2 turbine shaft frequency."

three times propeller shaft frequency and four times propeller shaft frequency, in spite of the fact that they were obtained from analysis based on the frequencies given. In any event, the component of three times propeller shaft frequency, which would be the chief component due to propeller excitation, must have been of relatively small magnitude. As far as the higher frequency components are concerned, inspection of the oscillograms clearly shows that they are respectively turbine shaft frequency and twice turbine shaft frequency, and not six times and twelve times propeller shaft frequency.

During the period preceding the speed runs, visual observations on the oscillograph indicated very strong torsional oscillations with a period approximately equal to the time of one propeller shaft rotation. This effect was at a maximum while the shaft was being jacked over prior to getting underway; it gradually decreased as time went on and as speed was gradually increased. The wave form shown in Figure 3 on page 4, which was recorded prior to starting the speed run, is typical of wave forms observed during this interval and is quite different from wave

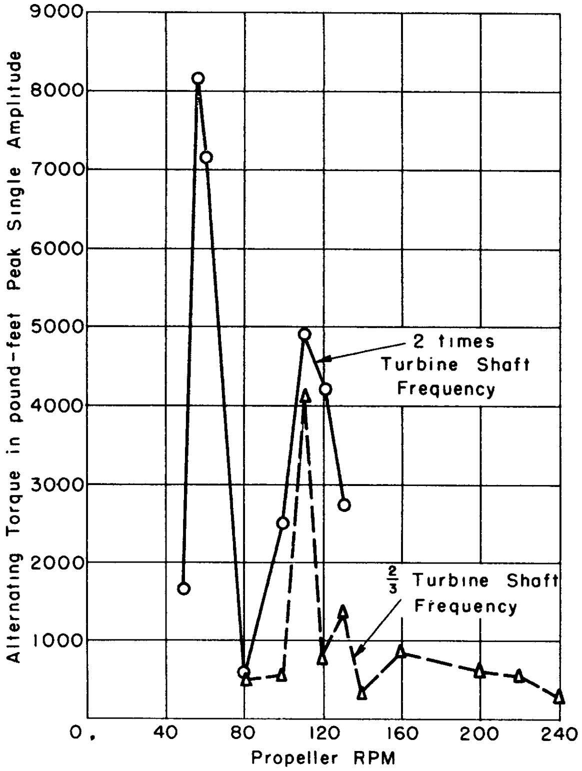

Figure 9 - Harmonic Analysis of Alternating Torque Components of Twice Turbine Shaft Frequency and Two-Thirds Turbine Shaft Frequency

forms obtained later. This oscillogram is a replica of the one from which entry 4 of Table 1 and point A of Figure 7 were obtained. It will be seen that the total alternating torque is noticeably higher than would be expected from the trend of the other determinations. As can be seen from Table 2, the discrepancy chiefly affects the component of approximately propeller shaft frequency. Unfortunately, the propeller shaft contactor did not record on this oscillogram so that it is not certain whether the period was 1 propeller revolution or 6 turbine revolutions.

The 140 RPM measurement, entry 10 of Table 1 and point B of Figure 7, was also taken prior to the speed run but did not show this anomaly.

The enhanced low-frequency component did not recur when speed was again reduced after the test. The 55 RPM measurement, entry 2 of Table 1 and point C of Figure 7, was taken after the speed run had been completed and agrees quite well with the other data.

Observable torsional oscillations did not occur at speeds in excess of 230 RPM. This is illustrated by the oscillogram of Figure 6 on page 5, which was taken at maximum usable sensitivity at 250 RPM.

CONCLUSIONS

1. Torsional oscillations are present in the low-pressure turbine shaft of the USS MOFFETT, particularly at low speeds. The maximum peak single amplitude of alternating torque measured was 15,550 pound-feet, corresponding to an alternating stress of 3220 pounds per square inch. This occurred at 55 propeller revolutions per minute. It probably represents excitation of the first-order torsional natural frequency by irregularities in the pinion occurring once per pinion revolution.

2. The exciting forces responsible for this oscillation originated in the reduction gear, as shown by the frequency of oscillation.

3. Propeller-excited torsional oscillations, if present, were of very small amplitude, as shown in Figure 8 on page 7.

4. The highest amplitude of torsional oscillation at speeds of 140 propeller RPM and above was 1520 pound-feet, corresponding to a stress of 315 pounds per square inch. This amplitude occurred at 230 RPM. This is doubtless the second-order torsional oscillation. Its amplitude is obviously much less than that of the oscillation occurring at 55 RPM. Amplitudes above 230 RPM were much below this value.

REFERENCES

(1) BuShips letter C-DD362/S41-1(457) of 5 October 1942, to Director, David W. Taylor Model Basin.

(2) "Electronic Methods of Observation at the David W. Taylor Model Basin, Part 2 - Measurements of Steady and Alternating Stresses in Rotating Shafts," TMB Report R-~~76~~ 54, January 1942.