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DAVID TAYLOR MODEL BASIN
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ALTERNATING BENDING STRESSES IN THE SHAFT OF A 110-FOOT SUBMARINE CHASER

by

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[redacted]

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PERSONNEL

The tests were conducted on the vessel by F.B. Bryant and L.E. Wedding of the David Taylor Model Basin staff, under the direction of Commander J.P. den Hartog, USNR, of the Bureau of Ships. The report was written by F.B. Bryant.

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ABSTRACT

In tests aboard a 110-foot subchaser of the U.S. Navy, alternating strains in bending and in thrust of a propeller shaft were measured underway and found to correspond to stresses of 500 pounds per square inch or less.

The apparatus and the procedure for this work are described in some detail.

INTRODUCTION

Recently several cases have been reported of shaft failures in 110-foot submarine chasers of the U.S. Navy with General Motors Corporation "pancake" engines and adjustable-pitch propellers. Each reported failure consisted of a fracture of the propeller shaft just outboard of the stern tube. Visual examination of the broken surface of the metal showed grooves and ridges arranged in a pattern with symmetry about radii spaced about 120 degrees apart.*

The fact that the break was perpendicular to the shaft axis suggested that it was caused by bending rather than by torsion. The three-fold nature of the stress pattern in the broken surface, and the fact that the vessels involved all had three-bladed propellers, suggested that the bending reached a peak value three times per shaft revolution.

To investigate this hypothesis, it was decided to measure the bending strains in the shaft with the vessel underway, using SR-4 metalectric strain gages cemented to the shaft as the strain pickup. It was considered impractical, however, to locate the gages at the exact point of fracture, since no satisfactory technique has as yet been developed for insulating these gages on surfaces which are to be exposed to salt water. Furthermore, it would be difficult to bring in leads from the gages outside the vessel to a point on the shaft inside the vessel where the slip rings could be installed. The nearest suitable point, then, at which the gages could be placed was just inboard of the stern tube; see Figure 1. Through arrangements made by the Bureau of Ships with the Navy Section Base at Tompkinsville, Staten Island, New

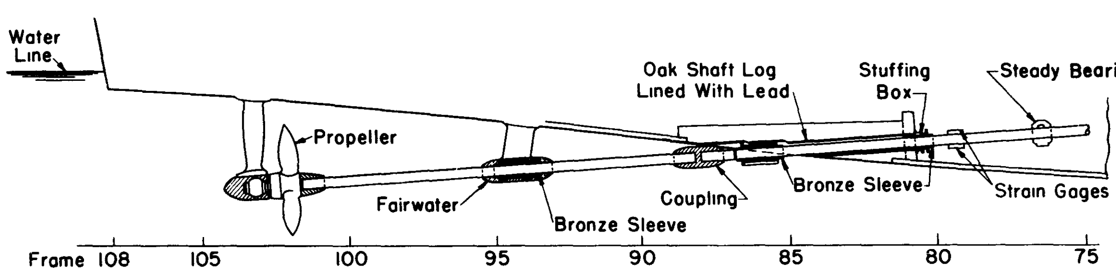

Figure 1 - Arrangement of Propeller Shafting and Bearings on SC-1019

* This examination was performed by personnel of the Bureau of Ships and reported orally to the David Taylor Model Basin. No photographs are available.

York, the 110-foot subchaser SC-1019 was made available and the David Taylor Model Basin was charged with conducting the test and obtaining the measurements (1) (2).*

Instruments and equipment for measuring the strains in the port propeller shaft were installed on the vessel on 16 and 17 March 1943. The tests were conducted on 18 March as the vessel was run through the speed range several times.

TEST APPARATUS

Nine strain gage circuits were installed on the port shaft at a distance of about 14 inches forward of the packing gland at the inboard end of the stern tube. The shaft was hollow at this point, with the blade-shifting gear on the inside. Each circuit consisted of two SR-4 metalectric strain gages located 180 degrees apart on the circumference and cemented to the shaft with their strain axes parallel to the axis of the shaft. The two gages in each circuit were connected in series with a battery in a potentiometer circuit so as to provide an electrical output signal proportional to the bending in the shaft at that point.

The gage circuits were spaced at intervals of 15 degrees around the circumference of the shaft, as shown in Figure 2. One circuit, selected arbitrarily, was connected permanently to a pair of slip rings. The other eight circuits were wired to a selector switch, so that any one of them could be connected to another pair of slip rings. The slip rings were made of brass, 1/2 inch wide and 1/4 inch thick, rolled to a diameter slightly larger than that of the shaft, and insulated from it by sheets of plastic. The brushes which took the electrical signals from the shaft consisted of copper wipers, bearing on the rings. These signals were fed into two amplifier channels, and the amplified signals then went through an electronic switch which permitted observing both signals on one cathode-ray oscillograph.

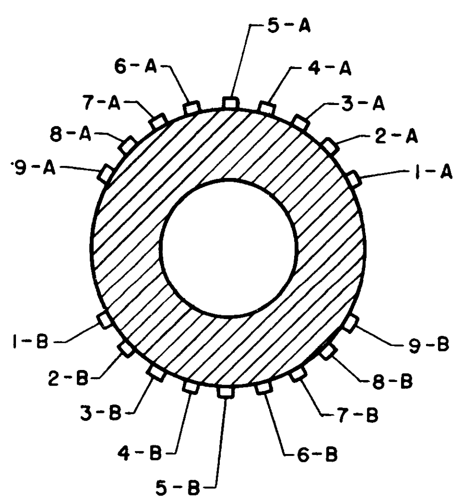

Figure 2 - Location of Strain Gages on Shaft

The electrical circuits used are explained in the Appendix.

TEST PROCEDURE

The signals from each of the strain gage circuits were observed on the oscillograph as the vessel was run through the speed range, while the engine RPM was changed from 800 to 1600 in 100-RPM steps. The signal from the gage circuit which was permanently connected was used as a reference throughout the test. The other

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* Numbers in parentheses indicate references on page 4 of this report.

eight gage circuits were observed in turn, on successive runs of the vessel, by turning the selector switch on the shaft from one position to the next. The electronic switch* then made it possible to observe and record the stress cycle from two gages simultaneously on the oscillograph.

The amplitudes of the electrical signals from the gages were converted into terms of strain by comparing them with a signal of known voltage and frequency from a calibrated oscillator.

After a complete set of observations of bending strains had been made one of the gage circuits was re-wired in a circuit that would give a signal proportional to the thrust in the shaft, and alternating components of thrust were measured at various speeds of the vessel.**

RESULTS AND CONCLUSIONS

The alternating bending strains measured in the shaft corresponded to stresses of approximately 500 pounds per square inch peak single amplitude and occurred with a frequency of once per shaft revolution. The amplitudes were approximately the same for all the gage locations and were independent of speed. No component at blade frequency, or any other clue to the observed shaft failures, was found.

The alternating stresses due to thrust were of lower magnitude than the bending stresses and were also predominately of shaft frequency.

Since the visual observations showed the alternating stresses in the shaft to be small and practically independent of gage location and shaft RPM, only a few photographic records were taken. The recorded signal from Gage 1 and Gage 7, for two shaft revolutions, is shown in Figure 3. These two gages were 90 degrees apart on the circumference of the shaft, and the resulting phase difference in the stress cycle is clearly evident in the record.

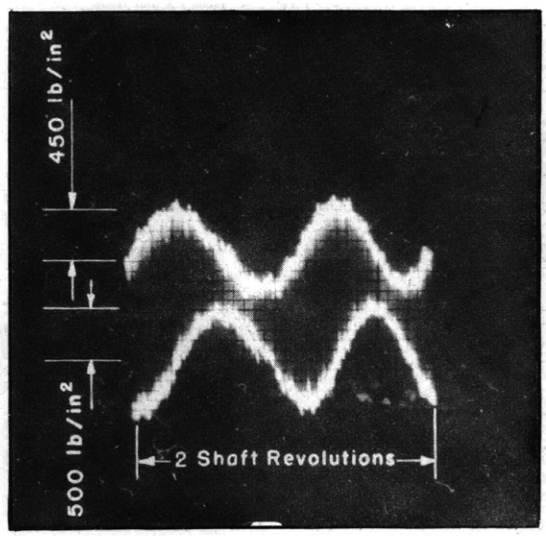

Figure 3 - Oscillogram Showing Bending Stresses in Port Shaft of SC-1019

The top trace is from Gage 7 and the bottom trace from Gage 1. This record was taken at 800 ENGINE RPM. Two SHAFT revolutions are shown.

The observed alternating stresses were apparently due to a very slight misalignment of the shafting, and are negligible. The effect that

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* This instrument was an RCA Type 315-A electronic switch.

** For an explanation of this circuit change, see the Appendix.

had been expected, i.e., large alternating bending stresses of blade frequency, caused by reaction of the propeller blades, was not observed at the position on the shaft at which the gages were placed.

REFERENCES

(1) Bureau of Ships Memorandum 457 of 25 February 1943.

(2) Bureau of Ships Memorandum 457 of 20 March 1943.

APPENDIX 1

CIRCUITS USED IN MEASURING ALTERNATING STRAINS DUE TO BENDING AND TO THRUST VARIATIONS IN SHAFTS

The fundamental circuit in which resistance-type strain gages are generally used for dynamic or periodic strain measurements is shown in Figure 4. In this circuit, V is a battery, R_A is the strain gage, R is a fixed resistance, and C is a condenser which serves to transmit the changes in voltage, and only the changes, which appear across the gage. When the resistance R is equal or nearly equal to the resistance R_A, it can be shown that if the gage resistance changes by an amount ΔR_A, due to strain, the change in voltage across the gage is

$$\Delta V = \frac{V}{4R_A} \Delta R_A$$

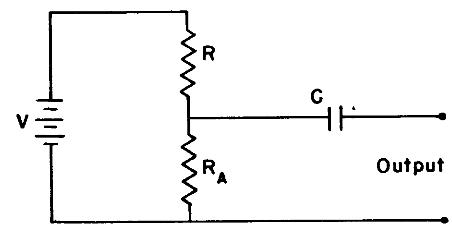

Figure 4 - General Strain Gage Circuit

This voltage, appearing at the output, is the signal that is amplified and observed on an oscillograph.

When the strain gages are used to measure alternating bending strains in shafts, only a slight modification is necessary. Two gages having approximately equal resistances are cemented to the shaft on opposite sides, with their strain axes parallel to the axis of the shaft, as shown in Figure 5. These gages are connected in a circuit, as shown in Figure 6, with Gage B taking the place of the fixed resistance

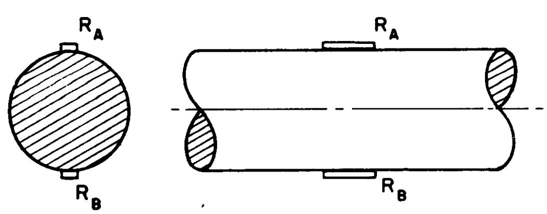

Figure 5 - Strain Gage Locations for Determining Bending Stresses or Thrust

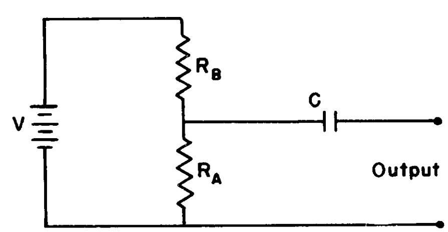

Figure 6 - Strain Gage Circuit for Determining Alternating Bending Stresses

R of the circuit in Figure 4. When the shaft bends, Gages A and B are under cpposite strain and therefore ΔR is positive for one gage and negative for the other but of equal magnitude. This effect gives a voltage sensitivity which is greater than that of the setup shown in Figure 4 and is as follows:

$$\Delta V = \frac{V}{2R_A} \Delta R_A$$

This voltage is proportional to the bending stress in the shaft.

In this installation the gages are also subject to strains due to thrust, but since such strains change the resistance of both gages in the same direction and by the same amount, there is no change in voltage across the pair of gages and therefore no output signal due to thrust.

The same pair of gages, however, can be made sensitive to thrust and insensitive to bending by another slight modification in the circuit, in which the gages are connected as shown in Figure 7. R is a fixed resistance whose value is approximately equal to the sum of R_A and R_B. Thrust in the shaft causes a resistance change $\Delta R_A + \Delta R_B$ in the sensitive elements which produces a voltage change

$$\Delta V \doteq \frac{V}{4(R_A + R_B)} (\Delta R_A + \Delta R_B)$$

For a pure bending strain, R_B changes resistance in one direction, R_A changes resistance by the same amount in the other direction, and the net change in total resistance due to bending is zero; therefore the output voltage also is zero.

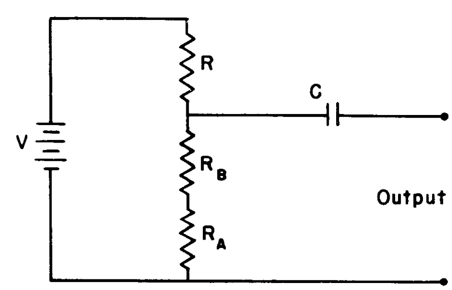

Figure 7 - Strain Gage Circuits for Determining Alternating Thrust

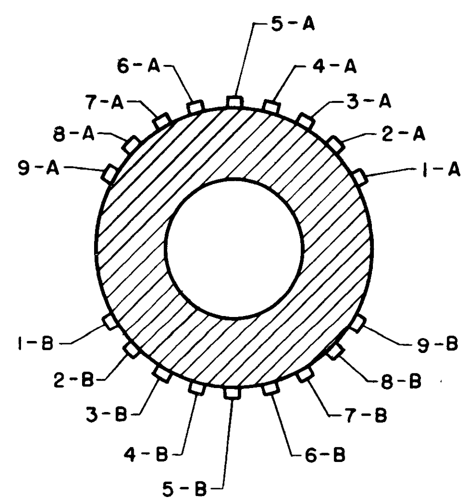

Figure 2 - Locations of Strain Gages on Shaft of SC-1019

The spacing from gage to gage is 15 degrees, each group of nine gages occupying 120 degrees of arc. The A and B gage of corresponding numbers are diametrically opposite on the shaft.

The location of the nine gages on the shaft of the SC-1019 is shown in the sketch, Figure 2. For the bending measurements, the A and B gages of each number are connected as shown in Figure 6. One gage circuit is connected permanently to a battery and a pair of slip rings. Connections from another battery and another

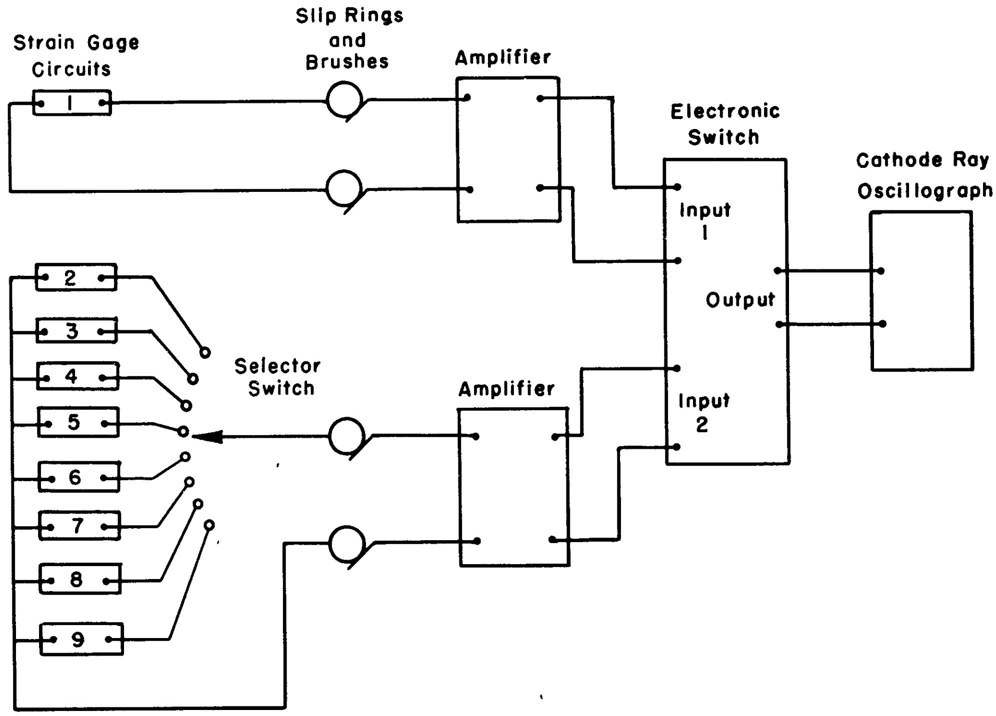

Figure 8 - Simplified Diagram of Instrument Connections for the Test

pair of slip rings are transferred to any of the other gage circuits as desired by a selector switch, operated by hand when the shaft was stopped.

A simplified wiring diagram for the complete test installation is shown in Figure 8.