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DEPARTMENT OF THE NAVY

DAVID TAYLOR MODEL BASIN

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APPLIED MATHEMATICS

THE TMB FLEXING STRESS MONITOR

by

Sheng-Lun Chuang

STRUCTURAL MECHANICS LABORATORY

RESEARCH AND DEVELOPMENT REPORT

February 1962

Report 1560

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ABSTRACT

A Flexing Stress Monitor has been developed to measure the strains and to compute, record, and display the associated stresses experienced by a ship at sea. The data are displayed by monitor lights, and by meters to aid the captain in ship handling. The continuous records are suitable for statistical analysis at a later date to provide general information of use in ship design. The monitor requires only standard 115-volt 60-cps electrical power, and is intended for continuous operation for weeks aboard ship with a minimum of care. Analysis of the records from tests in the laboratory and at sea have shown that the prototype monitor performed well as an automatic data recorder. The usefulness of the stress monitor concept for ship operations remains to be evaluated. A method of establishing peak-to-peak and rms stress levels for the monitor lights is suggested.

INTRODUCTION

The David Taylor Model Basin is conducting a long-range investigation of the strains in ships at sea[1] to evaluate ship girder stresses and improve the methods of establishing structural design levels for ship girders. One objective is to relate sea wave loads to ship response to the degree that the designer can design the ship hull to withstand stated sea conditions and the captain, recognizing the onset of a more severe environment, can take appropriate action.

However, the information now available is insufficient to determine accurately the most severe sea wave loads to which the ship will be exposed and the structural response of the ship to such loads. To offset this lack of information, an interim objective of the long-range investigation is to determine the possibility of sensing, recording, and displaying the actual structural response of the ship to real environment. The TMB Flexing Stress Monitor was developed to fill this gap. The primary purpose in the development of the monitor, therefore, was to provide a display warning of approaching critical sea wave loads as an aid to ship handling. A secondary purpose was to aid in the collection of data on ship hull bending stresses.

The monitor presents both direct measurements of hull bending stresses and the statistical data calculated from the direct measurements. These measurements are described in detail in the "Principles and Descriptions of Instrumentation."

The direct measurements of stresses give an indication of how the random sea waves cause hull bending stresses to vary with respect to ship response. The statistical data on the hull stresses can be used to predict the probable maximum stresses during the ensuing,

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[1] References are listed on page 28.

say, 15 min of operation. The monitor will therefore furnish the captain more accurate information on the environment which his ship may encounter and will provide him with an objective basis for changing ship speed or course when the predicted or direct measured stresses become excessive. In addition, the data recorded by the monitor supplement the limited amount of statistical data on ship response and therefore contribute to rational design levels.

It is not within the scope of this report to present methods for analyzing the recorded data statistically. The report, however, presents some statistical background as a basis for the design of the monitor. General considerations, principles and descriptions of the instrument, and results of laboratory and sea tests are described.

STATISTICAL BACKGROUND AND DESIGN CONSIDERATIONS

The main feature of the monitor is its ability to perform root-mean-square (rms) calculations at the time the direct measurements are taken. This calculated rms is available to the captain at any time during the operation of the ship.

Analysis of experimental data accumulated during the past several years indicates that the hull bending stresses; the pitching, rolling, and heaving motions of ships; and the heights of sea waves all follow the same general amplitude distribution pattern. The pattern can be represented by the one-parameter Rayleigh distribution when the environmental conditions of the sea, ship speed, and course remain constant.[2] Since the Rayleigh distribution is applicable to a limited set of conditions, such as a given combination of sea, ship speed, and course, it is called the "short-term" distribution. The Rayleigh distribution of N cycles of peak-to-peak variation x is defined by the single parameter E, the mean square value of x, i.e., $E = \frac{\sum^{N} x^2}{N}$. The root mean square rms is defined as the square root of E, i.e., rms = $\sqrt{E}$. The probable maximum stresses can reasonably be predicted from the measured rms for a time immediately preceding the prediction. The method of maximum rms prediction is given in Appendix A.

During the design and development of the monitor, three major considerations predominated:

1. The monitor should be rugged and reliable. The main purpose of installing the monitor on a ship is to ensure safety under the roughest possible sea condition. Accordingly, the monitor should operate from a power source normally available on most ships at all times, even during a storm.
2. The monitor should be small, simple to operate, and easy to install.
3. The monitor should be reasonably low in cost so that such apparatus may be installed on many ships.

The specifications for the design of the monitor are given in Appendix B. The monitor in its present form was developed by the Sierra Research Corporation, Buffalo, New York, in accordance with specifications drawn up by the David Taylor Model Basin.

PRINCIPLES AND DESCRIPTIONS OF INSTRUMENTATION

The monitor utilizes electric analog computer techniques to extract the desired rms of hull bending stresses. The heart of the computer is the operational amplifier first used in computers by Ragazzini in 1947.[3] For maximum life and minimum power drain of the monitor, transistorized circuitry is utilized throughout.

The direct and statistical measures presented by the monitor are as follows:

1. The direct measures:

    a. The resulting horizontal and vertical longitudinal bending stresses of the hull amidships at or near the port and the starboard strength deck edges where strain gages are mounted. These measurements include still-water bending stresses, ordinary wave bending stresses, and whipping bending stresses caused by slamming forces or by other vibratory forces.

    b. The average instantaneous vertical longitudinal bending stresses amidships. Measurements include ordinary wave bending stresses and whipping bending stresses.

    c. The average peak-to-peak vertical longitudinal bending stresses amidships. Measurements include ordinary wave bending stresses and whipping bending stresses.

2. The statistical measure presented by the monitor is the root-mean-square magnitude rms which is calculated from the direct measurements of the average vertical longitudinal bending stresses of the hull caused by the ordinary wave loads.

The monitor consists of two strain gage bridges and associated strain gage amplifiers, a computer-recorder console, and a remote display unit; see Figure 1. The major components of the system (Figure 2) include:

1. Sensor
2. High-pass filter
3. Instantaneous and peak-to-peak displays
4. Low-pass filter
5. Squaring circuit
6. Time-constant averaging device
7. Square-rooting device
8. RMS display
9. Power supplies and monitor lights

SENSOR

Two strain gage bridges, mounted port and starboard of the ship, pick up signals caused by stress variations in the ship girder. Separate oscillators, amplifiers, and demodulators are provided for each bridge. To minimize noise from the 60-cps power source, the strain gage excitation of 1000 cps is adopted by the use of a Hartley oscillator operating at approximately 1000 cps. The output is amplified and clipped to form a 1000-cps square wave. Final amplification is performed by a push-pull stage, the output of which is applied to a conventional temperature-compensated strain gage bridge.

An a-c amplifier and a demodulator are used to transform the bridge output to direct current to permit high-pass filtering and to allow transmission of reasonably high-level d-c

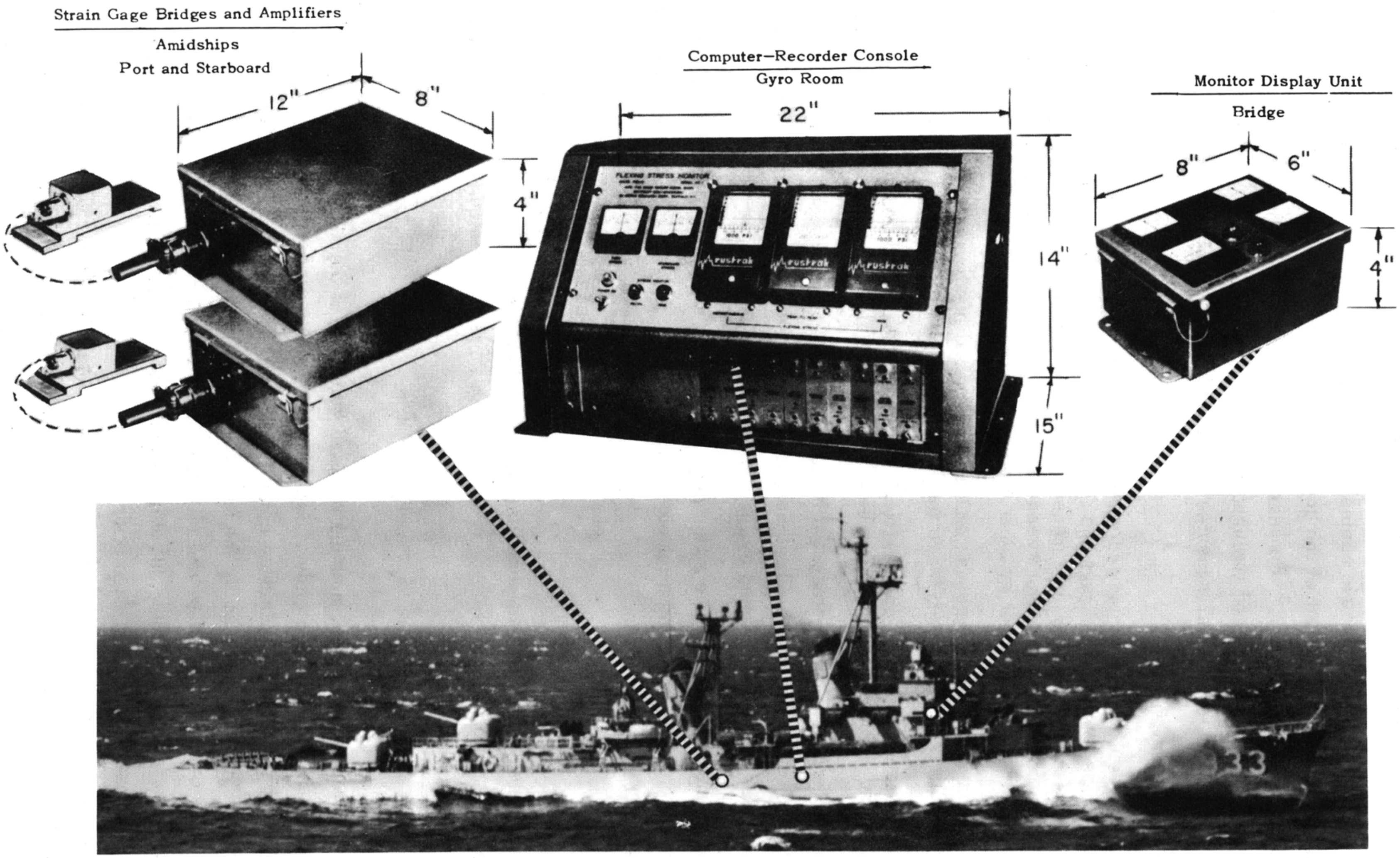

Figure 1 – The TMB Flexing Stress Monitor

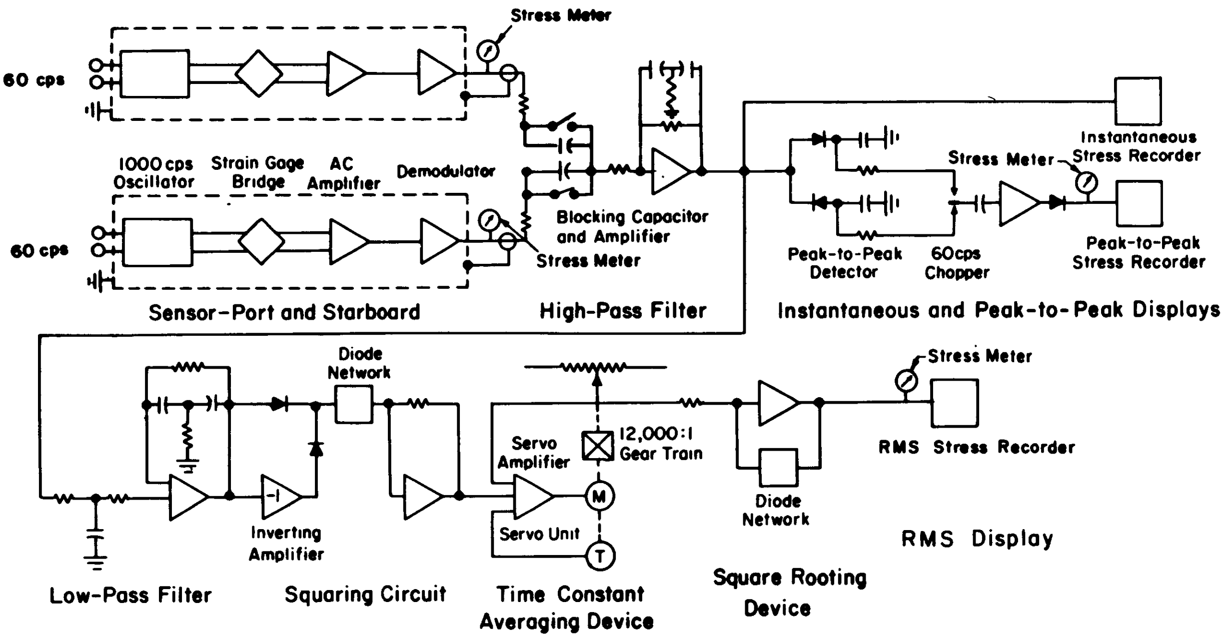

Figure 2 – Block Diagram of Flexing Stress Monitor

signals from the amidships location of the strain gages to the remotely located computer-recorder console. The port and starboard demodulated signals are transmitted over a twisted, shielded pair of wires to the console where they are combined and applied as an input to the high-pass filter.

HIGH-PASS FILTER

To eliminate or minimize the thermal drift in the equipment and the steady-state stresses induced by the shifted or changed ship loads, a high-pass filter must be incorporated into the system. It is designed for a time constant of 110 sec with a 3-db attenuation at approximately 0.009 radians/sec (0.00145 cps).

INSTANTANEOUS AND PEAK-TO-PEAK DISPLAYS

After high-pass filtering, the d-c signal is fed to a Rustrak instantaneous paper recorder. The pressure-type stylus of the recorder strikes against the pressure-sensitive chart paper at 3.75 marks/sec to obtain a nearly continuous trace without the use of ink, electric current, or heated stylus. However, this speed of 3.75 marks/sec may fail to record or to show clearly on a chart paper the peak stress variations due to high-frequency slamming. It is therefore necessary to peak-detect the signals as they arrive at the recorder.

The method of peak-detection involves a positive and a negative peak-detector with an electromechanical chopper to sample between these two signals. The output is amplified, rectified, and then displayed on a Rustrak peak-to-peak recorder. Since the peak-detector does not give every peak-to-peak stress variation or show the occurrence of slamming, both the instantaneous and the peak-to-peak displays are adopted to compensate for the limitations of each display.

LOW-PASS FILTER

The low-pass filter will remove from the d-c signal the high-frequency components of stress variations caused by slamming or other vibratory forces. The filter is 0.6 critically damped at a cutoff frequency of 0.242 cps; see Figure 3. Filter response has a 2- to 3-percent overshoot between 0.1 and 0.2 cps, about 8 percent down at 0.25 cps, and at least 93 percent down at 1 cps. Laboratory tests show that use of the present filter is quite adequate for eliminating the high-frequency components from the combined stress variations. Thus only the ordinary wave bending stresses will be measured.

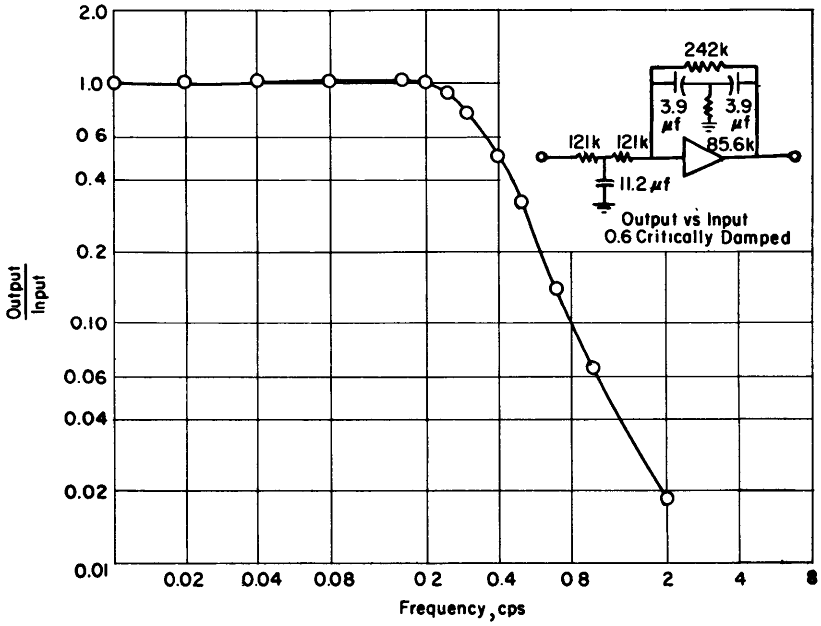

Figure 3 – Measured Filter Transfer Function

SQUARING CIRCUIT

The squaring circuit is a multidiode-squaring network operated with a d-c signal. Two d-c amplifiers are used to permit full-wave squaring and to meet the necessary increased accuracy associated with extraction of rms flexure.

TIME-CONSTANT AVERAGING DEVICE

The long time-constant averaging device is a servotachometer system which operates with a fixed gear train and functions as a low-pass filter. It is essentially an averaging device with a 15-min time constant.

SQUARE-ROOTING DEVICE

The square-rooting device used to obtain rms stress variations is nothing more than a multidiode-squaring network in the feedback of a d-c amplifier. It provides useful readings of a stress level corresponding to about 10 percent of the maximum stress level (10,000 psi versus 1000 psi). The mean-squared stress is down to 1 percent (i.e., squared value of 10 percent) of full scale. Obviously, a very accurate squaring device and good d-c amplifiers are needed, as specified in Appendix B.

RMS DISPLAY

The Rustrak recorder is used for the rms display. The recorder operates at 1 in./hr and one mark every 2 sec and provides a 31-day record on a 63-ft roll of chart paper.

POWER SUPPLIES AND MONITOR LIGHTS

To simplify installation, utilization, and operation, the monitor uses only 115-volt 60-cps a-c power which is available on most ships.

Two pairs of monitor lights are provided, one pair mounted on the console and the other on the display unit. Lights go on when either the peak-to-peak stresses or the rms stresses exceed some preselected value. The lights stay on for a time to call the captain's attention to the monitor meters. A method to set monitor lights is described in Appendix C-8.

DISCUSSION AND EVALUATION

The monitor was checked in the laboratory for correlation of outputs among the three recorders and also for linearity and frequency response and other functional characteristics of each recorder. Several selected frequencies of stress inputs were applied to the monitor, and data were taken simultaneously by the three recorders. Amplitude and frequency outputs shown on the recorders agreed within their tolerances. Errors in linearity of the peak-to-peak and the instantaneous recorders were approximately 2.5 percent of full scale and were within the tolerance specified for the recorders. The drift characteristics of the peak-to-peak and the instantaneous recorders showed no appreciable error during the operating period. The drift of the rms recorder showed no noticeable error when checked near zero scale. It can be concluded that the drift of the entire range of the rms recorder is negligible.

As described previously, the mean-squared stress is calculated by means of a servo-tachometer system with a fixed gear train. To perform calibration and zero-checkout tests of the rms recorder, a waiting period of as much as two hr is necessary between adjustments because of the time constant. The servo has a certain tachometer null-error that is variable. This trouble, however, does not affect the overall accuracy of the system since the circuitry which extracts the square root of the mean-square stresses will greatly amplify small errors in the very low ranges yet will add no significant error in the high ranges.

The monitor was also checked in the North Atlantic in May 1961 during a series of seakeeping trials on a 380-ft Dutch destroyer conducted by the David Taylor Model Basin and the Netherlands Research Center T.N.O. for Shipbuilding and Navigation. Data were recorded continuously for about 6 hr during trials in a sea which was visually observed to have significant wave heights of about 17 ft peak-to-peak. The ship was proceeding in head (000-deg relative heading) and quartering (060-deg relative heading) seas at speed from 3 to 17.5 knots.

Figure 4 shows samples of records taken during these maneuvers. The solid line shown in Figure 4a represents the data actually taken by the monitor rms recorder; the broken line was obtained by calculation from the instantaneous records, a portion of which is shown in Figure 4c. The maximum difference between the recorded and the calculated rms values was about 1 kpsi. This difference was attributed mainly to the frequent changes in ship speeds and headings during the period when the records were taken, since the electric circuit for the rms values was built with a long time-constant and evidently did not response to quick changes. However, after the monitor was retested in the laboratory, it was found that the manufacturer had erroneously set a 55-min time-constant instead of the 15-min required for rms values. When this error was corrected and the monitor retested using a prerecorded actual hull bending stress random signal, the output rms by the monitor agreed very well with the input rms from the random signals. The technique of testing by means of actual random signals will be presented separately at a later date.

Several minor corrections were also made during the retesting of the monitor. For example, the odd scale of the rms record, Figure 4a, was corrected to a scale which is easier to read. This change only necessitated replacing an appropriate resistor in the circuit.

The monitor gave a trouble-free performance while installed on the ship and is considered satisfactory as an automatic data recorder in its present form. It is rugged, dependable, and sufficiently accurate under test conditions. It is compact, lightweight, simple to install and operate and requires only standard 115-volt 60-cps electrical power. The record provides a clear, immediately visible trace of the hull bending stresses that cannot be smudged by ordinary handling.

The cost of the first monitor was about three times the target cost of $5000 per unit. However, this is attributed to the extensive development and engineering cost, and the cost of additional units should be greatly reduced.

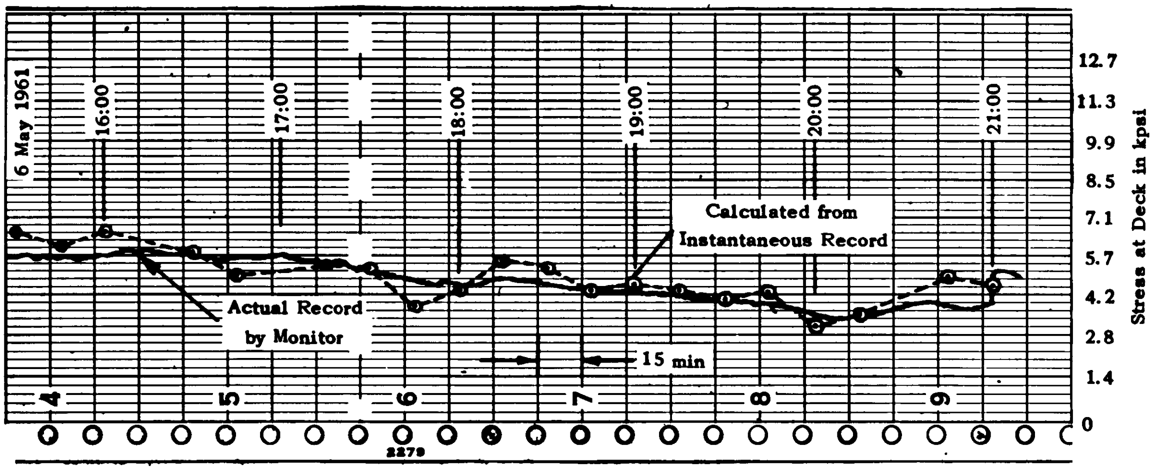

Figure 4a – RMS Record

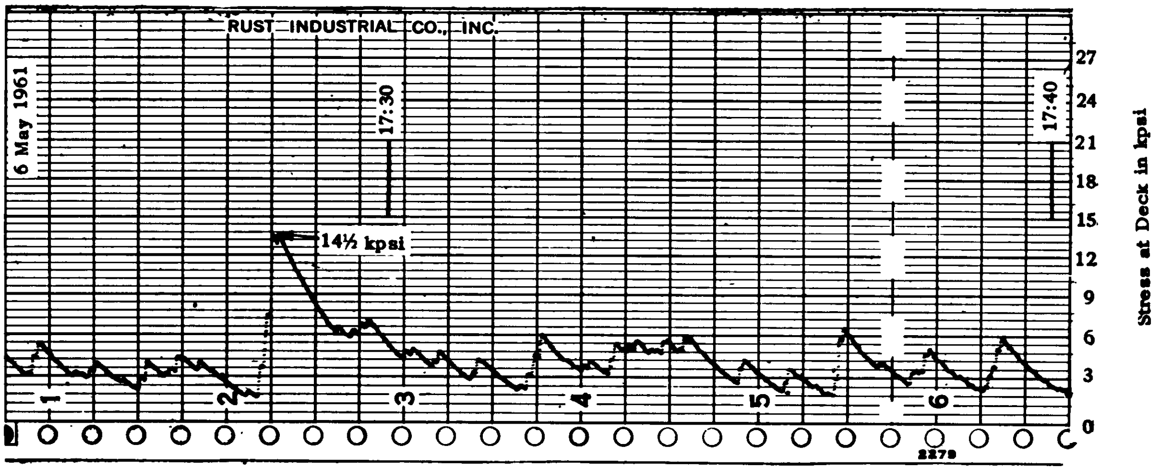

Figure 4b – Peak-to-Peak Record

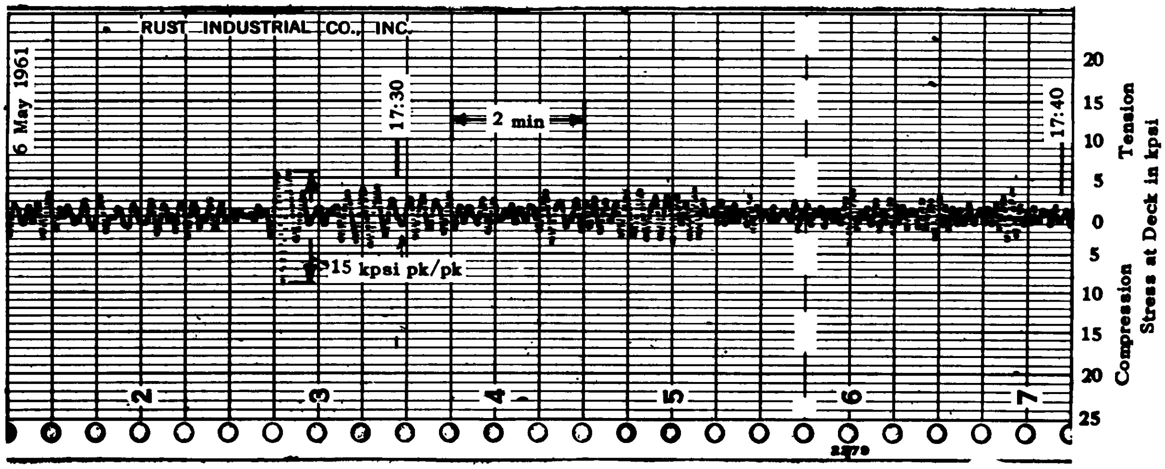

Figure 4c – Instantaneous Record

Figure 4 – Sample Records

The usefulness of the monitor, to the ship's crew, as a stress warning system has not yet been evaluated. This evaluation should be performed prior to further improvement of the instrument.

SUMMARY

The hull bending stress monitor is based on the concept that the probable maximum ship girder stresses can reasonably be predicted from the rms values obtained during a time immediately preceding the prediction.

The main feature of the monitor is its ability to perform rms calculations during ship operations at sea. It utilizes electronic analog computer techniques with servo mechanism to extract the desired rms from measured hull bending stresses. This information, together with instantaneous and peak-to-peak bending stresses, are displayed and recorded.

Installation of the monitor on ship is intended to serve two purposes, i.e., to assist the captain in handling of his ship and to collect data on hull bending stresses for further statistical analysis in order to derive rational design levels for the ship girder.

Hardware evaluation tests have been performed in the laboratory and at sea, and the prototype monitor has shown itself to be rugged, dependable, and reasonably accurate. The monitor is compact, lightweight, and simple to install and to operate. It requires only standard 115-volt 60-cps electrical power and provides trouble-free performance. However, the present monitor costs are somewhat higher than anticipated.

The evaluation of the concept of a stress monitor as an aid to the ship operator has not yet been made. However, a method to determine the critical stress levels of the hull in terms of the peak-to-peak and rms variations is suggested (Appendix A).

RECOMMENDATIONS

The following recommendations are made on the basis of the evaluation tests:

1. The prototype monitor should be installed on several selected ships which operate continuously over typical routes at sea in order to determine the usefulness of the apparatus in ship handling.

2. If the concept is shown to be useful, the present monitor should be improved by:

   a. Providing additional connections for the separate fast-speed recorder. Whenever necessary, this separate recorder can be connected to the monitor to check out whether three recorders of the monitor are operating properly, or to record a clearer continuous trace during the period when the ship is under slamming.

   b. Facilitating comparison of the peak-to-peak and the instantaneous stress variations with a dual-channel recorder. Such recorders are now available.

3. A method should be proposed for analyzing the rms data obtained by the monitor, and also a method for improving hull design from the data analyzed.

4. The fundamental idea of the monitor should be extended to other applications where it is desired to measure cyclic variations, e.g., sea waves, ship motions, voltages, currents, pressures, temperatures, atmospheric conditions, and so forth.

ACKNOWLEDGMENTS

Most of the success of the development work is due to the persistent efforts of Messrs. M.R. Bates and R.B. Russell of the Sierra Research Corporation. Much of the laboratory and field work carried out in connection with the evaluation of this device was done by Mr. G.J. Kliegel of the Instrumentation Division and Mr. A.L. Dinsenbacher of the Ship Dynamics Division. The author is indebted to Captain M.daC. Vincent and Mr. S.E. Lee of the Structural Mechanics Laboratory, Messrs. P. Golovato, E.E. Zarnick, and F.C. Carr of the Hydromechanics Laboratory, and TNO personnel who gave every possible assistance in the early evaluation of the monitor. The project was accomplished under the direction of Dr. N.H. Jasper and the author. The author also wishes to acknowledge his indebtedness to Mr. J.W. Church and Dr. A.H. Keil for their support.

APPENDIX A

METHOD TO DETERMINE THE PEAK-TO-PEAK AND THE RMS STRESS LEVELS FOR MONITOR LIGHTS

In order to arrive at some reasonable conclusion on how to set the monitor lights, types of stresses induced in the hull girder were investigated briefly. The induced stresses may be composed of the following items:

1. Bending stress in smooth water caused by the difference in ship deadweight and buoyancy force.
2. Ordinary wave bending stresses, the time variations of which are associated with period of wave encounter.
3. Dynamic whipping bending stresses, the time variations of which usually correspond to the two-noded mode of flexural hull vibration.
4. Stress concentrations at opening or discontinuity of structure.
5. Built-in stresses during the manufacture of the material or caused by welding, straightening, and mounting.
6. Thermal stresses due to temperature gradients over the structure.
7. Vibratory influences caused by propellers and machinery.

In conventional design practice, failure of the hull girder is based on the elastic buckling of the strength deck or bottom shell panels; only the longitudinal bending stresses, items 1, 2, and 3, need be considered since the other items no longer present any serious problem in failure. When welding was first introduced in shipbuilding, a series of total disasters at sea was due to structural failure starting at hatch openings and discontinuities of hull girders. Continuous improvements in structural designs and in welding techniques eliminated most of the serious stress-concentration problems. As far as buckling stresses are concerned, built-in and thermal stresses have little influence on the load at point of collapse. Hull vibrations initiated by propellers and machinery can be minimized to have no appreciable influence on the longitudinal strength of the hull girder.

In determining maximum stress levels for monitor lights, it is necessary to consider the following points which are findings from various studies.

1. The few measurements available indicate that girder stresses due to the horizontal moment lie between 10 percent and 50 percent of the stresses due to the greatest vertical moment.[4, 5, 6] The stresses caused by the horizontal and the vertical moments are only additive at the corners of the cross section of the hull girder. Thus they do not have a full effect on the buckling of the panel.
2. The shearing forces have no substantial influence on the stress amidships, since they are relatively insignificant where the maximum bending stress occurs.

3. The torsional stresses also have only a small influence and can be disregarded.

4. The longitudinal location of the maximum bending moment along the hull girder varies with ship speed and block coefficient.[7] For a ship with a block coefficient finer than 0.75, the maximum bending moment usually occurs at or near the half length of the ship. For a ship with a higher block coefficient, the location of the maximum bending moment is generally shifted forward, thus requiring a model test to determine the proper location of the monitor strain gage if more precise prediction is desired. Because of changes in section modulus of the cross section along the hull-girder, the maximum bending stress may not occur at the same location as the maximum bending moment. The locations at which maximum stress and maximum bending moment occur should be carefully investigated, especially for ships without parallel midship body.

5. If peak-to-peak stresses are measured, approximately 60 percent of the stress will be for sagging and 40 percent for hogging.[5, 6]

6. As stated previously, the distribution patterns of the ordinary wave bending stress variations can be approximated by the Rayleigh distribution for a given condition of steady operations (sea state, ship, and heading). For any operating condition, characteristic and extreme values can be predicted on the basis of the corresponding rms value. Useful statistical estimates are made as follows:[8]

   a. The most frequent magnitude of variations is 0.707 rms.

   b. The average magnitude of variations is 0.866 rms.

   c. The most probable extreme value $x_{\max}$ experienced in a sample of N variations is $x_{\max} \cong k$ (rms), where k is a constant required for the prediction of probable maximum value in a sample from a Rayleigh distribution, and may be represented by

$$k^2 = \log_e N - \log_e \left[1 - \frac{1}{2k^2} (1 - e^{-k^2}) \right]$$

From actual measurement at sea on ships 300 ft long and longer,[5, 6, 9] the values of N are below 500 during 15 min of operation. If 15 min of operation is used for prediction, $k \leq 2.5$ for all ships more than 300 ft in length.

From the foregoing findings, it is concluded that the stress levels of the monitor lights may be set in the following manner:

1. For peak-to-peak monitor light:

   a. Calculate vertical smooth-water bending stress σ_s at the strength deck.

   b. Calculate elastic buckling stress σ_b of the strength deck.

   c. Calculate allowable sagging stress σ_{sag} at deck from

$$\sigma_{sag} = \sigma_b - \sigma_s$$

which is 60 percent of peak-to-peak stress $\sigma_{p/p}$ including slamming.* Thus

$$\sigma_{p/p} = \frac{1}{0.60} (\sigma_b - \sigma_s) = 1.67 (\sigma_b - \sigma_s)$$

d. Add 10 percent for instrument error and 25 percent to allow time for the captain to change ship course and/or speed. Thus

$$\sigma_{p/p} \text{ for monitor light} = 1.23 (\sigma_b - \sigma_s)$$

and correction should be made from the strength deck to the location of the active strain gage, if strain gage is not mounted on strength deck.

2. For rms monitor light:

a. Calculate σ_s, σ_b, and σ_{sag} as for peak-to-peak monitor light. It should be noted that σ_{sag} used for rms monitor light is 60 percent of peak-to-peak value excluding slamming stress. Therefore,

$$\sigma_{max} = \frac{1}{0.60} (\sigma_b - \sigma_s)$$

Since $\sigma_{max} = k$ (rms) = 2.5 (rms) for 15 min of operation, the rms value for monitor light with 35-percent margin will be

$$\text{rms for monitor light} = 0.5 (\sigma_b - \sigma_s)$$

Correction should also be made from strength deck to the location of the active strain gage if the strain gage is not mounted on strength deck.

The stresses measured by the monitor are the averages of the port and the starboard stresses, which include vertical and horizontal bending at each side. Stresses at one side may be higher than those at the other. If the calculated elastic buckling stresses are higher than 1/1.5 of the elastic limit of the material used, the structure may fail at the strength deck edges before collapse occurs at the center of the deck. Therefore, the allowable stress used should be either 1/1.5 of elastic limit or elastic buckling stress limit of the structure, whichever is lower. Buckling at the ship bottom should also be investigated.

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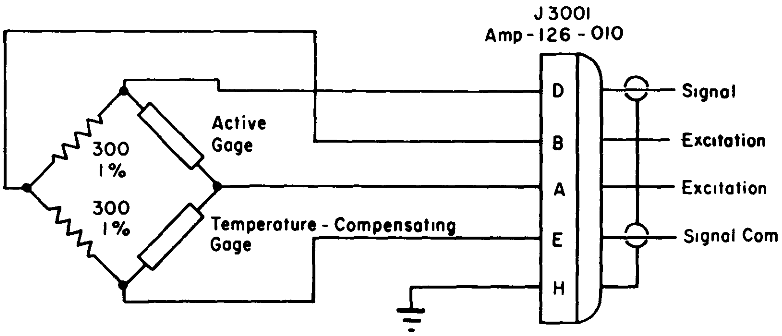
*Dr. Jasper used 60 percent for ordinary bending stress and 50 percent for slamming.[5, 6] The use of 60 percent for both simplifies the calculation considerably and is safer.

APPENDIX B

SPECIFICATIONS FOR FLEXING STRESS MONITOR

The stress monitor as described in this report is built to the following specifications:

1. Strain gage bridges (Figure 5):



Strain Gages are SR-4 Type A-6
Resistance = 298 ± 1 ohm
Gage Factor = 2.04 ± 1 percent

Figure 5 – Schematic Diagram of Strain Gage Bridge

Two strain gage bridges are used, one port and one starboard. Each bridge consists of:

a. Two 300-ohm ± 1 percent fixed resistors.

b. One temperature-compensation gage: Baldwin-Lima-Hamilton SR-4 strain gage Type A-6, 298 ± 1 ohm, 2.04 ± 1 percent gage factor.

c. One active strain gage: Baldwin-Lima-Hamilton SR-4 strain gage Type A-6, 298 ± 1 ohm, 2.04 ± 1 percent gage factor.

d. Scale factor: 1-volt direct-current per 3.3 μ in./in. of active gage, or equivalent to 1 volt per 1000 psi stress of steel on which the active gage is mounted.

2. Strain gage amplifiers (Figure 6):

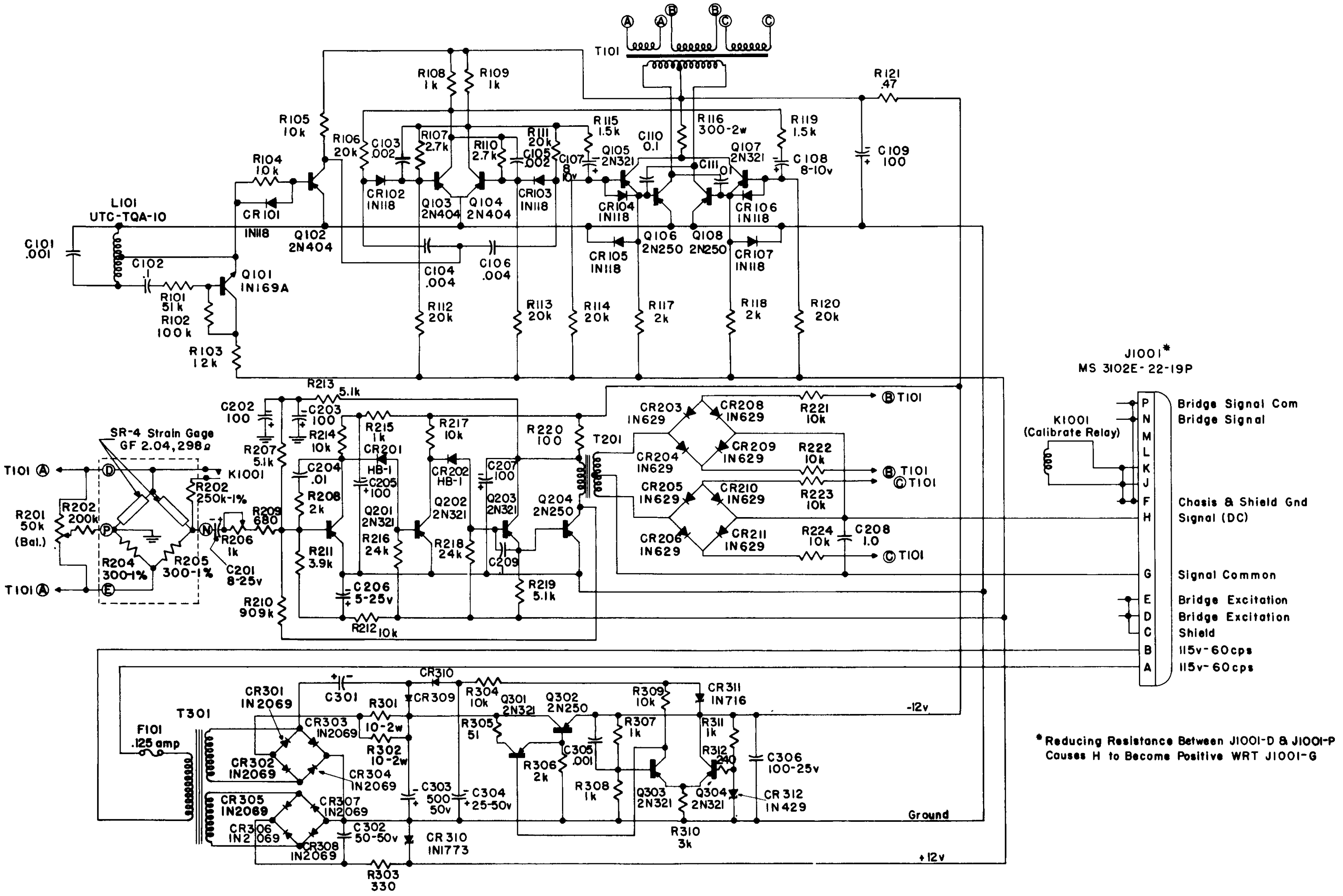
a. Two strain gage amplifiers, each housed in a rugged watertight enclosure.

b. Ambient temperature range: 20 deg F (–7 deg C) to 122 deg F (+50 dec C).

c. Power requirement: Approximately 5 w, 115 volt ± 10 percent, 60 cps ± 10 percent.

d. Output impedance: 2000 ohms shunted by 1 μf.

e. Maximum linear output: ± 50-volt direct-current, corresponding to ± 50,000 psi.



*Reducing Resistance Between J1001-D & J1001-P Causes H to Become Positive WRT J1001-G

Figure 6 – Schematic Diagram of Strain Gage Amplifier

f. A floating 24-volt peak-to-peak square wave at approximately 1 kc for excitation of the strain gage bridge.

g. Size and weight of amplifiers: 4 in. × 8 in. × 12 in., 18 lb each.

3. Computer-recorder console (Figure 7):

a. The console contains relatively sensitive and complex circuitry. It is not watertight and should be located in a dry area.

b. Ambient temperature range: 50 deg F (10 deg C) to 110 deg F (44 deg C).

c. Power requirement: Approximately 50 w, 115 volt ± 10 percent, 60 cps ± 10 percent.

d. Calibration factor: 1 volt per 2500 psi

e. Maximum dynamic signal input: 50 volt peak-to-peak of instantaneous average of two input (equivalent to 50,000 psi peak-to-peak).

f. D-C wash-out: Attenuates any signal with a period longer than 600 sec.

g. Monitor lights: Peak-to-peak stress, may be adjusted to light between 9000 and 30,000 psi.

Rms stress, may be adjusted to light at 3000 psi and above.

h. D-C amplifiers: No. of amplifiers – 5
Manufacturer – Burr Brown
Each amplifier consists of a basic a-c amplifier (four Model 1602, and one Model 1603) and chopper stabilizer (Model 1604).
Maximum output: approximately 2.5 μa at ± 10 volt for Model 1603.
approximately 17.5 μa at ± 10 volt for Model 1602.

i. Servo unit: Manufactured by Daystrom Transicoil.

j. Peak-to-peak recorder: Rustrak, single-channel, 22.5-in./hr paper speed, 32 hr per roll of paper, 3.75 marks/sec, accuracy ± 5 percent for 1 cps, ± 10 percent for 0.1 cps.

k. Instantaneous recorder: Rustrak, single-channel, 22.5-in./hr paper speed, 32 hr per roll of paper, 3.75 marks/sec, accuracy ± 3 percent.

l. RMS recorder: Rustrak, single-channel, 1-in./hr paper speed, 31 days per roll of paper, 2 sec/mark, accuracy ± 500 psi.

m. RMS output decay: 30 min.

n. Meter accuracy: ± 3 percent.

o. Size and weight of console: 14 in. × 15 in. × 22 in., 70 lb.

4. Monitor display unit (Figure 8):

The monitor display unit contains four meters and two monitor lights which are relatively insensitive to the environment. The four meters are used to indicate port stress, starboard stress, peak-to-peak stress, and rms stress. The two lights are for peak-to-peak monitor and rms monitor. The accuracy of meters is ± 3 percent. The size of the display unit is 4 in. × 6 in. × 8 in., and the weight 10 lb.

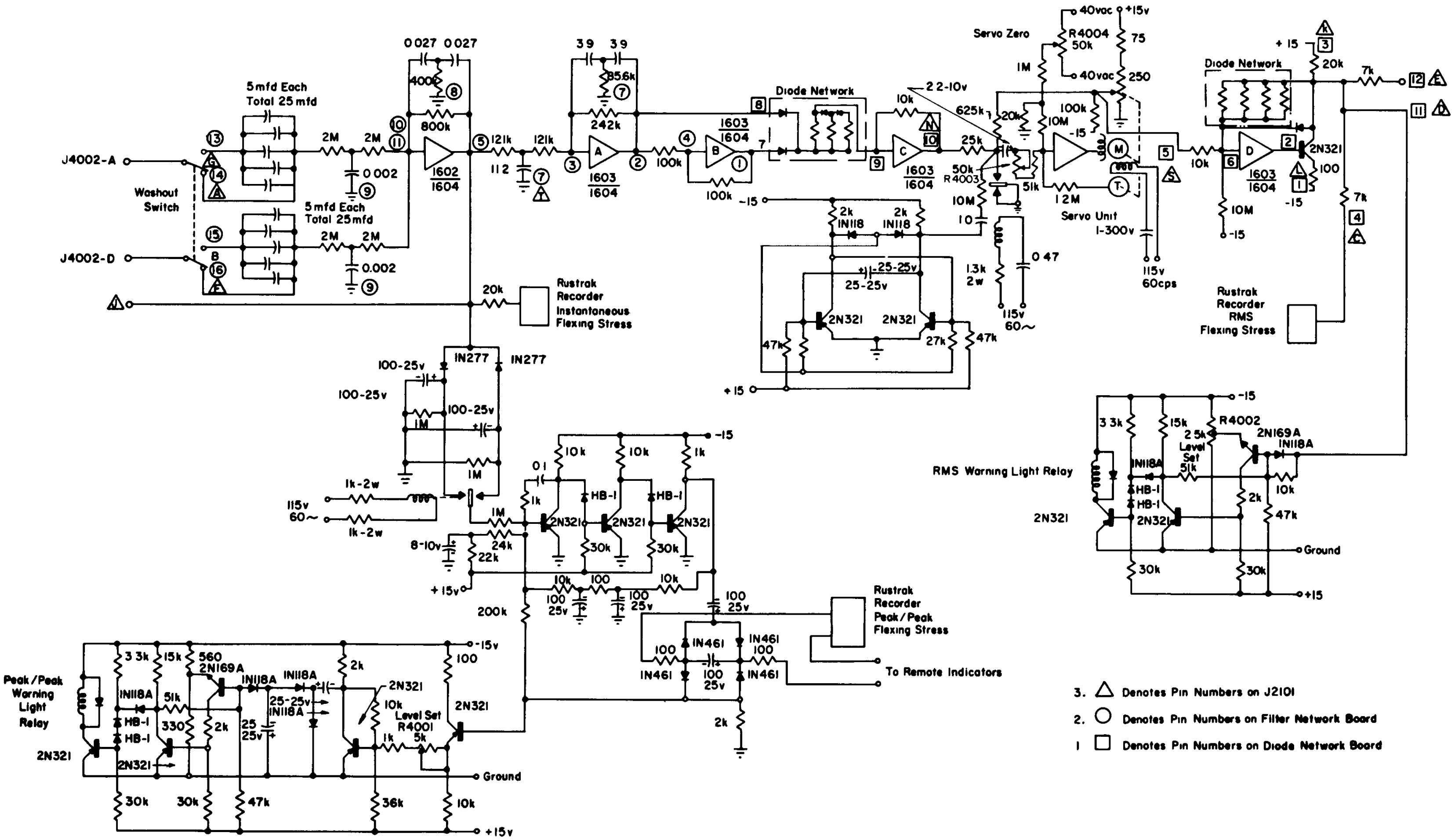


Figure 7 – Schematic Diagram of Computer and Recorder Console

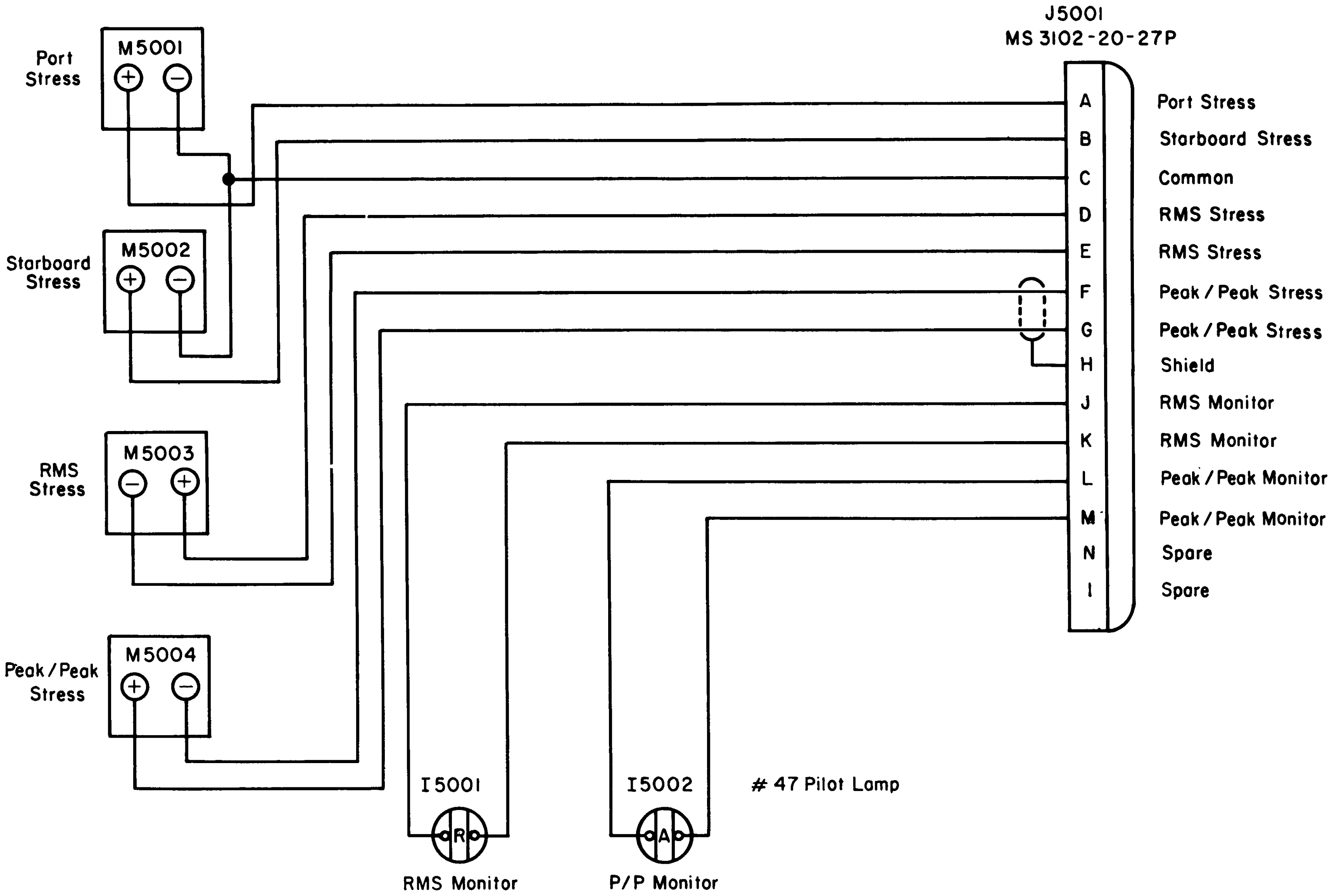


Figure 8 – Schematic Diagram of Monitor Display Unit

APPENDIX C

INSTRUCTIONS

For proper functioning of the stress monitor, detailed instructions regarding installation of gages, meters, and calibration of the system, etc., are presented as follows.

1. Strain gage bridge installation:

The strain gage bridge consists of two units:

a. A steel chassis containing two inactive resistors of the bridge and a temperature-compensating strain gage mounted on a specimen plate.

b. An SR-4 active strain gage.

The strain gage bridge is installed as follows:

The strain gage bridge is to be mounted longitudinally to the structural strength member at or near the half length of the ship under the strength deck and inside or near the sheer strake; see Figure 9. The active gage is to be cemented to the structure by mounting techniques approved by the manufacturer and protected from the effects of moisture by the application of a coating of petrosene wax or equivalent. The steel chassis must be kept directly adjacent to the active gage, and the lead length between the chassis and the active gage is to be kept to a minimum. After the location of the chassis has been determined, its heel plate is to be tack-welded to the structure; then the chassis is to be fastened to the heel plate with the two screws provided. To avoid damaging the active strain gage by excessive heat, it is advisable to weld the heel plate before the gage is mounted.

2. Strain gage amplifier installation:

The strain gage amplifier is contained in a rugged waterproof box and may be mounted in any position and location where the ambient temperature is within the range indicated in Appendix A. Since the stability of the strain measurement system depends to a degree on the wiring between the strain gage bridge and the strain gage amplifier, short, direct runs and twisted, shielded pairs of telephone wires are desirable. The use of intermediate junction boxes between strain gage bridge and strain gage amplifier should be avoided. Although it is preferable to keep the length of the cable connecting the bridge and the amplifier less than 50 ft, it is not necessary to use an extremely short cable which might require the amplifier to be inconveniently located.

3. Computer and recorder console installation:

To permit convenient adjustment and calibration at the top of the console, it is recommended that the console be mounted 2 to 3 ft above the deck with at least a 5-in. clearance in the back. A dry area relatively insensitive to ship motions, such as the gyro room, is preferable. The temperature of the environment is also an important factor for any

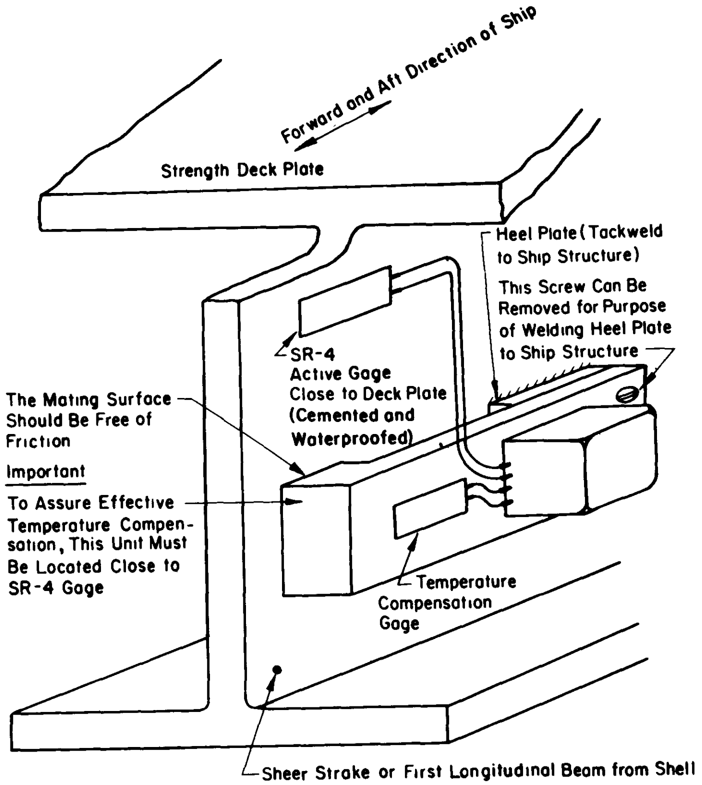


Figure 9 – Typical Strain Gage Bridge Mounting

temperature outside of the specified range indicated in Appendix A may result in a noticeable instrument drift.

4. Monitor display unit installation:

The monitor display unit should be mounted on the bridge so that the flexing stress information is available to the captain. This unit consists solely of meters and lights and is insensitive to the environment. The main problem is to ensure that the wiring is correct.

5. Wiring:

The appropriate connections for wiring are shown in Figure 10. After all wire connections have been completed in each installation, a polarity check should be made by shunting the active strain gage.

6. Powering-up:

A power switch is provided at the left side of the front face of the console. At "ON" position the switch automatically starts the rms recorder. The instantaneous and the peak-to-peak recordings are made by opening the console cover and turning the instantaneous and peak-to-peak "ON-OFF" switch to "ON" position.

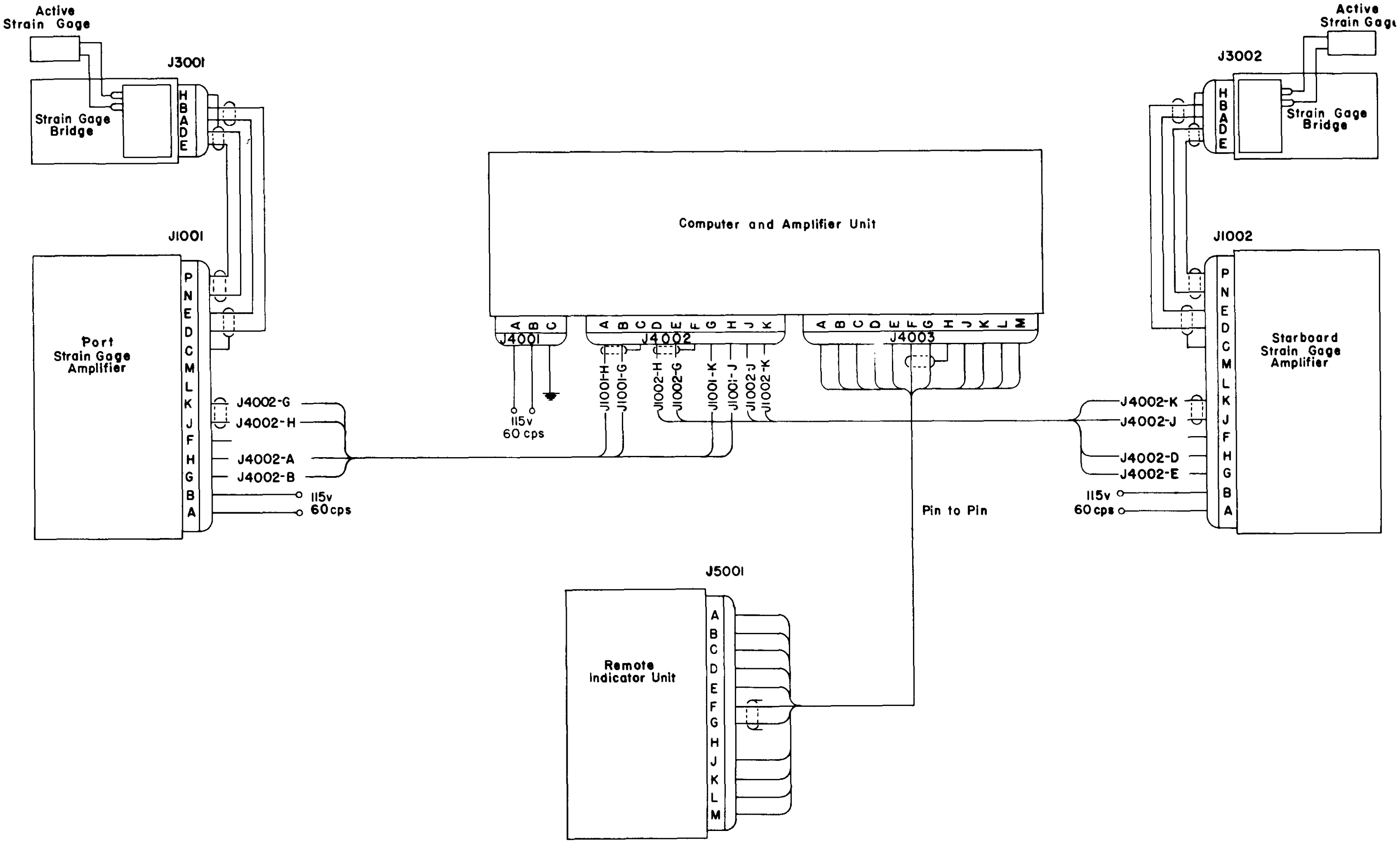
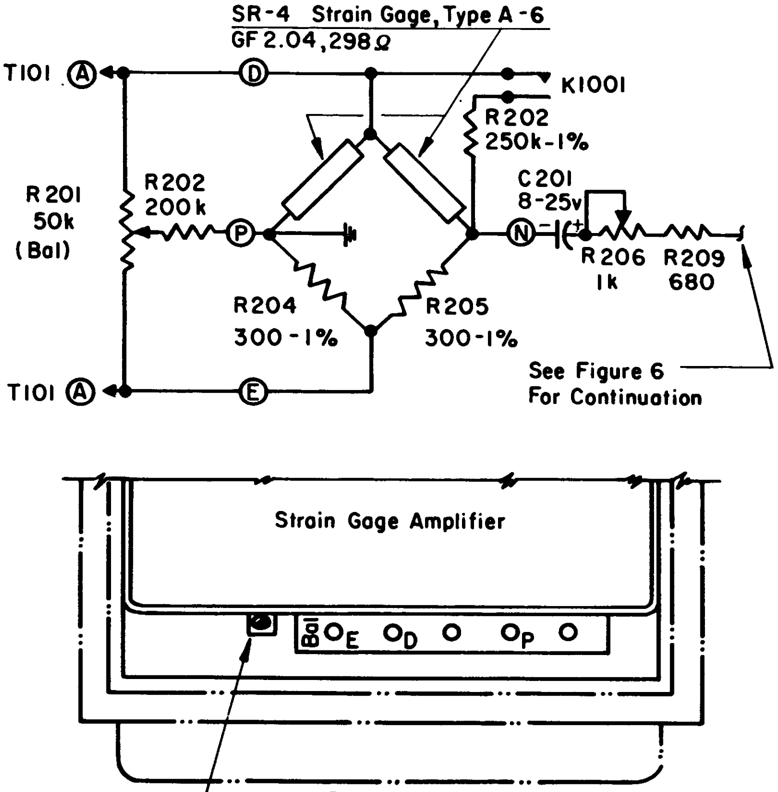


Figure 10 – Wiring Diagram

7. Strain gage bridge balancing:

To avoid overload of the strain gage amplifier, each strain gage bridge must be balanced after each installation. Balancing is required only once and can be accomplished as follows: Open the cover of the console, and throw the P/S cal-operate switch to the "OPERATE" position. The port or the starboard stress meter, which is connected directly across the port or the starboard input before the d-c washout, will read the amplified d-c output of the port or the starboard strain gage bridge. It is necessary to open the cover of the strain gage amplifier and to adjust the balance screw (marked "BAL") until the port or the starboard stress meter reads the predetermined deadweight stress at the gage. If the balance screw does not yield sufficient range for necessary correction, connect a suitable resistor between pins P and E or P and D (Figure 11) depending upon the polarity, to get a coarse balance, and then use the balance screw for final adjustment.



See Figure 6 For Continuation

Use This Balance Pot to Get Proper Reading on Port or Starboard Stress Meter. If Balance Does Not Have Enough Range, Connect a Suitable Resistor Between Pins P and E, or P and D (Depending upon Polarity) To Obtain a Coarse Balance. Use Balance Pot for Final Adjustment.

Figure 11 – Strain Gage Balancing Diagram

8. Adjustments:

Monitor lights for rms stress and peak-to-peak stress appear on both the console and the monitor display unit. The stress level to energize the lights can be adjusted by the following procedures: To set the peak-to-peak monitor light, use a low-frequency d-c signal generator, apply a d-c signal of approximately 0.25 cps to the input of the console, and adjust this signal until the magnitude shown on the peak-to-peak recorder is equal to the desired value. Turn the peak-to-peak monitor pot slowly until the peak-to-peak monitor light goes on. To set the rms monitor light, apply a d-c voltage to the console until the desired indication is seen on the rms recorder. Turn the rms monitor pot until the light goes on. Because the circuit has some latching characteristics and drops out at a lower voltage than it pulls in, it is important to adjust the peak-to-peak or the rms monitor pot so that the light goes on rather than to adjust it until the light goes out.

Zeroing adjustment on the rms recorder, a long and tedious process, can be accomplished as follows: Disconnect the strain gage amplifier from the console, leave the console on for 4 hr, and then adjust "SERVO-ZERO" clockwise for downscale and counterclockwise for upscale. Wait for another 4 hr, and repeat the procedure until the proper adjustment is acheived.

The Burr-Brown d-c amplifier zeroing adjustments are provided on the chopper stabilizer units. These have been adjusted in the factory and should be left undisturbed. A thin plexiglas sheet has been installed to prevent tampering with such adjustments.

9. Calibration:

Switches are provided in the console to calibrate the instantaneous and the peak-to-peak circuits. Each strain gage amplifier is furnished with a 250,000-ohm resistor which can be switched across the temperature-compensating strain gage of the strain gage bridge. This corresponds to a change in output of 18 volt (18,000 psi). When the port or the starboard calibration switch is on the "CAL" position, the corresponding meter on the console will show a shift of 18,000 psi. The instantaneous recorder, which corresponds to the average instantaneous stress of two strain gages, should show a 9000-psi change if only one strain gage amplifier is calibrated and an 18,000-psi change if both amplifiers are calibrated.

Similarly, the peak-to-peak recorder should also show a 9000-psi change if one amplifier is calibrated and an 18,000-psi change if both amplifiers are calibrated. During this calibration, the d-c washout-pass switch should always be on the "D-C PASS" position. If the d-c washout-pass switch is on the "WASHOUT" position, readings on the instantaneous and the peak-to-peak recorders will first show the appropriate calibration values when the calibration switch is turned to the "CAL" position; then the recorded signal will tend to decay towards zero with a 100-sec time constant.

The same calibration method is used for the rms circuit. By connecting a suitable resistor across the temperature-compensating strain gage, an apparent stress will be noted. After a period of 1 hr, the rms reading may be noted. The rms reading on the recorder should be 2.8 times* the value shown on the other two recorders. An alternate method of checking this calibration is to apply a d-c voltage to the input terminals of the console. The voltage may be driven from a 3-volt battery. It should agree with the input voltage on the basis of 1 volt equals 2800 psi within ± 500 psi. It should be noted that ± 500 psi of error is independent of voltage input. The d-c washout-pass switch is, of course, on the "D-C PASS" position during the calibration.

10. Time and date marks:

Each recorder is fitted with a hinged plexiglas cover which permits the operator to label time and date on the paper chart. Coincident data on the sea state and ship operating conditions must be collected in a logbook maintained by the officers; otherwise, it will be difficult to analyze the records.

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*Conversion factor from narrow spectrum rms to d-c signal rms.

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A Flexing Stress Monitor has been developed to measure the strains and to compute, record, and display the associated stresses experienced by a ship at sea. The data are displayed by monitor lights, and by meters to aid the captain in ship handling. The continuous records are suitable for statistical analysis at a later date to provide general information of use in ship design. The monitor requires only standard 115-volt 60-cps electrical power, and is intended for continuous operation for weeks aboard ship with a minimum of care. Analysis of the records from tests in the laboratory and at sea have shown that the prototype monitor performed well as an automatic data recorder. The usefulness

1. Monitors--Equipment
2. Monitors--Effectiveness
3. Ship hulls--Stresses--Measurement

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