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Fiber-Optic Strain Monitoring on a Navy Cruiser

J.M. Nichols,[1] M. Seaver,[1] S.T. Trickey,[1]
K. Scandell,[2] and L.W. Salvino[3]
[1]*Optical Sciences Division*
[2]*NSWC Norfolk*
[3]*NSWC Carderock*

Introduction: A number of CG class vessels in the U.S. Navy are experiencing cracking at various locations on the aluminum superstructure. The cracking has been observed on the 04 level deckplate, the overhead of one of the AN/SPG-62 Illuminator (radar) rooms, the intake bulkhead, and several other locations on one particular class of vessel.[1,2] The cracking is, in many cases, persistent, recurrent (even after repairs), and has the potential to influence mission critical operations aboard ships.

Currently, the cause of this cracking has been investigated and is believed to be stress corrosion caused by sensitization of the aluminum alloy used in construction (5456 material). However, in order for this type of cracking to initiate and persist, the material must be sustaining large stresses. The origin of these stresses is still in question. The goal of this work was to instrument one of the affected areas, monitor the stresses over a 36-hour period during transit, and try to discern the types of ship maneuvers or ambient conditions that are leading to stress concentrations. The specific area under observation was the deckplate (overhead) of the #4 Radar room (05-316-0-C) onboard a ship from the affected class. This location was chosen because there has been repeated cracking of this deckplate and because this room provided the most convenient, unobstructed location for installation.

Sensing System and Installation: The sensing system used for this application was a fiber-optic strain-sensing system developed at the Naval Research Laboratory. This system is ideal for use in monitoring stresses in corrosive environments (in this case, a marine environment), is lightweight and unintrusive, and is capable of measuring slowly varying stresses (down to DC) with high accuracy.

The sensing system was installed during a single day on May 15, 2007. Four fiber Bragg grating (FBG) rosettes (referred to as A, B, C, and D in this article) were installed in the overhead of #4 Radar (05-316-0-C) where the ship had previously experienced cracking. This space houses mission-critical equipment (both communications and weapons) and was therefore deemed an ideal candidate for monitoring. Additionally, this particular location allowed for the simplest, most unintrusive installation of all potential areas surveyed. The FBG strain rosettes, each consisting of three FBG sensors, were used to monitor the principal strains experienced by the deck plate. Figure (7(a)) shows the inside of the radar room and the sensing equipment used to record the strain data while Fig. (7(b)) shows the locations of the strain rosettes.

Strains on this deckplate were monitored over a two-day period during a variety of maneuvers at a sampling rate of 360 Hz. First, a series of tests was coordinated with the ship's Captain whereby the ship performed "hard turns" at a variety of increasing speeds. The goal here was to discern the effects of inertial loading on the deckplate resulting from simulated combat maneuvers. Next, the AN/SPG-62 Illuminator was rotated to determine its influence on the deck strains. The maximum rotational speed this particular AN/SPG-62 Illuminator can achieve is roughly 1/6 Hz (thus the sampling rate is more than sufficient).

Deck Plate Response to Ship Maneuvers: Figure 8 shows plots of the principal stresses vs time for rosettes C and D (see again Fig. 7 for rosette placement). In this figure, note that the measured stresses are all compressive, with the largest magnitudes beginning about 2000 hours and ending near 0600 the next morning. Also plotted is a measure of engine load (shaft rpm × pitch). The data shows a strong correlation between engine load and deckplate compressive stress. As the ship picks up speed, the stress observed in the deckplate tends to increase. This may be due to thermal loading from the engine transferring to and stabilizing in the ship structure or perhaps direct structural loading resulting from drag created by speed increases. Engine load appears to be one of the primary mechanisms causing excessive stress in the deckplate. Also plotted in Fig. 8 is the yield stress for the deckplate material, σ_{yield} . The observed strain variations are 50% yield of the base metal.

A series of turns was performed at varying speeds to determine the influence of ship maneuvers on the deck strains. Beginning at approximately 19:24, the ship's speed was reduced to 8 knots. The speed was then slowly increased to 20 knots over the course of the next 45 min. At 20:11, moving at 20 knots, the ship performed a sharp right turn ("hard rudder right"), followed by a hard left turn, followed by another hard right turn. The entire sequence lasted approximately 5 minutes. The ship's speed was then increased to 27 knots and the same sequence of turns was conducted. Finally, the ship's speed was set in excess of 27 knots and the sequence repeated once more. This final set of turns was completed at 21:00. Figure 9 displays the sequence of data recorded during maneuvers. The time axis shown in Fig. 9 is shown relative to the beginning of the maneuvers. Several observations can be made regarding the deckplate response to high speed turns. First and foremost, the maximum strains observed due to the ship maneuvers were roughly ± 10 $\mu\varepsilon$. These values are extremely small and are not likely to be the cause of any significant structural damage. Although the magnitudes of the strain values do increase with speed, the ship will not likely see maximum knots for prolonged periods, thus hard turns at speed are not an issue in deckplate cracking.

As was previously mentioned, testing was also performed to see whether or not slewing of the AN/SPG-62 Illuminator mounted to the surface of the deckplate caused excessive strain. No such strain was observed throughout these tests. We could discern no difference from the ship's ambient vibrations and therefore conclude that AN/SPG-62 Illuminator motion is not an issue with regard to the deck cracking.

Conclusions and Recommendations: The data collection from this particular ship was largely successful and resulted in some preliminary results that are useful in understanding the cause of the recurring deck cracking. First of all, the primary source of strain on the deckplate cannot be attributed to ship maneuvers or slewing of the AN/SPG-62 Illuminator. Neither action resulted in more than 10 $\mu\varepsilon$ of load. Secondly, the primary strain does not appear to be the result of thermal affects. Rather there exists a large compressive load, correlated with engine speed, that forms in the deckplate as the ship gets under way.

Future Enabling Technology Vision: Integrating this technology, with proper engineering design, into hull forms at new construction and capturing real-time hull load data could significantly expand Fleet operator's envelope for ship performance by reporting actual forces acting on the hull at any given point in time. This could enable ships to operate in higher sea state at higher speeds; enable submarines to dive deeper and faster; and enable Commanding Officer's power of informed decision, each of which is not enabled based on ship operational parameters being limited by modeling and safety factor alone.

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[Sponsored by ONR]

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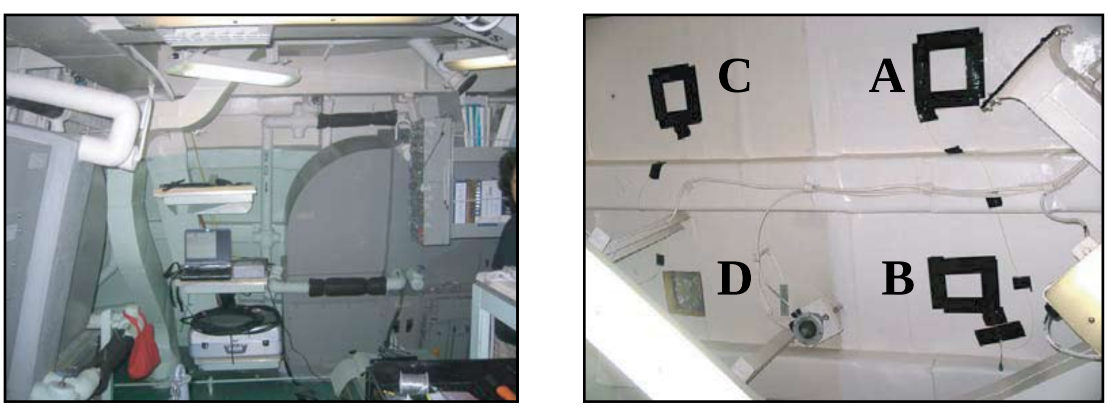

(a) (b)

FIGURE 7
(a) The computer and demodulation hardware are located on the middle shelf in the back corner of the radar room. (b) The overhead directly above the shelves is where the gratings were located. The four FBG rosettes (A, B, C, and D) are shown with most of the insulation replaced.

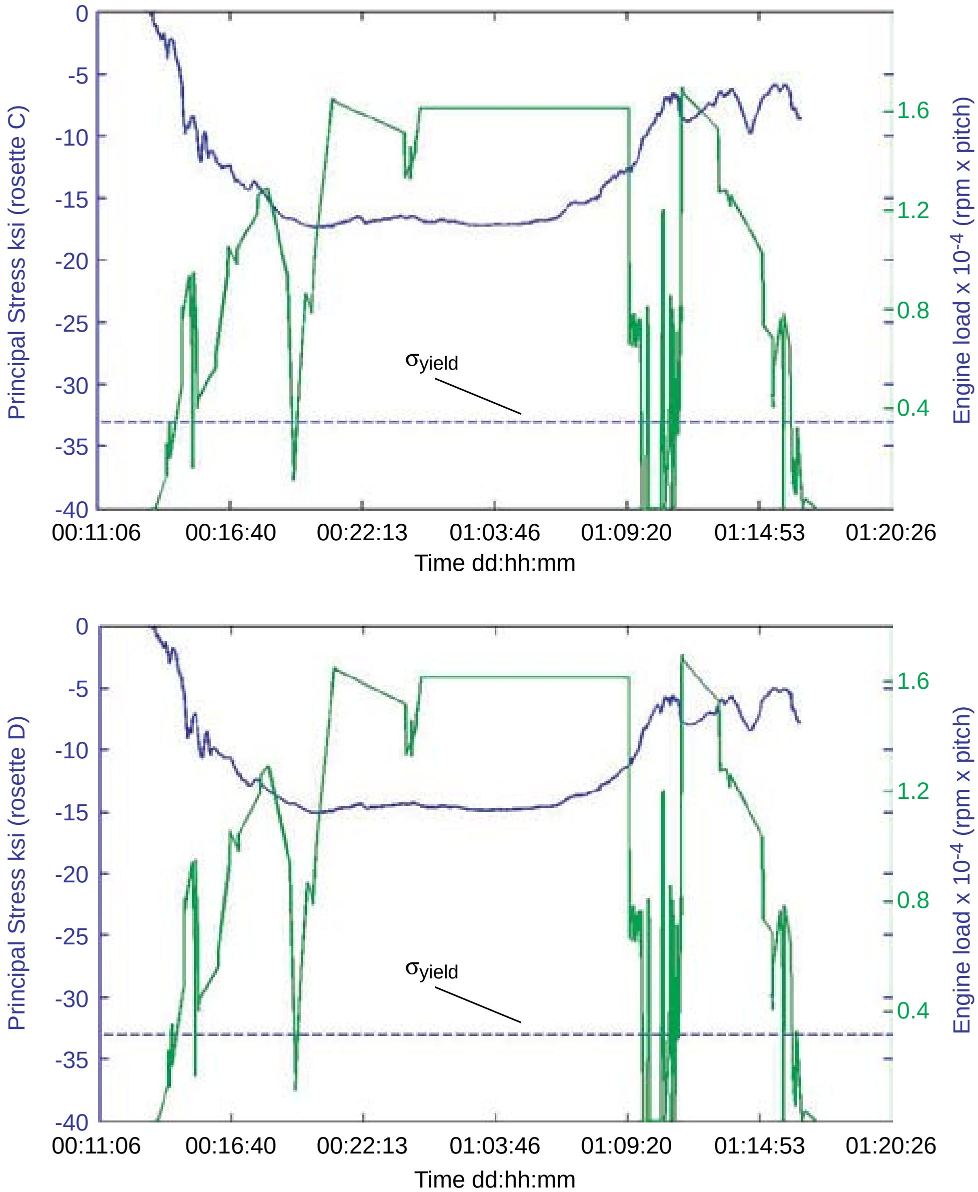

FIGURE 8
Principal stresses recorded during the trip from rosettes C and D. Also shown is the yield stress for the deck material. Note that the largest stresses began near sunset on 6/7/07 and ended about sunrise on 6/8/07. Stress correlates well with engine load.

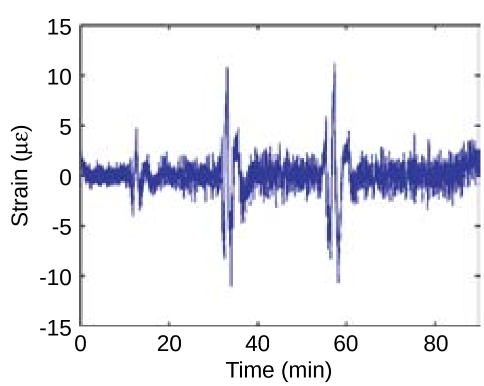

FIGURE 9
Sensor data recorded from sensor 3 of rosette C showing the strain values recorded during a series of hard turns at high speed.