DAMAGE MONITORING OF SHIP FRP DURING EXPOSURE TO EXPLOSION IMPACTS

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1 Introduction

Fiber Reinforced Plastics (FRP) has been used by Kockums' shipyard in the manufacturing of ships over 35 years, during which time is has been proven to be durable and practical. The light weight makes it a more and more attractive material as energy and material expenditure decreases are required. A special application is the *Composite Superstructure Concept* [1] where composite materials are added on top of a steel hull, which decreases the weight and running costs considerably, and makes it possible to even add extra levels while keeping the same center of gravity.

If efficient condition monitoring systems can keep track of emerging damages of the structure, the weight may be even more reduced and the interval between maintenance inspections may be prolonged. As important steps in this process, a ship mock-up section was subjected to increased levels of explosive underwater impacts, and the damage progression in the hull was monitored by a nonlinear acoustic technique.

2 Description of monitoring technique

The hull condition monitoring system use as input acoustic vibrations that exist in the hull structure. When a sensor is close to a damaged part of the hull, specific indications will be detected by the damage indication algorithm. This will be interpreted as damage levels.

The analysis technique is based on nonlinear acoustics [2-6]. Damage in a ship hull is directly related to the nonlinearity of the material. This will show itself as a distortion of the waves.

As a first example of how the system can monitor the obtained signals for damage, we will show how the nonlinearity affects a single frequency. In Figure 1, top is seen the signal when a material is un-damaged. A single frequency exist. Below is seen how the frequency spectrum includes many more frequencies when the material is damaged. Higher harmonics are created.

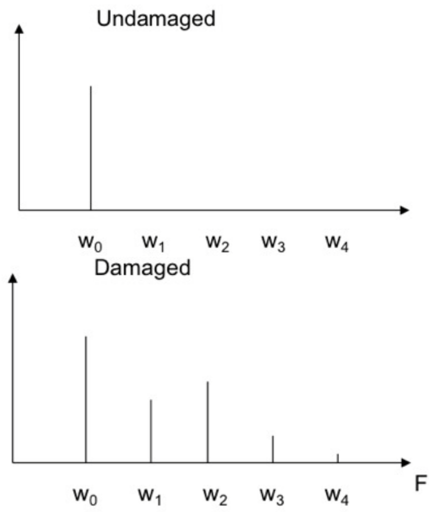

Figure 1. When a single frequency is input to the material, the same frequency is measured when the material is undamaged, top. When the material is damaged, higher harmonics are created, below.

3. The Fiber Reinforced Plastic ship mock-up

A ship section made by Glass Fiber Reinforced Plastics was especially manufactured for this test at the Kockums ship yard in Karlskrona, Sweden, see Figure 2. It has the dimension 12*10*6.5 meters, and contained a few parts of steel machinery necessary to imitate a real vessel's local inertia.

Figure 2. The ship full scale test section during its construction at Kockums, Karlskrona. The PZT ship hull sensors were later placed where the white plate on the bottom and on the vertical sides where the plastic tubes are, see Figure 5.

The composite hull techniques has several advantages like low weight, long lifecycles, simple maintenance and supreme shock resistance the double skin sandwich is twice as tough as conventional steel hulls [7].

Figure 3. A cut of the Fiber Reinforced Plastics manufactured by Kockums and DIAB.

The core material is Divinycell, a polymer foam which is produced by DIAB through a vacuum assisted infusion technique [8].

Figure 4. Another sample of a the Divinycell core material from DIAB.

4. The explosive impact test on the ship full scale test section.

A test with fixed sensors, see Figure 3, measuring the progressive damage as a result of increased levels of blasts from exploding underwater charges were performed during two weeks in November 2010. This was one of few opportunities to measure real life progressive damage on a large floating ship structure. This particular opportunity comes rarely - the previous one on the same order of magnitude was done in 1974.

Figure 5. The PZT sensors were placed in regions where damage was expected.

Normally, the types of damage for vessels during regular operation occur either during many years, or as a result of sudden impact. Neither of these is of the kind that are convenient to perform during testing phases.

The blasts were increasing in impact level successively. The sensors were during the blasts left on the ship hull, while the rest of the equipment could not be left on the ship because of the high risk for damage. This meant that in between the blasts there was a time scope within which the equipment had to be transported to the ship and set up. Then the measurements were made and the equipment had to be brought back to land again.

Figure 6. Explosives were detonated underwater some distance from the test section.

The result of this test, after the post-processing of the data, is seen in Figure 7.

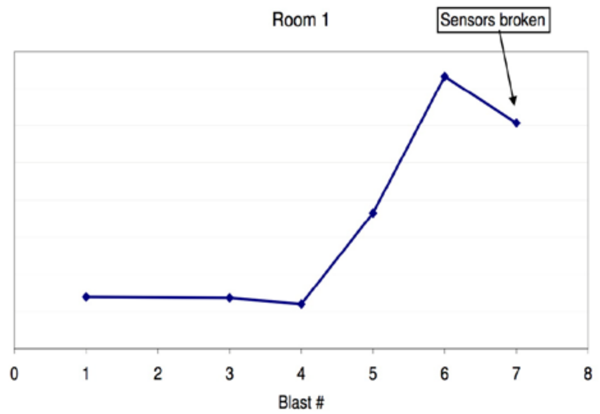

Figure 7. The evolution of measured damage amplitude as a function of number of under water shock load.

The curve is showing the expected result. For the low level explosions, almost no damage occurred. For the higher levels, there was a "continuous" increase in the indicated damage. For the last explosion, the sensor attachments were damaged and the damage indication decreased. This was a very good result showing two things: 1) that the system responded to the increased damage; and 2) that the sensors were to a high degree coping with extreme external forces.

5. Discussion

An extended use of sensors to parts of the structures on the ship would make it possible to detect damages on any part of the structure. For example - if this knowledge is being used already at the design stage of the ships, the structure safety factors may be reduced. This means that a further weight reduction would be possible through using thinner materials. A decrease in both material use and in energy use during operation would ensue. This is especially important when using new materials or new types of joints, whose long-term behavior are not well known.

Similar techniques based on nonlinear acoustics may be used in the manufacturing of parts and in the assembly of parts into structures. This would ensure the highest quality of the parts during different stages in the production process so that the final product does not consist of materials already at a small way in the damage progress. Another evident use is in ship maintenance.

The techniques under development in this sub-project may be used for other types of vessels, for other types of materials, and even outside the shipping industry - for example within aeronautics.

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