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Measuring global impact forces on the CCGS *Terry Fox* with an inertial measurement system called MOTAN

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Abstract

This paper describes the forces that were measured on the CCGS *Terry Fox* during just over 50 collisions with glacial ice. Global impact forces on the ship were estimated by an inertial measurement system called MOTAN, using two different approaches. The global force can be calculated at the point of impact (POI) from the POI Approach or, if the impact location is not known, at the ship's origin (SO) using the SO Approach. Forces from MOTAN are corroborated with local forces from two instrumented areas of the hull, when possible. Resultant global impact forces ranged from 0.5 to 6.7 MN using the POI Approach and from 0.9 to 10.6 MN using the SO Approach. The stem-on symmetrical impacts produced higher global forces than the glancing-type impacts. The glancing-type impacts usually generated a series of impacts, as the ice moved aft along the ship's hull. MOTAN captured the first impact, which usually produced the highest force, and subsequent impacts if they occurred at least 2 s after the previous impact. Measurements from the bergy bit collisions are compared to the forces that were measured during previous ship ramming trials in multi-year ice, since no other data on ship impact forces in glacial ice are available. Forces measured on the strain gauged area of the hull during the Bergy Bit Trials and global forces from past field programs in multi-year ice confirm that MOTAN is a viable approach for measuring global impact forces.

Keywords: MOTAN; Inertial measurement; Global impact loads; Bergy Bit Trials; Icebergs; Ships

1. Introduction

During the Bergy Bit Trials, the CCGS *Terry Fox* (6800 tonnes) conducted more than 150 controlled collisions with glacial ice, at speeds up to 12.8 kt (6.6 m/s), as discussed in Gagnon et al. (2008-this issue). The purpose of the Bergy Bit Trials was to measure the forces and pressures during ship collisions with glacial ice because the open literature contains virtually no data of that kind, despite its relevance to offshore structures and ships operating in bergy waters. The Bergy Bit Trials were, in fact, the first time that a ship had purposely impacted glacial ice for the sake of documenting ice forces and pressures. Two different techniques were used to measure local impact forces and pressures on the ship. The first type of instrumentation consisted of a 3.5 m^2 external optical Impact Panel (Gagnon, 2008-this issue). About 4 m aft of that, an array of 120 strain gauges was used to measure the forces and pressures on a 5.4 m^2 area of the hull (Ritch et al., 2008-this issue). The third type of force measurement system, an instrument called MOTAN, was used to measure the net resultant of the local forces that were applied at various contact areas

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along the ship's hull, or the global impact force. The three systems were complimentary: the strain gauges and the Impact Panel provided detailed information about the local forces and pressures on a pre-defined area of the ship's hull, and MOTAN measured global impact forces on the ship.

Three types of collisions were conducted during the Bergy Bit Trials: oblique, lateral and symmetrical collisions. Most of the 178 bergy bit collisions classified as oblique type collisions that involved the ship using a near-straight trajectory to produce impacts on the instrumented areas of the hull. The lateral collisions also registered on the instrumented hull, however a unique approach trajectory was used to slowly move sideways and nudge the berg with the ship's port side. About 18 stem-on, symmetrical collisions occurred when the ship used a full frontal attack to impact the bergy bit. Although the symmetrical collisions were fewer in number because neither area of the instrumented hull was affected, they resulted in some of the most significant impacts of the trials.

This paper includes detailed force records for 12 collisions with four different bergy bits to illustrate how the forces varied spatially and temporally during an impact. While impact forces from MOTAN are the focus of this paper, data from the other two force measurement systems are used to corroborate MOTAN data, where possible. The reader is referred to the companion paper by Johnston et al. (2008-this issue) for a detailed comparison of forces from the different instrumentation systems.

2. Background

Traditionally, local and global ice impact forces are estimated from the measured ship's deflections, by installing strain gauges at strategic positions throughout the ship's bow and/or along the ship's length. Two of the earliest trials that used strain gauges to measure local ice impact forces on a ship involved the CCGS *Louis S. St-Laurent* (Noble et al., 1978; Blount et al., 1981). Strain gauges have also been used to estimate global ice impact forces on ships such as the M.V. *Robert LeMeur* and *Canmar Kigoriak* (Ghoneim et al., 1984), M.V. *Arctic* (German and Milne and VTT, 1985), USCGC *Polar Sea* (Minnick et al., 1990) and the USCGC *Polar Star* (Minnick and St. John, 1990). While the strain gauge technique has been used successfully to estimate local and global ice impact forces on ships, it has drawbacks: installing strain gauges can be invasive, labor intensive and costly.

This paper describes a non-invasive method of estimating global impact forces on ships. An inertial measurement system called MOTAN is used to measure the impact-related ship motions in six degrees of freedom, and those motions are used to calculate the resultant global impact force. MOTAN, which stands for MOTion ANalysis, is a two-part package that consists of (1) a physical sensor to measure ship motions in six degrees of freedom and (2) specially developed software to calculate the whole ship motions and the global exciting forces and moments (Fig. 1). Johnston (2006)

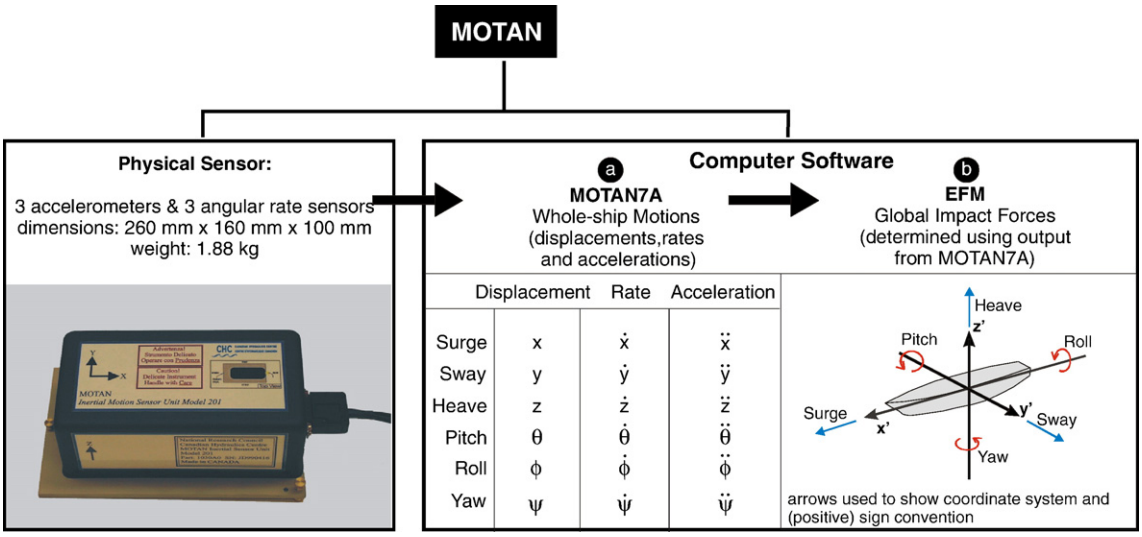

Fig. 1. Schematic showing hardware and software components of the MOTAN system. Hardware consists of a physical sensor unit that contains three accelerometers and three rotational rate sensors. The software consists of (a) MOTAN7A for calculating the whole ship motions and (b) EFM for calculating the global exciting forces and global exciting moments.