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Identification of slam events experienced by a high-speed craft

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ABSTRACT

Ship structures are prone to fatigue cracking due to fluctuating loads caused by the seaway. This is especially the case for high-speed craft (HSC), as the slamming loads and associated response are known to significantly impact the stress magnitudes experienced by the structure. Therefore, slamming may have a considerable influence on the fatigue life of HSC when compared to accounting for the global wave induced stresses alone. This paper presents an investigation into various methods for identifying slams for structural response analysis. Measurements of hull girder stresses of an aluminium high-speed patrol boat are utilised to explore the characteristics of slam events. The approach to analyse full-scale time records, decomposition of the wave-induced and impact components of stress, and definition and detection of slam events are discussed. With respect to fatigue life, identification of slam events enables the evaluation of the influence of slamming and the associated whipping response in a range of speeds, headings and sea states. Such knowledge supports informed decision-making in regards to the sustainability and maintainability of the vessel.

1. Introduction

Fatigue damage of a structural item occurs when exposed to numerous cycles of stress peaks (tensile) and troughs (compressive). The fatigue damage accumulates until the load-bearing capacity of the structural item falls below the applied load. Sources of cyclic loads experienced by a ship structure include wave action, inertial reactions from contents, hydrodynamic loads from appendages and propulsive devices, rotating machinery, and transient vibration induced by impact loads such as slamming (Hughes and Paik, 2010).

A slam event occurs when a vessel experiences sufficiently large heave and pitch motions such that the bow emerges from the water and re-enters with a heavy impact or slam. Slam loading is characterised by a rapid increase during water re-entry followed by high frequency transient vibration in the structure, or whipping, which decays rapidly (Dessi and Ciappi, 2013; Mansour and Liu, 2008).

The slamming loads and associated response of high-speed craft have been known to have a significant impact on the stress magnitudes experienced in the structure (Thomas et al., 2006, 2003). Slamming may have a considerable influence on the fatigue life of high-speed craft when compared to accounting for the global wave induced stresses alone (Thomas et al., 2003; Zhu and Collette, 2011). In full-scale measurements of ships, stress components varying with the two-node hull girder vibration frequency have been observed. In general, these higher frequency stress amplitudes are much smaller than those seen in the direct wave-induced frequency range and therefore are usually not explicitly accounted for in the structural design of ships (Nielsen et al., 2011; Thomas et al., 2003). Further, fatigue damage measured from a flexible model of a large ocean-going ship showed that the wave-induced vibrations contributed approximately 40% of the total fatigue damage (Drummen et al., 2008).

Owing to operational requirements such as fast transport of troops and equipment and improved interception and apprehension capability, high-speed craft are being increasingly used in naval applications. In Australia, the Royal Australian Navy (RAN) operates a fleet of thirteen Armidale Class Patrol Boats (ACPBs). These vessels have a deep "V", hard-chine, semi-planing hullform, are constructed from marine-grade aluminium alloys, and operate in a tropical environment. The operational requirements of naval vessels are often demanding (Gudze et al., 2006; Kramer et al., 2006), and the loads applied to high-speed craft can feature a high degree of non-linearity. Knowledge of the structural behaviour of relatively high-speed craft supports informed decision-making in regards to the sustainability and maintainability of the current fleet and future acquisitions.

In order to improve understanding of the influence of slamming on the fatigue life of high-speed craft, the definition of a slam event needs to be established. Treating slamming- and wave-induced stress components separately can also be practical in structural integrity assess-

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Nomenclature

a, m	Fatigue curve parameters
ACPB	Armidale Class Patrol Boat
CL	Centreline
D	Fatigue damage
DSTG	Defence Science and Technology Group
F_c	Cut-off frequency [Hz]
F_e	Average encounter wave frequency [Hz]
F_s	Sampling rate [Hz]
F_{valley}	Frequency of valley between the first two peaks in a spectral response [Hz]
FP	Forward Perpendicular
GPS	Global Positioning System
HMAS	Her Majesty's Australian Ship
HMS	Hull Monitoring System
Hz	Hertz, cycles per second
n	Number of stress cycles
N	Number of stress cycles to failure
RAN	Royal Australian Navy
RMS	Root Mean Square
$\Delta\sigma$	Stress range [MPa]
β	Multiplication factor
σ/σ_{allow}	Stress non-dimensionalised by allowable stress

ments performed analytically or numerically. Similarly, the contributions of wave-induced and whipping stresses to the total stress can be related in a probabilistic manner. The peak values of the wave- and slamming-induced (whipping) loads may be asynchronous; the relationship between wave and slamming effects is dependent on the sea state, vessel speed, and wave frequency (Ćorak et al., 2013; Mansour and Liu, 2008). Therefore, slam event identification can be used to establish both the requirement and a practical approach to account for slamming loads in ship structural assessment based on a fatigue criterion.

Slam detection is also useful information in structural health monitoring and operational guidance. This can take the form of a slam avoidance system that predicts the possibility of a vessel approaching operating conditions that could induce slamming. Alternatively, a slam monitor can also indicate the trend over time in relation to impacts that exceeds warning levels. Colwell and Stredulinksy (2008) discussed the development of polar plots to indicate which combinations of vessel speed and heading can lead to a high probability of exceedance levels for slamming loads on the KINGSTON Class Maritime Coastal Defence Vessel. The authors also examined ways to provide real time operator guidance to enable informed evaluation of the risk of severe slamming versus the urgency of the mission. Part of this work was selection of an appropriate parameter to indicate slam severity, such as centreline vertical bow acceleration or structural response provided by strain gauges. Even so, efforts to improve operational advice regarding slamming and its effects on the structure have tended to be focused on larger vessels. Barhoumi and Storhaug (2013) presented an assessment of whipping and springing of a large container vessel. Data from an installed hull monitoring system was used to study fatigue damage rates with respect to re-routing and speed reduction and the associated whipping contribution. Nielsen et al. (2011) outlined a procedure for hull-girder fatigue damage rate prediction, taking into account whipping stresses, for hypothetical changes in ship course and speed. The proposed spectral method was verified against full-scale results of a container ship analysed by the rainflow counting method.

As driven by the need to improve fatigue life prediction of relatively high-speed craft, this paper presents an investigation of different approaches to characterise and count slam events using full-scale measurement data from an ACPB. Attention is directed to determining a robust method to decompose stress time records into its wave and whipping stress parts, indicative fatigue damage induced by slamming, and slam event definition and detection. Finally, areas of further work are discussed.

2. Hull monitoring system

The Defence Science and Technology (DST) Group is conducting research aimed at improving understanding of the structural integrity of welded aluminium high-speed craft. Critical to this research is gathering data on the operational profile and the response to global and localised loading of a vessel in service. As such DST Group collaborated with Austal Ships to install and commission a Hull Monitoring System (HMS) onboard an ACPB, HMAS GLENELG. The aims of the project were to develop a capability for structural fleet management and Life-of-Type assessment, and to demonstrate the application of a versatile network using specialised sensors on a naval platform (Gardiner et al., 2008).

The HMS was comprised of accelerometers, strain gauges, torsion meters to measure shaft power, a six degree of freedom rigid body motion reference unit, and a Global Positioning System (GPS) (Vincent

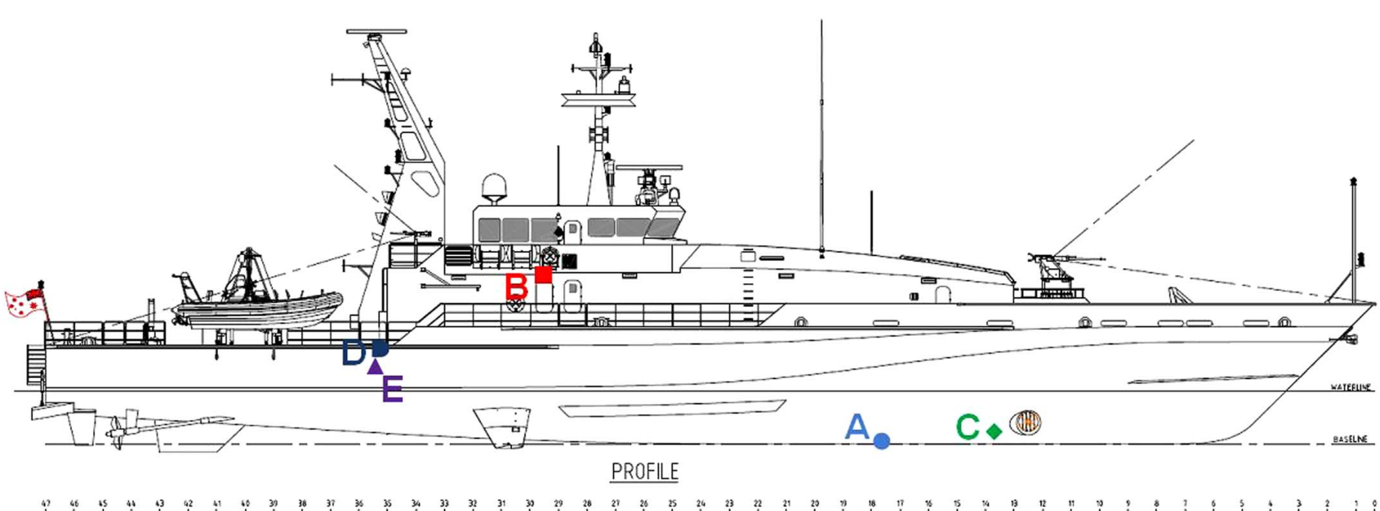

Fig. 1. Profile view of ACPB showing strain gauge locations.