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Live crack damage detection with local strain measurement on solid bodies subjected to hydrodynamic loading

P. Fanelli[a*], A. L. Facci[a], E. Jannelli[b]

[a]*Department of Economics, Engineering, Society and Business Organization, University of Tuscia, Largo dell'Università, 01100 Viterbo, Italy*
[b]*Department of Engineering, University of Naples Parthenope, Isola C4 Centro Direzionale, 80133 Napoli , Italy*

Abstract

The interaction of water free surface with solid bodies is object of interest in several mechanical, ocean, aerospace and civil engineering problems. The presence of impulsive loading and large local deformation leads to complex coupled dynamics. The possibility of live monitoring of these body could provide information about damage detection and fatigue life estimation. The definition of appropriate signal processing and modeling tools enabling the extraction of useful information from distributed sensing signals is a relevant scientific challenge. On the basis of previous works by some of the authors, this paper deals with the application of a method for real-time deformed shape reconstruction of solid bodies subjected to impulsive loadings using distributed numerically generated strain measurements signals, such as those produced by Fiber Bragg Grating (FBG) sensors. A numerical study is carried out considering a simplified model of the problem of hull structures subjected to hydrodynamic loading. The hull, analyzed in a simplified section, has been studied both in healthy condition and with the presence of crack damages. The potential for detecting, localizing and quantifying this damage using the reconstruction algorithm is investigated, by leveraging the proposed concept of control sensors, that are FBG sensors used for comparing reconstructed strains and/or displacements with measured quantities. The positioning and number of sensors and the effect of sensor layout on damage detection is investigated, with the aim of developing a real time damage detection methodology.

Keywords: Damage Detection; Structural Health Monitoring; FBG; Modal Reconstruction

* Corresponding author. Tel: +39-0761-357046; fax: +39-0761-357046.
E-mail address: pierluigi.fanelli@unitus.it

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1. Introduction

The wide range of applications in civil, mechanical, ocean and aerospace engineering of the problem of solid bodies impacting the water surface have focused the attention of the scientific literature (Faltinsen (1990); Cavalagli et al. (2017)). The impact of a solid body on the water generates large local strains and displacement and high vibration (Cui et al. (1999)) and needs to be taken into account for the design of marine structures, aircraft fuselages in sea landing, rockets, boosters and other structures interacting with water in the presence of a free-surface, as reported in (Faltinsen (1990); Seddon and Moatamedi (2006). Several works, presented by Moyo and Greenhow (2000); Scolan (2004); De Rosis et al. (2014); Facci et al. (2015); Facci and Ubertini (2015); Facci et al. (2016), deal with the prediction of hydrodynamic loading and related deformation, analytically and numerically. On the other hand, most of the experimental investigations are focused on rigid structures (Garrison (1996); Chu et al. (2005); De Backer et al. (2009)) and rarely address flexible bodies (Qin and Batra (2009); Maki et al. (2011); Stenius et al. (2011); Russo et al. (2017). An experimental methodology to reconstruct the deformed shape of bodies entering the water free surface, starting from a finite number of local strain measurements have been developed in Panciroli et al. (2015) and Panciroli et al. (2016). The methodology uses fiber optic sensors with Bragg gratings (FBG) as sensing devices. FBGs are suitable for high frequency measurements and are practically insensitive to water and moisture, as reported by Yeo et al. (2008) and Majumder et al. (2008). Live measurement of structural deformation (Panciroli et al. (2015); Panciroli et al. (2016); Kuang and Cantwell (2003)) through FBG technology is possible thanks to its characteristics such as high resolution, lightness, flexibility, small size and response speed. The enhancement of this methodology could lead to the definition of real-time Structural Health Monitoring (SHM) systems to track the evolution in structural performance during operation and to verify the integrity of the system time wise. With the development of new sensing technologies, the increasing availability of high computational capacities and the steady improvement of signal processing algorithms, the use of distributed strain measurements is becoming popular for real time analysis and SHM of large structures and surfaces (Ubertini et al. (2013); Laflamme et al. (2016); Balageas et al. (2006); Materazzi and Ubertini (2011)). The structural monitoring of bodies subjected to fluid-structure interaction due to impulsive loading is still to be developed in depth. A further development of the deformed shape reconstruction method for curved structures is presented in Fanelli et al. (2017), where a novel methodology for damage detection is proposed. The main challenge is performing damage diagnosis, localization, and prognosis on structures where traditional sensing solutions can be used with difficulty because of technical limitations. The use of advanced sensing solutions, capable of performing distributed strain monitoring, is a fruitful research direction to achieve an effective SHM. In Fanelli et al. (2018) the sensors layout is investigated in order to detect design instruction for monitoring systems implementation. FE models of cylindrical bodies subjected to impulsive loads are realized and sensors signals generated numerically and processed to detect damage presence, extension and position.

This paper deals with the application of the method for real-time deformed shape reconstruction of solid bodies subjected to impulsive loadings using distributed numerically generated strain measurements signals. Such signals may represent those produced by Fiber Bragg Grating (FBG) sensors and the proposed procedure may be applied for structural health monitoring.

A numerical study is carried out considering a simplified model of the problem of hull structures subjected to hydrodynamic loading. The hull, analyzed in a simplified section, has been studied both in healthy condition and with the presence of crack damages. The potential for detecting, localizing and quantifying this damage using the reconstruction algorithm is investigated, by leveraging the proposed concept of control sensors, that are FBG sensors used for comparing reconstructed strains and/or displacements with measured quantities. The positioning and number of sensors and the effect of sensor layout on damage detection is investigated, with the aim of developing a real time damage detection methodology.

2. Real-time damage detection

The real time monitoring of the structure is based on the processing of the FBG signals performed through a modal decomposition method. The analytical procedure, presented in Panciroli et al. (2015) and enhanced for curved bodies in Fanelli et al. (2017), is here briefly reported.