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Crack detection in offshore platform structure based on structural intensity approach

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ABSTRACT

Structural intensity approach is introduced to study the crack detection for offshore platform in the paper. The Line Spring Model (LSM) of surface crack is proposed based on plate crack structure, and thus the relationship between the additional angle, displacement and crack relative depth is achieved. Besides, the concept of appended structure-borne sound intensity is introduced. The expression of appended structural intensity for crack damage is derived. By observing the input energy, distribution, transmission and vibration performance of structure intensity, evidence is provided for detection of crack location. Vibration analysis is conducted on the whole platform under multi environment load. Using the structural intensity approach, the crack is detected on the key point easily. Moreover, the K-shape welded pipe point is detected using structural intensity approach, and the crack can be detected accurately. Therefore, development structural intensity approach would be extremely useful to spread out technologies that can be applied for offshore platform crack detection accurately.

1. Introduction

During the service life, offshore platform are exposed to high levels of external loads such as waves, wind, earthquakes, ship-berthing impacts, and other kinds of operational loads. Therefore, platforms are prone to damage due to extreme loads, fatigue, corrosion and ship collision. Once cracks appear, the strength and rigidity of platform structure will be greatly affected, and even major safety accidents may happen. In 1980, a fatigue crack appeared on a supporting tube of the Alexander Keeland drilling platform operating in the north sea of the UK [1,2]. Since no timely discovery and maintenance were conducted on the crack, the crack extended and ruptured, and thus the massive structure of the platform overturned, causing 122 deaths. It's necessary to detect the damage degree and location of an offshore platform in timely fashion to ensure the safety. Detection of damage occurring in offshore platform is an important topic in mechanical and structural engineering applications.

Damage which causes structure to danger, usually affects the dynamic features of the system. Thus, several researches have been done in this field using measuring vibration responses of structures since 1970s [3,4]. It is easily to recognize structural damage based on the change of inherent frequency, modal shape, curvature mode and strain mode of the structure. There are many ways to identify the damage location or damage intensity based on the vibration characteristics.

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In the particular application to offshore platform, most recent publications include modal strain energy method, Modal Assurance Criterion (MAC), Coordinate Modal Assurance Criterion (COMAC), Modal Scale Factor (MSF), Mode Shape Relative Difference Method (RD) and Change in Modal Vector Perpendicular to Predominant Modal Direction, are all used for the offshore platform damage detection and location.

Li et al. [5] proposed the Cross-model cross-mode (CMCM) method, which is capable of identifying the damage to individual members of offshore platforms, under limited, spatially incomplete modal data. This method requires only a few modes measured from the damaged structure. And the investigation reveals that the CMCM method in conjunction with iterative Guyan reduction approach yields the best damage location and severity estimate. Wang [6] also applied the iterative modal stain energy method to locate and quantify the damage for three dimensional frame structures. Numerical studies are conducted for a 3D offshore platform based on data generated from limited element models. Liu [7] proposed an improved modal stain energy method for damage localization in jacket-typed offshore wind turbines. He calculated the modal strain energy(MSE) without utilizing the stiffness matrix of the finite element model as an approximation by defining a series of stiffness-correction factors. The numerical and experimental results demonstrated that this method could be properly located utilizing the first two measured modes. These method assumes a damage causing the changes in the dynamic/vibration characteristics of the structure is a justifiable assumption. There are many uncertainties in dynamic modeling of a structure including measurement noise in data or the uncertainties of physical parameters. Therefore, some artificial intelligent method have been introduced. Jamalkia [8] proposed a fuzzy-based damage detection method, using dynamic response of the floating wind turbine, to identify the damage classes with acceptable success rate. Asgarian et al. [9] developed an efficiency of rate of signal energy using Wavelet Packet Transform for damage detection of steel jacket type offshore platforms. Wavelet packet analysis was used to determine the location of damage for different damage scenarios, by using a continuous measurements and monitoring of platform response. Malekzehtab and Golafshani [10] utilized the genetic algorithm to investigated the application of finite element model updating in damage detection of an offshore jacket platform.

Although many of the works in the damage detection are about dynamic/vibration characteristics of the structure, the modal identification method is mainly used under serious damage conditions, and a certain difficulty exists for the recognition of incomplete damage of partial component. Other methods are also developed for damage identification and location in recent years. Bayesian networks is used for fault diagnosis to deal with the uncertainty problems for marine structure [11,12]. Acoustic emission technology is also proposed for the offshore platform fatigue crack damages by using a series of sensors [13]. But these method is still in study and has not been used for offshore platform in practical application successfully.

One relatively new technique for damage detection is based on the power flow or structural intensity (SI). The concept of structural intensity was introduced to extend the vector acoustics approach to energy flow in structure-born sound fields [14–16]. The development of structural intensity formulations by Pavic [17] led to a growing interest in this field during the last two decades. Structural intensity is the power flow per unit cross-sectional area in elastic medium and it is analogous to acoustic intensity in a fluid medium due to structural vibration or dynamic response. Since the structural intensity field indicates the magnitude and direction of vibration and transient energy flow at any point of a structure, it is very interesting to investigate structural intensity from a practical point of view. Currently, many scholars study vibration performance of structure by using structural intensity, which has also been used for recognizing position of crack damage. Wong et al. [18] analyzed the variation of the modal reactive power distribution of a damaged plate. Khadem and Rezaee [19] introduced the energy method and analyzed the vibration of a simply supported rectangular cracked plate. Li et al. [20] proposed the diagnosis of flaws for damaged beam structures using vibrational power flow. Lee et al. [21] investigated the overall behavior of power flow patterns of the cracked plate using the finite element method. Liu et al. [22] studied the transmissions of transient energy flow and dynamic transient response of plate structures under low velocity impact. Roozen et al. [23] calculated the structural intensity for flexural wave motion in plate-like structures by means of test functional series expansion.

The vibrational power flow is only related to the force and velocity. And the vibrational energy would changes a lot if the change of inherent frequency is very small, which is very different from modal identification method. The modal identification method is mainly used for large crack damage, and is often necessary to extract modal parameters from output signals. It is a certain difficulty exists for the recognition of incomplete damage of partial component. Therefore, this methods has high accuracy for little crack of large structures. Through the study of vibrational power flow, the major structure-borne sound source is not only identified, but also the position and size of damage can be detected accurately. It is easier to apply for offshore platform damage detection in practice by using the power flow.

In this study, SI techniques are used for the offshore platform crack detection. Especially, the influence of crack depth on vibration parameter of structure and structure-borne sound are investigated. In Section 3, the model of platform and K-shape welded pipe is established by using finite element method. The vibration sound intensity and total energy is calculated. In Section 4, crack detection of platform is executed by using SI technology. At last, conclusions are given.

2. Structural intensity theory for crack detection

Structural intensity is the power flow per unit cross-sectional area in elastic medium and it is analogous to acoustic