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Deflection measuring system for floating dry docks

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ABSTRACT

Reliable measurement of a deflection magnitude refers to one of the most important tasks in floating dry dock operation. Current and accurate information about the deflection can prevent structural damage and failure by activating alarms and on-board deflection compensation systems. This paper describes the development of a deflection measuring system for floating dry docks. The measuring system is capable of measuring the actual deflection of a dock structure in real-time and fully automatic mode. The system consists of a set of reference marks based on light emitting diodes and a measurement unit with two oppositely directed camera-based channels. The measurement unit is placed in the middle of a wing deck of the dock. The measurement unit and the reference marks are aligned along the wing deck. The accuracy of deflection measurement of ± 1.5 mm in the range of ± 150 mm for the docks in length more than 100 m was achieved during laboratory tests. The system resistance to harsh environment (salt fog, temperature gradient, high humidity, etc.) and the ability to perform measurements in 24/7 regime was proved through field tests at a floating dry dock in operation.

1. Introduction

Floating dry docks are large scale structures designed for building and maintaining ships. Dimensions of floating dry docks (length, width, and depth) depend on the size of ships to be docked. As sizes of modern ships tend to grow, the length of the modern docks can exceed 200 m, while the height and width can reach 50 and 100 m, respectively (Gaythwaite, 2004). As it is a huge structure, a dry floating dock experiences heavy loads both from its own weight and from a docked ship. These loads can significantly vary in time during floating or refloating stage of docking procedure, and also depend on the type of the docked ship and its location on the pontoon deck. Moreover, the loads usually have a highly uneven distribution owing to the complexity of the weight distribution of the docked ship, as shown in Fig. 1. This leads to uneven deformations of the dock structure. Floating dry docks mainly suffer from longitudinal deflection (plane $Y'Z'$ in Fig. 1), rather than in transverse directions (plane $X'Y'$). Excessive allowable deflections can cause severe structural damage and failure. Floating dry docks typically have a system of ballast tanks to compensate the arising deformations. But this system requires accurate and reliable information about the current dock deflection distribution as an input parameter in order to provide effective deflection compensation. At the same time current deflection is of general interest for the dock crew. That is why the deflection measurement is one of the most important tasks in floating dry dock operation.

Several types of deflection measurement systems for floating dry docks were reported, among them: strain measurement devices based on strain gauges or optical fiber sensors (Froggatt and Moore, 1998; Sannerhaugen and Hellvik, 1999; Zou et al., 2006), deflection and inclination measurement systems based on wired and wireless sensor networks (Lynch et al., 2006; Yang et al., 2013), inspection based on geodetic devices (Stiros and Psimoulis, 2012; Carbonari et al., 2013) and automatic camera-based measurement systems (Newman and Jain, 1995; Korotaev et al., 2000; Gorbachev et al., 2007). Besides of strong points, each type of systems has limitations. Therefore, according to international regulations in safety a dock has to be equipped with at least two deflection measurement systems based on different physical measuring principles (Germanischer Lloyd Aktiengesellschaft. Rules for Classification and Construction. Floating Docks, 1993; Rules for Classification of Floating Docks, 2009; Rules for Building and Classing. Steel Floating Dry Docks, 2009; Rules for Technical Supervision during Construction of Ships and Manufacture of Materials and Products for Ships, Part V Technical Supervision During Construction of Ships, 2014).

Strain measurement systems allow measurement of local strain changes of an optical fiber distributed along the hull structure (Froggatt and Moore, 1998; Sannerhaugen and Hellvik, 1999; Zou et al., 2006). A central unit calculates strain profile based on

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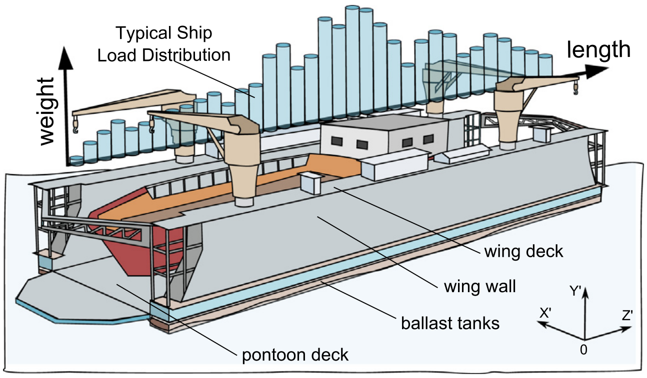

Fig. 1. A floating dry dock and a load distribution of a typical ship under inspection.

Table 1
Measurement task specification.

Parameter	Value
Dock length	up to 200 m
Measurement range along Y'-axis vertical direction)	$\pm$ 100 mm
Measurement accuracy along Y'-axis	$\pm$ 5 mm
Measurement resolution	0.1 mm

measured data. One of the difficulties of this method implementation is a complexity of fiber sensor installation along the whole hull with multiple bays and bulkheads. The inclination-based method also suffer this inconvenience (Vincent et al., 2008; Swartz et al., 2012). Deflection calculation in this case is based on a relative angle displacement of sensors installed along the hull (Lynch et al., 2006; Yang et al., 2013). The angular displacement can be measured by accelerometers, liquid inclinometers and other techniques (Smith and LeVezu, 2012).

Optical and camera-based measurement methods define a reference line, a so-called sighting line, so the transverse displacements of an observed point are measured in the coordinate system based on this line (Maraev and Timofeev, 2013; Maraev et al., 2014; Kleshchenok et al., 2014). According to the practice manual vision inspection performed by a person with conventional optical measurement systems is time consuming and includes human factor (Korotaev et al., 2012). Modern camera-based solutions have the ability to fully automate the process due to recent advances in machine vision techniques by automatic target detection and data processing (Newman and Jain, 1995; Nixon et al., 2012; Sonka et al., 2014).

This paper introduces an approach to deflection measuring of a floating dry dock. The approach is based on a non-contact measuring of linear shifts of finite number of marks placed along a wing wall of a dock. The measurements are done by a designed and developed camera-based system that employs machine-vision techniques. A camera-based solution was chosen for a non-contact method of measuring which minimizes a number of sensors and wires to be installed at a dock. The camera-based solution also has a high potential for an automation and has a low dependence on the human factor.

2. Deflection measuring of floating dry docks: Task definition

Deflection of a floating dry dock causes three-dimension linear displacements of any point of its wing deck. Extreme values of the linear deformations and typical requirements for deflection measuring systems are shown in Table 1.

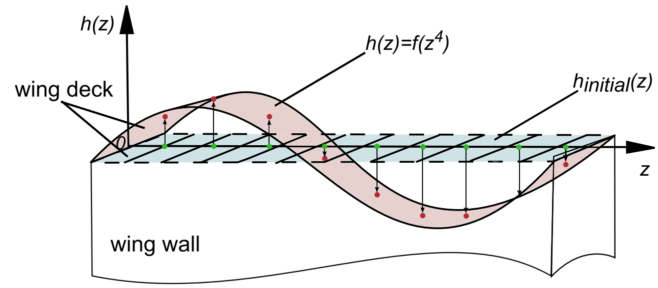

Fig. 2. An approximation of the dock wing wall deformation by polynomial.

The defined measurement task can be resolved by an implementation of a measuring system, which is capable of measuring a spatial position of predefined points along the wing deck of the dock. Special markers or sensors could be placed in these predefined points in order to visualize their displacements or to measure the displacements directly. The points location along the deck have to be defined by dock designer, however, points with the highest displacements are of interest.

According the material strength theory (Smith and Hashemi, 2006; Mott, 2014) and practice, the magnitude of the dock deflection depends on the distance to the power of four, so the dock deflection profile can be approximated by fourth-degree polynomial. This polynomial determines the deformation of the construction at distance z from the origin of the coordinate system presented in Fig. 2. So the measurement procedure for reliable estimation of the actual deformation profile of the floating dock requires the next steps:

Step 1. A prior measurement of the initial deformation profile $h_{initial}(z)$ at the unloaded state.
Step 2. Measurement of the deformation profile $h(z)$ at the loaded state.
Step 3. Measurement of the normalized deformation profile at the loaded state $h_{normalized} = h(z) - h_{initial}(z)$.

When the displacements $h(z_1), h(z_2), \ldots, h(z_n)$ at the chosen points with positions $z_1, z_2, \ldots, z_n$ are measured, the deformation profile of the wing deck can be calculated by solving the following system of equations:

$$\begin{bmatrix} z_1^4 & z_1^3 & z_1^2 & z_1 & 1 \\ z_2^4 & z_2^3 & z_2^2 & z_2 & 1 \\ \vdots & \vdots & \vdots & \vdots & \vdots \\ z_n^4 & z_n^3 & z_n^2 & z_n & 1 \end{bmatrix} \begin{bmatrix} k_4 \\ k_3 \\ k_2 \\ k_1 \\ k_0 \end{bmatrix} = \begin{bmatrix} h(z_1) \\ h(z_2) \\ \vdots \\ h(z_n) \end{bmatrix}. \tag{1}$$

where k_4, k_3, k_2, k_1, k_0 are the polynomial coefficients to be identified.

In most of the cases (especially for a 100 m dock or less) the deflection of the dock represents a parabola (Hedger, 2007). Thus, the minimum number of the measurement points can be reduced to three, because only three unknowns k_2, k_1, k_0 have to be defined to fully describe second-degree polynomial, which is a parabola. In this case, two measurement points have to be located at each end of the wind deck, third one has to be placed in the middle of the deck. Then, Eq. (1) can be simplified as follows:

$$\begin{bmatrix} z_1^2 & z_1 & 1 \\ z_2^2 & z_2 & 1 \\ z_3^2 & z_3 & 1 \end{bmatrix} \begin{bmatrix} k_2 \\ k_1 \\ k_0 \end{bmatrix} = \begin{bmatrix} h(z_1) \\ h(z_2) \\ h(z_3) \end{bmatrix}. \tag{2}$$

According to our practice, if the length of the dock exceeds 100 m, the minimum number of measurement points should be five or more, so three of them are placed as in the previous case (at