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A Study on Hull Deflection and Shaft Alignment Interaction in VLCC

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Abstract : Modern ship hulls of large oil carriers and container carriers have become more flexible with scantling optimization and increase in ship length. On the other hand, as the demand for power has increased with the ship size, shaft diameters have become larger and stiffer. Consequently, the alignment of the propulsion system has become more sensitive to hull girder deflections, resulting in difficulties in analyzing the alignment and conducting the alignment procedure. Accordingly, the frequency of shaft alignment related bearing damages has increased significantly in recent years. The alignment related damages are mostly attributed to inadequate analyses, changes in the design of the vessel, shipyards′ practices in conducting the alignment, and a lack of well defined analytical criteria. The hull deflections should be considered at the design stage to minimize the bearing damage caused by hull deflection. Hull deflections can be estimated by analytical approach and reverse calculation using the measured data. The hull girder deflection analysis using the reverse calculation will be introduced in this paper.

Key words : Shaft alignment, Hull deflection, Strain gauge method, Reverse calculation

1. Introduction

Hull girder deflections are the most significant disturbance that affects the bearing offset after the vessel construction. Inability to account for hull deflections may result in poor alignment design with serious consequences on the bearing life. The problem, however, is a difficulty in predicting and evaluating the hull deflections[1].

Accordingly, the frequency of shaft alignment related bearing damages has increased significantly in recent years. The alignment related damages are mostly attributed to inadequate analyses, changes in the design of the vessel, shipyards′ practices in conducting the alignment, and a lack of well defined analytical criteria.

As the alignment analysis is the first step in the alignment process, it is

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important to define it with the largest possible error allowance, ensuring a relatively robust design with low sensitivity to disturbances affecting the propulsion shafting and the main drive[2].

Accounting for hull girder deflections is one of the most important issues in that process. However, hull deflections are not of constant magnitude, but rather are a function of different vessel loading conditions as well as sea conditions the vessel operates in. The ability to predict hull deflections with sufficient accuracy is of the foremost importance in order to ensure robust alignment design and consequently less alignment related casualties.

Hull deflection data is needed during the design stage of the alignment process in order to prescribe bearing offsets which will result in acceptable bearing reactions for ballast, laden and all operating conditions in-between. At that time, the vessel is not yet under construction and the only option that we have is to rely on the ship hull deflection data by analytical approach or measurements conducted on similar vessels.

Hull deflections can be estimated by an analytical approach and defined by measurements[2],[3]. The analytical approach is time-consuming and expensive. It requires detailed modeling (e.g., finite element) of the vessel, in particular, the stern part, with a comprehensive model of the engine room, the engine and the shafting. The analytical approach is seldom undertaken solely for the purpose of investigating the hull deflections′ effect on the alignment. It is more common to take advantage of the full scale vessel modeling conducted for the dynamic loading analysis (or similar) to extract the data on hull deflections that may be applied in alignment analysis.

We have conducted the hull deflection analysis by using analytical and measurement approach and taking the similar results from both methods. The measurement approach has been selected to analyze the hull deflections due to the time and cost ineffectiveness of analytical approach.

The existing installations may be used for investigating the hull deflections, mostly in cases when alignment related troubles are experienced to trouble-shoot the problem. However, information on hull deflections can be collected for future applications. Normally, the hull deflection data obtained by measurements may be utilized on vessels of identical design.

Hull deflection measurements can be conducted by investigating the bearing offset change from one vessel condition to another. For such a task, a strain gauge measurement combined with either the crankshaft deflection measurements or the main engine(M/E) bearing reaction measurements should be applied. It would also be possible to consider M/E bedplate deflection measurements combined with the strain gauges if the accuracy of the readings can be trusted.

This paper will introduce the hull deflection analysis method by using the reverse calculation and show the analysis results taken from the actual vessel.

2. Bearing Reaction Measurements

In this paper, the jack-up[4] and strain gauge method[5]-[9] have been used as a basic data to analyze the hull deflection in this paper.

2.1 Jack-up Method

Jack-up method is a direct way to check bearing reactions. Due to its simplicity, it is the most widely used method in the industry. Measurements are conducted by hydraulic jacks which are placed in close proximity of the bearing whose reaction is to be measured.

Advantages of the jack-up method are:

1. Simple measuring equipment such as hydraulic jack and dial gauge.
2. Accuracy is significantly improved in combination with load cell measurement.
3. Only method that provides reaction load directly.

The disadvantages of the jack-up method are:

1. It requires the same preparation time for each repeated measurement.
2. Measurement results in wide hysteresis if load cell is not used.
3. Installation inaccuracies due to: Misalignment of the hydraulic jack & Misalignment of the dial gauge. Although it directly records the load, jack-up method does not measure bearing reaction directly, as the jack is fitted next to the bearing. This requires application of correction factors which introduce error.

Fig. 1 shows the bearing reaction measurement method for intermediate shafting bearing and Fig. 2 shows the bearing reaction measurement methods for main engine bearings installed inside the diesel engine.

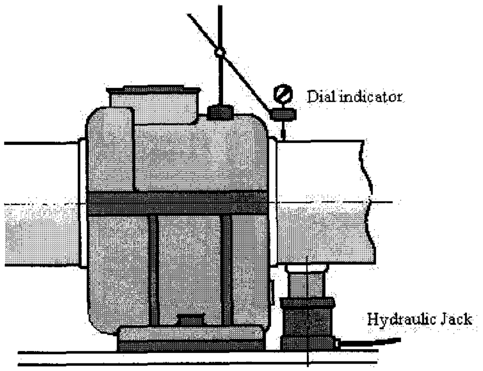


Fig. 1 Reaction Measurement at Inter. Shaft Brg.

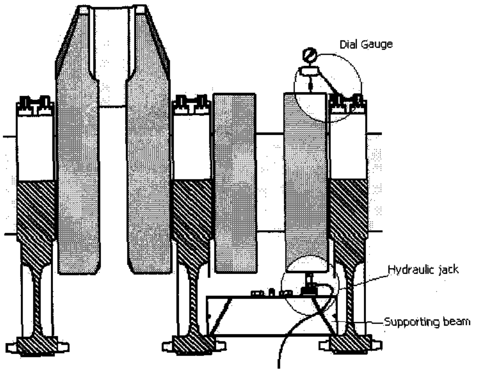


Fig. 2 Reaction Measurement inside Diesel Engine

2.2 Strain Gauge Method

Advantages of the strain gauge method are:

1. Provides information on the bearings not accessible in jack-up measurements.
2. Once the strain gauges are mounted, measurement can be easily repeated for vessels different modes of operation.
3. Instantly provides data about vertical load and shaft runout.

4. Provides simultaneous information on more than one bearing load.

The disadvantages of the strain gauge method are:

1. Requires a relatively long time for equipment installation.
2. Accuracy of the data depending on system modeling.
3. Requires sophisticated and expensive equipment.

The strain gauge technique for shaft bending moment measurement is based on a basic beam relationship.

$$M=\epsilon \cdot E \cdot W \tag{1}$$

where
E = Young's modulus, ε = strain,
W = section modulus
(for circular shape $= \frac{\pi}{32}\frac{(d_o^4-d_i^4)}{d_o}$,
where d_o : out diameter, d_i : inner diameter)

Strain gauges measure strain. The shaft's flexion deforms, strains the gauges glued on the shaft's surface, thus changing the gauges' resistance. Accordingly, the strain can be calculated using the following formula.

$$\epsilon=\frac{\Delta R}{R\times k} \tag{2}$$

where
R = is bridge resistance, in Ω
ΔR = change in bridge resistance, in Ω
k = bridge factor

To increase precision (error correction) of the measurements, more than one gauge can be installed to measure the strain at the same location. Usually, there are four gauges installed in the so called Wheatstone bridge. Two pairs of gauges should be positioned 180°apart from each other and connected in Wheatstone bridge as shown in Fig. 3.

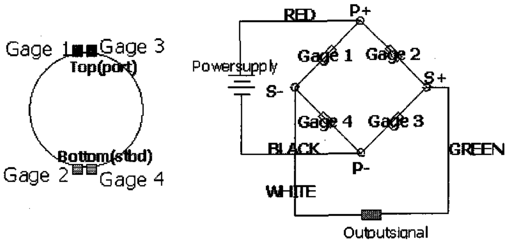


Fig. 3 Wheatstone Bridge Connections

3. Modeling and Measurement Results

This chapter explains the shafting system, its modeling, strain gauge, strain gauge equipment used and analyzes the measured results. Table 1 shows the specifications of the shafting system for this project.

Table 1 Specification of the Shafting System

Vessel Type	320,000 DWT VLCC
Main Engine	B&W 6S90MC-C, MCR 40,000BHP at 76 rpm
Crankshaft Dia.	840 mm/ 150mm
Line Shaft Dia.	725 mm
Propeller Shaft Dia.	810 mm
Propeller	4 blade fixed pitch, Dia. 9900 mm

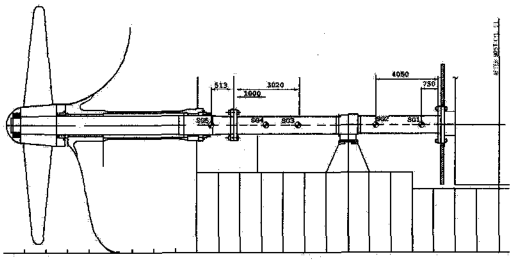


Fig. 4 Strain Gauge Positions

Four (4) strain gauges were installed on the intermediate shaft and One (1) strain gauge was installed on the propeller shaft as shown in Fig. 4.

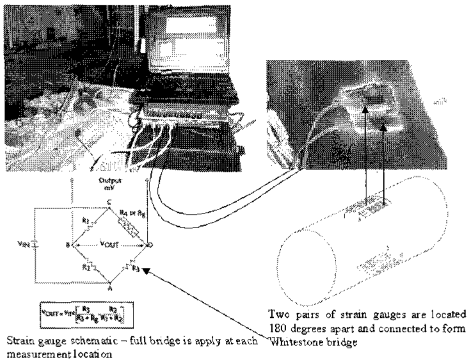
Table 2 indicates the specification of the strain gauge and its equipment for this project. Fig. 5 shows the installation of the strain gauge and strain gauge equipment.

The following Seven (7) conditions are measured for the bearing reaction by strain gauge and jack-up.

- ▣ dry dock - cold
- ▣ after launching before final adjustment
- ▣ after launching after final adjustment
- ▣ Sea trial: ballast: hot: APT empty
- ▣ Sea trial: ballast: hot: APT full
- ▣ Sea trial: laden: hot: APT empty
- ▣ Sea trial: laden: hot: APT full.

Table 2 Strain Gauge and Its Equipment

WaveBook	Maker : IOtech, Inc. Function : High-speed portable data acquisition device
WBK16	Maker : IOtech, Inc Function : 8-channel strain-gauge signal-conditioning module
Strain Gauge	Maker : Kyowa Type :KFW-5-350-C1-11L1M2R Gauge Resistance : 348.8 ± 1.2 ? Gauge Factor : 2.14 ± 1.2 %



Strain gauge schematic – full bridge is apply at each measurement location

Two pairs of strain gauges are located 180 degrees apart and connected to form Whitestone bridge

Fig. 5 Strain Gauge Installation and Equipment

Fig. 6 and 7 indicate bending moment measured by the strain gauge method under the dry dock condition. The average value from ahead and astern is used as a bending moment to increase the accuracy. The change of bending moments caused by each loading condition is shown in Fig. 8.

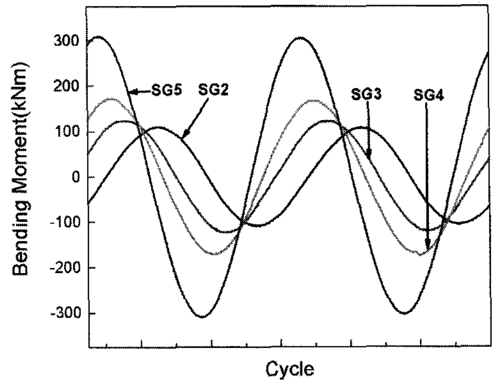


Fig. 6 Bending Moments on Dry Dock_Ahead

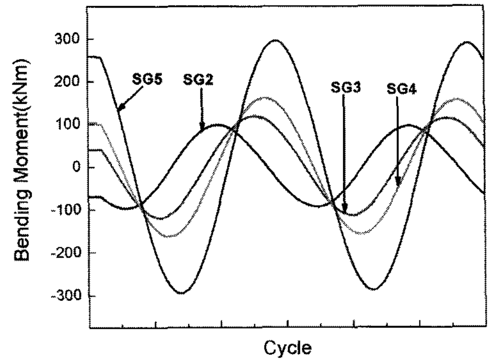


Fig. 7 Bending Moments on Dry Dock_Astern

Fig. 9 indicates the bearing reactions by the jack-up method for each condition. Only Three (3) aftmost main engine bearing could be measured under all conditions due to the shipyard construction tight schedule. All main engine bearings have been measured after bearing offset final adjustment and after full laden hot condition. Bearing reactions have been changed by each loading condition.

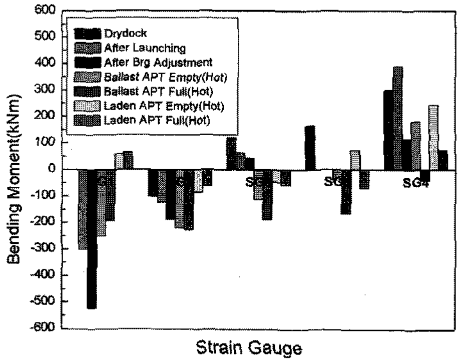


Fig. 8 Bending Moments on Each Condition

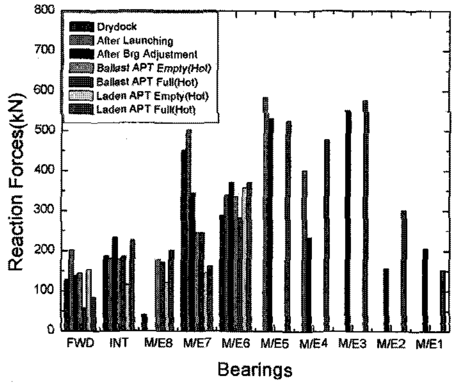


Fig. 9 Bearing Reactions on Each Condition

4. Hull Deflection Analysis

4.1 Reverse Calculation

Reverse analysis is a procedure in which bearing offset is obtained from the measured bending moments and bearing reactions. The genetic algorithm is used for this calculation. We first recalculated the absolute bearing offsets for the dry dock and each measured draught condition of the vessel.

Accuracy of the reverse analysis depends on the accuracy of the individual measurements. The strain gauge moment measurement is considered to result in at least the same, if not greater accuracy then the jack up measurement. Moreover the strain gauge measurement is highly consistent when successive measurements are conducted.

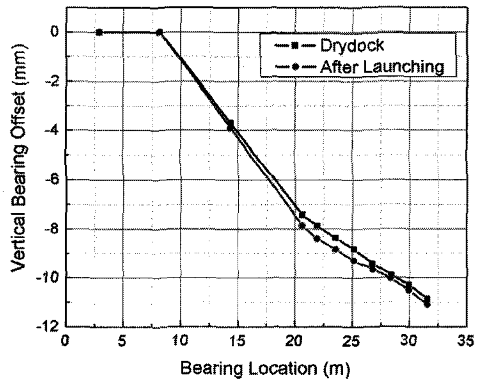


Fig. 10 Bearing Offset(Dry Dock to Launching)

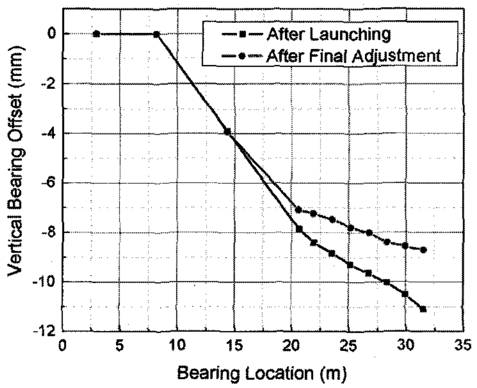


Fig.11 Bearing Offset(Launching to Adjustment)

Fig. 10 shows the bearing offset from dry dock to launching. The bearing offset from dry dock to launching does not change a lot, because there is no significant hull deflection from dry dock to launching. Fig. 11 shows the bearing offset between the launching and after bearing adjustment. The different offset between two conditions is due to the adjusted bearing offset.

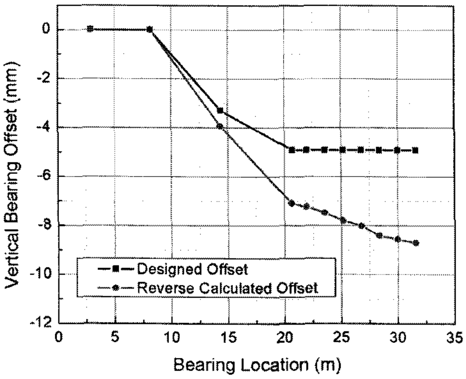


Fig. 12 Bearing Offset(Design and Actual)

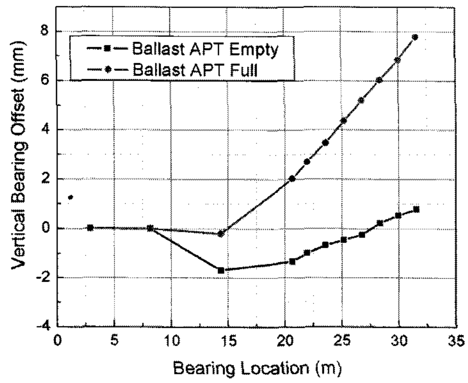


Fig. 13 Bearing Offset(Ballast APT Empty to Full)

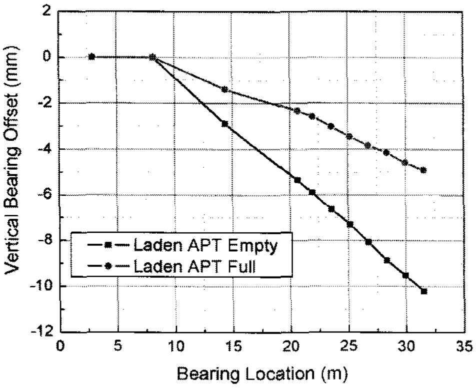


Fig. 14 Bearing Offset(Laden APT Empty to Full)

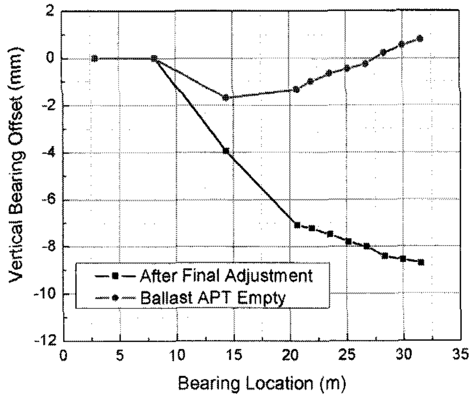


Fig. 15 Bearing Offset(Launching to Ballast APT Empty)

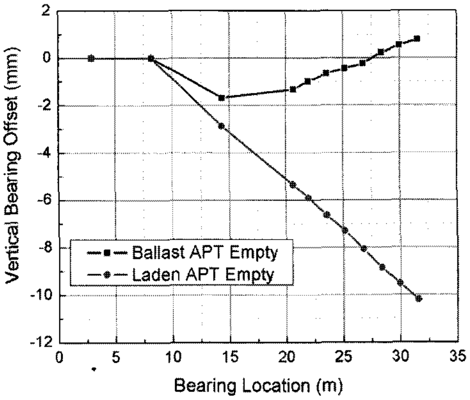


Fig. 16 Bearing Offset(Ballast to Laden APT Empty)

Fig. 12 shows difference between design bearing offset and actual final bearing installation offset. Since only the intermediate bearing and aftmost main engine bearing can be used for the adjustment, it is difficult to install the bearing with the design bearing offset. Normally, ± 20% tolerances are used as an acceptable limit of installation in Korean shipyard. However, this tolerance varies from shipyard to shipyard. Fig. 13 shows the bearing offset change from after peak tank(APT) full to after peak tank full under the ballast condition. The bearing offset is effected significantly by the after peak tank condition. Fig. 14, 15 and 16 show the bearing offset being changed significantly by each loading condition.

4.2 Hull Deflection

Hull deflections are evaluated as a difference in bearing offsets at respective bearing locations between two different vessel conditions. Accordingly, the hull deflections are calculated as a change of the bearing vertical offset from the dry dock condition to one of the six following waterborne conditions of the vessel:

- ◦ dry dock to after launching before bearing adjustment
- ◦ dry dock to after launching after bearing adjustment
- ◦ dry dock to ballast with after peak tank empty
- ◦ dry dock to ballast with after peak tank full
- ◦ dry dock to laden with after peak tank empty
- ◦ dry dock to laden with after peak tank full

Since the hull deflection in the shaft alignment is effected from after stern tube bearing to No. 1 main engine bearing, the offset of Two (2) bearings is defined as Zero (0) to make the reference point. We note from Fig. 17 that the hull deflection from dry dock to launching can be ignored for this vessel.

Fig. 18 shows the hull deflection from launching to final bearing adjustment. Fig. 19 and 20 show the hull deflection from dry dock to ballast APT full and empty. The hull deflection has changed significantly from dry dock to ballast APT full and empty.

Fig. 21 and 22 show the hull deflection from dry dock to laden APT full and empty. The hull deflection is also changed significantly from dry dock to laden APT full and empty.

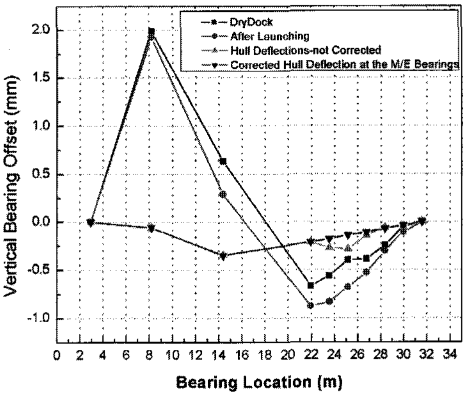


Fig. 17 Hull Deflections(Dry Dock to Launching)

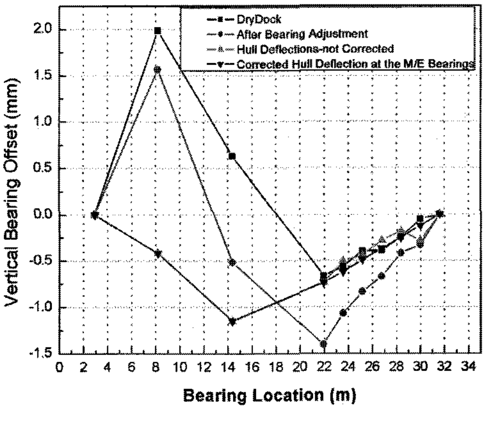


Fig. 18 Hull Deflections(Dry Dock to Adjustment)

The thermal expansion of engine bed from cold condition to hot condition is normally considered in the shaft alignment calculation. The thermal

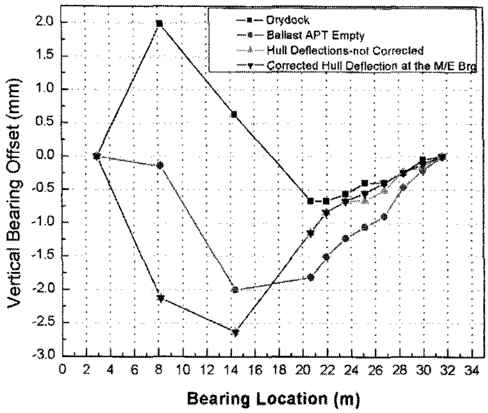


Fig. 19 Hull Deflections(Dry Dock to Ballast APT Empty)

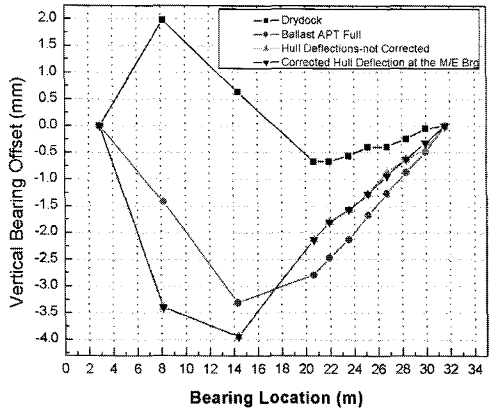


Fig. 20 Hull Deflections(Dry Dock to Ballast APT Full)

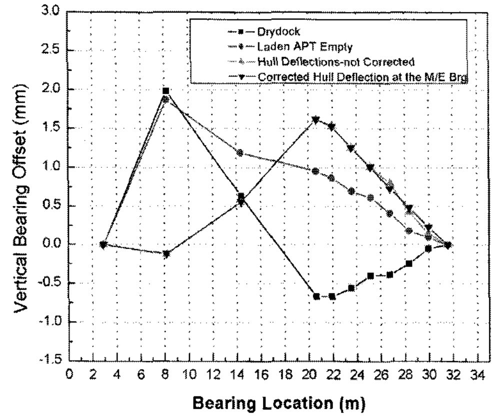


Fig.21 Hull Deflections(Dry Dock to Laden APT Empty)

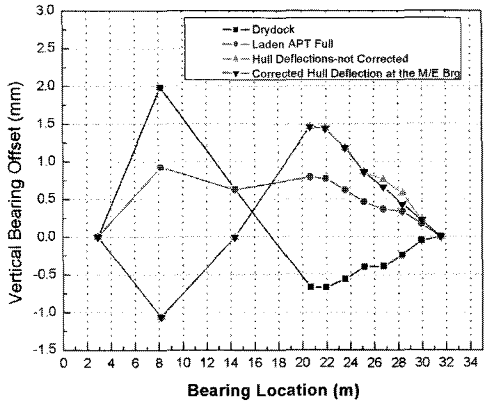


Fig. 22 Hull Deflections(Dry Dock to Laden APT Full)

expansion of the subject vessel is 0.39mm. Comparing the bearing offset change caused by thermal expansion to offset caused by the load conditions, demonstrates that the bearing offset caused by the load conditions is much higher than that caused by the thermal expansion.

5. Conclusion

This paper demonstrates how the hull deflection data may be obtained by the reverse calculations using the bending moments from strain gauge and bearing reactions from jack-up method. Following conclusions can be made;

1) The engine bed deflection has normally been considered during the shaft alignment analysis. However, the hull deflections caused by different loading conditions result in much higher bearing offset.

2) The bearing offset is significantly changed by the after peak tank loading conditions(full/empty).

3) The hull deflection from dry dock to launching is not big in VLCC. However, this depends on given shipyard practices.

4) Where the hull deflection data obtained by this research will be used for the shaft alignment analysis of similar vessels, time and expense will be reduced, and the bearing damage will be prevented.

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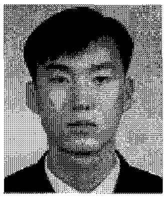
Author Profile



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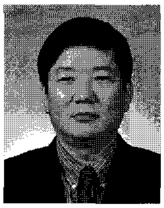

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