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Analysis of measurement methods and influence of propulsion plant working parameters on ship shafting alignment

SUMMARY

In the paper three different experimental investigation methods of propulsion shaft alignment are discussed. A new original method of direct measurement of the bearing reactions on the foundation pads is presented.

Possible application of the method was analyzed by means of computations and experimental investigations carried out on a 2000 TEU containership at quay and during sea trials. Discussion of results of the analysis and tentative recommendations are included.

INTRODUCTION

This work is a part of the purpose project on „ Engineering processes applied to ship main propulsion installations " realized jointly by a shipyard and Ship Design and Research Centre (CTO) in Gdańsk (performer of R&D part of the project) and financially supported by The State Committee for Scientific Research.

The shaftline of 2000 TEU containership was selected for the analysis. A part of computational and measurement works was performed by the shipyard's personnel in compliance with its own standard titled „Guidelines for ship shaftline assembling". A new measurement method was elaborated by a team of Ship Structures Division of CTO which also analyzed results of measurements.

During shafting alignment works onboard the ship lying at the quay, bearing reactions were measured with the use of strain gauge dynamometers developed by CTO. The measurements were performed in parallel with the standard ones carried out by the shipyard. During the ship's trials static and dynamic reactions of the intermediate bearing, measured by means of the dynamometric pads, as well as transverse vibrations and static stresses in the intermediate shaft were recorded. The intermediate shaft bending stresses were measured in two points by using complete strain-gauge bridges fitted with telemetric systems.

Three applied measurement methods were compared and on that basis appropriate conclusions and guidelines were proposed as well as the assumptions supplemented concerning the computational and measurement methods to be elaborated within the purpose project in question.

The selected 2000 TEU containership had the following characteristics:

Hull particulars:	
Length	188.0 m
Breadth	30.0 m
Draught	11.5 m
Deadweight	30300 t
Speed	19.5 knots
Main engine:	
Producer	MAN B&W
Type	6 S70MC
Output	17900 kW
Speed	95 rpm
Average indic. pressure	19.31 bar
Propeller:	
Diameter	7.06 m
Number of blades	5
Pitch ratio	0.979
Area ratio	0.742
Mass	34400 kg
Inertia moment (in air)	81400 kgm^2

The Hottinger Baldwin Messtechnik telemetric measuring systems were used in the experimental investigations on the intermediate shaft bending. Bearing pad loading measurements were carried out with the use of KWS 673D8 strain-gauge bridge and 3817 calibrator. The measured dynamic magnitudes were recorded by means of COMPAQ 486/64 digital recorder and OMNI BOOK 4000 C recorder. Measurement results were analyzed by using the MATLAB and DADISP software as well as that developed by Ship Structures Division, CTO.

MEASUREMENT METHODS

Review of applied measurement methods

The correct shafting alignment is very important for the failure-free propulsion system operation. Incorrect one can cause a failure of the intermediate bearings, main engine bearings or stern tube bearing [3, 4]. It can also generate abnormal stresses in the intermediate shafts or crankshaft [5,6]. Such failures are very dangerous in sea conditions.

In the first stage the base axis is determined which contains the stern tube, intermediate shafts and main engine shaft [2]. Optical methods prevail in the stage of measurements and determination of the theoretical axis of the propulsion system. The string-based measurement methods have been almost entirely abandoned due to their low exactness.

After boring the tube for the stern bearing and assembling the propeller shaft together with the propeller, the main engine should be installed onto its foundation and the intermediate bearings assembled. The bearings should be appropriately displaced as to cause parameters of shafting alignment to maintain within their working ranges during service [1,9]. Various methods are used to determine the correct position of the axis of the intermediate shafts. The oldest one (and the least exact) is the method of breaks and displacements. It consists in disassembling the particular shaftline segments and measuring the relative linear and angular displacements. The method is recently not recommended by the classification societies and engine producers [2].

The next method consists in lifting the intermediate shafts by means of the jacks installed as close to the bearings as possible [7,8]. During the shafting alignment its vertical displacement is controlled (by using displacement gauges) and the oil pressure in the jacks, i.e. static reaction which appear in the bearing. It is a very simple and exact method of the direct determination of bearing reactions. The method is now most often applied; it is also used by the shipyard. A drawback of it is that only static reactions can be determined during the shaftline alignment process, at the very early stage of ship construction, far from service conditions. Controlling the shaftline during the propulsion system's operation is not possible.

The last applied method of shafting alignment control is based on measurements of bending stresses in the intermediate shafts [2]. The method has not the drawbacks of the previous one although it is rather rarely used because of difficulties in interpreting the measurement results. To precisely determine the relationship between shaft bending stresses and bearing reactions, nonlinear calculations of the system should be performed (accounting for the oil film stiffness). Such calculations are not widely used. Moreover the stresses due to torsional vibrations prevail in the working propulsion system. This is one of the main reasons of serious difficulties in interpreting the results of measurements appropriately.

Applied measurement methods

As it was stated earlier the measurements were assumed to be carried out by means of the standard method used in the shipyard, based on the direct determination of bearing reactions by measuring pressure in a hydraulic jack [7]. It was decided to supplement it with two other methods to practically verify, a.o., applicability of the extensometric methods.

The first extensometric method is based on the identification of shafting alignment by measuring the bending stresses in the intermediate shaft [2]. The following measurement points were assumed for bending stresses determination:

1 - the points located on the propeller shaft as close as possible to the connecting flange

2 - those located on the intermediate shaft as close as possible to the intermediate bearing from the side of the main engine.

This attempt at the direct extensometric measurement of bearing reactions by determining the stresses in the bearing foundation pads is an important novelty of the elaborated measurement method applicable to shafting alignment process. It is assumed, in accordance with the shaftline assembling technique, to seat the bearing on

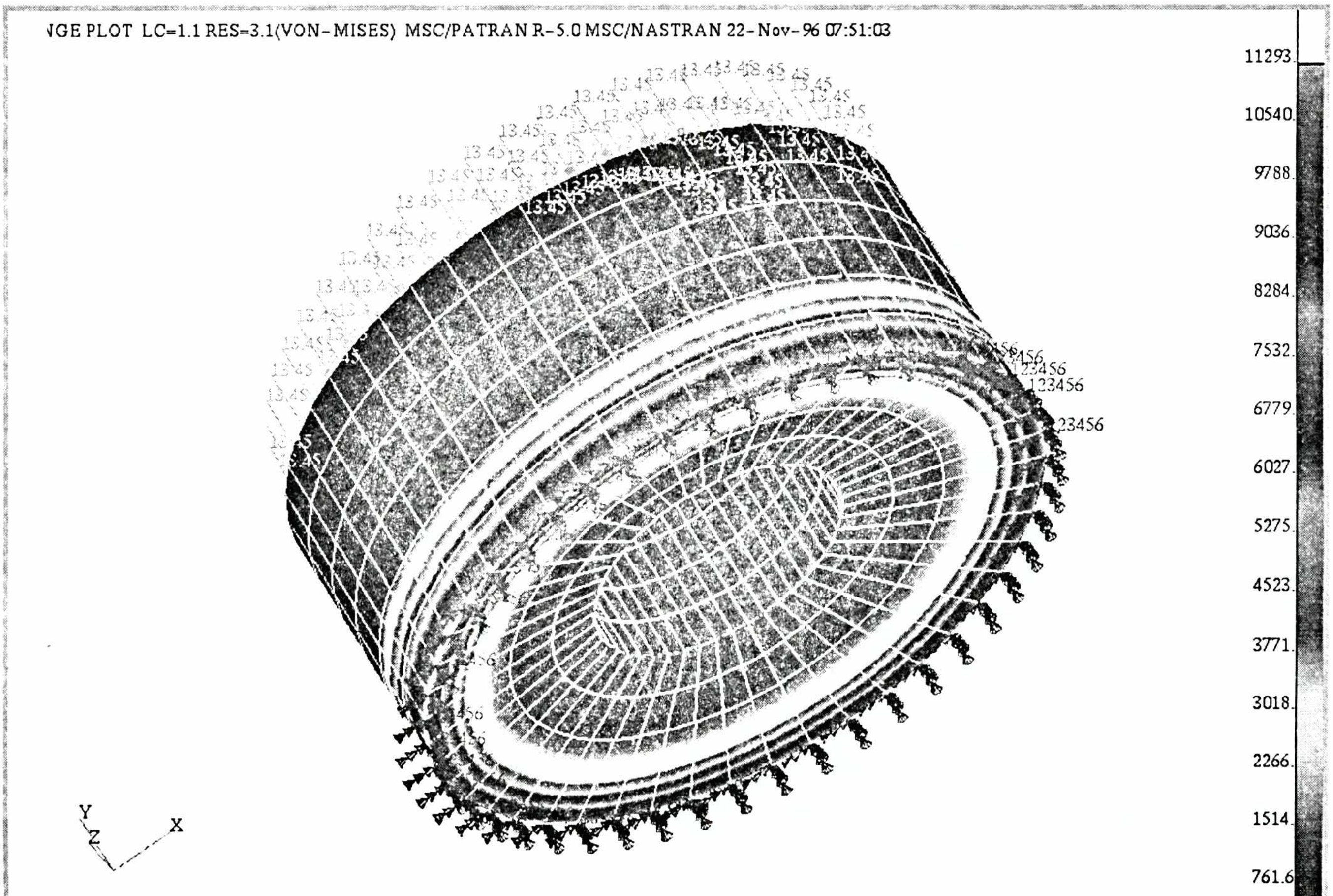

Fig.1. Huber-von Mises stress distribution in the pad supported on its edge only

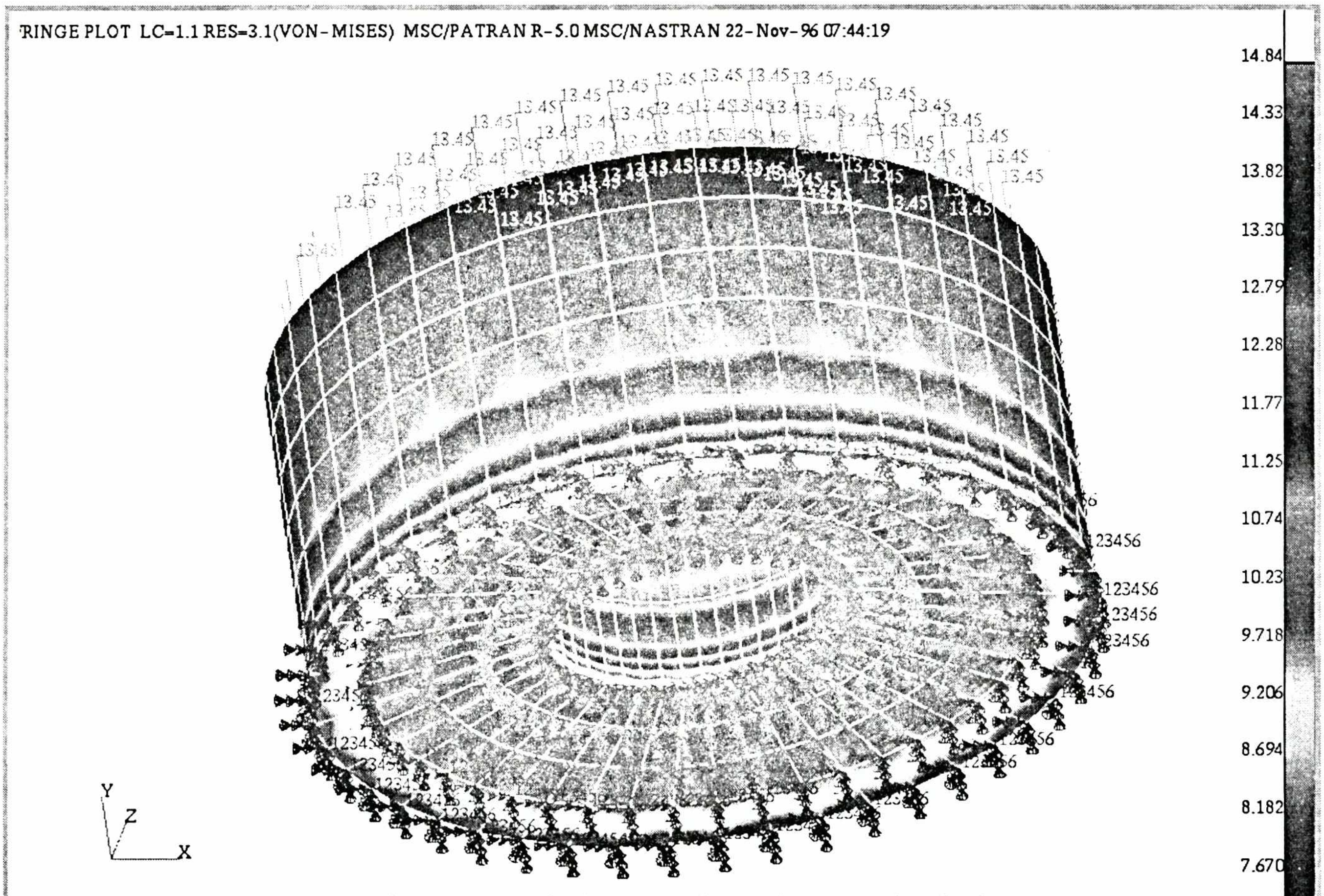

Fig.2. Huber-von Mises stress distribution in the pad supported on its entire spherical surface

its foundation with the use of four spherical pads. A short computational analysis of stress distribution in such pad was performed to appropriately elaborate the measurement method and program in question.

It was assumed that strain gauges had to be glued on the upper part of the pad, at the middle of its height. The analysis of this part of the pad was performed for two types of boundary conditions by means of PATRAN-NASTRAN software based on the finite element method. In the first case, the external edge support of the pad spherical surface was only assumed. The second type of boundary conditions modelled the ideal support of the pad on its entire spherical surface. The Huber-von Mises stress distributions are presented in Fig.1 and 2.

It was concluded from the analysis that the way of supporting the pad had very substantial influence on the deformations and stresses on the external surface of the pad. Large differences should be expected between measured stresses in particular pads, depending on the exactness of workmanship of spherical contact surface of each of them. Therefore it was decided to test all complete sets of pads by means of a testing machine. During the tests the pads were compressed up to 100 kN and full hysteresis course determined. 5 kN load increment within the range up to 50 kN and that of 10 kN within 50 to 100 kN range was assumed.

In Fig.3 the pad characteristics are collected , obtained in result of scaling the dynamometers. The measurement results were approximated by the *spline* functions with the use of the MATLAB software. The symbols „x" stand for the measurement results obtained at the amplification 5 of the strain - gauge bridge. The approximation was performed for the test result points connected with the increasing load upon the dynamometers.

In order to determine bearing reactions, measuring the stresses (deformations) on the foundation pads was assumed to be carried out on all four pads. The location scheme of the dynamometers and their numbering is shown in Fig.4. The experimental investigations were performed in two variants: on the ship at quay and during sea trials.

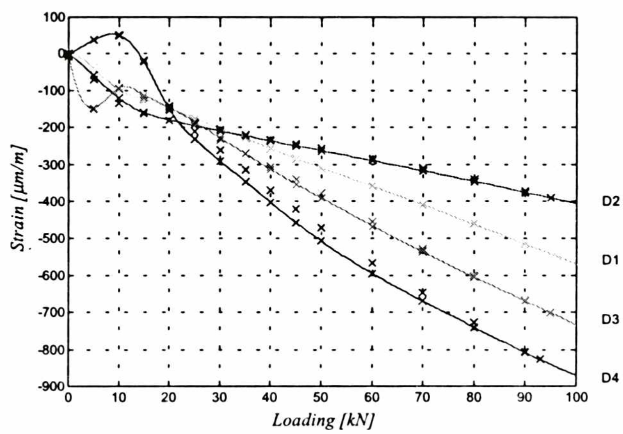

Fig.3. Set of the dynamometer characteristics obtained at the amplification 5 of the strain - gauge bridge (D1, D2, D3, D4 - dynamometer numbers)

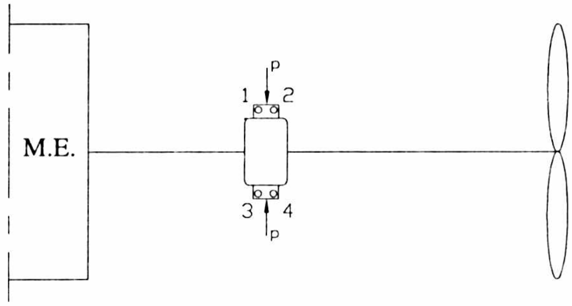

Fig.4. The location scheme of the dynamometers and their numbering

EXPERIMENTAL INVESTIGATIONS ON THE SHIP AT QUAY

The extensometric investigations on the ship at quay were carried out in parallel with the measurements performed by the shipyard's team with the use of hydraulic jacks. The points of application of the jacks used to lift the intermediate bearing are indicated in Fig.4 by the arrows „p". The described phase of shafting alignment proceeded as follows: two hydraulic jacks were installed under the intermediate bearing of the assembled shaftline, then an appropriate reaction was induced by lifting the bearing. In the next step the heights of the pads were adjusted to the bearing position and the foundation bolts fastened. The required value of the reaction (with the bearing weight of 1346 kg accounted for) was determined equal to183 kN which corresponded to 32.5 MPa pressure value in the jacks.

In the first stage of the extensometric investigations all measuring channels were set to zero at the time when the intermediate bearing was standing on the dynamometers and not yet lifted to an appropriate level. Next, while lifting the intermediate bearing (unloading the dynamometers) the pad deformations were measured at two different pressure values in the jacks: initially of 20 MPa and then 32.5 MPa. It was revealed that in second variant the dynamometers were fully unloaded. The recorded measurement results were put onto the dynamometer characteristics curves.

In the second stage of the investigations all the measuring channels were set to zero again during the full unloading of the dynamometers (the lifted bearing by the jacks). Next, the load on the pads was investigated at the released pressure in the jacks. Three measurements of the pad loading were performed with the time delay of 15 min after each measurement. The residual pressure of about 6 MPa was observed in the jacks. Then the proper and final shafting alignment process was commenced. The pressure of 32.5 MPa was induced in the jacks, but difficulties in keeping the appropriate pressure level was observed. The pressure was dropping to about 30MPa; nonetheless two measurements were performed during the time. The measurement results of the considered stages are depicted in Fig.5.

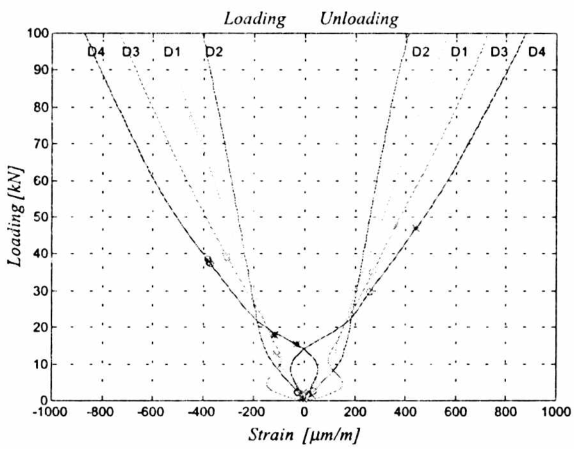

Fig.5. The dynamometers' loading measured during shafting alignment (D1, D2, D3, D4 - dynamometer numbers)

The final stage of the shafting alignment consists in adjusting the pad heights, then tensioning the foundation bolts and taking away the hydraulic jacks. At the end of the alignment process the loading on the dynamometric pads was measured. Three groups of readouts were performed with 30 min time delay after each readout group to determine measurement scatter values and obtain a stable load in each case. The measurement results obtained in this stage are presented in Fig.6.

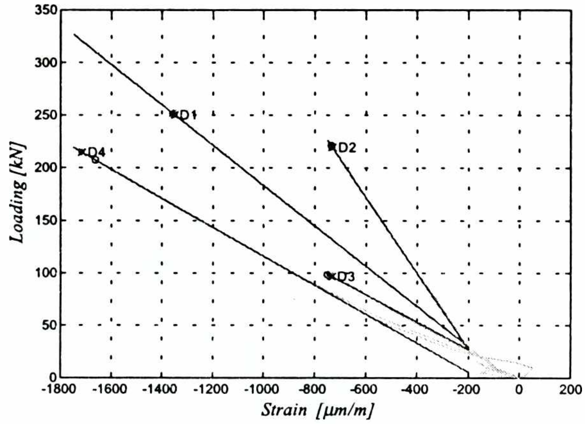

Fig.6. The dynamometers' loading measured while tensioning the foundation bolts (D1, D2, D3, D4 - dynamometer numbers)

It can be stated on the basis of the first group of measurements that the preliminarily seated bearing does not transfer load to the pad no.2; however this is not of any substantial importance. The pressure in the hydraulic jacks of less than 30 MPa value does not unload the dynamometers as it does not lift the shaftline. The total reaction of the bearing is 183.2 kN i.e. of the value which had to be reached after the shafting alignment - the shaftline was preliminarily aligned in advance. The second group of measurements disclosed difficulties in controlling precisely the pressure in the jacks. The summary reaction of the bearing reaveals the residual pressure of about 6 MPa, in compliance with the observations. „ Floating " of the signals in the measurement points (Fig.5) confirms that the pressure is of a nonzero value. During the final assembling process it was not possible to maintain the required pressure value of 32.5 MPa. It is evidenced a.o. by not fully unloading the pads and „ floating " of the load of them. It may be stated that the reaction value is correct because it was exactly determined earlier. The described process was carried out only in order to distribute more load onto the not fully loaded pads.

The last phase of the technological cycle consisted in tensioning the foundation bolts. The shafting alignment cycle was in compliance with the binding procedure, however it could be stated, on the basis of the extensometric measurements, that the D3 dynamometer was not fully loaded, i.e. the intermediate bearing was seated on three pads only. The alignment process can be deemed correct as no „ floating " of the pad loads (Fig.6) is observed. In the today used technological process it is not possible to control the tensioning level of the foundation bolts (the tensile stresses in them could reach 120 MPa), reaction distribution onto particular pads and shafting alignment state after completing the process.The today used process of generating the assumed bearing reactions is very useful because it is simple and reliable. However it should be supplemented with the recommendations on the use of the torque spanner for tensioning the bolts and on the control of the load distribution onto particular pads by means of the extensometric measurements.

(to be continued)

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