VIBRATION ANALYSIS IN SHIP STRUCTURES BY FINITE ELEMENT METHOD

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Abstract. *An investigation about excessive vibration in the aftbody region of a bulk carrier ship can be considered the initial motivation of this paper. The dynamic analysis performed in this ship includes results from finite element model and vibration measurements. Superstructure, engine room and rudder natural frequencies and respective mode shapes were obtained and compared with measurements data. Model characteristics like geometry, loads and boundary conditions are presented and discussed. Hydrodynamic aspects were considered in order to find the causes of excessive vibration problem since the behavior of the ship is sea depth dependent. Other influences such as ship load condition, virtual mass and propeller wake were also considered. Possible resonance conditions were investigated considering the excitation forces frequencies from engines, propeller and power transmission systems (shafts) near the engine speed (revolution per minute) and blade frequencies. Ship structure's vibration was evaluated using mathematical models (F.E.M.) during the project and typical corrective action was proposed in order to reduce vibration levels during ship operation.*

Keywords*: Vibration, Finite Element Model, Structure.*

1. INTRODUCTION

In a general way, ship's vibration is considered excessive whenever one or more of the following problems are described by the crew: discomfort, cracks in structures / components of machines and repeated machines failures, particularly the electronic components.

The construction of ships with smaller plating thickness and the increase of machine's power have, in some cases, caused the coincidence between the excitation forces frequencies and the structure natural frequencies. This phenomenon, known as resonance, is responsible for the majority of the excessive vibration problems in naval structures: ships and petroleum platforms.

In this work, possible causes of excessive vibration in a bulk carrier ship are investigated. This ship with 110 m of length, 16 m of breadth, 4,5 m of load draft and 5,2 m of depth operates in shallow waters (navigating in the *Lagoa dos Patos*), with capacity to transport 4100 tons of grains (soy, wood shavings or fertilizer). This ship has 3 medium-speed diesel engines with reducing gears in all the three (3) shaft lines and with fixed pitch propellers

2. THE SHIP VIBRATION PROBLEM

During the operation, this ship presented excessive levels of vibration, mainly when it is transporting soy, which is the heaviest load, and is navigating in the shallowest part of the lake. The vibration severity can be illustrated by the navigation lights that were broken, as showed in Fig. 1. This happened in the Rio Grande to Porto Alegre trip, with the ship in this maximum load condition, while the portside and starboard engines operating with 1650 rpm and the central engine was turned off: this is the critical situation, in the vibration point of view.

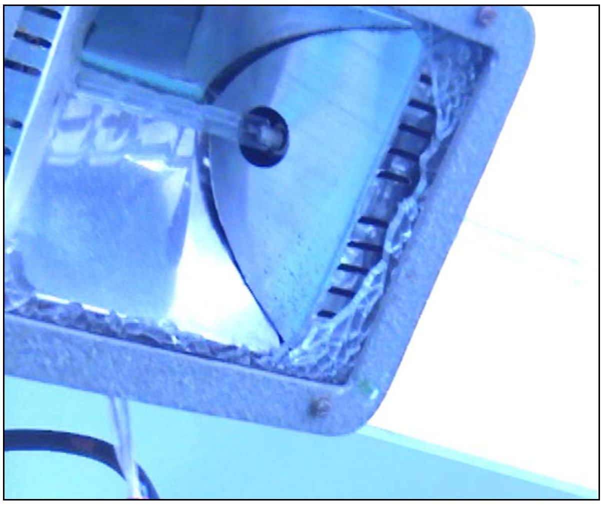

Figure 1. Navigation Lights broken due to Excessive Vibration

To study this problem, three measurement services were performed with the objective of discovering the cause(s) of excessive vibration in the ship's aftbody region. In the first service, the torsional vibration of the shaft line was investigated. A torque measurement system was installed in the shaft lines which allowed the determination of the torque variation and the comparison with tolerable limits.

In the 2nd service it was possible to make measurements of local vibration in engine supports, accommodations floor, as well as in the wheelhouse (Fig. 2).

Measurement results revealed high vibration amplitude in a frequency close to the blade frequency passage, as we can see in the fig. 3. Besides the vibration measurement, impact tests were performed in the rudders with the aim of identifying their natural frequencies. These tests were accomplished through impacts in the rudder's lower part, in both side of the ship. These impacts were separated from each other by a time interval sufficient for recording the decay of the signal.

In the third service it was possible to obtain the vibration signals for the critical condition of the ship, which is the draft close to the maximum (when the ship is closer to the lake's bottom). Simulations in different operational conditions showed that when only the central engine is turned off, this increases the ship vibration amplitude. Another important fact is the abrupt reduction (almost total disappearance) in ship vibration when it passes from the shallow to the deeper point of the lake (the depth increases more than 6 times).

Figure 2. Wheelhouse Vibration Measurement

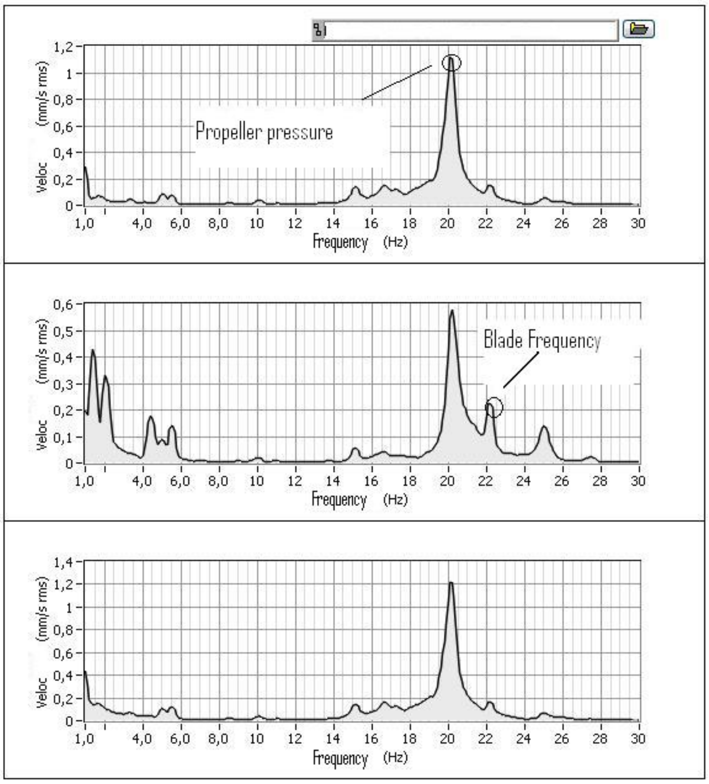

Figure 3. Vibration levels in Blade Passage Frequency for X, Y and Z Axis – Measured Data

3. METHODOLOGY

Figure 4 shows the main sources of ship's vibration: the propeller, the slow-running diesel engine and the propeller shaft. Generating the structure models with the finite elements method allows the analysis of free vibration (in order to obtain the natural frequencies) and the forced vibration (to obtain the structural responses of high amplitude excitations forces).

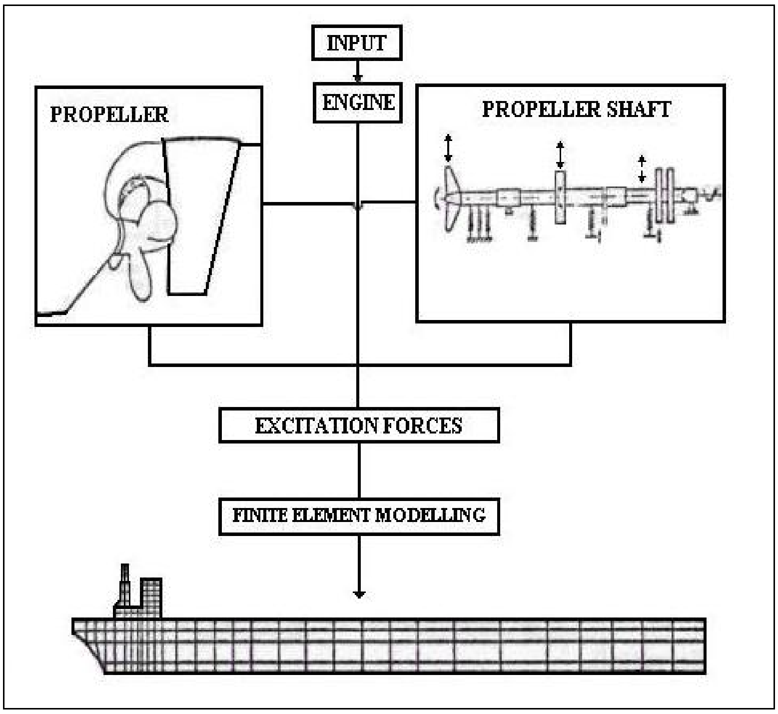

Figure 4: Vibration Elements for Analysis

4. FEM MODEL

The study of ship vibration can be represented by a dynamic balanced system of discrete differential equations (Dimarogonas, 1996, Rao, 1995), given by Eq. (1):

$$[M]\{\ddot{x}(t)\}+[C]\{\dot{x}(t)\}+[K]\{x(t)\}=\{f(t)\} \quad (1)$$

The exact determination of the linear and non-linear parameters which represent the stiffness matrix *[K]* (starting from the elastic potential energy), the mass matrix *[M]* (starting from the system kinetic energy), along with the vector of the external forces *{f(t)}* and the damping matrix *[C]*, were modeled by the method of the finite elements which allows the numeric solution of the system of differential equations, where the vectors, $\ddot{x}, \dot{x}, x$ correspond to, respectively, acceleration, velocity and displacement of the system's degrees of freedom.

The biggest damages in mechanical systems are usually caused by resonance conditions that happen when the frequency of the excitation force is close to the natural frequency, *w* (rad/s), of the structure. In the study of free vibrations without damping, it is considered that *[C]=[0]* and *{f(t)}={0}*, and the solution is given by Eq. (2):

$$\{x(t)\}=\{A\}\cdot sen(w\cdot t) \quad (2)$$

Where *{A}* e w^2 represent, respectively, the eigenvector and the eigenvalue of the free vibration equation, given by Eq. (3):

$$[K]\{A\}=w^2\cdot[M]\{A\} \quad (3)$$

As for the solution of the eigenvalue problem, the accurate results of the complete problem of forced vibration, in time or frequency domain, depend on the correct representation of stiffness, the structural mass, the virtual mass of the adjacent fluid and, mainly, the damping and the external force, usually obtained through measurements in real scale.

A model for the rudder and the aftbody region of the ship was created in finite elements. The solution of the eigenvalue problem allows the natural frequencies and respective vibration modes of those structures to be found. The use of numeric models and the comparison with experimental results constitute an efficient technique for identifying possible structure resonance conditions.

Figure 4 present the internal and external views of the ship's aftbody region, after modelling. The group identified as "Engine Room" is composed of 18289 nodes and 24512 elements of plate type. Flanges from the main frames, some stiffeners and shaft lines were modeled as beam elements. The rudder model is composed of 963 nodes and 996 plate elements.

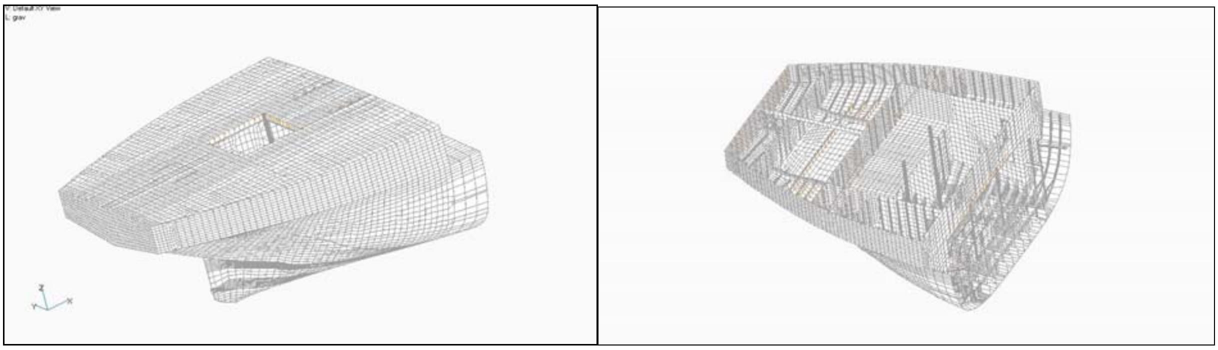

Figure 4. Aftbody Region Model: Internal and External View

The equation of free vibration includes the inertia (mass) and the stiffness terms. The damping, that limits the vibration amplitude in the resonance condition, it's not considered in the natural frequencies calculation. In the Finite Elements Method, this equation in matrix form is solved (Eigenvalue Problem) and the Figures 5 and 6 shows, respectively, the first natural frequencies for the aftbody region and for the rudder.

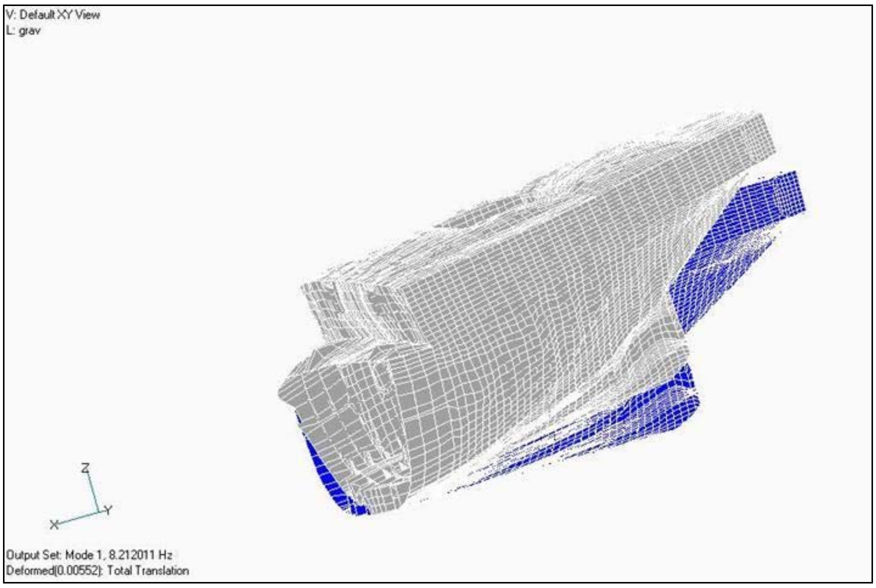

Figure 5. Aftbody: 1st Natural Mode in 1.8 Hz

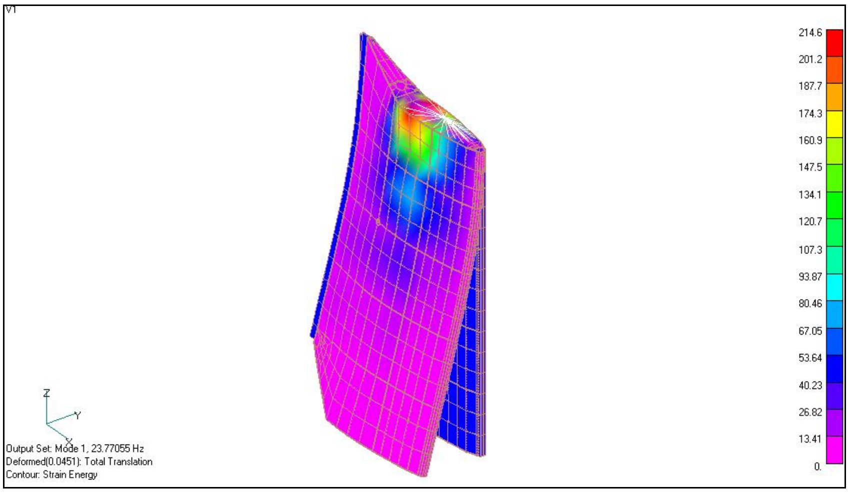

Figure 6. Rudder: 1st Natural Mode in 23.7 Hz

5. THE ANALYSIS OF THE RESULTS AND CONCLUSION

Several possibilities were considered before achieving the actual cause of excessive vibration: torsional and longitudinal shaft vibrations, diesel engine free moment excitation, propeller cavitation, rudder resonance and excessive impulse pressures. Gradually, these possibilities have been eliminated.

The ship torsional vibration is caused by:

1) The torque variation in the propeller shaft line due to the irregular flow around the blade (wake variation);
2) Forces and moments from the engine;
3) Non-homogeneous mass distribution in the system.

The excitation frequencies are, in general, equal to the RPM multiplied by the number of propeller blades, or equal to a multiple of the RPM. Measurements were made which led to small torque variations, showing that there's no excessive torsional vibration in the shaft line.

The longitudinal vibration in the propeller shaft is caused by thrust pulsations or due to internal engine forces. The natural frequency for the longitudinal vibration of the propeller system, including the crankshaft, the propeller and the intermediate shaft, can be found in the range of 500 to 800 rpm. A resonance condition can occur with engine harmonics of 5^{th} to 7^{th} order, due to pressures variation inside the cylinders, for an engine operation ranging from 110 to 200 rpm.

When exists a resonance due to the longitudinal vibration of the propeller system, the longitudinal excitation force (aft-forward) is transmitted to the hull structure and to the deckhouse (Payer, 1985). The vibration is amplified due to the propeller system that acts as a resonator. As a consequence, an excessive deckhouse vibration appears.

Measurements done in the engines supports didn't indicate significant values of longitudinal vibration. Additionally, the disappearance of the vibration in the condition of infinite bottom eliminates any possibility for internal sources (engines and transmission by shaft lines) to be responsible for the excessive vibration.

Vibration peaks measured close to the blade frequency and the calculated value of the natural frequency related to 1st rudder mode, indicated the possibility of resonance between these two frequencies. The ship was driven without the rudders, with the aid of tugboats and with the engines turned on. Values of excessive vibration were registered even in this condition, which completely eliminates the possibility of rudder resonance.

On board vibration measurement and ship's dynamic analysis with Finite Elements allowed to characterize the problem as being related to an hydrodynamic factor: do exist an influence of the depth in the propellers operation (in the shallow water), mainly when the central engine is turned off.

It is also possible to affirm that the vibration doesn't present a transient behavior, which means that this is not a cavitation related problem. Besides, visual inspections were made in the propeller blades and no sign of erosion were found.

According with Johannessen & Skaar (1980) "a wake variation from 0.1 to 0.85 is, by experience, found to give rise to excessive propeller excitation". It was reported that brackets angles of the ship is 90^{o}. Since propulsion is performed by three four blade propellers it can be expected some influence in wake variation. The same paper suggested an upper limit of 8.5 kPa for induced pressure in the hull (Wilson, 1991).

Figure 7 presents the main forces and moments acting on the hull surface.

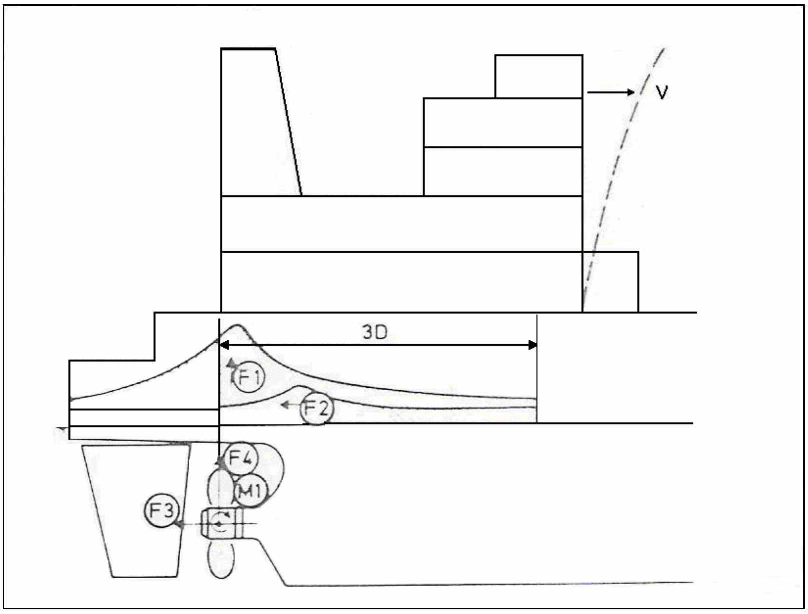

Figure 7: Propeller induced forces and moments

The next stage of this work includes the measurement of pressures induced on the hull. The measured values in the critical condition will be compared with the suggested limit of 8.5 kPa. If the pressure amplitudes are higher than recommended upper limit, possible solutions can be implemented like the use of skewed propellers.

6. REFERENCES

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