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FEM FREQUENCY ANALYSIS OF THE NAVIGATION MAST OF AN ASD TUG

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ABSTRACT

In this paper the natural frequency of the navigation mast has been calculated with the aid of the Finite Element Analysis. The calculated natural frequencies are compared to the dominant excitation frequencies. The purpose of the analysis is to have a margin of 15-20% between the natural frequency and the excitation frequencies.

Keywords: FEM, tug, natural frequency, Fourier transform.

1. INTRODUCTION

A tugboat (tug) is a boat that manoeuvres vessels by pushing or towing them. Tugs move vessels that either are unable to move, such as ships in a crowded harbour or a narrow canal,[1] or those that cannot move by themselves, such as barges, disabled ships, log rafts, or oil platforms. Tugboats are powerful for their size and strongly built, and some are ocean-going. Some tugboats serve as icebreakers or salvage boats. Early tugboats had steam engines, but today most have diesel engines. Many tugboats have fire fighting monitors, allowing them to assist in fire fighting, especially in harbours, [3].

Tugboats are generally smaller and the width-to-length ratio is often higher, due to the need for a lower draught. In smaller harbours these are often also termed lunch bucket boats, because they are only manned when needed and only at a minimum (captain and deckhand), thus the crew will bring their own lunch with them [4]. The number of tugboats in a harbour varies with the harbour infrastructure and the types of tugboats. Things to take into consideration include ships with / without bow thrusters and forces such as wind, current and waves and type of ships (i.e. in some countries there is a requirement for a certain amount and size of tugboats for port operations with gas tankers). [5]

Fig.1. Example of Tug [4]

The important parts and equipment are mentioned in Figure 2.

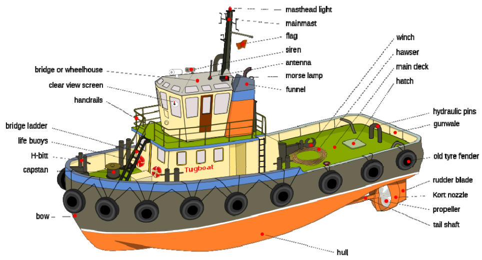


Fig.2. Diagram of components [4]

The mast is constructed to hold the navigation lights at the regulative location; the additional function is to hold aerials needed for the nautical equipment. The location of the lights depends on the length and width of the vessel. Depending on the application of the ship, the mast has the possibility to fold. The main reason for the possibility to fold the mast is pushing under the flare of a ship. The picture below shows this situation.

Fig.3. Tugs pushing an aircraft

Other reasons for the possibility to fold are bridges and other obstructions. The folding of the mast is possible by hand or with hydraulics.

2. MAST COMPONENTS

There are several components in the mast of an ASD tug. It is important to know what the properties of these components are (masses, dimensions and more). These properties are necessary to design and evaluate a modular mast.

A mast can be equipped with all antennas or with, for example, only half of them. Most of the antennas are prescribed by rules and regulations, some antennas are mounted in the mast on customer request. The new mast must be able to hold all component configurations. The masses and dimensions of all the antennas are listed in the table below.

Table 1. Mast equipment

No.	Equipment	Mass [Kg]	Quantity
1.	Navtex	3	1
2.	GPS	1	1
3.	VHF	1	2
4.	DSC	1	1
5.	SSB antenna	8	1
6.	TV antenna Delta 32M	1	1
7.	Inmarsat C	1	2
8.	Navigation light (with foundation)	6	9
9.	AIS/VHF	1	1
10.	Satelite compass SC-50	1	1
11.	Comrod AC15P	1	1
12.	Anemometer	2	1

All the tugs must be delivered with the certificate from a classification society. The classification societies use international rules and regulation in combination with their own rules and regulation [3].

The International rules and regulation:

- DSC Code - Code of Safety for Dynamically Supported Craft Resolution
- COLREGS - International Regulations for Preventing Collisions at Sea
- SOLAS - International Convention for the Safety of Life at Sea

Specific rules and regulation from the following classification bureaus:
- Lloyd's Register Rules and Regulations
- BV's Rules and Regulations
- DNV's Rules and Regulations
- RINA's Rules and Regulations

3. MATERIAL DESCRIPTION

The modular mast can be made from a range of different materials: regular mild steel, high strength steel, stainless steel, aluminium and composites. These materials where chosen because they are suited to make a construction such as a modular mast.

But in this case the material was steel, it is the most common used steel for construction purposes.

There is a reason why steel is used so much, it is a homogenous isentropic material, relatively cheap, easy to machine and also easy to repair. The properties of a homogenous isentropic material are the same in every direction. So, as disadvantage, there is a lot of material in places where it is not needed for strength or stiffness. This means the construction has more mass than needed.

Regular carbon steel is resistant to fatigue; it has a fatigue limit. This means that if the dynamic load does not exceed a certain level, the construction does not fail because of fatigue. Steel is a ferrous material which means it can be strongly magnetized by a relatively low magnetic force. This has adverse effects on instruments which use magnetic fields, such as a compass. The material needs to be protected against corrosion. The electromagnetic shielding properties are good, from 2 mm thickness and upwards, all the frequencies between 150 kHz - 1 GHz from an electric magnetic field will be blocked. [5]

Material: Steel

Mass density: 8070 kg/m^3

Young's modulus (E): 210000 N/mm^2

Poisson's ratio: 0.3

2.1. Excitation frequencies and safety margins

The excitation frequencies were considered to be:
1. The shaft frequency 16.66 Hz.
2. The blade passing frequency 18.26 Hz.

Analyzed margins of 20% from the excitation:
1. 13.3 - 19.9 Hz for the shaft frequency.
2. 14.6 - 21.9 Hz for the blade passing frequency.

4. MODELING THE MAST WITH RHINOCEROS

Rhinoceros is one of the standard three-dimensional modelling programs, providing efficiency in the layout, design and execution program, with high accuracy of three-dimensional objects and beyond.

Rhinoceros program was chosen because it is compatible with other 3D software programs (AutoCAD, Femap, etc.), and its use is very simple (in the case of 2D models, the commands are identical to those in AutoCAD). Modelling the mast in Rhino is reduced to the use of two distinct types of objects: curves and surfaces. It will be taken into account the fact that any area is a rectangular grid that can be deformed until the overlapping of opposite edges and that any edge of an area is a curve that can be reduced to a point. Moreover, surface properties are also used: closures, singularities, cuts, unions.

5. FEM ANALYSIS OF THE NAVIGATION MAST

One of the major design criteria for designing a ship is represented by the natural frequencies of the different parts. This is because of the many excitations a ship encounters when in service. If the natural frequency of a part and the excitation frequency congregate, the part will be excited excessively. This can cause excessive noise, annoying vibrations and even electrical failures.

The most important excitation frequencies for a mast are the wave frequency, blade passing frequency and the ignition frequency.

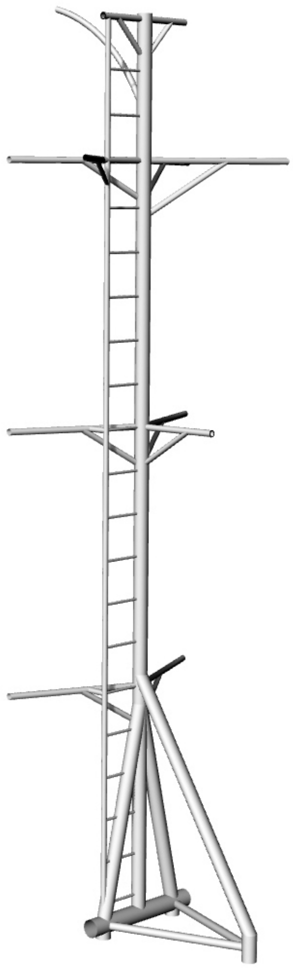


Fig.4. Navigation Mast with Rhino

The blade passing frequency is the most important frequency. This is because of the relatively high engine power for the size vessel. A lot of energy is passed through to the hull by the pulses caused by the propeller blades. An ASD tug has rotatable thrusters which cause a different load depending on the direction. This causes excitation frequencies with a lot of energy. Due to this, the energy that comes with the blade passing frequency on an ASD Tug is even higher than it would be with a fixed propeller.

Further on in the process, it is essential to look if the construction of the top deck of the wheelhouse has influence on the natural frequencies of the mast.

The natural frequencies are calculated with the finite element program Femap. The top deck of the wheelhouse is made with plate elements, the mast with beam elements and the parts (lights, antennas, etc.) in the mast are added as mass.

In Figure 4 the top deck of the wheelhouse with mast can be seen as well as the mass added and the constraines.

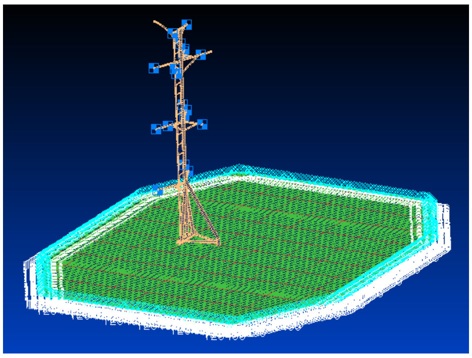


Fig.5. FEM model

The top deck construction of the different tugs is a deck plate with HP stiffeners beneath. The stiffening of the deck is a combination of HP 160x8 and HP 80x6. The deck plate has a thickness of 6 mm.

6. RESULTS AND CONCLUDING REMARKS

The first 2 natural frequencies.

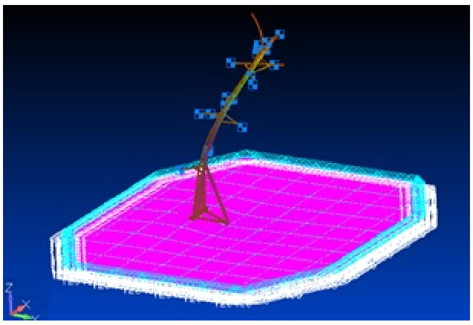


Fig.6. Mode 1, 2.027134 Hz

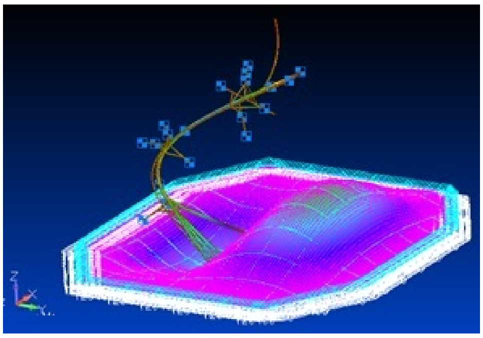


Fig.7. Mode 2, 3.144418 Hz

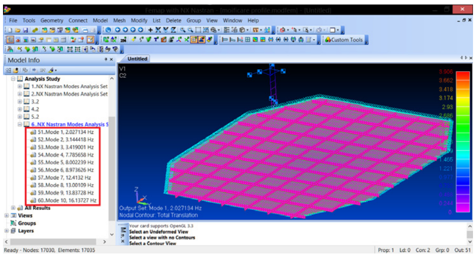


Fig.8. FEM results

After the analysis was carried out, it can be observed that the natural frequencies of the mast do not coincide with the ship propeller and engine vibrations.

Table 2. Frequency results

FEM Results	
Mode 1	2.027134 Hz
Mode 2	3.144418 Hz
Mode 3	3.419001 Hz
Mode 4	7.785658 Hz
Mode 5	8.002239 Hz
Mode 6	8.973626 Hz
Mode 7	12.4132 Hz

7. DETERMINATION OF FREQUENCIES WITH THE ELECTRIC RESISTIVE TENSOMETRY METHOD

The purpose of this test is to analyze the vibration modes of the mast on 1:5 scale using electric resistive tensometry.

Some strain gauges were put on the model mast as in the picture below.

Fig.9. Strain gauges

After the specific deformation was measured, the distribution of normal stress was calculated on the transversal axis (Figure 10) and on the diametric plan of the mast (Figure 11).

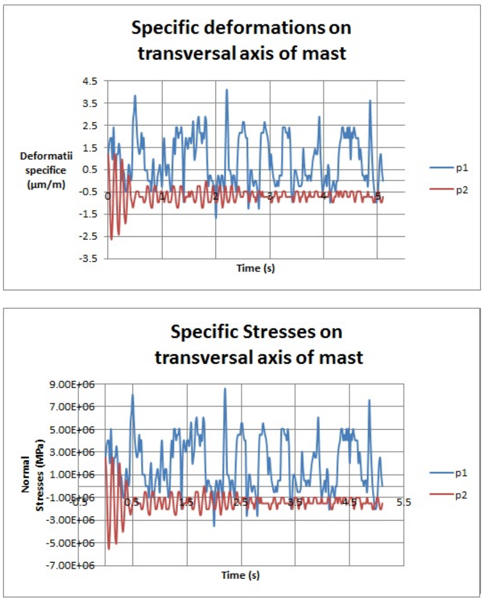
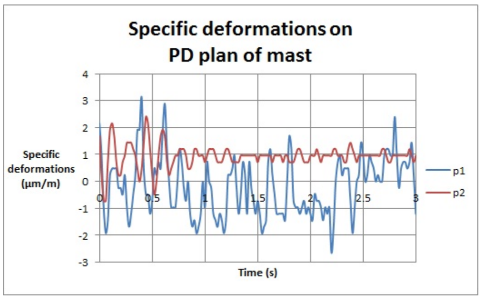


Fig.10. Strain and Stress on transversal axis



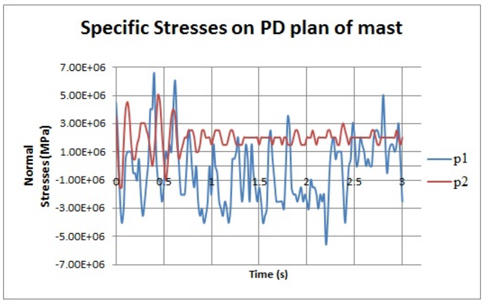
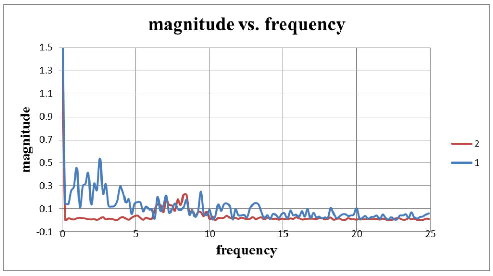


Fig.11. Strain and Stress on PD

7.1. Fourier transform

After applying the Fourier Transform, we obtained the following charts for the two tests.



8. CONCLUDING REMARKS

After the analysis was run, it can be observed that the natural frequencies of the mast do not coincide with the ship propeller and engine vibrations.

Some research studies point out that a symmetrical construction and the largest "jump" can be used regarding natural frequencies. This means that sometimes the first and second vibration modes have almost the same frequency, and the third and fourth modes also have a similar frequency. The gap between the second and third vibration mode can be large. With a symmetrical construction, the natural frequencies can be outside the harmful excitation frequency range. The geometry of the mast is strongly influenced by the rules and legislation prescribed by classification societies.

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