Study of extensions of navigation bridges from different materials by FEA and analytical method

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Abstract. This paper focuses on the study of local vibration occurring in the structure of the ship's navigation bridge wings. Research and methods: The modal shapes and own frequencies of this wings, that are designed like beam type structures with different lengths and sustaining angles, are determined with the Finite Element Analysis (FEA) in the FEMAP v11.2 software. The test patterns are [00-00] and [20-45]. The purpose of the modal analysis is to determine the shapes of own modes of vibration and their frequencies, from this we can get information about the resonance frequencies and how it can affect the structure. By changing the construction materials defined in modal analysis from SAE-AISI 1025 Carbon Steel to Grade 23 Titanium, the results obtaining are comparing. Results: From the analysis of these models we can deduct a visible decrease in natural frequency of structures with the support element, in comparison with the structure without support. We can see that natural frequencies obtained by finite element method are superior to those obtained by analytical methods. Also, we can see a visible decrease in the own frequencies of the titanium structures compared to the steel ones.

1. Introduction
The need for a fast transport of goods and passengers led to increasing larger vessels and power plants of propulsion on board. The undesirable effect of this phenomenon was the strong increase in vibration levels, thus affecting the safety of ship's operation, rest and work performance of sailors. In addition, excessive ship vibrations can lead to fatigue of local structures or inappropriate operation of machinery and equipment.

Currently, for the prevention of these negative effects, classification societies have developed international standards for limiting vibration levels on board, as well as recommendations for the calculation and measurement of vibration [1], [2]. Experience in the design of large vessels has shown that, in addition to the longitudinal and transverse vibrations of the ship's body generated by the main and propulsion engine, local vibrations, such as beams, railing, roofing, etc. may occur. Generally, these local vibrations of structures are considered to be of small magnitude, and their removal leads to the elimination of vibrations. [3]
1.1. Navigation deck wing models

The wings of the navigation deck are those side-by-side constructions extending to the ship, from where the mooring and questing of the ship can be monitored. Vibration measurements carried out on board have shown that these areas are often affected by the vibration problem. Vibrations may be transmitted to the upper deck, adversely affecting the performance of sensitive electronics on the control deck or in the deck. This is a particularly important aspect in analysing vibrations of local structures.

This paper focuses on the study of local vibrations occurring at the wing structure of the ship's navigating bridge. The paper presents the analytical and scalar solving of the local vibration problem by modelling the wing structure. In the analysis, the structure of the wing was simplified and represented by beams with rectangular section of 50x30 mm, with a wall thickness of 2 mm.[4] Two models were constructed for analysis; (00-00) and (20-45); they have been defined 2 materials: SAE-AISI 1025 Carbon Steel and Grade 23 Titanium.

The model (00-00) is represented by a horizontal beam of fixed length that is attached to the ship's body only at one end, the other end being free.

The model (20-45) has a support beam mounted on the horizontal beam at a distance of 20 cm from its outer end and inclined at an angle of 45 °.

The model (00-00) is not met in practice. Because in its composition it does not have a support beam, the model does not trust either statically or dynamically. Thus, in practice, it is not possible to achieve it. The reason for this analysis is the observation of the influence of the angles under which the supporting beams encountered in the wing construction are mounted.

1.2. Comparison between constructive materials

The structures chosen for the analysis will be studied as being made of 2 types of materials: SAE-AISI 1025 Carbon Steel and Grade 23 Titanium. Two models were constructed for analysis: (00-00) and (20-45); they have been defined 2 materials: SAE-AISI 1025 Carbon Steel and Grade 23 Titanium.

SAE-AISI 1025 Carbon Steel belongs to the iron alloys classification, while Grade 23 Titanium belongs to the titanium alloys. SAE-AISI 1025 Carbon Steel is a low- to medium-carbon alloy suitable for general engineering and construction applications. Offering good machinability, AISI 1025 can be normalized, hot and cold-worked, or water quenched and tempered. [5]

There are 12 materials properties with values for both materials. Properties with values for just one material (7 in this case) are not shown. [6]

Before starting the proper analysis of structure made from SAE-AISI 1025 Carbon Steel and Grade 23 Titanium, these materials were compared in terms of chemical composition and mechanical properties. Table 1 shows the common properties of the two materials used.

| Properties               | SAE-AISI 1025 Carbon Steel | Grade 23 Titanium |
|--------------------------|---------------------------|-------------------|
| Base metal price         | 2.9% rel                  | 60% rel           |
| Density                  | 7.9 g/cm³                 | 4.4 g/cm³         |
| Elastic modulus          | 210 GPa                   | 110 GPa           |
| Elongation               | 17 to 29%                 | 6.9 to 12%        |
| Unit resilience          | 150 to 440 kJ/m³          | 3440 kJ/m³        |
| Poisson’s Ratio          | 0.29                      | 0.32              |
| Specific Heat            | 450 J/kgK                 | 560 J/kgK         |
| Strength-to-weight       | 58 to 65 kNm/kg           | 220 kNm/kg        |
| Yield strength           | 250 to 430 MPa            | 870 MPa           |
| Thermal expansion        | 12 µm/mK                  | 9.4 µm/mK         |
| Ultimate resilience      | 66 to 77 MJ/m³            | 64 MJ/m³          |
The comparison of the two materials emphasizes their not in common properties. These are presented in table 2.

**Table 2. Properties not in common for SAE-AISI 1025 Carbon Steel and Grade 23 Titanium.**

| Properties             | SAE-AISI 1025 Carbon Steel | Grade 23 Titanium |
|------------------------|----------------------------|-------------------|
| Brinell                | 130 to 140                 | -                 |
| Electrical conductivity| -                          | 1.0% IACS         |
| Electrical resistivity | -                          | -6*10^-6 Ωm      |
| Rockwell C             | -                          | 32                |
| Shear modulus          | -                          | 43 GPa            |
| Thermal conductivity   | -                          | 7.1 W/mK          |
| Thermal diffusivity    | -                          | 2.9 m^2/s         |

Even if the two alloys come from different categories, we also analyzed their chemical composition. (See table 3)

**Table 3. Alloys composition comparison between SAE-AISI 1025 and Grade 23 Titanium.**

| Elements      | SAE-AISI 1025 Carbon Steel | Grade 23 Titanium |
|---------------|----------------------------|-------------------|
| Aluminium (Al)| 5.5 to 6.5%                | -                 |
| Carbon (C)    | 0.22 to 0.28 %             | 0 to 0.080 %      |
| Hydrogen (H)  | -                          | 0 to 0.013 %      |
| Iron (Fe)     | 99.03 to 99.48%            | 0 to 0.25 %       |
| Manganese (Mn)| 0.3 to 0.6 %              | -                 |
| Nitrogen (N)  | 0 to 0.030 %               | -                 |
| Oxygen (O)    | 0 to 0.13 %                | -                 |
| Phosphorus (P)| 0 to 0.040 %               | -                 |
| Residuals     | 0 to 0.4 %                 | -                 |
| Sulphur (S)   | 0 to 0.050 %               | 88.1 to 91 %      |
| Titanium (Ti) | 3.5 to 4.5 %               | -                 |

2. Research and methods: FEA analysis and analytical method
For finite element analysis, the patterns were originally created in NX v.8 under the .prt extension, and then exported under the .stp extension in FEMAP v.11. Once models imported into FEMAP, the material and properties of the structure were defined; model meshing was performed; the constraints were defined and then the modal analysis was run. Finally, the results obtained by the finite element analysis method were compared with the results obtained by the analytical method.

2.1. Analysis of deck wings by finite element method
The purpose of modal analysis is to determine the shapes of vibration modes and vibration frequencies, information on resonant frequencies can be obtained, and how they can affect the structure.
The equations of the free vibrations of a conservative system with N degrees of freedom can be written as:

\[ [K][\ddot{q}] + [K][q] = \{0\} \]  

(1)

The matrix of the masses \([M]\) and the matrix of the elastic constants \([K]\) are defined positively, non-singularly and usually symmetric, and \([q]\) is the column of the generalized coordinates.

\[ ([K] - \omega^2 [M]) \cdot [\psi_i] = \{0\} \]  

(2)

The system has solutions only if:

\[ \det([K] - \omega^2 [M]) = 0 \]  

(3)

It only deals with linear systems with a finite number of degrees of freedom, because most methods of identifying elastic structures are based on discrete models of continuous real structures.[7]

The own pulses of the analysed structure result from the extraction of the roots of this characteristic equation. The finite element method used calculates the stiffness and mass matrices of the system, depending on the type of the element and the arrangement used to model the structure. Then, by numerical methods, the roots of the characteristic equation to obtain their own frequencies are calculated.

In this paper, for the determination of the roots of the characteristic equation, the Block-Lanczos algorithm was used as a numerical method. All structures were modeled with 5 mm tetrahedral elements and 10 knots, and the wall thickness was considered as a single element.

Determining their own frequencies has led to their own vibrational forms. In order to accomplish these steps, software packages of finite elements such as NX and FEMAP were used, and the values obtained from the analysis for each studied model were listed in table 4.

| Model code | Elements number | Knots number |
|------------|-----------------|--------------|
| (00-00)    | 4536            | 9144         |
| (20-45)    | 9794            | 19682        |

2.2. Analytical method of navigation deck wings

The frequencies of the wing models were calculated from the analytical point of view. The material from which the beams are made was considered to be linear, homogeneous and isotropic. It has also been taken into account that the bar profiles are very small in size.

The coordinate system of the beam consists of: the z axis representing the axis of the bar and the axes x and y that are perpendicular to the cross section. (See figure 1)

**Figure 1.** Forces and moments of the beam.
Wing patterns to be studied from the analytical point of view are made up of 3 segments. In figure 2 we can see the analytical model of the wing. In this system, the ends A and B are fixed, and the end D is free.

Points A and B are considered fixed, and for each one there are 6 equations (3 translations and 3 rotations) and a total of 12 equations is obtained. Since the end D is free and the external loads do not influence the cross section, 6 equations (3 for force and 3 for the moment) will be written at this point. Point C has 18 continuity equations. As a result, a total of 36 equations are obtained. (See figure 5)

By using the 36 equations obtained by writing the boundary conditions and continuity, formed primary matrix on the order of 36, and this matrix was then solved using MATLAB R2011b wings for all models proposed for study. The determination of its own frequencies is limited to the determination of the quadratic matrix's own values. To solve this matrix, the eig (eigenvalue) function is used, with 2 output arguments, thus obtaining its own vectors and its own values.

3. Results
The wings models made of the two materials were studied in turn by the FEA method and the results were centralized.

3.1. FEA analysis results of (00-00) model
The first analyzed model is (00-00) beam without support on the main deck. Figures 3-12 show the first 10 modes of vibration and indicate the values of their own frequencies.

In vibration mode 1, the bend phenomenon appears in the vertical plane (see figure 3), and in mode 2 the beam is bent in the horizontal plane (see figure 4). For other frequencies we can see bending, torsion and stretching phenomena. Modes 3, 6 and 9 show bend in the vertical plane (see figure 5, 8, 11), and bending modes 4 and 7 in a horizontal plane (see figure 6, 9). Module 8 is the first mode of axial deformation (stretching) (see figure 10). Modes 5 and 10 are torsion (see figure 7, 12). In the case of rigid deformation models, the deformation points can be observed.

Figure 2. The boundary and the continuity conditions.

Figure 3. Mode 1 of vibration.

Figure 4. Mode 2 of vibration.
3.2. *FEA analysis results of (20-45) model*

In the case of the model (20-45) only the first 5 modes are shown, these being the most relevant. (See figure 13-17). The figures show both the initial shape of the molded structure and its deformed shape.
In this model, the first deformation occurs horizontally, the end of the beam being the most affected. In the second mode, the bends are in the vertical plane and the support beam is subjected to high voltages.

In mode three horizontal bends and twisting phenomena appear, and the areas affected are the springs beam and the end of the main beam. (See figure 15)

It can be noticed that torsion and bending overlap in beam behaviour, and the effect of these phenomena is stronger as they increase their own frequency values.

In Mode 4, both beams move in a vertical plane, but in opposite directions, there is a risk that they collide. (See figure 16)

The higher the frequency values, the more bending and torsion modes are more obvious.

3.3. Comparing the results obtained through the MEF and the analytical method

The purpose of the modal analysis is to determine the shapes of own modes of vibration and their frequencies, from this we can get information about the resonance frequencies and how it can affect the structure. By changing the construction materials defined in modal analysis from SAE-AISI 1025 Carbon Steel to Grade 23 Titanium, the results obtaining are comparing.

The values of their own frequencies were taken from the previous figures in which the vibration modes were presented.
The percentages differences are calculated using the following relationships:

\[
\text{The difference} = \frac{(FEM_1 - AM)}{FEM_1} \cdot 100
\]  

(4)

\[
\text{The difference} = \frac{(AM - FEM_2)}{AM} \cdot 100
\]  

(5)

FEM 1 = finite element method used for model made by SAE-AISI 1025 Carbon Steel
FEM 2 = finite element method used for model made by Grade 23 Titanium
AM = analytical method

Table 5. Results.

| Mod | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
|-----|---|---|---|---|---|---|---|---|---|----|
|     | \((00-00)\) |     |     |     |     | \((20-45)\) |     |     |     |     |
| FEM 1 [Hz] AISI 1025 | 53.607 | 80.301 | 326.213 | 485.213 | 797.156 | 871.889 | 1288.403 | 1578.25 | 1597.89 | 2079.15 |
| FEM 2 [Hz] Titanium 23 | 42.693 | 63.952 | 259.797 | 386.425 | 634.858 | 694.374 | 1026.089 | 1256.93 | 1272.56 | 1653.45 |
| AM [Hz] | 53.56 | 79.96 | 325.62 | 475.67 | 781.42 | 80.01 | 135.443 | 256.484 | 283.493 | 397.80 |
| FEM 1 – AM [ % ] | 0.087 | 0.425 | 0.182 | 1.966 | 1.974 | 0.972 | 6.855 | 1.891 | 1.974 | 2.895 |
| AM – FEM 2 [ % ] | 20.289 | 20.020 | 20.214 | 18.762 | 18.755 | 21.134 | 25.793 | 21.865 | 22.665 | 20.943 |
|     | \((00-00)\) |     |     |     |     | \((20-45)\) |     |     |     |     |
| FEM 1 [Hz] AISI 1025 | 79.232 | 170.007 | 322.053 | 355.966 | 494.156 | 514.865 | 522.194 | 858.582 | 861.504 | 1071.55 |
| FEM 2 [Hz] Titanium 23 | 63.101 | 135.443 | 256.484 | 283.493 | 397.80 | 410.040 | 415.877 | 683.777 | 686.105 | 853.838 |
| AM [Hz] | 80.01 | 135.443 | 256.484 | 283.493 | 397.80 | 521.73 | 569.16 | 898.36 | 933.85 | 1151.38 |
| FEM 1 – AM [ % ] | 0.972 | 6.855 | 1.891 | 1.974 | 2.895 | 1.316 | 8.252 | 4.428 | 7.747 | 6.933 |
| AM – FEM 2 [ % ] | 20.289 | 20.020 | 20.214 | 18.762 | 18.755 | 21.134 | 25.793 | 21.865 | 22.665 | 20.943 |

4. Conclusions

From the analysis of these models we can observe a visible decrease of the natural frequency of the structures with supporting beams compared to the structures without supporting beams, the situation being slightly different only in the first two deformation modes.

Following the comparison, it was found that:

- Regardless of the model adopted in the construction, the values of the frequencies of the Titanium 23-degree structures are inferior to the frequencies obtained by the analytical method. These values are about 18% lower for the model (00-00) and about 24% for the model (20-45);
- For model (00-00) of SAE-AISI 1025 Carbon Steel, the lowest values of the own frequencies were recorded by the analytical method. The reason for obtaining higher values using FEA is that no damping is used in this method;
Deformations do not vary in appearance in the two analyses, for AISI 1025 and Titanium 23 degrees. Instead, the proprietary frequencies obtained for the SAE-AISI 1025 model (00-00) are 20.36% higher than those of the Titanium 23 grade.

As the construction material of the navigation deck wing, it is recommended to use the Titanium 23 degrees because it is very resistant to mechanical shocks, and as a model, from the two models studied, the model (20-45).

5. References
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