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OPERATION FACTORS INFLUENCE ON THE DYNAMIC BEHAVIOR OF MARINE PROPULSION SYSTEMS

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Abstract: *This paper represents a step forward toward the introduction of engineering advanced research methods for the study of dynamic behavior of marine propulsion systems. The large dimensions of this work and the theoretical and research materials developed in it via numerical simulation are witnessing the author's effort for an exhaustive treatment of the proposed theme. Via numerical models/simulations, the behavior of the marine engines and propulsion systems is easy to be done, more economical, allowing various design solutions and optimization studies. As it was mentioned before, the process described in the paper is based on the numerical simulation and had as departure point a real marine diesel engine.*
Keywords*: marine engines, propulsion systems, dynamic behavior, finite element analysis*

1. INTRODUCTION

The operation of the marine engines depends heavily on its dynamic behavior, the understanding and modeling of such phenomena is resulting in robust designs, refined solutions and higher efficiency of the final design. The existing models for the dynamic behavior of marine engines are mostly experimental ones, the literature regarding this subject is extremely rich, but once the emergence of the great power computers and Finite Element Analysis, the usual complications related to the variations of the input data, dimensions, materials which are milestones for the classic experimental research, were easily overcame, the numerical simulation allowing solutions very close to the real model and offering solutions which are usually inaccessible for the common experiment [1]. Via numerical models/simulations, the behavior of the marine engines and propulsion systems is easy to be done, more economical, allowing various design solutions and optimization studies. The objectives of the paper are as follows:

- the geometrical modeling of the marine engine and its main components including the shafting, using advanced Computer Aided Design;
- the modeling of the dynamic behavior of the marine engine taking into account the inertial loads and boundary conditions;
- the modeling of the dynamic behavior of the shafting, taking into account the inertial loads and boundary conditions;
- determination of the natural frequencies for the naval engine and shafting;
- the determination of the most heavily loaded bearing due to the elastic deformation of engine's structure;
- the qualitative evaluation of the elastic deformation of engine's structure over the functioning of the above mentioned bearing.
- the study of the dynamic response of the naval engine to the specific excitation loads.

2. WORK DESCRIPTION

The naval engines are complex systems for the specificity of their application range which is imposing big power and big dimensions. Therefore the processes and the existing phenomena have specific characteristics and their functioning is quite different in comparison with the normal diesel engines. The numerical models developed until now use as theoretical basis, the zero-dimensional thermodynamic models capable to describe globally the phenomena within the marine diesel engines, the result being a lack of the significant detail. The paper was thought to describe the dynamic behavior and complex vibrations of marine engines which is a vast and summary researched area of interest. The complexity of the phenomena is given by the interconnection between the engine-shafting-ship's body, without which any serious and thorough study may be started, and, on the other hand, the complexity of the engine itself, its complex operation and its big dimensions. The process described in the paper is based on the numerical simulation and had as departure point a real marine diesel engine. The method is easy to be done, more economical, allowing various design solutions and very important, familiarizes the students with a phenomenon that could be met at the ship board [2], [3]. The start of the work is based on the study of the mathematical formulation for the dynamic phenomena present on board of ships, like the vibrations of marine engine, of shafting, ship's body structure, ship's propeller, and dynamic sea effects. The focus was on the vibrations of shafting system driven by the marine engine with the deduction of free vibration equations for torsion, bending and axial loads along with a rich mathematical baggage. Subsequently in the following steps it is analyzed the excitation sources for the vibrations of shafting. Then the forced vibrations of shafting are approached, taking into account the torsion, bending and axial vibrations. During the next step are mathematically described the coupled vibrations of shaft line and marine engine, along with some numerical excerpts and examples. The numerical simulation had as departure point a real marine diesel engine, produced by Wärtsilä type 8L20, used for propulsion of small and medium ships as shown in the Fig. 1.

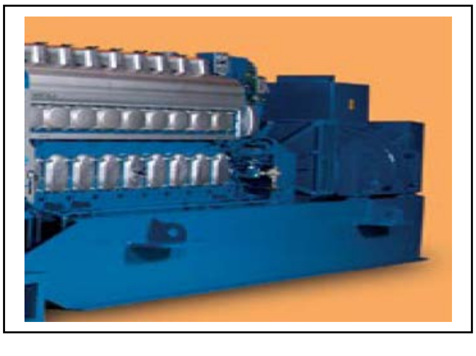

Fig. 1: Wärtsilä type 8L20 diesel engine

Since for simulation the FEA was involved, this method was reviewed being underlined some of the basic concepts using an accessible mathematical formulation.

The FEA treatment of the marine engine mechanical simulation started but not before being pointed out some hypothesis [3]:

- under consideration were 4 load cases depending of the ignition sequence into the 8 cylinders of the engine;
- for the sake of coverage, the worse loading case was considered, when the entire pressure developed by cylinders was deemed to action in vertical direction;
- also the weight of all the engine's structure was took into account, the gravity axe being Oy;
- the temperature gradients were disregarded they being small in the region of the engine modeled.

3. SIMULATION RESULTS

The results of the simulation comprised the calculation of tensions, strains and deformations of engine structure for all the four loading cases considered, resulting a rich palette of solutions and with the final conclusion that the engine acts satisfactory as toughness in each of these cases [3].

For the loading case 1 (the ignition sequence in the first and the last cylinders), some of the results are shown in the figures 2, 3 and 4, as follows:

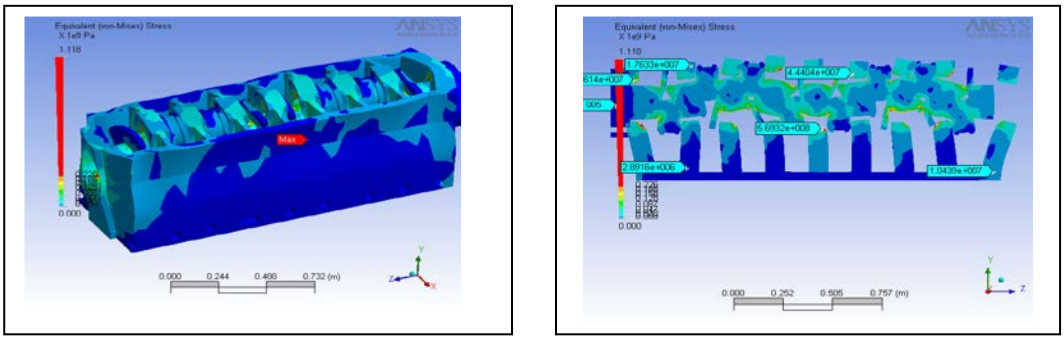

Fig. 2: Von Mises tensions for loading case 1

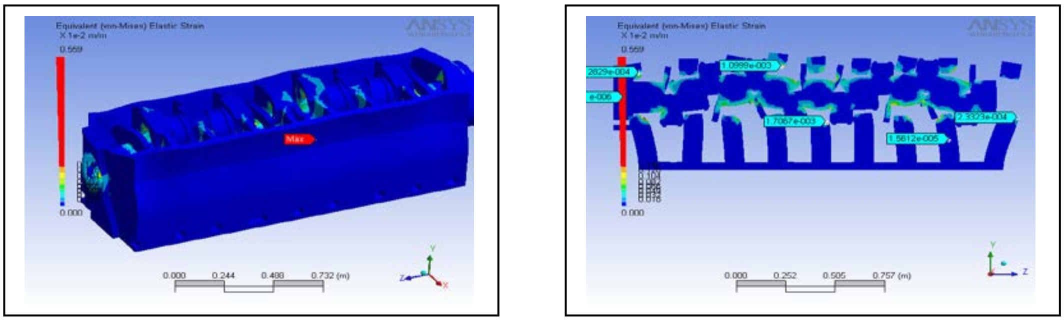

Fig. 3: Von Mises elastic strain for loading case 1

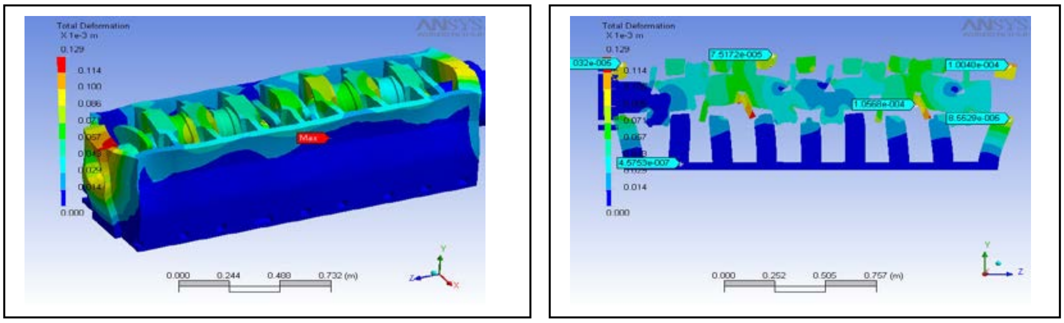

Fig.: 4: Total deformation for loading case 1

The following conclusions can be concluded based on the analysis of the distributions, strains and deformations for the loading case 1:

- The assembly will resist for the considered loading case, the maximum equivalent stress having a maximum level of 1.12 × 108 Pa, in the median area of the crankshaft, half from its material resistance in an extension operation.
- The directional deformation on the Oy axis (the direction of the loading) is important for the analysis of the bearing strains and has a maximum level of 1.1 × 10-4 m in a median area of the crankcase.
- All the tensions, strains and deformations can be used by the plant designer in order to establish the areas where it is necessary a redesign to increase the local stiffness and the whole assembly.

Furthermore, it is analyzed using FEA the free vibrations and natural frequencies for the engine structure and shafting system. A final conclusion is the angular speed and the exciting loads frequencies are far below the frequencies determined and thus, the engine operates smoothly in its functioning domain. Some results are shown in the Figures 5 and 6, as follows:

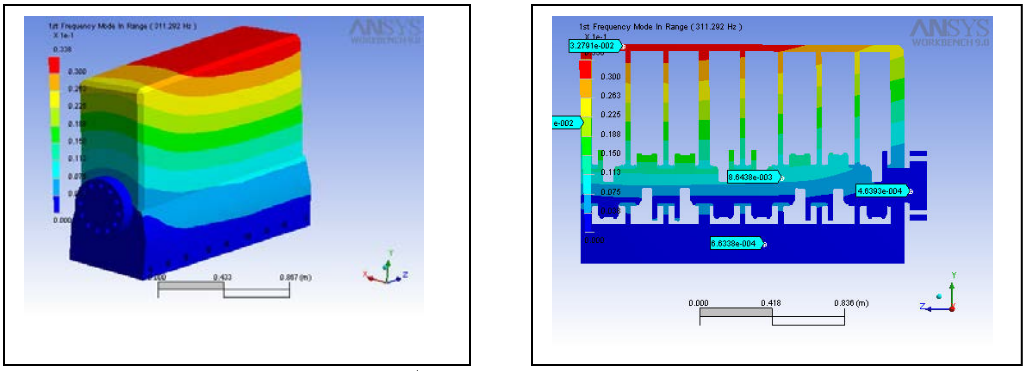

Fig.: 5: 1st frequency mode in range for the engine structure

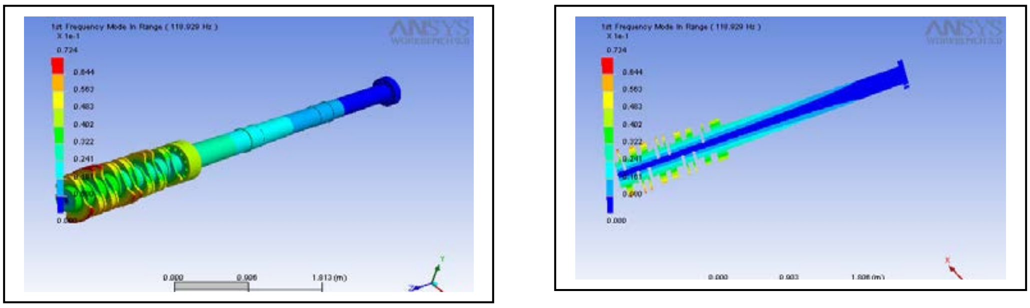

Fig.: 6: 1st frequency mode in range for the shafting

4. RESULTS AND VALIDATION

This section has as main objective the validation of the model considering the following facts [3], [4]:

- the study of dynamic behavior for each mechanical system depends heavily on the mass, damping and stiffness matrix, or, in other words, is depending on geometry, materials and the boundary conditions of any particular structure; consequently, it isn't expected that two different marine engines to have the same dynamic behavior due to the existing differences as regard to materials and dimensions;
- for the marine diesel engine Wärtsilä 8L20 the experimental data are proprietary of the manufacturer.

Given the two above reasons, it was proposed in the paper a more elaborate validation, by studying the frequency response of the given structure and the comparison with some existing data for the engine Sulzer 3 AL 25/30.

Some of the results are shown in the figures 7, 8 and 9, as follows:

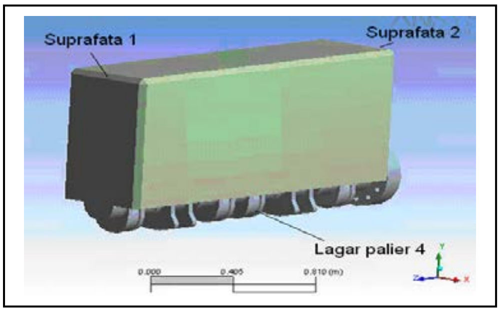

Fig.7: Surfaces considered in the study of frequency response

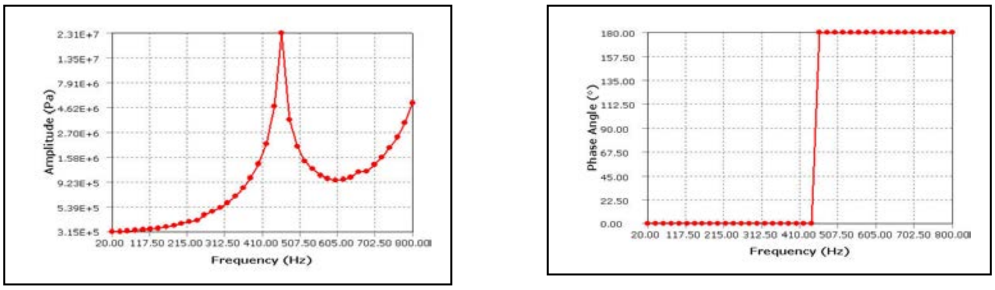

Fig. 8: Normal tension on Ox direction behavior on surface no.1-frequency response

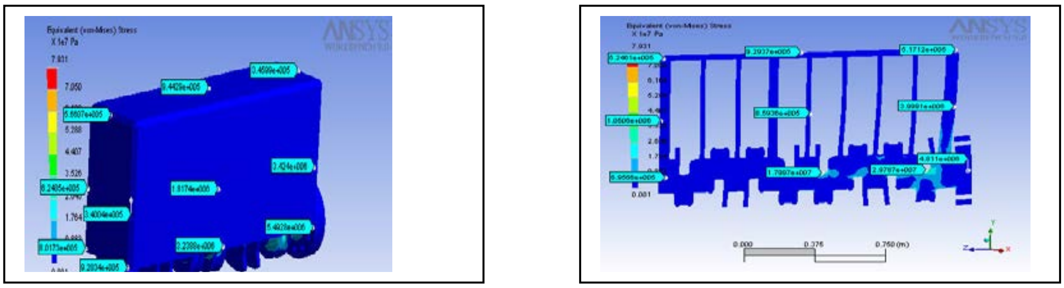

Fig. 9: Von Misses tension at loading excitation frequency of 60.25 Hz

For the frequency of 60.25 Hz, the most distorted area is that one of the connected flange with the propelling screw axle, the maximum level being 0.222 × 10-3 m. The calculated total deformation is 1.50 × 10-5 m, at the middle of the surface no. 1.

5. CONCLUSIONS

The naval engines are complex systems for the specificity of their application range which is imposing big power and big dimensions. The dynamic behavior and complex vibrations of marine engines were described and analyzed in the present paper. The results of the simulation comprise the calculation of tensions, strains and deformations of engine structure for all the considered loading cases and the final conclusion is the engine acts satisfactory in each of the four considered cases.

Based on the obtained results, the paper comes to improve the information related to the treated subject. It is a good start for the study of the dynamic behavior of others components of the naval engine via simulation model.

The method is easy to be done, more economical, allowing various design solutions and very important, familiarizes the students with a phenomenon that could be met at the ship board.

The results of the research bring new and fresh information on the dynamic behavior of marine propulsion systems, complex theme through the specificity of its application range.

For the future works, it is recommended the study of the dynamic behavior of others components of the naval engine.

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