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Matching simulated and measured eigenfrequencies of medium speed diesel engines

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Summary. The aim of this article is to present a method to predict the dynamic behavior of a new engine design on the basis of a correlation between simulations and measurements of a similar engine.

Key words: natural frequency, damping

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Introduction

Simulation is widely used for the prediction of the dynamic behavior of new engine design configurations. In order to increase the level of accuracy of the simulation results, a *Dynamic Response Tuning Method* process of correlation with experimental data was developed. A good correlation between experimental measurements and simulation is only possible with proper modeling. In the years, different methodologies for accurate modeling were developed. Some examples are available in [5] and [8].

Method description

The *Dynamic Response Tuning Method* permits to obtain an accurate estimation of the dynamic behavior of a new engine, or an engine with some modification, on the basis of a previous Engine FEM (finite element method) [9, 4] model and previous vibration measurement results on different engines.

An accurate response analysis is needed to validate a new engine from the dynamic point of view. The accuracy of the simulation depends on two main "parameters": *Mode shape and frequency* and *Damping value to apply.* The *Dynamic Response Tuning Method* improves the accuracy of the simulation by acting on those two aspects.

The initial inputs of the whole process are the FEM model of an engine (Modal Analysis and Response Analysis calculation in Frequency Domain) and the real vibration measurements (propeller curve and experimental modal analysis) of the same engine type. An

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initial correlation is performed by doing the modal assurance criterion (MAC) [3] in order to pair the mode shapes simulated with the mode shapes measured. It was noticed that the FEM model is usually more rigid than the actual running engine and, consequently, the frequency simulated is slightly higher than the frequency measured. It is possible to define the frequency shift in order to compensate this difference and tune the FEM model.

Then, the actual damping is established by analyzing the vibration measurement values acquired, and those values are available to be used to calculate the response analysis of the next new engine.

The innovative method is based on the creation of a set of "parameters" per each relevant mode shape recognized to tune the FEM model of the new engine. The "parameters" take into account:

- *Frequency Shift*: the difference between the frequency of the FEM modes and the actual modes identified from a vibration measurement along the propeller curve.
- *Damping Analysis*: an innovative procedure based on the correlation of measurement and the simulation per each harmonic order normalized to 1 to define the correct damping to be used in the dynamic calculation of the new engine.

To apply correctly per each mode the correct "parameter" (Damping and frequency shift), it is necessary to pair the mode shapes of the new engine model with the mode shapes of the previous engine. This pairing is performed by calculating the MAC between the two cases, and after that it is possible to associate the damping and the frequency shift to the relevant modes, obtaining an accurate response analysis estimation of the dynamic behavior of the new engine.

1. Model CROP/SIMPLIFIED comparison measurement points

The CROP model is a reduction of the complete FEM model from about millions of degrees of freedom (dof) to 87 dof that corresponds to the 29 points of the measurement. In this way you reduce the consumption of the calculation time and the huge size of the FEM models files. The CROP model is used in the calculation of the Response Analysis FEM.[1]

2. CORRELATION measurement vs FEM

The first step is to correlate the mode shapes of the FEM model with the measured modal shapes [2, 7]. Then, once the Response Analysis is performed, the next step is to correlate the results with the measurement data. The analysis studies in detail each harmonic order and each direction for each point.

3. Calculate parameters

It was noticed that the FEM model is usually more rigid than the real running engine and, consequently, the frequency simulated is slightly higher than the frequency measured. It is possible to define a frequency shift in order to compensate this difference and tune the FEM model [6]. Then, the real damping is established by analyzing the vibration measurement values acquired, and those values are available to be used to calculate the response analysis of the next new engine. The innovativeness of the method lies in the creation of a set of "parameters" per each relevant mode shape recognized to tune the FEM model of the new engine. The "parameters" take into account:

3.1 Frequency shift:

The frequency shift is defined for each relevant mode shape recognized, see (1). It is the difference between the frequencies of the FEM modes and the real modes identified from the vibration measurement along the propeller curve.

$$\Delta f = \frac{f_{meas} - f_{FEM}}{f_{FEM}} * 100, \tag{1}$$

where f_{meas} is the identified resonance frequency measured along the propeller curve and f_{FEM} is the natural frequency calculated in the FEM model

3.2 Damping analysis:

It is an innovative procedure based on the correlation between measurement and simulation per each harmonic order normalized to one to define the correct damping to be used in the dynamic calculation of the new engine. Damping is studied starting from vibration measurement along the propeller curve. The ratio of the amplitude peaks is normalized to one, as visible on side, in order to avoid any distortion from the amplitude point of view.

The peaks in the vibration measurement results are fitted to a single spring-mass-damper-model , and the damping can be determined. When the Frequency Shift and Damping are determined for all recognized modes, "Parameter Table Values" can be created and used in the next step.

4. Pairing modified engine - old engine

Once the 'Parameters' are defined, it is possible to estimate the behavior of any modified engine. The first step is based on the Modal Analysis and the calculation of MAC (modal assurance criterion) between the old and modified engine models. It identifies the similar mode shapes when MAC tends to one, and it helps you to take the decision on which mode to apply the parameters.

5. Accurate dynamic behavior estimation of modified engine

The results of the response analysis tuned provide an accurate dynamic behavior estimation of a modified engine with the application of the "Parameters". Additionally, this innovative process reduces the consumption of calculation time since it can be applied to evaluate all possible engine configurations.

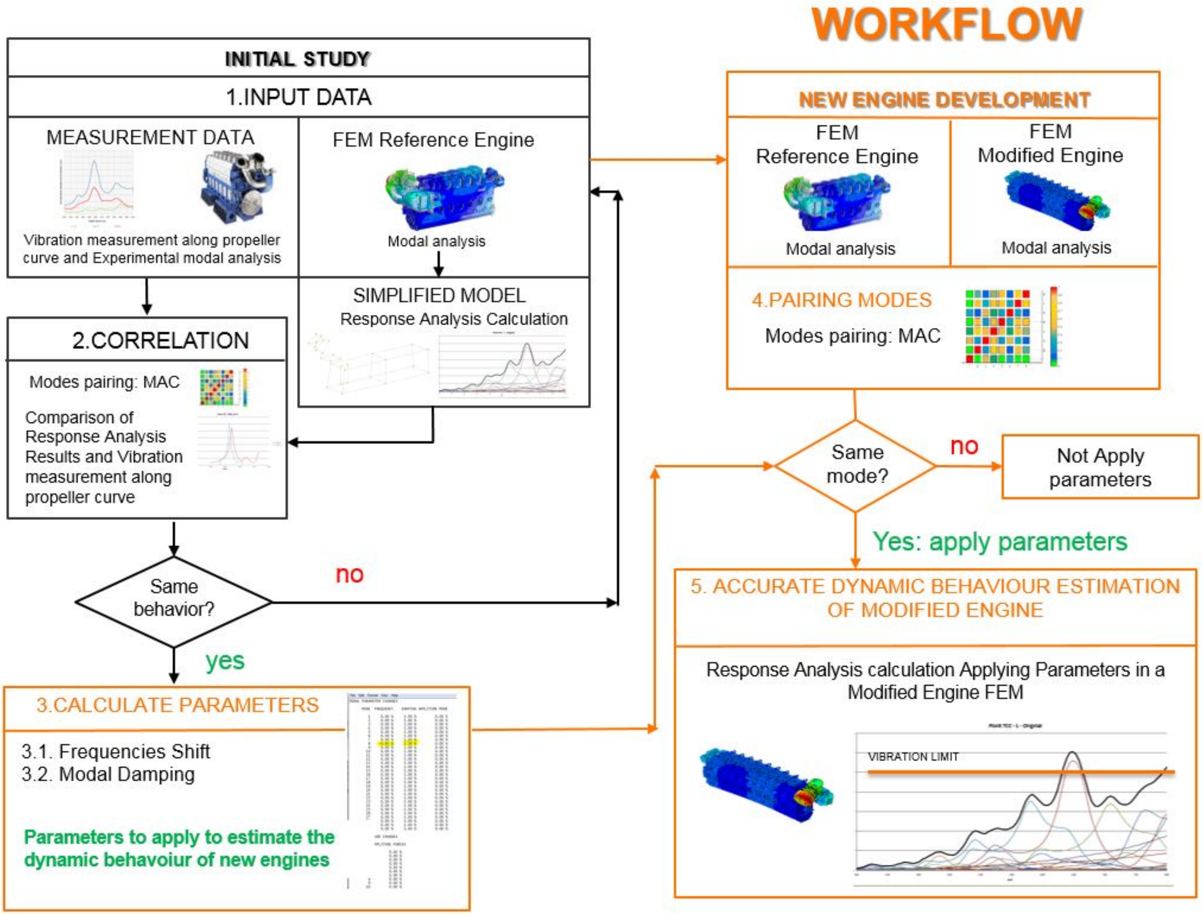

Figure 1. Workflow chart.

Figure 1 presents the Work-flow for the *Dynamic Response Tuning Method* process.

Conclusion

The Dynamic Response Tuning Method is a proposal for a new way of working in the correlation and validation of the dynamic behavior of a new engine. By applying this method, it is possible to obtain an accurate estimation of the dynamic behavior of a new engine (or an engine with some modification) on the basis of a previous Engine FEM (finite element method) model and previous vibration measurement results on different engines.

The more you correlate measurement and simulation, the more you learn about the validation of the simulation.

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