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PARAMETRIC CAD/CAE TOOL IN MODAL ANALYSIS: NUMERICAL RESULTS AND EXPERIMENTAL OUTCOMES

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ABSTRACT
This paper focuses on the development of an automated macro for increasing the interaction between CAD (computer-aided design) software, CAE (computer-aided engineering) software and numerical computing environments. This tool is able to evaluate a large number of configurations for modal analysis purposes by piloting a geometric parameter in the designed 3D assembly. It makes possible a computational analysis time reduction and an easier post-processing of results data. The aforesaid macro has been applied to the design and analysis of an experimental test structure in order to investigate crossing and veering phenomena, namely the coincidence of two eigenfrequencies or the abrupt divergence of natural frequencies trends when a coupling effect between two modes is present. Moreover, it was possible to plan the experimental setup and the identification modal analysis, and carry out a correlation between numerical and experimental results.
Keywords: Parametric CAD/CAE, Crossing-Veering phenomena, Modal Analysis.

1. INTRODUCTION
Many CAD software applications are now able to solve static and dynamic finite element model (FEM) problems without making use of external CAE software. This useful integration enables to take into account modifications of the geometry in the following analyses (static, dynamic, fatigue, frequency, buckling, thermal) the user wants to perform. In most cases a parametric analysis, in which a geometrical variable can be changed and a study is computed for a range of values, would be necessary. This feature is not implemented as an open-source approach in any CAD software known by the authors. A parametric analysis could represent an important step on component and assembly design both for static and dynamic problems, such as monitoring the maximum stress values with respect to the radius of a shaft, or evaluating the natural frequencies trends due to changes in the relative position or size of a component. This paper presents an application of a parametric FEA tool, used to investigate the dynamic behaviour of an experimental structure characterized by the chance of easily changing its geometrical shape. This structure was designed with the purpose of tuning it on configurations for which two eigenvalues (or natural frequencies) are coincident or very close [1]. Two phenomena could occur in such configurations: “crossing” or “veering” behaviour. In the former, by changing the angular parameter two eigenvalues converge, then become coincident and switch their mode order. In the latter, two modes swap their shapes without reaching an intermediate configuration for which their frequencies are coincident. Their frequency trends abruptly veer and they never cross. These modal properties are typical of cyclic or symmetric structures [2, 3]. The sentence of Leissa “a dragonfly one instant, a butterfly the next and something indescribable in between” can effectively describe the “veering” phenomena [4]. Interest has been focused on difficulties to numerically predict and evaluate these behaviours and on the experimental design of test rigs [5]. The CAD/CAE software used is Solidworks2010®, while to manage the results of the macro in terms of charts and mode shapes a set of MATLAB® routines was developed.

The prediction of crossing and veering phenomena on the designed test rig is discussed and some preliminary experimental results are compared to underline the integrated-tool capabilities.

2. THE PARAMETRIC FEA TOOL

The goal of the developed tool is to perform a loop of dynamic analyses at discrete steps, between two boundary configurations, chosen by the user, of the assembly model. The macro code, developed in C-sharp, is a set of command lines that allows executing functions, that should otherwise be manually done. In doing so, repetitive and time consuming operations are avoided and an easy post-processing is made possible. Only few shrewdnesses have to be taken into account: the driven parameters and the grounded constraints must be defined, fixed faces have to be bound, and materials must be previously assigned to the components. The user can transfer few values of the macro by means of a graphic interface, as shown in Figure 1. At each loop the macro sets the value of the chosen parameter, e.g., an angular mate (Figure 2), eventually fixes the faces to restrain, generates the mesh, then runs the analysis and stores the results into ASCII files arranged into vector/matrix form. All the relevant data, i.e. natural frequencies, mode shapes and mesh details, are saved into files collected in different subfolders.

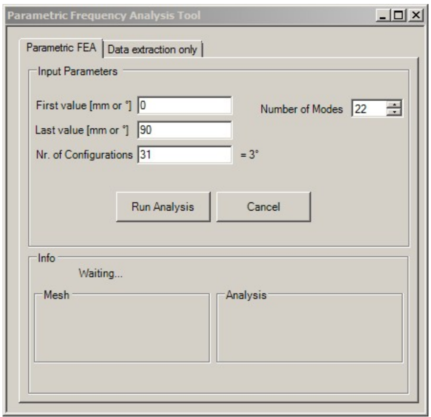

Figure 1. Input interface of Parametric Frequency AnalysisTtool

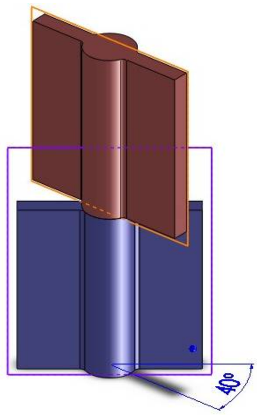

Figure 2. Parametric simplified model with rotating mate

3. THE COINCIDENT EIGENVALUES TEST-RIG

The Parametric FEA tool has been applied to the test case shown in Figure 3. This structure is designed to be not symmetric or cyclic and not to have uncoupled dynamic systems [1]. It is made of three beams and three cylindrically shaped masses. A rotating table placed between *beam*$_1$ and *beam*$_2$, and another simpler joining element between *beam*$_2$ and *beam*$_3$ enable to change the middle beam orientation. The first configuration, namely α=0°, occurs when *beam*$_2$ and *beam*$_3$ are aligned and 90° rotated with respect to *beam*$_1$. The angular parameter is defined by the offset between the third and the second beam. This mate is named "ConfigParam1" in order to be recognized by the macro as the driven parameter. The performed analysis is grounded, and the constraint is set on the lower face of the horizontal beam that has the function to simulate an ideal clamp. This face is named "FixFace1" to be recognized by the macro.

4. RESULTS AND CONCLUSIONS

In order to manage the output files and to print out the results of the automatic analysis, Matlab routines are developed to pilot the tool. The target is to evaluate crossing and veering behaviour through chart of frequencies with respect to an angular parameter. The Modal Assurance Criterion [6] is evaluated between two subsequent configurations:

$$MAC = \frac{[\{\Phi\}_{c1}^{H} \cdot \{\Phi\}_{c2}\}]^{2}}{[\{\Phi\}_{c1}^{H} \cdot \{\Phi\}_{c1}\}] \cdot [\{\Phi\}_{c2}^{H} \cdot \{\Phi\}_{c2}\}]}. \tag{1}$$

$\{\Phi\}_{c1}$ and $\{\Phi\}_{c2}$ are respectively the eigenvectors of two configurations. It makes possible to correctly associate the natural frequency to its related mode shape in case of crossing behaviour, and to plot natural frequency trends.

Figure 3. Experimental test-rig (left) and detail of the rotating table (right)

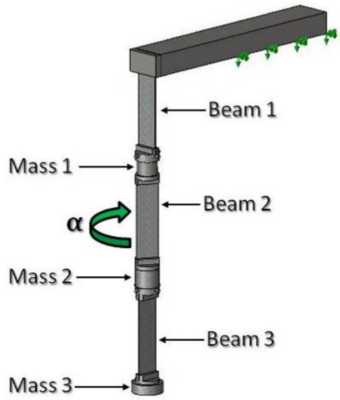

Figure 4. Equivalent CAD model

The MAC coefficient goes from 0% to 100% and indicates the correlation between the mode shapes of the configurations. A value near 100% implies that the two eigenvectors are parallel and the mode shapes are similar. The orientation angle α is varied from 0° to 90° with 1° step resolution.
There is a crossing behaviour between the 4th and the 5th modes followed by a veering behaviour between the 4th and the 6th mode (Figure 5, left). Modes are numbered considering the first configuration, i.e. 0°, as reference.
Experimental identified data (black dots) are in good agreement with the numerical model. Moreover, the MAC matrix for the pinpointed regions (Figure 5, right) are computed.
In the first case the MAC index shows a very high correspondence between the 4th mode of the 68° configuration and the 5th mode of the 69° configuration and vice versa. The mode shapes plot confirms this result, The involved mode are torsional and bending modes.
In the second case the interesting zone is between the 5th mode of the 72° configuration and the 6th mode of the 81° configuration. The correlation is not as high as in the previous case and there is still a correspondence between a mode and itself in the two configurations. This is a typical veering MAC layout, and the mode shapes plot confirms that even if the two frequency curves do not reach a contact point, the mode shapes are exchanged. The phenomenon is between two bending modes of two different orders.

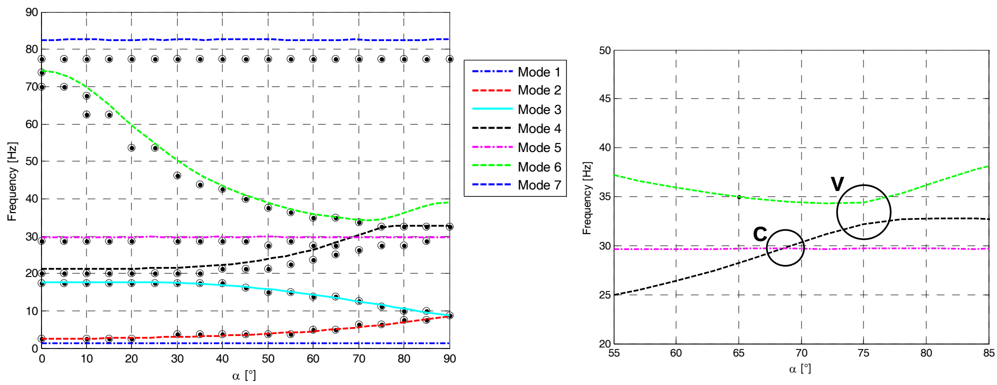

Figure 5. Natural frequency vs rotation angle (left), crossing and veering region detail (right)

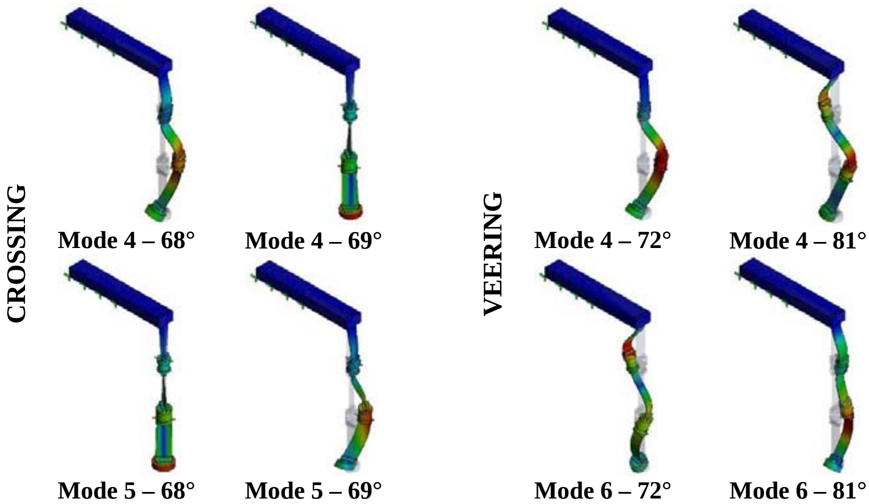

Figure 6. Mode shapes in the crossing (left) and veering region (right)

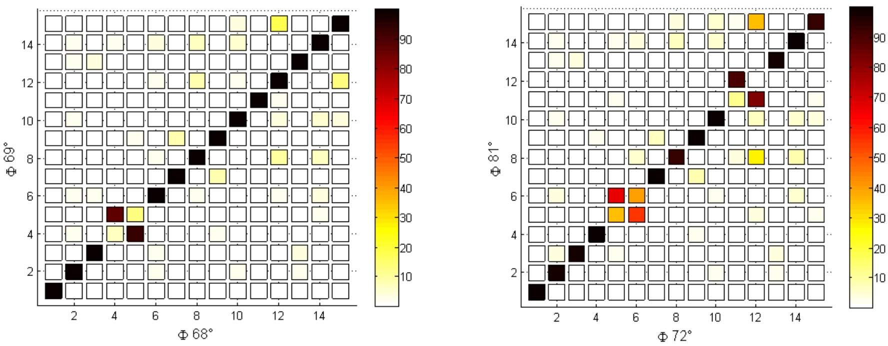

Figure 7. MAC coefficient for the crossing region (left) and veering region (right)

A CAD/CAE platform that implements the possibility of developing macros allows to build powerful tools that could represent an important feature in the optimization step of a project.
A dynamic analysis is not the only type of study that can be performed but little modifications to the macro code can implement any other analysis available on Solidworks with the possibility to store all the possible results according to the study type.

6. REFERENCES

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