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ROTATIONAL DEGREES OF FREEDOM: AN INVESTIGATION OF THEIR INFLUENCE ON THE PREDICTION OF THE DYNAMIC BEHAVIOUR OF A COUPLED STRUCTURE

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1. INTRODUCTION

If the prediction of the dynamic behaviour of a coupled structure is under examination, the substructuring techniques can be used. These methods overcome the majority of the problems encountered during the application of the analytical modeling and the modeling through the experimental approach [1-4], since they make direct use of the measured frequency response functions of the individual substructures. However, despite all the promising features of these methods as well as the fact that the mathematical formulation of the substructure techniques is well established, it is common the coupling predictions to fail to give acceptable results. One of the main reasons is the incompleteness of the measured data which stems from the difficulty to obtain excitation and response measurements at the Rotational Degrees of Freedom (RDOFs). This paper investigates the influence of the rotational degrees of freedom in a laboratory assembly through finite element simulations. The presentation of the work is organised as follows: Firstly, a basic theoretical background is given. Afterwards, the experimental procedure is briefly described. The main part of the present work is comprised of the FE simulations where the RDOFs are taken into account. An analysis of the retrieved results is made (performance of predictions) and a comparison of the behaviour of the FE calculated results and the measured results take place. The conclusions which are obtained from the analysis, are explained in physical terms through the modes of the involved structures.

2. BASIC THEORY

Consider two components (A and B) which are coupled together at s interconnection points in order to form a new structure (C). The FRFs of the coupled structure can be calculated by means of the following equations [5]:

If both DOFs i and j are on substructure A :

$$H_{C_{ij}} = H_{A_{ij}} - \lfloor H_A \rfloor_{iS} \left([H_A]_{SS} + [H_B]_{SS} \right)^{-1} \{H_A\}_{Sj} \qquad \text{(Eq. 1)}$$

If both DOFs i and j are on substructure B

$$H_{C_{ij}} = H_{B_{ij}} - \lfloor H_B \rfloor_{iS} \left([H_A]_{SS} + [H_B]_{SS} \right)^{-1} \{H_B\}_{Sj} \qquad \text{(Eq. 2)}$$

If DOF i is on the substructure A and DOF j on the substructure B :

$$H_{C_{ij}} = \lfloor H_A \rfloor_{iS} \left([H_A]_{SS} + [H_B]_{SS} \right)^{-1} \{H_B\}_{Sj} \qquad \text{(Eq. 3)}$$

Finally, if DOF i is on the substructure B and DOF j on the substructure A:

$$H_{C_{ij}} = \lfloor H_B \rfloor_{iS} \left([H_A]_{SS} + [H_B]_{SS} \right)^{-1} \{H_A\}_{Sj} \qquad \text{(Eq. 4)}$$

Obviously, for the coupling points, each of the above formulations is valid. In the present research, investigations concerning only the coupling points are carried out, and during the predictions of the dynamic behaviour of the coupled structure equation (3) is used.

3.EXPERIMENTAL PROCEDURE

Test Structure

The test structure on which the measurements and the simulations were performed is depicted in Fig.1. The connection between the two components was feasible through three foreseen connecting flaps. A very strong structural glue was used, in order to achieve a coupling as rigid as possible. In order the free-free boundary conditions -under which the measurements were obtained- to be simulated, the structures were suspended by soft shockcords [6].

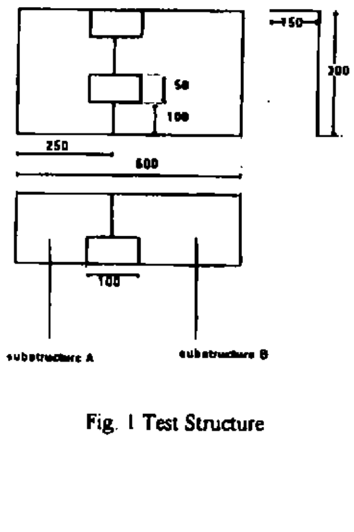

Fig. 1 Test Structure

Measurements
The FRFs at the points on the coupling interface were measured for both substructures and the coupled structure. The latter is used as a base of comparison with the results which are derived from the prediction formulae. The excitation, that was used, was the roving-hammer type of excitation. As far as the direction of the measurements is concerned, only the orthogonal vibration pattern to the plane was measured for each point, since the other patterns were negligible compared to the orthogonal one. A complete description of the experimental procedure can be found in [6].

Quality of Measurements. Reciprocity tests were carried out and gave very good results for both substructures, as well as for the coupled structure. Furthermore, the position of the natural frequencies was found to be stable. Finally, the peaks at the natural frequencies were sharp, something that is a direct consequence of the fact that the structure under examination was very lightly damped.

4. INVESTIGATION OF THE EFFECT OF THE ROTATIONAL DEGREES OF FREEDOM IN THE PREDICTION OF THE DYNAMIC BEHAVIOUR OF A STRUCTURE

In Fig. 2, a comparison between a directly measured FRF of the coupled structure and the one derived by means of Eq. 3, using measured FRFs of the substructures, is depicted.

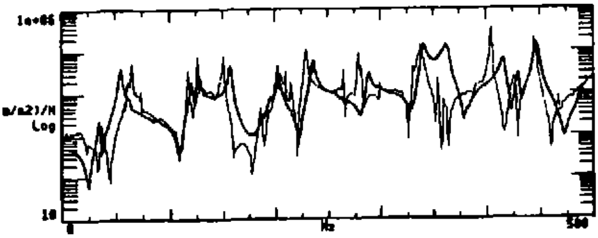

Fig 2. Thick line : measured FRFs of the coupled structure
Thin line : synthesized FRFs of the coupled structure using measured FRFs of the substructures

The results reveal differences, as far as the correspondence of relative peaks is concerned. Specifically, a negative frequency shift is observed at a number of peaks. Finite element simulations were performed, in order to investigate the influence of the RDOFs on the predictions. It must be mentioned here, that as far as the translational degrees of freedom (TDOFs) are concerned, only the ones that were used during the experimental procedure were taken into account in the simulations.

In Fig.3 two plots are given using numerically (FE analysis) calculated FRFs of the two substructures and the coupled structure. From the upper half, where only the TDOFs were taken into account, a behaviour similar to the one that was observed when experimental data were used, can be shown. In the lower half all the RDOFs were included. Apparently, there is a much better match between the compared FRFs. However, two new problems arose. The first problem concerns the appearance of some new peaks at the lower frequencies. A close investigation of the effect that each rotational degree of freedom has on the predictions, proves that the appearance of the majority of the new peaks can be attributed to the additional rotational information which are introduced in the predictions. The remaining peaks are believed to be a by-product of the direct inversion which is used during the application of (Eq. 3) [7].

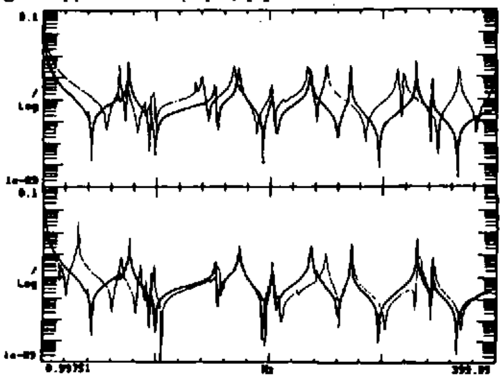

Fig.3 : Thick line : FRFs of the coupled structure (FE simulations)
Thin line : (upper) synthesized FRFs using TDOFs (FE simulations)
(lower) synthesized FRFs using TDOFs & RDOFs
(FE simulations)

The second problem is about the fact that some peaks are not any more so well predicted when RDOFs are included. An interpretation is sought through the extraction of the modes of the coupled structure and the substructures. Particularly, two representative cases are chosen to be investigated. In one case, better predictions are achieved while in the other case, the predictions are worse when the RDOFs are included. As a "good" example, the peak that exists at the 171.91 Hz is examined. By examining the modes of the two substructures a mode of substructure A at 166.73 Hz and one at 176.58 Hz for the substructure B can be found. By observing the modes of the two substructures and of the coupled structure, it becomes apparent from the motion of the coupling points that these are in phase. Furthermore, it can be seen that these modes are neither pure translational nor pure rotational modes. This fact provides an explanation to the improvement which is observed in the predictions when RDOFs are used [7].

As a "bad" example, a peak that is placed at 235.73 Hz is investigated. Obviously, the prediction of this peak is becoming worse when RDOFs are included (Fig. 3). A detailed examination of the effect that each rotational degree of freedom has on the predictions, proves that the responsible RDOF for the movement of the predicted peak is the rotation around the Y-axis. This observation leads to the following explanation : when the two substructures are coupled, the rotation around the Y-axis is eliminated for the points that belong at the coupling interface. Taking also into consideration that the mode of the coupled structure is a pure translational, Fig. (4), then it can be claimed that by inserting the rotation around Y the results are distorted [7].

Finally, from Fig.(3) it becomes apparent that two new peaks are introduced in the adjacent area of 235.73 Hz during the predictions. One at 226.28 Hz and one at 241.00 Hz. A close study reveals the following : In the first case, there is a mode at i.e. 226.28 Hz which becomes evident when the motion of the coupling points in the Y-direction is considered. However, this mode has not have a component in the Z-direction which is shown in Fig.3 As far as the second peak is concerned (241.00 Hz), it is claimed that is a false one produced by the direct inversion, since no mode of the coupled structure found to be located at this frequency.

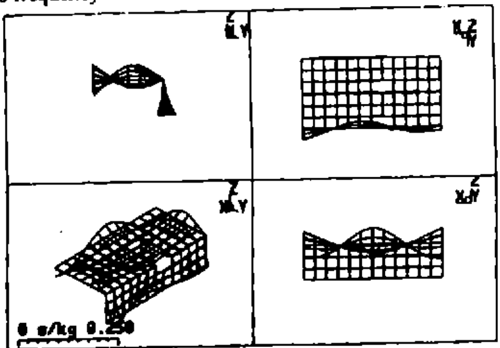

Fig. 4 Mode of the coupled structure at 235.73 Hz

5. ACKNOWLEDGMENT

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