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ANALYSIS IN MEDIUM FREQUENCY RANGE USING THE FINITE ELEMENT METHOD

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ABSTRACT
The paper presents the new approach to the modal analysis in medium frequency range. This method is specially dedicated for large complex mechanical systems where classical numerical modal analysis is not applicable due to number of elements. Presented method relay on subdivision of large model into several subsystems and finding the interactions between systems from the measurements. For definition of parameters of interaction between subsystems the results derived from Transfer Path Analysis are used. On these subsystems are done the analysis using the FE method. The new approach leads to much faster and hence increased productivity in modelling and analysis of mechanical systems specially in case of model updating. Concepts are illustrated using real-life examples of investigation of elements of helicopter structure.

1 - INTRODUCTION
The presented work is the part of wider problem connected with modal analysis done by the numerical and experimental methods. It is obvious that most often method used in numerical modal analysis is the Finite Element method. Integration of experimental and numerical methods gives wide possibilities of analysis of mechanical behaviour of complex structures. The case of special interest are the modal model updating for further numerical analysis, virtual prototyping, structural modification and sensitivity analysis. The restrictions of Finite Element method due to computational possibilities (computer memory and speed of calculations) can be omitted by the division of large structures into subsystems and finding the interaction parameters such as forces and accelerations. These parameters can be measured if possible or find indirectly with the aid of Transfer Path Analysis method (TPA). This method spreads the application of FE method to the higher frequencies and gives the promising increase of productivity in modelling and analysis of mechanical systems. The presented work does not give the exact solution but shows the way of analysis helped with experiment. Method is specially dedicated for the cases when the experiment is possible. The given below analysis of the problem and example shows the possibilities of application of TPA to the estimation of interaction parameters between subsystems modelled by the FE method even in case of use of incomplete sets of data originating from experiments and numerical simulations.

2 - APPLICATION OF TRANSFER PATH ANALYSIS TO INTERACTION PARAMETERS ESTIMATION FOR FINITE ELEMENT METHOD MODELLING
In the industrial practice usually forces acting within structural connection of the tested object may not be measured directly due to technical complexity as well as cost of such a measurement. That is why the forces F_i are to be estimated basing on operational measurement of the system response accelerations a_j to the unknown operational forces for the structural properties of the tested object at the considered set of points described by accelerance FRFs H_{ij} defined for pairs of measuring directions (i, j =1, 2,..., n).

$$\begin{bmatrix} a_1 \\ \vdots \\ a_n \end{bmatrix} = \begin{bmatrix} H_{11} & \dots & H_{1n} \\ \vdots & \ddots & \vdots \\ H_{n1} & \dots & H_{nn} \end{bmatrix} \begin{bmatrix} F_1 \\ \vdots \\ F_n \end{bmatrix} \tag{1}$$

Formula (1) shows that knowledge of the full accelerance FRFs matrix as well as matrix inversion are necessary for operating force spectra estimation. Usually, like for the considered helicopter, only a single column (verse) of the FRFs matrix is known from experiment. The other elements might be synthesised basing on the identified experimental modal model. This approach was used in the presented example. Furthermore sometimes location of an operating measurement point does not coincide with the location of the assumed transfer path due to its inaccessibility (this problem is not addressed in the presented example). In such a case application of the finite element model, that was updated to the experimental results, seems to be the best solution.
Result of inversion of the FRFs matrix is sensitive to the numerical conditioning, which in turn depends on both the measuring data quality and measuring points/directions selection. Thus obtaining of the credible results requires some expertise in vibration testing and performing of a set of analyses in order to assure acceptable repeatability.

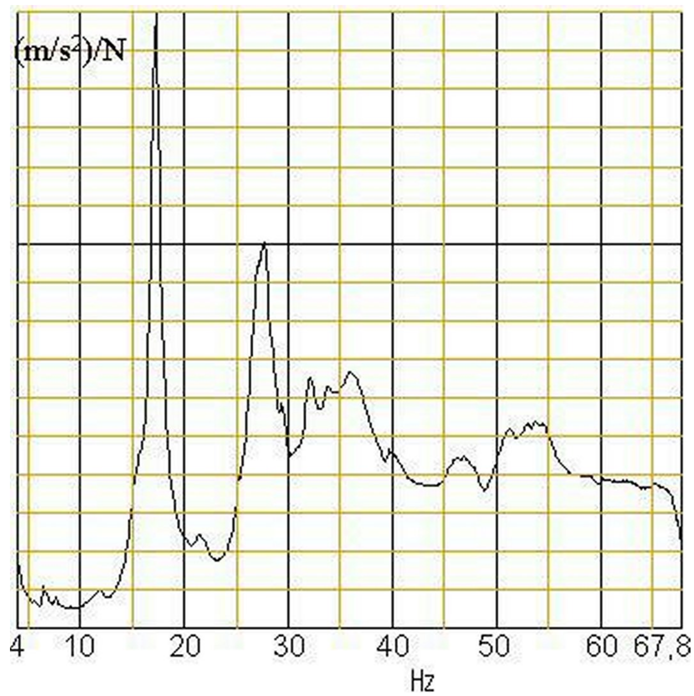

Figure 1: Plot of a weighted sum of amplitude of the measured FRFs.

3 - CASE STUDY - TRANSFER PATH ANALYSIS FOR HELICOPTER FUSELAGE

The aim of the carried out simulation was to show practical difficulties that might be encountered during vibration energy transfer analysis. Example of a helicopter fuselage vibration analysis was chosen for presentation. Ground modal testing [1] of the helicopter fuselage was performed in the frequency range of 4-67.875 Hz. Single excitation with use of electrodynamic shaker was applied to the helicopter suspended above the testing room floor by the main rotor mast (shaft) tip. The measuring point net of 287 points (in each point response acceleration in 3 mutually perpendicular directions was measured) was used.
Operational data (acceleration) was measured during flight in 30 measuring points 3 measuring directions for 10 flight conditions [2]. For further analysis climbing with take-off power data were used.
In the analysis it was assumed that 4 points located in the vicinity of main gearbox attachment to the fuselage and a single point located near tail rotor hub assembly area, denoted by a circle in Fig. 2, correspond to considered vibration energy transfer paths from the rotors to the fuselage. As the target point and direction the vertical vibration under pilot's seat was selected.
Fig. 3 shows an example of vibration acceleration spectrum amplitude plot measured during flight. Local maxima corresponding to polyharmonic excitation components dominate the presented spectrum amplitude plot. Rigid connection of the main gearbox and tail rotor hub assembly structure to the fuselage was assumed. Determination of the contribution of the considered 15 transfer paths (5 points times 3 directions in each point) to the response at target point and direction requires knowledge of: FRF between each transfer path and target direction and spectra of forces acting in each transfer path.

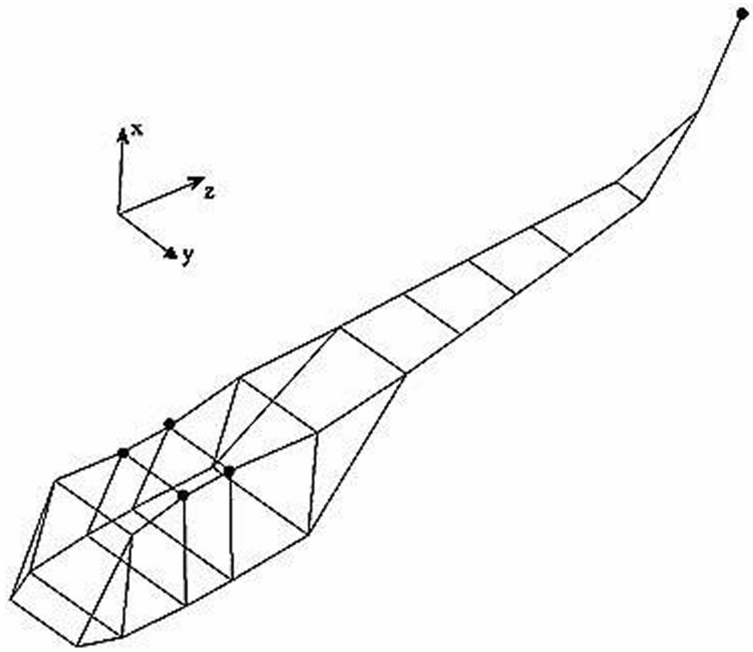

Figure 2: Measuring point net used during operational (flight) vibration testing; circles denote assumed assembly points of the main gearbox and tail rotor.

In the presented example Transfer Path Analysis module of LMS CADA-X software package was used [3]. The obtained results are presented in the following figures.
Fig. 4 shows an example of force spectrum amplitude calculated for a single transfer path. The above plots are dominated by amplitude components corresponding to the first and forth harmonic of rotational speed of the main rotor, what is justified for the considered helicopter rotor design (4 blade main rotor).

In Fig. 5 contribution of the amplitude corresponding to a single transfer path (solid line) to the summed amplitude of acceleration response of all the considered paths (dotted line) in the target point and direction in the whole frequency range is presented.

4 - CONCLUSIONS

Presented example case study shows that experimental results might be in practice insufficient for vibration energy transfer path analysis. When a credible experimental modal model and a convergent finite element model are available for the considered object, that complies with modal modelling assumptions, both the models might be used concurrently to complete the data set required for transfer path analysis purpose. Care should be taken as inaccuracies of measurement results and finite element modelling as well as numerical problems (eg. matrix inversion numerical ill-conditioning) might lead to erroneous results. That is why further investigations leading to formulation of objective algorithms of vibration energy transfer analysis that make use of incomplete sets of data originating from experiments and numerical simulations are needed.

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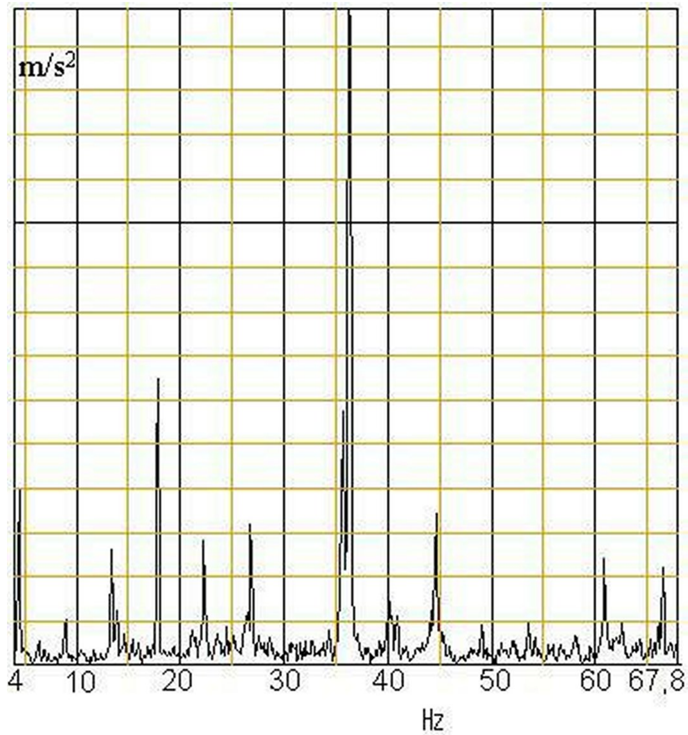

Figure 3: Example of amplitude of vibration acceleration spectrum measured during flight.

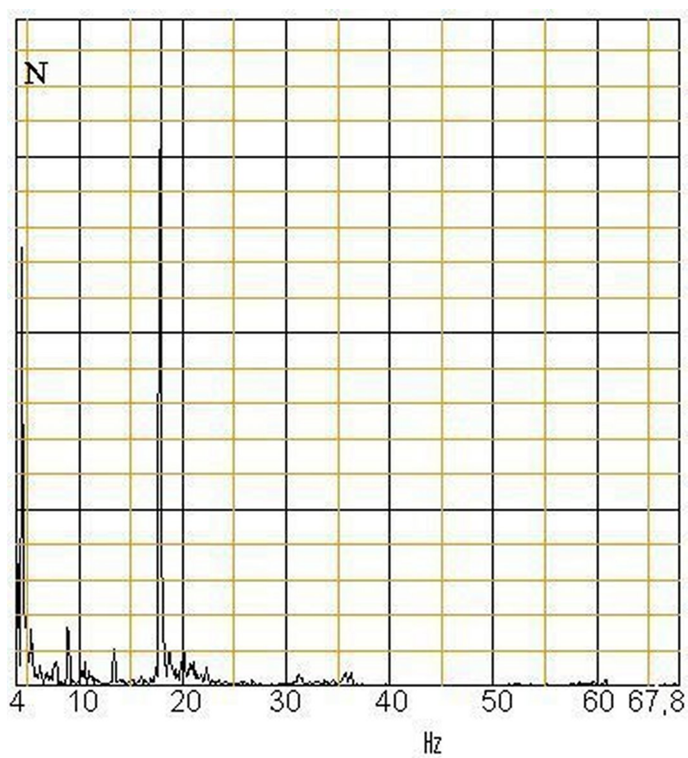

Figure 4: Example of estimated spectrum amplitude for a single transfer path.

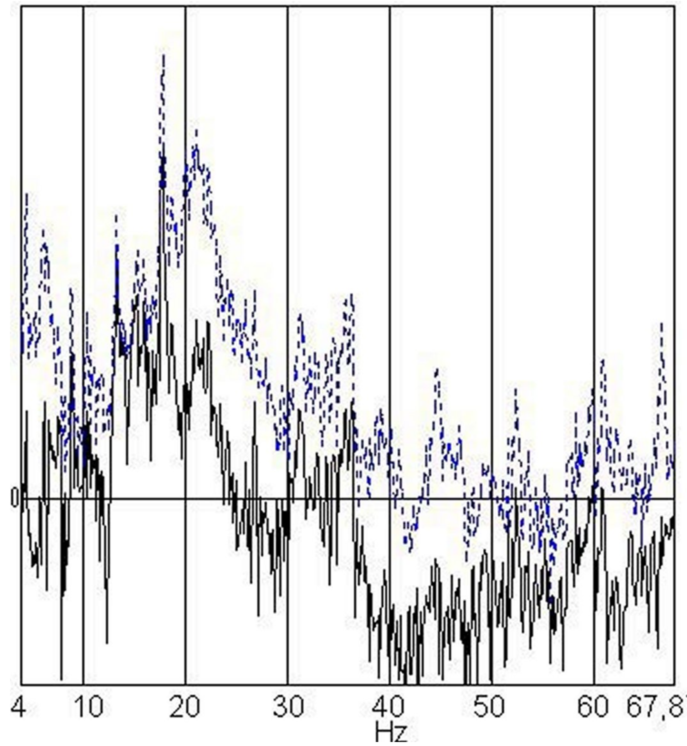

Figure 5: Contribution of amplitude of one transfer path (———) to summed amplitude of acceleration response of all considered paths (— — —) at the target point and direction in whole frequency range.

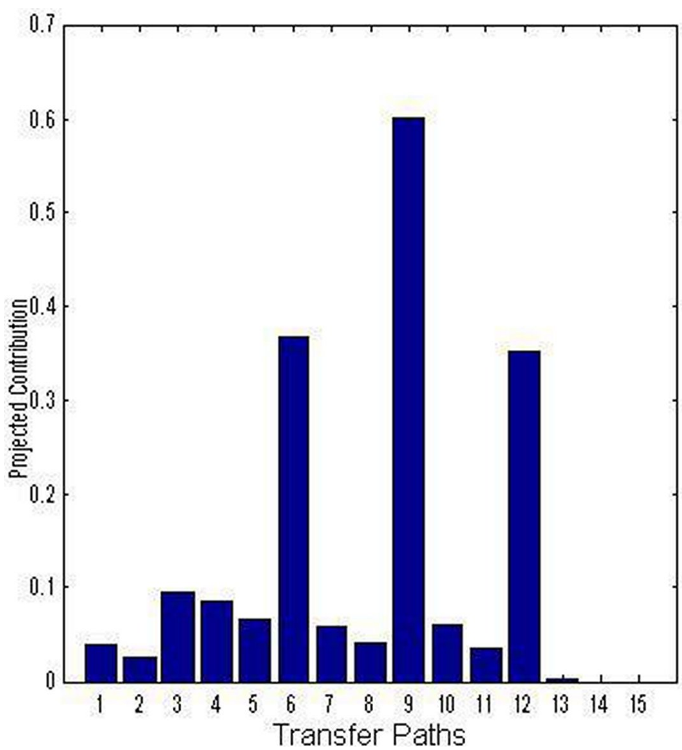

Figure 6: Example of the projected contribution of transfer paths to response amplitude (normalised to 1) at target direction for a single frequency value.