Uncertainty Assessment in Acoustics by Using Boundary Element Simulation and Fuzzy Arithmetic

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Introduction

Uncertainties in radiated sound fields may result from uncertain parameters in vibrating structures as well as from uncertainties in the acoustic domain. In the following, the influence of uncertain parameters on the acoustic field of a vibrating structure is analyzed for the example of the radiated sound from a stiffened cylindrical shell (Fig. 1). In the simulation, a combination of finite element method (FEM) for the structural domain and boundary element method (BEM) for the acoustic domain is used for the analysis, both are embedded into a fuzzy-arithmetical scheme for the uncertainty assessment.

Modeling Uncertain Sound Radiation

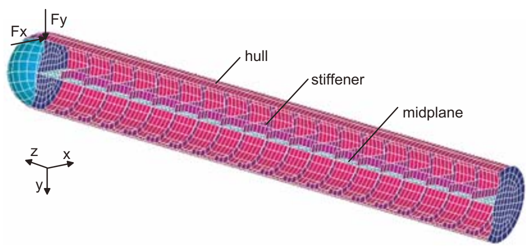

Figure 1: FE model of the test structure by ANSYS.

The FEM is employed to model the structural dynamics in an harmonic analysis whereas a Fast Multilevel-Multipole boundary element method is used to compute the acoustic field. The structure is excited by monofrequent forces, F_x and F_y, as shown in Fig. 1. Weak structural damping is considered by assuming Rayleigh damping. Uncertain parameters are modelled by fuzzy numbers. In the structure, they include the wall shell thickness and the driving frequency of the point load (Fig. 2). In the acoustic domain, the air density and the sound velocity are assumed to be uncertain.

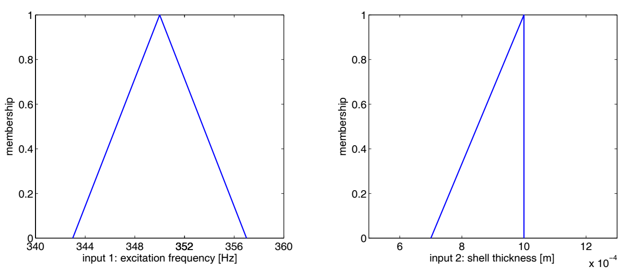

Figure 2: Fuzzy number representation of parameters.

Simulation procedure

For the fuzzy uncertainty analysis, the academic software package `FAMOUS` is extended to be applicable to the presented structural acoustic simulation problem. The use of fuzzy arithmetics in combination with appropriate transformation methods allows to recast the problem into subsequent analysis steps with usual crisp number arithmetics [1]. It is worth noting that the uncertain parameters represented by the fuzzy parameters affect both the structural and the acoustic simulation. The basic interaction between the applied simulation tools is illustrated in Fig. 3.

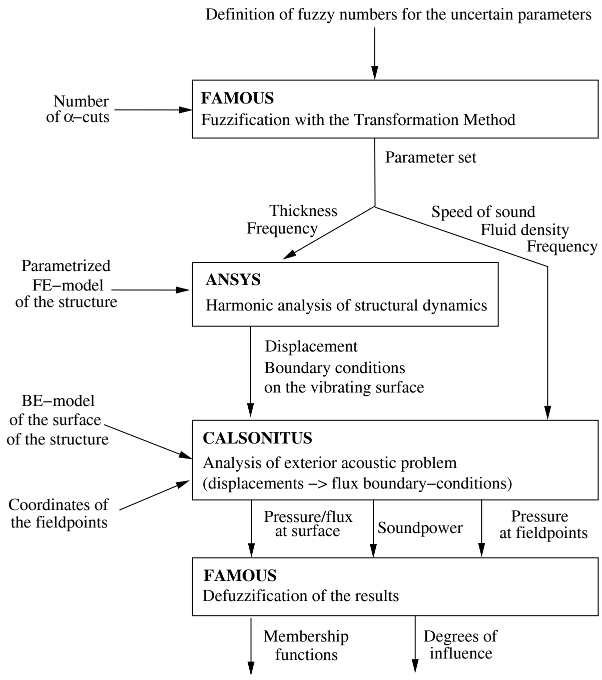

Figure 3: Flowchart of the proposed FuzzBEM-approach.

For the investigated problem, the BEM calculation conducted by the academic software `CALSONITUS` uses the results of a harmonic FEM calculation with `ANSYS` as boundary data. Hereby, the FEM and BEM models are parameterized in accordance with the defined fuzzy input numbers and the chosen number of membership levels, i.e. α-cuts. The FEM calculation yields the complex surface displacements at the outer surface of the shell structure for the given excitation frequency. These results are used as Neumann boundary data for the subsequent BEM calculation to obtain the resulting sound field.

Results

As output quantities, the acoustic pressure at chosen field points of interest and the radiated sound power are considered as fuzzy output numbers. The nominal sound field is depicted in Fig. 4.

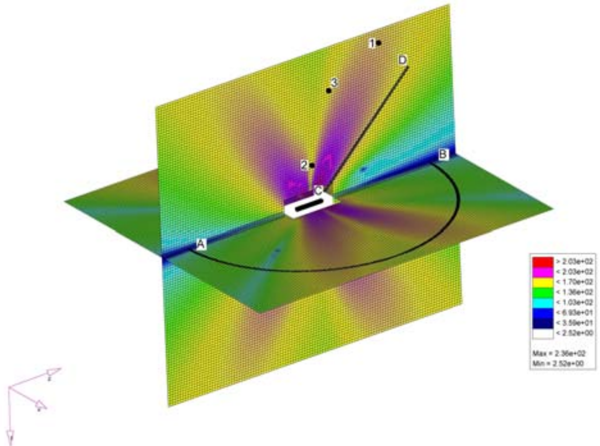

Figure 4: Location of the fuzzy-evaluated field points and sound field due to the vibrating benchmark structure for the nominal parameter combination.

The obtained fuzzy output numbers are depicted in Fig. 5. They include sound pressure levels (SPL) at the discrete field points 1-3 as well as the overall radiated sound power. The worst-case deviations are noticeable on the dB-scales. This is due to the fact that the structure may be excited close to resonance frequency for some parameter combinations. It is not guaranteed that the largest (worst) SPL or sound power is included without an internal search of the extreme parameter combination. This becomes even more obvious when looking at a comparison of the sound power level between the results obtained by the generalized transformation method and the reduced transformation method [1] as shown in the right graph of Fig. 5. The reduced transformation method clearly underestimates the worst-case scenario, since the analysis does not include as many parameter combination as the general transformation method, and tends to lose important information about the system dynamics. As a result, it becomes obvious that the detection of the lower and upper bounds for all parameter combinations requires an internal optimization loop. A fuzzy directivity patters (Fig. 6) shows the SPL at field points on the circle line A-B indicating main and side lobes of the radiated sound field.

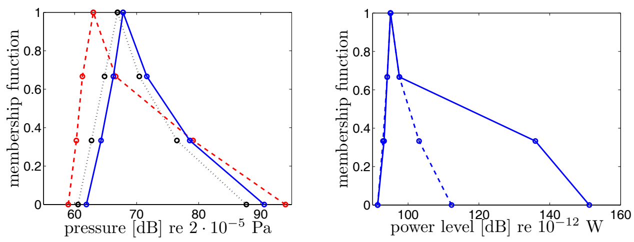

Figure 5: Membership functions of fuzzy acoustic pressure (left): field point 1 (-), point 2 (- -), point 3 (. . .). Membership function of the radiated sound power (right)

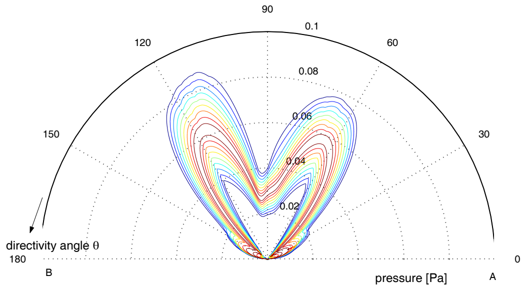

Figure 6: Directivity pattern of the fuzzy acoustic pressure along half circle line AB indicating main lobes.

Figure 7 shows the normalized degrees of influence. Here, the driving frequency has the most significant influence. The shell thickness of the structure has the second largest influence on the results.

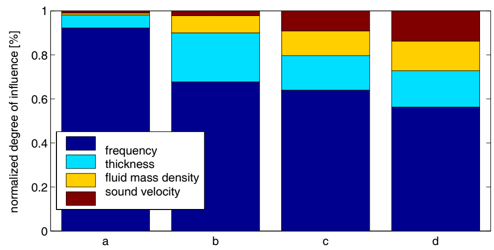

Figure 7: Normalized degrees of influence.

Conclusions and Further Applications

Engineering knowledge can be used for the parameterization of the fuzzy input numbers representing the uncertain design parameters of the model. Although standard sensitity analysis is more efficient than fuzzy analysis with respect to model evaluations, it gives only sensitivities at a chosen local nominal point in the parameter space. On the other hand, compared to probabilistic methods (e.g. Monte-Carlo), the fuzzy arithmetic approach strongly reduces the usually high number of model evaluations. Furthermore, the model evaluation time is strongly reduced from 104 hours to 30 hours by making use of the fast-multipole BEM [2] for the solution of the acoustic problem.
Due to the highly nonlinear relationship between input parameters and assessed output variables, it is found that the full transformation method must be used in order to obtain appropriate estimates of the fuzzy output numbers which is in agreement with the underlying fuzzy analysis theory [1]. Due to the discretization by the transformation method, it cannot be guaranteed that the maximum output value of a certain output number over the whole input parameter range is found. This necessitates finer fuzzy number discretization or future research towards special treatment of worst–case scenarios.

References

[1] Hanss, M.: Applied Fuzzy Arithmetic – An Introduction with Engineering Applications, Springer, Berlin, 2005.

[2] Fischer, M.: The Fast Multipole Boundary Element Method and its Application to Structure–Acoustic Interaction. Bericht aus dem Institut A für Mechanik, Universität Stuttgart, 2004.