Experimental and numerical acoustic modal analysis of a hydroacoustic testbasin

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Introduction

Experimental modal analysis is the process of extracting modal parameters from measured transfer functions. In the discipline of mechanical structural dynamics, experimental modal analysis is widely used. The applied methods and technical tools are mature: a variety of mathematical methods to identify modal parameters from damped structural responses are available; and, users can choose from a diversity of technical equipment in order to conduct an experimental modal analysis. Conversely, for an acoustic system, especially a hydroacoustic system, sound pressure can only be reliably measured using a microphone/hydrophone. The measurement of the volume velocity is very difficult. In this paper a procedure for measuring the volume velocity is described. The procedure involves measuring the input signal from the acoustic source and identifying the eigenfrequencies and the associated acoustic modes. A final verification of the measured results with a finite element model shows an excellent agreement between both results.

Acoustic modal analysis

Starting with the governing equation for a closed three dimensional acoustic one can show, that the acoustic transfer impedance with residues r_{kl} and eigenvalues λ_i

$$Z_{kl}(\omega) = \frac{p_k(\omega)}{q_l(\omega)} = j\omega \sum_{i=1}^{n} \frac{(r_{kl})_i}{j\omega - \lambda_i} + \frac{(r_{kl})_i^*}{j\omega - \lambda_i^*} \qquad (1)$$

is similar to that defined in structural dynamics [1, 2]. The customary structural analysis methods and software packages can therefore be used in the current acoustic analysis without modification.

The above considerations lead to an experimental technique for extracting the modal parameters of an acoustic cavity from FRF measurements where the sound pressures across the volume are referenced to the volume velocity of the source. The pressure p can be measured reliably by a hydrophone, but the volume velocity source causes difficulties for hydroacoustic measurements. An excitation source can be a loudspeaker having a sealed housing behind its diaphragm. A good reference signal for the volume velocity can be derived by measuring the pressure in the back cavity of the loudspeaker with a microphone [1]. This concept has one practical drawback: making the back cavity accessible for measurements will destroy the sealed housing and proper operation of the watertight loudspeaker is therefore questionable. Nevertheless, if only modal frequencies and corresponding modeshapes are of interest and a correct modal model is of no importance, a simple loudspeaker can be used as the volume velocity source. The reference signal can be taken directly from the input clamps of the loudspeaker [1]. It must be pointed out that the loudspeaker itself becomes now an element in the hydroacoustic system under investigation, and any resonance of the loudspeaker appears in the analysis as a supplementary mode which has to be distinguished from the acoustic modes.

Experimental setup

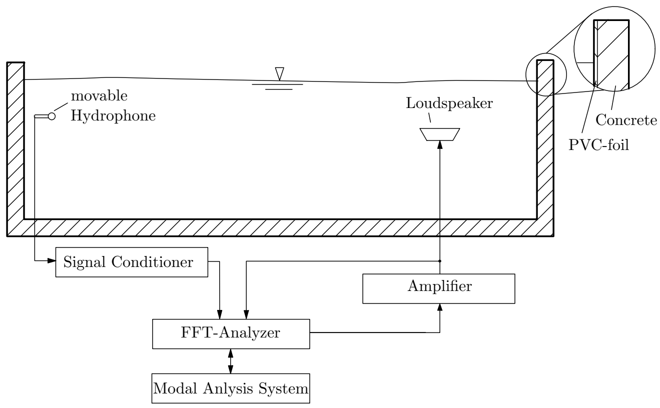


Figure 1: Experimental setup for the modal analysis of the hydroacoustic basin

Figure 1 shows schematically the experimental setup and instrumentation. The system under investigation is a (6.6 m x 3 m x 1.35 m) hydroacoustic testbasin having 25 cm thick concrete sidewalls. Three sidewalls and the basin floor are in direct contact with the building foundation, and the remaining sidewall is free. The concrete walls are lined with a 1.5 mm thick PVC-foil in order to guarantee impermeability. A loudspeaker is placed in the hydroacoustic basin, and the signal at the input clamps is used as a measure of the volume velocity. Figure 2 shows the transfer function between the input voltage and the velocity of the diaphragm of the loudspeaker. The FRF has only one broad maximum at 950 Hz, and therefore it is possible to obtain the eigenfrequencies and associated eigenmodes of the hydroacoustic basin below 950 Hz without having to account for supplementary modes from the loudspeaker. The pressure responses are measured at the center basin depth at 63 locations with 9 and 7 measuring stations along the length respectively

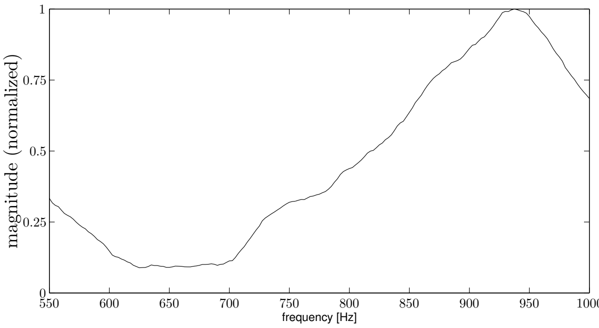


Figure 2: FRF of the loudspeaker

the width of the basin. 20 averages are taken for each transfer measurement to assure good spectral estimation over 0–1 kHz with a frequency resolution of 0.27 Hz. Figure 3 shows the transfer function at a single measurement location. Sharp peaks in the FRF plot correspond to eigenfrequencies of the enclosure. Using all measured acoustical FRFs, a modal analysis is performed with ME'scope®. The experimentally determined eigenfrequencies are summarized in Tab 1 and compared to finite element predictions.

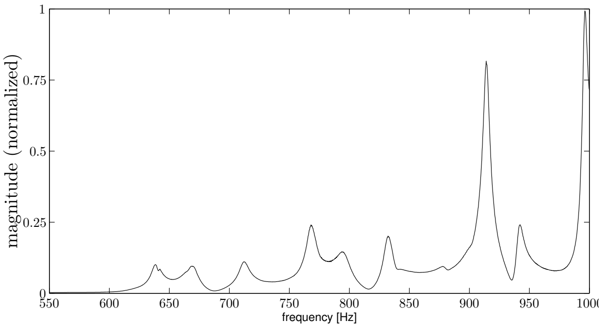


Figure 3: Measured FRF for one hydrophone station

Finite Element Model

A numerical model of the hydro-acoustic basin is developed with the commercial finite element tool Ansys®. The walls of the hydro-acoustic-basin are discretized with solid45 elements and layered solid46 elements. The layered elements are used to model the thin PVC foil. The water is discretized with the acoustic fluid30 elements and the fluid-structure interaction at the boundary is taken into account. The model contains 13132 dofs. A modal analysis yields the eigenfrequencies and the eigenmodes. Results of the finite element analysis are presented and compared to the measured results below.

Results

Tab. 1 compares measured and simulated eigenfrequencies. The associated eigenmodes are presented in Fig. 4. The acoustic modes are described by two integers which indicate the number of pressure maxima along the length and width of the basin. There is a good agreement between experiment and simulation. Sources of error in the

Mode	f_{meas}[Hz]	f_{sim}[Hz]	error [%]
(1,1)	638.0	641.8	0.59
(2,1)	669.0	666.2	-0.42
(3,1)	712.0	706.6	-0.76
(1,2)	768.0	763.5	-0.59
(2,2)	796.0	785.0	-1.38
(3,2)	832.0	820.0	-1.44

Table 1: Comparison of measured and simulated eigenfrequencies for the hydroacoustic basin

simulation include inaccurate material properties and the idealization of the basin geometry.

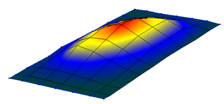
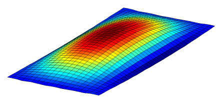
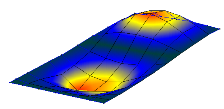
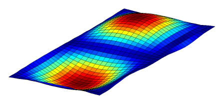
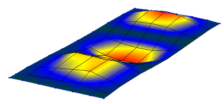
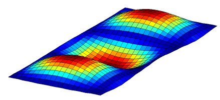
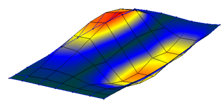
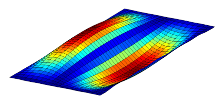
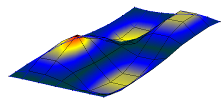
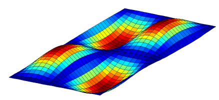
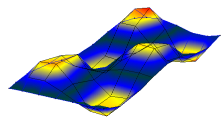
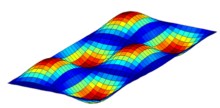
Mode	Measured	Simulated
(1,1)		
(2,1)		
(3,1)		
(1,2)		
(2,2)		
(3,2)		

Figure 4: Comparison of measured and simulated eigenmodeshapes of the hydroacoustic basin

References

[1] Sas, P.; Augusztinovicz, F.: Acoustic Modal Analysis. In: Modal Analysis and Testing, ed. by J. Silva and N. Maia, 487- 506, NATO Science Series, 1999

[2] Kung, C.; Singh, S.: Experimental modal analysis technique for three dimensional acoustic cavities, *J. Acoust.Soc.Am.* **77** (1985), 731-738