Three-way flexible cantilever probes for static contact

In micro four-point probe measurements, three-way flexible L-shaped cantilever probes show significant advantages over conventional straight cantilever probes. The L-shaped cantilever allows static contact to the sample surface which reduces the frictional wear of the cantilever tips. We analyze the geometrical design space that must be fulfilled for the cantilevers to obtain static contact with the test sample. The design space relates the spring constant tensor of the cantilevers to the minimal value of the static tip-to-sample friction coefficient. Using an approximate model, we provide the analytical calculation of the compliance matrix of the L-shaped cantilever. Compared to results derived from finite element model simulations, the theoretical model provides a good qualitative analysis while deviations for the absolute values are seen. From a statistical analysis, the deviation is small for cantilevers with low effective spring constants, while the deviation is significant for large spring constants where the quasi one-dimensional approximation is no longer valid.

Investigation of internal feedback in hearing aids

There are many aesthetics and structural design requirements to modern hearing aids and their size has been reduced considerably during the last decades. This has led to designs where the receiver (loudspeaker) and microphones are placed closely together. As a consequence, problems with vibroacoustic transmission from the receiver to the microphones often occur during the use of hearing aids. This transmission causes feedback at certain critical gain levels where it produces a loud uncomfortable squealing. Consequently feedback often constitutes the limiting factor for the maximum obtainable gain in the hearing aid and it therefore represents a critical design problem. Feedback in hearing aids is usually divided into external and internal feedback. External feedback is caused by the leakage of sound from the ear canal whereas internal feedback is due to transmission of sound and vibrations internally in the hearing aid. As a result of reducing the size of hearing aids, manufacturers have experienced an increase in internal feedback problems. The main objective of the present thesis is therefore to examine the vibroacoustic mechanisms responsible for internal feedback in hearing aids. This is approached by the development of a full vibroacoustic 3D-model of a so-called “behind the ear” hearing aid manufactured by Widex A/S. The 3D-model is developed using finite element analysis and it is capable of...
simulating the so-called "open-loop" transfer functions. These open-loop transfer functions relate the microphone output voltages and the receiver driving voltage when the receiver and microphones are electrically disconnected. The main scientific part of the thesis consists in the study and extension of a relatively recent method. This method is the "Theory of fuzzy structures" and it is intended for predicting the vibrations of a deterministic "master" structure with one or more attached complex "fuzzy" substructures with partly unknown dynamic properties. An important part of the theory regarding the modeling of fuzzy substructures attached to the master through a continuous interface is thoroughly examined and reformulated in a more simple form. Such fuzzy substructures are modeled by including spatial memory in the fuzzy boundary impedance. The main effect of an attached fuzzy substructure is the introduction of high damping in the vibration response of the master structure, but, it is shown that spatial memory reduces this damping. The method of including spatial memory is hereafter extended such that it also comprises modeling of fuzzy structures with a two-dimensional interface. Furthermore, a novel experimental method for estimating the fuzzy parameters of complex substructures is developed by the author. Using this method the damping of the structural fuzzy is estimated and the fuzzy parameters are subsequently derived. The developed method is finally utilized for estimating the fuzzy parameters of certain internals in the considered hearing aid. The estimated fuzzy parameters are experimentally validated and they reveal a high spatial memory in the fuzzy boundary impedance. Different methods are used for determining the properties of the remainder components in the hearing aid. The determined properties include the stiffnesses of the rubber suspensions, vibration forces of the receiver and the vibration sensitivity of the microphones. Moreover, the sound pressure in the tube system from the receiver to the ear canal is simulated and validated experimentally. All the determined properties including the fuzzy parameters are incorporated into the full 3D-model. Simulated results for the open-loop transfer functions show good agreement with measurements on the hearing aid considered. By analyzing the simulations results, it is revealed that feedback is caused by local pressure generated by the vibrations of the shell close to the microphone inlets. These vibrations are mainly caused by the reaction forces from the high pressure in the tube system of the hearing aid.

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**Simple vibration modeling of structural fuzzy with continuous boundary by including two-dimensional spatial memory**
Many complicated systems of practical interest consist basically of a well-defined outer shell-like master structure and a complicated internal structure with uncertain dynamic properties. Using the "fuzzy structure theory" for predicting audible frequency vibration, the internal structure is considered as one or more fuzzy substructures that are known in some statistical sense only. Experiments have shown that such fuzzy substructures often introduce a damping in the master which is much higher than the structural losses account for. A special method for modeling fuzzy substructures with a one-dimensional continuous boundary was examined in a companion paper (L. Friis and M. Ohlrich, "Vibration modeling of structural fuzzy with continuous boundary," J. Acoust. Soc. Am. 123, 718-728 (2008)). In the present paper, this method is extended, such that it allows modeling of fuzzy substructures with a two-dimensional continuous boundary. Additionally, a simple method for determining the so-called equivalent coupling factor is presented. The validity of this method is demonstrated by numerical simulations of the vibration response of a master plate structure with fuzzy attachments. It is revealed that the method performs very well above a nondimensional frequency of 500 of the master, and it is shown that errors below this frequency are caused mainly by simplifying assumptions concerning the shape of the master vibration displacement.

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Vibration modeling of structural fuzzy with continuous boundary

From experiments it is well known that the vibration response of a main structure with many attached substructures often shows more damping than structural losses in the components can account for. In practice, these substructures, which are not attached in an entirely rigid manner, behave like a multitude of different sprung masses each strongly resisting any motion of the main structure (master) at their base antiresonance. The "theory of structural fuzzy" is intended for modeling such high damping. In the present article the theory of fuzzy structures is briefly outlined and a method of modeling fuzzy substructures examined. This is done by new derivations and physical interpretations are provided. Further, the method is extended and simplified by introducing a simple deterministic approach to determine the boundary impedance of the structural fuzzy. By using this new approach, the damping effect of the fuzzy with spatial memory is demonstrated by numerical simulations of a main beam structure with fuzzy attachments. It is shown that the introduction of spatial memory reduces the damping effect of the fuzzy and in certain cases the damping effect may even be eliminated completely.
Effect of cross-coupling on the injection of vibratory power from sets of point forces into a periodic support structure

Round Robin test of technique for characterizing the structureborne sound-source-strength of vibrating machines

Two-dimensional model of the vibro-acoustic feedback in a hearing aid
Coupling of flexural and longitudinal wave motion in a finite periodic structure with asymmetrically arranged transverse beams

A companion paper [J. Acoust. Soc. Am. 118, 3010–3020 2005] has examined the phenomena of flexural-longitudinal wave coupling in a practically undamped and semi-infinite periodic waveguide with structural side-branches. The effect of structural damping on wave coupling in such a waveguide is examined in the first part of the present paper, and the damping-dependent decrease in wave coupling is revealed for a structure with multiresonant side-branches. In the second part, the simplifying semi-infinite assumption is relaxed and general expressions for the junction responses of finite and multicoupled periodic systems are derived as a generalization of the governing expressions for finite, monocoupled periodic systems [Ohlrich, J. Sound Vib. 107, 411–434 (1986)]. The present derivation of the general frequency response of a finite system utilizes the eigenvectors of displacement responses and wave forces that are associated with the characteristic wave-types, which can exist in a multicoupled periodic system [Mead, J. Sound Vib. 40, 19–39 (1975)]. The third part of the paper considers a finite specific test-structure with eight periodic elements and with structural terminations at the extreme ends. Audio-frequency vibration responses of this tri-coupled periodic structure are predicted numerically over a broad range of frequencies and a very good agreement is found with the measurement results obtained from an experiment with a nominally identical, periodic test-structure which is freely suspended.

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Coupling of flexural and longitudinal wave motion in a periodic structure with asymmetrically arranged transverse beams

In this paper we investigate the coupling of flexural and longitudinal wave motions in a waveguide with structural side branches attached at regular intervals. The analysis is based on periodic structure theory, and considers wave transmission in a fully tricoupled and semidefinite periodic assembly of beam-type elements or plane-wave transmission for normal incidence in a similar plate assembly. Receptances of a composite periodic element with offset resonant beams are derived and used for computing the frequency-dependent propagation constants of three coupled wave types as well as the distribution of motion displacements in each wave type. This is used for calculating the spatial variation of the forced harmonic responses of a semi-infinite periodic structure to point excitations by a longitudinal force and by a moment. Numerical simulations reveal the complicated wave coupling phenomena, which are clarified by calculating the ratio of flexural and longitudinal kinetic energies in the wave-carrying component for each wave type. In contrast to a corresponding, but uncoupled, system with significant broadband attenuation of flexural waves, the numerical results further show that the flexural-longitudinal wave coupling in a system with resonant side branches results in a highly enhanced wave transmission with very little attenuation from element to element.
Projects:

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