2:30

1pPA4. The use of acoustic resonance in particle manipulation and separation. Todd L. Brooks and Robert E. Apfel (Dept. of Mech. Eng., Yale Univ., New Haven, CT 06520-8286)

Particles in an acoustic standing wave experience a force directed towards pressure nodes or antinodes depending upon particle and host fluid properties. The observation of cork dust banding in air was first reported in 1866 by Kundt, but only recently has there been a renewed interest in utilizing such acoustic forces as a means for practical separation processes in liquids. Applications in biotechnology include two-phase partitioning, agglutination, electro-acoustic cell fusion, and cell retention systems. This talk describes a continuous flow stream with a perpendicularly oriented standing wave in a half or quarter wavelength resonator. This allows a continuous separation process in which the output flow can be split into several streams of different particle concentration, type, or size. Since the acoustic force depends on a particle's compressibility (as well as size and density contrast), there exists a unique opportunity to separate particles based on this property, not currently available in other separation methods. Competing effects, such as thermal convection, acoustic cavitation, and streaming, reduce separation efficiency, and these must be understood and controlled. A survey of applications will be presented along with recent experimental work and numerical simulations done in the Yale Acoustics Laboratory. [Work supported by NASA through Grant No. NAG8-1351.]

3:00–3:15 Break

Contributed Papers

3:15

1pPA5. Acoustic resonators as air quality sensors. Ralph T. Muehleisen (Dept. of Civil, Environ., and Architectural Eng., Univ. of Colorado, Boulder, CO 80309)

The past decade has seen a dramatic rise in concern for the quality of air that we breathe in our homes and workplace. Inexpensive sensors to measure changes of the composition of air are required. One can measure changes in the speed of sound of air by measuring the change in the resonance frequency of an open air acoustic resonator. If the air is treated as an ideal gas, changes in the speed of sound are directly related to changes in the gas composition. This presentation will discuss common indoor contaminants and the concentrations at which they contribute to poor indoor air quality (IAQ) and occupational safety. It is found that acoustic resonant sensors are not sensitive enough for use as IAQ sensors but are sensitive enough to be used as occupational safety monitors. [Work supported by ONR.]

3:30

1pPA6. Use of radiation pressure to move small particles in an air flow-through resonator. Ralph S. Budwig, Joseph G. Frankel, Michael J. Anderson, and K. Scott Line (Dept. of Mech. Eng., Univ. of Idaho, Moscow, ID 83844-0902)

It has been demonstrated many times in the past that particles suspended in a fluid medium can be manipulated with radiation pressure. Resonant cavities are often used to achieve large acoustic amplitudes. While most investigations have used water as the fluid medium, few have reported using a gas such as air. Little is known about the effect of openings, required for mean fluid flow through the cavity, on acoustic resonant amplification. Finally, few investigations report actual sound pressures that can be achieved, and correlate them to the movement of the particles. We present experimental measurements that quantify the ability of a flow-through resonator to move small water particles in air as the flow velocity and sound pressure levels are changed. The small water particles were generated with an ultrasonic humidifier. A commercial electrostatic transducer was employed to excite a one-wavelength longitudinal resonance of the cavity at a frequency near 60 kHz. Preliminary results show that sound pressure levels in excess of 150 dB *re*: 20 μPa can be attained, and significant particle movement is observed at flow velocities up to 11 cm/s. Observed particle movements will be compared to simple theoretical predictions based upon measured sound pressure levels and flow velocities.

3:45

1pPA7. Resonant sonic spectroscopic studies of aerogel solids. Edward Tucholski, Andres Larraza (Naval Postgrad. School, Phys. Dept., Monterey, CA 93943, larraza@physics.nps.mil), and Michael Droege (Ocellus Technologies, Livermore, CA 94550-9291)

Measurements similar to those performed using resonant ultrasound spectroscopy (RUS) were carried out in the audible frequency range for isotropic silica aerogels in air. This solid material has attracted significant attention due to its interesting physical properties. It has a density only 100 times greater than air, an optical index of refraction nearly equal to air (1.0–1.05), and a thermal conductivity of ~0.017 W/mK (~R10/in.). The acoustic measurements, conducted on a series of aerogel spheres ranging in diameter from 1.1 to 4.6 cm, demonstrated the two elastic moduli are four orders of magnitude less than that of dense silica and correspond to a longitudinal wave speed one-third that in air. The results are compared to pulse-receiver sound speed measurements. Sample spherical imperfections are demonstrated.

4:00

1pPA8. Radiation-pressure induced frequency shift of liquid capillary bridge transverse modes: A string approximation. Philip L. Marston and David B. Thiessen (Dept. of Phys., Washington State Univ., Pullman, WA 99164-2814)

Liquid capillary bridges in air have been stabilized by placing them at the velocity anti-node of an ultrasonic standing wave. This radiation-pressure induced stabilization depends on an acoustic parameter q that is proportional to the square of the ultrasonic pressure amplitude [M. J. Marr-Lyon *et al.*, Phys. Rev. Lett. **86**, 2293–2296 (2001)]. An approximation developed here suggests that an independent measure of *q* could be obtained by measuring the increase in the natural frequency of the lowest transverse bridge mode. That mode is known as the (1,1) mode. Even for an inviscid bridge, the exact (1,1) mode description is complicated. This complication is avoided by showing that the natural frequency for long round bridges is approximately that of a string having an effective tension CT/2 where C is the bridge circumference and T the surface tension. The additional restoring force (associated with the acoustic radiation pressure) for a bridge at a velocity anti-node is modeled as a uniform elastic support. When q is small, the frequency shift is predicted to be proportional to q. The calculation should also apply to the use of vibrating strings to measure acoustic standing wave amplitudes. [Work supported by NASA.]

4:15

1pPA9. Acoustic resonance determination of the rigidity modulus. Kenneth G. Foote (Woods Hole Oceanogr. Inst., Woods Hole, MA 02543)

Acoustic resonance methods are acknowledged to be particularly powerful in the determination of elastic properties of materials. Three measurement techniques for determining the rigidity modulus are described.

These involve comparison of the echo spectrum, energy, or waveform with the respective theoretically computed quantity, where the rigidity modulus, or shear-wave sound speed, is a free parameter. The value of this parameter is adjusted to achieve the best fit with measurement. The second technique is illustrated to specify the rigidity modulus of electrical-grade copper. An echo sounder operating at 120 kHz, calibrated by reference to the echo from a 30.05-mm-diam copper sphere, is used to excite a resonance in a 60.07-mm-diam sphere of the same material. The rigidity modulus is found to be 46.86±0.06 GPa and shear-wave sound speed, 2288±2 m/s.

MONDAY AFTERNOON, 3 DECEMBER 2001 ROOM 221, 2:00 TO 5:00 P.M.

Session 1pSA

Structural Acoustics and Vibration: Energy-Based Methods

Rudolph Martinez, Chair
Cambridge Acoustical Associates/Anteon Corporation, 84 Sherman Street, Cambridge, Massachusetts 02140

Contributed Papers

2:00

1pSA1. Predicting variability in SEA. Richard H. Lyon (RH Lyon Corp, 691 Concord Ave., Cambridge, MA 02138)

The variability that exists between an SEA estimate of the response of an ''average'' system and the actual response of a particular system has been estimated in various papers and books by the author. This estimate is in the form of a central limit theorem in which the variance, normalized by the square of the mean, is reduced by a factor that is the number of independent interacting mode pairs. A review of that result indicates that this parameter is overestimated, resulting in an underestimate of the actual variance. A new estimate of the variance is derived, which appears to have the correct asymptotic behavior under conditions of both low and high modal overlap. [Research supported by Cambridge Collaborative, Inc.]

2:15

1pSA2. Radiation from nonhomogeneous structures using SEA. Jerome E. Manning (Cambridge Collaborative, Inc., 689 Concord Ave., Cambridge, MA 02138)

Prediction of the acoustic radiation from vibrating structures at high frequencies can be accomplished using statistical energy analysis models. However, the basic formulations of radiation efficiency used in these models are often based on assumptions regarding boundary conditions and structural homogeneity that are not valid. Recent work carried out for nonhomogeneous structures with realistic boundary conditions is presented. An impedance approach is used that allows the radiation to be defined in terms of the forces acting on the structure from boundaries and added components. Examples are used to demonstrate the changes in radiation efficiency resulting from realistic boundaries, frame stiffeners, and added components.

2:30

1pSA3. Experimental statistical energy analysis in the time domain. Joseph Gregory, Richard Keltie, and Hubert Hall (Dept. of Mech. & Aerosp. Eng., North Carolina State Univ., Raleigh, NC 27695-7910, keltie@eos.ncsu.edu)

A technique for identifying an experimentally based power flow model from transient measurements is described. The technique was validated using a range of test simulations and then with true physical tests conducted on a structure comprised of coupled thin plates. The identified power flow model was used to successfully update and improve an existing computational statistical energy analysis (SEA) model. It was found that utilization of time domain data allowed for an overdetermined power balance providing favorable numerical conditions for the identification. Useful insight into system order/dimension was obtained during the identification process. It was observed that a full matrix of measured inputs and outputs was not required. However, inclusion of the extra measurements was seen to further increase overdetermination, yielding an even better least squares estimate of model parameters. It was found that the identification procedure indicated true parameters that were easily distinguished from those associated with noise in the data and, hence, seemed well suited for this SEA application. Results indicate that the methodology has the potential to enhance standard experimental SEA procedures.

2:45

1pSA4. Provided the modal overlap parameters exceed a threshold, statistical energy analysis (SEA) is not challenged by energy analysis (EA). G. Maidanik and K. J. Becker (NSWCCD, David Taylor Model Basin, 9500 MacArthur Blvd., West Bethesda, MD 20817-5700)

A structural complex is modeled by an externally driven master oscillator that is coupled to a set of satellite oscillators. In this model the satellite oscillators are not coupled to one another and the resonance frequencies of the satellite oscillators centrally span that of the master oscillator. The response of the model is cast in terms of the modal coupling strength $\zeta(y)$. This quantity is the ratio of the energy typically stored in a satellite oscillator to the energy stored in the master oscillator, (y) is the normalized frequency (ω/ω_0) and (ω_0) is the resonance frequency of the master oscillator. The modal coupling strength $\zeta(y)$ determined via the statistical energy analysis (SEA) is invariably less than unity; $\zeta(y)<1$. This quantity determined via the energy analysis (EA) is not necessarily so restricted. Indeed, the (EA) $\zeta(y)$ can be maintained below unity only if a typical modal overlap parameter (b_s) of the satellite oscillators exceeds a threshold (b_t); $b_t<b_s$. This threshold is required if the validation of SEA is not to be challenged by EA. Cited is a reasonable complex with strong couplings; e.g., satellite oscillators as sprung-masses, for which (b_t) exceeds unity. Therefore, to validate the SEA, modal overlap in this set must prevail.

3:00

1pSA5. Application of the mode isolation algorithm for experimental modal analysis to a system with close natural frequencies. Jerry H. Ginsberg and Bassem R. Zaki (G. W. Woodruff School of Mech. Eng., Georgia Inst. of Technol., Atlanta, GA 30332-0405)

Experimental modal analysis techniques in current use have difficulty with modes whose natural frequencies are very close or whose drive point mobility is very low. How well these issues are addressed by the Mode Isolation Algorithm (MIA), see M. V. Drexel and J. H. Ginsberg, ''Modal parameter isolation using state space mode isolation,'' in Proceedings of the 19th International Modal Analysis Conference, Orlando, Florida, February 5–8, 2001, is the topic of this presentation. MIA is an iterative procedure that employs frequency domain response data. The application