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1a MON. AM

NOTE: All Journal articles and Letters to the Editor are peer reviewed before publication. Program abstracts, however, are not reviewed before publication, since we are prohibited by time and schedule.

MONDAY MORNING, 1 DECEMBER 1997 EL CAMINO/ADOBE ROOMS, 8:15 A.M. TO 12:00 NOON

Session 1aAO

Acoustical Oceanography: Acoustic Measurement of Ocean Processes

Eric Wolin, Chair
Hughes Aircraft, Naval and Maritime Systems, 8080 Dagget Street, San Diego, California 92111

Contributed Papers

8:15

1aAO1. Acoustic monitoring of flow through the Strait of Gibraltar. Peter F. Worcester (Scripps Inst. of Oceanogr., Univ. of California at San Diego, La Jolla, CA 92093, pworcester@ucsd.edu), Uwe Send (Univ. of Kiel, 24105 Kiel, Germany), Bruce D. Cornuelle, and Christopher O. Tiemann (Univ. of California at San Diego, La Jolla, CA 92093)

The Strait of Gibraltar Acoustic Monitoring Experiment was conducted during April–May 1996 to determine the feasibility of using acoustic methods to make routine, rapidly repeated, transport measurements in the Strait of Gibraltar, as well as to explore the acoustic scattering caused by the internal wave bores generated in the Strait. Three different approaches to monitoring the flow were explored: (i) high-frequency (2-kHz) reciprocal transmissions; (ii) high-frequency (2-kHz) horizontal arrival angle measurements of ray bending due to currents; and (iii) one-way transmissions from a low-frequency (250-Hz) source to a vertical receiving array on the opposite side of the Strait. Extensive independent measurements of the temperature, salinity, and velocity fields were also made. The deep-turning rays are stable and yield differential travel times that give reasonable values for the current components along the acoustic paths. Horizontal arrival angles (phase differences) are strongly correlated with rough estimates of the current perpendicular to the acoustic path made using current meter data, suggesting that this approach is feasible at ranges up to at least 15 km. Finally, the acoustic signals show the effects of the nonlinear internal waves present in the Strait. [Work supported by ONR.]

8:30

1aAO2. Direction and speed of internal waves in SESAME II, and their effect on acoustic transmission. Jacob George, Robert L. Field, and Zachariah R. Hallock (NRL, Stennis Space Center, MS 39529)

Analysis of thermal data from SESAME II has revealed variations of both long and short durations. Variations of long durations have been clearly identified with tidal cycles, and are nearly identical at two thermal arrays 433 m apart in range, with no significant relative time lag between the two. Though a zero relative time lag would imply a southeastern direction for the wave vector, the long wavelengths involved and the short range between the arrays make such a prediction inconclusive. Variations of shorter durations arrive at the two arrays with a relative time lag that ranges between 5 and 26 min. Wavelet analysis has confirmed this time lag, and shows that it holds for a range of wavelengths. This puts constraints on the direction and speed of the short-duration components. The implications of these results on acoustic propagation will be discussed. [Work supported by ONR and NRL.]

8:45

1aAO3. Forward propagation analysis for the summer Shelfbreak PRIMER Experiment. Brian J. Sperry, Jim Lynch (Dept. of Appl. Ocean Phys. and Eng., Woods Hole Oceanogr. Inst., Woods Hole, MA 02543), Ching-Sang Chiu (Naval Postgrad. School, Monterey, CA), Glen G. Gawarkiewicz, Robert S. Pickart (Woods Hole Oceanograph. Inst., Woods Hole, MA 02543), James H. Miller (Univ. of Rhode Island, Narragansett, RI), and Allan R. Robinson (Harvard Univ., Cambridge, MA)

One of the primary objectives of the 1996 Shelfbreak Primer Experiment, located in the Mid-Atlantic Bight south of Nanucket Shoals, was to investigate the effects of the shelfbreak front on the propagation of acoustic signals. The acoustic component of the experiment consisted of two 16-element vertical hydrophone arrays (VLAs) along the northern edge of the region (inshore of the shelfbreak), and three sources (one 224 Hz and two 400 Hz) along the southern edge (seaward of the shelfbreak). Source-to-receiver path lengths ranged from 40–60 km. The high-quality oceanographic data collected, including SeaSoar sections and numerous thermistor records, are critical to modeling and interpreting the acoustics. From a modal perspective, there is strong coupling from not only the front, but also from the sloping bathymetry and from scattering by solitons. The receptions at the northeast VLA coinciding with a 6-day period of SeaSoar

deployment are considered here. Fluctuations in the signal arrivals are consistent with the picture provided by the measured oceanography. Results from coupled-mode propagation modeling are also discussed. [Work supported by ONR.]

9:00

1aAO4. Pulse propagation through continental-shelf internal solitary waves. Altan Turgut and Stephen N. Wolf (Naval Res. Lab., Acoust. Div., Washington, DC 20375)

A newly developed pseudospectral numerical model is used to study pulse propagation through continental-shelf internal waves. A time-domain mode coupling analysis is performed on plane-wave pulses propagating through a simple internal solitary wave (ISW) described by downward undulation of a thermocline having the shape of hyperbolic secant. Initial acoustic fields made up of eight-cycle Hanning-weighted sine waves with 224- and 400-Hz center frequencies (vertically shaded by desired acoustic mode shapes) are used. Two-dimensional and three-dimensional numerical results were compared to investigate the validity of two-dimensional techniques in the case of nonparallel acoustic-ISW alignment. Similar to the results of Preisig and Duda [IEEE J. Oceanic Eng. **22**(2) (1997)], it has been observed that the horizontal refraction and azimuthal scattering seem to be minor for up to 65-deg oblique incidence angle. Results of two-dimensional propagation and mode-coupling analysis for the ISW packets measured during the SWARM95 experiment are also discussed. [Work supported by ONR.]

9:15

1aAO5. Acoustic field propagation through a shallow water waveguide dominated by internal waves. Steven Finette, Marshall Orr (Acoust. Div. Naval Res. Lab., Washington, DC 20375), John Apel (Global Ocean Assoc., Silver Spring, MD 20908), and The SWARM Group

The continental shelf off the New Jersey coast is a site of intense internal-wave activity. The space–time variability of an acoustic field in this shallow-water region was studied using oceanographic measurements along a 42-km track from the SWARM95 [shallow-water acoustics in a random medium] experiment. A sound–speed model based on the KdV equation was developed to include the nonlinear contribution of the internal wave field, with parameters estimated from towed yo-yo ctd data, ship radar images of internal-wavesurface expression and acoustic backscatter images of subsurface internal-wave structure. The linear internal-wave contribution was modeled by an ADCP-derived displacement power spectrum. Bathymetry and sub-bottom parameters were previously estimated from wave-field inversions using chirp sonar surveys. Simulation results are presented for acoustic propagation at frequencies of 224 and 400 Hz using a wide-angle parabolic equation method to compute realizations of the acoustic field. Results include estimates of the intensity fluctuations and coherence for two vertical arrays located at 33 and 42 km from the moored sources. [Work supported by ONR.]

9:30

1aAO6. Normal mode analysis of acoustic thermometry of ocean climate receptions using short-time Fourier techniques. Kathleen E. Wage, Arthur B. Baggeroer (Res. Lab. of Electron., MIT, Cambridge, MA 02139 and Appl. Ocean Phys. and Eng. Dept., Woods Hole Oceanogr. Inst.), and James C. Preisig (Woods Hole Oceanograph. Inst.)

The effects of internal waves on the coherence of propagating modes and the validity of the adiabatic assumption are very important issues in both matched-field processing and acoustic tomography. While much theoretical research has been done on long-range propagation of modes in deep water, there have been few opportunities to compare theoretical predictions with experimental measurements. Deployment of mode-resolving vertical arrays as a part of the Acoustic Thermometry of Ocean Climate (ATOC) experiment has provided data sets, which may offer insights about mode coherence at long ranges. This study examines the modal composition of ATOC receptions using the short-time Fourier techniques described in earlier work [Wage *et al.*, J. Acoust. Soc. Am. **101**, 3113(A) (1997)]. Initial results reveal a frequency selectivity in the arrivals for the lowest ten modes. Since frequency-selective effects can be modeled by a random multipath channel, the problem of estimating channel characteristics from pulse-compressed M-sequence receptions is discussed. In particular, this study investigates various techniques of averaging across receptions to obtain the mean arrival time and spread for each mode. [Work supported by ONR.]

9:45

1aAO7. MFP geoacoustic inversion applied to the WORKSHOP97 data. A. Tolstoy (Integrated Performance Decisions, Inc., Honolulu, HI 96816)

Application of the refined iterated grid search (RIGS) MFP inversion method to four of the WORKSHOP97 test cases (SD, AT, SO, and WA) has resulted in some surprisingly accurate estimates for some geoacoustic parameters, i.e., sediment densities and attenuations, source ranges and depths, and some sediment gradients. Another surprise was the sensitivity of the inversion to small errors in the KRAKEN propagation model. This paper will discuss recent efforts to understand the benefits and shortcomings of the RIGS method and to propose future directions.

10:00–10:15 Break

10:15

1aAO8. Modeling of broadband time signals in shallow water using environmental inversion. Peter L. Nielsen (Saclantcen, Viale S. Bartolomeo 400, 19138 La Spezia, Italy, nielsen@saclantc.nato.int), Peter Gerstoft (UCSD, La Jolla, CA 92093-0704), Francesco Bini-Verona, and Finn B. Jensen (Saclantcen, La Spezia, Italy)

A numerical modeling scheme is applied to perform broadband environmental inversion by using explosive data acquired in the Mediterranean Sea in May 1997. The area shows a moderate range dependency, and the received time signals from explosive charges cover a frequency band of several kilohertz. The acoustic propagation model is based on a layered normal mode approach, which is capable of efficiently predicting broadband sound propagation in shallow water [Westwood *et al.*, ''A normal mode model for acoustic–elastic ocean environments,'' J. Acoust. Soc. Am. **100**, 3631–3645 (1996)]. This model has been extended to handle range-dependent environments using the adiabatic approximation. Thus calculation of broadband transfer functions from 0 to 10 kHz of range-dependent, shallow-water waveguides can now be done within a few minutes. The combination of the above propagation model and a state-of-the-art global inversion scheme [Gerstoft, ''SAGA user manual 2.0: An inversion software package,'' SACLANTCEN SM-333 (1997)], makes it possible to perform environmental focusing by optimizing the correlation between the numerical and experimental received time signal at one or more receiver locations. The broadband inversion scheme is introduced to extract the uncertain acoustic parameters in the waveguide, and to assess how accurate broadband signals can be modeled in complex shallow-water regions.

10:30

1aAO9. Broadband mode inversion for oceanographic and geoacoustic parameters. Gopu R. Potty and James H. Miller (Dept. of Ocean Eng., Univ. of Rhode Island, Narragansett, RI 02882)

A genetic algorithm was used for the inversion of sound speed in the water column and sediment layers south of New England in the Middle Atlantic Bight. The experimental data were SUS charge explosions acquired on a vertical hydrophone array during the Shelf Break Primer Experiment conducted in August, 1996. A genetic algorithm was used to search for optimal parameters in a wide space; the EOF coefficients in the ocean and the compressional sound–speed values in the sediment layers. A range-independent normal-mode routine was used to construct the replica fields corresponding to the parameters. Comparison of group speeds for modes 1–4 and for a range of frequencies from 10–100 Hz was used to arrive at the best parameter fit. A linear perturbative inversion also was done on the same data as described by Rajan *et al.* [J. Acoust. Soc. Am. **82**, 998–1017 (1987)]. This linear method also gives estimates of resolution and variance. Analysis was also done to compute the degree of convergence of each of the parameters. Group speeds for the inverted sound–speed fields provide an excellent match to the experimental data. An efficient hybrid optimization scheme using genetic and linear techniques is presented. [Work supported by ONR.]

10:45

1aAO10. Observations of attenuation during the Scripps Pier bubble experiment. Jerald W. Caruthers, Paul A. Elmore, Philip A. Beben, and Stephen J. Stanic (Naval Res. Lab., Ocean Acoust. Branch, Stennis Space Center, MS 39529)

An experiment that measured the effects of bubbles just offshore from active surf was performed in the spring of 1997 off the pier at the Scripps Institution of Oceanography. A region from a few tens of meters to 1000 m from the beach was instrumented by several researchers. An emphasis was placed on a region approximately 400 m^2 in area and about 300-m offshore where most of the instruments were clustered. Located in this area was a triangular-shaped frame called the Delta Frame, which had sources at two vertices and eight hydrophones along the perimeter (each side was 9.4 m long). Eight frequencies, from 39 to 244 kHz, were propagated sequentially from each source and received on each hydrophone. All 16 transmissions occurred within 12 ms and were repeated at a 1-s interval during each of ten 88-min data runs. Bubbles produced in the surf zone were carried out to the experimental region by rip currents and had dramatic effects on all the instruments. This paper discusses their effects on attenuation as measured at the Delta Frame. [Work supported by ONR.]

11:00

1aAO11. Bubble clouds, velocity distributions, and high-frequency propagation in the Scripps bubble experiment. David M. Farmer, Svein Vagle (Inst. of Ocean Sci., 9860 West Saanich Rd., Sidney, BC V8L 4B2, Canada), and Grant Deane (Scripps Inst. of Oceanogr., La Jolla, CA 92093)

As part of an experiment to determine the distribution and acoustical effects of bubbles near the surf zone, resonators, cameras, a coherent Doppler, and horizontally oriented Doppler sonars were deployed in the vicinity of Scripps Pier. With these instruments, evolution of the waves as they traveled toward the shore were detected and the bubble size distributions, rip currents, turbulence dissipation, and patterns of bubble cloud motion were measured. Propagation tests at 100 kHz along a 230-m path between the end of the pier and the surf were conducted. Bubble size measurements in the surf and on a bottom-mounted frame allowed identification of the spatial evolution of bubble characteristics. The sonar measurements show bubble clouds ejected offshore at discrete intervals and at speeds of $\sim$0.3 m/s. Pulse propagation into the surf was occasionally completely attenuated by bubble clouds. However, it is interesting that prior to total blocking of the signal the pulse arrival time is delayed, implying an apparent decrease in sound speed. This is unexpected since our frequency (100 kHz) was above the resonance of the dominant bubbles. An explanation is proposed in terms of selective blocking of direct path propagation by bubble clouds. [Work supported by ONR Contracts Nos. N00014-96-C-6030 and N00014-97-1-0288.]

11:15

1aAO12. Tomographic reconstruction of shallow-water bubble fields observed in the Scripps Pier bubble experiment. Daniel Rouseff, Frank S. Henyey (Appl. Phys. Lab., College of Ocean and Fishery Sci., Univ. of Washington, Seattle, WA 98105), Jerald W. Caruthers, and Steven J. Stanic (Naval Res. Lab., Stennis Space Center, MS 39520)

An experiment was performed in the Spring of 1997 off the pier at the Scripps Institute of Oceanography. The objective was to measure the near-shore properties of bubble fields. A major component of the experiment was the Delta frame designed at NRL-SSC. The triangular frame, 9.4 m on each side, supported two sources and eight hydrophones. Measurements of acoustic travel time and attenuation were made at eight frequencies between 39 and 244 kHz. Details of the measurement apparatus will be presented elsewhere at this meeting [J. W. Caruthers *et al.*, ''Observations of attenuation during the Scripps Pier bubble experiment'']. In this paper, a tomography algorithm [D. Rouseff and F. S. Henyey, J. Acoust. Soc. Am. **101**, 3032 (1997)] is applied to a sampling of the data to produce cross-sectional mappings of attenuation. The bubble concentrations are shown to be inhomogeneous and carried across the frame by rip currents. Possible improvements to the tomography algorithm for imaging strongly attenuating structures are discussed. [Work supported by ONR.]

11:30

1aAO13. Attenuation estimates for bubbly sea water. R. R. Goodman (Appl. Phys. Lab., Penn State Univ., State College, PA), P. A. Elmore, and J. W. Caruthers (Naval Res. Lab., Stennis Space Center, MS 39529)

Acoustic techniques used for determining bubble distributions can be limited because a solution to an ill-conditioned inverse problem is required. Examining cases in which closed-form solutions are possible, however, may give us insight about the inverse procedure. In a previous ASA meeting [Goodman, Caruthers, and Elmore, ''Dispersion estimates for bubbly seawater,'' J. Acoust. Soc. Am. **100**, 3196(A) (1997)], exact solutions for dispersion for the inverse procedure in special cases of bubble distributions were explored. Here some of those special cases are examined in terms of how they apply to attenuation measurements. For cases in which the closed-form solution are not possible, the resonant bubble approximation allows for estimating the bubble population from attenuation measurements. This paper shows that there is observable error in this procedure, but that the error can be reduced by application of an iterative procedure discussed here. [Work supported by ONR.]

11:45

1aAO14. Measuring near surface ocean features using upward facing ADCPs. Brandon S. Strong and R. Lee Gordon (RD Instruments, 9855 Businesspark Ave., San Diego, CA 92131)

This paper presents the results of acoustic measurements of the ocean surface and near-surface features using a conventional broadband acoustic Doppler current profiler (ADCP). An analysis of the trade offs and error sources associated with surface detection reveals how transducer beam geometry and signal processing can affect surface measurement. Configurations are considered for the measurement of mean-surface height, ambient sound, wind speed, wind direction, surface currents, directional wave spectra, tidal flow, and entrained air. Observations of the sea surface conditions at Scripps Pier are compared with acoustic data collected using upward facing ADCPs of different beam geometries and a pressure sensor. Comparisons are made with previous studies [Zedel, Deep ocean wave measurements using a vertically oriented sonar, J. Atmos. Oceanic Tech. **11**, 182–191 (1994) and Terray *et al.*, Measuring wave height and direction using upward-looking ADCPs, to be presented at Oceans '97].

Session 1aPA

Physical Acoustics: Nonlinear Acoustics

Bart Lipkens, Chair
MacroSonics Corporation, 1570 East Parham Road, Richmond, Virginia 23228

Contributed Papers

8:30

1aPA1. Comparison between a nonlinear equation and acoustic measurement in a laminate graphite-epoxy composite. P. A. Elmore[a] and M. A. Breazeale (Jamie Whitten Natl. Ctr. for Physical Acoust., Univ. of Mississippi, University, MS 38677)

Measurements of longitudinal phase velocity and rate of harmonic generation (nonlinearity parameter) have been made in a laminate graphite-epoxy composite. Both quantities are observed to be frequency dependent between 3.5 and 8 MHz. The theoretical model of Van Den Abeele and Breazeale [J. Acoust. Soc. Am. **99**, 1430–1437 (1996)] has been applied to the data. Including dispersion terms and their nonlinear counterparts improves agreement over that obtained with the theory used for single crystals. The origin of this difference probably is in scattering from laminate boundaries. Some inadequacies still exist, however. Their origin has not been established yet. [a]Current address: Naval Res. Lab., Ocean Acoustics Branch, Stennis Space Center, MS 39529.

8:45

1aPA2. Modeling of harmonic generation and shock formation in nonlinear surface acoustic waves in several real crystals. R. E. Kumon, M. F. Hamilton (Dept. of Mech. Eng., Univ. of Texas, Austin, TX 78712-1063), Yu. A. Il'inskii, and E. A. Zabolotskaya (MacroSonix Corp., Richmond, VA 23228)

Harmonic generation and shock formation in nonlinear surface acoustic waves that propagate in anisotropic crystals were studied numerically on the basis of a new theoretical model presented earlier [Hamilton *et al.*, *Nonlinear Acoustics in Perspective*, edited by R. J. Wei (Nanjing University Press, Nanjing, 1996), pp. 64–69]. The theory applies for arbitrary elastic materials, surface cuts, and propagation directions. Numerical simulations were performed for initially sinusoidal signals propagating across the surface of KCl, Ni, and Si crystals for the (001), (110), and (111) cuts, and over the appropriate range of directions for each cut. Waveforms are shown to exhibit asymmetric distortion, well-defined shocks with cusped spikes in the horizontal waveform, and a phase shift in the zero crossings. Solutions for propagation in the (001) plane and in the ⟨100⟩ direction of KCl are shown to exhibit atypical trapping of energy in the lowest order harmonics. Analytical solutions derived for the fundamental and second-harmonic components for this particular case are in good agreement with the numerical solutions close to the source. Although the phenomenon resembles one observed in nonlinear optics resulting from dispersion, it is due instead to properties of the nonlinearity coefficient matrix. [Work supported by ONR.]

9:00

1aPA3. Measurements of macrosonic standing waves in oscillating cavities. Christopher C. Lawrenson, Bart Lipkens, Timothy S. Lucas, David K. Perkins, and Thomas W. Van Doren (MacroSonix Corp., 1570 East Parham Rd., Richmond, VA 23228)

Measurements of macrosonic standing waves in oscillating closed cavities are shown. These cavities (resonators) were designed by MacroSonix using resonant macrosonic synthesis (RMS) to shape the resultant waveform. By controlling the nonlinear processes by which energy is transferred to harmonic frequencies, RMS allows design of resonators that give high-amplitude shock-free waveforms. Measurements in cavities designed with RMS show standing-wave overpressures in excess of 340% of ambient pressure, compared to maximum overpressures in cylindrical cavities of about 17%. Power is delivered by oscillating the entire resonator along its axis with a linear actuator (entire resonator drive). Measurements are shown for four axisymmetric resonator shapes: cylinder, cone, horn-cone hybrid, and bulb. Resonators were filled with nitrogen, propane, or refrigerant R-134a (1,1,1,2-tetrafluoroethane). Ratios of peak-to-minimum pressures of 27 were observed. Since practical compressors for air, refrigerants, or other gases require pressure ratios (discharge to suction) of 3 or more, RMS technology can be used in a wide range of applications. Frequency sweeps show softening or hardening behavior, depending on resonator shape. High-amplitude resonance sweeps show significant hysteresis.

9:15

1aPA4. A theoretical model of nonlinear standing waves in an oscillating cavity. Yurii A. Ilinskii, Bart Lipkens, Timothy S. Lucas, Thomas W. Van Doren, and Evgenia A. Zabolotskaya (MacroSonix, 1570 East Parham Rd., Richmond, VA 23228)

A theoretical investigation of nonlinear standing waves in an acoustical resonator is presented. The motivation for this research stems from the new technology of resonant macrosonic synthesis (RMS) developed at MacroSonix. RMS creates high amplitude standing waves, e.g., overpressures in excess of 300% of ambient pressure. The analysis is based on a one-dimensional model equation for the velocity potential that is derived from the fundamental gas dynamics equations for an ideal gas. Nonlinearity, gas viscosity, and entire resonator driving are included. The resonator is assumed to be of an axisymmetric, but otherwise arbitrary, shape. Nonlinear spectral equations are integrated numerically for a two-point boundary-value problem. The harmonic amplitudes and phases of the velocity potential wave are obtained directly from the solution of the frequency-domain equations. The pressure wave shape, the harmonic amplitudes of the pressure wave, and harmonic amplitude distribution along the resonator axis are then calculated. Results are presented for three resonator geometries: a cylinder, a cone, and a bulb. Both hardening and softening behaviors are observed and shown to be geometry dependent. At high amplitude, hysteresis effects are present in the frequency-response curves. Comparisons between measured and calculated waveforms show good agreement.

9:30

1aPA5. Variation of B/A with $1/c$ for several liquids. M. Paul Hagelberg (Dept. of Phys., Wittenberg Univ., P.O. Box 720, Springfield, OH 45501-0720)

Theoretical models [B. Hartmann, J. Acoust. Soc. Am. **65**, 1392–1396 (1979), B. Frank and J. D. N. Cheeke, J. Acoust. Soc. Am. **101**, 1184–1186 (1997)] predict that the variation of B/A, the acoustical nonlinearity parameter, with the inverse sound speed $1/c$, should be linear or linear with a quadratic term. Confirmation of these models requires experimental data for B/A vs $1/c$ for individual liquids. Such data will be presented for several liquids including pure water, seawater, mercury, and a number of organic liquids.

9:45–10:00 Break

10:00

1aPA6. An improved theoretical model for highly nonlinear bubbly liquids. Zhemin Zhu, Xiaoliang Zhao, and Gonghuan Du (Inst. of Acoust. and State Key Lab., Nanjing Univ., Nanjing 210093, P. R. China)

Strong nonlinearity of bubbly liquids is a most interesting property not only for its theoretical importance in nonlinear acoustics but also for its potential application in, for example, ultrasound imaging technology. A physical model which describes the nonlinear property of liquids containing uniform size bubbles is presented [Ultrasound Med. Biol. **21**, 545–552 (1995)]. The theory is successful to some extent but still has some limitations since the sizes of the bubbles are usually not exactly the same. In this paper, a model dealing with more practical situations, i.e., liquids containing many bubbles whose sizes are randomly distributed is extended. The effective nonlinearity parameter B/A (as high as about 10^4) and attenuation coefficient for these bubbly liquids are given. Calculations and comparisons show that the improved model explains the existent experiments more satisfactorily. [Work supported by the National Science Foundation of China.]

10:15

1aPA7. Nonlinear phenomena of high-amplitude vibration of a piston in a gas-filled liquid. Oleg Rudenko and Valery Andreev (Dept. of Acoust., Phys. Faculty, Moscow State Univ., Moscow 119899, Russia)

Nonlinear phenomena are known to be significant after the wave of moderate amplitude passes a long distance through a weakly dissipative medium. Such ''accumulative'' effects are studied exhaustively by nonlinear wave physics. In contrast, the ''local'' nonlinearities are studied incompletely. Such nonlinear behavior can be demonstrated by a piston immersed in liquid and vibrating with high amplitude. This piston subjected to a harmonic load can radiate not only the fundamental frequency but high-order harmonics as well. Moreover, reaction to high-power radiation can create an additional nonlinear resistance to a piston motion. Local nonlinear phenomena are expessed clearly at vibration velocities comparable with the sound speed of the surrounding medium. Such a case can be realized using liquids containing gas bubbles where sound velocity is much less than one in a pure liquid. This work is devoted to the theoretical calculation of the temporal and spectral characteristics of a nonlinear wave radiated by a piston subjected to a harmonic external force. Two different problems are discussed corresponding to the piston considered as a linear and as a nonlinear vibrating system. [Work supported by RFFI and CRDF.]

10:30

1aPA8. Shock-wave collisions in bubbly liquids: Numerical studies. Valery K. Kedrinskii (Lavrentyev Inst. of Hydrodynam., Lavrentyev prospect 15, Novosibirsk 630090, Russia)

The results of numerical investigations of different effects arising in bubbly liquid due to wave interactions are presented. The influence of the gas content on the parameters and the structure of shock waves and of chemical reactions in the gas phase will be considered. The problem is solved within the framework of the two-phase mathematical model including the kinetic equations for the description of the medium-state dynamics, thermoexchange as well as of bimolecular reaction kinetics. The purpose is to estimate the amplification level of the wave intensity as the result of such kinds of interactions. The wave amplitudes in a passive bubbly media turned out to be amplified by one order of magnitude in the collision plane and their amplification depends on the bubble concentration k_0 as $p_{\max}=2+24.5\cdot k_0^{1/4}$. The possibilities of simulating the hot-spot mechanism of liquid explosive detonation ignition and the mechanism of the large-scale explosions of containers filled with a fuel by bubbly detonation wave interactions are discussed. [Work supported by RFFR, Grant 96-02-19369.]

10:45

1aPA9. Fast numerical algorithm for simulation of nonlinear acoustic waves with shocks of finite thickness. Oleg A. Sapozhnikov and Vera A. Khokhlova (Dept. of Acoust., Phys. Faculty, Moscow State Univ., Moscow 119899, Russia, olegs@na.phys.msu.su)

In an earlier work [V. A. Khokhlova and O. A. Sapozhnikov, J. Acoust. Soc. Am. **96**, 3321 (1994)], a modified spectral approach was proposed for the description of nonlinear waves containing shocks. An abrupt shock has an analytical high-frequency ω^{-1} asymptote. This asymptotic result was used in the numerical algorithm to model strongly nonlinear waves with a relatively few number of harmonics $N\sim 20$ [Pischal'nikov *et al.*, Acoust. Phys. **42**, 362–367 (1996)]. However, in real dissipative medium the shock front is not a discontinuity, but a transition region of finite thickness. This region can be adequately described by a hyperbolic tangent profile, so that the correspondent wave spectrum at high frequencies is governed by the Fay solution. Here, the Fay spectrum asymptote of the finite thickness shock is used, instead of the ω^{-1} asymptote of the abrupt shock, to derive a set of coupled differential equations for the harmonic amplitudes. Several model problems are considered. It is shown that this method permits increasing the accuracy and stability of the modified spectral approach, and still leads to a reduction in the number of equations by a factor of 10–100 in comparison with direct frequency domain schemes. [Work supported by FIRCA and RFBR.]

11:00

1aPA10. Nonlinear effects for torsional waves in rods with cracklike defects. Igor N. Didenkulov, Alexander E. Ekimov, and Vyacheslav V. Kazakov (Inst. of Appl. Phys., 46 Ulyanov St., Nizhny Novgorod, 603600, Russia)

The enormously high nonlinear response of solids with cracks to an acoustic excitation makes nonlinear methods possible for nondestructive testing (NDT). Among the problems to be solved are the mechanisms of such nonlinear responses and the development of NDT methods. Results of an experimental study of nonlinear effects for elastic waves in metal rods with cracklike defects and their dependence on the type of contacts in the cracks are given. Unlike earlier works concerned mainly with longitudinal and flexural waves in solids, the present experiment shows that a high degree of nonlinearity is found for torsional waves as well. The crack was modeled by cutting a rod and tightly filling a crack with metal plates. Two types of contact were studied: dry and lubricated contacts. Modulation of high-frequency torsional waves (20 kHz and 22.8 kHz) in a rod by low-frequency flexural vibrations was studied. Flexural vibrations were excited in two ways: with a shock and with the help of a vibrator. Amplitude modulation was observed only in a rod with a crack, the level of this modulation drastically decreasing in the presence of liquid lubricant. [Work supported by RFBR, Russia—Grant No. 97-02-17524—and by INCAS, Nizhny Novgorod, Russia.]

Session 1aSA

Structural Acoustics and Vibration: Structural Vibration and Radiation

Courtney B. Burroughs, Chair
Applied Research Laboratory, The Pennsylvania State University, P.O. Box 30, State College, Pennsylvania 16801

Contributed Papers

8:15

1aSA1. A vibro-acoustic method for measuring Young's modulus of building materials. Wing Chu (Indoor Environ. Program, Inst. for Res. in Construct., Natl. Res. Council Canada, Ottawa, ON K1A 0R6, Canada)

The current ASTM standards for the measurements of Young's modulus are designed specifically for ceramics, bricks, carbon and graphite materials, and concrete. The techniques used are based on the measurement of either sonic velocity or the resonant frequency in the flexural mode of vibration of the specimen. The latter method has been adapted for determining the Young's modulus of building materials, such as wood, gypsum board, and oriented-strand-board (OSB), in the Acoustics Laboratory of IRC/NRC using modern digital-signal processing. This paper will discuss the method and provide results for a number of building materials tested.

8:30

1aSA2. Radiation of sound by two concentric free-flooded cylindrical shells excited by a point force. K. Steven Kim (Signatures Directorate, Carderock Div., Naval Surface Warfare Ctr., 9500 MacArthur Blvd., West Bethesda, MD 20817-5700)

Radiated acoustic pressure fields are obtained when two concentric free-flooded cylindrical shells of finite lengths are excited by a time-harmonic point force. Integral equations are formulated for the two elastic thin shells with simply supported boundary conditions at both ends. Near and far-field acoustic pressures are calculated and effects of acoustic coupling between two shells are discussed.

8:45

1aSA3. Radiation from small acoustic sources located close to a submerged, compliantly coated cylindrical shell. Michael D. Gray, Gary W. Caille (Undersea Res. Program Office, Georgia Tech. Res. Inst., 505 Tech Way N.W., Atlanta, GA 30318), John R. Bogle, and Peter H. Rogers (Georgia Inst. of Technol., Atlanta, GA 30332)

Measurements were made of the radiation from individual, small acoustic sources located close to a submerged, compliantly coated, thin cylindrical shell in the $1<ka<20$ frequency range, where k is the acoustic wavenumber, and a is the radius of the coated cylinder. The behavior of the radiated pressure field is shown to have two distinct frequency regimes. For $ka>5$, the field is simple, and is well approximated by a source and its negative image. For $ka<4$, the pressure field is characterized by significant spatial variations, owing to contributions from the elastic response of the coated cylinder. Finite-element model results are compared with the measurements, and are used to provide insight into the interactions between the source and the coated shell. [Work supported by ONR.]

9:00

1aSA4. Far-field acoustic holography onto cylindrical surfaces using pressure measured on semicircles. Andrew Norris (Dept. of Mech. and Aerosp. Eng., Rutgers Univ., Piscataway, NJ 08855-0909, norris@jove.rutgers.edu)

A simple formula was recently proposed by Williams [J. Acoust. Soc. Am. **99**, 2022–2032 (1996)] for imaging pressure and velocity on a vibrating circular cylindrical shell using the far-field pressure measured along a meridional semicircle. The method is discussed and some new results are presented. The procedure is generalized to handle cylindrical surfaces of a noncircular but convex cross section. It is demonstrated that Williams' formula predicts a supersonic surface intensity, which gives the same meridional energy flux as the exact radiated far-field pressure. A modification of Williams' formula is suggested, which uses pressure data from several neighboring semicircles, although complete spherical coverage is not required. The modified imaging formula is based upon the first two terms in an asymptotic expansion in the dimensionless wave number. The leading-order term yields the original formula, and the second term results in a boundary layer type of correction in the circumferential direction. Numerical examples compare the exact supersonic acoustic intensity on a cylinder with that from the original and the modified formula. These indicate that the circumferential on-surface resolution is significantly enhanced by combining data from neighboring semicircles, even when the total far-field spherical coverage is small. [Work supported by ONR.]

9:15

1aSA5. Acoustic modeling of oscillatory hydrodynamic loading and fluid–structure interaction. Ashok Gopinath and Gary W. Sweany (Dept. of Mech. Eng., Code ME/Gk, Naval Postgrad. School, Monterey, CA 93943, gopinath@nps.navy.mil)

An experimental study has been conducted of forces on a cylinder in a standing acoustic wave. The cylinder is representative of the leg of an offshore structure or platform, while the acoustic field is representative of the oscillatory wave loading on such a structure. A piston oscillator drive mechanism provides the requisite large acoustic amplitudes in the pressure vessel resonator that houses the test cylinder. The use of a high-pressure gas allows the desired high values of the Reynolds numbers to be achieved. Both in-line drag forces and transverse (lift) forces on the cylinder, along with the phasing information, have been measured with the help of suitably mounted strain gauges, and corroborated with existing data in the literature. Higher harmonic forces and resonant interactions, typical of compliant structures, have also been measured and analyzed. This experimental technique appears to have a promising potential for studying the large amplitude, large Reynolds number regime of hydrodynamic loading and the resulting fluid–structure interactions.

1aSA6. Abstract withdrawn

9:30

1aSA7. Modification of the four-load method to compute source impedance in a pipe system. B. S. Sridhara (Dept. of Eng. Technol. and Industrial Studies, Middle Tennessee State Univ., Murfreesboro, TN 37132)

This paper discusses a new method used to obtain the source impedance from the four-load method. The three nonlinear algebraic equations of the four-load method were modified to give three equations of a circle. At each frequency, the intersections of these circles give the real and imaginary parts of the source impedance. A computer program was developed to calculate these intersections and extract the realistic values. A frequency range from 0 to 800 Hz was considered for a 0.2286-m (9-in.) diam pipe system with a loudspeaker as the sound source. At each frequency, the circles were scanned from 0° to 360° in intervals of 0.5° allowing small percentage errors such as 0.001, 0.005, and 0.01. The computed source impedance values were compared with those obtained from the direct method. The results agree well with the decrease in the percentage error.

9:45

1aSA8. Method for broadband measurement of complex shear modulus and Poisson ratio of viscoelastic materials. L. Sheiba (NRaD, 53560 Hull St., San Diego, CA 92152-5001)

This method is based on the inverse solution to the vibration problem of a finite elastic cylinder with reinforced torsion surfaces by rigid septa or plates. In all cases the polymer layer to be tested is bonded to rigid plates; therefore, the radial displacement is zero at the boundary between the polymer layer and the septum. The admittance matrix Y of the element with abovementioned boundary conditions is constructed within the framework of the hypothesis for planar cross sections. The dimensionless shear wave number $k_t(\omega)h$ and compression wave number $k_\lambda(\omega)h$, which are the unknown variables, are obtained by measuring the transfer matrix of a known structure and as a result of solving the transcendental equation in a designated frequency range. Data are attained over a broadband of frequencies and temperatures without dependence on the time-temperature superposition principle.

10:00

1aSA9. A combined experimental and numerical method for computing sound radiation from underwater vibrating structures. John B. Fahnline, Matthew J. Erickson, Dean E. Capone, Stephen A. Hambric, and Courtney B. Burroughs (Appl. Res. Lab., Penn State Univ., 16 Applied Science Building, University Park, PA 16804)

Underwater measurements of the radiated sound power from a vibrating structure are conventionally performed either by direct measurements in a large body of water or by reverberation measurements in a water tank. Both methods have inherent drawbacks. Direct measurements in a large body of water require a large scale operation and are relatively expensive. Reverberation measurements are only accurate at high modal densities, and thus a very large tank is required to obtain accurate low-frequency predictions. To avoid both difficulties, a hybrid approach has been devised. Experimental measurements of the vibrations of the structure are taken in a water tank using a scanning laser Doppler vibrometer, where the laser beam is shone onto the submerged structure through an optical quality window. The surface vibration data are then used to derive the specified normal velocity for a numerical calculation of the radiated sound power radiated in free-field conditions. The laser allows dense surface meshes to be defined such that the calculations can be performed to relatively high frequencies. To demonstrate the general accuracy of the calculations, radiation efficiencies are computed for submerged unbaffled plates, and the results are compared to reverberation measurements and to fully numerical predictions.

10:15–10:30 Break

10:30

1aSA10. Mechanical and radiated power and radiation efficiency of point driven panels. J. Ertel (Phys. Dept., U.S. Naval Acad., 572 Holloway Rd., Annapolis, MD 21402-5026, jpe@nadn.navy.mil), J. Dickey, and G. Maidanik (David Taylor Res. Ctr., Annapolis, MD)

The radiation and partial radiation efficiencies from point and line driven panels were previously defined and investigated by the authors [J. Acoust. Soc. Am. **98**, 2888(A) (1995) and J. Sound Vib. **144**, 71–86 (1991)]. In this paper, the mechanical power dissipated in a point driven fluid loaded panel is studied and compared to the radiated power. The interdependence of the mechanical and the radiated powers is investigated, and they are related as fractions of the total input power. The dependencies of the mechanical and radiated power on frequency, fluid loading, and mechanical loss are further studied. In the present paper, the mechanical power as well as the radiation efficiency is shown to increase with increased damping in a panel while the radiated power decreases, as it must. These results again show the fallibility of the conclusion that ''a higher radiation efficiency necessarily implies more radiated power.'' The results of computer experiments are cited in numerical examples.

10:45

1aSA11. Interaction between wave-number pairs. Jean-François Ille and Jerry H. Ginsberg (G. W. Woodruff School of Mech. Eng., Georgia Inst. of Technol., Atlanta, GA 30332-0405)

When acoustic-structure interaction is analyzed according to the wave-number-based version of the surface variational principle (SVP), considerable computational effort is required to generate each coefficient in the quadratic sum forming the variational quantity. Examination of the wet-surface impedance, which represents the spectrum of pressure amplitudes generated by a specified spectrum of surface velocity amplitudes, reveals that many cross-impedance terms are very small. This suggests that some coefficients need not be computed. The paper introduces several *a priori* criteria for selecting the impedance terms to be omitted, based on the supersonic cutoff wave number. Each scheme is assessed by comparing its predictions to the convergent SVP solution. For the nonsymmetric azimuthal harmonics, the field quantities and the radiated power are well predicted if subsonic waves are ignored. In contrast, for the axisymmetric component, substantial errors (6 dB or more) for radiated power arise, unless a broad spectrum of subsonic waves are included in the formulation. The power is mostly reactive, being associated with an evanescent field, even for the supersonic spectrum. The study shows that small interactions between subsonic waves in the axisymmetric case can result in substantial radiative effects that are not modeled in ray theory analyses.

11:00

1aSA12. Does the Rayleigh–Ritz method for vibratory continuous systems actually converge to the analytical eigensolution? Jerry H. Ginsberg (G. W. Woodruff School of Mech. Eng., Georgia Inst. of Technol., Atlanta, GA 30332-0405)

The Rayleigh–Ritz method for continuous systems uses an N-term series with unspecified coefficients as the trial function for the Rayleigh ratio. Extremizing that ratio leads to N approximate natural frequencies $\omega_j^{(N)}$, $j=1,...,N$. The upper bound theorem states that the true values obtained by solving the field equations are such that $\omega_j \leqslant \omega_j^{(N)}$. The separation theorem states that adding a single term to the aforementioned series yields new estimates $\omega_j^{(N+1)}$, $j=1,...,N+1$, such that the previous $\omega_j^{(N)}$ fall in the intervals between the new values. Taken together, these theorems constitute a proof that the lower eigensolutions obtained from the Rayleigh–Ritz method should converge to the true eigensolution. However, both theorems assume infinite precision arithmetic. This paper uses the simple case of a cantilever beam to examine the behavior of the Rayleigh–Ritz method with increasing series length. Natural frequencies derived from different classes of kinematically admissible basis functions, drawn from monomials, trigonometric functions, and Bessel functions are examined relative to the upper bound and separation theorems. Most selections fail to yield properly behaved solutions if the series length is extended beyond 10–12 terms. In some cases the eigenvalue solver fails to find real eigenvalues, or to find the correct number of eigenvalues. Some of the basis function sets permit formulating the Rayleigh ratio functional analytically, rather than by numerical integration, but the results are the same. The failure of the method is shown to stem from ill-conditioning that arises as a consequence of similarity in the appearance of higher-order basis functions.

11:15

1aSA13. An overview of interaction between friction and vibrations. Adnan Akay (Mech. Eng. Dept., Carnegie Mellon Univ., Pittsburgh, PA 15213)

Friction is a function of both the interface properties and dynamic response of a friction pair. The true contact area and thus the total time-dependent friction and normal forces change as a result of the relative motion of the surfaces with respect to each other. Friction in a dynamic system has the dual role of both exciting vibrations as well as dissipating vibratory energy. In this presentation, mechanisms by which friction induces vibrations in dynamic systems are reviewed and the fundamental issues involved in friction force modeling are discussed.

11:30

1aSA14. Effects of laser stroke parameters on quantitative vibration measurements with stroboscopic shearography. Benjamin A. Bard (Appl. Res. Lab., Penn State Univ., P.O. Box 30, State College, PA 16804, bab132@psu.edu)

Digital shearography is a full-field speckle interferometric technique similar to electronic holography. Traditionally, shearography and holography have been used for vibration measurement with either time averaged or stroboscopic techniques. Time averaging images sinusoidal motion of an object's surface over many periods of vibration, resulting in a fringe pattern representative of the magnitude of the displacement mode shape. Stroboscopic illumination synchronizes short bursts, or *strokes*, of laser light with extrema of vibration. This essentially freezes motion of the vibrating surface, allowing it to be studied with techniques normally reserved for static deformation. In particular, phase stepping, an established technique for capturing a series of images and calculating the exact displacement at every point, can be applied to vibration measurement. If displacement amplitudes calculated from laser strobing and phase stepping are to be used for measurement of peak vibration response, corrections are necessary to compensate for errors due to the finite duration of the laser strokes as well as their improper timing due to system impedance. In this presentation, effects of stroke duration will be expressed mathematically and trends demonstrated experimentally. Potential solutions for stroke offset correction will be discussed and experimental validation provided. [Work sponsored by the PSU Applied Research Laboratory.]

MONDAY MORNING, 1 DECEMBER 1997 CALIFORNIA ROOM, 11:00 A.M. TO 12:30 P.M.

Session 1aSC

Speech Communication: Workshop: Basic Science at the Intersection of Speech Science and Communication Disorders

Lynne E. Bernstein, Cochair
Spoken Language Processing Laboratory, House Ear Institute, 2100 West Third Street, Los Angeles, California 90057

Gary Weismer, Cochair
Waisman Center, University of Wisconsin, 1500 Highland Avenue, Madison, Wisconsin 53705

11:00

1aSC1. Chair's introduction to the workshop on basic science at the intersection of speech science and communication disorders. Lynne E. Bernstein (Spoken Lang. Processes Lab., House Ear Inst., 2100 West Third St., Los Angeles, CA 90057) and Gary Weismer (Univ. of Wisconsin, Madison, WI 53705)

In the study of speech perception and production, there is a history of developing, evaluating, and revising models and theories based on data collected exclusively from talkers and listeners judged to be free of communication disorders. Basic research with clinically relevant disorders is sometimes confused with, and dismissed as, clinical/applied research. In other branches of science, including, for example, psycholinguistics and biology, study of clinical disorders is regularly employed as one of the avenues for building and testing more comprehensive theories and/or models, and is viewed as a major source of knowledge concerning the physiological structures responsible for normal processes. The intent of the workshop format is to provide a forum for discussion of the significance of clinical disorders for the scientific areas of speech perception and production. A group of distinguished scientists has been invited: (1) to describe their own work involving disorders in speech production and/or perception; and (2) to comment on scientific, data analytic, philosophical, and pragmatic issues that are specific to the enterprise of incorporating data from clinical disorders into their work and their fields. The organizers encourage the attendance of scientists with and without research involving clinical disorders, as well as students.

Session 1pAO

Acoustical Oceanography: Acoustic Observations of Ocean Ridge Processes

Christian P. de Moustier, Chair
Marine Physical Laboratory, Scripps Institution of Oceanography, 9500 Gilman Drive, La Jolla, California 92093-0205

Chair's Introduction—1:25

Special Lecture

1:30

1pAO1. Underwater acoustics for seafloor geodesy. Fred Noel Spiess (Marine Physical Lab., SIO, UCSD, 9500 Gilman Dr., La Jolla, CA 92093-0205)

Geodetic data, particularly using electronic distance measuring and space-based techniques, are central to terrestrial studies of crustal deformation. A decade ago, no comparable capabilities existed for use in the Earth's extensive ocean-covered areas. It had been clear for some time, however, that underwater acoustics could play a key role, replacing or extending the electromagnetic methods used in nearly all terrestrial systems. Three classes of centimeter-capable systems have emerged. For short ranges, direct path measurements using high frequencies are preferred. At intermediate ranges (1–10 km) marker transponders can be interrogated from an intermediate vehicle and their relative positions calculated. Beyond about 10 km, inadequate knowledge of sound speed limits purely acoustic systems, but a combined GPS/acoustic method has been devised to cope with the need for data over important longer base lines. Since 1990, several systems have been implemented in the context of geologically relevant problems, particularly in the northeast Pacific. As operating experience has grown and real data are being analyzed, useful initial results are emerging in conjunction with insights into the problems that must be solved when moving toward future developments. [Work reported has been supported by NSF, NASA, NOAA, PGC, and USGS.]

Contributed Papers

2:00

1pAO2. Possible seismic evidence for fluid migration at the eastern Juan de Fuca Ridge flank. L. Zuehlsdorff, V. Spiess, and C. Huebscher (Dept. of Geosciences, Univ. of Bremen, Bremen, 28334, Germany)

Young and permeable crust along oceanic ridges is often characterized by large-scale fluid migration depending on permeability and heat distribution. The eastern flank of the Juan de Fuca Ridge off the west coast of North America is buried under an unusual thick sediment cover and is therefore suitable for detailed studies on fluid exchange processes. In autumn 1996 a high-resolution seismic survey was carried out in the vicinity of ODP Leg 168 drill sites to collect detailed information about sedimentary structures and acoustic anomalies in relation to basement morphology. The seismic equipment was optimized for high lateral and vertical resolution to identify small-scale features from the surface down to the basement as potential migration paths for fluids. The acquired seismic sections exhibit numerous vertical zones with reduced reflection amplitudes which may represent paths for fluid advection. The lateral amplitude changes are visible using seismic sources with different frequency content and are apparently related to basement topography. Observations on parallel profiles indicate a 2-D geometry. Theoretical studies suggest that local porosity changes may be the reason for the acoustic visibility of the proposed advection zones.

2:15

1pAO3. Sonar observations of deep ocean hydrothermal flows. Darrell R. Jackson, Christopher D. Jones, Timothy Wen (Appl. Phys. Lab., College of Ocean and Fishery Sci., Univ. of Washington, Seattle, WA 98105), Peter A. Rona, and Karen G. Bemis (Rutgers Univ., New Brunswick, NJ 08903-0231)

A mechanically scanned sonar operating at 330 kHz has been used to image hydrothermal flows on ocean ridges using two different techniques. Scattering from particulates is used to image smoker plumes [Rona *et al.*, Geophys. Res. Lett. **18**, 2233–2236 (1991)], and scintillation of seafloor backscatter is used to image diffuse flows. Results will be presented from cruises on the East Pacific Rise and the northern Cleft segment of the Juan de Fuca Ridge. Plume images have been analyzed to extract physical parameters relevant to plume theory. Observations of diffuse flow employ cross correlation of ping doublets. Scattering theory is used to relate the correlation levels to the variance of temperature fluctuations. [Work supported by the NOAA National Undersea Research Program through the West Coast Undersea Research Center.]

Invited Paper

2:30

1pAO4. Seismoacoustic recordings of a volcanic event on the Mohns Ridge, 1995. Donna K. Blackman and John A. Orcutt (Scripps Inst. of Oceanogr., La Jolla, CA 92093-0225, dblackman@ucsd.edu)

A swarm of earthquakes occurred on an oceanic spreading center north of Iceland in late 1995 and was recorded by U.S. Navy hydrophone arrays in the Norwegian Sea. About two dozen of these events on the Mohns Ridge were detected by onshore seismic arrays. Analysis of the hydrophone array data shows that 7000 events occurred; the greatest number (40/h) took place in a 3-day period in the middle of the 70-day duration of the swarm. Recorded arrivals include P waves, water-borne T waves, PT pairs, and P waves reflected at the seasurface. Separation in arrival times of P and T waves are used to determine relative locations of events and their spatial evolution throughout the swarm. The locus of activity shifts by 30–40 km during the swarm but steady migration of activity is not apparent. This suggests that surface breaks during dike injection did not occur or, at least, did not generate T waves, or that the swarm was not associated with a simple dike emplacement along the ridge. The time history of the activity, on the other hand, is quite similar to that seen associated with two known volcanic events on the Juan de Fuca and Gorda ridges.

Contributed Papers

2:50

1pAO5. Earthquake studies using under-ice hydrophone data (''Spinnaker''). Robert A. Sohn, John A. Hildebrand (Scripps Inst. of Oceanogr., 8602 La Jolla Shores Dr., La Jolla, CA 92093-0205, ras@mpl.ucsd.edu), and Barbara J. Sotirin (Naval Command, San Diego, CA 92152)

Preliminary studies indicate that the Spinnaker array, a network of hydrophones currently deployed in the Arctic Ocean, may be used to monitor seismicity of the Arctic Basin, as well as long distance teleseismic arrivals from the Southern Hemisphere. The Arctic Basin is a tectonically complex region that has seen few seismic studies, and the Spinnaker array has the potential to monitor some of its most interesting features, such as the Nansen–Gekkel Ridge (the slowest spreading ridge in the world), in near real time. In addition, teleseismic arrivals at the array may have raypaths that coincide closely with the Earth's spin axis. These data may prove useful to current studies of the crystalline alignment and differential spin of the Earth's inner core.

3:05

1pAO6. Locating ridge seismicity near Ascension Island using hydroacoustic and seismic data. Jeffrey A. Hanson and Holly K. Given (Inst. of Geophys. and Planetary Phys., UCSD, La Jolla, CA 92093)

Recently, there has been a surge of interest in monitoring small-scale, mid-ocean ridge seismicity as made possible by the increasing availability of data from military-run hydrophone arrays. In the past, long-term ridge seismicity has been studied using the global networks of seismic stations. Since the young lithosphere at the ridge is relatively weak, it is not able to support large earthquakes and much of the seismicity associated with active deformation is not detected by the seismic networks. In addition to seismic body waves, mid-ocean ridge earthquakes usually produce a T phase—a water-borne acoustic wave—which travels great distances with little attenuation and is well recorded by hydrophones. This paper examines earthquakes from a section of the Mid-Atlantic Ridge near Ascension Island, using data collected from five U.S. Air Force hydrophones that surround the island and the seismic station ASCN located on the island. By integrating the hydroacoustic T phase and the local body-wave phases, earthquakes can be located down to a magnitude of 2.8 on a segment of the ridge with an accuracy of about 5 km.

3:20

1pAO7. Implications of nonfractal seafloor stochasticity on acoustical scattering from the Mid-Atlantic Ridge. Vincent Lupien and Arthur B. Baggeroer (MIT, Cambridge, MA 02139)

Acoustical and bathymetric data were collected near the Mid-Atlantic Ridge as part of the Acoustical Reverberation Special Research Program (ARSRP) in 1993. The wideband time-domain envelope statistics of backscatter from prominent bathymetric features exhibit a non-Rayleigh character which previous researchers have described as event-like. The envelope probability density functions (pdf's) show enhanced tails at high levels which can be a source of active sonar clutter. It is proposed that the origin of such clutter is single-scale, nonfractal roughness. High-resolution bathymetry reveals a power spectral density (PSD) with power-law form. Wavelet analyses reveal a single-scale character to the roughness. In order to test the hypothesis, multiscale and single-scale realizations of the measured PSDs are used in numerical simulations of time-domain backscatter. At the range and azimuthal resolutions in the experiment, the envelope pdfs for multiscale surfaces are Rayleigh, while the single-scale surfaces lead to enhanced tails as observed in the data. The conclusions drawn are that along with an interface's rms height, correlation length, and power spectral shape, one should also be concerned with its *scale structure* because it plays an important role in the physics of wave interaction at random interfaces.

3:35

1pAO8. Fractals, wavelets, and stochastic interface modeling. Vincent Lupien (MIT, Cambridge, MA 02139)

The seafloor is one of many natural interfaces which, when viewed as a random process, exhibits a power law decay, i.e., the power spectral density (PSD) decays as A/f^b, $A>0$, $b>0$ as $f\rightarrow\infty$. Power law spectra are usually taken as evidence that the stochastic process is multiscale or fractal. Multiscale interfaces exhibit features at all scales and their acoustical properties are distinct from those of single-scale interfaces, which contain features closely clustered about a mean size. Thus, determination of the *scale structure*, or size distribution of component features, is important in characterizing random interfaces for acoustical applications. However, because the PSD is only a second moment characterization, a power law PSD can allow both single-scale and multiscale processes. Only if the process is Gaussian is the PSD a complete description. Wavelet representations succeed where Fourier methods fail, as they are ideally suited for determining scale structure. In the case of fractal interfaces, the wavelet coefficients are Gaussian and independent across scale and space. Single-scale interfaces lead to a dependence of wavelet coefficients across scale for a given spatial location and vice-versa.

Session 1pPA

Physical Acoustics: Thermoacoustic Engines

William P. Arnott, Chair
Desert Research Institute, Atmospheric Sciences Center, P.O. Box 60220, Reno, Nevada 89506-0220

Contributed Papers

1:30

1pPA1. Thermoacoustic measurements on a single pore with an applied temperature gradient. Larry A. Wilen, Gabriela Petculescu, and Andi G. Petculescu (Dept. of Phys. and Astron., Ohio Univ., Athens, OH 45701, wilen@helios.phy.ohiou.edu)

Previous measurements [L. Wilen, J. Acoust. Soc. Am. **101**, 3022(A) (1997)] probed the geometry-dependent thermal coupling between a gas and the walls of single pores over a wide range of ratios of the thermal penetration depth to pore size. A volume modulation method was described which allows one to measure the complex compressibility of the pore directly. The present work extends those results to pores with an applied temperature gradient. Unlike the earlier experiments, the results are sensitive to terms in the thermoacoustic equations which depend on a gradient, and the theoretical predictions can be tested in a direct way. After a brief review of the experimental technique, data for pores of different lengths and gradients will be presented and discussed. Possible new applications of the technique will be proposed. [Work supported by Ohio University Research and Sponsored Programs.]

1:45

1pPA2. Experimental investigation on the transition to steady state of self-oscillation of a thermoacoustic prime mover. Bosen Zhao, Fathi Jebali, and Maurice X. Francois (LIMSI, CNRS, B.P. 133, F-91403 Orsay, Cedex, France)

A thermoacoustic prime mover can be considered as a nonlinear system in which an initial small perturbation is amplified until nonlinear mechanisms lead to a new balanced state. A series of experiments were carried out to help understand the nonlinear mechanism. The transition process is divided into three periods: a growing period in which the pressure grows exponentially with time to its maximum; a falling period in which the pressure decreases to its minimum; and a period in which the pressure is restablished slowly until the steady state. A rapid decrease in temperature difference between the cold and hot heat exchangers is observed when the pressure arrives at the maximum. The difference between maximum pressure and steady-state pressure depends on the mean pressure in the prime mover: the higher the mean pressure, the greater the difference. A model of positive feedback amplifier with nonlinear resistance is proposed to describe this phenomenon.

2:00

1pPA3. Improvements in an experimental thermoacoustically driven thermoacoustic refrigerator. Thomas J. Hofler and Jay A. Adeff (Dept. of Phys., Naval Postgrad. School, Code PH/HF, Monterey, CA 93940, hofler@physics.nps.navy.mil)

A thermoacoustically (heat) driven, thermoacoustic refrigerator apparatus, having a novel topology, has produced significant cooling power and efficiency. It has achieved a cooling temperature span of 60 °C, and 91 W of cooling power at a span of 25 °C, with an overall COP of 0.15. These numbers were produced with a porous carbon refrigerator stack and a driver stack comprised of stainless steel wire mesh disks. While easy to fabricate, the wire mesh stack is known to produce poor efficiency with the commercially available wire sizing. New modifications currently being fabricated include: a stainless steel foil roll stack for the driver, a plastic film roll stack for the refrigerator, as well as improved heat exchangers. Substantial increases in amplitude, cooling power, and overall COP are anticipated as a result of these modifications. [Work supported by Office of Naval Research.]

2:15

1pPA4. Numerical optimization of a novel thermoacoustically driven thermoacoustic refrigerator. Thomas J. Hofler (Dept. of Phys., Naval Postgrad. School, Code PH/HF, Monterey, CA 93940)

Previous modeling work on a novel heat-driven refrigerator has generated overall COP numbers in the range of 0.45 using pure helium gas. The modeled conditions are for commercial or air-conditioning cooling temperatures, with a hot drive temperature of 400 °C. The method used for these results involved the manual optimization of a modest number of engine parameters. New modeling work utilizes optimization algorithms in conjunction with a larger parameter set. A more aggressive choice of operating conditions including binary gas mixtures and higher drive temperatures are also explored, resulting in much higher overall COP values. [Work supported by the Office of Naval Research.]

2:30–2:45 Break

2:45

1pPA5. Numerical investigations of a two stack annular prime mover. Hsiao-Tseng Lin (Vehicle Eng. Dept., Chung Cheng Inst. of Technol., Taiwan), Ralph T. Muehleisen (Dept. of Phys., Naval Postgrad. School, Monterey, CA 93943), and Anthony A. Atchley (Penn State Univ., University Park, PA 16802)

A numerical analysis of the two-stack thermoacoustic prime mover in an annular resonator has been made. It was found that the addition of a second stack significantly alters the eigenmodes of a single stack annular prime mover such that thermoacoustic growth may be supported. Simulations predict that one mode of the two-stack prime mover could reach onset at a reasonable temperature. The performance of the two-stack prime mover with various spacings between the stacks is presented. The results are compared to the performance of single-stack annular prime mover in a constricted annular resonator. [Work supported by the Office of Naval Research and the American Society for Engineering Education.]

3:00

1pPA6. Design of a thermoacoustic refrigerator for visualization measurements. Martin Wetzel and Cila Herman (Dept. of Mech. Eng., Johns Hopkins Univ., 3400 N. Charles St., Baltimore, MD 21218, herman@titan.me.jhu.edu)

In previous studies, holographic interferometry (HI) combined with high-speed cinematography was applied to investigate the oscillating temperature field in a thermoacoustic refrigerator model [Wetzel *et al.*, J. Acoust. Soc. Am. **100**, 2846(A) (1996)]. While important flow parameters of thermoacoustics could be matched in these experiments, it was not possible to model all length scales because of design requirements imposed by HI. In order to resolve this problem, a novel design algorithm was developed based on the short-stack boundary-layer approximation.

The advantage of this algorithm is that all design parameters are presented in normalized form, and therefore, the design optimization can be performed in the normalized multidimensional parameter space without determining the actual dimensions of the device. Once this optimization has been completed, the actual dimensions can be determined according to the design requirements imposed by HI. At the meeting, the design as well as initial measurements with the thermoacoustic refrigerator will be presented. [Work supported by the Office of Naval Research.]

3:15

1pPA7. Analogy between the circular acoustic waveguide with axial temperature gradient and the electrical transmission line with source and loss. Bosen Zhao, Fathi Jebali, and Maurice X. Francois (LIMSI, CNRS, B.P. 133, F-91403 Orsay, Cedex, France)

A current source introduced by an axial temperature gradient in a circular acoustic waveguide has been examined. It is shown that the effect of the axial temperature gradient is to amplify (or attenuate) the acoustic power in the waveguide where losses due to viscous effect and thermal effect are described, respectively, by a series impedance per unit length and a shunt admittance per unit length. This analogy is very useful for calculating transmissions for cases such as thermoacoustic machines, automotive mufflers, or pulse combustors. Examples of application for a thermoacoustic prime mover calculation and its experimental comparison are presented.

3:30

1pPA8. Determination of source data for a thermoacoustic prime mover by the multiload method. Bosen Zhao, Fathi Jebali, and Maurice X. Francois (LIMSI, CNRS, B.P. 133, F-91403, Orsay, Cedex, France)

A thermoacoustic prime mover can be used as a sound source to drive thermoacoustic refrigerators. The nitrogen-filled prime mover studied is a quarter-wavelength resonator that produces sound at nominally 86 Hz for a temperature difference of $\Delta T \geqslant 430$ K. The pressure and specific impedance at the mouth of the prime mover were measured as a function of the load realized by different reservoirs. These measurements allow one to determine the characteristics of the prime mover at operation states and therefore to predict the maximum acoustic power at a perfect match. Nonlinear losses in the prime mover are analyzed by estimating the measured impedance.

MONDAY AFTERNOON, 1 DECEMBER 1997 — CHAMBER ROOM, 2:00 TO 4:30 P.M.

Session 1pSA

Structural Acoustics and Vibration: Acoustic Scattering from Elastic Structures

John J. McCoy, Chair
School of Engineering, The Catholic University of America, Washington, DC 20064

Contributed Papers

2:00

1pSA1. Local admittance fluctuations and the scattering from a cylindrical shell with many internal oscillators. J. A. Bucaro, D. M. Photiadis, B. H. Houston (Naval Res. Lab., Code 7130, 4555 Overlook Ave. S.W., Washington, DC 20375-5350, jbucaro@ccf.nrl.navy.mil), and A. J. Romano (Sachs Freeman Assoc., Landover, MD 20774-5322)

The angular and spectral scattering patterns from local admittance fluctuations, assumed to be caused by the presence of mechanical, dumbbell oscillators attached more or less randomly in the interior of a cylindrical shell, are predicted numerically and compared to the experimental measurements reported by Bucaro *et al.* [Proc. ASME, Noise Control and Acoustics Division, NCA **22**, 87–92 (1996)] and Photiadis *et al.* [J. Acoust. Soc. Am. **101**, 895–899 (1997)]. The numerical results are shown to be in reasonable agreement with what is observed experimentally. It is suggested that scattering contributions from such local admittance fluctuations can be a significant component in the midfrequency scattering patterns of submerged targets of interest. [Work supported by the Office of Naval Research.]

2:15

1pSA2. The radiation and vibratory response of a fluid-loaded structure with high internal complexity. B. H. Houston, D. M. Photiadis, and J. A. Bucaro (Naval Res. Lab., Code 7130, 4555 Overlook Ave. S.W., Washington, DC 20375-5350, houston@lpsa1.nrl.navy.mil)

Recently, experiments were reported in which complex internal structure was shown to dramatically influence the scattering cross section of fluid-loaded shells [Photiadis *et al.*, J. Acoust. Soc. Am. **101**, 895–899 (1997)] and where spatially varying local admittances were proposed to explain the observed scattering details [Bucaro *et al.*, J. Acoust. Soc. Am. **100**, 2721 (1996)]. Here, measurements of the *vibratory* response of this same structure [a ribbed shell with a large number (~1000) of internal oscillators] are shown. Comparisons are made to the response of an identical shell with no internal oscillators. For the complex structure, no distinct pass and stop bands for any of the circumferential orders is seen, and a high degree of localization at all circumferential orders and frequencies is observed. Generally speaking, the wave-number-frequency plots associated with the complex structure are significantly different than those for the simple framed cylinder at all but the highest azimuthal components $(n>17)$. Moreover, the wave-number decompositions of these data reveal a strong dominance of local bending in the response of the complex structure and evidence that strong coupling between the circumferential orders contributes to the significantly enhanced radiation levels. [Work supported by the Office of Naval Research.]

2:30

1pSA3. A multiresolution analysis of scattering by a pair of local regions of complex heterogeneity. John J. McCoy (Catholic Univ. of America, Washington, DC 20064) and Ben Z. Steinberg (Tel Aviv Univ., Tel Aviv, Israel)

The scattering applies to flexure waves in a beam. Each of the local regions have a spatial extent that is a small multiple, say 2 or 3, of the length of the waves in the homogeneous background beam. The complexity of the heterogeneity refers to an irregular variation on a length scale that is a small fraction, say 1/100, of the size of the scattering region. A multiresolution analysis refers to a two-step solution methodology, by which an ''effective'' property description of the scatterers is first obtained on accomplishing a formulation substructuring in a wavelet-based phase space. The spatially filtered component of the scattered field, i.e., the only component that obtains outside the regions of heterogeneity, is then obtained via a formulation expressed in this effective description. Demonstrated, both analytically and numerically, is that the interaction of

the scattering regions is accommodated in the second step of the solution procedure. Thus the effective description of each of the regions is that which applies in the absence of the second region, provided the regions do not overlap.

2:45

1pSA4. Local modeling of complex elastic structures. Douglas M. Photiadis (Naval Res. Lab., 4555 Overlook Ave. S.W., Washington, DC 20375)

Several recent results, both numerical and experimental, have indicated that the structural acoustic response of large vibratory systems with complex internal structure is dominated by local response in the midfrequency range. These results have clear implications regarding control strategies for noise control, but also may have a significant impact on the acoustic scattering characteristics of complex structures. In this paper, this phenomena is analyzed theoretically using two disparate models, a conventional stochastic wave scattering model and a new type of model, which treats the system instead as a set of coupled, local resonators. This local model more naturally accommodates the observations concerning the generally localized response but is somewhat more difficult to associate with the geometrical characteristics of the ''base structure'' than a more conventional elastic wave scattering model. A number of aspects involving the vibration are analyzed and contrasted between the two models; the occurrence of simple, relatively isotropic spreading of energy, increased damping resulting from the internals, increased damping resulting from radiation into the surrounding fluid, and last but not necessarily least, the impact of local resonance behavior.

3:00

1pSA5. Feature extraction based on eigenvector analysis applied to the monostatic scattered field of a ribbed finite cylinder. Angie Sarkissian (Naval Res. Lab., Washington, DC 20375, angie@aqua.nrl.navy.mil)

Feature extraction based on eigenvector analysis is applied to the monostatic response of a ribbed finite cylindrical shell with hemispherical end caps. The method, which is based on the Karhunen–Loeve expansion, is applied in the frequency domain to extract features for optimal representation of the data. An orthonormal set of eigenvectors that form a set of basis functions are computed by diagonalizing the correlation matrix. The expansion of the monostatic scattered field with the resultant set of basis functions is optimal because a small number of the functions is required to approximate the scattered field at each orientation of the scatterer. Such a representation reduces the dimensionality of the problem by more than an order of magnitude. The method is applied to two frequency ranges. In the first case, enhancements in target strength are present due to the phase matching of the elastic waves to the acoustic waves in the exterior fluid. In the second case, Bloch wave resonances are present due to the periodicity of the ribs. It is shown that as larger variations are present in target strength as a function of frequency, a larger number of eigenvectors are necessary to approximate the scattering response.

3:15–3:30 Break

3:30

1pSA6. Angle dependence of the meridional leaky-ray backscattering enhancement from the end of a tilted finite cylinder. Convolution analysis and a numerical test for shells. Philip L. Marston and Scot F. Morse (Dept. of Phys., Washington State Univ., Pullman, WA 99164-2814)

Reflection of a meridional leaky ray from the far end of a tilted cylinder produces a backscattering enhancement when the tilt angle is close to the leaky wave coupling angle. The ray lies in the meridional plane defined by the incident wave vector and the cylinder's axis. The peak magnitude of this enhancement was related to the end-reflection coefficient by a convolution surface integral [P. L. Marston, J. Acoust. Soc. Am. **102**, 358–369 (1997)]. The more difficult integrals descriptive of the dependence on tilt angle are numerically evaluated in the present study. Though the exact analytical solution of the problem considered is unknown, for comparison an approximate partial-wave series description is available where the boundary conditions at the ends of the cylinder are such that the end-reflection coefficients become unimodular. For antisymmetric leaky Lamb waves on long thick and thin shells, the enhancement width, magnitude, and location each agree with the result from the integral when a unimodular reflection coefficient is also assumed in the convolution formulation. The convolution analysis should also apply to meridional leaky Rayleigh waves reflected by the ends of a solid cylinder. [Work supported by the Office of Naval Research.]

1pSA7. Abstract withdrawn.

3:45

1pSA8. Observations of backscattering of obliquely incident plane waves by composite cylindrical shells constructed from isotropic and transversely isotropic layers. Gregory Kaduchak (Appl. Res. Labs., Univ. of Texas, P.O. Box 8029, Austin, TX 78713-8029)

Acoustic backscatteirng from finite, composite cylindrical shells in water is examined. The shells are comprised of N layers, which may be described by orthotropic or transversely isotropic materials. The present research examines experimental observations of the scattering signatures obtained from obliquely incident plane waves in the mid- and high-frequency regions. Scattering effects are viewed in both the time and frequency domains. Attention will be given to the similarities (and dissimilarities) of the scattering signatures, which are the chief contributors to the backscattering form function as the symmetry axis of the transversely isotropic layers is rotated away from the axial direction. To localize the sources of scattered radiation at oblique incidence, scattering effects are viewed with high-resolution techniques, which include narrow transmit/receive beams as well as synthetic aperture sonar. [Work supported by the Office of Naval Research.]

4:00

1pSA9. Applications of the causality condition to acoustic scattering. J. Gregory McDaniel (Dept. of Aerosp. and Mech. Eng., Boston Univ., 110 Cummington St., Boston, MA 02215)

The causality condition states that the response of a passive system cannot precede the cause. Under certain conditions, the causality condition leads to a Hilbert transform relation between the magnitude and phase of the complex Fourier transform of a system's response. This relation has profound implications for those attempting to design passive structures whose desired scattering characteristics are expressed in the frequency domain. Unless the causality condition is satisfied in the frequency domain, the structure is not physically realizable. In this presentation, some novel applications of this relation are developed for a one-dimensional fluid-loaded structure which scatters incident sound in the backward and forward directions. In each application the reflection and transmission coefficients, which are the complex Fourier transforms of the reflected and transmitted pressures due to an impulsive incident pressure wave, are subject to the causality condition. The Weiner–Lee transform, which is derived from the Hilbert transform but is more easily implemented numerically, is used to find complex reflection and transmission coefficients given only their frequency-dependent magnitudes. By using this information and structural reciprocity, one can find an impedance matrix of a structure which scatters sound in a specified way.

4:15

1pSA10. Acoustic excitation of generalized normal-mode vibrations on hemispherically endcapped and on infinite elliptic cylinders. G. Maze, J. Lanfranchi, D. Décultot, J. Ripoche (LAUE, URA CNRS 1373, Univ. of Le Havre, France), and H. Überall (Catholic Univ., Washington, DC 20064)

The concept of normal-mode vibrations of elastic objects, and their resonant acoustic excitation, can be straightforwardly demonstrated analytically for objects of canonical shape (spheres, circular cylinders) only, but it evidently remains valid for objects of completely general shapes. Mode analysis may be extended to these by invoking the principle of phase matching of surface waves (circumferential waves) that encircle the object after their acoustic excitation [H. Überall, L. R. Dragonette, and L. Flax, J. Acoust. Soc. Am. **61**, 711 (1977)], thereby creating standing waves around the object (resonances) that correspond to its normal modes of vibration. Experiments have been performed leading to the excitation of resonances of submerged spherically-endcapped circular cylinders, and of infinite elliptic cylinders, which were interpreted according to the phase-matching concept, thus leading to a description of their vibrations as generalized normal modes.

MONDAY AFTERNOON, 1 DECEMBER 1997 SENATE/COMMITTEE ROOMS, 1:30 TO 5:00 P.M.

Session 1pSC

Speech Communication: Workshop: Basic Science at the Intersection of Speech Science and Communication Disorders

Lynne E. Bernstein, Cochair
Spoken Language Processing Laboratory, House Ear Institute, 2100 West Third Street, Los Angeles, California 90057

Gary Weismer, Cochair
Waisman Center, University of Wisconsin, 1500 Highland Avenue, Madison, Wisconsin 53705

Continuation of Workshop—See Session 1aSC page 3068

Session 1pSP

Signal Processing in Acoustics and Structural Acoustics and Vibration: Signal Processing for Multi-Channel Vibrational Analysis

David J. Evans, Chair
National Institute of Standards and Technology, Building 233, Room A147, Gaithersburg, Maryland 20899

Chair's Introduction—1:00

Invited Papers

1:05

1pSP1. New techniques for nonlinear system analysis and identification from random data. Julius S. Bendat (J. S. Bendat Co., 833 Moraga Dr., No. 10, Los Angeles, CA 90049)

Direct and reverse MI/SO (multiple-input/single-output) techniques are new frequency-domain techniques that provide accurate practical methods to analyze and identify the dynamic properties of nonlinear systems. The Dirac MI/SO technique is applicable to nonlinear systems with specified parallel linear and nonlinear transformations. The reverse MI/SO technique is applicable to nonlinear systems that can be reasonably modeled by nonlinear integrodifferential equations of motion. Nonlinear systems are included where the coefficients can be constants or frequency dependent. Simulated or measured data can have arbitrary probability and spectral features. Each of the identified nonlinear components can be evaluated at any desired frequency with separate coherence functions. Thus these techniques represent a significant advance in using real-world data to help improve the design and understanding of nonlinear systems. This presentation will review the analytical basis of these new techniques and illustrate their application from material in the latest book by J. S. Bendat [*Nonlinear System Techniques and Applications* (Wiley-Interscience, New York, 1998)].

1:45

1pSP2. Measurement and analysis of structural wave types on fluid-loaded shells. David Feit and David C. Warwick (Carderock Div. Naval Surface Warfare Ctr., 9500 MacArthur Blvd., West Bethesda, MD 20817)

The frequency-wave-number spectrum of the vibration field of force excited, fluid-loaded cylindrical shells is a significant determinant of the shells' acoustic radiated field. This presentation discusses the procedures used and results obtained using accelerometer arrays to sample the vibrations on a number of different type shells. The arrays are formed by distributing accelerometers with uniform spacing, either along a longitudinal generator or around a circumference of the cylinder. Depending on the orientation of the accelerometers relative to the shell's midsurface, the dispersion characteristics found allow for the identification of the various wave types that exist on fluid-loaded cylindrical shells. These are the quasi-flexural waves and in-plane membrane waves, both longitudinal and shear. In an early set of measurements, made in 1986, the shell structure could be considered as unstiffened, while the other results show the effects of stiffening ribs in the frequency-wave-number plots. These effects manifest themselves as aliased quasiflexural waves. The shapes of the dispersion curves are in good agreement with numerical results arising from analytical expressions.

2:15

1pSP3. Power flow in structures. Gunnar Rasmussen (G.R.A.S. Sound & Vibration aps., Skelstedet 10B, 2950 Naerum, Denmark)

Power released in or transferred to a structure will cause noise radiation, fatigue, or mechanical malfunction in the structure or parts connected to the structure. Nonlinear behavior is of great significance to the integrity of any structure and is therefore of fundamental interest. An ideal machine would produce no vibration at all because all energy would be channeled into the job to be done. In practice, vibration occurs as a by-product of the normal transmission of cyclic forces through the mechanism. Machine elements react against each other and energy is dissipated through the structure in the form of vibration and acoustic noise. If the surface area is large compared to an acoustic wavelength, acoustic intensity is a good indicator of dynamic activity. If the area is small compared to a wavelength at the frequencies in question, surface measurements using the vibratory motion on the structure's surface will be a good indicator. If the energy transfer takes place between two separate structures coupled at points, the point power measurement method should be applied. Two accelerometers, accelerometer and force gauge, two microphones, multi microphone arrays or laser techniques may be used for transduction. Signal processing and interpretation will be discussed.

2:45

1pSP4. Order tracking with multiple shafts and crossing orders. Håvard Vold (Vold Solutions, Inc., 1716 Madison Rd., Cincinnati, OH 45206)

Transient sinusoids that cross in frequency exhibit interaction phenomena that defy conventional tracking filter techniques. The Vold–Kalman filter explicitly uses shaft speed information from multiple shafts to decouple interacting orders through a simultaneous estimation. The estimation uses energy constraints to distribute the total signal energy between the orders. The outputs of the filter are time histories of complex envelopes of the order functions, without beating interactions and with no phase bias. The estimation is also independent of slew rates, such that highly transient events may be tracked with high fidelity. By modulating the complex envelopes by suitable carrier waves, time histories of the individual orders are obtained which can be used for sound quality studies and sound synthesis. The phase information allows for the construction of operating deflection shapes as a function of shaft, order, and shaft speed. Examples will be shown for vibrations in continuous rate belt drive transmissions and sound synthesis for torque converters.

3:15–3:30 Break

Contributed Papers

3:30

1pSP5. A comparison of partial coherence and singular value partial field decomposition in the context of near-field acoustical holography.
Hyu-Sang Kwon, J. Stuart Bolton (1077 Ray W. Herrick Labs., School of Mech. Eng., Purdue Univ., West Lafayette, IN 47907-1077), and J. K. Hammond (Univ. of Southampton, Southampton SO17 1BJ, England)

Sound fields radiated by complex noise sources, e.g., automotive engines, generally comprise superposed individual fields generated by incoherent subsources. When applying near-field acoustical holography (NAH) to such fields it is first necessary to decompose the total sound field measured on the hologram plane into coherent partial fields, each of which is then projected to a reconstruction plane where they are summed on an energy basis. The partial field decomposition is performed after first calculating the cross spectra between a number of reference microphone signals that have been conditioned by using either partial coherence or singular value decomposition procedures, and the spatially sampled sound pressures on the hologram plane. That cross-spectral information then allows the partial fields to be created. In this presentation, the performance of the two reference signal decomposition procedures will be compared theoretically and experimentally. In particular, it will be shown that partial coherence decomposition allows the partial fields to be associated with the fields radiated by individual subsources if the latter are sufficiently separated spatially. In contrast, the singular value decomposition procedure usually results in partial fields that combine the properties of the subsources, and are thus not directly related to the fields radiated by individual subsources.

3:45

1pSP6. Vibroacoustical multichannel diagnostics of energetic systems.
Leonid M. Gelman (Dept. of Nondestructive Testing, Natl. Tech. Univ. of Ukraine, 37, Peremogy pr., Kiev, 252056, Ukraine)

A new multichannel low-frequency vibroacoustical diagnostics method of energetic systems is considered theoretically and experimentally. The proposed method represents one of the approaches to efficient energy use and conservation. This method is based on processing of the low-frequency vibroacoustic noise of energetic systems. The main advantages of the method: early preventive nondemountable automatic diagnostics on all operating regimes of energetic systems.

4:00

1pSP7. Spectral function of the shocks of acoustic fluctuation phenomena.
Dat H. Tran and Alexsandr J. Krasilnikov (Dept. of Electron., Ukrainian Natl. Tech. Univ., Kiev, 252057, Ukraine)

In the description of the acoustic fluctuation phenomena (AFP), for example, sonocavitation noise, the signals of the acoustic emission, scattering on the heterogeneity, reverberation, and others, the model of shot noise is often applied and the principle of distribution is considered to be Gaussian. This model of AFP is proposed and proven with the conjecture that the shape of the impulse depends on the time of its generation, and amplitude of the impulse is subjected to the inhomogeneous Poisson process. It was shown that the characteristic function of the linear process is an unlimited dividend and, therefore, the function of the distribution or the probability density cannot be obtained in the evident mode, even through the mixed function. The spectral function of shocks (SFS) was proposed for the investigation of the principle of distribution and for the determination of the characteristic function. The algorithm was obtained that permits finding the SFS. Komologov, Levin, and some properties of SFS as well and the results of the calculation of SFS of the different AFPs are shown.

4:15

1pSP8. Statistical characteristics of the acoustic emission signals.
Dat H. Tran and Alexsandr J. Krasilnikov (Dept. of Electron., Ukrainian Natl. Tech. Univ., Kiev, 252057, Ukraine)

The typical block of signal processing in the instrument of diagnostic and construction damage prediction by the acoustic emission (AE) method was proposed, which consists of an inertial detector, comparator, and counter. The correlation between the registered parameters (number of impulses, activity, average level, density of amplitude distribution) and the initial AE flux on the input of the signal was described by the method of linear random processes. On the basis of phenomenon modeling, it was shown that, in an ideal condition, the discrete AE signal fits the gamma distribution. The dynamical approach to the model also attempts to extend it in relation to the three-dimensional coordinates. The deviations of the relation between the registered and proper AE meanings and the method of the results correction are shown.

4:30

1pSP9. Vibroacoustical multichannel nondestructive evaluation method of fatigue cracks.
Nadezhda I. Bouraou (Dept. of Orientation and Navigation, Natl. Tech. Univ. of Ukraine, 37, Peremogy pr., Kiev, 252056, Ukraine), Leonid M. Gelman, and Natalia Yu. Ossokina (Natl. Tech. Univ. of Ukraine, Kiev, 252056, Ukraine)

For nondestructive testing (NDT) and nondestructive evaluation (NDE), the low-frequency vibroacoustical free-oscillation method is used. For the first time, a theoretical investigation is carried out to differentiate between spectral density and decrement of free oscillations of testing objects in the presence and the absence of fatigue cracks taking into account the internal friction in the object material. The new analytical dependencies of the spectral density and decrement of testing object-free oscillations from the relative crack size, factor of internal friction, duration of NDT(E), and initial object speed are received, on the basis of which the new multidimensional vector of testing data for NDT(E) is proposed. Experimental results with aircraft engine blades in the presence and the absence of fatigue cracks, which match with theoretical results, are presented. The received results are common; therefore, they have been found to be expedient in taking into account the obtained results for forced oscillation NDT(E) methods.

Session 1eID

Interdisciplinary: Tutorial Lecture on The Dolphin Echolocation System

Alexandra I. Tolstoy, Chair
Integrated Performance Decisions, 224 Walalae Avenue, Suite 5-260, Honolulu, Hawaii 96816

Chair's Introduction—7:00

7:05

1eID1. The dolphin echolocation system. Whitlow W. L. Au (Marine Mammal Res. Program, Hawaii Inst. of Marine Biol., P.O. Box 1106, Kailua, HI 96734)

The sonar of dolphins may be the most sophisticated of all sonar systems, biological or man-made, in shallow waters and for short ranges. The Atlantic bottlenose dolphin emit short-duration (50–70 μs), high-frequency (120–140 kHz), broadband (40–50 kHz) echolocation signals with peak-to-peak amplitudes up to 228 dB *re*: 1 μPa. The type of signals used by dolphins play a significant role in their sonar discrimination capabilities. They have been observed detecting, classifying, and retrieving prey that is buried in sandy bottom up to a depth of about 0.3 m. In addition, controlled echolocation experiments have shown that dolphins can discriminate wall thickness, material composition, shape, and size of targets. The echolocation system of dolphins will be discussed in three parts. The first part will consider the properties of the receiving system (auditory capabilities). The second part will deal with the characteristics of echolocation signals, and the third part will consider several sonar capabilities.