The musical saw-operational features and simple dynamical theory

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ture of the welds. Experimental results were analyzed based on existing theories.

11:30

NN9. Nondestructive evaluation of subsurface flaws. V. V. Varadan, V. K. Varadan, T. A. K. Pillai (Wave Propagation Group, Department of Engineering Mechanics, The Ohio State University, Columbus, OH 43210), R. B. Thompson, and D. Shu (Ames Laboratory, University of Iowa, Ames, IA 50011)

Ultrasonic NDE is a convenient tool for detecting subsurface flaws in structural parts since the eddy currents technique is unsuitable when the flaw is more than a millimeter below the surface. Further, in most applications it is not possible to make measurements by bonding the transducer directly to the part to be tested due to difficult geometry. In this paper we propose an analytical method to study the scattering of waves from a subsurface flaw in an elastic half-space that interferes a fluid half-space (i.e., the part to be tested is immersed in water). The numerical results so obtained will be compared with experimental results for subsurface oblate spheroidal (flat cracks) cavities and the results will be critically analyzed to obtain information about the size and depth of the flaw.

11:45

NN10. The use of ray theory in locating and sizing cracks. A. N. Norris and J. D. Achenbach (Department of Engineering Sciences and Applied Mathematics, Northwestern University, Evanston, IL 60201)

The problem of crack sizing is one of fundamental concern to the nondestructive testing community. In this paper, two methods based on ray theory are proposed for the mapping of cracklike flaws in elastic media. The methods require as input data the arrival times of diffracted ultrasonic signals, which can be either directly measured or computed from high-frequency amplitude spectra. The first method maps points on the crack edge by a process of triangulation with the source and receiver as given vertices of the triangle. By successively shifting the source and/or the receiver incrementally, the direction of signal propagation, which is the necessary constituent required to complete the triangle, can be computed. The inverse mapping is global in the sense that no *a-priori* knowledge about the location of the crack is necessary. The second method is a local edge mapping which determines planes relative to a known point close to the crack. Each plane contains a flash point. The envelope of the plane maps an approximation to the crack edge. This procedure is an extension of the inversion scheme proposed by Achenbach *et al.* [Wave Motion **1**, 299–316 (1979)].

THURSDAY MORNING, 29 APRIL 1982 — ROOM 8, 9:00 A.M. TO 12:00 NOON

Session OO. Musical Acoustics VI: Instruments that Twang

Gabriel Weinreich, Chairman

Department of Physics, University of Michigan, Ann Arbor, Michigan 48109

Chairman's Introduction—9:00

Invited Papers

9:05

OO1. Vibrating plates as musical instruments. Thomas D. Rossing (Department of Physics, Northern Illinois University, DeKalb, IL 60115)

Vibrating plates are the source of sound in many percussion instruments and also serve as sound radiators in most string instruments. In string instruments the plates vibrate with small amplitude and thus exhibit linear behavior. In some percussion instruments, on the other hand, the initial amplitude may be large enough to introduce nonlinearity. Nonlinear behavior, for example, is largely responsible for the pitch glide noted in certain Chinese gongs [T. D. Rossing and N. H. Fletcher, J. Acoust. Soc. Am. Suppl. 1 **70**, S23 (1981)]. Plates can exhibit nonlinearities of either the hardening or softening type, depending upon their exact shape and state of stress. The modal frequencies of circular plates vibrating in the linear range can be fitted to a relationship $f = c(m + bn)^k$, where m and n are the numbers of nodal diameters and nodal circles. By proper choice of c it is possible to satisfy Chladni's law ($b = 2$, $k = 2$) over quite a wide range of frequency in flat plates. Nonflat plates require different choices of b and k.

9:35

OO2. The musical saw-operational features and simple dynamical theory. Arnold Tubis and Robert E. Davis (Department of Physics, Purdue University, West Lafayette, IN 47907)

The bowing of a flexed handsaw blade produces very nearly pure musical tones. The musical saw has been a staple of 19th and 20th century American folk music. It reached its peak of popularity in vaudeville acts of the 1920's especially in central U.S.A. Several composers including Katchaturian and Crumb have included saw solos in their orchestral compositions. The higher the musical note to be produced on the saw, the larger is the required blade flexure, and the farther from the handle end is the bowing point. These operational features of saw playing may be semiquantitatively accounted for by modeling the saw blade as a plate with two free edges and two clamped edges. The fourth-order nonlinear dynamical blade equation is solved exactly in the time-independent case to yield static shapes of the flexed blade. The static shape functions are then used in a linearized dynamical equation to obtain the modal frequencies and shape functions for small transverse oscillations about the static shapes. The required bowing points correspond to the antinodal positions of the dominant plane modes.

10:05

OO3. Sitar spectrum properties. A. H. Benade and W. G. Messenger (Department of Physics, Case Western Reserve University, Cleveland, OH 44106)

The main strings of a sitar are tuned to pitches corresponding closely to $F_3\#$, $C_2\#$, $G_2\#$, $G_3\#$, $G_3\#$, $C_4\#$, and $C_5\#$ (i.e., in 4ths, 5ths, and octaves). Playing is predominantly on the $F_3\#$ string, the tonic (*sa*) being at the 7th fret ($C_4\#$). There are also 11 sympathetic strings tuned to the notes of the raga. The measured and calculated inharmonicity is far less than that of Western stringed instruments. Sitar strings are thin, giving small stiffness inharmonicity and low wave impedance that reduces random inharmonicities from bridge/belly resonances. String length variations from first mode rolling and/or sliding on the curved bridge profile produces FM and AM sidebands of $\pm f_1$ from the upper partials. These components join with both plucked and sympathetic string partials to give harmonically related narrow-band clumps. The resulting tone has complex time behavior but well-marked pitch. Tuning to just frequency ratios is required since the beats arising from excitation of a mistuned string are not smeared by roughness due to inharmonicity. Raman's observation that plucking at $L/4$ need not remove the 4th partial from the tone is confirmed. Bridge-generated FM/AM provides part of the explanation; shock excitation of sympathetic strings via the bridge provides the rest.

10:35

OO4. Controlled retuning of guitar tuned-string groups during musical performance. Daniel W. Martin (Baldwin Piano and Organ Company, Cincinnati, OH 45202)

The chordal portamento effects produced by the pedal steel guitarist are now widely recognized as musical components of recordings and performances of popular music, especially in the country western category. This paper will describe the instrument, the means by which these effects are achieved, and the physical actions which occur, which are not so well known.

Contributed Papers

11:05

OO5. Temporal and spectral characteristics of Tambura tones. Adrian J. M. Houtsma (Room 36-755, Massachusetts Institute of Technology, Cambridge, MA 02139) and Edward M. Burns (G-26 Heavilon Hall, Purdue University, West Lafayette, IN 47907)

The tambura is a stringed instrument of the lute type that is used as a drone accompaniment in Indian concert music [V. L. Janakiram and B. Yegnanarayana, J. Acoust. Soc. Am. Suppl. 1 **62**, S43 (1977)]. A distinctive feature of this instrument is its bridge, which terminates the four strings on a slightly rounded surface rather than on a sharp edge. The instrument is typically played with a silken thread ("Jivali" or "life giver") wedged between strings and bridge surface, so that the strings "buzz" against the bridge. If the instrument is played without this thread, the curved bridge creates a nonlinear modulation effect by periodically changing the effective string length. Partials up to order 30 are found to be very nearly harmonic. Temporal, short-term spectral and perceptual characteristics of tambura tones played with and without the "jivali" are discussed.

11:20

OO6. Modes of vibration and modal coupling in a tamtam. Thomas D. Rossing and N. H. Fletcher (Department of Physics, University of New England, Armidale, New South Wales, 2351, Australia)

When a large tamtam is struck near its center with a heavy padded mallet, the initial deep sound slowly gives way to a delayed sound of shimmering overtones due to high-frequency modes excited by nonlinear coupling to the modes of low frequency. Although the exact nature of this coupling is not known at the present time, it can be described by a semi-quantitative theory which is consistent with experimental data observations. Coupling between two modes of high and low axial symmetry appears to depend upon one or more rings of hammered bumps. Modes of low frequency have decay times as long as 18 s, whereas modes of high frequency decay more rapidly. [Work supported by the U.S.-Australia Cooperative Science Program and by the Australian Grants Committee.]

11:35

OO7. The nonlinear vibrations of the spring doorstop. W. M. Hartmann (Institut de Recherche et Coordination Acoustique/Musique, 31 rue Saint-Merri, 75004, Paris, France)

The sonorous twang of the spring doorstop is known and beloved throughout the United States. The waveform consists of a series of impulses of partly random character with significant spectral energy up to 8 kHz. The inverse of the impulse spacing is the fundamental frequency and the waveform exhibits well-developed harmonics at least up to the 20th. Two polarizations of spring vibrations may be excited, but there is a preferred orientation. As the doorstop vibration decays the polarization rotates into the preferred orientation. The fundamental frequency rises by more than an octave (16 to 40 Hz is typical). The fundamental frequency increases linearly with the number of cycles; therefore it increases exponentially with time. Stroboscopic observation reveals no indication of wave motion along the spring axis. Therefore it is possible to model the system as two coupled, damped oscillators. The nonlinearity presumably arises from the compression of the spring, which produces a force discontinuity at the origin. Numerical solution of the coupled nonlinear differential equations reproduces most of the features of the spring vibrations, but as of this writing the computed frequency increase with increasing cycle number is not linear, as observed experimentally, but has positive curvature.