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Invited Paper

MODE COUPLING IN TONE SECTIONS OF A TENOR STEEL PAN.

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ABSTRACT

Since the SV IV[1] review report on modal analysis studies in steel pans a relatively complete survey of normal modes of a tenor steel pan has been conducted using electronic speckle interferometry. Like holographic interferometry, this technique relies on the time average of comparisons of quasistationary images in the extreme positions of normal mode motion. Computer image processing techniques enable contrast enhancement and close to real time interference pattern observation. A number of interference patterns associated with particular note section normal modes will be shown to illustrate mode patterns, linear coupling and amplitude dependent nonlinear coupling between note sections.

INTRODUCTION

The Steel Pan is likely the only truly original acoustic, as opposed to electronic, musical instrument of the twentieth century. It emerged out of the native culture of Trinidad and Tobago in the 1940s, and has since then spread to become an integral part of many percussion programs in US Universities. It has crossed the oceans to become a means for generating enthusiasm for music among Swiss school children

Traditionally the instrument is hand-crafted from commercial 55 gallon oil drums. The top with its filling holes is discarded, and the bottom will eventually become the playing surface. The next step in transforming the oil drum into a musical instrument is the sinking of the pan. In this phase the flat

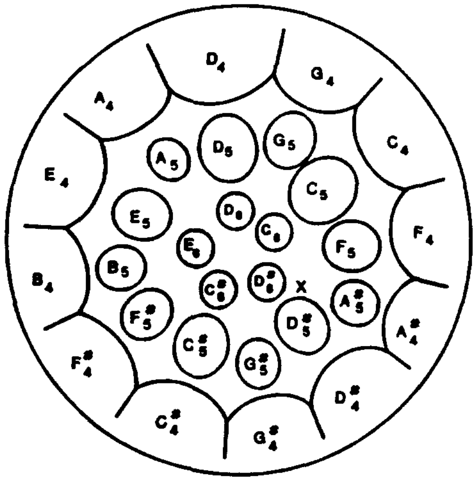


Fig. 1. Note layout for a double tenor pan

bottom is hammered into a segment of a hemispherical bowl. The depth of the bowl is determined by the intended pitch range of the instrument. The higher pitched pans receive the greater depth. The length of the skirt retained for the side of the pan also depends on the pitch range. For a bass pan almost the entire drum length is used for the skirt, while only a very short skirt is kept for a lead pan. Boundary lines for each note section are scribed and grooved with a punch into the playing area. Figure 1 shows a note layout pattern for one pan of a double tenor instrument. Raising the center of each note section to give it a small degree of curvature in a direction opposite to the general bowl curvature prepares the note sections for tuning[2]. Prior to tuning some surface hardening is accomplished either over an open fire, with subsequent quenching, or in some instances with a nitriding process[3]. The fundamental pitch of each note section is primarily determined by the size of the section, the mass distribution, the stiffness of the metal plate and the curvature. Tuning of each note section does not only adjust the pitch of the fundamental to the desired note value, but a skilled tuner attempts to tune at least three partials harmonically. This is done reasonably consistently for the low pitches in the large note sections.

It is interesting to note that while only the lowest frequency partials are actively tuned in harmonic relationships, the spectra of the instrument are rich in harmonic overtones. As many as 10 partials have been observed to be harmonically related. Figure 2 gives an example of the spectrum of the E_6 section of a Tenor steel pan. This rich harmonic content is ascribed to three sources[4,5]:

1.Radiation by harmonically tuned partials of the note section struck by the performer.

2.Coincidence of overtone frequencies in nearby sections with different fundamental resonance frequency.

3.Non-linear harmonic generation

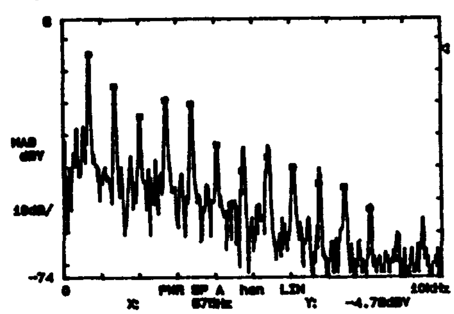


Fig. 2. E_6 Spectrum of a Double Tenor Pan

All three of these will be illustrated using electronic holography on a pan of a double tenor instrument.

EXPERIMENTAL TECHNIQUE

Holography relies on phase comparison of two self-coherent laser beams for image formation. Phase information is impressed on the object beam by letting it reflect from the surface of the vibrating pan. At resonance frequencies, the standing wave patterns of the bending waves on the pan surface result in a holographic interferogram, where images corresponding to the pan surface in positions of maximal displacement during the vibration interfere with each other. This gives rise to standard "bulls-eye" type interference patterns. The center of the bulls-eye identifies locations of maximal displacement and the brightest lines show the location of the nodal lines.Electronic holographic devices use fibre optic transmission lines to control the reference beam and a CCD camera to record the image. The CCD output is subsequently processed by a computer. The speed of computer processing permits near real time operation. Figure 3 shows the details of the instrumental arrangement of the electronic holographic interferometer.

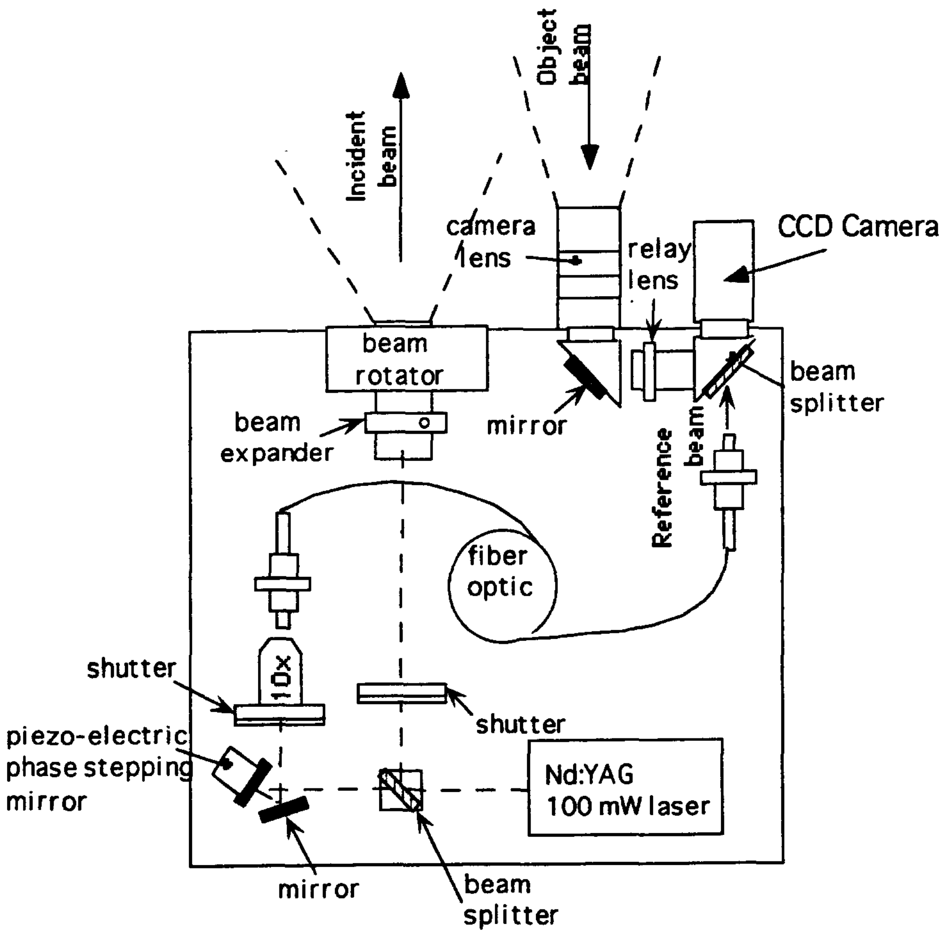


Fig. 3. Electronic holography system configuration

OBSERVATIONS

The pan is firmly clamped at three points as shown in figure 4, and mounted on a vibration isolation table along with the holographic interferometer.

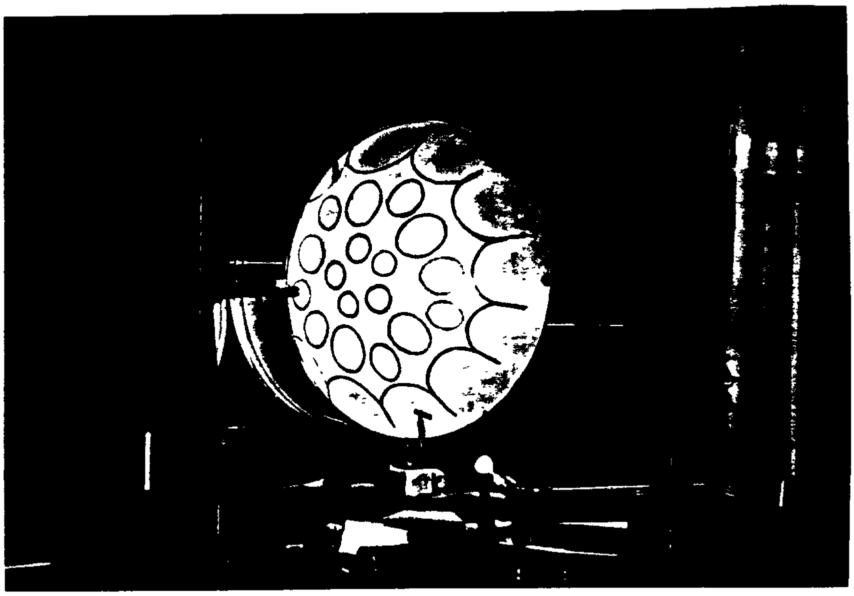


Fig. 4. Pan mounting arrangement

Pan excitation is accomplished by magnetic coupling. A small rare earth magnet is cemented to the back of the pan at the location marked by an X on fig. 1. Locating the drive point outside a note area avoids two problems. All possible normal modes can be driven, since the drive point will never be located on a nodal line, and the mass loading does not occur on a note section, so possible frequency shifts are minimized. A small coil is placed in very close proximity of the magnet. The coil is driven by an amplified sinusoidal audio signal, the drive current of which is monitored. Varying the drive current provides control of the driving force, and thus the vibration amplitude. Initial frequency choices were made to optimize the fundamental resonances of all 29 note sections. Subsequently frequencies were chosen to excite selected higher partials in various note sections. The images were copied from the thermal paper printer output of the computer. The information in the upper left corner of each picture gives a pan identification, followed by the note designation, followed by the frequency and the current through the drive coil. Figures 5 - 16 show examples of the interferograms obtained by electronic holography. In these figures the modes in the D#$_4$ note section are labeled, where the first index gives the number of horizontal nodal lines, and the second index the number of vertical nodal lines.

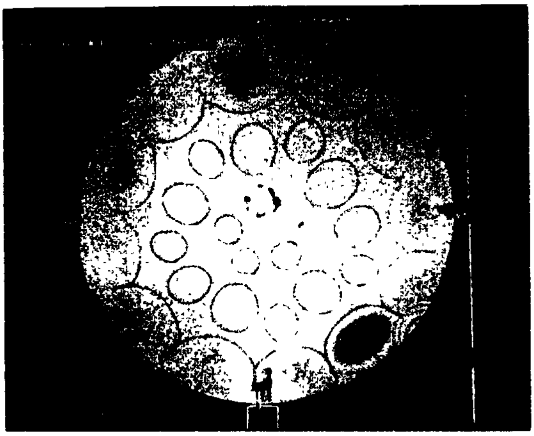


Fig.5: Mode (0,0) 311.4 Hz

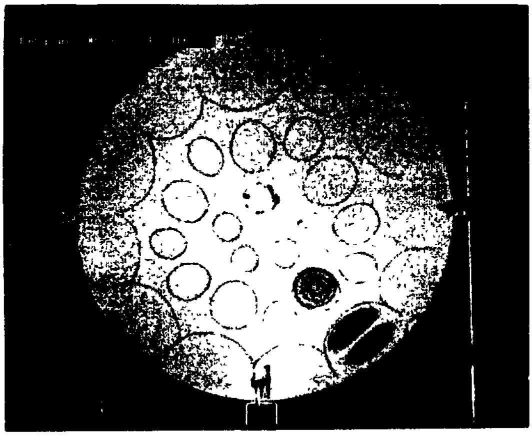


Fig. 6: Mode (1,0) 623.4 Hz

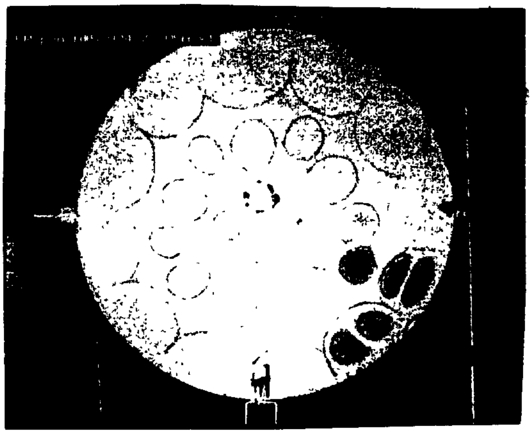


Fig. 7: Mode (0,1) 934.73 Hz

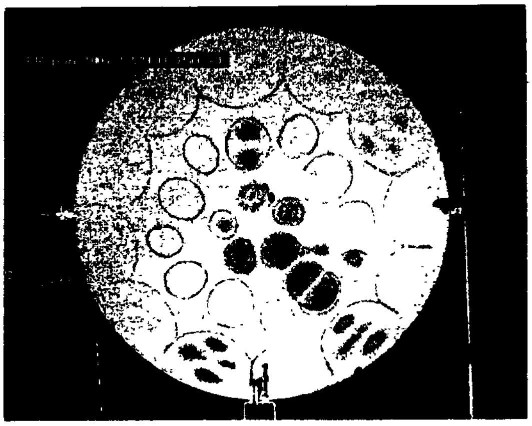


Fig. 8: Mode (2,0) 1229 Hz

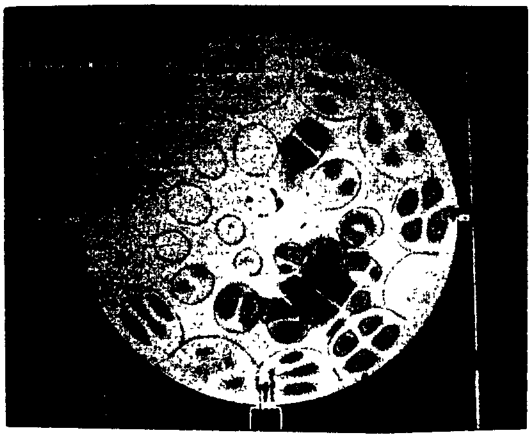


Fig. 9: Mode (1,1) 1545.5 Hz

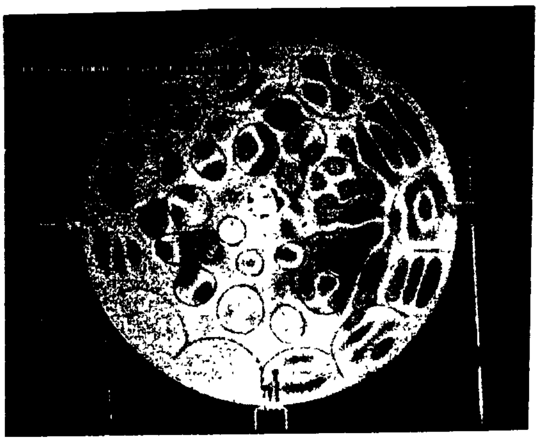


Fig. 10: Mode (3,0) 1869.9 Hz

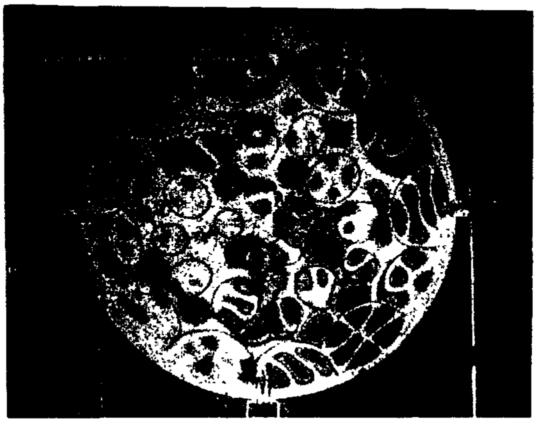


Fig. 11: Mode (2,1) 2120 Hz

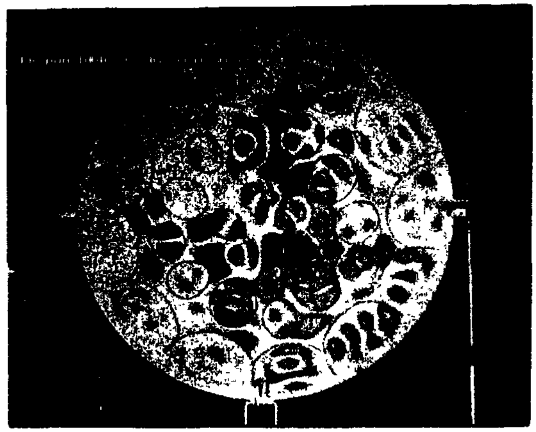


Fig. 12: Mode (0,3) 2462 Hz

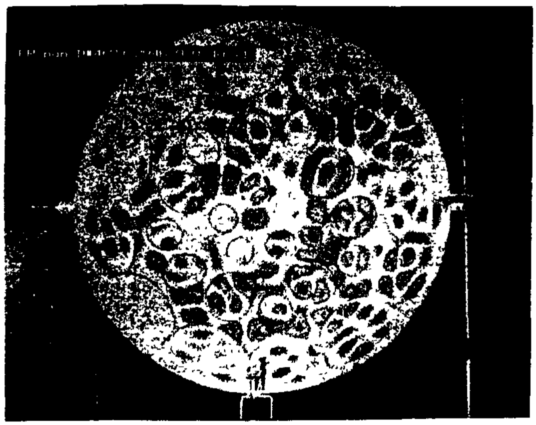
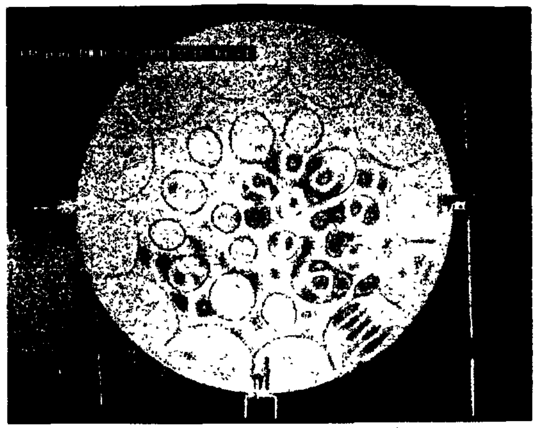


Fig. 13: Mode (3,1) 2946.9 Hz



Fig, 14: Mode (4,0) 2989.7 Hz

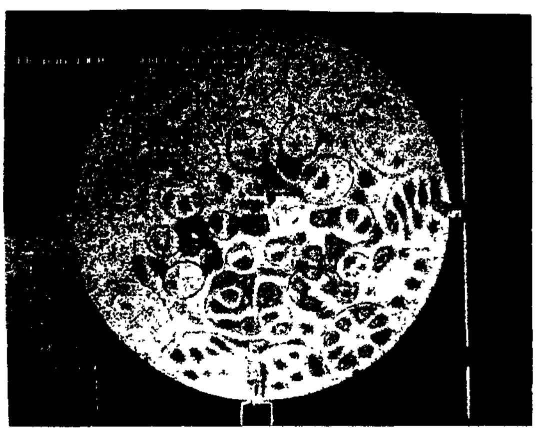


Fig. 15: Mode (2,2) 3049.7 Hz

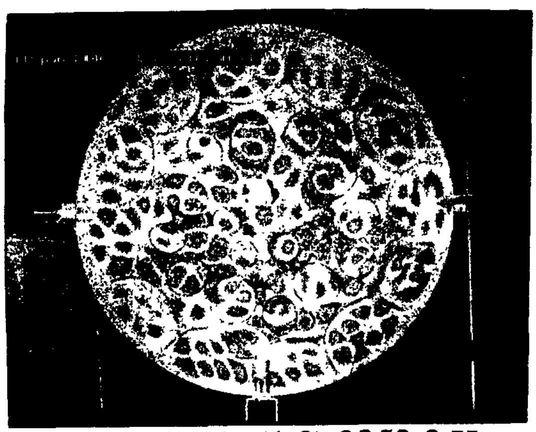


Fig. 16: Mode (1,3) 3252.9 Hz

As seen in figure 5, excitation at 311.4 Hz causes the D#$_4$ note section at the lower right to vibrate in its fundamental (0,0) mode. The fundamental resonance frequency of the D$_4$ and the E$_4$ sections are not too far from that, so barely beginning normal mode vibrations are perceptible in those sections. The D#$_5$ section is tuned an octave higher, and the second partial of the D#$_4$ is also tuned to the octave, so as seen in figure 6, both respond to 623.4 Hz excitation. Figure 7 gives a good example of linear harmonic mode coupling between sections. The A#$_5$ section has its fundamental a fifth above the D#$_4$ note. The third partial of D#$_4$ is harmonically tuned an octave and a fifth above the fundamental, consequently all three sections respond at the same frequency, A#$_5$ with the fundamental, A#$_4$ with the second harmonic, and D#$_4$ with the third harmonic. In figure 8 it is noted that all three D# sections respond. They are tuned in octaves, so the D#$_6$ section vibrates at the fundamental frequency, the D#$_5$ at the frequency of its second harmonic, and the D#$_4$ responds with the fourth harmonic. The central note circle includes the notes from C$_6$ to D$_6$ and with the relatively close proximity in frequency of the excitation frequency corresponding to the D#$_6$ all five note areas show some indication of response. The slight amount of darkening just to the right of the D#$_6$ note area and above the D#$_5$ note area shows the location of the drive point. For all the remaining pictures (fig. 9 - fig 16) the excitation frequency was chosen to optimize higher modes of the D#$_4$ note area. The mode index for each of the modes represented is given in the figure caption. The control variables for mode optimization were the drive frequency and the excitation force which was controlled by varying the audio signal current through the drive coil. The complexity of the response at higher frequencies is ascribed to harmonic tuning of the lower partials as discussed for figures 6,7, and 8. Careful frequency analysis of the higher frequency images shows many further examples of that. The relative frequency broadness of the pan section resonances is also responsible for coupling to other pan sections which are close in frequency. Previous studies[6] on nonlinear amplitude effects suggest that the almost universal response of all sections at high frequencies and high drive amplitudes must include some nonlinear response at frequencies other than the drive frequency. Details of that effect are still under investigation.

SUMMARY

A total of 66 interferograms were recorded in this mode survey. Additional different excitation point choices, careful amplitude dependent studies and output spectral studies for single frequency excitation are currently in progress. This study, along with previous work[7,8], has helped in identifying the mode shapes of the lower partials. This in turn has been of assistance to pan artisans in their effort to tune the lower partials harmonically. A knowledge of the location of the nodal lines identifies positions on the note section where physical changes have the most significant impact on frequency shifts of individual modes. The multiplicity of note section responses at higher frequencies gives some indication of the reason for the spectrally rich response of the instrument with its tonal characteristics.

ACKNOWLEDGEMENTS

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REFERENCES

1. Uwe J. Hansen, Thomas D. Rossing, D. Scott Hampton, and Ingolf Bork, *Modal Analysis Applied to Musical Instruments: The Caribbean Steel Pan.*, Proceedings the Fourth International Congress on Sound and Vibration, St. Petersburg, Russia, 1513 - 1520, (1996)

2. Uwe J. Hansen, Thomas D. Rossing, Ellie Mannette, and Kaethe George, *The Caribbean Steel Pan: Tuning and Mode Studies,* MRS Bulletin **20** (3), 44-46 (1995)

3. Felix Rohner, "Empirical Steel Pan Development: Materials, Shapes and Musical Concerns", paper presented at International Conference on Advanced Materials, Cancun, Mexico (1995)

4. Thomas D. Rossing, D. Scott Hampton, and Uwe J. Hansen, *Music From Oil Drums: The Acoustics of the Steel Pan,* Physics Today **49** (3), 24-29 (1996)

5. Neville H. Fletcher, and Thomas D. Rossing, *The Physics of Musical Instruments,* Springer-Verlag, New York (1991). See chap. 20.

6. D. Scott Hampton, C. Alexis, and T. D. Rossing, "Note coupling in Caribbean steel drums", paper presented at 115th meeting of ASA (1987)

7. Uwe J. Hansen, Felix Rohner, and Thomas D. Rossing, "Materials Considerations in Steel Pan Manufacture and Mode Studies", paper presented at Symposium Q of the Spring meeting of the MRS, San Francisco, (1994)

8. Uwe J. Hansen, "Modal Analysis Studies in Steel Pans", paper presented at International Conference on Advanced Materials, Cancun, Mexico (1995)