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EXPERIMENTAL VIBRATIONAL ANALYSIS OF DRUM CYMBALS.

Gianluca Di Giulio Enrico Esposito Claudio Santolini and **Lorenzo Scalise.**

Dipartimento di Meccanica, Universita' di Ancona.
Via Brecce Bianche
60131 Ancona - ITALY
Phone: +39-71-2204487
Fax: +39-71-2204813
e-mail: espo@mehp1.unian.it

ABSTRACT

Music has always played an important role in everyday life both as a universal amusement source and the ideal accompaniment for special occasions, like religious and civil ceremonies, battles and deaths. Not all sounds are created equal, and in particular it is common experience that high frequency sounds are generally stressing for the human auditory system and are associated with a sense of alarm.

However there exist musical sounds containing a handful of high frequency tones that are commonly regarded as pleasant and exciting: these are the clashes emitted by drum cymbals.

In this work we will present a detailed vibrational analysis of a cymbal, namely a "crash", produced by a small world famous Italian company. Scanning laser Doppler vibrometers will be employed to perform all measurements, thus allowing remote and contactless data acquisition on a large quantity of points.
Studied cymbal is entirely handmade and an acoustical analysis will also be conducted to better characterize its musical characteristics.

1. MUSICAL SIGNALS

Many investigations have studied the characteristics of musical signals and its relationship with human senses[1-5], trying to define a set of agreed values for frequency bandwidth and acoustic signal levels. Moreover, due to the high acoustic levels encountered in modern music reproduction, questions have been raised about users' safety[6-8].

1.1 Frequency spectra

High quality home hi-fi systems are designed to manage a frequency band of about 50 Hz to 18 kHz extending to about 20 Hz by adding subwoofer systems. A detailed survey of music spectra found in modern CDs put in evidence that in some cases the low limit of these systems is reached and 10 Hz tones are also found. Human pitch perception is limited at 12 Hz, so these signals represent extremely rare cases of limited practical interest[3]. A more frequent low frequency limit is given by the lowest A note on the piano keyboard, about 27 Hz.

Highest note on the same keyboard extends to about 4200 Hz, but electronic instruments could show more extended ranges. We must note that "the proportion of energy above 20 kilohertz is low for most instruments; but for one trumpet sample it is 2%; for another, 0.5%; for claves, 3.8%; for a speech sibilant, 1.7%; and for the cymbal crash, 40%"[5]. A practical usable limit may thus be fixed at 15 kHz.
However, traditionally accepted frequency limits are much restricted than those indicated, namely 50-8500 Hz, and also international standards for acoustic devices testing, for example DIN 45573, recommend to filter signals above 2 kHz and below 100 Hz.

To evaluate the present actual situation in comparison with old recordings, a brief investigation has been conducted on several CD spanning different musical genres and recording dates[9]. CDs have been sampled using a Pentium II 266 MHz based PC equipped with a Yamaha OPL3-SA sound card and a portable 200 MHz system hosting a Turtle Beach Tahiti sound card. Wave files have been analyzed with the Bruel and Kjaer Sound Quality Type 7698 analysis program. No remasterized CD has obviously been considered for this investigation. Some conclusions may be derived as regards frequency band extension. Improvements of both recording techniques and reproduction devices have generally decreased the signal low frequency limit. This fact it is particularly evident when looking at traditional rock music spectra, where in forty years the limits has moved from 80 down to 40 Hz.
Higher frequencies have not followed this tendency, with the only exception of the traditional rock spectra again. In

any case, measured spectra do not appear to show any significant content above 15 kHz.
As expected, classic music shows a spectrum roughly limited to 50-8000 Hz, thus confirming the oldest data.

1.2 Signal dynamic features

A high dynamic range that can be expressed by crest factors (CF) characterizes musical signals. In Table 1 we report average, maximum, and minimum values of CF measured from the same sampled CDs previously employed for spectral investigation. As can be seen, classic music has the highest values and also shows the highest difference between max and min values; max values of 20 dB are also reported in the literature[10].

Crest factors (dB re 1 V)				
	Average	Max value	Min Value	Δ
Classic	17.16	22.21	13.9	8.31
Disco	11.93	14.79	9.33	5.46
Trad. Rock	12.94	13.89	12.02	1.87
Hard rock	12.87	14.47	10.79	3.68
Jazz	14.58	18.71	11.34	7.37
Ambient	11.72	14.19	9.68	4.51

Table 1 - Crest factors of musical signals.

Peak pressure values recorded during live exhibition vary among musical genres but levels in the range of 100 dB are quite common. An orchestra playing a fortissimo will reach 118 dB[4] and during a brief survey conducted by one of the authors in churches to establish sound levels during masses, average peak levels of almost 97 dB were recorded.
Values reported in the literature[1] for rock groups remain in the range of the 105-110 dB but nowadays PA systems are designed to deliver peak levels of 130 dB, so these figures look quite limited.

2. DRUM KITS

The most common drum set is known as the "Jazz Drum"[11], and consists of five drums: 14" snare drum, 22" bass drum, 16" floor tom, and 12" and 13" rack toms (usually simply called toms). Two cymbals and one hi-hat complete this set of drums (see Figure 1). It was developed in the US around 1935 and since then has undergone numerous variations, due to different musical genres and playing styles.

2.1 Cymbals

Cymbals are very old instruments. In 1500 BC, the Hindus already made highly evolved music. They used cymbals with a small, diameter, usually in combination with singing and dancing. Because of various trading-routes, the cymbals, as well as other instruments, like the bass drum, were spread over Asia. Since 700 AD, especially the Armenians appeared to be very competent at making

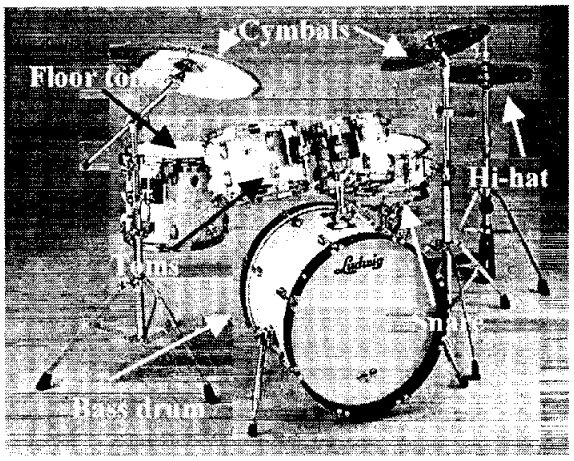

Figure 1: Jazz drum set.

cymbals. Then, in 1100 - 1300, the crusaders brought these cymbals to Europe. The Turkish introduced the cymbals again in 1550, but this time together with their bass drum and toms. However, it was only after the 80's that drummers could rely on a very wide range of cymbals of different dimensions and acoustic properties.
Best cymbals are produced nowadays using the "Bronze Bell" alloy, formed by 80% copper and 20% tin. Lower cost cymbals are made of brass and may be mass-produced by stamping. On the contrary, the most valuable types are made entirely by hand following a five steps process:

1. casting
2. tempering
3. lathing
4. shaping and first hammering session
5. shaving

Passing from the first to the last step 2/3 of the material is removed and final selection is done by ear. In Figure 2 an example of manual lathing is shown.

In this work we will investigate a 14" crash cymbal, a type of cymbal usually employed not to play rhythms or patterns on, but to give an accent to some important musical moment.

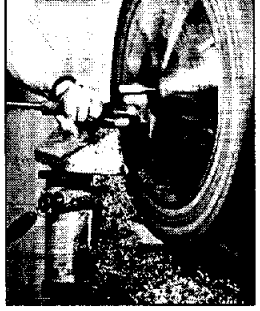

Figure 2: Cymbal hand lathing.

3. MEASURMENTS ON SAMPLE CYMBAL

Three sets of vibrations measurements have been conducted on a sample 14" crash, each set differing for the excitation method, namely a woofer loudspeaker, a horn loudspeaker and a piezo exciter[12]. In all cases a Scanning Laser Doppler Vibrometer (SLDV) has measured surface vibration levels. One set of acoustical measurements has also been conducted to evaluate the acoustic spectrum of the cymbal and its decay time.

3.1 Equipment and experimental set-ups

A scheme of the measurement set-ups that have been implemented is reported in Figure 3. Three different exciting signals have been used: white noise in two different bands (0.02 - 1 kHz and 1-20 kHz) and single sinusoids at different frequencies. The signal generator contained in the SLDV system has implemented all signals

A Gearing&Watson PA30 amplifier has been employed to boost signals for both the loudspeaker types, while a custom built high power amplifier has been employed for the piezo actuator.
An SLDV system from Ometron has been employed to measure vibrations of body, namely a VPI4000 scanning system. This system measures up to 1 m/s with a full scale bandwidth of about 200 kHz.
A Bruel & Kjaer PULSE multi channel system has been used to acquire and analyze acoustical signals measured by a Bruel & Kjaer Falcon 4188 prepolarized capacitor microphone and Type 2671 high impedance preamplifier.
Acoustical sources are represented by two custom built enclosures, for an 8" woofer and a 150 W high efficiency horn respectively.

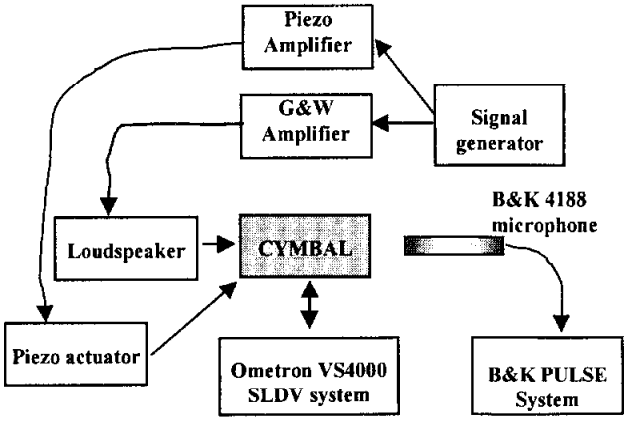

Figure 3: Scheme of experimental set-up.

In Figure 4 a photo of the laboratory is shown. The cymbal as not been superficially treated by the constructor to better preserve the musicality of the bronze. To maintain this characteristic no diffusing medium has been deposited on the metal disk. However, we had to slightly defocus the laser beam to avoid photo detectors overload.

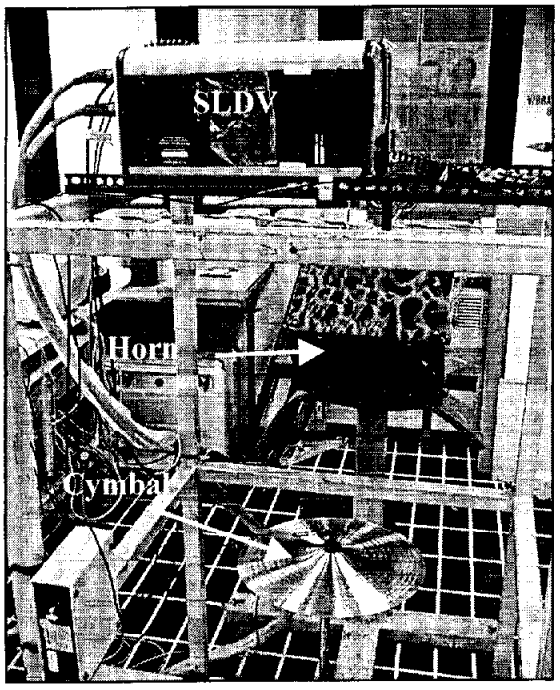

Figure 4: Photo of experimental set-up.

3.2 Measurement results

3.2.1 Acoustic response

The crash cymbal has been hit in two different positions by a standard wooden drumstick:

1. in the middle of the dish (the most common location for hitting);
2. near the central dome.

Figure 5 and 6 show frequency and time response as measured by the PULSE system for the first situation. Largest peaks are to be found in a bandwidth confined to 8 kHz with a sharp decrease after 15 kHz. Some values have been identified and reported on the same figure for later comparison.

Time response has been zoomed to the first 15 ms, to show the extremely fast signal decay. The measured waveform has been acquired and stored as a wave file and then post processed by the Bruel & Kjaer "Sound Quality" software package. A CF of 27 has been calculated, the highest value ever measured during our sessions and a possible treat for even the most sophisticated instrument.

Figure 7 reports the frequency spectrum obtained by hitting the central dome of the crash. The spectrum shows a similar decrease after 15 kHz but the central part of the spectrum is much more populated of strong resonance peaks. This could be expected since the dome represents the thickest and most rigid part of the cymbal.

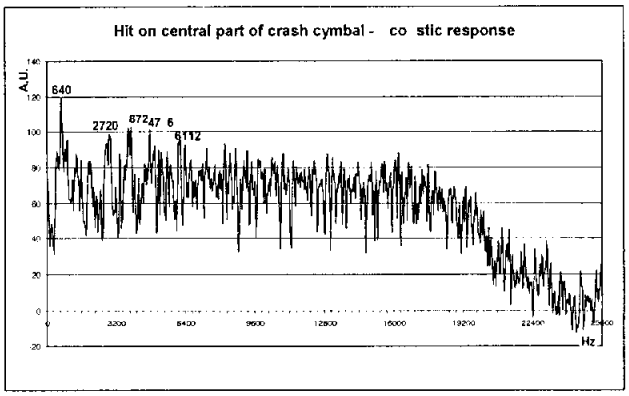

Figure 5: Frequency spectra of centrally hit cymbal.

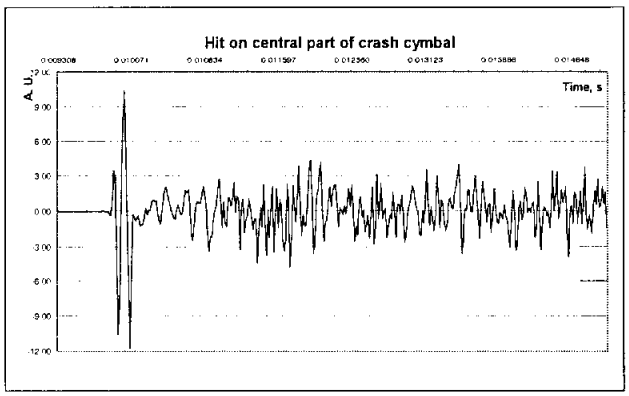

Figure 6: Time response of centrally hit cymbal.

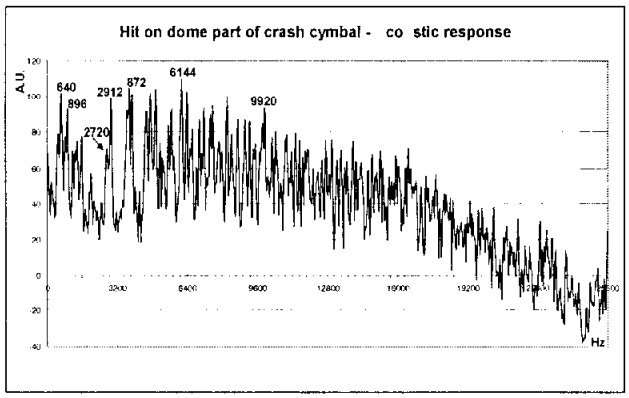

Figure 7: Frequency spectra of dome hit cymbal.

We observe in both cases an high frequency limit of about 15 kHz, thus confirming our previous measurement of musical spectra. However the cymbal may show a frequency spectrum quite rich of upper order harmonics.

3.2.2 SLDV measurements

In Figure 8 a 10 kHz spectra obtained by the SLDV measuring on the central part of the crash is reported. The cymbal has been acoustically excited.

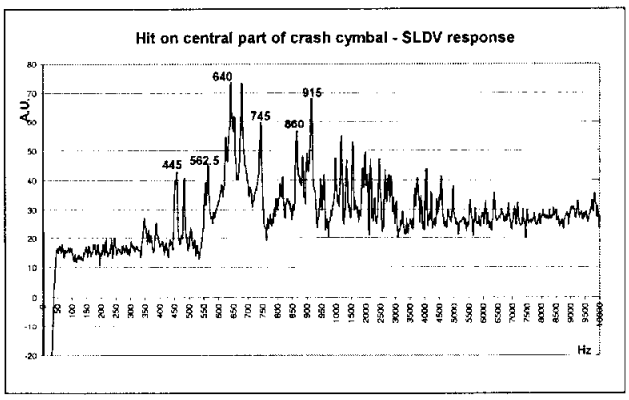

Figure 8: Frequency spectra of centrally hit cymbal (SLDV).

The first relevant peak is observed at 445 Hz, followed by a mode at 562.5 Hz and finally the first peak observed by the acoustic measurement system, that is to say 640 Hz. More than 60 peaks have been considered and measured using the different signals and exciters mentioned above. In Table 2 modes reported in following figures are summarized along with employed exciters.

Frequencies of modes and type of exciter (W=woofer, H=Horn, P=Piezo)			
440	W	2775	H
580	W	3875	H
640	H	6112	P
745	H	9920	P

Table 2. Frequencies of modes and exciters.

To properly excite higher modes the piezo actuator has been used. The horn loudspeaker was effective, too, but the necessary SPL was beyond safety limits.
Modes do not always show a perfect circular symmetry due to the hand working of the cymbal; this is particularly evident in mode 0,1 at 440 Hz.
Circular nodes develop approximately above 1 kHz and mode shapes becomes increasingly complicated also for the presence of the central rigid dome.

4. CONCLUSIONS

The acoustical and vibrational behavior of a hand made 14" crash cymbal has been investigated.
When compared to average musical spectra, this instrument presents a wider than usual frequency response, with a full 15 kHz bandwidth. A crest factor of 27 has been calculated by its time response, an extremely high value even for a musical instrument.

Modes have been investigated starting by frequency spectra acquired by actually playing the cymbal, so to concentrate on the most practically relevant ones. Hand production greatly influences results in terms of modes' symmetry and makes each cymbal a case study.

With the present study a first approach to the systematic characterization of cymbals has been performed and most important modes have been individuated.
This will constitute a first step for a complete study aimed at better understanding the relationship between human perception of cymbal sound and technically measured data.

Following this direction, a sound quality study will be performed, comparing expensive hand made cymbals with cheaper pressed brass ones. Moreover a new cymbal, a 20" ride, will also be investigated.

5. ACKNOWLEDGEMENTS

We wish to thank a lot Mr. Luigi Tronci, co-owner of UFIP, Pistoia-Italy, who kindly presented us with the crash cymbal we empèloyed for the measurement sessions. He also furnished the ride cymbal that we will be the object of the next publication and in general gave us a lot of precious advice about cymbals and their production process.

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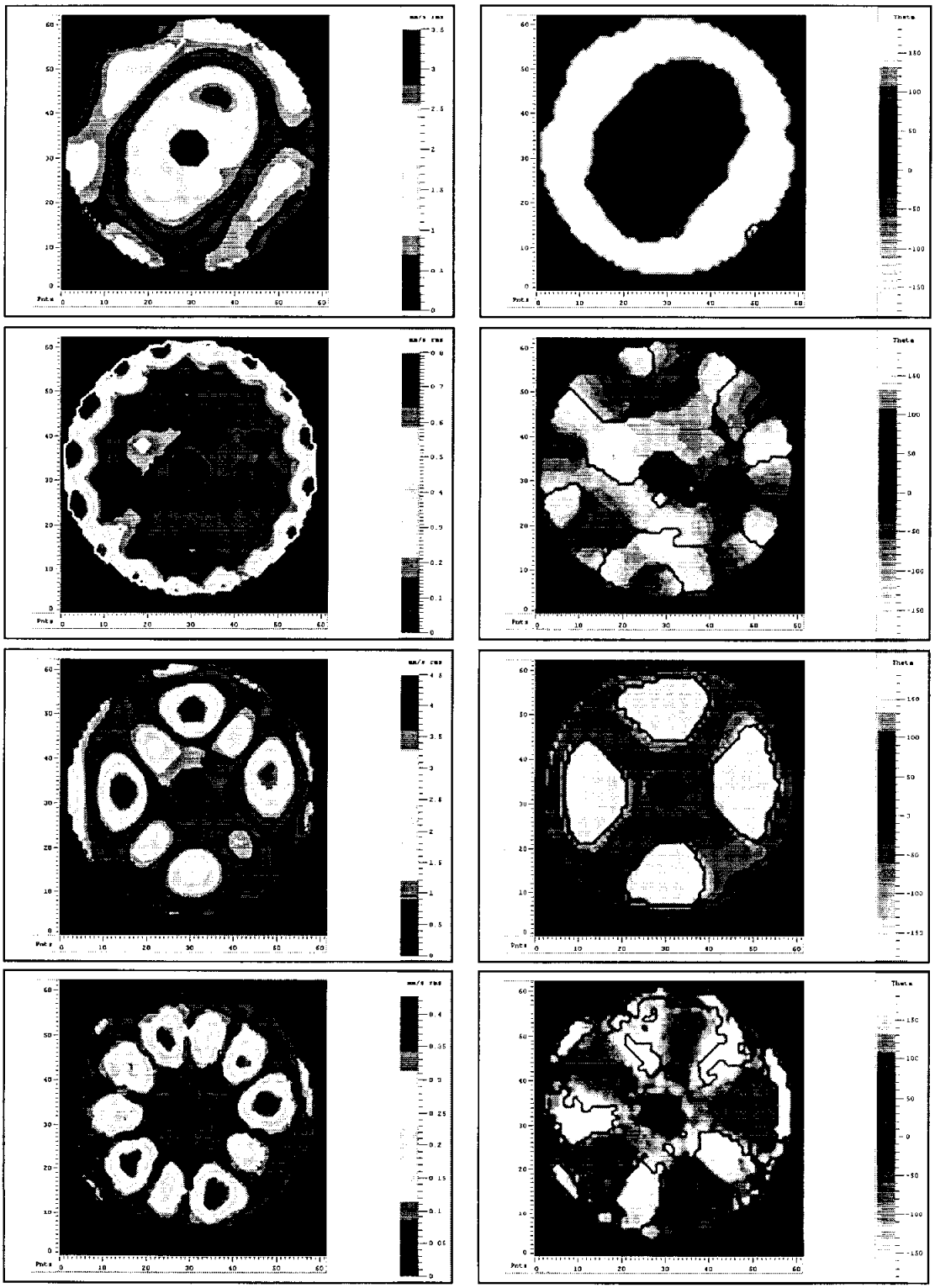

Figure 9: Amplitude (left) and phase (right) of modes at 440, 580, 640, and 745 Hz.

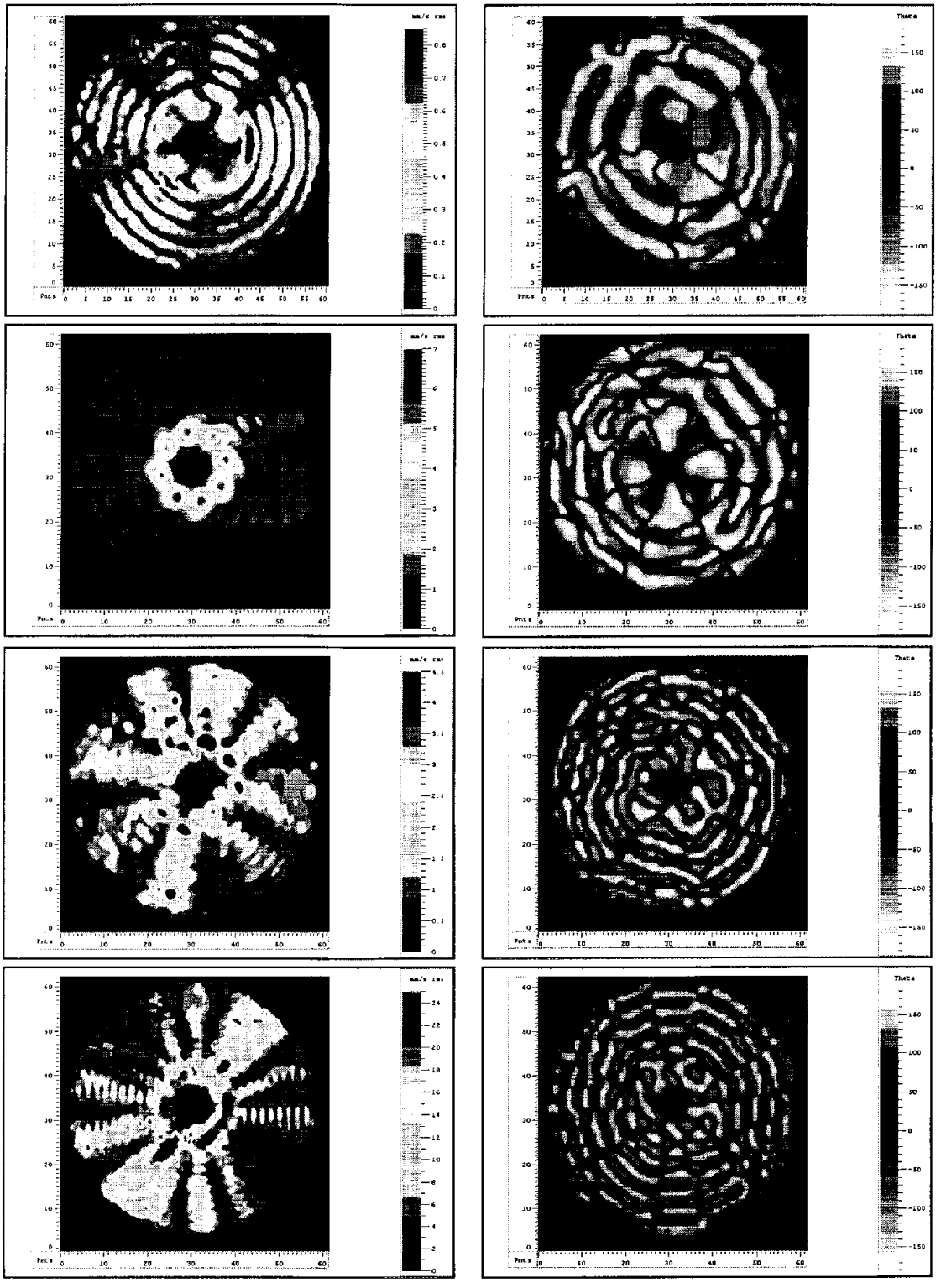

Figure 10: Amplitude (left) and phase (right) of modes at 2775, 3875, 6112, and 9920 Hz.

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