Cymbals with Harmonics Sound, a Method for Design the Cymbals, and Percussion Instruments with Cymbals

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(一)Introduction

This work aims to design a special type of percussion instrument. Wang and Hsieh [1] adopted finite element analysis (FEA) as well as optimization method to design two types of metal plates that have special triad chord sound effect. Wang et al. [2] designed a set of stainless tubes as the percussion instrument that contains two octave musical notes. The analytical FE model is validated by comparing modal parameters obtained from FEA and experimental modal analysis (EMA). The pitch frequency of each tube can be well tuned to fit standard musical note frequency.

In the part of percussion instrument design, model verification is an important technique to be applied by adopting FEA and EMA on the target structures. Wang and Tsai [3] studied the copper gong and developed the FE model to obtain structural vibration modes. The percussion sound can be identified from face mode of $(r,\theta)=(1,0)$, $(2,0)$ and $(3,0)$. Wang and Chang [4] investigated another type of traditional cymbal to obtain both theoretical and experimental modal parameters, respectively, and showed the percussion sound related to vibration modes.

Wang et al. [5] discussed the sound radiation mechanism for the cymbal set and adopted three metrics to categorize the percussion instrument, i.e. pitch frequency, overtone frequencies, and continuity. This work is inspired from their investigation that they found a near harmonic sound effect for the basic geometry of the cymbal. Therefore, the objective is to design the percussion instrument with cymbals that can produce exact harmonic sound for different musical notes.

(二)Design Concept

The original design idea comes from the study of Wang et al. [5]. They showed the basic geometry of two layers circular disks are very potential for making harmonic sound effect. This work constructs the parametric geometry model of the cymbal and adopts FEA to perform structural modal analysis and obtain natural frequencies and mode shapes. The optimization analysis is then performed to get the optimum structural design that can generate the percussion sound with harmonic sound effect. The overtone frequencies over the fundamental frequency of the cymbal maintain integer number of ratios. This type of sound is so called harmonic sound effect. Actually, those string instruments, such as violins, cellos and guitars, are able to generate the harmonic sound that is considered a kind of good sound with harmony.

This work shows the special design of two layered circular disk with different diameters and thickness for the cymbal. Through the aid of FEA, the structural geometry can be well controlled to obtain the harmonic sound effect of the cymbal for different musical note s standard frequencies. Two octave musical notes of cymbals have been completed their designs. Table 1 shows the cymbal's natural frequencies obtained from FEA and EMA for Note F6, and Figure 1 summarizes those corresponding mode shapes. Results show both the analytically predicted and experimentally measured vibration modal parameters agree to each other very well. The averaged natural frequency error is 0.8004% and the root-mean-square (RMS) error is 0.979%. In particular, the fundamental frequency matches with the pitch frequency of musical notes, while the overtone frequencies have the integer ratios with respect to the fundamental frequency.

Table 1. Natural frequencies of cymbal for Note F6 from FEA and EMA

EMA			FEA			Error of freq. (%)	Physical meaning of mode shape
mode	Natural freq. (Hz)	Ratio of freq.	mode	Natural freq. (Hz)	Ratio of freq.		
E-01	1395.1	1	F-01	1396.9	1	0.12	$(r,\theta)=(1,2)$
--	--	--	F-02	1396.9	1	--	$(r,\theta)=(1,2)$
E-02	2441.6	1.75	F-03	2434.7	1.74	-0.28	$(r,\theta)=(2,0)$
E-03	2793.3	2.00	F-04	2802.9	2.01	0.34	$(r,\theta)=(1,3)$
--	--	--	F-05	2802.9	2.01	--	$(r,\theta)=(1,3)$
E-04	4135.5	2.96	F-06	4198.6	3.01	1.52	$(r,\theta)=(1,4)$
--	--	--	F-07	4198.6	3.01	--	$(r,\theta)=(1,4)$
E-05	4693.3	3.36	F-08	4733.6	3.39	0.85	$(r,\theta)=(2,1)$
--	--	--	F-09	4733.6	3.39	--	$(r,\theta)=(2,1)$
E-06	5563.3	3.98	F-10	5618.5	4.02	0.98	$(r,\theta)=(1,5)$
--	--	--	F-11	5618.5	4.02	--	$(r,\theta)=(1,5)$
E-07	6715.2	4.81	F-12	6740.2	4.83	0.37	$(r,\theta)=(2,2)$
--	--	--	F-13	6740.2	4.83	--	$(r,\theta)=(2,2)$
E-08	7046.7	5.05	F-14	7145.1	5.11	1.39	$(r,\theta)=(1,6)$
--	--	--	F-15	7145.1	5.11	--	$(r,\theta)=(1,6)$
E-09	7302.6	5.23	F-16	7346.4	5.26	0.59	$(r,\theta)=(3,0)$
E-10	8700.7	6.23	F-17	8844.8	6.33	1.65	$(r,\theta)=(1,7)$
--	--	--	F-18	8844.8	6.33	--	$(r,\theta)=(1,7)$
E-11	8957.3	6.42	F-19	9008.1	6.45	0.56	$(r,\theta)=(2,3)$
--	--	--	F-20	9008.1	6.45	--	$(r,\theta)=(2,3)$
$(\bar{\varepsilon})$ mean value of freq. error						0.8004	
(ε_{rms}) RMS value of freq. error						0.9779	

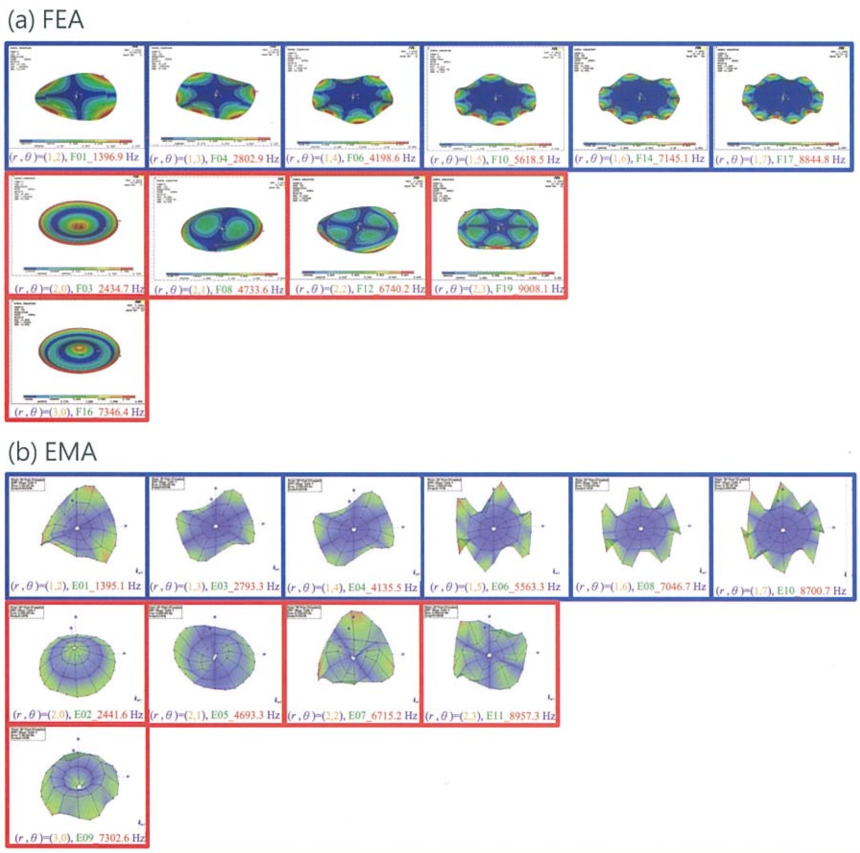

Figure 1. mode shapes of cymbal for Note F6

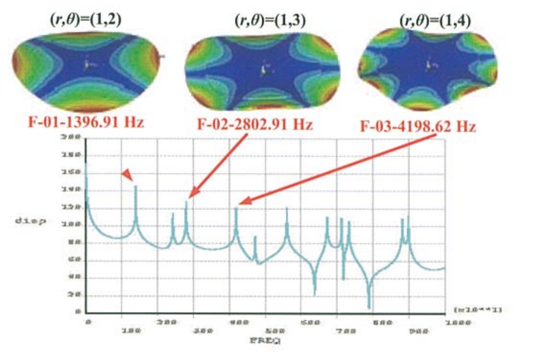

Figure 2. Theoretical FRF of cymbal for Note F6

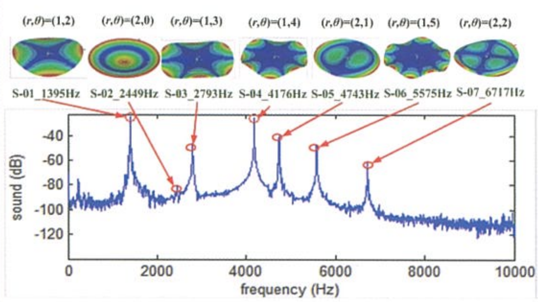

Figure 3. Percussion sound spectrum of cymbal for Note F6

Table 2. Frequency comparison of cymbal for Note F6

Note		Target freq. f_t (Hz)	Analysis freq. f_a (Hz)	Freq. ratio for f_a	Measured freq. f_e (Hz)	Difference between f_a & f_e (Hz)	Error between f_t & f_a (%)	Difference between f_a & f_e (Hz)	Error between f_a & f_e (%)	Allowable error (%)
F-01	F6	1396.91	1396.91	1.00	1395	0.00	0.00	-1.91	-0.13	±0.34
F-02		2793.82	2802.91	2.01	2793	-9.09	0.33	-9.91	-0.35	
F-03		4190.73	4198.62	3.01	4176	-7.89	0.19	-22.62	-0.53	

Figure 2 shows the predicted frequency response function (FRF) and those corresponding mode shapes depicted on the top of resonances for Note F6. Figure 3 is the percussion sound spectrum of Note F6. On the top of each resonant frequency, there reveals the corresponding mode shapes. Table 2 summarizes the frequency ratio analysis that the overtone frequencies are 1.00 : 2.00 : 3.02 with harmonic sound effect. The fundamental frequency match the target pitch frequency within ±0.34%.

(四) Technological Competitiveness

This work presents the new finding for special geometry design of two layer cymbal with different diameters and thickness that can produce harmonic sound effect. The patent is filed and under review process. The new type of cymbal can generate better sound quality for musical performance.

Figure 4. Complete set of two octave percussion instrument for cymbals

(五)R&D Result

This work has applied scientific and engineering approaches to design the new type of percussion instrument. Figure 4 shows the complete set of percussion instrument of cymbals that consist of 25 pieces of cymbals for two octave musical notes. The instrument has been well designed and manufactured and is ready for commercial applications. Hopefully, the cymbal set percussion instrument can be promoted and performed by professional players in the near future.

References

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