DOI: 10.61782/fa.2023.0309

forum acusticum 2023

EXPERIMENTAL AND COMPUTATIONAL VIBROACOUSTIC STUDY OF CYMBALS

S. Brezas [1*] **E. Kaselouris**[1] **Y. Orphanos**[1]
M. Bakarezos[1] **V. Dimitriou**[1] **N. A. Papadogiannis**[1]
[1] Physical Acoustics and Optoacoustics Laboratory, Hellenic Mediterranean University, Greece

ABSTRACT

The study of percussion instruments is a wide section of musical instrument acoustics. Some percussion instruments exhibit harmonic frequency characteristics, while others do not. The present work focuses on cymbals, which show nonlinear vibrational characteristics, providing extra specificity. We apply a new methodology, combining experiments and finite element simulations, for the study of the acoustomechanical vibrational characteristics of a bell-shaped, alloy cymbal. The frequency response is obtained using the roving hammer technique and the modal analysis Electronic Speckle Pattern Interferometry is also employed, which enables the visualization of the vibration modes. A finite element model is developed utilizing computational aided parametric design analysis and the simulation results are compared to the experimental modal results. This combination allows the detailed investigation of the instrument's acoustodynamics, enabling the development of accurate simulation results, capable of providing inputs for machine learning models via further transient finite/boundary element simulations.

Keywords: *cymbal, modal analysis, finite element model, ESPI.*

1. INTRODUCTION

Cymbals are widely used percussion instruments, being among the most popular both in terms of use and study. Usually, cymbals are part of a drum kit, which has been continuously evolving [1]. Recent developments focus on bridging hit discrepancies intentionally imposed by the player with the manufacturing process, using motion capturing [2]. Towards improvement of manufacturing, machine learning models are intended to be used, which require input data from simulations. The accuracy of the simulated results must be high for the machine learning models to train correctly. The study presents both experimental and simulation results as a first step towards our research target, which is the development of models capable of synthesizing sound, which will be validated by experimental results. Additionally, the aforementioned results will provide inputs for machine learning models that can estimate the mechanical parameters, which can be further used on the model based on the radiated sound of the cymbal.

2. EXPERIMENTAL MEASUREMENTS

The frequencies of the vibrational modes of the cymbals are determined and the respective modes are visualized using a holographic interferometry method, namely Electronic Speckle Pattern Interferometry (ESPI) [3].

Figure 1 depicts the experimental setup for the ESPI measurements. The laser beam of a single longitudinal mode laser (Oxxius, Model LCX 532, 532 nm, 170 mW) is guided through a periscope (PER) and a mirror (M1) to a beam splitter (BM1), which splits the incoming beam into two parts. The first part of the beam illuminates the vibrating cymbal (OBJ) after being diverged by two lenses (L1, L2).

The cymbal is sinusoidally excited by a mini piezoelectric actuator, which is fed by a signal generator connected to a power amplifier. The second part of the laser beam passes through a variable neutral density filter and by the use of two mirrors (M2, M3) enters a beam expander (EXP). The

[*]***Corresponding author***: *sbrezas@hmu.gr.*

reflection from the vibrating cymbal and the beam after the expander are combined into a single beam using a second beam splitter (BS2), which is located in front of a CCD sensor of a camera. The subtraction of two consecutive images, which is recorded and further analyzed utilizing a custom made image analysis software, provide the amplitude information. The reader may refer to [3] for further reading about ESPI. Figure 2 shows four representative vibration modes, namely (2,0), (3,0), (3,1) & (4,1) along with the occurring resonant frequencies.

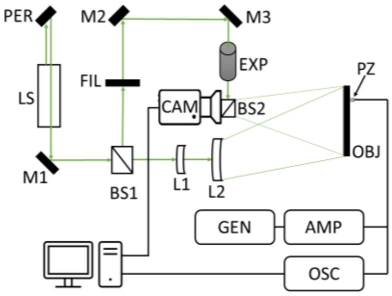

Figure 1. Electronic speckle pattern interferometry experimental setup.

3. MODELING AND SIMULATIONS

Cymbals emit their sound by reacting to a force load applied by the drumstick. This leads to the vibration of the cymbal and the consequent sound emission through the medium (air). The prediction of the previously mentioned process, along with the subsequent effects from the environmental conditions (e.g. temperature and relative humidity) can be performed using the finite element method (FEM) [4,5].
The study of the vibrational characteristics of an 8" MS63 brass alloy cymbal is the main aim of the present study. The geometry of the instrument is of great importance due to strong relation to the simulation results.
According to the geometry of the cymbal presented in Figure 3, a good approximation may be performed by interpolating the bell geometry of the cymbal by arcs. Since an 8" cymbal geometry is modeled, the axisymmetric profile of a cross section of the global geometry is designed on the XZ plane and revolved about the Z-axis. The CAD profile, where the basic construction dimensions are depicted, is presented at the top of Figure 3 above the real image. The mass weight of the cymbal is 0.380 kg and it is assumed that the material thickness is constant and uniform. The cymbal's radius is 101.6 mm and its height is 28 mm. The radius of the flat mounting plateau including the hole is 16 mm. Given these predefined dimensions, oriented by orange points in Figure 3, the curve inflection of the cymbal is indicated at three points, marked green. Based on their spatial position, the curved geometry is interpolated by two three-point arcs. The two arcs, after applying the tangent constrain at their connection point, have a radius of ~190 mm and ~138 mm, as presented in Figure 3.

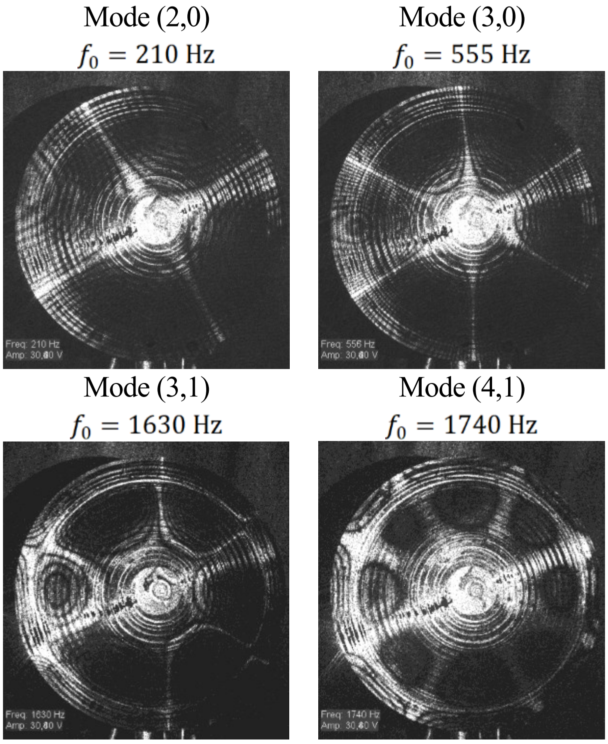

Figure 2. Four vibration modes and the related resonant frequencies after ESPI measurements.

The revolved surface geometry of the developed profiles is generated and is further discretized in the FEM pre-processor Ls-Prepost. Approximately 25000 shell (tetrahedral) finite elements are generated to model the cymbal. Regarding the boundary conditions, a clamped constraint is imposed on the nodes bounding the central hole, simulating the cymbal's attachment to a supporting structure, as performed in the experiments. The material properties of MS63 brass alloy used in the simulations can be found in [6]. The thickness of the cymbal is measured to vary in a range from 1.2 mm to 1.4 mm, therefore three models of constant thickness 1.2 mm, 1.3 mm, 1.4 mm are developed, which result to mass weights of 0.340 kg, 0.368

kg and 0.396 kg respectively. FEM modal analysis for the three cases is then performed using LS-DYNA FEM software [7]. Table 1 presents simulation results of representative modes of vibrations, for the varying thickness models vs experimental ESPI results, which are used as reference. According to Table 1, the results of the model with 1.3 mm thickness and mass weight closer to the real cymbal, exhibit better agreement with the experimental results. The mean average error is also shown in the last row.

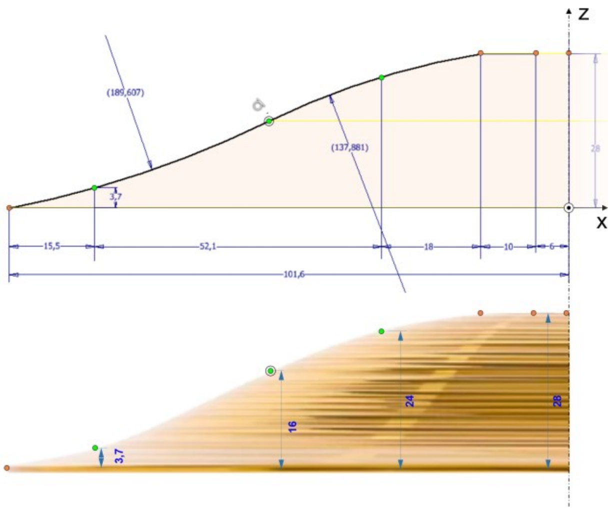

Figure 3. CAD modeling of the cymbal axisymmetric profile.

Table 1. Resonant frequencies and mean error

Modes	ESPI (Hz)	FEM (1.2mm) (Hz)	FEM (1.3mm) (Hz)	FEM (1.4mm) (Hz)
(2,0)	210	215	225	240
(3,0)	555	515	540	560
(4,0)	1040	920	940	965
(5,0)	1520	1200	1235	1275
(3,1)	1630	1585	1655	1730
(4,1)	1740	1600	1705	1825
(2,1)	1760	1855	1900	1950
(5,1)	2030	2010	2160	2300
Mean error %		7.4	7	9.2

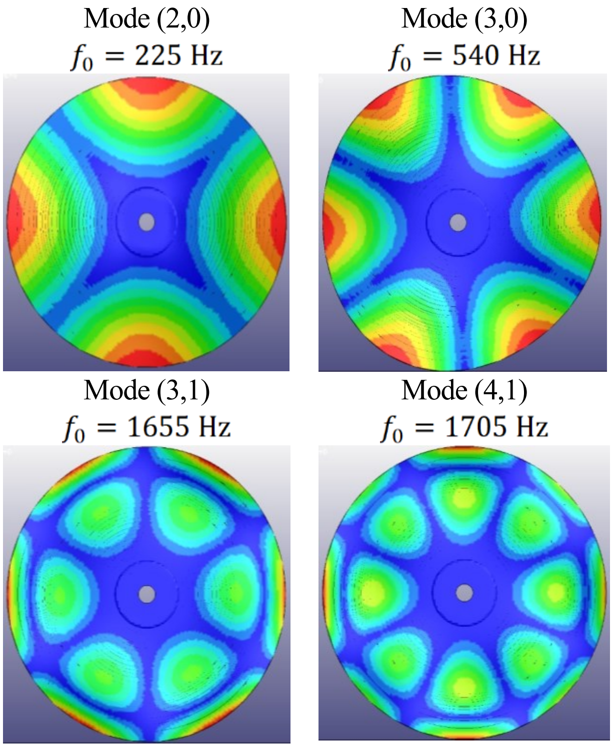

Figure 4. Four vibration modes and the related resonant frequencies using FEM modal analysis.

4. CONCLUSIONS

This is an initial CAD approach to the modeling of the complex geometry of the curved cymbal. The CAD model indicates the critical points of curvature changes and allows for a good approximation by two three-point arcs, able to interpolate the cymbals' curved geometry. A uniform thickness is assumed for the developed geometry without considering the hammering and turning processes applied in the finishing procedures of the cymbals manufacturing. Therefore, to increase even more the accuracy of the FEM models, CAD models may be further improved to include the hammering sub-geometries and the lathe engravements. These CAD models will be capable to include all the non-uniformities of the cymbals and the thickness changes along the instrument's 3D volume. The thickness profile may be a variable for models optimization. Their FEM simulation results may provide inputs for machine learning models. Furthermore, the radiated sound is currently measured and will be used in synergy of multiphysics simulations for the complete vibroacoustic characterization of the cymbal.

5. ACKNOWLEDGMENTS

This research was funded by the Hellenic Mediterranean University, within the project «Recording and metrological analysis of the vibro-acoustic characteristics of musical instruments for the investigation of alternative and low-cost materials and geometries with relevant sound characteristics».
This work was supported by computational time granted by the Greek Research & Technology Network (GRNET) in the National HPC facility-ARIS-under project ID pr013024-LaMPIOS II.

6. REFERENCES

[1] E. K. E. Scott and A. Morrison: "The acoustics of the modern jazz drum kit," *Acoustics Today*, vol. 18, no. 4, pp. 31–39, 2022.

[2] E. Kaselouris, S. Paschalidou, C. Alexandraki, and V. Dimitriou: "FEM-BEM vibroacoustic simulations of motion driven cymbal-drumstick interactions," *Acoustics*, vol. 5, pp. 165–176, 2023.

[3] E. Bakarezos et al.: *Laser-based interferometric techniques for the study of musical instruments. In: Bader, R. (eds) Computational phonogram archiving. current research in systematic musicology, vol 5*., City: Cham, 2019.

[4] E. Kaselouris, T. Papadoulis, E. Variantza, A. Baroutsos, V. Dimitriou: "A study of explicit numerical simulations in orthogonal metal cutting," *Solid State Phenomena*, vol. 261, pp. 339-346, 2017.

[5] E. Kaselouris, C. Alexandraki, M. Bakarezos, M. Tatarakis, N. A. Papadogiannis, V. Dimitriou, "A Detailed FEM Study on the Vibro-acoustic Behaviour of Crash and Splash Musical Cymbals," *Int. J. Circuits Syst. Signal Process.* vol. 16, 948–955, 2022.

[6] https://barneelloyd.files.wordpress.com/2013/03/barnee-lloyd-frequency-analysis-of-a-cymbal-paper-incl-all-references.pdf, Last access on 26/04/2023

[7] J. O. Hallquist, *LS-DYNA Theory Manual*, California: Livermore Software Technology Corporation, 2006.