The Study of Geometric Parameters of the Mong Impact on Natural Frequency

Joompon Bamrungwong1, * and Bancha Arthibenyakul2

1Industrial Physics and Medical Instrumentation, Faculty of Applied Science, King Mongkut’s University of Technology North Bangkok, 10800 Bangkok, Thailand
2Industrial Physics and Medical Instrumentation, Faculty of Applied Science, King Mongkut’s University of Technology North Bangkok, 10800 Bangkok, Thailand

joompondej@gmail.com*

Abstract. The Mong or Tam-tam is sometimes also called Gong, which is a percussion instrument in Thailand. The Mong with boss generates a tone with less chim and a one-key sound. A player has to percuss the Mong to create a rhythm with a hard rubber mallet. The sound of the Mong is usually generated from the vibration of its own structure. The aims of this analysis were to study the eigen modes and identify the important parameters to generate a natural frequency, in which the boss of the Mong are excited. Finite element analysis and the design of the experiment were used to find the relation of geometric parameters that impact the eigen mode. In this paper, the inertia relief method was used to study the natural frequency of the Mong, while the spectrum analyzer was used to measure the eigen mode. The results showed that the diameter of the horizontal flange and the thickness of the Mong had a significant effect on the eigen natural frequency, which is similar to the Gong. This implies that the thickness and horizontal flange diameter must be increased if wanting to use the Mong with many key tones. The analysis agreed with the actual behavior of the structure of the Gong of Khong Wong Yai.

1. Introduction
The melodies and rhythms are necessary to every form of music in all cultures. A Thai percussion instrument that looks like a Khong (Ḳhxng) is sometimes called Mong (H̄om̀ng) in Thai. In English, it is called Gong or Tam-Tam. A tam-tam is a flat-faced gong of indefinite pitch. In other words, it does not have a boss at its center. Gongs have a boss at the center or a small boss more around the center boss. Its first use may have been to signal peasant workers in from the fields and telling time in ancient Thailand because the Mong’s are loud enough to be heard from up to 8 km away. Nowadays, it is used as a percussion instrument often involving some kind of striking on the object, which causes vibrations that produce the sound. The boss or nipple is embossed in the center of the Mong. The Mong is made of circular-shaped metal plates with the same thicknesses, which are struck with soft beaters. The Mong does not need to be tuned with beeswax under the circular metal disc like the Khong. Mong’s are now used in Thai temples as well as Chinese temples for worship. They come in various sizes of approximately 15 to 51 cm [1]. Mong’s have varying degrees of quality and resonance with a tone and less chim. However, the engineering principles were applied to design and produce handmade gongs, while they were constructed with the experience and skill of the maker. Thus, the application of finite element analysis was used to better understand the geometry of the Mong.
Bor-Tsuen Wang studied the Chinese Gong by finite element method and attempted to verify by experimental modal analysis (EMA) [2]. However, Euler-Bournoulli’s equation is often used for studying the vibration of the object. Four parameters are needed for the solution of the equation for only fixed supports [3]. Actually, the Mong is suspended vertically by a cord passed through two holes adjacent to the top rim of the bowl structure, which can be assumed as free in the space, not fixed support. Thus, it is impossible to determine the eigen modes of the gong by Euler-Bournoulli beam theory [4,5]. Joompon B. and Pattaraweerin W. studied the factors of the Gong impacting the natural frequency by using inertia relief, which found that the main effect is the diameter. The thickness of the flange and the thickness of cylinder of the Gong are important factors for tuning the sound. Furthermore, this study found that it is impossible to make the Gong without beeswax. It always needs beeswax for tuning the sound [6]. This research proposed to investigate the structure and modes shape of the Mong with no constraint body using inertia relief by FEM. The results of finite element analysis were validated by comparison with the experiment results.

2. Materials

An individual Mong has the same shape, but some Mongs have different structures by adding smaller nipples to emboss around the center of the Mong. In this study, the structure of the Mong was analyzed regarding the generated natural frequency. Starting from a Mong with no boss (Tam-Tam), a Mong with one boss at the center of the Mong and a Mong with various boss around the center of the Mong were studied. Although the general shapes of both the Mongs are the same, their sizes are different. Therefore, the eigen modes were validated by spectrum analyzer. The 3D model with actual size 25 cm in diameter of the Mong was created for analysis by finite element software. A Tam-Tam is shown in Fig. 1, while a type of Mong is shown in Fig. 2. The Mong with single boss is embossed at the center of the Mong, as shown in Fig. 2a, while the Mong with added smaller boss is embossed around the boss center of the Mong, as shown in Fig. 2b.

In this study, the Mong was made of brass (Basically used for the Thai Mong). The engineering data of material properties used for FEA are density 8,600 kg/m$^3$, Young’s modulus 1.06 $\times$ 105 MPa and Poisson’s ratio 0.31.

Figure 1. The Tam-Tam
Figure 2. (a) The Mong is 25 cm in diameter (b) The Mong with added smaller boss embossed around the bossed centre.

3. Method
Due to the vibration of the Mong being a free vibration, it can be considered as having a free elastic body without constraint. In previous research [4], the inertia relief approach was combined with finite element analysis in the modeling and analysis of the unconstrained systems. In this study, the commercial finite element package is used for analysis. The Mong with 250 mm diameter, 0.5 mm thickness and 40 mm vertical flange were studied. The Mong with no boss was the first study (Like a Tam-Tam), while the Mong with a single boss at the center was studied with the same size of the previous Mong analyzed. After that, the Mong with given a smaller boss embossed in around the bossed center of the Mong. In addition, the name of the parameters for this study is shown in Fig.3a. Fig.3b shows the parameters that were studied, with A being the vertical flange, B being the angle of the vertical flange, C being the thickness of the vertical flange, D being the diameter of the horizontal flange, and E being the diameter of the boss.

Figure 3. The name of parameters (a) and the parameters studied (b)

The frequencies in hertz were recorded to study the natural frequency of the Mong. The Mong was considered as having no constraint on the Mong. For the sake of simplicity, the beam was assumed as two masses, as shown in Fig. 4.
The two masses \((m_1 \text{ and } m_2)\) were connected by a spring having stiffness \(k\) and there was no external force applied. Assume that both masses have the same weight, in which \(W_1\) and \(W_2\) are the weight of \(m_1\) and \(m_2\), respectively. Assume the spring and two masses can only move vertically (\(y\) direction in Figure 5). Because of the applied force, the system will move freely in a vertical direction only. The mass \(m_1\) starts moving downwards when compressing the spring, while the mass \(m_2\) is at the rest while also compressing the spring. When the spring is compressed enough to produce a reaction force more than \(W_1+W_2\), \(m_2\) will start moving downwards. After some time, the system will arrive at a steady state, in which both \(m_1\) and \(m_2\) are moving in constant acceleration together. Considering the overall spring mass system, the equation of motion for free vibration can be written as:

\[
\begin{bmatrix}
  m_1 & 0 \\
  0 & m_2
\end{bmatrix}
\begin{bmatrix}
  k & -k \\
  -k & k
\end{bmatrix}
\begin{bmatrix}
  x_1 \\
  x_2
\end{bmatrix}
= \begin{bmatrix}
  0 \\
  0
\end{bmatrix}
\]

(1)

Theoretically, it is impossible to determine the position of the two masses because they are not constrained in the system. Nevertheless, the relative displacement can be found by restraining either \(x_1\) or \(x_2\).

If \(x_1 = 0\), then \(x_2 = \frac{am_1}{k}\)

If \(x_2 = 0\), then \(x_2 = \frac{am_2}{k}\)

This shows that the relative displacements \(x_1 - x_2\) were the same for either constraint. The result of the acceleration and the deformation of systems were not affected by the selection of constraints in this system, which is called the inertia relief analysis [5]. Most frequently, the inertia relief approach is combined with finite element analysis in the modeling and analysis of unconstrained systems.

4. Results

Five cases of the Mong model have been studied by FEA simulation. Only the experiment of case 4 has been done. The result from the experiment and FEA result were compared, as shown in Fig. 5.
The first case is the Mong with no boss at the center. Case 2 is the Mong with one boss at the center. Case 3 is the Mong with one boss at the center and a smaller boss around the center boss. Case 4 is the Mong with one boss at the center and a curved horizontal flange. The last case is the Mong with one boss at the center and a curved horizontal flange as well as a smaller boss around boss center. The parameters in Fig. 3b were varied by more than 3 points, as shown in Fig. 6 to Fig. 8. From the analysis results, the parameters severe by consider the slope of the graph, shown parameters A, B, C, D and E in Table 1 and found that parameter C had the most significant effect on natural frequency by consideration from the value of the unit per effect (slope).

**Figure 5.** The same order eigen mode resulting from FEA and the experiment

**Figure 6.** (a) Length of the vertical flange and mode shape  
(b) Angle of the vertical flange and mode shape

**Figure 7.** (a) Thickness of the flange and mode shape  
(b) Diameter of the horizontal flange and mode shape
The design of experiment (DOE) was created to find the parameter relationship. Parameters A, B, C, D and E were used to create the run in design of experiment, as shown in Table 2. The finite element analysis was used to study the natural frequency following the run order.

**Table 2. Created Factorial Design for Run**

| SubOrder | RunOrder | CenterPt | Blocks | A | B | C | D | E | Freq (Hz) |
|----------|----------|----------|--------|---|---|---|---|---|-----------|
| 8        | 1        | 1        | 1      | 1 | 0 | 0 | 0 | 0 | 684.82    |
| 20       | 1        | 0        | 0      | 0 | 0 | 0 | 0 | 0 | 546.95    |
| 19       | 0        | 0        | 0      | 0 | 0 | 0 | 0 | 0 | 1880.32   |
| 27       | 1        | 0        | 0      | 0 | 0 | 0 | 0 | 0 | 684.82    |
| 25       | 1        | 0        | 0      | 0 | 0 | 0 | 0 | 0 | 748.91    |
| 24       | 1        | 0        | 0      | 0 | 0 | 0 | 0 | 0 | 684.82    |
| 23       | 1        | 0        | 0      | 0 | 0 | 0 | 0 | 0 | 546.95    |
| 22       | 1        | 0        | 0      | 0 | 0 | 0 | 0 | 0 | 1880.32   |
| 21       | 1        | 0        | 0      | 0 | 0 | 0 | 0 | 0 | 684.82    |
| 20       | 1        | 0        | 0      | 0 | 0 | 0 | 0 | 0 | 748.91    |
| 19       | 0        | 0        | 0      | 0 | 0 | 0 | 0 | 0 | 546.95    |
| 18       | 0        | 0        | 0      | 0 | 0 | 0 | 0 | 0 | 1880.32   |
| 17       | 1        | 0        | 0      | 0 | 0 | 0 | 0 | 0 | 684.82    |
| 16       | 1        | 0        | 0      | 0 | 0 | 0 | 0 | 0 | 748.91    |
| 15       | 0        | 0        | 0      | 0 | 0 | 0 | 0 | 0 | 546.95    |

**Figure 8.** Diameter of the boss and mode shape

**Table 1.** Unit per effect of the Mong’s parameters

| Parameters | Remark                  | Unit | Unit/Effects |
|------------|-------------------------|------|--------------|
| A          | Length of Vertical Flange | mm   | 1            |
| B          | Vertical Flange Angle   | Deg  | 1.2          |
| C          | Flange Thickness        | mm   | 53.9         |
| D          | Horizontal Flange Diameter | mm  | 6.7          |
| E          | Boss Diameter           | mm   | 3.3          |

**Figure 9.** (a) The main effects plot of the five factors and (b) the surface plot
The results show that factor D was the first parameter impacting the natural frequency, as shown in Fig. 9(a). P-Value less than 0.05 when considering R-Sq (adj) was found to be high enough at 99.36%. The preliminary discussion found that factors C and D impacted the eigen mode. Thus, the surface plot of the natural frequency and factors C and D is shown in Fig. 9b.

5. Conclusion and Summary

This study revealed that the Mong without a center boss has a lower tone key than the Mong with center boss. This can be considered that they are Tam-tam and Mong, respectively. The Mong with added curve on the horizontal flange has a higher tone key than a flat horizontal flange. Adding a smaller boss around the center boss causes a decrease in the natural frequency. The initial and designed experimental study found that the thickness and diameter of the horizontal flange of the Mong was a key parameter related to tuning the natural frequency, which is in agreement with the actual percussion instrument, like the Thai Gong (Khong Wong Yai). The response surface function plot reveals that the smaller diameter of the horizontal flange of the Mong has a higher tone key than a horizontal flange with a larger diameter. If a high tone key is required, a horizontal flange with a small diameter and low thickness should be used. However, the thickness of the Mong has to be optimized if needed. The natural frequency of the Mong has the eigen modes generated from bending mode, which involves the entire horizontal flange of the boss moving upwards and downwards. It should be noted that drilling holes to hold the gong should be near a horizontal flange to balance the Mong in a vertical direction.

6. Reference

[1] Gong. [Online]. 30 May 2016, available: https://en.wikipedia.org/wiki/Gong.
[2] Bor-Tsuen Wang, 2011, Intergation of FEA and EMA Techniques for Percussion Instrument Design Analysis. International Conference on System Science and Engineering, China (2011).
[3] J. Bamrungwong, 2006, Analysis and Design The Natural frequency of a Treble Gamelan Using FEA. MENETT#20, Thailand (2006).
[4] J. Bamrungwong, 2016, The Natural frequency Analysis of the Khong Wong Yai by FEM. International Conference Facilitating Autonomous Learning via Research-Based Approaches (FCAL), Thailand (2016).
[5] J. Bamrungwong, 2016, The Application of Inertia Relief Method in Ranat and Xylophone, International Conference on Electrical, Mechanical and Industrial Engineering, Thailand (2016).
[6] J. Bamrungwong and Pattaraweerin W., The Effect of the Khong Wong Yai Parameters on Sounds by FEM, International Conference on Advanced Materials and Engineering Materials, March 11-12nd, Singapore, 2017.
[7] J. Bamrungwong and W. Amarin, 2017, DOE for Study of the Sound Factor of the Gong, International Conference on Industrial Engineering, Thailand (2017).
[8] Raymond A. Serway and John W. Jewett, Jr. “Physics for Scientists and Engineers with Modern Physics” 9th ed, Cengage Learning, 2014
[9] Benson H. Tongue, “Principles of Vibration” 1st ed, Oxford University Press, 1996.
[10] Daryl L. Logan, “A First Course in the Finite Element Method” 4th ed, Cengage Learning, 2007
[11] Robert D. Cook, “Finite Element Modeling for Stress Analysis” John Wiley and Son Inc., 1995
[12] Bathe, “Finite Element Procedure”, Prentice Hall of India Private Limited, 2007