Acoustic signal of Javanese 56 cm brass kempul

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Abstract. The 56 cm Brass Kempul Gong is regarded to produce better musical sound compared to its sibling one that made of iron. This study aims to investigate the spectral and temporal properties of that Gong. Acoustic measurements were conducted and sounds analyzed using the PC program, ARTA. Both frequency and time domain signals were explored and compared to a similar kempul made of iron. The fundamental frequency, which decays much more slowly than the other harmonics, starts with a lower, increasing frequency. The wave-like sound of the Gong is due to signal behavior that resembles the primary and secondary mistuned beats of its second and third harmonic frequencies.

1. Introduction
Kempul is the second largest Javanese gong which hang in a crossbar supported by two side posts as shown in Figure 1. A kempul may be crafted from iron as well as brass. Traditionally a good gamelan (the metal section) was made of brass. However because of budget concern the iron made gamelan became popular as well. [1], [2] It is believed that brass kempul has musical sound than the iron sibling. There have been lacks of studies in the past that attempt to describe the spectrum of gongs both theoretically and experimentally to better comprehend such analyses. Previously we have investigated an iron made kempul gong [3-6].

This paper considers the spectral and temporal properties of brass kempul to examine the spectral harmonics and partials of these gongs, and how they are put together to produce the continuous beats.

Generally a gong has about a dozen prominent exponentially decaying partials, with some component frequency ratios that closely correspond to harmonics and other that are inharmonic. [7-10] Many of the partials have a slow amplitude and frequency modulation of a few Hertz, and a faster modulation around 20 Hz resulting from multiple components falling into the same harmonic bin. The studies in [12-13] indicated that gongs show a pronounced nonlinear behavior. The pitch of the larger gong glides downward as much as three semitones after striking, whereas that of the smaller gong glides upward by about two semitones. Rossing et al. [14] investigated some vibrational modes of the larger gongs. Some of the modes were confined pretty much to the flat inner portion, some to sloping shoulders, and some involve considerable motion in both parts. When the gong was hit near the center, the central modes clearly dominate the sound. When the gong was hit lightly on the shoulder, the lowest mode is heard. It was also found that the Gong Kempul possesses a degree of harmonicity, making it sounds with targeted pitch.
2. Experimental Investigation

2.1. Measurement Setup
A controlled gong striker was utilized to exert a controlled impact force upon the kempul’s boss, as seen in Fig. 2. A measurement ECM 8000 condenser microphone acquired the acoustic signal by near field measurement from behind the boss, externally powered by a Samson phantom power. A sound card then interfaced and digitized this signal in order that computers are able to recognize. We recorded and analyzed the 48 kHz sampled acoustic signal using ARTA PC Software.

2.2. Brass kempul partials
From the brass kempul smoothed spectrum we found with strong consistency from 7 trials that there were at least 9 partial in a span from the fundamental to the third harmonic (91.59 Hz to 274.84 Hz) as shown in Figure 3 and Table 1, compared to the only 6 partials of the iron kempul measured previously [3]. The harmonic partials interestingly be equally spaced with three inharmonic partials in between. Regularity of the harmonic partials leads to the clearer pitched sound of the brass kempul. This may explain why brass kempul has better musical sound compare to its iron sibling.
Figure 3. 1/24 oct smoothed brass kempul spectrum.

Table 1. A slightly more complex table with a narrow caption.

| Partials (Hz) | Harmonics (Hz) | Freq. ratio to fundamental | Primary beats (Hz) | Mistuned harmony beats (Hz) |
|---------------|----------------|---------------------------|-------------------|-----------------------------|
| 91.59         | Fundamental    |                           |                   |                             |
| 132.92        |                | 1.45                      | 41.33             |                             |
| 151.44        |                | 1.65                      | 18.52             |                             |
| 158.65        |                | 1.73                      | 7.21              |                             |
| 182.44        | 2nd            | 1.99                      | 23.79             | 0.74                        |
| 224.97        |                | 2.46                      | 42.53             |                             |
| 241.24        |                | 2.63                      | 16.27             |                             |
| 256.29        |                | 2.80                      | 15.05             |                             |
| 274.84        | 3rd            | 3.00                      | 18.55             | -0.07                       |

2.3. Mistuned Harmonics

Figure 4. The brass kempul sound time domain signal.
The slowly decaying sound of the kempul that can be seen in Figure 4 opens up the possibility of those partials to interfere, resulting in various beats. The harmonic and or inharmonic partials that occur in fairly close frequency beat together and form the roaring sound which is often associated with Bima’s laughter (Bima is one of the Pandawa brothers in the story of Mahabarata).

There are two kinds of beats, i.e. primary and second–order or secondary beats. The primary beats occur between closely existing partials in the spectrum, while the secondary beats occur between a tone and its mistuned harmonics [7].

When there are two discrete tones with frequency $f_2$ higher than $f_1$ and $n$ is an integer number, then those two tones will produce a beat frequency of $f = f_2 - nf_1$. For $n = 1$, we obtain primary beat, for $n>1$ we obtain second-order or mistuned harmonic beats. Since, if $f_2 = n f_1$ we get exact harmonically related tones.

Primary beat:

$$\delta f = f_2 - f_1 \quad (1)$$

Second-order mistuned $n$ harmonic beats:

$$\delta f = f_2 - nf_1 \quad (2)$$

A beat is perceptible as a fluctuating sound if its frequency is less than 10 Hz [8]. And, in the case of this brass kempul, we found one primary beat of 7.21 Hz and two mistuned 2nd harmonic at 0.74 Hz and 3rd harmonic at –0.07 Hz.

We investigate further into the kempul wave form at the beginning, mid and tail section of the signal. We found that the signal repetition period drifted from 87.91 Hz to longer lasting 89.89 Hz that span approximately 1.98 Hz.

Looking at the energy decay curve as shown in Figure 5 we can see that energy fluctuation was prominent in the 250 Hz octave band with periodic peak interval of 598.5 ms or, 1.6 Hz in frequency. This one octave band filter contained the 2nd and 3rd harmonics of the kempul signal.

![Figure 5. Brass kempul energy decay.](image)

![Figure 6. Brass kempul burst decay.](image)

Figure 6 shows the burst decay graph to investigate the most prominent partials along a certain time intervals at the opening and tail of the sound, respectively. A complex Morlet wavelet analytic signal is used in convolution with kempul time domain wavelet scalogram, represents the envelope of the shaped burst response decay. A complex Morlet wavelet analytic signal is defined as:

$$w(t) = e^{-\frac{t^2}{\tau^2}}(\cos \omega_0 t + j \sin \omega_0 t) \quad (3)$$

The Fourier transform of the Morlet wavelet is equal to:

$$W(\omega) = e^{-\left(\omega-\omega_0\right)^2\tau^2/4} \quad (4)$$
It can be seen that in Figure 6, the fundamental frequency at 91.59 Hz decays much more slowly than the other harmonics and increases in dominance as the other partials weaken in decaying tone. We can also see that signal energy 2\textsuperscript{nd} and 3\textsuperscript{rd} fluctuate and decreasing with time.

3. Comparison to iron kempul
A short impulse can be represented as the instantaneous and gentle strike on the boss of the kempul. Thus, an impulse-generated response was recorded to analyze in the time domain. Figure 4 shows the impulse response of the kempul within about 8000 ms in which the sound gradually vanishes. The time plot shows fluctuation indicating at least seven prominent peak on the signal (Javanese: ombak pitu).

With regard to the behaviors of the iron kempul that we studied previously [3-6], The brass kempul acoustic sound as shown in Figure 4 clearly has longer sustain sound compares to its iron sibling as depicted here in Figure 7 for a direct comparison.

![Figure 7](image1.png)

**Figure 7.** The iron kempul sound time domain signal [3].

While wave sound of the brass kempul has approximately 7 waves compare to approximately 3 wave only produced by the iron one.

Harmonic partials of brass kempul were more regularly spaced between inharmonic partials, this produced better pitched sound compares to the iron kempul that we studied previously.

The burst decay graph of brass kempul in figure 6, shows that its energy fluctuation was occur at combined 2\textsuperscript{nd} and 3\textsuperscript{rd} mistuned harmonics that finally sifted at the 3\textsuperscript{rd} harmonic. The iron kempul burst decay was related mainly to the 2\textsuperscript{nd} mistuned beat, as can be seen from Figure 7 below.

![Figure 8](image2.png)

**Figure 8.** Iron kempul burst decay [3].
In the effort of tracing the origin of the wave sound this work found that the mistuned 2nd harmonic frequency that was 0.74 Hz does not agree with the fluctuation frequency in the energy decay that was around 1.6 Hz.

It may be that the kempul itself can be considered as non-linear system. A nonlinear system may produce higher harmonic of its input excitation. If we considered 0.74 Hz as the excitation input then 1.6 Hz is in the vicinity of its 2nd harmonic. And, that human tactile beats perception becomes more sensitive as the vibration [9] frequency of stimulation increases.

Perception of beats by human hearing and brain are another area that need to be study since. Hearing is a sensation and just like every other sensation it is an esoteric process. One is not able to decouple and independently vary any of the variables of interest (however those might be defined) and even if one could, the principle of superposition, in general, does not apply [10-11].

4. Conclusions
The 56 cm brass kempul has a nature of harmonicity with fundamental frequency at 91.59 Hz, while the second, third, mistuned harmonics are, respectively, at 182.44 Hz, 274.84, with three partials lie between each harmonics. The primary and mistuned harmonics beats together resulted in a kempul ombak pitu (7 waves) sound. This experimental investigation shows that brass kempul produces longer sustaining and cleaner pitched therefore has partially support some believes that the brass kempul produces better sound to it inexpensive iron sibling. However it has not able to showed conclusively the origin of the wave sound of the kempul.

5. References
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