

SOME STUDIES ON THE UNDERSTANDING THE DIFFERENT TONES QUALITY IN A BONANG SET

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Abstract

The acoustic spectra were carried out on a bonang set by investigating the vibration overtones. The spectra were measured from a set of just-tuned cast bronze bonang from Indonesia (low octave bonang barung and high octave bonang penerus). The bonang was beaten with padded mallets. The acoustic spectra were recorded by PicoScope oscilloscopes. Picoscope reading are in good agreement with those from Melda analyser in Cubase version 9. Only bonang barung 2 show a greater frequency increase in the first overtone frequency (only 10% deviant from the octave). Bonang penerus 1, 4 and 5 and bonang barung 3 showed an octave from the second overtone frequency (with only 5% deviant from the octave). Bonang penerus 3, 4 and 5 sustained 3 peaks (fundamental, first overtone and second overtone frequency) from the beginning until $t=1.5s$. Since the two types of bonang give different data on the harmonic and pitch, therefore, the aim of the study is to identify the similarities and differences of harmonic, pitch and size as well as the functions based on tuning of the Bonang Penerus and Bonang Barung in Malay and Javanese gamelan ensemble.

Keywords: Acoustic spectra, Bonang barung, Bonang penerus, Vibration overtone.

1. Introduction

Acoustics and human perception have created new musical theories where western music is interpreted along with eastern music. The advances in acoustics address the relation between timbre, pitch, consonance and harmony. Western orchestras exclude instruments with non-harmonic overtones because it might interfere with the harmonic overtones [1]. Gongs are traditional musical ensembles typically from Asia, Malay archipelago between Indonesia and Indo-China. There are very little literature on the manufacturing and acoustical behaviour of the gongs [2-7]. Sadie [8] mentioned that the shape and diameter vary between ~150 mm to more than 1 meter. This paper explores the pitch implications of a set of bonang penerus and bonang barung from gamelan musical instruments.

The master crafter of the traditional musical instrument in South-East Asia made musical instruments through knowledge inherited from their ancestors. Unfortunately, these techniques remained undocumented. The manufacturing involves various copper-based alloys using casting or forging [9-11]. Recently mild steel or sheet steel are forged or fabricate for economic reasons. A hemispherical dome called a boss is made in the centre of the bonang surface. The fundamental frequency is increased to a specific pitch by beating the boss. The fundamental frequency is lowered to the required pitch by thinning the surface of the bonang with a grinder. Based on studies by Rossing [12], a mass loading effect on the boss was proposed as the mechanism to set the first two modes with nodal rings, which has an octave relationship. The metal on a steel bonang is worked thin and work hardens when the boss is beaten. Although beating the boss does not affect the mass loading, the stiffness is reduced due to the work thinning and increased due to work hardening. The set of tuned bonang is tune forged by the crafter using the boss. Most bonang regardless of specific pitch or not have rims.

The quality of one set of gamelan instruments is distinguished from the other through its tuning. Each instrument in a gamelan is carefully tuned to match the others. It is only quite impossible to exchange instrument between gamelan. Spiller [13] proposed that although each gamelan is unique, individual gamelan tunings follow either one of two tuning systems. Since the two types of bonang gives different data on the harmonic and pitch, therefore, this research identifies the similarities and differences of harmonic, pitch and size as well as the functions based on tuning of the Bonang Penerus and Bonang Barung in Malay and Javanese gamelan ensemble. Each set of bonang displayed its own unique role in all the pieces the musician play on it. What sounds acceptably in tune and out of tune are difficult to detect by hearing and become a subject of passionate discussion among Javanese musician.

Bonang is a gong chime with a two-octave range. In modern Central Javanese gamelan, two rows of small bonang gongs are laid over ropes in a frame. Each row consists of one octave's worth of gongs. In most Central Javanese gamelan, the two members of the bonang family are consists of the lower pitched bonang barung and the higher pitched bonang penerus. The upper octave of the bonang barung is in the same range as the lower octave of the bonang penerus. The bonang gongs are not arranged in numerical order. It is arranged to ease playing the five pitched subsets of pelog. The arrangement is not fixed permanently, therefore, the musician can rearrange them to facilitate playing another 5-pitch subset.

Sounds having harmonic partials are called tone. Complexes partials that are harmonically related have a very special perceptual status that makes them useful in music. It is our purpose in this work to make clear the nature of this special status. According to Benade [14], a strong pitch is obtained from a tone made up of a set of harmonic partials. The diameter of the bonang and the material thickness affect the pitch. The larger diameter produces lower pitch and the thicker material produce higher pitch. If a boss is added or enlarge at the centre the bonang become more convex. The periphery can be folded back to form a rim. This makes the bonang more rigid and thus, increase the pitch. This eventually brings out the fundamental and make a distinct pitch. A good sound from bonang is create using metal of appropriate thickness relative to the diameter. Thin bonang yield weak fundamental frequency. The thickness of a bonang for a particular diameter depends on the type of metal, the presence or absence of boss, rim or general concavity and the maker's taste.

The thickness and geometry of the bonang were decided from experience in fabricating bonang. For the ease of the manufacturing process all, the bonangs had a cylindrical rim. In general, most bonangs have rim inverted like truncated cones shape. Figures 1 and 2 show bonang penerus and bonang barung respectively. Increasing the angle of the rim with regard to the vertical axis affect the modes with nodal diameters only (the modes with nodal rings are less affected [15]. Increasing rim angles will increase the frequencies of modes with nodal diameters sharply (the frequencies of modes with nodal rings remain nearly constant). The purpose of the small rim is to increased stiffness in the vibration plane. Thus, the frequencies predicted for modes with (2, 0), (3, 0), (4, 0), etc., nodal diameters only can increase dramatically (m, n where m for nodal diameter and n for nodal circles) [16, 17]. These frequencies reach maxima and rapidly decrease with the rim size [15]. The predicted frequencies for the rim depth about 1/3 the diameter are close to a freely vibrating circular disk.

How can we explain and understand the two types of bonangs? Table 1 gives some data on the harmonic, pitch and size of the bonangs. Therefore, the aim of the study is to identify the similarities and differences of harmonic, pitch and size as well as the functions based on tuning of the Bonang Penerus and Bonang Barung in Malay and Javanese gamelan ensemble.

Table 1. Harmonic, pitch and size of bonang penerus and bonang barung.

Bonang penerus	Bonang barung
Wide harmonic~ 589 Hz-2137 Hz	Narrow harmonic~296 Hz-1624 Hz
High pitch (Pelog) C6 (1073 Hz), D5(589 Hz), E5(661 Hz), G5 (784 Hz), A5 (879 Hz)	Low pitch (pelog) C5 (533 Hz), D4 (296 Hz), E4 (333 Hz), G4 (396 Hz), A4 (438 Hz)
Smaller size (21-22 cm diameter)	Larger size (22-23 cm diameter)



Fig. 1. Bonang penerus.



Fig. 2. Bonang barung.

2. Methodology

The cast bronze bonang were chosen from a range of gamelan ensemble. Figure 3 shows a set of 10 bonang ensemble. The acoustic spectra of the measured sets of just-tuned cast bronze bonang, which were made in Indonesia were captured using PicoScope oscilloscopes and Melda analyser in Cubase version 9 to investigate the fundamental and the overtone frequencies. Excitation was done by beating the bonang with padded mallets by an expert bonang player. The microphone was held above the top surface along the axis of symmetry of the bonang at a distance of about 20 cm (Fig. 4).



Fig. 3. A set of 10 bonang ensemble (upper row bonang penerus, lower row bonang barung).

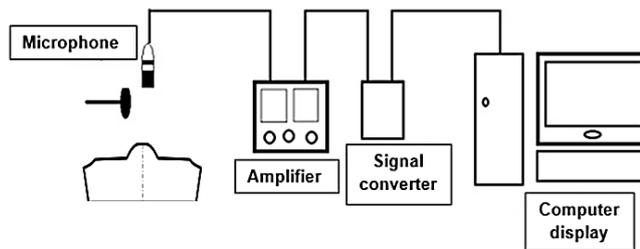


Fig. 4. Schematic diagram of experimental setup.

The PicoScope computer software (Pico Technology, 3000 series, Eaton Socon, U.K.) was used to view and analyse the time signals from Pico Scope oscilloscopes (Pico Technology, 3000 series, Eaton Socon, U.K.) and data loggers for real-time signal acquisition. Pico Scope software enables analysis using Fast Fourier Transform (FFT), a spectrum analyser, voltage-based triggers, and the ability to save/load waveforms to a disk. Figure 4 shows the schematic diagram of the experimental setup. The bonang was placed to where the sound could be captured with minimum interference. The amplifier (Behringer Powerplay Pro XL, Behringer, China) ensured the sound capture was loud enough to be detected by the signal converter.

The bonang spectra were also digitally recorded using the Melda analyser in Cubase version 9. In conducting this study, the audio signal derived from the striking of the bonang played by an expert bonang player is recorded. The audio signal is recorded in mono, at 24-bit resolution, 48 kHz sampling rate. The audio signal is recorded with the aid of a digital audio interface in a .wav format. To ensure the

recorded audio signal of the striking of the bonang is at the optimum level, audio signal calibration of the recording system is carried out. A test tone of 1 kHz sine wave is used in calibrating the recording system. Here the 'unity' calibration level is at +4dBu or -10dBV and is read by the recording device at '0 VU'. In this regard, the EBU recommended the digital equivalent of 0VU is that the test tone generated to the recording device of the experimentation is recorded at -18 dBFS (Digital) or +4dBu (Analog), which is equivalent to 0VU. In this thorough procedure of calibration, no devices are unknowingly boosting or attenuating its amplitude in the signal chain at the time of the recording is carried out. The recording apparatus was the Steinberg UR22 mkII audio interface, Audio-Technica AT4050 microphone, XLR cable (balance), with microphone position on axis (<20 cm), microphone setting with low cut (flat) 0dB.

3. Results and Discussion

The acoustic spectra for the bonang vary substantially due to variation in shape, size and dimensional irregularities created during manufacture and whilst tuning by hand grinding. Figures 5 and 6 shows the acoustic spectra recorded after excitation of 10 bonang captured using PicoScope oscilloscopes. The first five spectra (Fig. 5) are of high octave bonang penerus (1P-5P) whereas the second five spectra (Fig. 6) are of low octave bonang barung (1B-5B). There is little difference between the spectral data for bonang penerus and bonang barung shown in Figs. 5 and 6. Figures 5 and 6 only display the frequency of the fundamental and the overtone. This figure is important as a basis to determine the fundamental, first overtone and second overtone frequencies. From these values, Table 2 is derived to show the ratio between the first and second overtone with the fundamental frequency for both bonangs. Table 2 shows frequencies of the fundamental spectral peaks with the overtones observed between 0 and 10 kHz. The ratios of these frequencies to the fundamental of each bonang are expressed numerically or as an octave equivalent just interval. The percentage deviation of the numerical from the octave equivalent just intervals is also given in the bracket. The bonangs were developed with fundamental frequency for just-tuned ensembles and their partials are shown to indicate the degree of consonance of their partials. Examination of the data in Table 2 does show a greater frequency increase in the first overtone frequency for bonang barung 2B (with only 10% deviant from the octave frequency).

Table 2. Fundamental frequencies with overtones using PicoScope oscilloscopes.

	Fundamental frequency (f)	1st overtone	Ratio to (f)	2nd overtone	Ratio to (f)
Penerus 1	f (1073 Hz C6)	1.3 f (1454 HzF#6)	1.3 (35%)	2 f (2118 HzC6)	2.0 (0%)
Penerus 2	f (590 Hz D5)	1.4 f (849 HzG#5)	1.4 (30%)	-	-
Penerus 3	f (658 Hz E5)	1.5 f (1015 HzB5)	1.5 (25%)	-	-
Penerus 4	f (788 Hz G5)	1.4 f (1117 HzC#6)	1.4 (30%)	2 f (1556 HzG6)	2.0 (0%)
Penerus 5	f (879 Hz A5)	1.4 f 1266 HzD#6)	1.4 (30%)	2 f (1749 HzA6)	2.0 (0%)
Barung 1	f (529 Hz C5)	1.6 f (836 HzG#5)	1.6 (20%)	2.9 f (1531 HzG6)	2.9 (3.3%)
Barung 2	f (295 Hz D4)	1.8 f (535 HzC5)	1.8 (10%)	5.2 f (1531 HzE6)	5.2 (13.3%)
Barung 3	f (332 Hz E4)	1.6 f (546 HzC#5)	1.6 (20%)	1.9 f (637 HzD#5)	1.9 (5%)
Barung 4	f (397 Hz G4)	1.7 f (676 HzE5)	1.7 (15%)	2.6 f (1024 HzC6)	2.6 (13.3%)
Barung 5	f (441 Hz A4)	1.5 f (672 HzE5)	1.5 (25%)	2.8 f (1225 Hz D#6)	2.8 (6.6%)

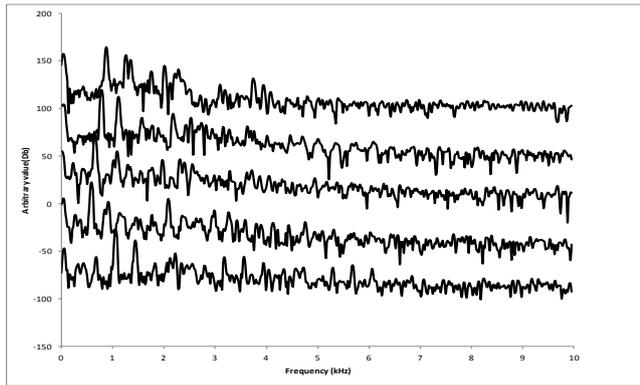


Fig. 5. Acoustic spectra of 5 high octave bonang penerus using PicoScope oscilloscopes.

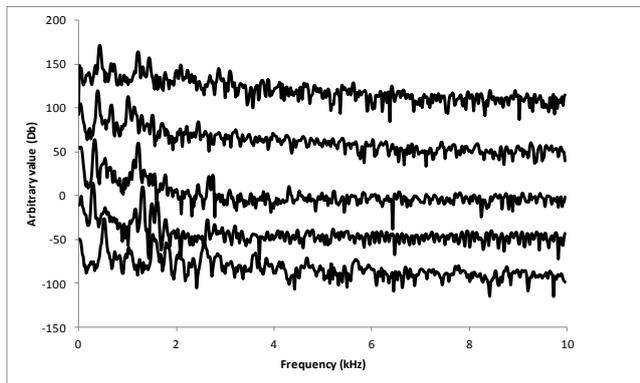


Fig. 6. Acoustic spectra of 5 low octave bonang barung using PicoScope oscilloscopes.

From the acoustic spectra of 5 high octave, bonang penerus using PicoScope oscilloscopes, bonang penerus 1, 2, 3, 4 and 5 spectrum has partials at $(f, 1.3f$ and $2f)$, $(f$ and $1.4f)$, $(f$ and $1.5f)$, $(f, 1.4f$ and $2f)$ and $(f, 1.4$ and $2f)$ respectively. Over the whole set of instruments, 2 partials appear consistently. From the acoustic spectra of 5 low octave, bonang barung using PicoScope oscilloscopes, bonang barung 1, 2, 3, 4 and 5 spectrum has partials at $(f, 1.6f$ and $2.9f)$, $(f, 1.8f$ and $5.2f)$, $(f, 1.6f$ and $1.9f)$, $(f, 1.7f$ and $2.6f)$ and $(f, 1.5$ and $2.8f)$ respectively. Over the whole set of instruments, 3 partials appear consistently. There is a significant difference in tone quality among different bonang sets of the same manufacturer. From Table 2 the ratio between the first overtone frequency and the fundamental frequency for bonang penerus is 1.3-1.5, whereas the ratio between the first overtone frequency and the fundamental frequency for bonang barung is 1.5-1.8.

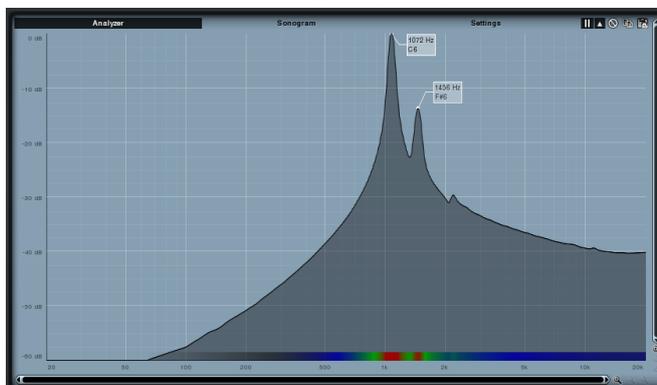
During the tuning process, the manufacturer can bring out the fundamental for a clearer pitch by raising a small boss at the centre of the bonang. Hammering a small boss in a previously un-bossed bonang brings the pitch up considerable for both the fundamental and most of the higher notes. Progressively enlarging the boss continues to raised the pitch but more and more slowly. This explain why bonang barung 2B (with

only 10% deviant from the octave frequency) show a greater frequency increase in the first overtone frequency. Hopkin [18] mentioned that adding the boss will allow to raise the pitch a maximum of fifth or sixth typically above that of the original flat disk.

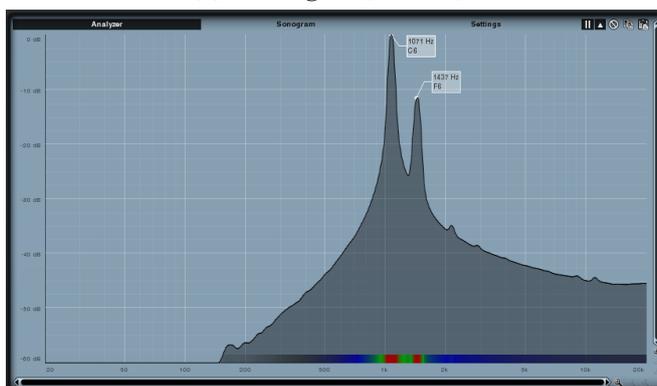
The sound spectra of the bonang are further shown in Figs. 7 and 8 (digitally recorded using the Melda analyser in Cubase version 9).



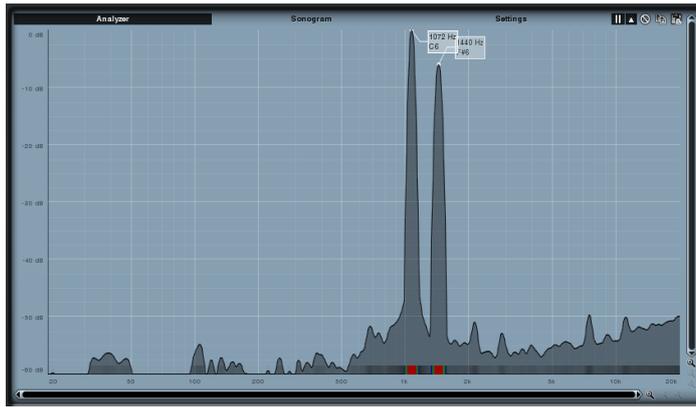
(a) Bonang 1P ($t = 0$ s).



(b) Bonang 1P ($t = 0.5$ s).

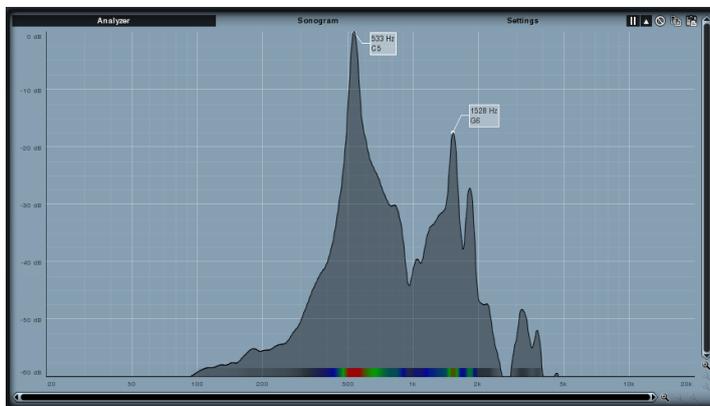


(c) Bonang 1P ($t = 1$ s).

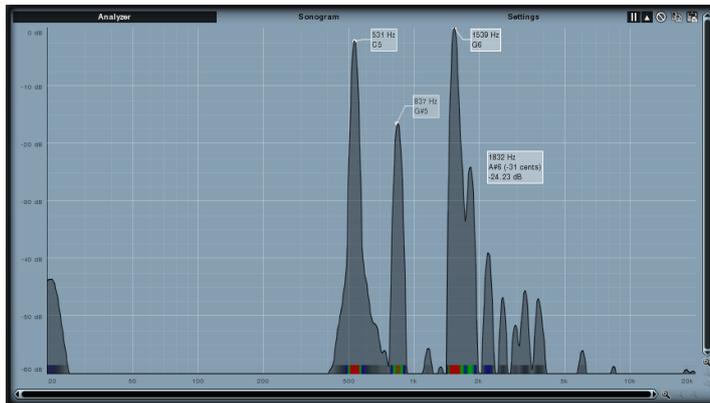


(d) Bonang 1P ($t = 1.5$ s).

Fig. 7. Typical spectra from bonang penerus 1P (high octave bonang penerus) displaying the spectra at $t = 0, 0.5, 1$ and 1.5 s using Melda analyser in Cubase version 9.



(a) Bonang 1B ($t = 0$ s).



(b) Bonang 1B ($t = 0.5$ s).

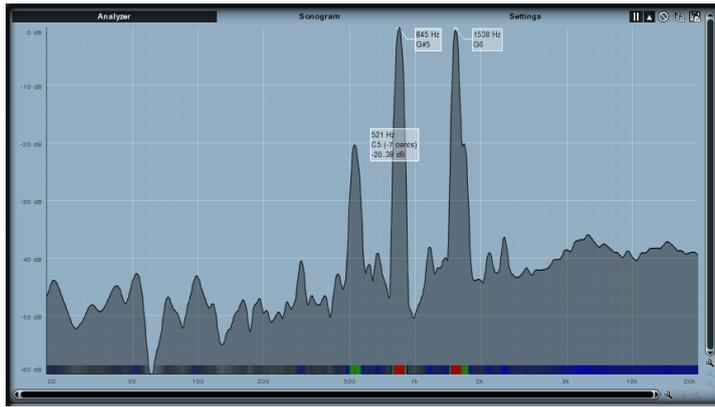
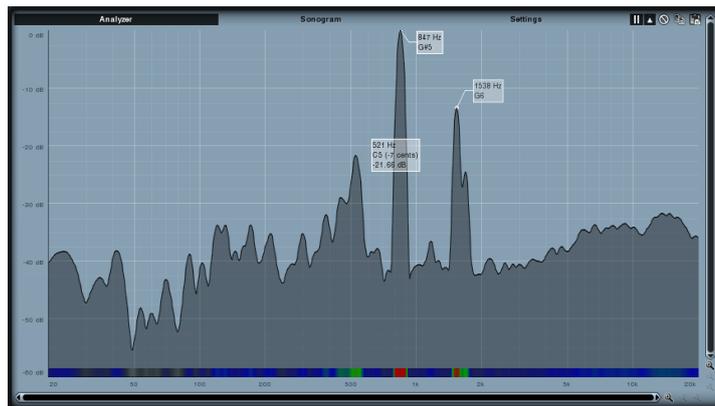
(c) Bonang 1B ($t = 1$ s).(d) Bonang 1B ($t = 1.5$ s).

Fig. 8. Typical spectra from bonang barung 1B (low octave bonang barung) displaying the spectra at $t = 0, 0.5, 1$ and 1.5 s using Melda analyser in Cubase version 9.

3.1. High octave bonang penerus

Note that the initial sound (at $t = 0$ s) using Melda analyser in Cubase version 9 for bonang penerus 1P comes from 3 different distinct frequencies as shown in Table 3. PicoScope oscilloscope (see Table 2) detect the octave in the second overtone frequency, i.e., at $1.97f$. From Table 3, at $t = 0.5$ s only 2 different distinct frequencies appear. At $t = 1.0$ s the 2 different distinct frequencies appear, i.e., sustained. At $t = 1.5$ s once again 2 different distinct frequencies appear and sustained. From the start until $t = 1.5$ s, the 2 different distinct frequencies are sustained with the $1.54f$ only appear at $t = 0$ s. For bonang penerus 2, the spectra display 3 peaks namely f , $1.56f$ and $3.59f$ at the start ($t = 0$ s). At $t = 0.5$ s, 2 peaks are sustained, i.e., f and $1.56f$ became significant. For both $t = 1$ s and $t = 1.5$ s peaks f , $1.4f$ is still sustained with $3.62f$ reappear quite significant. These peaks at f and $1.4f$ both at $t = 1$ s and $t = 1.5$ s agrees very well with the PicoScope at f and $1.4f$. Bonang penerus 2 display the disappearance of $3.59f$ at $t = 0.5$ s and reappearance of $3.62f$ at $t = 1$ s and 1.5 s.

Table 3. Three different frequencies for bonang penerus obtained from Melda analyser in Cubase version 9 recorded at $t = 0, 0.5, 1$ and 1.5 s.

	Time	Fundamental	1 st Overtone	2 nd Overtone
Penerus 1	$t = 0$ s	f (1073 Hz-C6)	$1.35f$ (1457 Hz-F#6)	$1.54f$ (1655 Hz-G#6)
	$t = 0.5$ s	f (1072 Hz-C6)	$1.35f$ (1456 Hz-F#6)	-
	$t = 1$ s	f (1071 Hz-C6)	$1.34f$ (1437 Hz-F#6)	-
	$t = 1.5$ s	f (1072 Hz-C6)	$1.34f$ (1440 Hz-F#6)	-
Penerus 2	$t = 0$ s	f (589 Hz-D5)	$1.56f$ (920 Hz-A#5)	$3.59f$ (2115 Hz-G7)
	$t = 0.5$ s	f (590 Hz-D5)	$1.56f$ (920 Hz-A#5)	-
	$t = 1$ s	f (590 Hz-D5)	$1.4f$ (849 Hz-G#5)	$3.62f$ (2137 Hz-C7)
	$t = 1.5$ s	f (590 Hz-D5)	$1.4f$ (849 Hz-G#5)	$3.62f$ (2137 Hz-C7)
Penerus 3	$t = 0$ s	f (661 Hz-E5)	$1.65f$ (1091 Hz-C#6)	-
	$t = 0.5$ s	f (658 Hz-E5)	$1.55f$ (1022 Hz-C6)	-
	$t = 1$ s	f (658 Hz-E5)	$1.56f$ (1032 Hz-C6)	-
	$t = 1.5$ s	f (658 Hz-E5)	$1.5f$ (1022 Hz-C6)	-
Penerus 4	$t = 0$ s	f (784 Hz-G5)	$1.41f$ (1111 Hz-C#6)	$2.15f$ (1689 Hz-G#6)
	$t = 0.5$ s	f (788 Hz-G5)	$1.4f$ (1107 Hz-C#6)	$1.97f$ (1556 Hz-G6)
	$t = 1$ s	f (788 Hz-G5)	$1.38f$ (1088 Hz-C#6)	$1.97f$ (1556 Hz-G6)
	$t = 1.5$ s	f (788 Hz-G5)	$1.38f$ (1088 Hz-C#6)	$1.97f$ (1556 Hz-G6)
Penerus 5	$t = 0$ s	f (879 Hz-A5)	$1.44f$ (1265 Hz-D#6)	$2.32f$ (2036 Hz-C7)
	$t = 0.5$ s	f (879 Hz-A5)	$1.44f$ (1266 Hz-D#6)	$2.32f$ (2036 Hz-C7)
	$t = 1$ s	f (879 Hz-A5)	$1.44f$ (1266 Hz-D#6)	$2.32f$ (2036 Hz-C7)
	$t = 1.5$ s	f (879 Hz-A5)	$1.44f$ (1265 Hz-D#6)	$2.32f$ (2036 Hz-C7)

Bonang penerus 3 sustained both f and $1.65f$ peaks from the beginning until $t = 1.5$ s. The PicoScope also displays only 2 peaks f and $1.6f$ in Table 1. It is suggested that bonang penerus 3 maintain both frequencies in the whole spectra. Unlike bonang penerus 3 (with only 2 peaks sustained), bonang penerus 4 sustained 3 peaks f , $1.4f$, $1.97f$ from the beginning until $t = 1.5$ s. The PicoScope also displays all 3 peaks f , $1.41f$ and $1.97f$ in Table 1. Similar to bonang penerus 4, bonang penerus 5 sustained 3 peaks f , $1.44f$, $2.32f$ from the beginning until $t = 1.5$ s. The PicoScope display all 3 peaks f , $1.44f$ and $1.99f$ in Table 1 with the third peak at $1.99f$ instead of $2.32f$. In general, for high octave bonang, the only bonang penerus 1 and 2 showed un-sustain peaks from the start at $t = 0$ s where both bonang penerus 1 and 2 eventually have 2 peaks after $t = 0.5$ s. Bonang penerus 3 (sustained with 2 peaks), bonang penerus 4 and 5 (sustained with 3 peaks) seems to be well tuned.

3.2. Low octave bonang barung

From Table 4, the low octave bonang barung 1 at $t = 0$ s displayed 3 distinct peaks f , $2.86f$ and $3.43f$. At $t = 0.5$ s additional peak $1.57f$ appear making 4 distinct peaks at f , $1.57f$, $2.89f$ and $3.45f$. The 3 lower peaks f , $1.59f$ and $2.89f$ were sustained at $t = 1$ s where the highest peak at $3.45f$ disappear. At $t = 1.5$ s these 3 lower peaks f , $1.62f$ and $2.95f$ are still sustained. The appearance of $1.57f$ at $t = 0.5$ s was replaced by the disappearance of $3.45f$ at $t = 1.0$ s, which eventually gave 3 lower peaks at $t = 1.5$ s. Although bonang barung 1 produces 4 peaks initially with the highest frequency at $3.45f$, eventually only 3 peaks are sustained at f , $1.62f$ and $2.95f$. For bonang barung 2, 4 peaks namely f , $1.8f$, $4.4f$ and $5.48f$ are distinctly shown at $t = 0$ s. At $t = 0.5$ s these 4 peaks are still sustained. At $t = 1$ s similar peaks are still sustained. At $t = 1.5$ s all peaks are sustained. Bonang barung 2 sustained all 4 peaks from the beginning until the end at $t = 1.5$ s.

Table 4. Three different frequencies for bonang barung obtained from Melda analyser in Cubase version 9 recorded at $t = 0, 0.5, 1$ and 1.5 s.

	Time	Fundamental	1 st Overtone	2 nd Overtone	3 rd Overtone
Barung 1	$t = 0$ s	f (533 Hz-C5)	$2.86f$ (1528 Hz-G6)	$3.43f$ (1832 Hz-A#6)	
	$t = 0.5$ s	f (531 Hz-C5)	$1.57f$ (837 Hz-G#5)	$2.89f$ (1539 Hz-G6)	$3.45f$ (1832 Hz-A#6)
	$t = 1$ s	f (531 Hz-C5)	$1.59f$ (845 Hz-G#5)	$2.89f$ (1538 Hz-G6)	-
	$t = 1.5$ s	f (521 Hz-C5)	$1.62f$ (847 Hz-G#5)	$2.95f$ (1538 Hz-G6)	-
Barung 2	$t = 0$ s	f (296 Hz-D4)	$1.8f$ (534 Hz-C5)	$4.4f$ (1317 Hz-E6)	$5.48f$ (1624 Hz-G#6)
	$t = 0.5$ s	f (296 Hz-D4)	$1.8f$ (534 Hz-C5)	$4.4f$ (1318 Hz-E6)	$5.48f$ (1624 Hz-G#6)
	$t = 1$ s	f (296 Hz-D4)	$1.8f$ (534 Hz-C5)	$4.4f$ (1304 Hz-E6)	$5.48f$ (1624 Hz-G#6)
	$t = 1.5$ s	f (296 Hz-D4)	$1.8f$ (544 Hz-C#5)	$4.4f$ (1304 Hz-E6)	$5.48f$ (1624 Hz-G#6)
Barung 3	$t = 0$ s	f (333 Hz-E4)	$1.63f$ (545 Hz-C#5)	$3.67f$ (1223 Hz-D#6)	$4.62f$ (1539 Hz-G6)
	$t = 0.5$ s	f (330 Hz-E4)	$1.63f$ (544 Hz-C#5)	$3.67f$ (1235 Hz-D#6)	
	$t = 1$ s	f (330 Hz-E4)	$1.63f$ (544 Hz-C#5)	$3.48f$ (1149 Hz-D6)	
	$t = 1.5$ s	f (330 Hz-E4)	$1.63f$ (544 Hz-C#5)	$3.48f$ (1143 Hz-D6)	
Barung 4	$t = 0$ s	f (396 Hz-G4)	$1.38f$ (547 Hz-C#5)	$1.72f$ (683 Hz-F5)	$2.57f$ (1018 Hz-C6)
	$t = 0.5$ s	f (399 Hz-G4)	$1.71f$ (677 Hz-E5)	$2.58f$ (1024 Hz-C6)	$3.29f$ (1304 Hz-E6)
	$t = 1$ s	-	$1.71f$ (678 Hz-E5)	$2.58f$ (1024 Hz-C6)	$3.29f$ (1301 Hz-E6)
	$t = 1.5$ s	-	$1.79f$ (678 Hz-E5)	$2.58f$ (1024 Hz-C6)	-
Barung 5	$t = 0$ s	f (438 Hz-A4)	$1.51f$ (665 Hz-E5)	$2.79f$ (1225 Hz-D#6)	$3.26f$ (1428 Hz-F6)
	$t = 0.5$ s	f (438 Hz-A4)	$1.51f$ (671 Hz-E5)	$2.79f$ (1225 Hz-D#6)	$3.29f$ (1445 Hz-F#6)
	$t = 1$ s	-	$1.51f$ (672 Hz-E5)	$3.26f$ (1441 Hz-F#6)	
	$t = 1.5$ s	-	$1.51f$ (671 Hz-E5)	$3.28f$ (1441 Hz-F#6)	

Bonang barung 3 displayed f , $1.63f$, $3.67f$, and $4.62f$ at $t = 0$ s. At $t = 0.5$ s the peaks become very significant at f , $1.63f$ and $3.67f$ only. At $t = 1.0$ s and $t = 1.5$ s similar peaks appear at f , $1.63f$, and $3.48f$. The 3 peaks are sustained from $t = 0$ s to $t = 1.5$ s except for the highest peaks at $4.62f$, which only appear at the beginning. For bonang barung 4, 4 peaks are displayed, i.e., f , $1.38f$, $1.72f$, and $2.57f$ at $t = 0$ s. At $t = 0.5$ s 4 peaks appear at f , $1.71f$, $2.58f$ and $3.29f$. At $t = 1.0$ s, 3 peaks appear at $1.71f$, $2.58f$ and $3.29f$. At $t = 1.5$ s, only 2 peaks $1.79f$ and $2.58f$ are sustained. The numbers of peaks decrease with time. Although PicoScope showed the fundamental at f , this fundamental was replaced by second overtone (high intensity) as proven by Melda analyser in Cubase version 9, i.e., at $1.71f$ and $2.58f$. The fundamental frequency of Bonang barung 4 had shifted from f at $t = 0$ s and $t = 0.5$ s to $1.71f$ at $t = 1$ s and $t = 1.5$ s. For bonang barung 5, $t = 0$ s showed 4 peaks at f , $1.51f$, $2.79f$ and $3.26f$. At $t = 0.5$ s this 4 peaks still appear. At $t = 1.0$ s only 2 peaks at $1.51f$ and $3.26f$ are sustained. At $t = 1.5$ s both peaks at $1.51f$ and $3.28f$ are sustained. In bonang barung 5 only 2 peaks are sustained, i.e., $1.51f$ and $3.28f$ at $t = 1.0$ s and $t = 1.5$ s whereas $2.79f$ and $3.26f$ only appear at $t = 0$ s and $t = 0.5$ s respectively.

3.3. Time-frequency analysis (TFA) spectrogram

Figure 9 shows a typical Time-Frequency Analysis (TFA) spectrogram from bonang barung 1 over time with the black part and the greyish part that explains its intensity at the frequency range stated on the vertical axis.

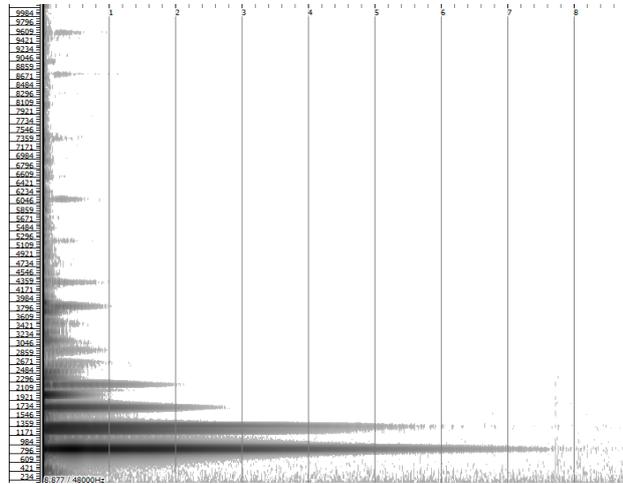


Fig. 9. A typical time-frequency analysis (TFA) spectrogram from bonang barung 1 over time with black part and greyish part that explains its intensity at frequency range stated on the vertical axis.

4. Conclusions

From this work, it can be concluded that the Picoscope reading is in good agreement with those from Melda analyser in Cubase version 9. Some concluding observations from the investigation are given below.

- The Picoscope only display the range of frequency obtained from the bonang at a set time or duration. From the Picoscope data, it is clear that only bonang barung 2 had been successfully manufactured to the just-tuned ensembles. Other bonang only show their partials (as described by the ratio to the fundamental to indicate the degree of consonance of their partials) as 1.3 for bonang penerus 1, as 1.4 for bonang penerus 2, 4, 5, as 1.5 for bonang penerus 3, bonang barung 5, 1.6 for bonang barung 1, 3 and 1.7 for bonang barung 4.
- With Melda analyser in Cubase version 9 a series of spectra between $t = 0$ s to $t = 1.5$ s was detected. Although the bonang ideally should sustained the fundamental frequency from the start $t = 0$ s to the end $t = 1.5$ s, it was found that some bonangs had shifted their fundamental frequency to the first overtone (where in this case the fundamental had reduced significantly and replace by the second overtone). The ratio 1.6, i.e., the frequencies relative to the fundamental (0, 1) mode indicate that the second mode is the (1, 1) mode [11].
- When the fundamental frequency shifts to the first overtone this means the initial fundamental key had shifted to a higher key. Ideally, the bonang should have maintained the series of frequency and should sustain it until the end of the spectra, i.e., maintaining a similar key along the time frame (i.e., sustained for the whole series of spectra).

- From a short visit by the authors to one manufacturer in Indonesia, it is learned that the tuning was basically done using a pianica where the initial fundamental frequency was used to decide the key of the bonang without taking into consideration of the following overtones that follow after the fundamental frequency.
- For the purpose of tuning, the quality of tones can also be assessed by expert and experienced piano tuner using purely on hearing the audible sound produced by the bonang. Unfortunately, the mother's nature creation cannot detect the frequency changes in the interval of 0.5 s as shown by the spectra using Melda analyser in Cubase version 9.

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