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EFFECT OF FRETS TO SOUND FREQUENCY OF SUNDATANG

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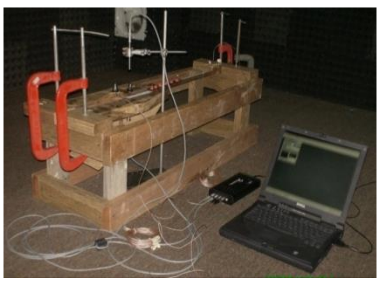
Graphical abstract



Abstract

Sundatang is a traditional musical instrument in Sabah, Malaysia, which is needs to be upgraded. The purpose of this study was to formulate equations that explaining the effect of frets to its sound frequency. Sound of sundatang was recorded using a microphone which was connected to ADC Harmonie system. In this study, it was found that the fundamental frequency of sound of the 1st string shifted to higher frequency when fretted at higher fret number. There are two equations formulated in this study which can be used to calculate the fundamental frequency of sound at each fret of sundatang, named Fundamental Frequency (FF) equation and Gradient Harmonic Frequency (GHF) equation. Where, the maximum average difference obtained between recorded and calculated frequency is 4.53 Hz. In addition, also formulated an equation that can be used to explain the correlation of the fundamental frequency and the length of the fretted of 1st string which is named as Correlation of Fundamental Frequency with Length of Fretted String (CFFLFS) equation. The formulated equations in this study can be used to develop a standard musical notation of sundatang.

Keywords: Fast Fourier transform, sundatang, sound frequency

Abstrak

Sundatang ialah alat muzik tradisional di Sabah, Malaysia yang perlu dinaiktaraf. Kajian ini adalah bertujuan menghasilkan persamaan yang dapat menerangkan kesan fret terhadap bunyi sundatang, alat muzik tadisional di Sabah, Malaysia. Bunyi sundatang dirakam menggunakan mikrofon yang disambung kepada sistem ADC Harmonie. Kajian ini mendapati bahawa frekuensi asas bunyi tali pertama berubah ke frekuensi lebih tinggi apabila difretkan pada nombor fret yang lebih tinggi. Dalam kajian ini, dua persamaan yang telah difomulasi boleh digunakan untuk menentukan frekuensi asas di setiap fret sundatang yang dinamakan *Fundamental Frequency (FF) equation* dan *Gradient Harmonic Frequency (GHF) equation*. Diperolehi bahawa purata beza maksimum antara frekuensi ukuran dan kiraan adalah 4.53 Hz. Selanjutnya, persamaan yang menjelaskan korelasi antara frekuensi asas dan panjang tali pertama yang difretkan juga dibangunkan. Persamaan ini dinamakan *Correlation of Fundamental Frequency with Length of Fretted String (CFFLFS) equation*. Persamaan-persamaan yang telah dibangunkan ini boleh digunakan untuk membangunkan notasi muzik piawai bagi sundatang.

Kata kunci: Jelmaan Fourier pantas, sundatang, frekuensi bunyi

1.0 INTRODUCTION

Sundatang is one of the traditional musical instruments among the Rungus and Kadazandusun communities in the state of Sabah, Malaysia. It is in the group of stringed musical instruments and has the basic shape of guitar with two strings as shown in Figure 1 [1-8]. The instrument normally made of acacia and vitex wood which are widely available in Sabah. The acacia is categorized as soft wood with density 0.51 gcm^{-3}, while, the vitex as hardwood with density 0.72 gcm^{-3} [8]. The present quality of this musical instrument shows that it need to be upgraded, in order to enhance it playability with other modern musical instruments such guitar, violin and etc. To achieve this goal, traditional construction technique of sundatang was studied as reported in our previous paper [7]. It was found that the construction of sundatang involves nine stages including material preparation, forming the basic shape of sundatang, making of the air cavity, construction of the back plate, the top plate and sound holes, the tuning pegs, the frets, fixing the fine tuner cord and finally tuning the strings of sundatang. This finding is very useful in modernization of the sundatang construction technique.

On the other hand, to more understand about sundatang, vibrational properties of its soundboards (without strings fixed to the instrument) were also studied [8], and found that in free edge, fundamental frequency of both plates of acacia sundatang is greater than the vitex sundatang in a range of 112 Hz to 230 Hz. However, in clamped edge (attached to its ribs), it was modified to a lower frequency and closer to each other in the range of 55 Hz to 59 Hz. In condition where both strings were fixed to the sundatang, apparently, the frets, one of the components of sundatang that has a great influence to its sound frequency, and need to be investigated.

There are six frets installed under the 1st string of this instrument, which perpendicular to the top surface of its neck (Figure 2). The frets are labeled as the 1st fret, 2nd fret, 3rd fret, 4th fret, 5th fret and 6th fret started from the nearest fret to the neck of sundatang. Measurement of the frets' heights shows that the average height of the 1st fret is around 2.15 cm, and increased to 0.1 cm when the fret number increased. Sound of sundatang was heard in different pitch when the 1st string was fretted at a different frets. Up to now, there no systematic explanation of the effect of frets to the sound of sundatang. Thus, the purpose of this study was to formulate equations that explaining the effect of frets to sound frequency of sundatang. Finding of this study is very important to understand the sound production of sundatang and to the development of its notation system. The finding also contributes to the research foundation on the traditional musical instruments in Sabah as reported by several previous researchers such as [9-16]. The research foundation is very useful to be used in the advancement of those traditional musical instruments in Sabah.

This paper is arranged in 4 sections. Following this introduction, materials and experiment methods to measure the sound frequency of sundatang using ADC Harmonie system is discussed in Section 2. Experimental results and discussion are discussed in Section 3 and the paper ends with some conclusion in Section 4.

2.0 MATERIALS AND METHODS

In this study, four units of sundatangs were used, two of them were made from acacia wood and another two were made from vitex wood (popular materials used in construction of sundatang). These sundatangs were labeled as sundatang A (acacia wood), sundatang B (acacia wood), sundatang C (vitex wood) and sundatang D (vitex wood) as shown in Figure 3. These sundatangs were made by Mr. Boginda Mokilin, a well-known sundatang maker and player from Kampong Tinangol in the district of Kudat, Sabah, Malaysia. This experiment was conducted in anechoic chamber at Vibration and Sound Laboratory, School of Science and Technology, University Malaysia of Sabah.

The sundatang was placed on a sundatang holder in order to let the body of sundatang in minimum movement and vibrate freely when its string was plucked by fingernail. The 1st string of sundatang was pressed down, until it touched the tip of fret by researcher's left hand finger, and pluck by right hand finger with moderate force at the position of sound hole. Sounds of sundatang at different frets were recorded using microphone which positioned at 15 cm from the top plate of this instrument. The microphone was connected to ADC Harmonie and computer. The recorded sounds were analyzed using FFT application as in Equation (1) in Matlab program [15, 17-20]. The experiment arrangement is as shown in Figure 4.

$$X(k) = \sum_{n=0}^{N-1} x(n) e^{-j\frac{2\pi}{N}nk}, \quad k = 0,1,2,..., N-1 \quad (1)$$

3.0 RESULTS AND DISCUSSION

3.1 Calculation of Fundamental Frequency

Sounds of the 1st string at different frets for the four units of sundatangs (A, B, C and D) were recorded and analyzed. The recorded sound shows that the fundamental frequency shifted to higher frequency when the string was fretted at higher fret number as shown in Figure 5 (as an example for the sundatang A) and in Table 1 (sound frequency of the 1st string at different frets of the sundatang A).

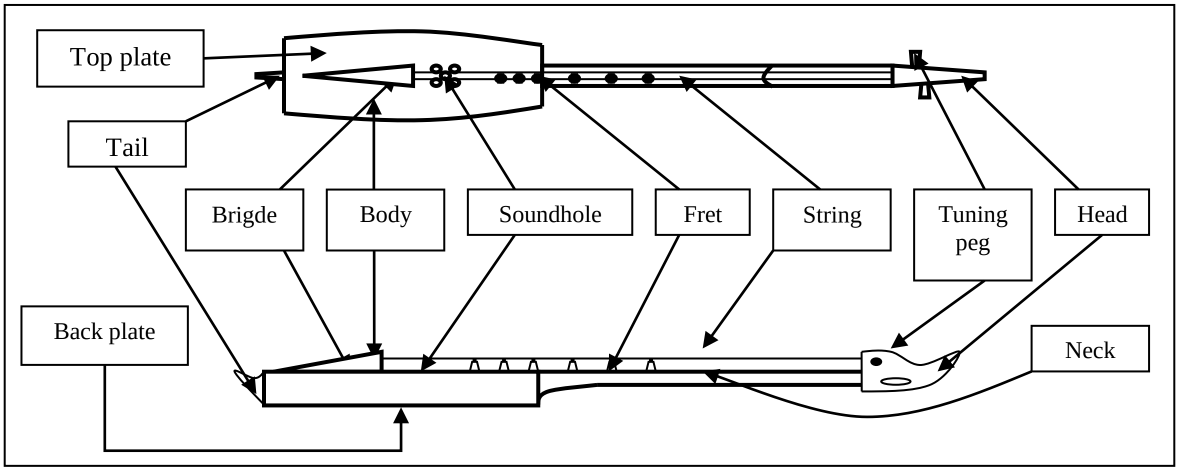


Figure 1 Anatomy of sundatang

Figure 2 Frets of sundatang

Figure 3 Photo of sundatang A,B,C and D

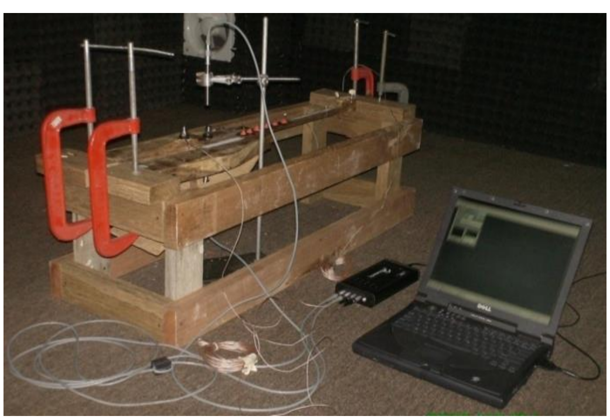


Figure 4 Experiment arrangement

From this figure and table, fundamental frequency at the 1st fret is 326 Hz, 2nd fret is 377 Hz, 3rd fret is 422 Hz, 4th fret is 506 Hz, 5th fret is 569 Hz, and 6th fret is 651 Hz. If the fundamental frequency from each fret is plotted in a graph of fundamental frequency versus fret number, it will give the equation of

$$f_o = 283.5e^{0.139n} \quad (2)$$

where, f_o is the fundamental frequency and n is the fret number as shown in Figure 6. In this study, the Equation (2) is named the Fundamental Frequency (FF) equation of the fretted string of the sundatang.

Sounds of the 1st string from each fret are in harmonic. This is proven through ratio analysis of f_i / f_o, where $f_o = f_1$ (the 1st harmonic frequency) and f_i is consequence frequencies, which i is started from 2,3,4,5….n.

The ratio of the fundamental frequency to the consequence frequencies is $f_o, 2f_o, 3f_o, ..nf_o$ as shown in third column of Table 1 (for sundatang A). In this study, graph of frequency versus harmonic number for each fret is plotted. As an example in Figure 7 for the sundatang A. From this figure, all the plotted graphs (sundatang A) are in linear function as written in Table 2 (second column). And, this pattern also determined in the sundatang B, C and D (third, fourth and fifth column in Table 2).

From Table 2, it is found that the value of gradient for each fret is very close to the value of its fundamental frequency. As an example, for the 1st fret of sundatang A, its fundamental frequency is 326

Hz (in Table 1) and its plotted graph gradient is 325 (in Table 2). Average difference of the gradient and the fundamental frequency at each fret, $\overline{m - f_o}$

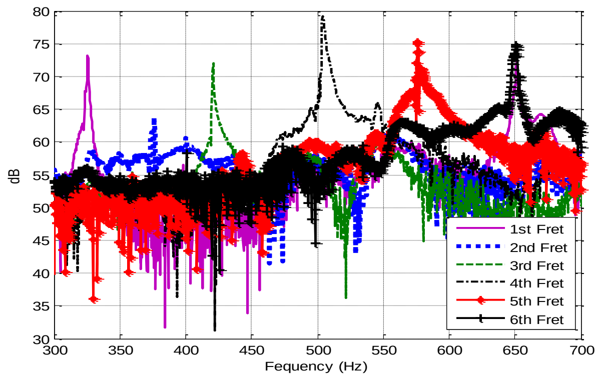


Figure 5 Fundamental frequency of the 1st string at each frets (sundatang A, acacia)

where m is gradient is -3.55 Hz as shown in Table 3 (as an example for sundatang A). If the gradient values of the plotted graphs in Figure 7 (as written in Table 2) are plotted versus the fret number, it gives equation of exponential form. For example for the sundatang A in Figure 8 with equation of $m = 2833e^{0.137n}$, because $m \approx f_o$, so this equation can be written as

$$f_o = 2833e^{0.137n} \qquad (3)$$

In this study, the Equation (3) is named Gradient Harmonic Frequency (GHF) equation of fretted string of the sundatang.

Table 1 Frequency analysis of sound from the 1st string at different frets of the sundatang A (acacia)

(a) 1st fret, 2nd fret and 3rd fret

Harmonic number	1st fret			2nd fret			3rd fret		
	freq., (± 1Hz)	ratio, f_i / f_o	dB	freq., (± 1Hz)	ratio, f_i / f_o	dB	freq., (± 1Hz)	ratio, f_i / f_o	dB
1	326	1.0	73	377	1.0	70	422	1.0	70
2	651	2.0	65	756	2.0	75	837	2.0	72
3	977	3.0	76	1133	3.0	72	1254	3.0	66
4	1301	4.0	76	1513	4.0	64	1674	4.0	60
5	1626	5.0	72	1890	5.0	61	2087	4.9	62

(b) 4th fret, 5th fret and 6th fret

Harmonic Number	4th fret			5th fret			6th fret		
	freq., (± 1Hz)	ratio, f_i / f_o	dB	freq., (± 1Hz)	ratio, f_i / f_o	dB	freq., (± 1Hz)	ratio, f_i / f_o	dB
1	506	1.0	79	569	1.0	76	651	1.0	75
2	1009	2.0	76	1138	2.0	71	1298	2.0	70
3	1507	3.0	70	1697	3.0	66	1939	3.0	67
4	2001	4.0	61	2260	4.0	61	2595	4.0	66
5	2502	4.9	62						

Note: $f_o = f_1$

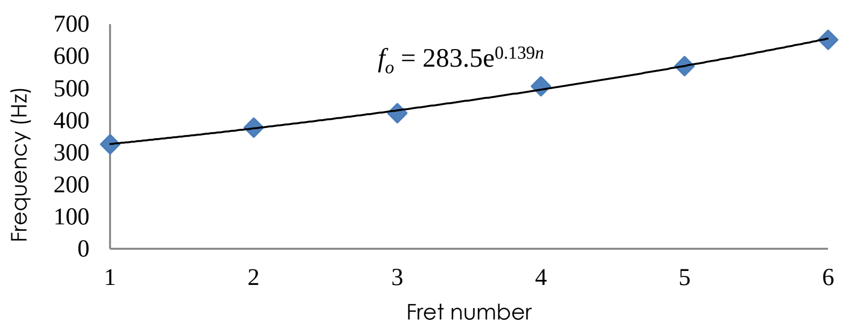


Figure 6 Fundamental frequency versus fret number of the 1st string of sundatang A (acacia)

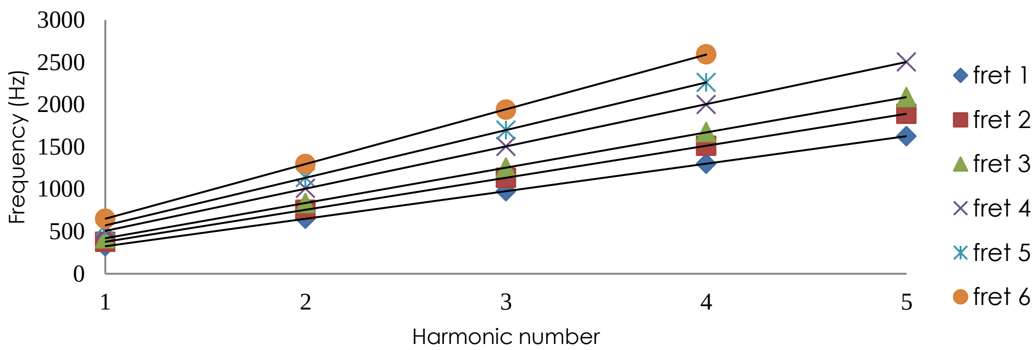


Figure 7 Harmonic frequencies of the sundatang A (acacia), when the 1st string was plucked at different frets

Table 2 Harmonic equations of sound for the sundatang A, B, C and D, when the 1st string was plucked at different frets

Fret no.	Sundatang A (acacia wood)	Sundatang B (acacia wood)	Sundatang C (vitex wood)	Sundatang D (vitex wood)
1st	$f = 325n + 1.11$	$f = 276.8n - 5.286$	$f = 397.1n - 2.114$	$f = 392.5n + 53.57$
2nd	$f = 378.3n + 1.35$	$f = 312.8n - 10.21$	$f = 446.1n - 2.88$	$f = 459.3n - 1.786$
3rd	$f = 416.7n + 4.7$	$f = 358.2n - 14.42$	$f = 508.0n - 6.18$	$f = 518.0n - 0.78$
4th	$f = 498.4n + 9.8$	$f = 426.5n - 16$	$f = 599.7n - 2.5$	$f = 615.5n - 1.8$
5th	$f = 563.1n + 8.3$	$f = 497.0n - 7.093$	$f = 707.6n - 5.7$	$f = 703.6n - 1.6$
6th	$f = 647.3n + 2.5$	$f = 594.7n - 1.44$	$f = 835n - 8$	$f = 813.7n - 2.866$

Table 3 Different of gradient value (frequency versus fret number) of each fret and the fundamental frequency for the 1st string of sundatang A (acacia)

Fret	Gradient, m (Hz)	f_o, (Hz)	m-f_0 (Hz)
1st	325.0	326	-0.1
2nd	378.3	377	1.3
3rd	416.7	422	-5.3
4th	498.4	506	-7.6
5th	563.1	569	-5.9
6th	647.3	651	-3.7
	$\overline{m - f_o}$		-3.55

The FF equation in Equation (2) and the GHF equation in Equation (3) were compared to find the similarities, and found that their coefficients are closer to each other. It was found that both equations can be used to calculate the fundamental frequency of the 1st string at each fret of sundatang A. However, FF equation is more accurately to determine the fundamental frequency compared to GHF equation. It is proven from the average difference of the recorded and calculated fundamental frequency of the 1st string at each fret is 0.92 Hz for FF equation and 4.53 Hz for GHF equation as shown in Table 4.

Sundatang B (acacia wood), sundatang C (vitex wood) and sundatang D (vitex wood) show similar pattern of sound characteristics. The equations of frequency versus fret number of the 1st string of sundatang B (third column), sundatang C (fourth column) and sundatang D (fifth column) are as written in Table 2. Graphs of gradient values (graph of frequency versus fret number) versus fret number of the 1st string of sundatang B, sundatang C, and sundatang D also plotted and their equations are obtained as shown in Table 5. It was found that, the sundatang B, C and D are keep a similar acoustical pattern.

In this study, general equation of the FF equation and the GHF equation acacia sundatang and vitex sundatang is can be written as

$$f_o = \alpha e^{\beta n} \quad (4)$$

Where, α (unit Hz) and β (without unit) are constant and n is fret number. It was also found that that the FF equation is more accurately to calculate the value of the fundamental frequency of the 1st string at each fret of sundatang.

Table 4 Comparison of recorded and calculated fundamental frequency at each fret (1st string of sundatang A)

a) FF equation

Fret number	1st	2nd	3rd	4th	5th	6th	Average difference
Recorded (Hz)	326	377	422	506	569	651	
Calculated (Hz)	324.90	374.36	430.18	494.33	568.05	652.76	
Difference	1.10	2.64	-8.18	11.67	1.25	-1.76	0.92

b) GHF equation

Fret Number	1st	2nd	3rd	4th	5th	6th	Average difference
Recorded (Hz)	326	377	422	506	569	651	
Calculated (Hz)	324.90	372.16	427.23	490.45	563.03	646.34	
Difference	1.10	4.84	-5.23	15.55	6.27	4.66	4.53

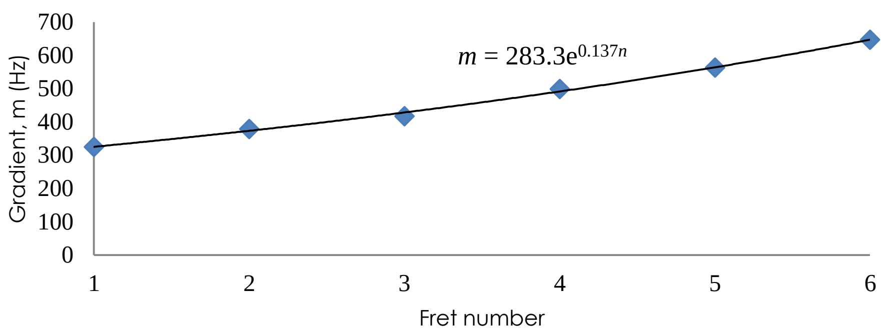


Figure 8 Gradient of harmonic frequency of each fret versus the fret number of sundatang A (acacia)

Table 5 FF equation and GHF equation of 1st string of sundatang B,C and D

Equation	Sundatang B	Sundatang C	Sundatang D
FF	$f_o = 229.5e^{0.153n}$	$f_o = 3322e^{0.149n}$	$f_o = 351.4e^{0.138n}$
GHF	$f_o = 2346e^{0.151n}$	$f_o = 3325e^{0.150n}$	$f_o = 3325e^{0.150n}$

3.2 Correlation of Fundamental Frequency and Length of Fretted String

Length of the 1st string from the bridge to the 1st fret is $l_{bf1} = l_1$ and length of the 1st string from the bridge to the 2nd fret is $l_{bf2} = l_1 - d_{1,2}$ where $d_{1,2}$ is distance of 1st fret to 2nd fret, so length of the 1st string from the bridge to *n*th-fret or called length of the fretted string is calculated using equation $l_{bfi} = l_1 - d_{1,i}$ where $i = 2,3,4,..n$ (as shown in Figure 2). In advance of this study of effect of frets to the sound frequency of sundatang, graphs of correlation between fundamental frequency and length of the fretted 1st string of the four units of sundatangs were plotted and investigated. One of the plotted graphs is as shown in Figure 9 (sundatang A), and correlation equations of the fundamental frequency and the length of the fretted string of the four units of sundatangs are obtained which summarizes in Table 5. The relationship between the fundamental frequency and the length of the fretted string can be expressed using two form of equations that are in exponent form and logarithmic form (refer to Table 5). Both equations can be used to calculate the fundamental frequency of the fretted string. This is proven through the values of average difference of the calculated and measured fundamental frequency, $\overline{f_m - f_c}$ of the fretted 1st string as shown in the table (third column). However, for acacia sundatangs, calculation of the fundamental frequency is more accurate in exponent form than in logarithmic equation. Where, the value of the $\overline{f_m - f_c}$ in exponent equation is smaller than in logarithmic equation. On the other hand, for vitex sundatang, the logarithmic equation is more accurate than the exponent equation. Where, the value of the $\overline{f_m - f_c}$ in logarithmic equation is smaller than in exponent equation.

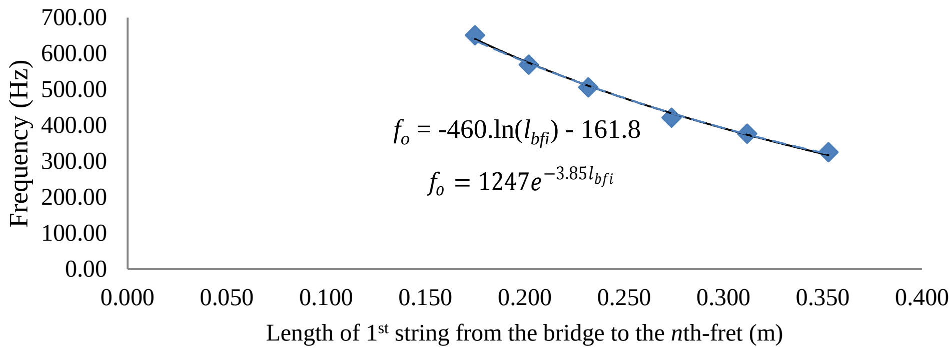


Figure 9 Plot of fundamental frequency versus length of the1st string from the bridge to the *n*th-fret of sundatang A (acacia)

Table 5 Correlation equation of fundamental frequency and length of fretted of 1st string

Set of sundatang	Correlation equation of f and l_{bfi} *logarithmic form **exponential form	Average difference of the calculated and measured values of fundamental frequency, $\overline{f_m - f_c}$ (Hz)
sundatang A (acacia)	* $f_o = -460\ln(l_{bfi} - 161.8$ ** $f_o = 1247e^{-3.85(l_{bfi})}$	10.80 10.73
sundatang B (acacia)	* $f_o = -402\ln(l_{bfi}) - 172.8$ ** $f_o = 1080e^{-4.12(l_{bfi})}$	12.52 12.20
sundatang C (vitex)	* $f_o = -601\ln(l_{bfi}) - 278.6$ ** $f_o = 1611e^{-4.26(l_{bfi})}$	13.65 13.91
sundatang D (vitex)	* $f_o = -584\ln(l_{bfi}) - 225.9$ ** $f_o = 1567e^{-3.95(l_{bfi})}$	12.09 12.23

General equation of this correlation is

$$f_o = -\rho \ln(l_{bfi}) - \sigma \quad (5)$$

where, ρ and σ are constant with unit Hz, or

$$f_o = \gamma e^{-\delta l_{bfi}} \quad (6)$$

where γ and δ are constant with unit Hz and m^{-1}, respectively. The –ve sign means the fundamental frequency of the fretted string is inversely proportional to the length of fretted string.

4.0 CONCLUSION

In this study, effects of the frets towards the sound frequency of acacia and vitex sundatang were determined. The result shows that the sound frequency of the 1st string of sundatang is in harmonic and its fundamental frequency shifted to higher frequency when fretted at higher fret number. There are two equations formulated in this study which can be used to calculate the fundamental frequency of sound at each fret of the sundatang, which are named Fundamental Frequency (FF) equation and Gradient Harmonic Frequency (GHF) equation. There is also an equation formulated that can be used to explain the correlation of the fundamental frequency at certain fret with the length of the fretted string which is named as Correlation of Fundamental Frequency with Length of Fretted String (CFFLFS) equation. Findings of this study are very important in order to understand the sound production of sundatang. The formulated equations in this study can be used to develop a standard musical notation of sundatang.

References

[1] Alman, J. H. 1961. If You Can't Sing, You Can Beat a Gong. *Sabah Society Journal*. 2: 29-42.

[2] Liew, R. 1962. Music and Musical Instruments in Borneo. *Borneo Society Journal*. 5: 10-17.

[3] Frame, E. M. 1975. A Preliminary Survey of Several Major Musical Instruments and Form-Types of Sabah, Malaysia. *Borneo Research Bulletin*. 7(1): 16-24.

[4] Frame, E.M.1976. Several Major Musical Instruments of Sabah, Malaysia. *Journal of the Malaysian, Branch of the Royal Asiatic Society*. Vol. XLIX Part 2.

[5] Pugh-Kitingan, J. 1992. Musical Instruments in the Cultural Heritage of Sabah. *Borneo Research Council Second Biennial International Conference* 1992, Kota Kinabalu.

[6] Pugh-Kitingan, J. 2004. *Selected Papers on Music in Sabah*. Kota Kinabalu: Universiti Malaysia Sabah.

[7] Batahong, R.Y, J. Dayou and J. Romut. 2014b. Traditional Construction Technique of Sundatang. *12th International Borneo Research Council Conference*, UMS. 5-7 August 2014.

[8] Batahong, R. Y., J. Dayou, S. Wang and J. Lee. 2014. Vibrational Properties of Sundatang Soundboard. *Archives of Acoustics*. 39(2): 177-187.

[9] Ismail, A., S. A. Samad, A. Hussain, C. H. Azhari, and M. R. M. Zainal. 2006. Analysis of the Sound of the Kompang for Computer Music Synthesis*, 4th Student Conference on Research and Development (SCOReD 2006), IEEE,* Malaysia.

[10] Ong, C. W., and J. Dayou. 2009. Frequency Characteristic of Sound from Sompoton Musical Instrument. *Borneo Science*. 25: 71-79.

[11] Tee Hao, W., J. Dayou, M. C. D. Ngu, J. H. W. Chang, and W. Y. H. Liew. 2013a. Clamped Bar Model for Sompoton Vibrator. *Archives of Acoustics*. 38(3): 425-432.

[12] Tee Hao, W., J. Dayou, M.C.D. Ngu, J.H.W. Chang and W.Y.H. Liew. (2013b). Analysis of Vibrator for Sompoton Using Cantilever Beam Model. *Borneo Science*. 32:13-19.

[13] Batahong, R.Y. and J. Dayou. 2003a. Mathematical Modeling of Sound Frequency Determination of Kulintangan [in Malay]. *The XI Science and Mathematics National Symposium*, Kota Kinabalu, Sabah.

[14] Batahong, R. Y., and J. Dayou. 2003b. Visualizing the Vibrational Modes of the Kulintangan. *National Postgraduate Seminar*, UMS, Kota Kinabalu, Sabah. 18-19 March 2003.

[15] Batahong, R. Y., C. W Ong, and J. Dayou. 2003. Accuracy, Precision and Sensitivity of Sound Frequency Measurement Using Matlab Software [In Malay]. *Technical Report*, LT/SST-UMS/2003/011.UMS.

[16] Batahong, R. Y., and J. Dayou. 2002. The Making of Kulintangan Musical Instrument in Kudat, Sabah [in Malay]. *BORNEO RESEARCH COUNCIL Seventh Biennial International Conference* (2002). Kota Kinabalu. 15-18 July 2002.

[17] Soliman, S. S. and M. D. Srinath. 1998. *Continous and Discrete Signals and Systems.* New Jersey: Prentice Hall.

[18] Wan Azizun, W. A., T. S. Lim, H. Salasiah. 2004. Fingerprint Recognition Wavelet Domain. *Jurnal Teknologi.* 41(D): 25-42.

[19] Shaymaa, M., B. Arifah, A.A. Zainal, S. Saim. 2014. Review of the Role of Analytical Modelling Methods in Riverbank Filtration System. *Jurnal Teknologi.* 71(1): 59-69.

[20] Syahrul, F. S., Roszilah, H. 2015. Effect of Moisture and Chloride Content on the Direct and Reflected Ground Penetrating Radar Waves Amplitude Ratio in Concrete slab. *Jurnal Teknologi*. 74(3): 1-5.