Experimental Study on Sound Characteristics of Ja-Khay Strings

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***Abstract*—This research explored sound characteristics of eight different strings on Ja-Khay, a Thai classical floor zither. The strings were investigated the suitability of being the first brightest string. Physical properties of each string such as linear density, elastic modulus and tension required to make a 262 Hz C_4-note sound were tested and measured. The sound produced by each string was recorded in the recording studio of Music Engineering and Multimedia Department, King Mongkut's Institute of Technology Ladkrabang. Temporal and spectral responses of the sound produced by eight test strings were analyzed. The relationship between physical properties and sound characteristics such as maximum loudness, sustain, richness and brightness of the sound was investigated. The good sound characteristics of three most well-liked strings according to the survey: construction string number 120, tennis string and Saw-U silk string, were confirmed by the analytical data.**

***Keywords*—Ja-Khay string, musical sound, sound characteristics, Thai classical music, Thai floor zither**

I. INTRODUCTION

Music is a form of art enjoyed in all human societies. Musical instruments have been evolving throughout the civilization of mankind. In order to better understand the musical instruments, analysis of temporal and spectrum responses of western instruments' sound has been widely conducted. S. Šali and J Kopač [1] proposed a method of frequency response measurement of classical guitar, and formed rule of consonance-dissonance to discern between the sounds of high and low quality guitars [2]. B. Toghiani-Rizi and M. Windmark [3] applied artificial neural network to observe frequency responses and categorize the types of musical instruments. To make the analysis simpler, X. Zhang and Z.W. Ras [4] classified the types of music and musical instruments using MPEG7 descriptions and standard classification algorithms.

Masterful crafting of Thai classical musical instruments has been passing down from generation to generation. To develop sound characteristics, it was always more of an art than a science. Scientific investigation on sound characteristics of Thai classical instruments was rarely conducted until recently. N. Chitnaont et al. [5] explored acoustic temporal and spectral response characteristics of Khlui Phiang-Aws or Thai recorders made from three different materials. Among three materials tested, bamboo was found to be the best material for proper sound characteristics.

Ja-Khay or Cha-khe is a traditional Thai classical plucked string musical instrument, a floor zither type. Ja-Khay is a Mon-Ramannadesa linage instrument. Its existence could be traced back to Ayutthaya era [6]. Similar instruments could be found in countries surrounding Thailand, such as Cambodia and Myanmar. The instrument is indeed a fruitful artifact of Indochinese Peninsula's mutual culture. This article presents the first step of analyzing sound characteristics of Ja-Khay. The physical properties of Ja-Khay strings were investigated. The temporal and spectrum characteristics of strings made from different materials were recorded and analyzed. The correlation between the string properties and sound characteristics would then be studied and reported.

II. JA-KHAY STRINGS

Fig. 1 Ja-Khay used in this study. Courtesy of Thai Classical Music Club, King Mongkut's Institute of Technology Ladkrabang (KMITL).

Ja-Khay is usually carved from a solid piece of wood. Among several types of wood that could be used, jackfruit wood is believed to be the best material [6]. Three strings are stretched between a brass saddle to the head of the

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instrument. The strings are tuned to the notes C-G-C. Fig. 1 shows Ja-Khay used in this study. It was crafted by master Uea Chatchalerm, one of the most prominent contemporary Ja-Khay crafting master [7]. There are no rules on what types of strings should be used, and there is no string especially manufactured for performing on Ja-Khay. Of the three strings, only the first brightest string would be the subject of this study.

The strings that are widely used on Ja-Khay are construction string no.120, construction string no.150, and brass string no. 28, starting from the first brightest string to the third string, respectively [6]. However, the string choices depend on the preference of Ja-Khay player. A survey for the preferred type of the first string was conducted among Ja-Khay players. Questionnaires were sent out to Thai classical music clubs in various universities. It was found that 58% of questionnaire returnees preferred construction string no.120, 33% preferred tennis string (no preference of string maker was informed), and 8% preferred silk string (the same string used in Saw-U, a Thai fiddle musical instrument).

The three strings recognized from the survey result and some others with the total number of eight strings were acquired for the test as the first brightest string in this study. They are:

1. construction string no.100 (C100)
2. construction string no.120 (C120)
3. construction string no.150 (C150)
4. Zons tennis string, no. 17 (Tenn)
5. Relix fishing string, 120 lb rated (Fish)
6. Saw-U silk string (Silk)
7. white cotton string, no. 60 (Cot)
8. yellow polypropylene string, no.5 (PP)

Fig. 2 shows Cot and PP strings.

Fig. 2 Subjects of the test: Cot (left) and PP strings (right).

Table I shows the physical properties of all test strings. The properties were measured at both unloaded and loaded conditions. For the loaded conditions, the strings were tightened such that Ja-Khay would produce a 262 Hz tone or C_4 note. Tension required to load each string is also shown in table 1. The diameters of Cot and PP strings decreased when loaded at higher rates than others since they are more loosely braided compared with others. The C100, C120, C150, Tenn and Fish strings had smooth surfaces. They were easy to slide fingers on, thus easy to play with. The surfaces of the Silk, Cot and PP strings are relatively rougher due to the braids, and these might cause inconvenience to some players.

All strings were put under tension tests with a universal testing machine. Stress-strain relationships of all strings were found to be not quite linear, therefore elastic modulus of each string was linearly approximated around the 262 Hz tension load condition. The value 262 Hz loaded tension varied linearly with string linear density and varied inversely with elastic modulation as shown in fig. 3 and 4, respectively. High tensioned string not only could possibly cause a shorter life of Ja-Khay due to a lot of stress acting on the instrument, but Ja-Khay player could also fatigue from employing extra effort to press and pluck the string.

TABLE I STRING PHYSICAL PROPERTIES MEASURED AT UNLOADED AND 262 HZ LOADED CONDITION.

Type	Unloaded		Loaded at 262 Hz	
	Diameter (mm)	Linear Density (gram/m)	Diameter (mm)	Tension (N)
C100	1.00	0.911	0.98	110
C120	1.26	1.367	1.16	167
C150	1.58	2.092	1.46	252
Tenn	1.30	1.452	1.22	182
Fish	1.05	0.990	1.00	122
Silk	1.65	2.271	1.57	250
Cot	2.06	1.970	1.67	229
PP	2.67	3.380	2.12	297

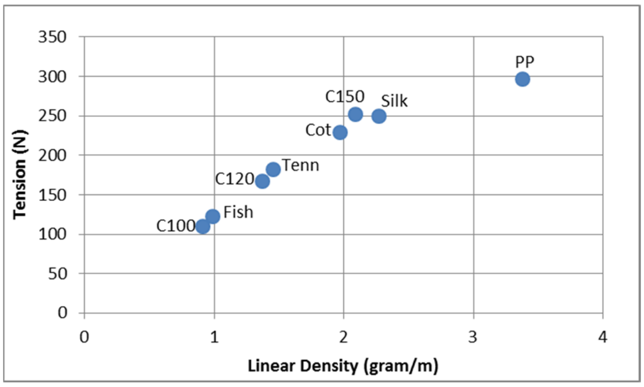

Fig. 3 Relationship between tension and linear density of test strings.

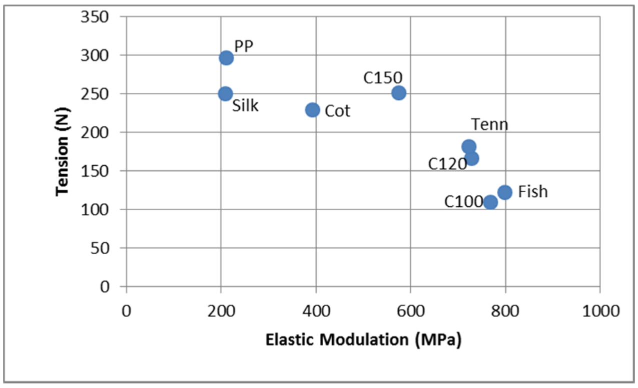

Fig. 4 Relationship between tension and elastic modulation of test strings.

III. METHOD AND RESULTS

The sound of Ja-Khay was recorded in the recording studio of Music Engineering and Multimedia Deaprtment, Institute of Music Science and Engineering, KMITL. Only the test string was stretched on Ja-Khay during the test and sound recording. The pluck, installed on a pendulum arm, was freely dropped on the string at the location of 90 mm measured from the brass saddle. Brüel & Kjær type 4190 microphone was placed 110 mm above the top of Ja-Khay's sound board and 170 mm from the string-plucked location (fig. 5). The microphone signal was amplified by Brüel & Kjær type 2804 microphone amplifier. The amplified signal was then fed to the computer via Brüel & Kjær Photon+ data acquisition module. The recorded signal was analyzed in time and frequency domains using RT Pro Photon 6.34.9104 software.

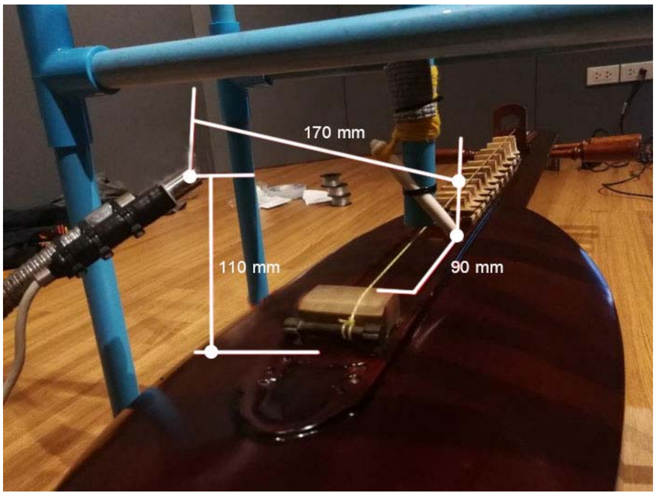

Fig. 5 Ja-Khay sound recording setup at Music Engineering and Multimedia recording studio, KMITL.

Fig. 6 shows the time response of the sound pressure produced by the C120 string. The sustain of the sound could be interpreted from logarithm decrement of sound pressure. Decrement asymptote was fitted as red dotted line (fig. 6), and the damping ratio of the decrement could be calculated from (1). δ is the logarithm decrement, x_i is the sound pressure amplitude at i^{th} step, T is the sampling time and ω is the frequency which in this case equal to 1646 rad/s (262 Hz). The damping ratio, ζ, of the sound pressure produced by C120 string (figure 6) was found to be ζ = 1.79/1646 = 1.09. The smaller value of damping ratio, the longer Ja-Khay sound sustains.

$$\delta = \ln\left(\frac{x_i}{x_{i+1}}\right) = \zeta\omega T \qquad (1)$$

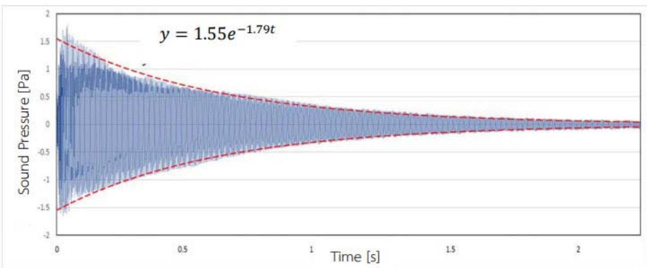

Fig. 6 Time response of the sound pressure produced by the C120 string.

The spectrum response of the C120 sound is shown in fig.7. The spectral centroid used to evaluate the brightness of the sound is calculated from (2), and is denoted as f_c. f_k is the k^{th} harmonic frequency, and P_k is the k^{th} harmonic sound pressure. The C120 string produced a spectral centroid of 784.457 Hz (fig. 7). The higher value of spectral centroid, the brighter the sound would be.

$$f_c = \frac{\sum_k f_k P_k}{\sum_k P_k} \qquad (2)$$

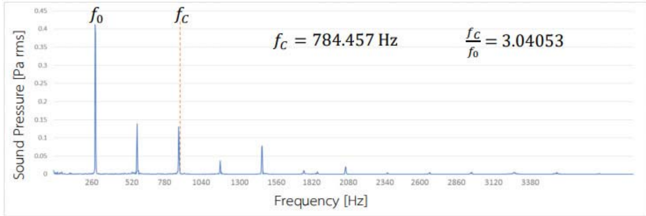

Fig. 7 Spectrum response of the sound pressure produced by the C120 string.

Fig. 8 shows the spectrum response of the acoustic power produced by the C120 string. Most of the power was provided by the first or fundamental harmonic frequency. The summation of the acoustic power components between the 2^{nd} and 6^{th} harmonic frequencies was calculated, and was taken as a mean to evaluate the richness of sound. The higher value of sound power summation yielded a richer sound.

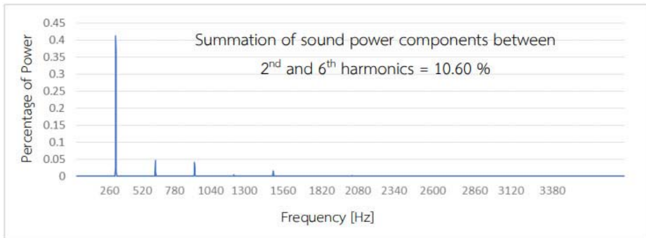

Fig. 8 Spectrum response of the sound power produced by the C120 string.

TABLE II DAMPING RATIO, SPECTRAL CENTROID AND 2^{ND} TO 6^{TH} HARMONICS SOUND POWER SUMMATION OF TEST STRINGS.

Type	Damping Ratio ($\times10^{-3}$)	Spectral Centroid (Hz)	2^{nd} to 6^{th} Harmonics Power Summation (%)
C100	0.95	786.9	4.14
C120	1.09	784.5	10.60
C150	1.55	724.6	3.22
Tenn	1.36	784.9	7.62
Fish	1.03	869.6	1.36
Silk	1.73	996.9	12.96
Cot	1.69	605.4	1.66
PP	2.26	684.7	3.21

Table 2 shows damping ratio, spectral centroid and summation of acoustic power between the 2^{nd} and 6^{th} harmonics of all test strings. The Silk string produced the brightest sound with its spectral centroid of 996.9 Hz. The most three popular choices for Ja-Khay first brightest string from the survey, C120, Tenn and Silk are the most rich-sounding strings, with summation of power between the 2^{nd} and 6^{th} ranging from 7.62% (Tenn) to 12.96% (Silk). These three strings also provided well-sustained sound with damping ratio ranging from 1.09×10^{-3} (C120) to 1.73×10^{-3} (Silk). Although the Silk string seems to be the best choice since it could produce the richest and brightest sound. It might not be the type preferred by all Ja-Khay players due to its rather high tension required. The tension required for the Silk string was 250 N, compared to 167 N of the C120 string

(Table 1). Higher tension causes more playing effort as well as shorter playing lifetime of the string.

The relationships between physical properties and sound characteristics were also investigated. Tension effected maximum loudness and brightness of the sound. Maximum sound pressure varied quite linearly with the tension (fig. 9), while spectrum centroid varied inversely with tension (fig. 10). Since tension changed with elastic modulus (fig. 4), these two sound characteristics also changed with elastic modulus.

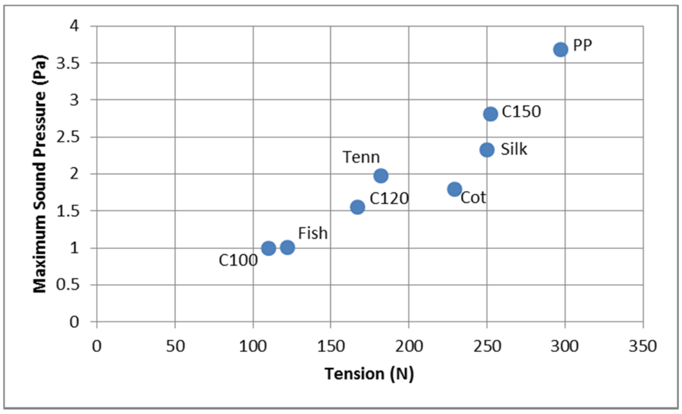

Fig. 9 Relationship between tension and maximum sound pressure.

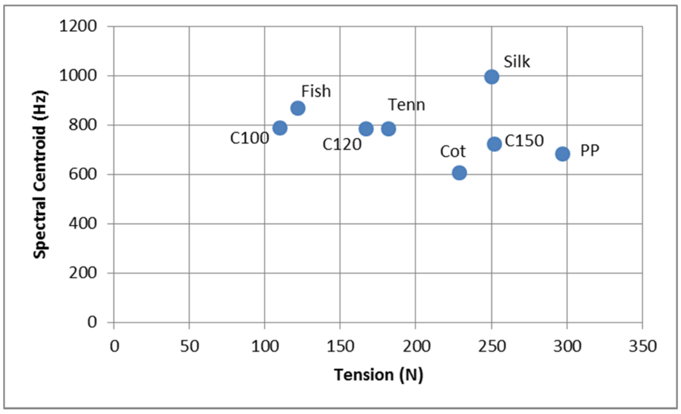

Fig. 10 Relationship between tension and spectral centroid.

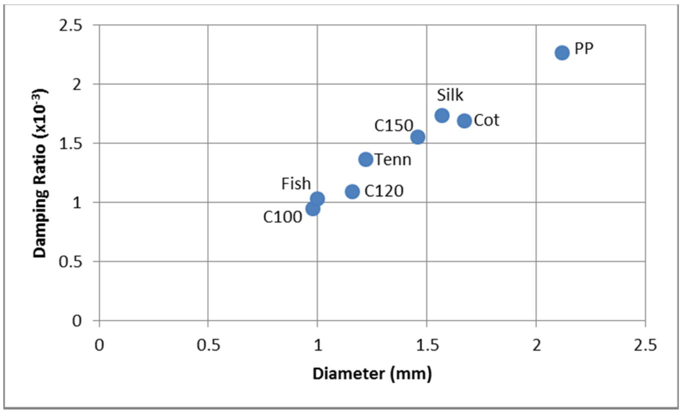

Fig. 11 Relationship between string diameter and damping ratio.

Damping ratio or the sustain of the sound changed with the diameter size of the string as shown in fig. 11. The bigger the string, the more friction string interacts with air due to larger contact area. This results in larger damping ratio and shorter sustain of sound.

IV. CONCLUSIONS

Eight different strings were investigated the suitability of being the first brightest string on Ja-Khay. Physical properties of all strings were tested and measured. Temporal and spectral response of the sound produced by each string was recorded and analyzed. The conclusions of the study can be summarized as follows.

1. Tension required to stretch the string varied linearly with string linear density and varied inversely with string elastic modulus.

2. Maximum sound pressure varied linearly with tension.

3. Damping ratio varied linearly with string diameter.

4. Good quality sound was achieved by C120, Tenn and Silk strings. The sound characteristics of these three strings: brightness (high spectral centroid), richness (high power summation of 2^{th}-6^{th} harmonics), and sustained sound (small damping ratio) were confirmed by being the players' chosen strings.

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