Acoustical Analysis of the Thai Duct Flute, Khlui

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***Abstract*—The purpose of this paper is to study the acoustical model of the Thai traditional duct flute, khlui. The relation between physical characteristics of the flute, such as acoustic length, playing hole, temperature effect, etc., and the frequency of each musical note of khluis is investigated. First, the fundamental frequencies of each finger hole of 10 khluis are measured. Then, data between the ideal musical notes and measured notes of khlui are analysed. The results indicate that the production process of khlui still has limits in accuracy. Finally, in order to develop a production standard of the Thai duct flute, a model of khlui is designed. The musical notes of the designed flute are measured. The accuracy of the designed flute is investigated to support the understanding of its acoustical model.**

***Keywords*—Khlui-Peang-Aw, Thai classical music, musical instrument, acoustics of flute, spectral properties**

I. Introduction

The Thai traditional duct flute, khlui has been familiar to Thai people for over 8 centuries. It was devised to be used as a solo instrument in Thai classical ensemble. Its physical body is similar to other Asian flutes such as the Indian flute, the khloy in Cambodia, and the suling in Indonesia [1]. There are many types of khlui. In this paper, we will focus on the Phiang Aw, the most popular Thai flute, that plays an important role in the Thai classical orchestra: Mahori. Figure 1 shows the physical feature of Khlui Phiang Aw.

There are 4 important parts in Khlui that helps it produce the sound. First, there is a part called dak, which helps in controlling the amount of wind that is blown into the tube. Secondly, there id the roo-pak-nokkaew which works as the ramp. It helps to separate the wind into two directions, which make the wind that stays within the tube vibrate and produce the sound. Finally, the note holes and the thumb hole are used by the player in order to make musical notes.

Most of the materials, used to make Khlui are wood. Bamboo, rose wood, tamarind and payoong are the most popular types of wood for making khlui. The production of khlui is originated by the local wisdom of the Thai people and is inherited from generation to generation.

At the present, many methods have been proposed for investigating the behavior of sound of the Western flute. For example, Alessandroet al. observed how the characteristics of materials affects the sound of the flute [2]. Joe et al. measured the impedance of the modern and classical flute to compare their feature of spectra [3]. Soizic et al. studied a toy model of flute-like instruments by using a numerical method [4]. Many researchers have studied the acoustics of Western flute [5]. On the one hand, the characteristics of Eastern flute sound have been investigated. For example, Somiya et al. used the dynamic PIV technique to measure the vibration of the Japanese bamboo flute [6].

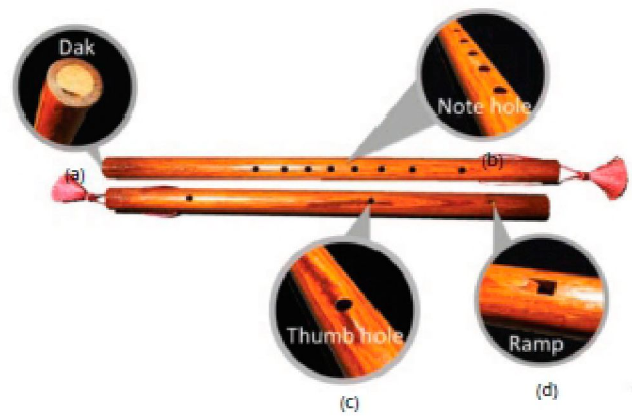

Fig. 1. Phiang Aw Khlui. (a) The top view illustrates the mouthpiece, (b) the front view including the 7 note holes , (c) The bottom view including the thumb hole (d) the ramp

Focusing on Thai traditional duct flutes, there are very few researchers who have studied it [7]. In particular, there is no one concentrating on developing the production of them. As we mentioned before, the production of khlui was inherited from generation to generation of Thai people. On the global level, there are a few people have studied the characteristics of Thai flute.

In this paper, in order to make a global standard of khlui, the acoustics of the Thai flute is studied. First, the acoustics and the important parameters of khluis, such as acoustic length, playing holes, etc. will be described. Then, the fundamental frequencies of the finger holes of 10 khluis are measured. The relation between physical characteristics and

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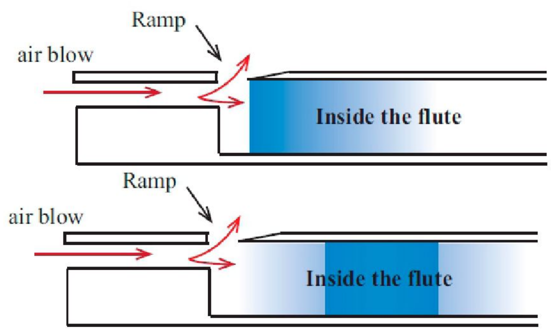

Fig. 2. Drawing of the direction of the air flow inside the khlui.

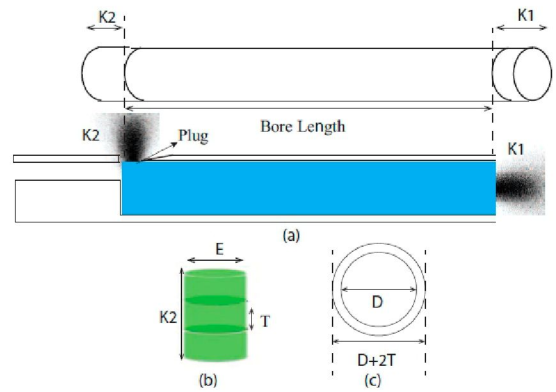

Fig. 3. Drawing of the acoustic length of the flute.

the frequency of each musical note of khluis are investigated. Finally, all results and suggestion for developing the khlui are discussed. The model of khlui is designed. The musical notes of the designed flute a re measured to support t he u nderstanding of its acoustical model.

II. Acoustics Of Khlui

The khlui is a Thai duct flute. The body of a khlui is normally made from a long length woods, such as bamboo, rose wood, tamarind and payoong etc. The most popular Thai flute is Phiang Aw. It produces a middle pitch from Bb4 to E6. Its size is around 1 inch in diameter and 18 inches long. In order to make the sound, the player blows the air from the dak as shown in Fig 1 (a), then uses their finger to control the pitch by closing and opening the finger holes. Blowing of the air makes the khlui body vibrate. The sound is created by the vibration of its body.

If we consider that the tube is the container that contains the air column, when the player blows air from the dak, the air will be split into two paths. First path, goes inside the cavity of the khlui. Another goes outside the khlui from ramp. Figure 2 shows the direction of the air flow inside the khlui. If the air blown is moved suddenly, the column of the air will be compressed like a spring at first. Then, the column beyond will be push by the coiled spring. This phenomena will occur until the end of the tube. After the compressed part reaches the end of the tube, the coiled spring will move down in the opposite direction to another end. In this case, the push of compression will need to be regular periodic cycle. The dark blue in Fig. 2 shows the behavior of the compression of the air that moves along the tube.

A. Acoustics length

As the khlui is an open end instrument, the fundamental frequency f_1 is represented as

$$f_1 = \frac{v}{2L} \tag{1}$$

where v is sound velocity and L is the acoustics length of khlui Al. However, the length of the khlui L is not the bore length Bl (the length from plug to the foot). It includes the end correction of the flute k_1 and sound hole k_2 as

$$Al = Bl + k_1 + k_2, \tag{2}$$

1) Acoustics End Correction at the Foot of the Bore: The sound of the khlui is created by the vibration of the khlui body. At the end of the opening tube, the vibrating air column is approximated by the cylinder Vc volume that is equal to a half sphere. The equation can be rewritten as

$$\frac{\pi D^2 k_1}{4} = \frac{\pi D^3}{12}, \tag{3}$$

where D is the diameter of the khlui that does not include the thickness as shown in Fig. 3 (c).Then we get

$$k_1 = \frac{D}{3}. \tag{4}$$

However, if we would like more precise,the estimation of the end correction k_2 and the wall thickness T is considered. The workout by Banade [8]can be presented as

$$k_1 = factor * D, . \tag{5}$$

where

$$factor = 0.411 - \frac{0.065}{(0.42 + 2T/D)^{0.54}}. \tag{6}$$

2) Acoustics End Correction at the sound hole: In this case, the acoustics end correction of the sound hole as shown in Fig.3 (b) is discussed. We assume that the acoustics end correction of the sound hole is a cylinder. From the magic ratio of Lew Paxton [9], the sound hole is converted to the same diameter as the bore by using the same magic ratio as follows

$$\frac{S_1}{L_1} = \frac{S_2}{L_2}, \tag{7}$$

According to the cross-section area of the sound hole and the bore the ratio becomes

$$\frac{E^2}{H} = \frac{D^2}{k_2}, \tag{8}$$

where

$$H = 0.61E + 0.33E + T, \tag{9}$$

$$k_2 = (D/E)^2((0.61 + 0.33))E + T, \tag{10}$$

and E is cross-section of the sound hole area.

B. Finger holes

In this subsection, the calculation of the effective length F is discussed. Figure 4 shows the the calculation of the acoustics length when the finger hole is opened. When each finger hole is opened the sound of the khlui will create a different pitch.

In this case, the length of the playing hole is found in the same way as the sound hole that we mentioned before. Then, the magic ratio [9] is calculated again. Thus, the effective length F can be represented as

$$F = [\frac{D}{P}]^2[\frac{2}{3}P + T], \tag{11}$$

where F is the effective length, P is the length of the finger hole, D is the diameter of the bore and T is the thickness of the flute. Figure 4 shows the drawing of the acoustic length of the flute related to the finger hole. In this case, Lr is the distance from the finger hole to the correction of the foot. Therefore, the part X_1 as shown in Fig. 4 (a) can be calculated as

$$X_1 = \frac{LrT}{Lr + F_1}. \tag{12}$$

A new substitution length, $Ls1$, relating to the first hole is created. Since multiple holes are considered, the next open hole can be obtained by using the same procedure as Eq. 14. Then we get

$$X_2 = \frac{(X_1 + L_12)F_2}{(X_1 + L_12) + F_2}. \tag{13}$$

Thus, the acoustic length relating to the M^{th} hole can be obtained as

$$X_M = \frac{(X_{(M-1)} + L_{sM})F_M}{(X_{(M-1)}L_{sM}) + F_M}. \tag{14}$$

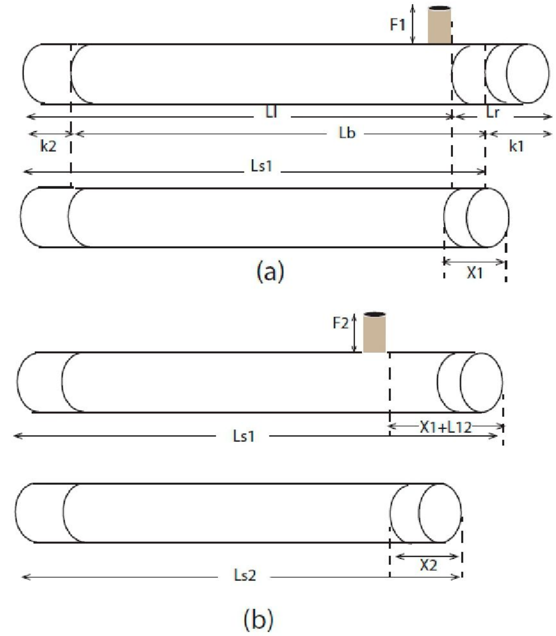

Fig. 4. Drawing of the direction of the air flow inside the Khlui.

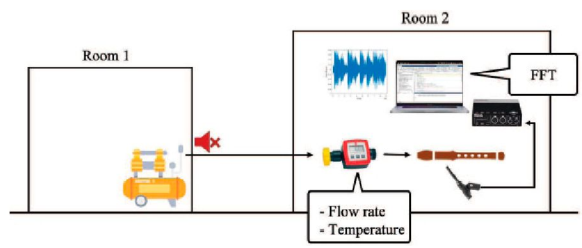

Fig. 5. Drawing of the direction of the air flow inside the khlui.

III. Experiments and Results

A. Experimental setup

Figure 5 shows the drawing of the experimental set up and recording of the fundamental frequencies of ten khluis. The two rooms were used for the recording. In this experiment, the air compressor was used to produce the air flow. Since its sound is loud, it was separated from the other apparatuses in a different room. Then, in order to control the blowing of air inside the khlui, the flow rate was controlled by the speed controller (SMC AS-2000). The flow sensor APM-400S was used to measure the flow rate. The sound produced by the khlui was recorded by the microphone dbx-rta-m. Then, the recorded signal was changed to a digital signal and was saved on the computer to analyse the frequencies.

B. Experimental results

In this paper, the fundamental frequencies of each note of ten khluis includes two kinds of wood: five chingchans and five makhams are recorded. The physical characteristics such as the sound hole, the finger hole, the thickness and the acoustic length of each khlui were investigated. Table I shows the physical characteristic of ten khluis. As can be seen, since the khlui is a handmade instrument, there are some errors of making the features of the khlui. In the same sense, there are some errors in making the finger hole and the acoustics length too.

TABLE I
THE PHYSICAL CHARACTERISTIC OF 10 KHLUIS INCLUDING CHINGCHAN WOOD (C) AND MAKHAM WOOD (M)

	Diameter (cm)	Thickness (cm)	sound hole (cm)
C(1)	1.56	0.47	0.72
C(2)	1.52	0.45	0.70
C(3)	1.56	0.43	0.72
C(4)	1.56	0.43	0.70
C(5)	1.50	0.41	0.73
M(1)	1.55	0.55	0.77
M(2)	1.68	0.42	0.70
M(3)	1.62	0.48	0.77
M(4)	1.60	0.42	0.70
M(5)	1.57	0.46	0.71

After measuring the fundamental frequencies of each note of the khlui, the error rate compared with the ideal note is found. Figure 7 and 8 show the error rate of each note of chingchan and makham khlui, respectively. It can be seen that, the maximum error is 11.41 percent which is the note B5 of the khlui mahkam (1) . According to the table I, it indicates that the sound holds and the thickness of the Makham (1) have a big difference from the others. Moreover, the note B5 get more error than other notes. This is because the note B5 relies a different technique to produce the sound. The last opened finger hole is the thumb hole that is located behind the Khlui. The player needs to produced more sound

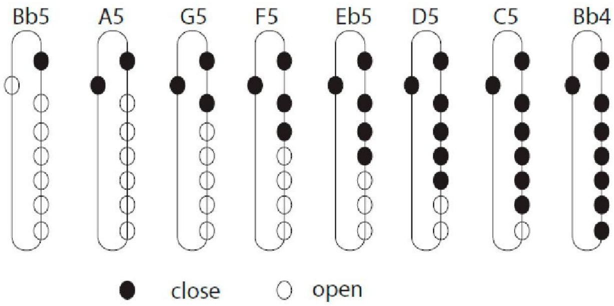

Fig. 6. The finger positions.

pressure to get the correct pitch on the B5 note. In this experiment, we use the constant flow rate to measure the musical note.

C. The Khlui Model

After investigating the problem of khlui production, a model of the khlui was designed to support the understanding of the acoustic model of the Thai flute. Figure 9 shows the design of the model of khlui. Then, the frequency of notes of the designed khlui were measured to support the understanding of the acoustical model of the Thai flute. It indicates that the accuracy of the acoustic length affects the accuracy of the pitch. However, the technique of making dak and ramp supports the sound production of the khlui.

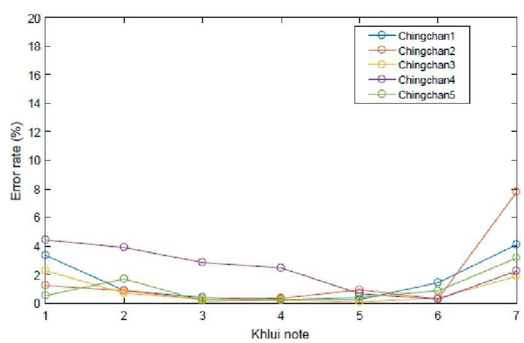

Fig. 7. The Error rate of the fundamental frequencies of the chingchan khlui.

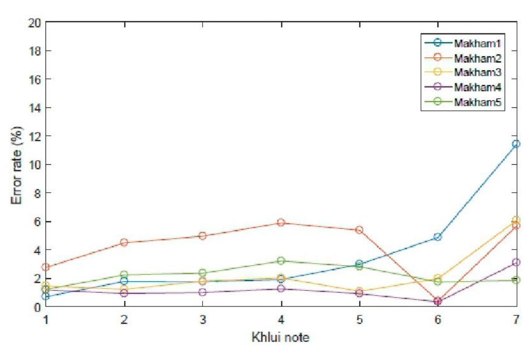

Fig. 8. The Error rate of the fundamental frequencies of the makham khlui.

IV. Conclusions

In this paper, the acoustics of the traditional Thai flute, khlui, was studied. The results indicate that the production

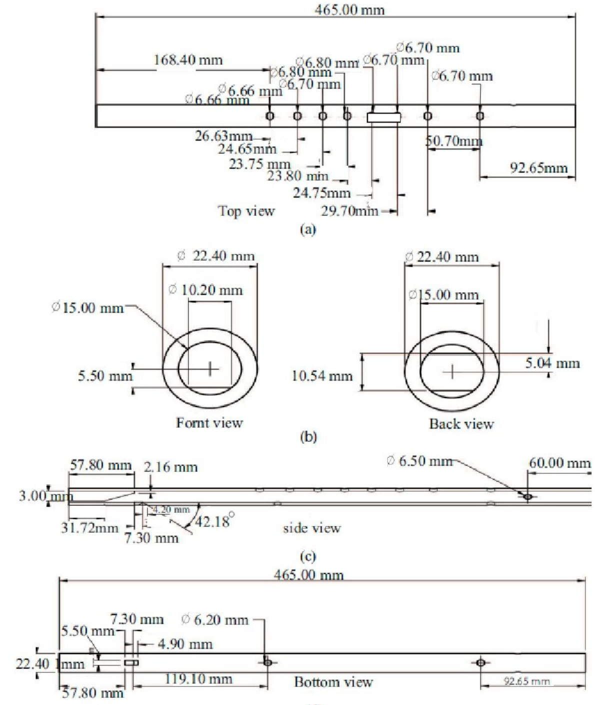

Fig. 9. Drawing of the model of the Thai flute.

standard of the khlui needs to be improved. To support the understanding of the acoustics of the khlui, the khlui model is designed to find a suitable way to develop the production of khlui in Thailand. For future work, the sound filed behavior will be visualized to support the understanding of the acoustics of the Thai flute.

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