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SPECTRAL SOUND ANALYSIS AND SOUND BOARD OPTIMIZATION OF TRADITIONAL MUSICAL INSTRUMENT QANUN*

*Serdar YILMAZ** - Ibrahim BELENLI*** - Zafer KURTASLAN*****

ABSTRACT

The present study was on the sound of a traditional instrument Qanun and investigated the effects of soundboards of different thickness on tone characteristics. Changes in sound level were observed. The acoustic envelopes contained three regions were drawn for all of pitches. The changes in the sound levels were studied on this graphic. Fourier Analysis was made on recordings. Frequency distribution curves were also drawn. Fundamental and overtone level distributions were shown on these graphics. The levels of harmonics were compared to fundamental level on these graphics. The structures of upper partial tones were studied. Frequency ranges of the graphics were limited to 100-10000 Hz. The numeric values on the all of graphics were analysed; and the differences between all overtones were noted. A typical sound level curve for the Qanun was shown. In 3.0 mm thickness, due to the irregular resonances resulting from the thin body, too many harmonics and long decay periods were observed. In higher thicknesses, the Qanun cannot show its unique timbre due the dimness and scarcity of harmonics. Because of the evaluation of graphics and numeric values, a 3.5 mm thick soundboard was suggested as the most appropriate soundboard. The findings obtained in the present study are valid for the standard structure that is commonly used. However, these findings can be guiding for qanuns of different structures.

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STRUCTURED ABSTRACT

The present study was on the sound of a traditional instrument Qanun and investigated the effects of soundboards of different thickness on tone characteristics. Changes in sound level were observed. Fourier Analysis was made on recordings. The structures of upper partial tones were studied. The numeric values on the graphics were analysed; and the differences between all overtones were noted. A typical sound level curve for the Qanun was shown. Because of the evaluation of graphics and numeric values, a 3.5 mm thick soundboard was suggested as the most appropriate soundboard. Because of the evaluation of graphics and numeric values, a 3.5 mm thick soundboard was suggested as the most appropriate soundboard only for the tested thickness values in this study.

<u>Analysis of Sound Level Change (β-t)</u>

Firstly, the acoustic envelopes contained three regions were drawn for all of pitches. These sound response curves (*β-t* graphics) were included as Sound Level (dB) curves versus time (ms). The changes in the sound levels were studied on this graphic. The first region on the graphic between the silent point and first peak of sound level was called "attack", the period from the attack to the moment that sound level started to decrease was called "steady state". Also as the third region, the period from the moment when the sound started to decrease to the moment when the sound went out was called "decay". Attack time is very important; it should not be late or for a very short time. In other words, the sound should reach its steady state in the appropriate period of time. For this reason, attack, steady state, and decay times were defined. The *β-t* graphics should show orderly and periodically change. In order to observe this, the sound level change curves on the graphic pattern during attack, steady state and decay were investigated and show the orderly chancing ones were detected.

Attack formation times for 4.5 mm and 3.9 mm thicknesses were hardly any. This immediate attack creates an effect like an explosion in the sound, and disturbs the ears. In 3.5 and 3.0 mm thickness, peak delayed and attack times increased. The increase in the thickness or the mass of the soundboard decreases the flexibility of the wooden material, and decreased the reaction time of the soundboard to the sound. For the same reason, elasticity coefficient of the wood plays an important role in the characteristics of the sound due to the amplitude of the resonance. The highest number of orderly changes in attack was observed in 3.5 mm thickness

The longest steady state time was observed in 3.5 mm thickness (Table-2). The regularity and the stability of sound level during steady state were observed as well (Fig.4). The highest number of steady state notes was observed in 3.5 mm thickness (Table-3). Simpler resonances were observed at higher frequency (Fig.5) and lower frequency (Fig.6 and Fig.7(a)). On the other hand, resonances that are more complex were observed in mid-frequency range (Fig.7). This indicates that the wooden material responds more regularly to certain sound ranges.

Decay times were shorter in 4.5 mm and 3.9 mm thickness. This also resulted from that the soundboards were not flexible enough. The

highest number of decays have orderly changes was observed in the recordings of 3.5 mm thickness (Table-3). These regular waves were not observed during sound but during various short time periods (Fig.5 and Fig.7). Regular waves were observed for long time periods in some pitches, but in others these were very short or instant.

Frequency Spectrum (f-β) Analysis

Secondly, frequency distribution curves (*f-β* graphics*)* were drawn. FFT analysis was applied on these frequency spectrums and the overtones were detected. Fundamental and overtone level distributions were shown on these graphics. The levels of harmonics were compared to fundamental level on these graphics. For this reason, sound level rates were not shown logarithmically but linearly. Musical instruments are generally made to produce the pitches within 27.5-4000 Hz frequency range. From these sounds, sounds up to around 12 kHz reach to the ear with harmonics. No distinctive harmonics of frequencies below 100 Hz and above 10 kHz were observed on the graphics. For this reason, frequency ranges of the graphics were limited to 100-10000 Hz.

In 3.0 mm thickness, due to the irregular resonances resulting from the thin body, too many harmonics and long decay periods were observed. Additionally, over strain of the strings cause in deformation in the soundboard of this thin. In higher thicknesses, the Qanun cannot show its unique timbre due the dimness and scarcity of harmonics.

Keywords: Musical Acoustics; Fast Fourier Transform; Frequency Spectrum; Timbre

KANUN GELENEKSEL ÇALGISINDA SPEKTRAL SES ANALİZİ VE SES TABLASI OPTİMİZASYONU

ÖZET

Bu çalışma geleneksel bir çalgı olan Kanun sazının sesi üzerinedir ve farklı ses tablası kalınlığının ton karakteristiğine olan etkisi araştırılmıştır. Üretilen Kanun'a dört farklı kalınlıkta ses tablası takıldı, her bir kalınlık için stüdyo ortamında ses kayıtları alındı. Her bir kalınlıkta ve her bir perde için ses düzeyi değişimi gözlendi. Tüm perdeler çin oluşturulan akustik zarflar üç bölgeli olarak gözlendi. Buradan Kanun sazına ait tipik ses seviye eğrisi gösterilmiştir. Ses kayıtlarına Fourier analizi yapıldı ve frekans dağılım eğrileri çizildi. Bu grafiklerde temel ve üzt-tonlar tespit edildi ve listelendi. Bu grafiklerde harmoniklerin düzeyleri temel harmonic ile kıyaslandı ve üst kısmi tonlar incelendi. İcelenen frekans aralığı 100-10000 Hz ile sınırlandırıldı. Grafiklerde yer alan tüm fekans ve ses düzeyleri listelenerek sayısal değerler birbirleri ile kıyaslandı ve harmonikler arasındaki ilişki yorumlandı. 3.0 mm kalınlıktaki ses tablasında, ince yapıdan dolayı meydana gelen düzensiz salınımlardan kaynaklanan çok sayıda harmonikler ve uzun süreli ses sönüm davranılşarı gözlendi. Daha yüksek kalınlıkta ise Kanun'un harmoniklerin sönüklüğü ve/veya azlığı nedeniyle kendine has tınısını ortaya koyamadığı gözlendi. Grafiklerin ve sayısal değerlerin değerlendirilmesi sonunda, ses tablası için 3.5 mm kalınlık önerilmiştir. Sunulan bu çalışmada elde edilen bulgular saz için yaygın olarak kullanılan standartyapı için geçerli olarak Kabul edilebilir. Bununla beraber bulgular farklı yapıdaki Kanun çalgıları için de yol gösterici niteliktedir.

Anahtar Kelimeler: Müzikal Akustik; Fast Fourier Transformu; Frekans Spektrumu; Tını

I. Introduction

Every musical instrument is made of materials that can resonate easily with the source which produces the sound on it. These materials vary in accordance with the structure of the mechanism that produces that sound. If strings are the sound source, mostly wooden materials are preferred since wood is the material that enhances string vibrations. The air space, which vibrates in the instrument, re-vibrates the body and the other strings which were not vibrating. This way, it strengthens and distributes the sound and produces new wave forms and overtones. This produces the instrument's distinctive timbre. The perception of a musical tone is the perception of several simple frequencies which reach the ear at the same time (Helmholtz, 1954:118; McNeil&Mitran, 2008:1169-1178). The characteristic features of the tones produced by a musical instrument are defined by timbre. Timbre is generally defined as tone quality or tone colour (Fletcher, 1934:59-69). The lowest of the frequencies that form the resounded tone is called fundamental. The other higher frequencies are called overtones (Helmholtz, 1954:118; McNeil&Mitran, 2008:1169-1178). Fundamental is the pitch perceived by the listener (McNeil&Mitran, 2008:1169-1178)]. The aerial tone quality is subject to overtone distribution. A change in over-tone structure changes the timbre (Helmholtz, 1954:118; McNeil&Mitran, 2008:1169-1178; Fletcher, 1934:59-69). Tone structure can be studied by the number, relative distribution and the level of overtones. In addition, the structures of overtones can be shown with graphs of overtone levels drawn in accordance to the frequencies [Abbot, 1935:111-116; Saunders, 1937:81-98). Among the harmonics, the first harmonic called "fundamental" have minimum frequency level and is expected to have the maximum sound level. As the harmonic frequency increases, the increases are indicated by increasing numbers. In other words, the frequency of the 3rd harmonic is higher than the frequency of the 2nd harmonic. The sound volume levels of the harmonics are expected to have decreasing levels after the 1st harmonic. For proper detection of harmonics, the strength and level of the harmonics provide information about the sound quality and the sound timbre. However, tones produced by the strings can be strengthened with top plate resonance to obtain pitches, and the fundamentals of these tones can be weaker relatively (Feng, 1984:599-602).

Determination of a sound as musical and the quality of a musical instrument is made possible by studying the timbre's physical features. According to Helmholtz, if the first six overtones are strong and the fundamental is dominant in a compound tone, that sound is musical, and is soft and sweet if there are not any high frequency upper partial tones (Helmholtz, 1954:118). If the first six overtones are strong, the tone can be defined as rich and vibrant in terms of quality (Helmholtz, 1954:118). The sound volume level of overtones not being higher than the fundamental, and being in a regular decreasing pattern defined the characteristic timbre of this soundboard material type. According to Miller, in an ideal musical tone, the levels of the upper partial tones should constantly decrease with the increase in their frequencies (Miller, 1916:213). A higher number and level of upper partial tones is undesirable. The existence of upper partial tones at the same level and type to an extent means that the tone is of metallic quality (Helmholtz, 1954:118). The change in the level of the aerial tone in time affects the timbre and the perceived quality accordingly. Musical tones can be explained precisely with the attack, release and duration of the tone. However, the examination of steady state duration is more important that other parts (Fletcher, 1934:59-69).

The Qanun is a Turkish stringed instrument. Many sources report that the instrument was invented by Farabi (AD 870-950). Generally, the Qanun includes 25 pitch and every pitch includes courses of strings with three same thickness strings per course. Pitch refers to frequencies defined by notes in Turkish music (Zeren, 1997:52). The Qanun's sound interval includes three and a half octaves from A2 to D5 (Table-1). Pitches are shown in Table-1 are the sounds within the range used in the present study. It is in the shape of a right trapezium, and played on the lap. The strings are plucked with two plectrums made with hard plastic, bone, horn or tortoise-shell. The plectrums are attached on index fingers with metal rings. Fine-tuning to obtain sharp or flat pitches is set with small metal (from now on called as *mandal*) in modern Qanun. There are around 200 metal mandals on a Qanun. These mandals enable the production of microtones. The sounds produced by the strings go to the leather through the bridge, and vibrate the leather like the eardrum. The sound bridge should be thin to prevent loss in sound energy, but thick enough to hold resistance. Some structural changes occurred throughout the Qanun's history and finally, with plastic strings and metal mandals, it took its present form. As in many musical instruments, vibrating soundboard and the sound level of air column are very important for defining the timbre of the spread sound. The soundboard defines the tone quality in qanun, as with many musical instruments played with plectrums. Free vibration of soundboard of the instrument plays a very important role in the control of tone quality, and the change of tone quality is easier to define (Ghosh, 1935:27-28). The change in the structures of the soundboard directly affects the frequency spectrum and the change of sound level. These changes are perceived differently by the ear. Perceived sound defines the sound quality of the instrument.

Table-1: Representation and Frequencies of Pitches for Turkish Maqam Music

No	Pitch	Pitch Symbol	Frequency (Hz)
1	Re2	A2	110
2	Mi2	B2	123.74
3	Fa2	C2	130.38
4	Sol2	D2	146.69
5	La2	E2	164.99
6	Si2	F#2	185.60
7	Do2	G2	195.57
8	Re3	A3	220
9	Mi3	B3	247.48
10	Fa3	C3	260.77
11	Sol3	D3	293.34
12	La3	E3	329.98
13	Si3	F#3	371.20
14	Do3	G3	391.14
15	Re4	A4	440
16	Mi4	B4	494.96
17	Fa4	C4	521.54
18	Sol4	D4	586.68
19	La4	E4	659.98
20	Si4	F#4	742.41
21	Do4	G4	782.28
22	Re5	A5	880
23	Mi5	B5	989.92
24	Fa5	C5	1043.08
25	Sol5	D5	1173.37

The present study, conducted tone analyses for all pitches of the Qanun instrument, and examined the effect of the changes in the thickness of soundboard on the tone quality. The present study is limited to sound-board. Since different body structures may produce different results, an entire study was done on the same body frame. Since the purpose of the present study is defining the acoustic reaction of the wooden material studied only, no theoretical analyses requiring advanced level mathematical procedures were done. Firstly, sound level changes in every pitch were shown. Sounds were separated into the overtones. The differences between the overtones were analysed. The reactions of the sound wave to soundboards of different thickness were defined, and the authors tried to offer a suggestion for the best wood thickness. The instrument of qanun was studied for the first time with this study. Additionally, the subject of the effect of changes in the thickness of the soundboard of a musical instrument is studied for the first time as well.

II. Experiment

The Qanun in the study was produced with a 4.5 mm thick soundboard. The leather material is of goat leather. The strings are standard Qanun strings (DuPont, USA). The pegs are made of rosewood. The back is made plywood. The bridge is made of white birch. The pegboard is made of hornbeam, and basswood. Sound balconies mounted under the soundboard are made of spruce tree. Long side of the length is 880 mm, and the short side is 260 mm. The width is 420 mm, internal height is 4 mm. The leather part is 120 mm square each side. The instrument is not varnished. But it is ready to be varnished. The Qanun was tuned with a digital chromatic tuner. The tuning was set to the required frequency as much as possible, though little lapses could not be prevented completely. The lapse ranges can be considered as small disharmonies that can be encountered during performance. This does not affect the experiment's objective. The recordings were made in the sound recording studio. The records were transferred to PC computers (48000 Hz sample rate, 16 bit quantization, mono) in WAV file format. Fast Fourier Transform (FFT) was applied to WAV files on the computer and Fourier analysis was done with Sound Forge 4.5 sound analysis software. The moments when the plectrum plucks the string and the sound of friction with the string are observed as noises in the graphics. These noises were separated from the sounds of strings and were erased on the graphics.

The Qanun was played on the lap and 63 cm above the ground. A multi-directional condenser microphone (Beyerdynamic MC-740N(C)P48) was placed at 72 cm from the ground, 16 cm away from the Qanun's short side, on the same leather at every time, parallel to the bridge and 6 cm higher than the bridge. The distance of the microphone was as short as possible to get more direct sound and to avoid room reflections. The strings were plucked with high quality plectrums of tortoise-shell. The plectrum plucked the strings towards the chest from 10-12 cm away to bridge from mezzo forte to forte. The strings that were not recorded were silenced with sponge pads. This way the effect of difference in the soundboard on only the related sound could be analysed. After the first recording with a 4.5 mm thick soundboard, the leather and pegboard of the instrument were dismantled. Soundboard was changed with a 3.9 mm thick soundboard. The same sound bridge and new leather were mounted on the Qanun. The same procedures were repeated with 3.5 mm and 3.0 mm thick soundboards, and all sounds were recorded for 4 times.

Firstly, the acoustic envelopes contained three regions were drawn for all of pitches. These sound response curves (β-t graphics) were included as Sound Level (dB) curves versus time (ms). The changes in the sound levels were studied on this graphic. The first region on the graphic between the silent point and first peak of sound level was called "attack", the period from the attack to the moment that sound level started to decrease was called "steady state". Also as the third region, the period from the moment when the sound started to decrease to the moment when the sound went out was called "decay". Attack time is very important, it should not be late or for a very short time. In other words, the sound should reach its steady state in the appropriate period of time. For this reason, attack, steady state, and decay times were defined. The *β-t* graphics should show orderly and periodically change. In order to observe this, the sound level change curves on the graphic pattern during attack, steady state and decay were investigated and show the orderly chancing ones were detected.

Secondly, frequency distribution curves (*f-β* graphics*)* were drawn. FFT analysis was applied on these frequency spectrums and the overtones were detected. Fundamental and overtone level distributions were shown on these graphics. The levels of harmonics were compared to fundamental level on these graphics. For this reason, sound level rates were not shown logarithmically but linearly. Musical instruments are generally made to produce the pitches within 27.5-4000 Hz frequency range. From these sounds, sounds up to around 12 kHz reach to the ear with harmonics. No distinctive harmonics of frequencies below 100 Hz and above 10 kHz were observed on the graphics. For this reason, frequency ranges of the graphics were limited to 100-10000 Hz.

III. Results and discussion

A. Analysis of Sound Level Change (*β-t*)

Attack, steady state and decay responses vary in the digital waveform graphics. These responses are scarcely any in some graphics, while pretty obvious in others. Still, the visuals are mostly similar in general terms. These digital waveforms show the typical sound level curves of the Qanun (Fig.2). These curves show differently in other musical instruments (Bora, 1993:26-50). The horizontal axes represent time (second), and the vertical axes represent sound level (-dB). Despite the effect of almost the same strengths, the thicknesses responded at high amplitude to some sounds, while responding weaker to others. This shows that wooden materials respond differently to different frequencies in different states. Amplitude fluctuations in the combination of two sounds from the same source are called sound-pulses (Zeren, 1997:52). beats (*vuru*) are received from human ear in increasing and decreasing levels. Fig.3 presents two examples of sound-pulses that can be observed clearly.

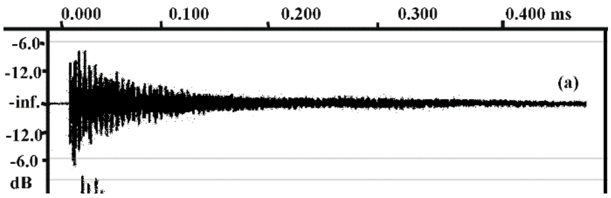

Figure 2: Typical digital waveform of Qanun (Do2 (195.57 Hz) and 4.5 mm).

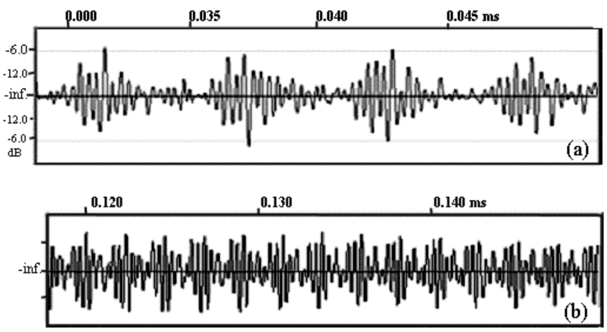

Figure-3. Two examples of sound-pulses that can be observed clearly: (a) La2 (164.99 Hz) and 3.5 mm (b) Re4 (440 Hz) and 4.5 mm.

For attack formation time, arithmetic average of the time of all pitches was taken in order to define the general reaction of the soundboard to a thickness. As the thickness decreased, attack formation time increased (Table-2). Attack formation times for 4.5 mm and 3.9 mm thicknesses were hardly any. This immediate attack creates an effect like an explosion in the sound, and disturbs the ears. In 3.5 and 3.0 mm thickness, peak delayed and attack times increased. The increase in the thickness or the mass of the soundboard decreases the flexibility of the wooden material, and decreased the reaction time of the soundboard to the sound. For the same reason, elasticity coefficient of the wood plays an important role in the characteristics of the sound due to the amplitude of the resonance. The highest number of orderly changes in attack was observed in 3.5 mm thickness (Table-3).

Table-2: Average attack, steady state and decay times for every board thickness.

Thickness (mm)	Average Times (ms)		
	Attack	**Steady State**	**Decay**
4.5	2.88	1.92	455.56
3.9	3.01	1.24	536.05
3.5	14.60	8.35	648.32
3.0	14.21	7.30	657.93

Table-3: Number of orderly attack, steady state and decay forms for every board thickness.

Thickness (mm)	Number of attacks	Number of steady states	Number of decays
4.5	1	4	13
3.9	0	3	16
3.5	12	15	16
3.0	11	11	6

The structure of the sound level within steady state time was studied. For all samples, the level within steady state time was constant except for some small changes. Small decreases and increases in the sound level were ignored in the graphics. Long steady state time means that the sound resonates for a long time and at a distinct sound level. Short time means that sound level starts to decrease early. It also refers to the decrease in the loudness of the instrument. The longest steady state time was observed in 3.5 mm thickness (Table-2). The regularity and the stability of sound level during steady state were observed as well (Fig.4). The highest number of steady state notes was observed in 3.5 mm thickness (Table-3). Simpler resonances were observed at higher frequency (Fig.5) and lower frequency (Fig.6 and Fig.7(a)). On the other hand, resonances that are more complex were observed in mid-frequency range (Fig.7). This indicates that the wooden material responds more regularly to certain sound ranges. Table-2 and Table-3 show that 3.5 mm thick soundboard presented the most and longest steady state times. This time is scarcely any for 4.5 mm and 3.9 mm thick soundboards (Table-2).

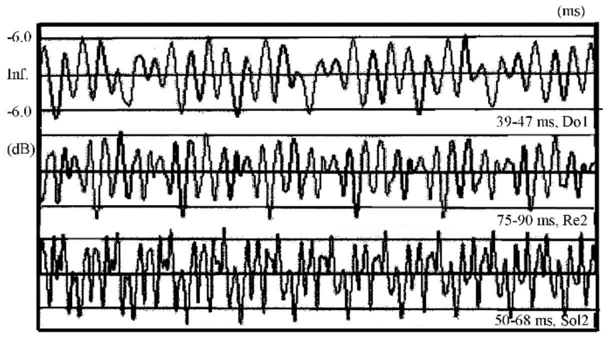

Figure-4: The regularity and the stability of sound level during steady state.

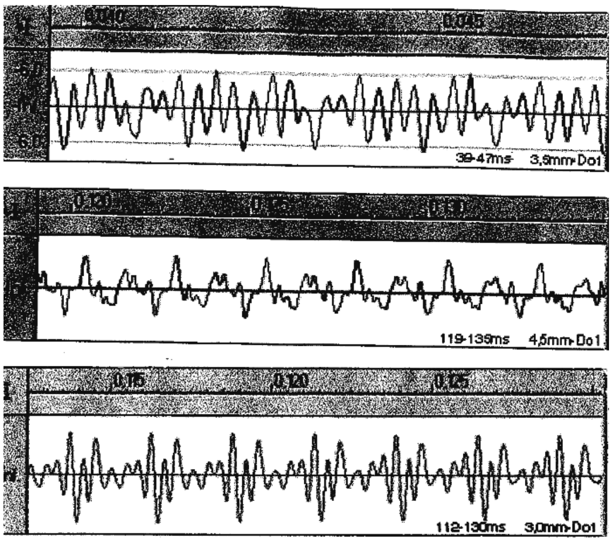

Figure-5: Samples periodic waveforms in higher-pitched sounds of Do3 (391.14 Hz) and in several time range.

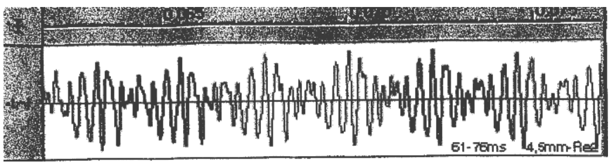

Figure-6: Samples periodic waveforms in lower-pitched sounds of Re4 (440 Hz) and in several time range.

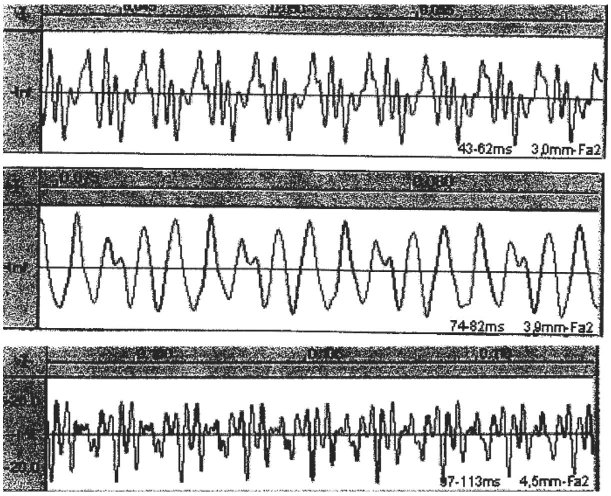

Figure-7: Samples for complex and periodic waveform curves of Fa4 (521.54 Hz) in several time range.

Decay in the sound level was observed as well. Short decay time means that sound dies quickly, and long decay time means that sound continues for a long time. Very long or very short decay time is not desired for musical sounds. If short, the sound dies quickly. If it long, sounds overlap and masking may occur. For this reason, decay should be of correct speed, and constant. As the soundboard got thinner, decay increased due to easier resonance, which was an expected finding (Table-2). Decays with pretty regular changes were also observed (Fig.9 and Fig.10). Decay times in 3.5 mm and 3.0 mm thickness were long enough (Table-2). Decay times were shorter in 4.5 mm and 3.9 mm thickness. This also resulted from that the soundboards were not flexible enough. The highest number of decays have orderly changes was observed in the recordings of 3.5 mm thickness (Table-3). These regular waves were not observed during sound but during various short time periods (Fig.5 and Fig.7). Regular waves were observed for long time periods in some pitches, but in others these were very short or instant.

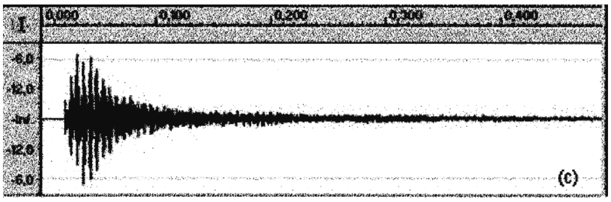

Figure-9: Digital waveform curves of La2 (164.99 Hz) on 3.5 mm sound board thickness.

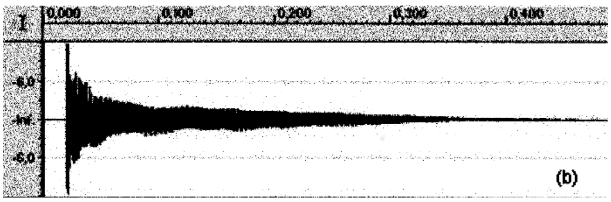

Figure-10: Digital waveform curves of Fa4 (521.54 Hz) on 3.9 mm sound board thickness.

B. Frequency Spectrum (*f-β*) Analysis

Frequency spectrums of the sounds obtained from 4.5 mm, 3.9 mm, 3.5 mm and 3.0 mm thick soundboards were drawn in graphics. Horizontal axes in the graphics represent frequency (Hz), and the vertical represent the sound level (-dB). The presence of the first 6 overtones was shown in the graphics. The dominance of the fundamental and the presence of high frequency overtones were observed. Additionally, changes in overtone levels were studied.

Many mid-frequency upper partial tones were observed in all graphics of 3.0 mm thick soundboard (Fig.11). Additionally, high frequency overtones were distinct in this thickness. This may have resulted from the irregular resonance of the thin structure. This situation is undesirable as it decreases tone quality. In 3.5 mm thickness, less high-pitched overtones were observed. From La1 pitch, the number of mid-frequency tones decreased and their level presented a regular decreasing course. In addition, fundamental sound level increased more distinctly as of this pitch (Fig.12).

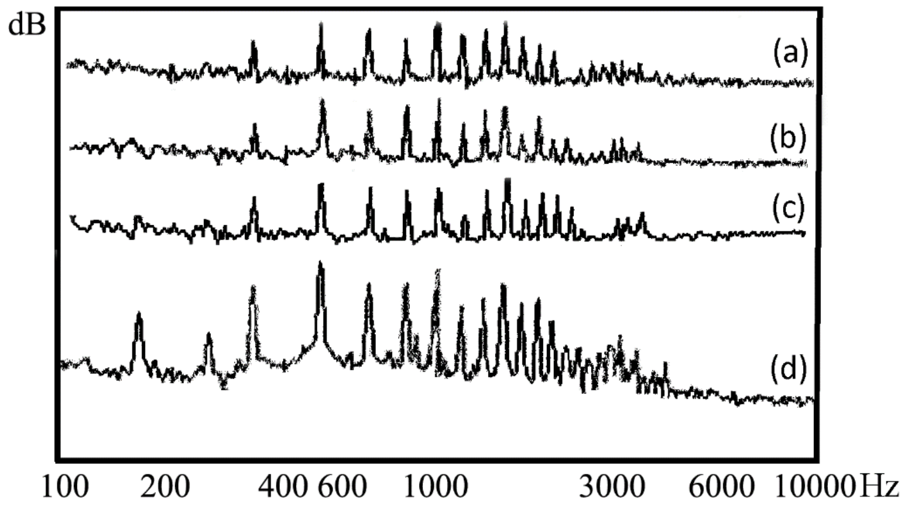

Figure-11: Frequency spectrums of La2 (164.99 Hz) on different sound board thickness a) 4.5 mm, b) 3.9 mm, c) 3.5 mm and d) 3.0 mm.

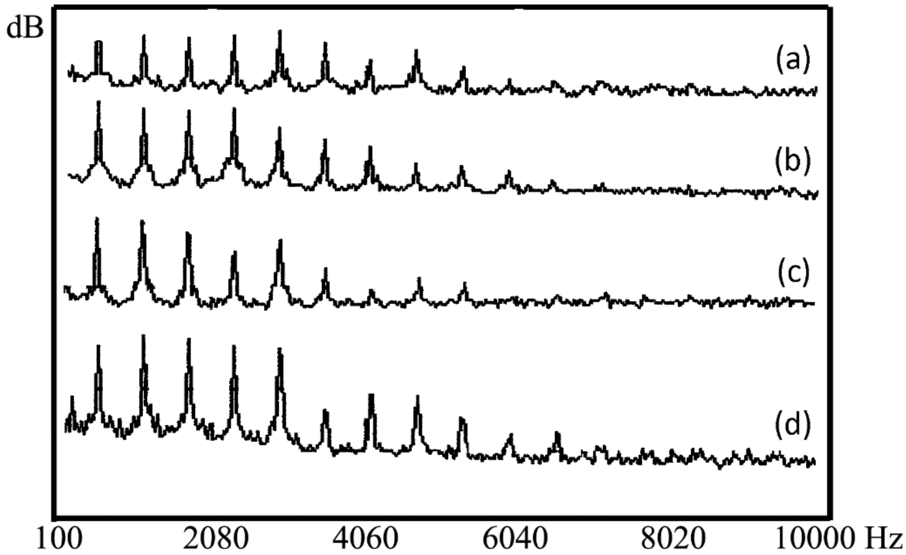

Figure-12: Frequency spectrums of Sol4 (586.68 Hz) on different sound board thickness a) 4.5 mm, b) 3.9 mm, c) 3.5 mm and d) 3.0 mm.

Sounds with least overtones, and the most distinct harmonics were observed in the recordings of 3.5 mm thick soundboard. Harmonic distribution became more orderly in the highest and lowest pitch sound areas. The fundamental note was weaker than the harmonics in these areas. In general, the most appropriate harmonic distribution was shown in pitches obtained from a 3.5 mm thick soundboard. In thick structures, high-pitched harmonics are high in number, and higher than the fundamental. Accordingly, metallic sound quality from the qanun are expected.

In 3.0 mm thickness, due to the irregular resonances resulting from the thin body, too many harmonics and long decay periods were observed. Additionally, over strain of the strings cause in deformation in the soundboard of this thin. In higher thicknesses, the Qanun cannot show its unique timbre due the dimness and scarcity of harmonics.

IV. Conclusion

The present study analysed the sound of qanun instrument, and presented the effects of soundboards of different thickness on tone characteristics. Because of the evaluation of graphics and numeric values, a 3.5 mm thick soundboard was suggested as the most appropriate soundboard only for the tested thickness values in this study. The sound from the Qanun not only depends on the soundboard but also on the sound balcony part right below the soundboard that is the second most important part following soundboard. The arrangement of these balconies controls the resonance of the soundboard. Every Qanun manufacturer has a different balcony system. Different balcony structures produce different timbres, and reveal the distinctions between tastes. The type and the quality of the leather in the bridge are also important.

Moreover, there are many other factors such as the type of the wood, humidity rates, and growing conditions. It is very difficult to provide perfect standards for all these variables. The findings obtained in the present study are valid for the standard structure that is commonly used. However, these findings can be guides for Qanuns of different structures. Accordingly, as long as the wood and crafting are of high quality in the Qanun structures, these findings related to the soundboard thickness will be valid. The measurement set-up, measurement process and the results in the present study can provide data for musical instrument analysis as an idea for further studies and qanun fabrication process.

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