The Yangqin: Acoustical Study of a Chinese Dulcimer

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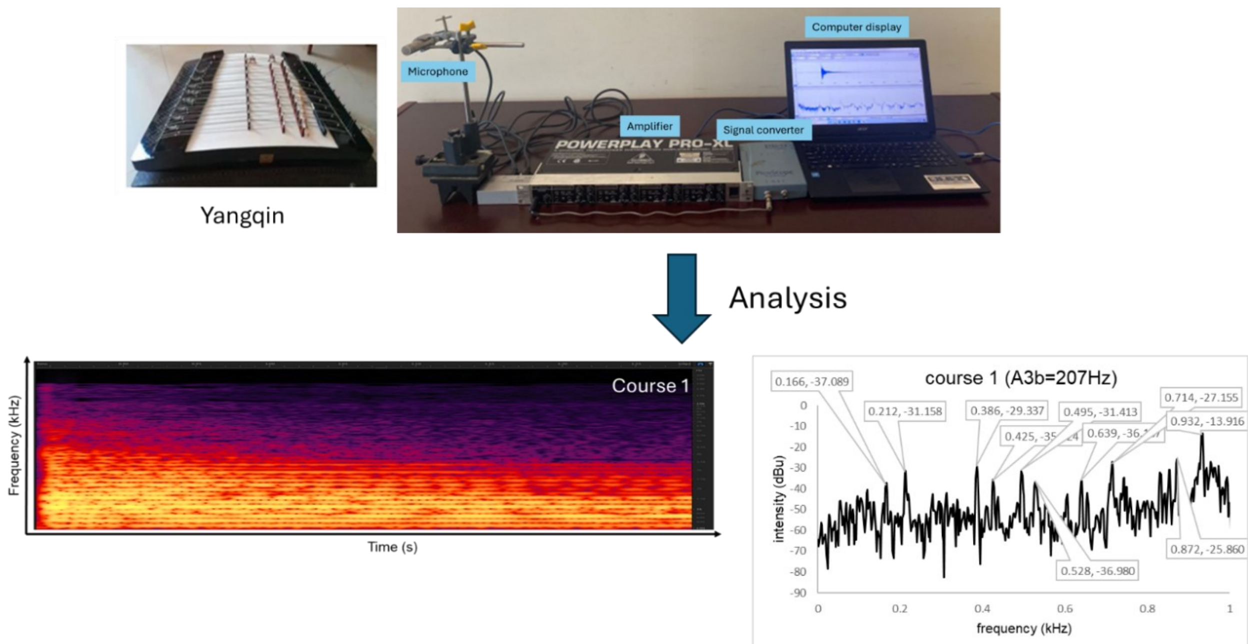
GRAPHICAL ABSTRACT



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A yangqin is a musical instrument that is played by striking it with handled hammers. The sound signals were captured using a PicoScope oscilloscope which enabled waveform viewing, Fast Fourier Transform (FFT), spectrum visualization, and voltage-based triggering. The progression from the bass bridge to the treble bridge is as follows: (G2, A2, B2, C3, D3, E3), (D3, E3, F3, G3, A3, B3), (C4, D4, E4), (F4, G4, A4, B4), (C5, D5, E5) (F5, G5, A5, B5), and (C6, D6, E6). Courses 1, 3, 4, 5, 6, and 7 have 3 strings, where courses 1, 4, and 5 have 3 harmonics, whereas courses 3, 6, and 7 have only 2 harmonics. Courses 2, 8, and 9 has 2 strings only, where course 2 has 4 harmonics whereas course 8 and 9 only has only 2 harmonics. The gradient (m) of the equation from frequency *versus* partial number from the tenor bridge do not fit any of the fundamental frequency (f_0). The difference ($d=f_0-m$) between m and f_0 is due to the number of partials which are not harmonic overtones. Due to the inharmonic overtones, the deviation ($D=d/f_0$) ranges from 6% (course no 6) to 70% (course no 7).

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Keywords: Yangqin; Dulcimer; Traditional Chinese instruments; Fast Fourier Transform (FFT)

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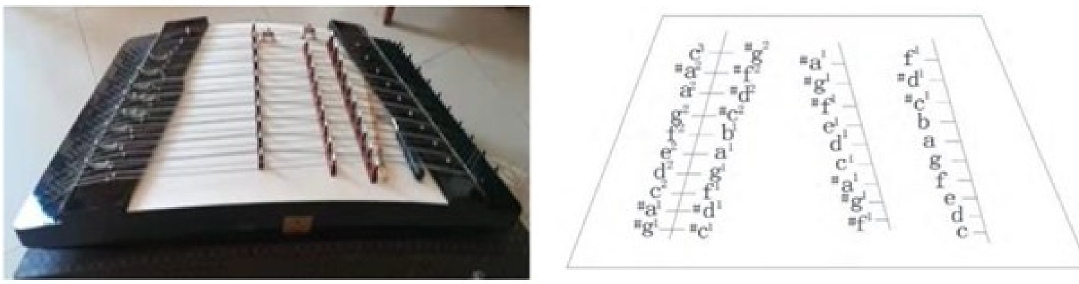
INTRODUCTION

The Yangqin shares many constructional characteristics with other hammered dulcimer instruments because it is a form of dulcimer. In ‘Comparison of Chinese and Foreign Yangqin’, which was published in the Chinese Music Journal, Pingxin (1998) outlines the distinctions between Chinese and world Yangqin with regard to form, scale, performing style, and technique through the development and innovation of rhythm, percussion instruments, form, and timbre in musical instruments. It has a sounding board or box usually trapezoidal in shape, where a course of strings of varying length are stretched. Additionally, elements of the Yangqin’s techniques were lifted from the guzheng, another classic Chinese instrument (Yang 2025). Its tuning scheme, bridge construction, relatively open back, adjustable cylindrical metal nuts for fine tuning, and hinged cover that opens to reveal the tuning pins are some of its distinctive features. With a range of just over four octaves the Yangqin is a chromatic instrument. The arrangement must be adjusted toward the extremities of the pitch range in order to fill out notes in the chromatic scale. A Yangqin often has four or five bridges. The treble bridge, upper tenor bridge, tenor bridge, lower tenor bridge, and the bass bridge are in order from left to right. The treble and upper tenor bridge course can be struck on either side of the bridge, whereas the tenor, lower tenor, and bass bridge course are struck on the left. Figures 1 and 2 showed the three bridges and new Yangqin, respectively with their responding phoneme figures. The contemporary Yangqin may be chromatically arranged and feature up to five bridges (Zhu *et al.* 2024).



(a) **(b)**

Fig. 1. (a) 3 bridges Yangqin; and (b) their phoneme figures (www.dunhuangguoyue.com)

(a) **(b)**

Fig. 2. (a) The new Yangqin; and (b) their phoneme figures (www.dunhuangguoyue.com)

With a tuning scheme that permits transposition and the playing of chords and arpeggios, the Yangqin is usually tuned chromatically across the majority of its range. Figure 3 shows the single tone bamboo beaters. In order to play the Yangqin, 2 beaters are required, representing left and right hand.

Fig. 3. The single tone bamboo beaters

Despite Ellis's scientific approach to music theory, in which he measured musical systems such as the Yangqin's scales using his precise cents system, revealing differences from Western equal temperament, there is a limited understanding of the Yangqin's precise tuning behavior when evaluated using modern digital technologies. Earlier research mostly relied on manual frequency measurements and lacked high-resolution spectrum data, resulting in inadequate insights into its overtone structure and harmonic stability. The lack of empirical, waveform-based documentation of the Yangqin's acoustic characteristics for long-term sound preservation is the research concern. In order to ensure that the tuning identity of the instrument may be digitally preserved and recreated for future generations, there is a research gap in the integration of scientific analysis with frameworks for cultural preservation. Although ethnomusicological research has thoroughly documented the Yangqin cultural role and repertoire, comparatively few have explored its acoustical behavior through quantitative and signal-based analysis. The majority of prior study stresses historical evolution, building craft, and genre classification. There has been a need to tie these to the quantitative metrics of sound radiation, harmonic balance, and frequency responsiveness. In this work, the Yangqin tonal qualities were studied utilizing a high-resolution digital oscilloscope (PicoScope) and Fast Fourier Transform (FFT) analysis to correlate between fundamental frequency, harmonic amplitude, and overtone decay.

EXPERIMENTAL

Figure 4 shows the Yangqin model 410 used in this study. It consists of 47 courses (sets) of 134 strings on 5 bridges. Table 1 displays the number of strings on each course for all bridges.

Fig. 4. The Yangqin model 410

Table 1. Number of Strings on Each Course for All Bridges

Course Number	No of strings on Treble Bridge	No of strings on Upper Tenor Bridge	No of strings on Tenor Bridge	No of strings on Lower Tenor Bridge	No of strings on Bass Bridge
1	4	4	3	2	2
2	2	4	2	2	2
3	4	4	3	2	2
4	4	4	3	2	2
5	4	4	3	2	2
6	4	4	3	2	2
7	4	4	3	2	2
8	4	4	2	1	2
9	4	4	2	1	2
10	2	4	-	-	-
Total	36	40	24	16	18

All recordings were conducted in an anechoic chamber to eliminate external sound reflections. An omnidirectional polar pattern microphone (Behringer condenser microphone) was positioned 20 cm in front the Yangqin to capture the radiated sound. It was hit in a conventional seated position to replicate typical playing conditions and ensure optimal sound resonance. The sound signals were captured in real time using a PicoScope 3000 series oscilloscope and accompanying data recorder (Pico Technology, Eaton Socon, UK). The PicoScope software enabled waveform viewing, FFT analysis, spectrum visualization, and voltage-based triggering. The apparatus used in the experimental setup is provided in Fig. 5.

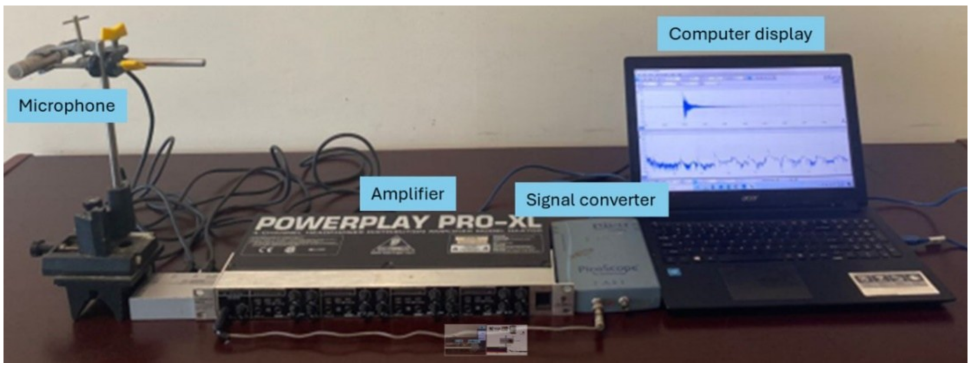
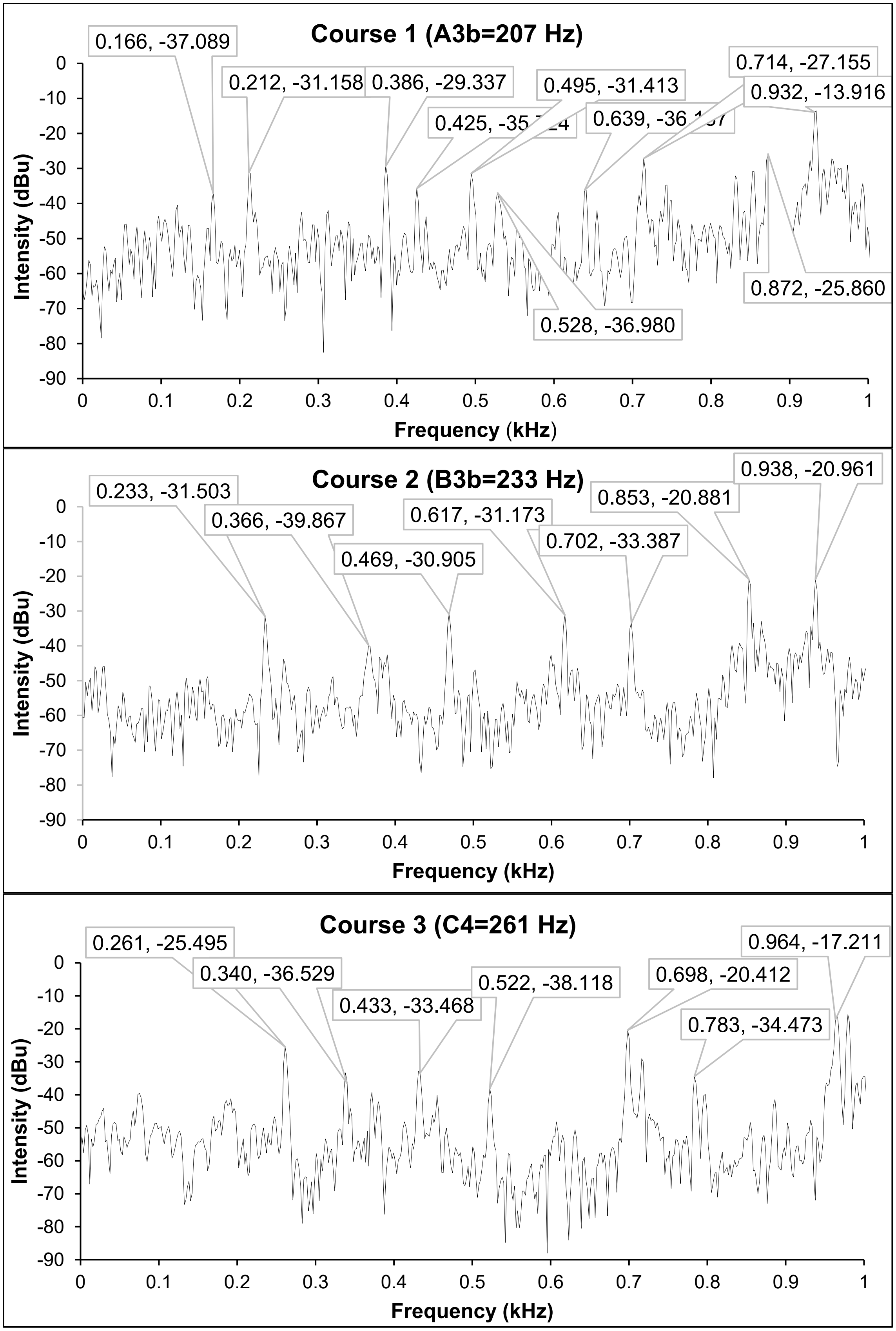


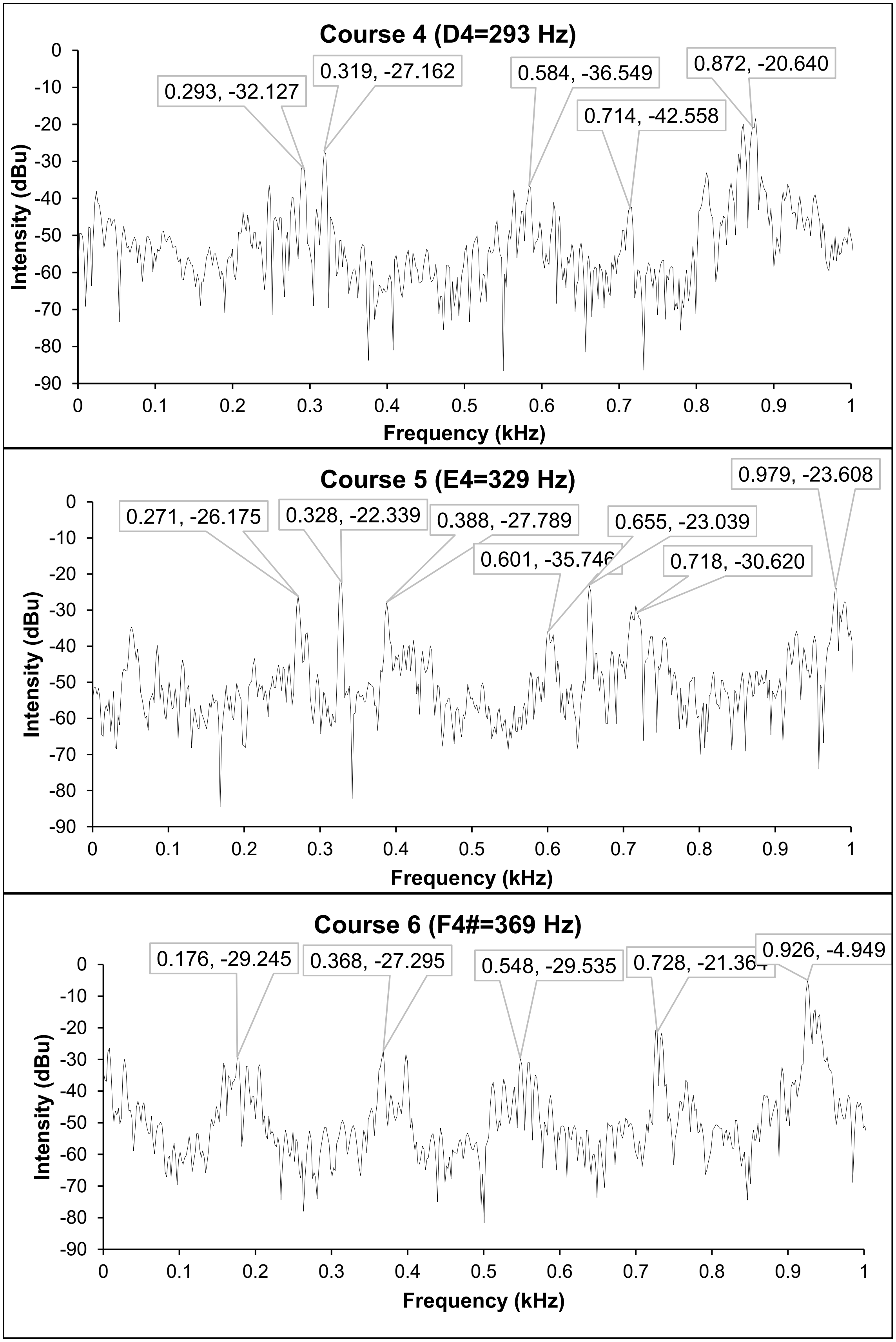
Fig. 5. The apparatus used in the experimental setup

To prevent distortion or bias, the Yangqin was recorded under identical conditions, including fixed microphone position, and orientation. The signal was amplified using a Behringer Powerplay Pro XL amplifier (Zhongshan, Guangdong, China) before being processed by the PicoScope. The resulting sound spectra were analyzed in Adobe Audition, where FFT analysis was used to extract dominant frequencies and evaluate tonal characteristics. The Fourier Transform technique enabled identification of fundamentals, harmonics, and subharmonics in the recorded waveforms. Sound data from the Yangqin was collected in multiple trials. Each iteration was recorded under the same conditions, and the resulting waveforms were averaged to reduce variability and noise. This approach ensured a robust and meaningful acoustic comparison. By employing controlled hitting, consistent recording parameters, and multiple rounds of measurement with averaged data, the methodology ensures a clear, accurate, and scientifically valid comparison of the acoustic performance of the Yangqin. To ensure accurate and repeatable sound production, a skilled player performed the hitting on the Yangqin. Consistency was ensured by maintaining the same technique and force for each attempt. Prior to recording, the player rehearsed the precise motions multiple times to minimize human variability and enhance the reliability of the sound comparison.

RESULTS AND DISCUSSION

Figure 6 shows the typical signals obtained from the courses at the tenor bridge. From Fig. 6, courses 1 to 9 showed the fundamental frequencies at 212, 233, 261, 293, 328, 368, 414, 439, and 455 Hz respectively, *i.e.* equivalent to A3b, B3b, C4, D4, E4, F4#, G4#, A4 and B4. Using similar method for courses at the treble, upper tenor, lower tenor, and bass bridges the notes obtained from all the courses are displayed in Table 2.


Course 1 (A3b=207 Hz)
0.166, -37.089
0.212, -31.158
0.386, -29.337
0.495, -31.413
0.714, -27.155
0.932, -13.916
0.528, -36.980
0.872, -25.860
Intensity (dBu)
Frequency (kHz)
Course 2 (B3b=233 Hz)
0.233, -31.503
0.366, -39.867
0.469, -30.905
0.617, -31.173
0.702, -33.387
0.853, -20.881
0.938, -20.961
Intensity (dBu)
Frequency (kHz)
Course 3 (C4=261 Hz)
0.261, -25.495
0.340, -36.529
0.433, -33.468
0.522, -38.118
0.698, -20.412
0.783, -34.473
0.964, -17.211
Intensity (dBu)
Frequency (kHz)


Course 4 (D4=293 Hz)
Intensity (dBu)
Frequency (kHz)
0.293, -32.127
0.319, -27.162
0.584, -36.549
0.714, -42.558
0.872, -20.640
Course 5 (E4=329 Hz)
Intensity (dBu)
Frequency (kHz)
0.271, -26.175
0.328, -22.339
0.388, -27.789
0.601, -35.746
0.655, -23.039
0.718, -30.620
0.979, -23.608
Course 6 (F4#=369 Hz)
Intensity (dBu)
Frequency (kHz)
0.176, -29.245
0.368, -27.295
0.548, -29.535
0.728, -21.364
0.926, -4.949

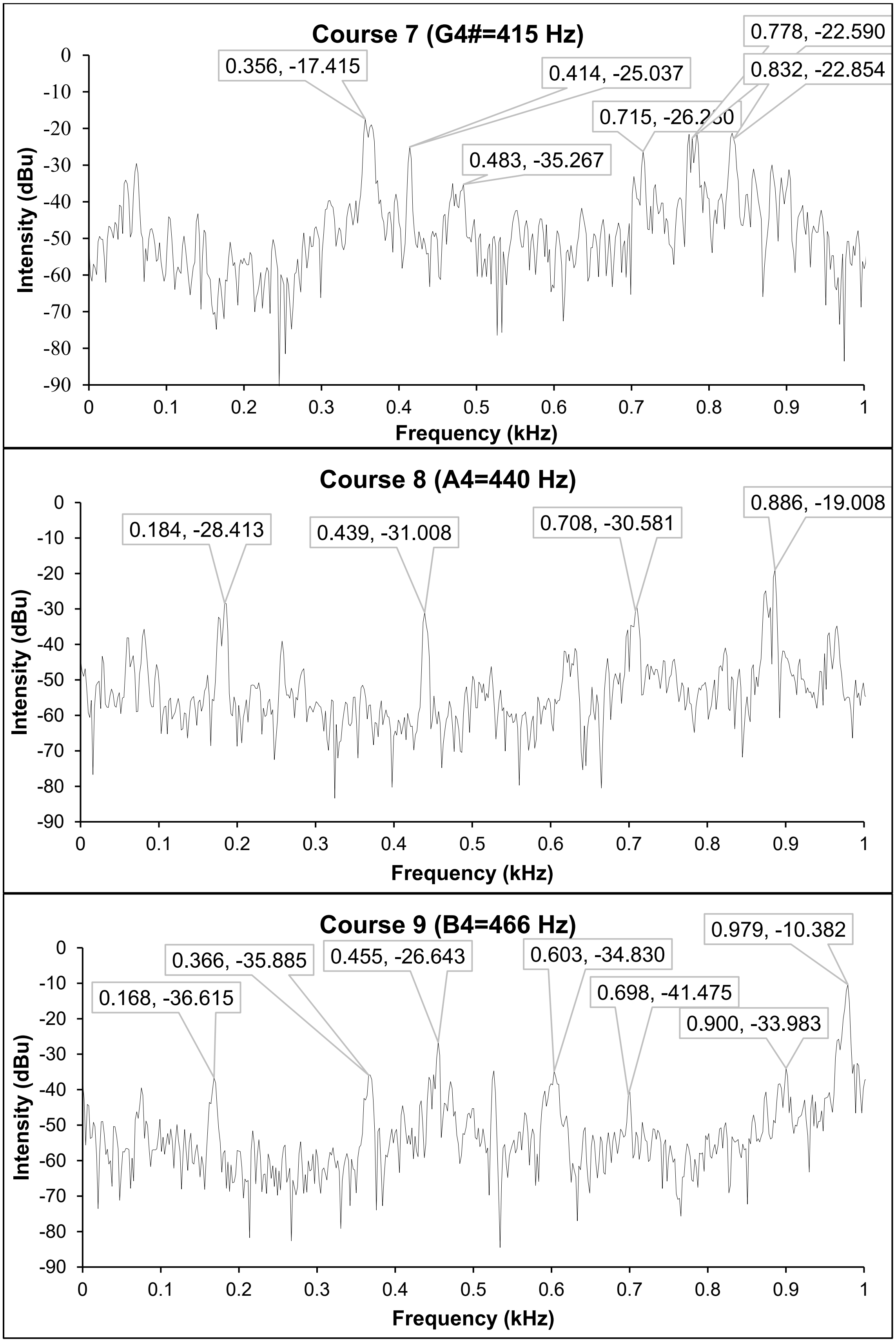


Fig. 6. The spectra obtained from the strings course at the tenor bridge

Table 2. The Notes Obtained from the Left and Right Sides of Treble and Upper Tenor Bridges, Tenor Bridge, Lower Tenor Bridge, and Bass Bridge

Course	Treble Bridge (Left)	Treble Bridge (Right)	Upper Tenor Bridge (Left)	Upper Tenor Bridge (Right)	Tenor Bridge	Lower Tenor Bridge	Bass Bridge
1	C5b	D5b	A4b	D4b	A3b	D3	G2
2	B5b	E5b	B4b	C4b	B3b	E3	A2
3	C6	F5	C5	F4	C4	F3	B2
4	D6	G5	D5	G4	D4	G3	C3
5	E6	A5	E5	A4	E4	A3	D3
6	F6#	B5	F5#	B4	F4#	B3	E3
7	G6#	C6#	G5#	C5#	G4#	C4#	F3#
8	A6#	D6#	A5#	D5#	A4	D4#	G3#
9	C7	F6	C6	F5	B4	-	A3#

Table 3. Harmonicity of the Course Spectrum on Tenor Bridge. Bold Ratio (f/f0) Indicates the Harmonic Partials

Partial	Course 1	f/f0	Course 2	f/f0	Course 3	f/f0	Course 4	f/f0	Course 5	f/f0
1	212	**1**	233	**1**	261	**1**	293	**1**	271	0.82
2	386	1.82=**2**	366	1.57	340	1.30	319	1.08	328	**1**
3	495	2.33	469	2.01=**2**	433	1.65	584	1.99=**2**	388	1.18
4	639	3.01=**3**	617	2.64	522	**2**	872	2.97=**3**	601	1.83
5	714	3.36	702	3.01=**3**	698	2.67			655	1.99=**2**
6	872	4.11	853	3.66	964	3.69			718	2.18
7	932	4.39	938	4.02=**4**					979	2.98=**3**

Partial	Course 6	f/f0	Course 7	f/f0	Course 8	f/f0	Course 9	f/f0
1	176	0.47	356	0.85	184	0.41	168	0.36
2	368	**1**	414	**1**	439	**1**	366	0.80
3	548	1.48	483	1.16	708	1.61	455	**1**
4	728	1.97=**2**	715	1.72	886	2.01=**2**	603	1.32
5	926	2.51	778	1.87	-	-	698	1.53
6	-	-	832	2.00=**2**	-	-	900	1.97=**2**
7	-	-	-	-	-	-	979	2.15

The scale starts from the third course on tenor bridge (C4, D4, E4), continues on the third course on the right side of upper tenor bridge (F4, G4, A4, B4), continues on third course on the left side of upper tenor bridge (C5, D5, E5), continues on third course on the right side of treble bridge (F5, G5, A5, B5), and lastly on the third course on the left side of the treble bridge (C6, D6, E6). The bass bridge starts with G2, A2, B2, C3, D3, E3, and continues on the lower tenor bridge with D3, E3, F3, G3, A3, B3. From the lower tenor bridge (B3), it continues to the tenor bridge (C4, D4, E4). The progression from the bass bridge to the treble bridge is as follows: (G2, A2, B2, C3, D3, E3), (D3, E3, F3, G3, A3, B3), (C4, D4, E4), (F4, G4, A4, B4), (C5, D5, E5) (F5, G5, A5, B5), and (C6, D6, E6). To provide a more thorough explanation, the left side of bass bridge is tuned chromatically. It is set up to play G2, A2, B2, C3, D3, E3, F3#, G3#, A3# on the left side of the bass bridge. The lower tenor bridge's left side is set up to play D3, E3, F3, G3, A3, B3, C4#, D4#. The tenor bridge's left side is set up to play A3b, B3b, C4, D4, E4, F4#, G4#, A4, B4. The upper tenor bridge's right side is set up to play D4b, C4b, F4, G4, A4, B4, C5#, D5#, F5. The upper tenor bridge's left side is set up to play A4b, B4b, C5, D5, E5, F5#, G5#, A5#, C6. The right side of the treble bridge is set up to play D5b, E5b, F5, G5, A5, B5, C6#, D6#, F6. The treble bridge left side is set up to play C5b, B5b, C6, D6, E6, F6#, G6#, A6#, C7.

Table 3 displays the harmonicity of the partials from the spectrum obtained from the tenor bridge. Courses 1, 4, and 5 have 3 harmonics (3 strings every course), course 2 has 4 harmonics (2 strings only), courses 3, 6, and 7 have 2 harmonics (3 strings every course), and courses 8 and 9 only have 2 harmonics (2 strings only).

Courses 1, 3, 4, 5, 6, and 7 have 3 strings, whereas course 1, 4, and 5 have 3 harmonics, and courses 3, 6, and 7 have only 2 harmonics. Courses 2, 8 and 9 have 2 strings only. Course 2 has 4 harmonics, whereas courses 8 and 9 have only 2 harmonics. From Table 3 the frequency of every partial *versus* partial number for course 1 to 9 from the tenor bridge is plotted in Fig. 7

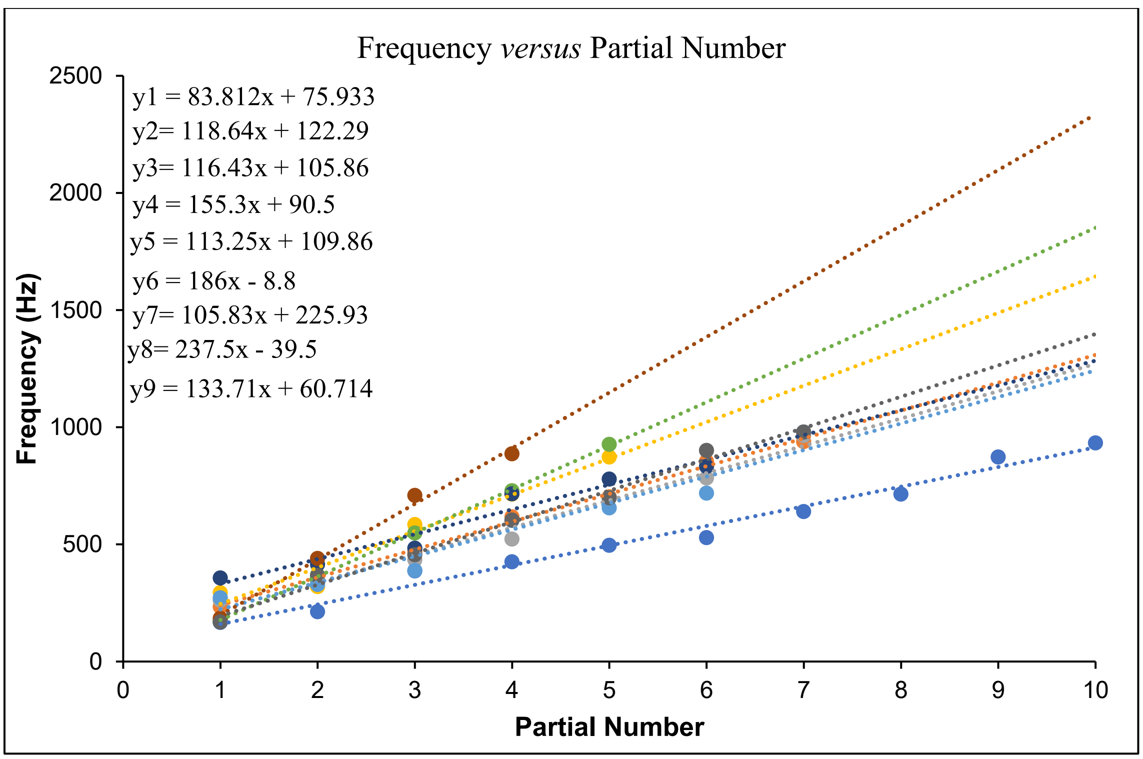


Fig. 7. Frequency *versus* partial number for course 1 to 9 from the tenor bridge

From Fig. 7, the gradient (m) of the equation from frequency *versus* partial number for course 1 to 9 from the tenor bridge do not fit any of the fundamental frequency (f_0) values. Table 4 shows the fundamental frequency (f_0), gradient (m), difference ($d= f_0-m$) and deviation ($D=d/ f_0$) between f_0 and m. The difference (d) between the gradient (m) and the fundamental frequency (f_0) is due to the number of partials that are not harmonic overtones. Due to the inharmonic overtones, the deviation ranged from 6% (course no 6) to 70% (course no 7).

Table 4. The Fundamental Frequency (f_0), Gradient (m), Difference ($d= f_0-m$) and Deviation ($D=d/f_0$) between f_0 and m

Course No	Fundamental Frequency (f0)	Gradient (m)	Difference (d=f0-m)	Deviation (%) (D=d/f0)
1	212	83	129	60
2	233	118	115	49
3	261	116	145	55
4	293	155	138	47
5	271	113	158	58
6	176	186	-10	**-6**
7	356	105	251	**70**
8	184	237	-53	-28
9	168	133	35	20

Musical and Organological Significance

The musical and organological significance of these findings can be summarized as follows:

1. *Musical performance implications*

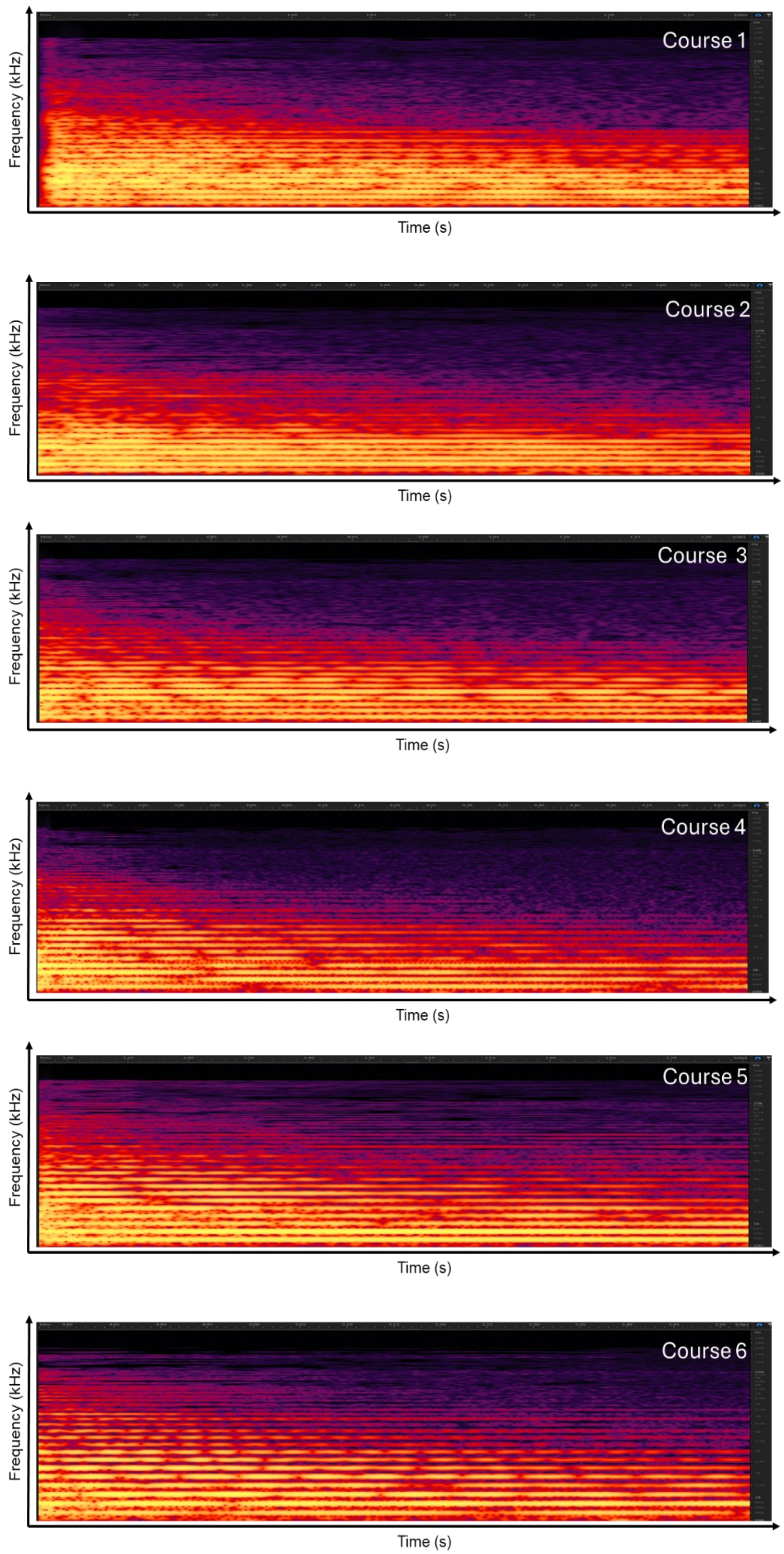
The deviation values indicate the degree to which each course departs from an ideal harmonic overtone series. A smaller deviation (*e.g.*, 6% in Course 6) suggests that the overtones are closer to harmonic, producing a clearer and more stable pitch. Conversely, a larger deviation (*e.g.*, 70% in Course 7) reflects stronger inharmonicity, which results in increased beating, a more complex timbre, and a 'chorus-like' quality. This aligns with performance practice on many traditional struck-string instruments, where slight inharmonicity contributes to tonal richness rather than being perceived as tuning error. The findings therefore indicate that the Yangqin's characteristic tone color is shaped by intentional or culturally accepted levels of inharmonicity across different courses.

2. *Instrument design implications*

The varying deviations suggest differences in structural tension, string gauge, string length, and soundboard response across the courses. Higher inharmonicity values may be related to:

i. thicker or stiffer strings,
ii. shorter string lengths,
iii. higher tension, or
iv. Construction asymmetries typical in handcrafted traditional instruments.

The analysis therefore highlights which parts of the instrument contribute most strongly to timbral complexity. This information can guide future makers or restorers in adjusting materials and dimensions if a more modern, less inharmonic sound is desired or preserving these characteristics to maintain historical authenticity.


Course 1
Frequency (kHz)
Time (s)
Course 2
Frequency (kHz)
Time (s)
Course 3
Frequency (kHz)
Time (s)
Course 4
Frequency (kHz)
Time (s)
Course 5
Frequency (kHz)
Time (s)
Course 6
Frequency (kHz)
Time (s)

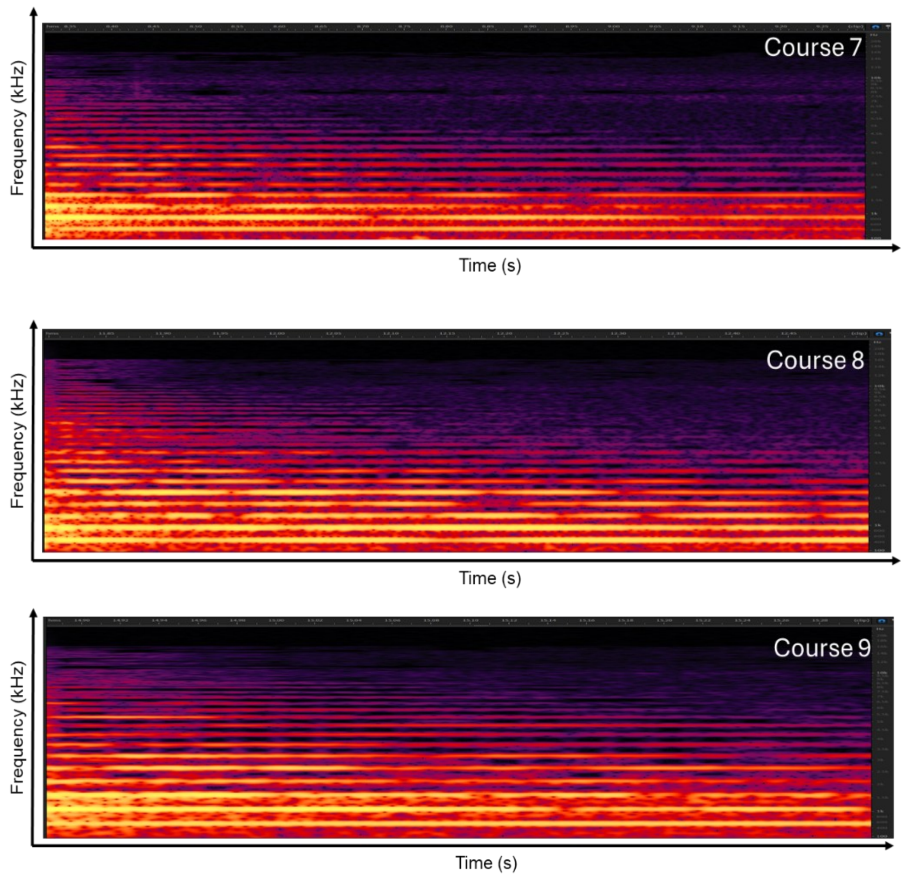


Fig. 8. Spectrograms of the nine courses from tenor bridge

3. Comparison with other dulcimers

Traditional dulcimers from different cultures (*e.g.*, Hungarian cimbalom, Appalachian dulcimer, Persian santur) also exhibit non-harmonic partials, but the magnitude varies depending on cultural aesthetics and structural design. The Yangqin values in Table 4, ranging from 6% to 70%, fall within the broad range documented for similar struck-string zithers, though the higher deviations (such as 70%) suggest a more pronounced inharmonic fingerprint. This supports the idea that each ethnic or regional dulcimer family develops a distinctive acoustic profile shaped by local tuning systems, performance traditions, and construction techniques. The Yangqin's higher deviations may therefore reflect a culturally unique tonal ideal rather than an unintended detuning effect.

In summary, the 6% to 70% deviation values provide insight into the Yangqin's characteristic timbre, reflect structural features of the instrument, and position it within the wider family of global dulcimers. Figure 8 shows a spectrogram of the nine courses from tenor bridge being excited in a succession from the lowest one, *i.e.* course 1 (A3b), to the highest, *i.e.* course 9 (B4). Course 9 (B4) showed the most distinct frequency distribution due to the high pitch compared to course 1 (A3b) with the lowest pitch.

Complementary spectrogram analysis in Adobe Audition was utilized to visualize timbral behavior and resonance stability across pitches. By linking acoustical data with traditional performance and tuning technique, this research strives to bridge the gap between scientific measurement and ethnomusicological interpretation. The findings give new insight into how traditional Yangqin intonation and construction materials influence the acoustic signature, boosting both the understanding of its sound uniqueness and the scientific foundation for investigating non-Western string instruments. For cultural preservation, the measurement data of the Yangqin acoustic behavior provides a scientific record of its traditional tuning and timbral identity, features that are increasingly endangered by modernization and material substitution. By documenting the precise frequency discontinuities and resonance characteristics, this study produces a replicable reference that helps the protection and digital archiving of Yangqin musical heritage, which align with UNESCO's (2017) framework. Understanding how traditional performers manage tuning and articulation to generate emotional nuance and how to recognize purposeful pitch discontinuities and octave-shifted fundamentals is helpful for performance preparation.

CONCLUSIONS

1. The sound analysis of the Yangqin is important as a recollection of the past, which is important as conceiving the future possibility. The present work has created an archive of what was once heard by the community.
2. This study has provided empirical documentation of the Yangqin unique tuning and acoustic characteristics, reinforcing its cultural and historical importance. By aligning this research with current technologies in AI, AR, and VR, the study not only has helped preserve intangible musical heritage but also has laid the groundwork for future innovations from digital twins in virtual museums to AI-assisted eco-material instrument design.
3. The work showed that the tonal and acoustic characteristics of the Yangqin can be systematically analyzed using frequency and time-frequency methods.
4. Its frequency *versus* partial number for courses 1 to 9 from the tenor bridge-based pitch system produced measurable polynomial relationships between frequency and partial number across all 9 courses.
5. The variations in the number of partials that are not harmonic overtones between the courses reflect the physical structure and tuning of the instrument, offering new insights into its musical adaptability and acoustic identity.
6. The tonal frequency analysis (TFA) from the Adobe Audition showed that each course had its own timbre characteristics, *i.e.*, course 9 (B4) showed the most distinct frequency distribution due to the high pitch compared to course 1 (A3b) with the lowest pitch.

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