MRNTI 18.41.01

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ACOUSTICAL ANALYSIS OF A KAZAKH DOMBRA WITH SMARTPHONES

Abstract. The aim of this paper is to provide physics teachers and physics students with an in-terdisciplinary cultural and scientific related content. The *dombra* is on the one hand a cultural symbol of Kazakhstan with a long tradition. On the other hand the dombra as a musical instrument is an object of interest in acoustics. The topic can lead to deeper insights into theory of musical instruments and acoustics and to positive students' moti-vational effects as well. The idea of this article originated in a guest lecture in physics at Taraz State Pedagogical University (Kazakhstan) where the author introduced physics teacher students to "New technologies in physics education". In this paper we discussed good practice examples of integration of mobile devices and their built-in sensors.

Keywords: dombra, acoustic analysis, smartphone, amplitude, oscilloscope, sound.

Staying and teaching in Kazakhstan for the author it seemed to suggest itself to analyse a traditional musical instrument from Central Asia. So the Kazakh dombra became the object of investigations. Because this instrument is part of the Kazakh soul it was easy to capture all students' attention. After exciting performances of some musically talented students the group approached the instrument and its sound from a physics perspective. There are interesting questions to deal with at different qualitative and quantitative levels: What are the functions of the different elements and their characteristics (sound hole, top plate, bridge, ...)? How are the fret distances determined? What are the characteristics of the strings?

The paper shows some ways to handle similar questions. Finally the authors' ex-periences with this teaching unit can prove positive effects on students' involvement whenever they are confronted with physics problems in context-oriented settings. Last but not least it is mentioned according to reports in social media that learning about the physics of an instrument can even enhance the ability to play this instrument.

1 The Kazakh Dombra – a short introduction

1.1 A brief history and cultural background. The Kazakh dombra belongs to the family of traditional long-necked lutes and is common in Kazakhstan and different regions of Central Asia, such as Kyrgyzstan and Uzbekistan. The origin of this musical instrument goes back to the Middle Ages. Similar instruments where even mentioned by *Al Farabi* in his works. Traditionally two or three sinew strings where used to play dombra-like instruments. The strings where also produced from sheep gut.

Playing the dombra for example in modern kui art is part of Kazakh folk tradition. Living in a world of increasing globalization the dombra folklore preserves national iden-tity and emphasizes the uniqueness of the people. This kind of folklore encourages the young generation to study the history and culture of their own country (Zhamenkeyev et al. 2016, p. 11428). Figure 1 shows the great Kazakh bard and dombra player *ZhambylZhabayev*who lived from 1846 to 1945.

Figure 1: The ZhambylZhabayev monument in Taraz, Kazakhstan (Photo: L. Kasper)

a) b) c)

Figure 2: Traditional Dombras, Museum of Kazakh Folk Music Instruments Almaty (Photos: L. Kasper)

The Almaty Museum of Kazakh folk music instruments owns a wonderful collection of instruments. Visitors can study more than forty types of Kazakh musical instruments including the dombra and the three stringed bowed instrument kobyz. The collection includes personal dombras of well-known Kazakh poets, performers and composers. Pic-ture 2 shows examples of some beautiful historical dombras: a) from 19th century, made from wood, bone, and gut; b) unknown time of manufacture, made of wood, bone, metal, and fishing line; c) made in 1940 by master K. Kasymuly, wood and fishing line.

1.2 Characteristics of the dombra. The Kazakh dombra (sometimes named *dombyra*) is characterized by a long thin neck, two strings and more than 18 tied-on nylon frets, joined to each other. The body with a very small sound hole is made of up to 10 ribs, glued together. Figure 3 shows the parts of a dombra. The body (*shanak*) as well as the top plate (*kakpak*) play an important role for radiation and amplification of sound. The wooden bridge – although a small element – is crucial for transmitting the vibrations of the strings to the top plate and to the body. Insofar the bridge is one of the key elements for the instrument's timbre. The strings, in past times made from gut, are nowadays simply fishing line (nylon) strings.

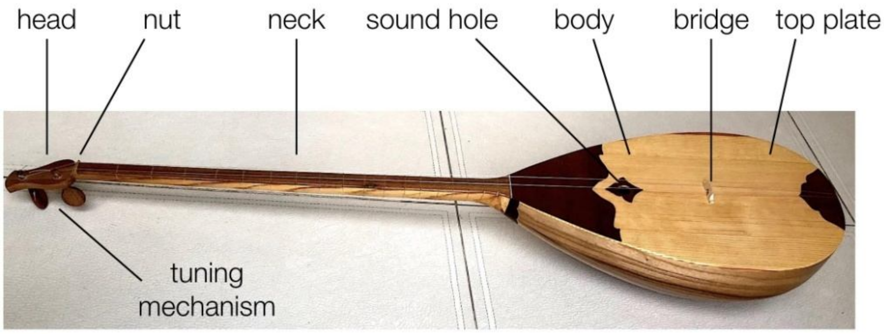


Figure 3: Parts of a Kazakh dombra

The modern Kazakh standard dombrais mostly tuned in DG like the middle pair of guitar strings. The dombrais played by strumming and plucking the strings with the fingers. Dombra music is instrumental and to accompany singing as well.

2 The dombra from a physics perspective

2.1 String acoustics. From an acoustical perspective a string can be treated as a rod with a cross-section A that is small enough to have no resistance against bending. To bring a string in an oscillating state it has to be fixed at both ends. The relationship of a stretched strings' frequencies and their physical properties is described by *Mersenne's Law*:

$$f_1 = \frac{n}{2l}\sqrt{\frac{F}{\mu}} \quad (1)$$

where$l$ is the length of the string, F is the pulling force due to the tension, and μ is the linear mass density in units mass per length.

By re-arranging the equation we get for the the fundamental frequency according to Lüders/von Oppen (2008, p. 539):

$$f_0 = \frac{1}{2l} \cdot \sqrt{\frac{F}{A\rho}} \quad (2)$$

where ρ is the density of the string material.

With equation (2) we can understand the different possibilities to change tones in plucked strings: The longer a string is the lower is the fundamental frequency, the bigger the density is the lower is the fundamental frequency, the bigger the pulling force is the higher is the fundamental frequency.

By basic transformations of the radicand in either equation (1) or (2) we get an expression for the wave velocity in the string:

$$\sqrt{\frac{F}{\mu}} = \sqrt{\frac{F}{A\rho}} = v_{wave} \quad (3)$$

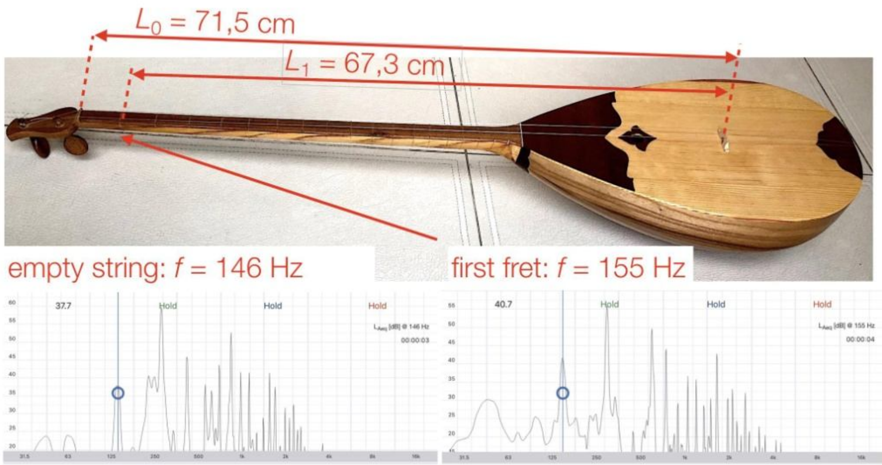
Therefore we can estimate the velocity of the wave propagation by using

$$v_{wave} = 2 f_0 l \quad (4)$$

Obviously $2l$ correspond to the wavelength λ for the fundamental frequency.

2.2 How to find the fret distances?

Figure 4: Length L_0 from nut to bridge and L_1 from 1st fret to bridge; frequencies (empty string and 1st fret)



A closer look at the neck and the distances of the dombra's frets shows a decreasing size in direction to the body. Is there a rule to determine each of those distances? Imagine there is an instrument without frets and you want to complete it. First of all you need to know the required scale. Modern dombras use a semitone scale. Then the twodombra strings correspond to the guitar's middle strings D and G. Therefore the empty lower dombra string with a length L_0 of 71,5 cm is in it's root frequency f_0 a D_3 and should have 146.8 Hz. The next semitone is a $D_3^{\#}/E_3^{b}$ and should have the frequency f_1= 155.6Hz. Figure 4 shows the measured frequencies $f_0$and $f_1$as well as the lengths $L_0$and L_1. The theoretically expected ratio of every pair of successive tone frequencies is given by

$$\frac{f_{n+1}}{f_n} = 2^{\frac{1}{12}} \approx 1.0596.$$

The ratio of the measured frequencies in figure 4 is 1.0616 which is close to the theoretically expected ratio.

The tables in figure 5 show complete raw data for measurements of both strings' frequencies depending on their lengths or rather on used frets. To develop an easy-to-do experiment we used the common smartphone app "phyphox" (free available for iOS and Android) for frequency measurement. This app records audio signals with the built-in microphone and calculates and displays a FFT-spectrum.

Obviously the mean values of the frequencies' ratios $\frac{f_{n+1}}{f_n}$ are even closer to the the theoretical ratio for semitones. The error is negligible. But what about the string length ratios? The tables in figure 5 show the fret-by-fret distances and the length ratios for each two successive frets of a typical dombra. Again we can observe ratios very close to the frequency ratios. Thus we can expect the same ratios for two successive string lengths like for two successive frequencies. For practical reasons we would have very small errors by using the estimation $\frac{18}{17} \approx$ 1.0588 instead of $2^{\frac{1}{12}} \approx 1.0596$.

It is just mentioned here that the fret distances estimated so far are based on the rough model "rule of 18". To be more exact it is necessary to consider a required compensation due to the string deformation when the player's finger the string is pressing down. An appropriate compensation model is introduced in Varieschi and Gower (2010, pp. 9-14).

Dombra D string				
Fret	Frequency (measured with phyphox App)	Ratio f_(n+1)/f_n	Length of string from nut to bridge in m	Ratio L_(n+1)/L_n
0	146		0,715	
1	156	1,068493	0,673	1,062407
2	164	1,051282	0,635	1,059843
3	174	1,060976	0,605	1,049587
4	184	1,057471	0,566	1,068905
5	194	1,054348	0,535	1,057944
6	206	1,061856	0,506	1,057312
7	217	1,053398	0,477	1,060797
8	229	1,055300	0,449	1,062361
9	246	1,074236	0,426	1,053991
10	260	1,056911	0,406	1,049261
11	276	1,061538	0,379	1,071240
12	293	1,061594	0,355	1,067606
13	308	1,051195	0,337	1,053412
14	328	1,064935	0,317	1,063091
15	346	1,054878	0,305	1,039344
16	370	1,069364	0,282	1,081560
17	392	1,059459	0,264	1,068182
18	415	1,058673	0,248	1,064516
Mean		1,059773		1,060631

Dombra G string				
Fret	Frequency (measured with phyphox App) in Hz	Ratio f_(n+1)/f_n	Length of string from nut to bridge in m	Ratio L_(n+1)/L_n
0	196		0,715	
1	208	1,061224	0,673	1,062407
2	220	1,057692	0,635	1,059843
3	233	1,059091	0,605	1,049587
4	247	1,060086	0,566	1,068905
5	261	1,056680	0,535	1,057944
6	276	1,057471	0,506	1,057312
7	293	1,061594	0,477	1,060797
8	310	1,058020	0,449	1,062361
9	329	1,061290	0,426	1,053991
10	350	1,063830	0,406	1,049261
11	370	1,057143	0,379	1,071240
12	392	1,059459	0,355	1,067606
13	414	1,056122	0,337	1,053412
14	438	1,057971	0,317	1,063091
15	460	1,050228	0,305	1,039344
16	490	1,065217	0,282	1,081560
17	522	1,065306	0,264	1,068182
18	558	1,068966	0,248	1,064516
Mean		1,059855		1,060631

Figure 5: Measured ratios of frequencies and string lengths depending on plucked frets

2.3 Sound radiation and timbre

Shape and size of the resonance body. Although it is not surprising that the shape of a musical instrument influences its timbre a thoroughly acoustical analysis is not trivial. Nevertheless it is possible to qual-itatively prove the influence of the instruments' shape with simple methods. For that a smartphone with a tone generator app is required. Using the "white noise" option the instruments' cavity can be excited. A simultaneous measurement of the frequencies will reveal some characteristic frequency peaks. Figure 6 shows results of those mea-surements for different musical instruments. One has to be careful with quantitative interpretations. There are too many uncontrolled variables like the body's and the air's resonance frequencies or the circumstance of extremely different sound hole sizes. At least we can see the expected order of frequencies depending on the instruments' sizes: lowest frequency for the acoustical bass guitar, middle frequency for the standard guitar and the highest frequency for the dombra.

Where to pluck the string. If a string is plucked at the center there will be a symmetrical situation of the prop- agated pulses in two opposite directions. If the string is plucked at any other point the situation will be clearly change. A thoroughly discussion of different situations is given in Fletcher/Rossing (1998, p. 41 ff.). Again there are some low-level experiments and half-quantitative interpretations for everybody who is interested in those questions. Just a stringed instrument like a dombra and a smartphone is required. Figure 7 shows the results of frequency measurements where a dombra string was plucked at two different points: (a) sound hole position, (b) middle of the string.

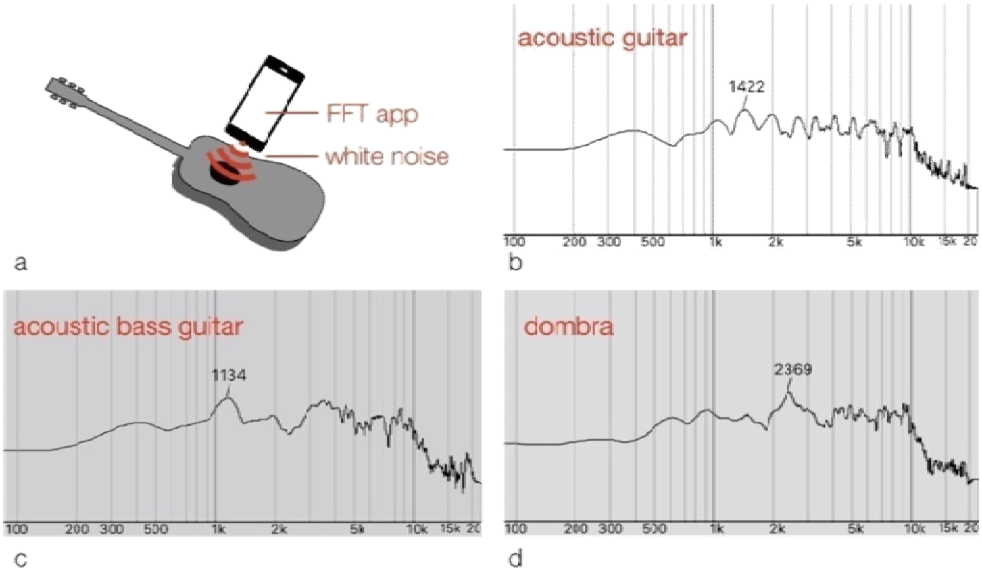
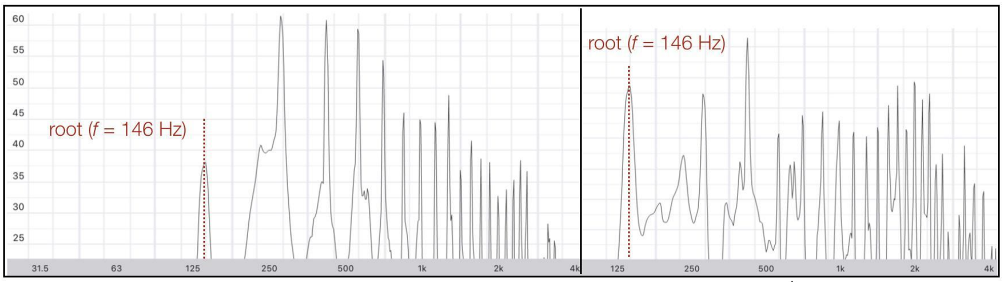


Figure 6: Measured frequency peaks after excitation with a white noise; a) experimental setup; b) resonance frequency of an acoustic guitar; c) resonance frequency of an acoustic bass guitar; d) resonance frequency of a Kazakh dombra



a b

Figure 7: Measured frequency spectrum of plucked empty D string at different points

2.4 Sound decay rate of dombra strings. If a string is plucked the string stores vibrational energy. This energy is transferred and lost by radiation. According to our every-day experience we can hear a single tone from a string just for a few seconds. This decay of hearable sound depends on the strings flexibility and therefore it depends on elastic constants and internal damping of the string material.

For a simple hands-on experiment we just need a smartphone equipped with an acous-tical app. The app *oscilloscope* (iOS) enables the user to modify the time basis. So it is possible to study the timely course of the vibration amplitudes. In figure 8 are the results for two different time basis. In (a) we can suspect that the vibration amplitude decays exponentially with a decay time of approximately 1000 ms in that example.

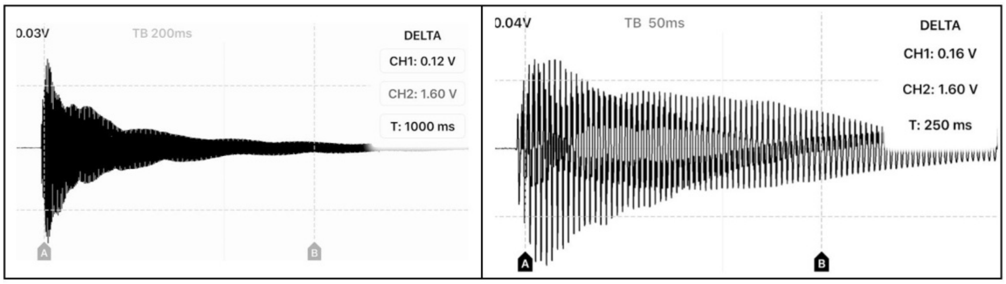


Figure 8: Vibrational amplitude decay measured with different time basis

In figure 8(b) the time basis is 50 ms instead of 200 ms in 8(a). So the differentcontri-butions of the sound with their different decay rates become visible as a superposition. One part of the sound comes from the string itself and decays faster than the other parts. This second and third part are the responses of the instrument’s cavity and body. Of course the decay rates depend on the frequencies. So it is a very complex situation at all. Nevertheless an instrument and a smartphone give students the opportunity to step into acoustics on a moderate half-quantitative level.

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Material received 12.08.21.

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АКУСТИЧЕСКИЙ АНАЛИЗ КАЗАХСКОЙ ДОМБРЫ СМАРТФОНОМ

Аннотация. Цель данной статьи - предоставить учителям физики и студентам-физикам междисциплинарный культурный и научный контент. Домбра - это, с одной стороны, культурный символ Казахстана с давними традициями. С другой стороны, домбра как музыкальный инструмент представляет интерес для акустики. Эта тема может привести к более глубокому пониманию теории музыкальных инструментов и акустики, а также к положительному мотивационному эффекту для студентов. Идея этой статьи возникла во время гостевой лекции по физике в Таразском государственном педагогическом университете (Казахстан), где автор познакомил студентов-учителей физики с "Новыми технологиями в физическом образовании". В работе обсуждены примеры передовой практики интеграции мобильных устройств и их встроенных датчиков на уроках физики.

Ключевые слова: домбра, акустический анализ, смартфон, амплитуда, осциллограф, звук.

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ҚАЗАҚ ДОМБЫРАСЫН СМАРТФОНМЕН АКУСТИКАЛЫҚ ТАЛДАУ

Аннотация. Бұл мақаланың мақсаты - физика мұғалімдері мен физика студенттеріне пәнаралық мәдени және ғылыми мазмұн беру. Домбыра -бір жағынан, қазақ халқының мәдени символы. Екінші жағынан, домбыра музыкалық аспап ретінде акустикаға қызығушылық тудырады. Бұл тақырып музыкалық аспаптар мен акустика теориясын тереңірек түсінуге, сонымен қатар студенттер үшін жағымды мотивациялық әсер беруі мүмкін. Бұл мақаланың идеясы Тараз мемлекеттік педагогикалық университетінде (Қазақстан) физика пәні бойынша дәріс кезінде пайда болды. Мақалада мобильді құрылғылар мен

олардың кіріктірілген сенсорларын біріктірудің озық тәжірибесінің мысалдарын талқыланды.

Тірек сөздер: домбыра, акустикалық талдау, смартфон, амплитуда, осциллограф, дыбыс.