Research of the Acoustic Characteristics of the Bell "Mazepa" of the Sofia Cathedral (Kiev) and their Comparison with Characteristics of Bulgarian Bells

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Abstract. Experimental researches of one of the eldest bells («Mazepa»-see Appendix1) in Ukraine, are considered in the article. The spectra and spectra-time analysis of bell ringing is embodied, main frequencies of oscillation and musical intervals of sounding are determined. Comparative description of bell sounding with the known bells of Russia and Bulgaria is given.

Keywords: bell "Mazepa", "Dutch system" of adjustment, fifth, third, spectrum, dissonance sounding, Bulgarian bells, interdisciplinary methods.

1 Introduction

The bells of orthodox cathedrals of Ukraine and of Bulgaria are national cultural property and have ancient history indissolubly connected to development of bell-foundry art of the countries of East Europe. However the research and documenting of their physical characteristics till now was not given of due attention. On the basis of experience of the Russian and Bulgarian scientists [1-6] the experimental researches of acoustic properties of the oldest of the kept bells - bell "Mazepa" are obtained. Time-frequency characteristics of the bell are done and the comparative analysis with the other Russian and Bulgarian bells is given.

On acoustic features the sound of a bell "Mazepa" essentially differs from the sound of an ideal bell of the so called "Dutch system" of adjustment. The sounding of the bell "Mazepa" is close to the sound of the bells of orthodox churches, but at the same time, has the unique features. Bell chime is one of the major elements of national culture. The chime of orthodox churches possess a special style, in which basic role belongs to a timbre and rhythm. It is based on well tempered scale.

The sound characteristics of Ukrainian bells have got the certain properties inherent in bells of orthodox churches. In whole their sounding is estimated as dissonant, and also having the special sound force, that is connected to the significant sizes of bells.

Despite of some distinctions of traditional profiles (cross-sections) of so-called Russian bells initial data for their construction are identical, therefore soundings of bells of orthodox churches are similar all over the world [1,2]. At the same time, even the small differences in thickness of walls of a bell and in the ratio of diameter and height definitely influence on the internal structure of a sound [5].

2 Experimental Researches of the Bell "Mazepa"

One of the most ancient bells of Ukraine – the bell "Mazepa", is mounted on the second circle of the Triumphal bell tower of the Sofia cathedral in Kiev- see Appendix2. The cathedral is a national monument of the XI century. The bell is moulded in 1705 by the Kiev foreman Afanasy Petrov by the order and on means of the hetman (prince) Ivan Mazepa. It is one of the largest kept ancient bronze bells of Ukraine (Fig. 1).

Fig. 1. A photo of the bell "Mazepa"

The cross-section of the bell and its exact sizes were determined with the help of laser scanning (Fig. 2). The form of the shell of the bell "Mazepa" is close on the proportions to Russian and Bulgarian bells [3-6], especially in a part of the bottom belt (zone).

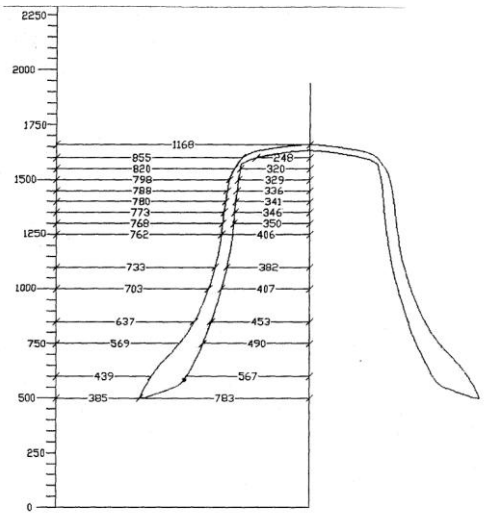


Fig. 2. The cross-section of the bell

The record of bell chime was made on a distance 5m from the bell with a microphone RFT, supplied with the instrument capsule MK-102. The analog-digital transformation of a signal was made in a sound card M-Audio Fast Track Pro, with 24-bit quality and discretization frequency 22,05 KHz. The form of the signal is shown in the Fig. 3.

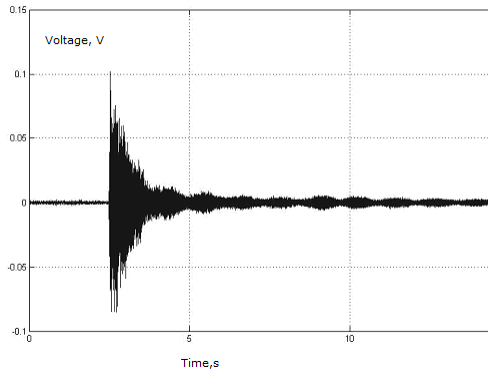


Fig. 3. Sound signals of the bell, written down on distance 5 m

The further processing of the signal is made in a package Matlab with the help of Fast Fourier Transform (FFT). It has allowed receiving the spectrum and spectrogram of the signal (Fig. 4, 5).

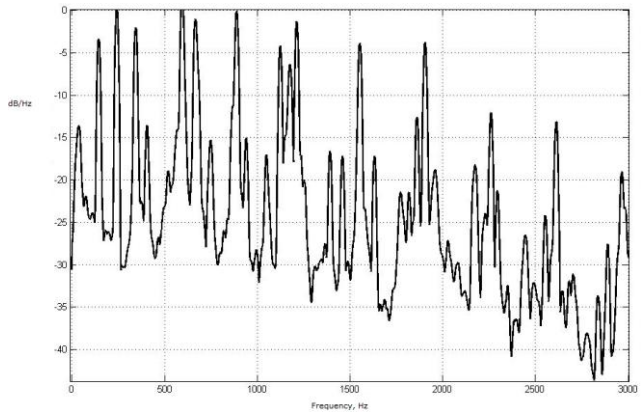


Fig.4. Spectrum of the bell "Mazepa"

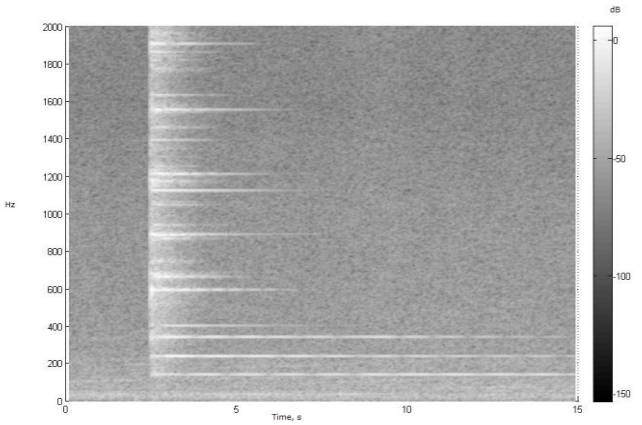


Fig. 5. Spectrogram of the bell

By results of measurements and data processing, the table of the acoustic characteristics of the bell is made, Table1.

Table1. Time-frequency characteristics of the bell

Acoustic parameters	Frequency of sound f_n, Hz	Relative level of overtone, dB	Standard level of attenuation, (-60 dB) T, s
f_0	144	-10	65
f_1	242	0	23
f_2	344	0	18

f_3	405	-12	7,8
f_4	593	0	5,0
f_5	666	0	2,9
f_6	888	0	4,3
f_7	1123	-3	4,9

3 Analysis and Estimation of Sounding of the Bell "Mazepa"

As a whole, the sounding of a bell is characterized by formation of 14 harmonics of the fundamental tone within the limits of 6 octaves. On frequencies higher then 8-th harmonic the spectrum is very compressed.

On loudness of sounding dominate the fundamental tone, second and harmonics between the fourth and the sixth that is frequency components in a range 200 - 900Hz. This fact gives to the timbre richness and depth.

At the moment of stroke a timbre of a sound is “noisy” with a metal shade, caused by high-frequency components of the signal.

Practically, 8 seconds after the stroke there is heard a sounding only of rumble tone (f_0), fundamental tone (f_1) and second harmonic (f_2). The sound becomes “sad” and dissonance with well appreciable amplitude modulation.

The ratio of frequencies and musical intervals of the bell sound is shown in Table 2 and in Fig.6.

Table 2. The basic frequencies of bell sounding and musical intervals in musical (note) record

№	Frequency of sounding f_n, Hz	Frequency interval, ratio f_n/f_1	Close frequencies of the musical notes, Hz	Intervals between the notes in cents
0	144	0,6 large sexta	146,8 D_0	-891
1	242	1 fundamental tone	247 B_0	0
2	344	1,42 reduced fifth	349,2 F_1	596
3	405	1,68 large sixth	415,3 Gis_1	901
4	593	2,45 decim	587,3 D_2	1506
5	666	2,75 reduced duodecim	659,3 E_2	1706
6	888	3,67 reduced double octave	880 A_2	2205

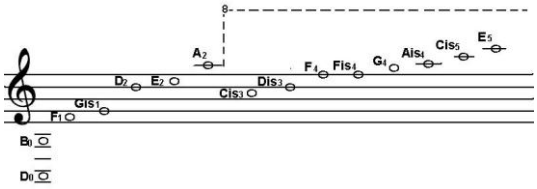


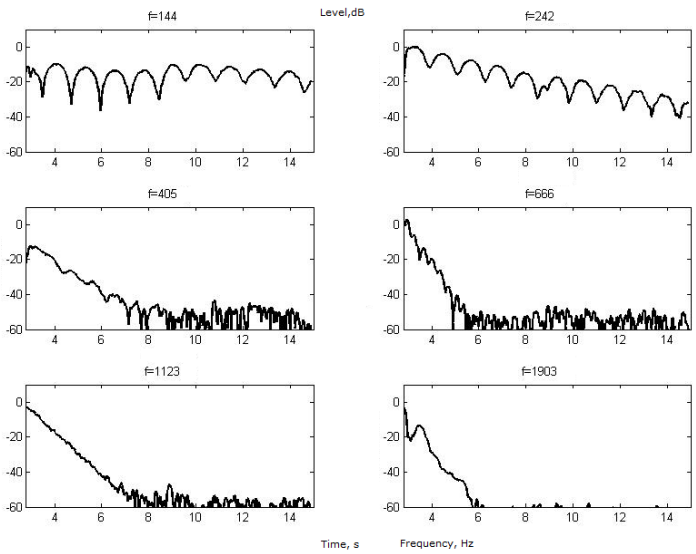
Fig. 6. Musical records of musical intervals of sounding

Typical feature of "Mazepa" bell sound is the formation of a large sexta between rumble tone and fundamental frequency, fundamental frequency and third harmonic, third and fifth, fifth and seventh, seventh and twelfth harmonics. The bell is as though adjusted on sextas that defines its minor rate of sounding. Between the fundamental frequency and sixth harmonic three fifths intervals are formed, and first of them, between the fundamental tone and second harmonic is reduced fifth, that gives dissonance of sounding.

The impression of dissonance is strengthen by semitones intervals between eighth, ninth and tenth harmonics also.

Time of attenuation of the basic tones is analyzed by their curves of attenuation, shown up to a level of -60 dB. They are given in Fig. 7. For low-frequency components the time of attenuation is determined by an angle of inclination of the approximate straight line.

a)



b)

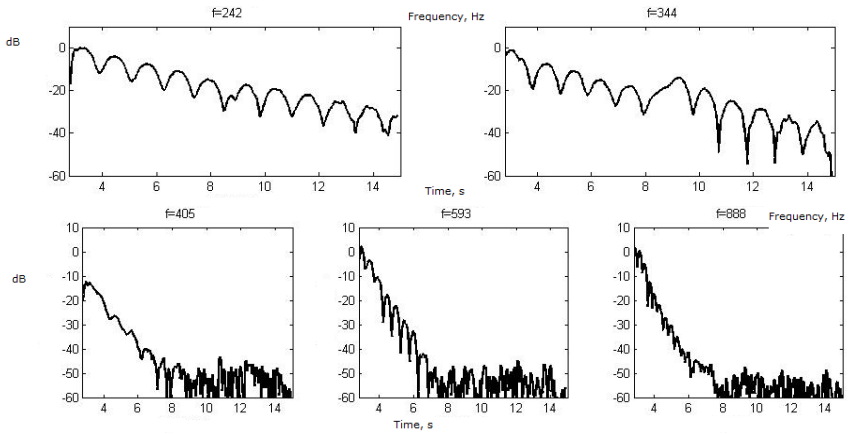


Fig. 7. Attenuation of the basic bell tones: Harmonics of a signal forming large sextas (a) and fifths (b).

The character of attenuation of different harmonics essentially differs. The rumble tone (f_0=144Hz) begins to fade on lower intensity, then in some seconds its intensity grows, after that the slow reduction of a level of tone continues. The rumble tone remains to the last, as it has the largest duration of sounding - 63 seconds. The fundamental tone begins to attenuate from more high level; process of attenuation is practically uniform. The second harmonic (reduced fifth) is like rumble tone: it grows in some seconds after the strike, and then the uniform process of attenuation is observed. As a whole, the time of attenuation of large sexta and fifths intervals is practically identical, that is, in the bell sound they are simultaneously heard.

On the attenuation curve the fluctuations of amplitude are clearly visible, that testifies to occurrence of beating, especially well heard on low frequencies. Their reason is the occurrence of two close located forms of fluctuations of the shell ("duplex"), which are caused by asymmetry of a bell and other defects formed at its molding.

On the average, time of attack of a sound is 10-40 ms, attenuation time of lowest overtones - 20-63 seconds, attenuation time of the highest overtones- 2-6 seconds.

3 Comparative Analysis of Ukrainian, Russian and Bulgarian Bells

The obtained data on the basic frequencies of sounding of "Mazepa" are compared to the similar characteristics of the Russian and Bulgarian bells (Tables 3 and 4). For comparison the bells of Rostov cathedral – well known bell "Sysoy", the bell with significant size- 32000 kg, moulded in 1688, and the bell "Baran" (1654), and also Bulgarian bell of a monastery "St. Nativity of Virgin Mary" in the town of Kilifarevo, (19 century), bell from the town of Melnik, moulded in 1220- one of oldest bells of

Europe and the bell from the village Pchelishte (20 century), near the town of Veliko Tarnovo, are chosen-see Appendix3.

It have to mention that the characteristics of Bulgarian bells are obtained with the very modern equipment: analyzer 3560B Brüel & Kjær, microphone 4193 Brüel&Kjær, connection modulus Bridge to MatLab, software PULSE12 etc. The measurements are made by team under the direction of the prof. Trifonov [6].

Table 3. The basic frequencies of sounding of a bell "Mazepa", bells of Rostov cathedral and Bulgarian bells.

Name of the bell	Frequencies, Hz					
	f_0	f_1	f_2	f_3	f_4	f_5
«Mazepa» (Ukraine)	144	242	344	405	593	666
«Sysoy» (Russia)	58	116	145	189	253	301
«Baran» (Russia)	148	308	369	461	639	816
«Kilifarevo» (Bulgaria)	302	592	698	954	1648	1774
«Melnik» (Bulgaria)	636	756	798	982	1378	1846
«Pchelishte» (Bulgaria)	551	977	1211	2037	-	-

Table 4. Relative frequency intervals of sounding of the bell "Mazepa", West-European and Bulgarian bells.

Name of the bell	Ideal bell of "Dutch system" of adjustment f_n/f_{n-1}							
	0,5 under-tone	1,0 funda-mental tone	1,2 minor third	1,5 fifth	2,0 octave nominal	2,5 decim	3,0 duo-decim	4,0 double octave
«Mazepa» (Ukraine)	0,6	1,0	1,42	1,68	-	2,45	2,75	3,67
« Sysoy » (Russia)	0,5	1,0	1,25	1,63	2,18	2,59	-	-
« Baran » (Russia)	0,48	1,0	1,2	1,5	2,07	2,65	-	-
«Kilifarevo» (Bulgaria)	0,51	1,0	1,18	1,61	-	2,8	3,0	-
«Melnik» (Bulgaria)	0,84	1,0	1,06	1,3	1,82	2,5	-	-
«Pchelishte» (Bulgaria)	0,56	1,0	1.24	-	2,08	-	-	-

At bells "Mazepa" the rumble tone makes with the fundamental tone large sixth, instead of octave, as at the West-European and Russian bells. On the underestimated first interval of adjustment the Ukrainian bell is closer to ancient Bulgarian bells ("Melnik", "Pchelishte").

Instead of characteristic sounding for the West-European bells of minor third (f_2/f_1), the bell "Mazepa" radiates reduced fifth, and instead of fifth (f_3/f_1) - large sixth, that gives the minor dissonance sounding. Let's notice that for a sound of the bell "Sysoy" is characteristic large third, and, hence, major, more light sounding. In the Bulgarian bells these intervals come nearer to West-European, though the ancient bell "Melnik" differs by dissonance semitone interval (f_2/f_1) and fourth instead of fifth (f_3/f_1).

The interval octave-nominal (f_4/f_1) in the sounding of the bell "Mazepa" not present, also, as well as in bells of Kilifarevo.

4 Conclusions

Thus, sounding of the bell "Mazepa" has general features of the orthodox churches sound, in particular, Russian and Bulgarian. However, the sounding of the Ukrainian bell differs by the uniqueness. Unusual is the adjustment of the bell on large sixths. This adjustment gives to sounding a shade of grief. It is interesting, that the large sixth adds minor third up to an octave, and on timbre coloring of sounding they are similar.

If in post sounding of the West-European bell remain an octave and minor third, in post sounding of the bell "Mazepa" - large sixth and reduced fifth. In result a minor sound is emitted, but with shade of dissonance, so characteristic for bells of orthodox churches.

In the end we want to emphasize that our future plans include research of bells of European and other countries by the advanced interdisciplinary methods and technologies to contribute to a world cultural and scientific heritage.

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Appendix 1:

Ivan Stepanovych Mazepa (Ukrainian: Іван Степанович Мазепа, Polish: Jan Mazepa Kołodyński; March 20, 1639—October 2, 1709), Cossack Hetman of the Hetmanate in Left-bank Ukraine, from 1687–1708.

Appendix 2:

Appendix 3:

«Mazepa»: Мазепа, male name, see app.1
«Sysoy»: Сысой, male name, with the meaning «white marble»
«Baran»: Баран-Ram in English.