The Investigation of Acoustical Characteristic of Russian Bells

5117 (H - 4)

I.Aldoshina (1) and A.Nicanorov (2)
(1) S-Pb.State University of Telekommunication, St-Petersburg, Russia
(2) Russian Institute History of Arts, St-Petersburg, Russia

Presented at
the 108th Convention
2000 February 19-22
Paris, France

AN AUDIO ENGINEERING SOCIETY PREPRINT

" THE INVESTIGATION OF ACOUSTICAL CHARACTERISTIC OF RUSSIAN BELLS"

Aldoshina I.-State University of Telecommunication, *Nicanorov A.*-Russian Institute History of Arts. S-Petersburg, Russia.

Bell ringing is one of the most important elements of Russian culture, for in no other country did it spread so wide being a necessary part of the Orthodox church rites. Bell shapes had been perfected during several centuries. As the result there were created huge in their sizes and inordinate in their soundings bells characteristic of Russia only. Cast in the 17[th] century, the bells of Rostov Uspensky Cathedral may serve as an example: the biggest one particularly weighs 32,760 kg, its lower diameter equals 3590 mm, upper one makes it 1745 mm, its height (apart from crown) amounts to 2730 mm, it is 310 mm thick, the frequency of its fundamental tone is 115.5 Hz. The outline is introduced in *fig. 1*. The inducement of fluctuations is produced by striking with the heavy clap against the lower brink.

In a long period of time (as early as since the 11[th] century) there had been made up a special style of playing on the bells, in which the leading role belonged to the rhythm and harmony, not the melody. The collected experience was handed on in writing form.

Starting with 1920-30s, during the "fight-against-church" period in Russia, thousands of bells were demolished, centuries-old traditions of playing inflicted, lost the technology of the bell production. This is exactly why Russian bells are the less learnt musical instruments.

At present, due to recuperation of the Orthodox traditions, restorations and rebuilding of churches, it has required to regain the art of manufacturing and the technique of performing on the bells, which defined the course of a big set of works of various researchers, targeted at the analysis of vibro-acoustic properties of the extant bells, working-out mathematical models of vibration processes in them, investigating technologies of their making, conducting psychoacoustic researches of their sound as well as creating methods of their music notation.

The experiences collected on this ground by Western researchers cannot have been used, for Russian bells substantially differ in their acoustic properties and quality of sound /1 /-/3 /.

Some of the results reached in this field (Zinchenko V.,Niynin B., Ivanov D and others)are summarized in the present report /4 /-/ 18/.

First of all, the analysis of acoustic properties of the best sounding ancient bells of Rostov Uspensky Cathedral has been fulfilled. Fifteen bells were involved: beginning with the biggest weighing 32,760 kg down to a small one of 24 kg.

With the help of recording and analyzing impulse responses by FFT method there were received frequency characteristics of sound pressure at different moments of time: a) the moment of strike; b) two seconds later; c) and ten seconds after the strike. The example is shown in *fig.2* for a bell weighing 16,380 kg. The spectrum contains up to 11 frequency components, whereas the main sound energy ranges from 100 to 1300 Hz. Ten seconds after the strike only the first three frequencies predominate. For the minor bells, the shift to the initial frequencies comes sooner – in 1.5 through 2 seconds. The similar observations were noted for all the bells, and an acoustic ID was issued for each bell. The example for "Sysoya", the largest bell is given in *table 1*.

Those measurements also allowed to discover that at the moment of strike the highest levels have f_6 and f_8 frequencies (101.5 dB and 102.5 dB). The fundamental tone and the undertone frequencies have lower than 83.4 dB and 84.5 dB. In 4-5 seconds their levels begin to increase and appear basic.

As it happened to determine through measurements, the bells were fitted together according to a certain relation of frequencies depending on their masses. The sound pressure decay process of some bells is followed by beat, adding the special emphasis to their sounding (*fig. 3*).

Along with the frequency responses of sound pressure analysis there were conducted researches on analyzing the spatial distribution of vibration accelerations upon the bells' surfaces by means of vibration detectors. The measurements were held in a anechoic chamber; the impact force was ensured by a constant. The observed data of the first and the second vibration modes gave the way to conclude that they have the form of ellipse (*fig.4*). Besides, measurements of the direction indication of acoustic radiation in space were made, which appeared to have the form of 3-dimensional cross.

To mathematically model the vibration processes in bells a MEE-based software was worked out ; it allowed to calculate the basic forms of bell fluctuations at different frequencies (*fig.5*).

Final results let create new models of large bells close in sounding to the old samples.

Together with the objective acoustic property analysis, examination of hearing perception of the bells` sounding by experienced musicians was undertaken as well as an attempt to notate it. The note records made by them were compared to the objective properties (i.e. acoustic spectra) of the same bells. *Fig. 6* shows the example of the spectrum analysis of one of the Pskovo-Pechersky monastery bells as a line of music. Over the line, the frequencies of the spectrum components are indicated in Hertz, below the line – their disaccord with the tones of homogeneously tempered mode in cents.

The final data permit to conclude the following:

=Notating the bell music by ear is linked with a range of acoustic hindrances, unlike the music of other musical instruments. The musicians say their work was hardened by flowing unstable sound, presence of sound trains.

=The musicians determined one through eight tones depending on the bell size, singularity of its sound and individual hearing abilities.

=The allocation of the heard tones for octaves has been impossible, thus was held conditionally.

=The easiest subjects to notation are the spectra of medium bells (400-1600kg in our experiment).

=The notations of medium bells mostly coincide with the objective characteristics and the results of spectrum analysis.

=The musician's evaluations of sound pitches of small (up to 480kg) and massive (over 4800kg) differentiate from one another as well as from the results of spectrum analysis.

=In most bells from the 16th – the early 17th centuries, augmented ninth and augmented tenth of the lower basic tone are determinable. These two tones are the most intensive and stable in time.

=Neither by ear, nor by technical ways were elicited the relations of such frequencies as octave, minor third or fifth in Russian bells, although they are typical for Western ones.

=The sound multiplicity (complexity) in the bell pitch sensing is present all the time. The conventionality of notating and designating to a bell a certain sole note is obvious.

The acquired data are the first part of a big set of work on creating electronic archives of the extant bells' sounding; on analysing their acoustic characteristics; methodological work-out of machinery modelling and optimization of their parameters which should encourage the keep and development bell ring – a unique phenomenon of Russian culture.

References

1. Acoustics of bells /Ed. T.D.Rossing.-New York: Van Nostrand Reinhold Company,1984.-411 p.

2. EGGEN J.H., HOUTSMA A.J.M. The pitch perception of bell sounds // Institut voor Perception Onderzoek (IPO).Annual Progress Report.-1986.-Vol.21.-H.15-23.

3. TERHARDT E., SEEWANN M. Auditive und objektive Bestimmung der Schlagtonhohe vonhistorischen Rirchenglocken // Acustica.-1984.-Bd.54, N 3.-S.129-144.

4. ZINCHENKO V., ANTOMOSHKIN A., NIKANOROV A. Acoustical characteristics of bells // NOISE-93:International Noise and vibration control conference.St.Petersburg,Russia:PROCEEDINGS.- V.3.-St. Petersburg, 1993.-P.181-183.

5. БАХРАХ М.Н., НИКАНОРОВ А.Б., МАГНИЦКИЙ О.Н. Реставрация звучания колокола // Музыка колоколов: Сб. исследований и материалов /Российский институт истории искусств; Отв. ред. и сост. А.Б.Никаноров.-СПб., 1999.-С.263-267.

6. ЗИНЧЕНКО В.И., АНТОМОШКИН А.Ю., НИКАНОРОВ А.Б. Акустические характеристики колоколов звонницы Ростовского Успенского собора // Музыка колоколов: Сб. исследований и

материалов /Российский институт истории искусств; Отв. ред. и сост. А.Б.Никаноров.-СПб., 1999.-С.126-139.

7. ЗИНЧЕНКО В.И., АНТОМОШКИН А.Ю., НИКАНОРОВ А.Б. Паспортизация колоколов по акустическим характеристикам // Соборная звонница Ростова Великого.-Ростов, 1993.-С.111-123.

8. ИВАНОВ Д.В., НИКАНОРОВ А.Б. Из опыта компьютерной обработки звука и создания музыкально-акустической базы данных о русских колоколах северо-западной России // Инструментоведение: Молодая наука: Сборник тезисов докладов Международной конф. "Интермодальное пространство в инструментальной культуре".-СПб., 1998.-С.36-38.

9. НИКАНОРОВ А.Б. Инструментоведческие проблемы русской кампанологии // Вопросы инструментоведения: Сб. реф. Международной инструментоведческой конф."Благодатовские чтения".-СПб., 1993.-С.94-97.

10. НИКАНОРОВ А.Б. Колокола и колокоьные звоны Псково-Печерского монастыря.-СПб.,1988-1991.-172 с. (рукопись).

11. НИКАНОРОВ А.Б. Экспериментальное исследование звуковысотности старых русских колоколов // Инструментоведение: Молодая наука: Сборник тезисов докладов Международной конф. "Интермодальное пространство в инструментальной культуре".-СПб., 1998.-С.52-54.

12. НИКАНОРОВ А.Б., САРАДЖЕВ Н.К. Списки "индивидуальностей" русских колоколов Константина Сараджева // Вопросы инструментоведения: Сб. реф. Международной инструментоведческой конф."Благодатовские чтения".-Санкт-Петербург: Россий ский институт истории искусств,1993.-С.83-85.

13. НЮНИН Б.Н. Колокола Храма Христа Спасителя // Русское возрождение.-1998.-№ 72.—С.145—166.

14. НЮНИН Б.Н. О некоторых итогах работы лаборатории колокольной акустики // Материальная база сферы культуры: Отечественный и зарубежный опыт решения управленческих, научных и технических проблем.-Информационный сборник /РГБ.-М., 1994.-Вып.3.-С.57-58.

15. НЮНИН Б.Н., ЛАРЮКОВ А.С. Русский церковный колокол // Колокола и колокольни (Консервация и реставрация памятников культуры.-Вып. 4) /РГБ, Информкультура.-М., 1994.-С.28-41.

16. НЮНИН Б.Н., МАШИН М.А., ЮДИН С.И., ЛАРЮКОВ А.С., ШАТОВ А.С., КОНОВАЛОВ И.В., ШИПОВ А.Ф., ЗАЙМАЛИН А.В. Способ изготовления колоколов: Патент N 2097165 // Изобретения (Заявки и патенты): Офиц. бюл. Рос. агенства по патентам и товарным знакам.-1997.-N 33, ч.2, 27 нояб.-С.303-304.

17. УОЛКЕР Дж. В колокольном звоне можно расслышать такие звуки, которые колокола не издают // В мире науки.-1984.-N 9.-С.100-105.

18. ШАШКИНА Т.Б. К морфологической проблеме монументальных инструментов с обертоновым интонированием (трембита, колокол) // Проблемы традиционной инструментальной музыки народов СССР /ЛГИТМиК.-Л., 1986.-С.68-71.

Acoustical parameters			F1	F2	F3	F4	F5	F6	F7	F8
frequency	Fi	ГЦ	58.5	115.5	145	189	252.5	301	319	381.5
Max SPL	L	дБ	84.5	83.5	99	89	97	101.5	90.5	102.5
Reverberation time	T	c	165	53	39	16.7	12.9	5.8	5.5	14.9
Fi/F0	m		0.51	1	1.26	1.64	2.19	2.61	2.76	3.30

Tab.1

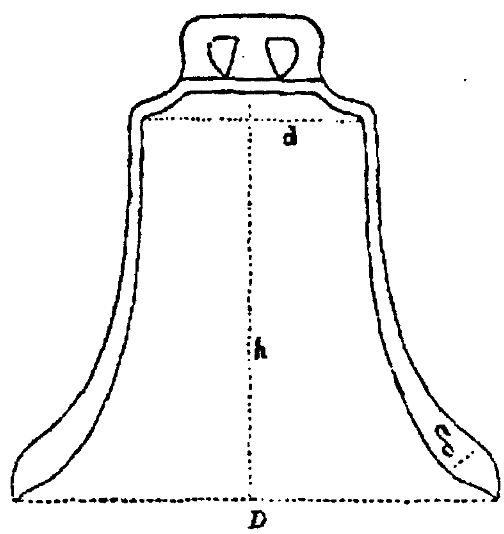

Fig.1 The shape of bell

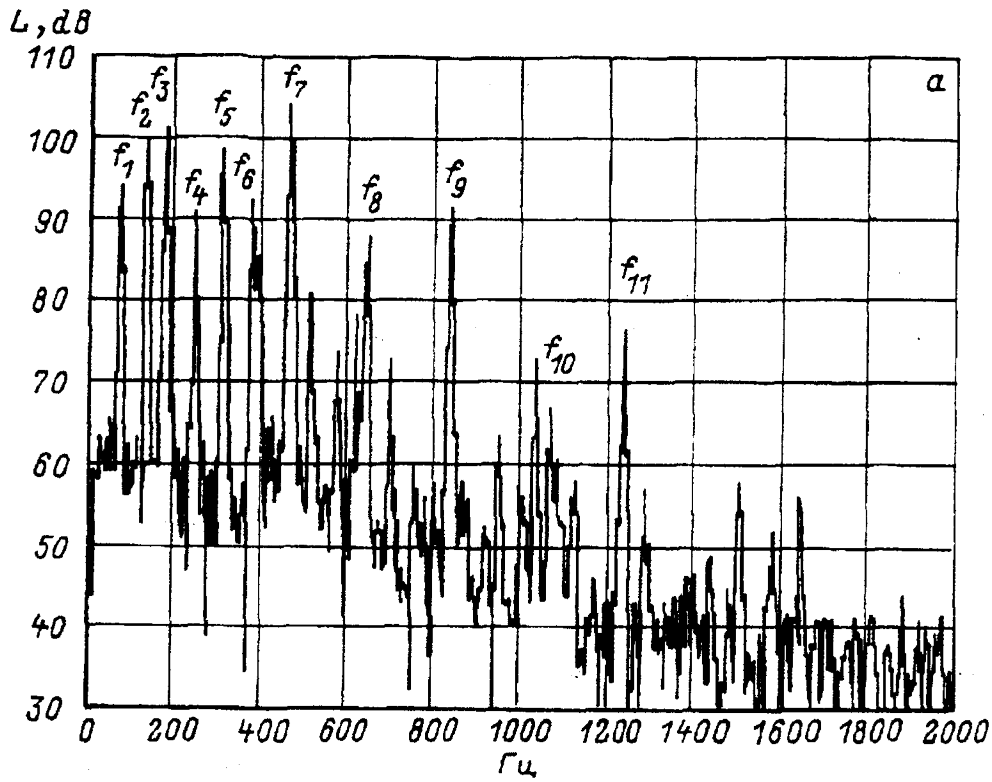

fig.2a Frequency characteristics of sound pressure at the moment two seconds later after strike;

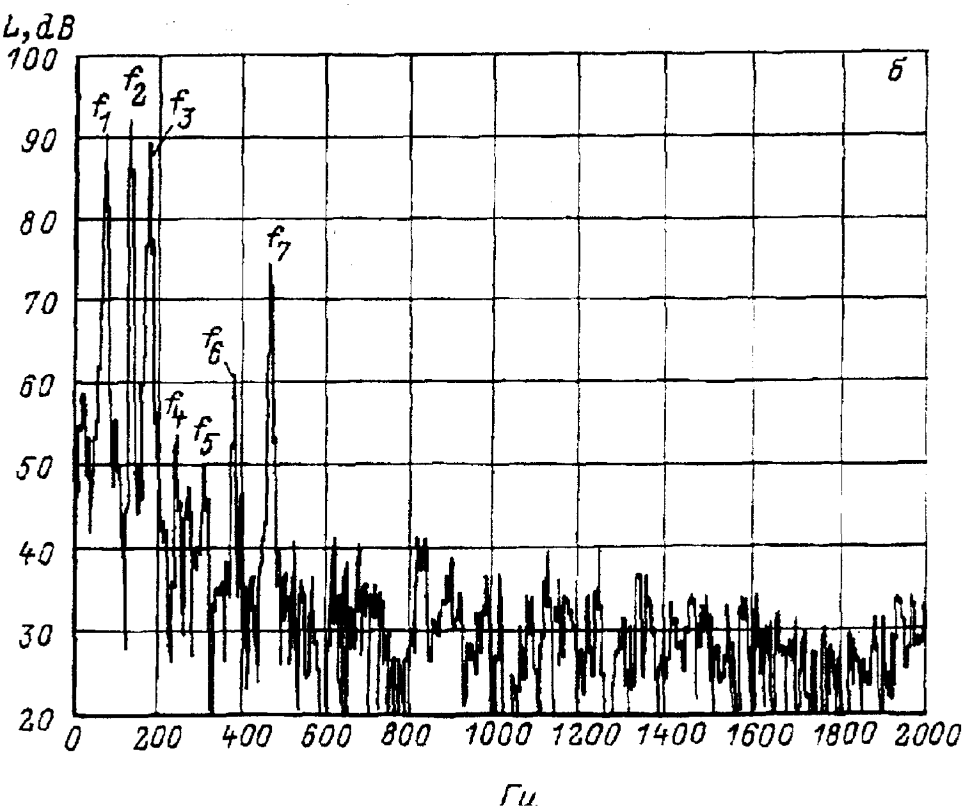

Fig.2b Frequency characteristics of sound pressure at the moment ten seconds later after strike

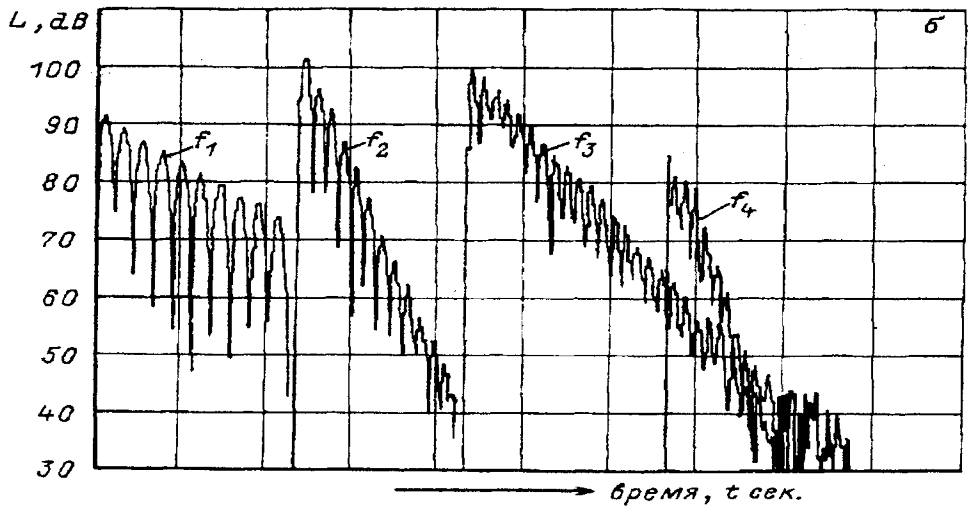

Fig.3.Transient process with beats

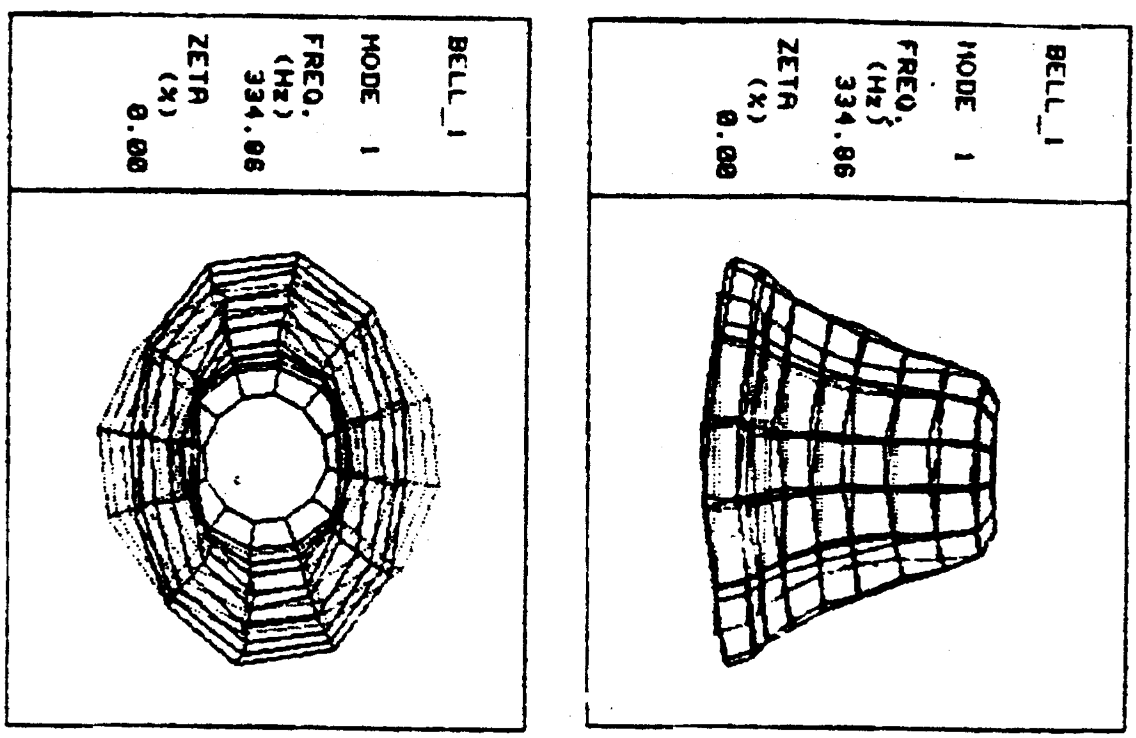

Fig.4 Measurement modes of bells vibration

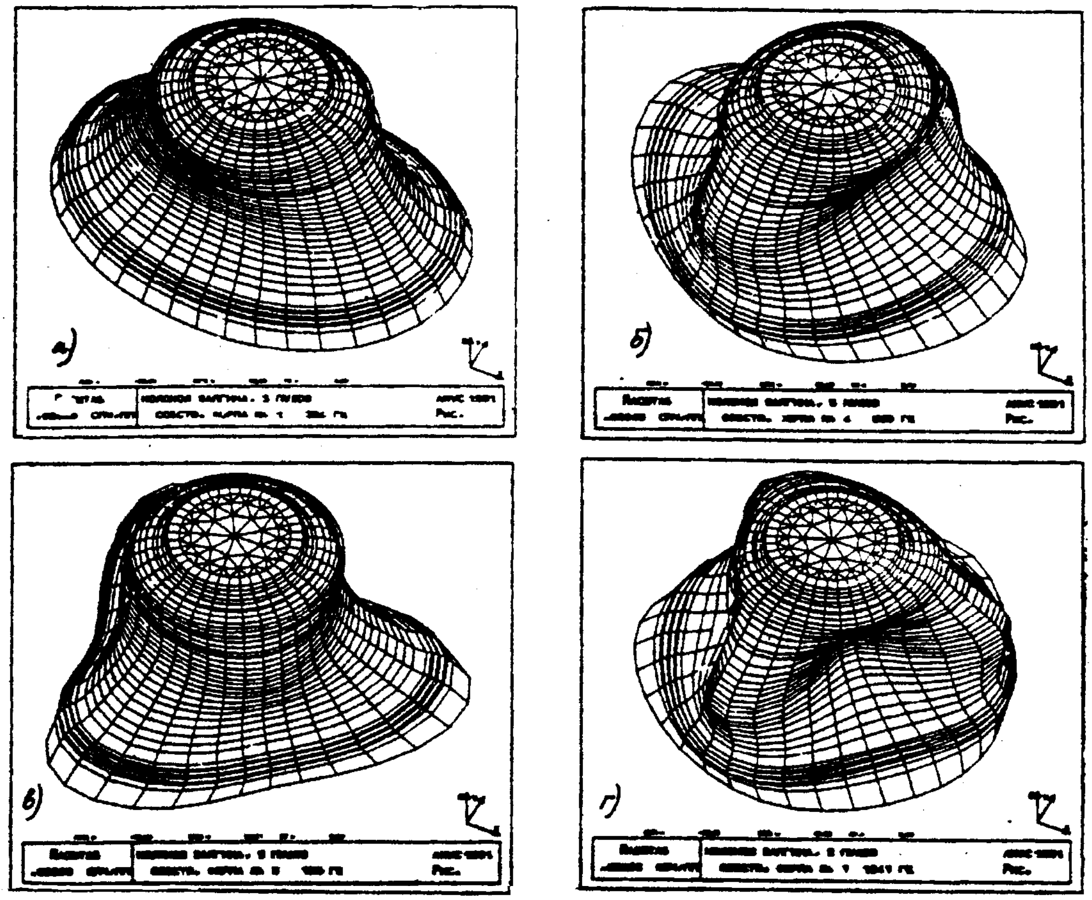

Fig.5 Calculated modes of bells vibration

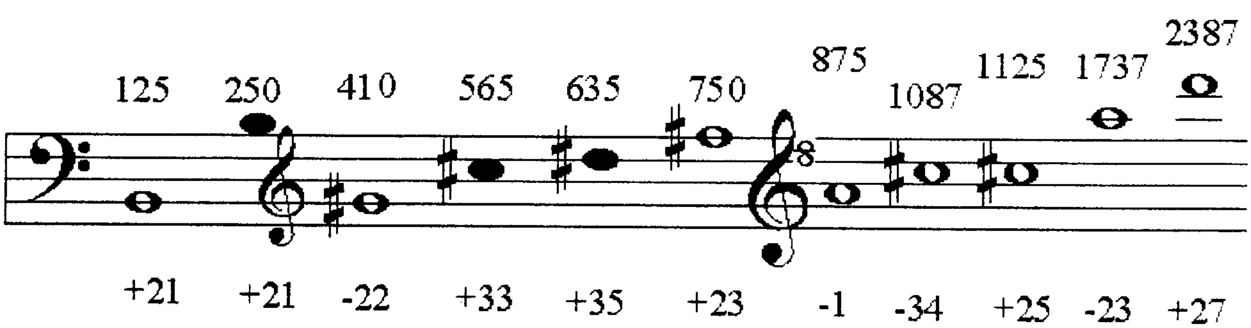

Fig.6 Notation and frequency spectrum sound of bell