19th INTERNATIONAL CONGRESS ON ACOUSTICS
MADRID, 2-7 SEPTEMBER 2007

VIBRO-ACOUSTIC BEHAVIOR OF SPANISH BELLS WITH METALLIC AND WOODEN YOKE

PACS: 43.40.-r

Ivorra, Savador[1]; Vera, Jenaro[2], Francés, Jorge[3]

[1]Departamento de Ingeniería de la Construcción, OO. PP. e I.U; Universidad de Alicante. Apartado 99, E-0380 Alicante, Spain; Sivorra@ua.es

[2] Departamento de Física, Ingeniería de Sistemas y Teoría de la Señal; Universidad de Alicante, Apartado 99, E-0380 Alicante, Spain; jenaro@dfists.ua.es

[3]Departamento de Física, Ingeniería de Sistemas y Teoría de la Señal; Universidad de Alicante. Spain; jorframo@dfists.ua.es

ABSTRACT

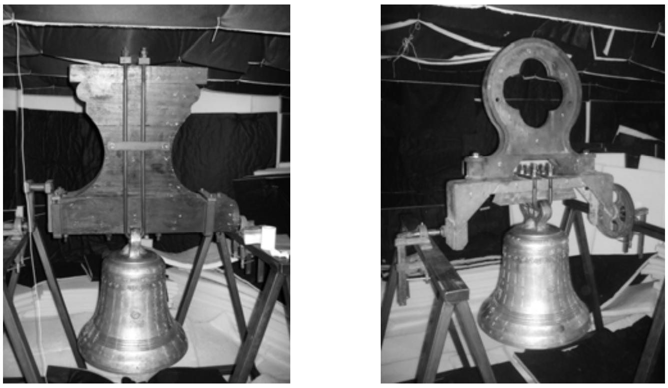
With the purpose of studying the acoustics of the same bell with wooden yoke and with metallic yoke, a bell to which have been installed both yokes has settled in the acoustically conditioned room of the University of Alicante and acoustic experiences have been carried out for separate for each one of them.
A Test protocol has been defined selecting points located in different quadrants and at different heights on the brass was hit with a hammer impact. The bell response has registered with a microphone and analyzed to permit compare under laboratory conditions the frequency response of oneself bell with two types of different yokes.

1. INTRODUCTION

In the reconstruction stage of numerous gropus of bells after del Spanish Civil War, and following a tradition imposed in centre-Europe in previous years, metallic yokes were introduced in the years 40-70 of last century in an important percentage of the existent bells until the moment and in practically all those of new foundry. The combined bell-yoke-ironwork varies its vibrational characteristic when changing part of the musical instrument and becomes more appreciable in the Spanish system without instrumentation: microphones and accelerometers.

Thanks to the collaboration with Valencian Generalitat, a brass bell with wooden yoke has settled - figure 1 (a) - in the acoustically conditioned room of the Department of Applied Physics of the University of Alicante with the purpose of evaluating the vibroacoustic characteristic of the group. The tests have been centered in the study of the frequency response - musical notes of the bell – under mechanical excitement, registering the data by means of accelerometers and microphones. For this same bell, the yoke has been substituted by one metallic - figure 1(b) - and the same test protocol was made to being able to justify in a quantitative way the variations that are appreciated listening the new sound of the bell qualitatively.

This work is a fundamental base to be able to justify the etnologic conservation of the cultural patrimony, so much tangible as acoustic, since the intervention has more than enough Goods of Cultural Interest it is regulated by the law of Patrimony



(a) (b)

Figure 1: Bell analysed. (a) Wooden yoke. (b) Metallic yoke.

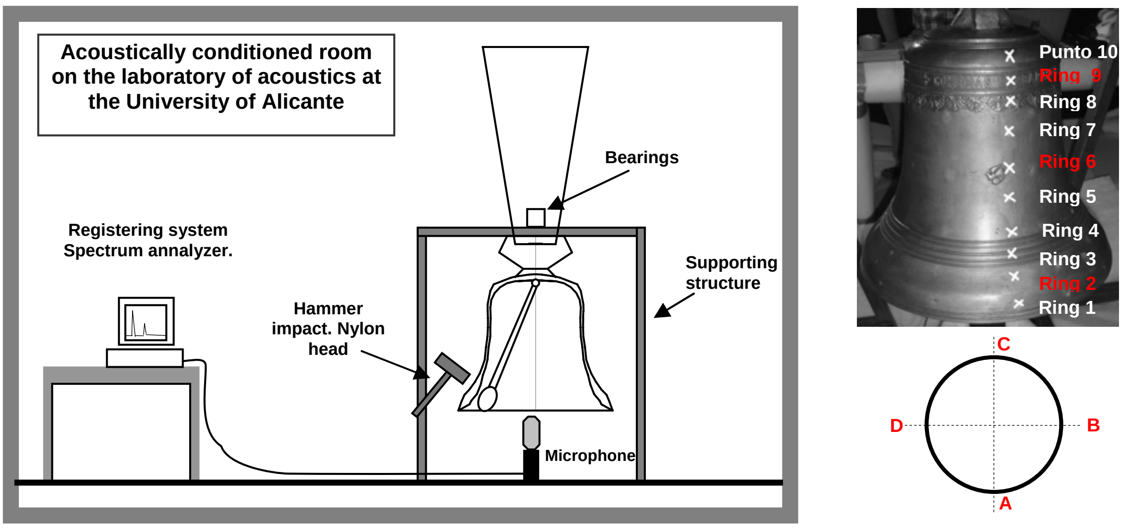
2. DESCRIPTION OF THE TEST CARRIED OUT

Initially the tests starts with the wooden yoke (figure 1(a)) located on a supporting structure designed to the effect, to those that it has been anchored by means of two bearing. The most important characteristics in the bell of the bell appear reflected in the table 1.

A free field microphone Type 40AF has situated to a height of about 25 cm under the mouth of the bell as it is indicated in the figure 2(a). Ten rings have been marked on different heights on the brass (figure 2(b). Four points are situated in each ring (figure 2(b). The ring 2 practically coincides with the position of the clapper impact. The bell was mechanically excited by means of a nylon head hammer with a weight of 500 g. On each point of each ring it has been hit during 25 times registering the response of the bell during the whole process by means the microphone. This process has repeated twice for point. The registration has been carried out with a SYMPHONIE acquisition system with a sampling frequency of 51.200 Hz. The annalysis of the registered data has been carried out by means of the commercial software dBFA32.

Table 1: Principal characteristics of bells studied.

	Mouth diameter m)	Brass height (m)	Total height (m)	Brass Weight (N)	Total weight (N)
Bell with wooden yoke	0.56	0.53	1.30	1020	1620
Bell with metallic yoke	0.56	0.53	1.34	1020	1630



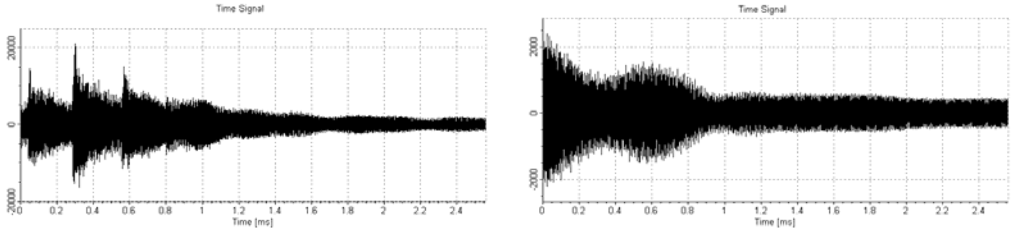
(a) (b)

Figure 2: Test made. (a) Position of the bell inside the acoustic room. (b) Pushing positions on bell.

When the wooden yoke is substituted for one metallic, an identical procedure has been carried out registering the response of the bell when it is mechanically excited by the hammer hit on the 40 points marked on this bell.

3. ANALYSIS OF THE OBTAINED SIGNALS

Once registered the signals of the bell with metallic and wooden yoke it has proceeded to extract of these the corresponding queue of damping. This has been normalized for all the registered points. Starting from this transformed signal it has proceeded to their frequency analysis, so much in fine band - analysis FFT - like in wide band - bark bands -. The figure 3 is an illustrative sample of two analyzed signals queues.

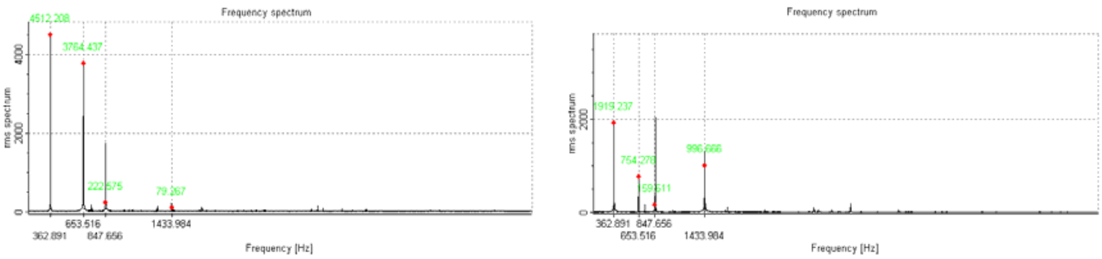


(a) (b)

Figure 3. Excitation response queue for the first ring in point A. (a) With metallic yoke. (b) With wooden yoke.

3.1. FFT Analysis

Through the analysis in fine band the predominant harmonics have been determined in the response of the bell and consequently their musical notes. It has been identified in a same way these frequencies with the denomination characteristic musical notes (Simpson, 1895).



(a) (b)

Figure 4. RMS Spectrum of registered signals. (a) Bell with metallic yoke. (b) Bell with wooden yoke

Of this analysis it can be proven that for the eighty signs analyzed by bell with wooden or metallic yoke, it cannot come off a differentiating conclusion; in both cases the behavior in each ring is very similar. Table 2 presents the main frequencies obtained.

Table 2: Main musical notes.

Frequency (Hz)	Bell note denomination	Musical note
362,50	HUM	FA(3) # -35
653,13	PRIME	MI(4)-16
851,56	TIERCE	LA(4) b +41
1431,25	NOMINAL	FA(5)+ 42

3.2. Identification of some psychoacoustic parameters.

Another type of psychoacoustic parameters have been obtained: Sonority, Sharpness, Force of Fluctuation, Tonality, Roughness, objective Nuisance and Sensation sound pleasure. Figure 5 presents the obtained results for some ring.

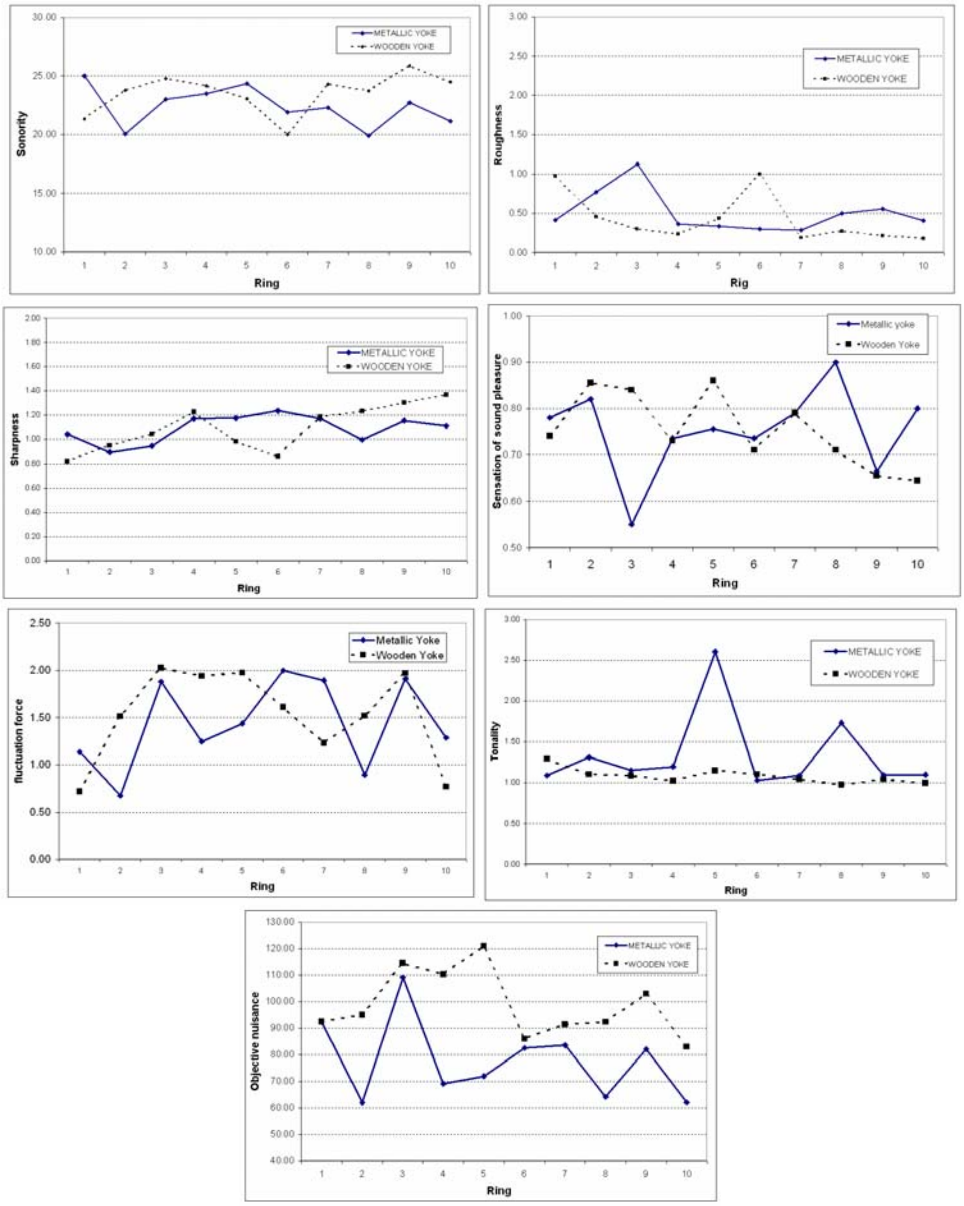
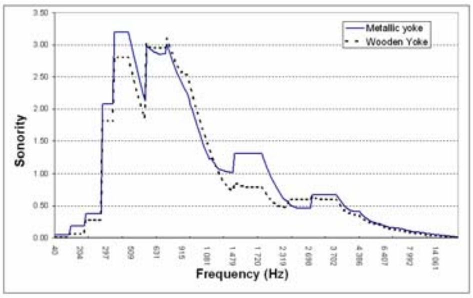


Figure 5. Psychoacoustic parameters mathematically obtained from bell records.

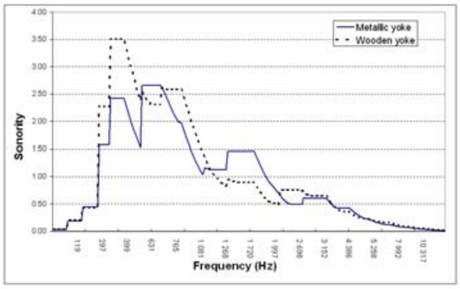
Through this quantitative analysis it is possibly to observe important differences in the response of the bell in function of the ring that is analyzed. The ring 2 are specially singular to be this the habitual position in which hits the clapper. The sonority of the bell with wooden yoke is bigger practically in almost all the rings save in the first one, the fifth and the sixth. This fact produces that the sensation of sound nuisance is bigger for the bell with wooden yoke. This same parameter influences in the tonality of the bell; the one that possesses with metallic yoke is always superior to that of the bell with wooden yoke. The sensation of sound pleasure is bigger in the points where it hits the one gotten for the case off that of wooden yoke, in the rest it doesn't present a clear tendency.

3.3. Wide band analysis. Bark bands

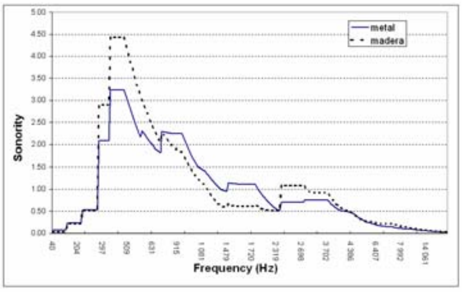
Starting from the damping queues of the bell response in each situation, an Bark bands analysis has carried out [E. Zwicker, et to the., 1957] with the purpose of defining the interval in frequency where the influence of the wooden yoke or of the metallic one it can be more perceptible for the human hearing. Has been used the conversion scales proposed by H. Traunmüller (1990). Figure 6 presents the results of this analysis.



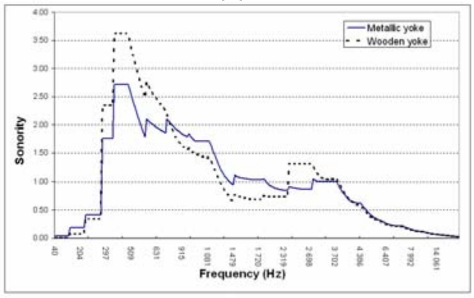
(a)



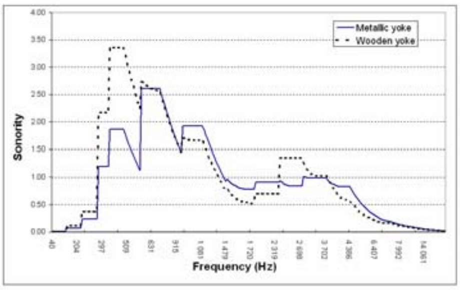
(b)



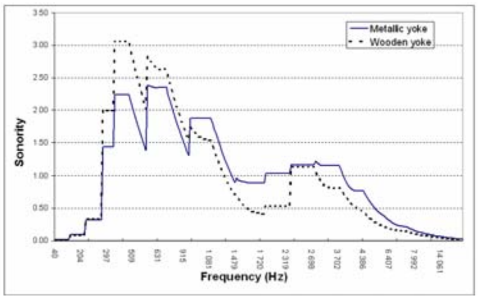
(c)



(d)



(e)



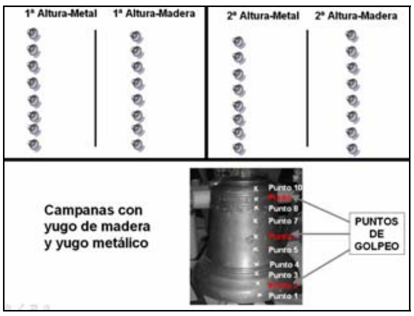
(f)

Figure 6.Bark results for 6th first rings. (a)…. (f). First ….. 6th ring.

The analysis in Bark bands shows – except for the first ring and in superior rings at the sixth - some very marked and differentiating tendencies of both yokes regarding the sonority. The bell with wooden yoke presents a bigger sonority in the intervals understood among]300, 630 [Hz and]2200-3000 [Hz. In the peculiar case of the ring 2 - position in which hits the clapper on the bell - the bell with wooden yoke possesses bigger sonority for low frequencies, prevailing practically for the whole rest of frequency the bell with metallic yoke. Through this analysis it is patent an acoustic difference between both systems of sustentation of the bell.

4. PSYCOACOUSTIC TEST

The obtained values for the first two rings have been presented to a group of music professionals to evaluate the capacity of the human hearing of distinguishing the same bell with different yokes.



(a)

(b)

Figure 8: Psychoacoustic test. (a) Personal trainer. (b) Excel test for automatic solution

The sounds of each bell presented to the musicians come from the queue of the response of the bell described in precedent sections. With the purpose of familiarizing them with the sound that is sought that they distinguish, a computer application denominated "personal trainer" has developed, -figure 8a-. Later on, and by means of another computer application, it has been evaluated the capacity of distinguishing between a sound and the other one -Figure 8b.The results of the psychoacoustic experience are shown on table 3.

Table 3.- Psychoacoustic test results (success (%)).

Professor of musical Instrument	Ring 1	Ring 2	Half Value
Trumpet	62.5	62.5	62.5
Trumpet	43.75	75	59.38
Clarinet	93.75	93.75	93.75
Saxophone	62.5	75	68.8
Oboe	68.8	65.6	65.6
Trumpet	62.5	62.5	62.5
Half value	65.63	72.40	68.75

With the purpose of having a size of more samples this test has spent to another group of people dedicated to the music's world, the global results are shown in the figure 9. It is interesting to highlight like in the second ring the percentage of successes is very superior to that of the first ring, in which the analysis in Bark bands also presents a tendency different to which is presented in the rest of rings.

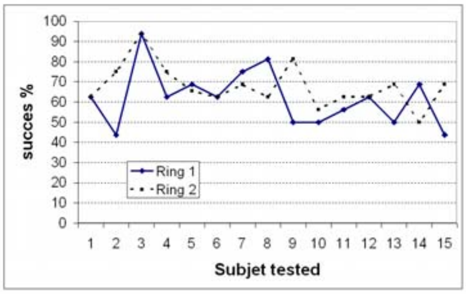


Figure 9: Success percentage among metallic and wooden yoke.

6. CONCLUSIONS

Under laboratory conditions, the acoustic response of a bell with metallic and wooden yoke has been studied. A quantitative - analysis in fine band and wide band- and a qualitative – psychoacoustic evaluation on people acoustically trained- analysis have been carried out and with the purpose of evaluating the perceived differences between the both instruments. It can be concluded that exists acoustic discrepancies among a bell with metallic yoke and the same one with wooden yoke: these they are able to be distinguished in 70% of the cases by means of the human hearing. The bell with wooden yoke presents to bigger sonority in the intervals understood among]300, 630 [Hz and]2200-3000 [Hz].

6. ACKNOWLEDGE

The authors gratefully thanked the collaboration of all musicians of Union Musical from Agost (Alicante-Spain) and the Conservatory of Muchamiel (Alicante-Spain) that have collaborated in this study.

7. REFERENCES

[1] Ivorra, S. et alter (2005) Dynamic forces produced by swinging bells. Meccanica. International Journal of the of the Italian Association of theoretical and applied mechanics. Ed. Kluwer Academic Press pub. Vol. 41- 1, 47 – 62

[2] A. B. Simpson (1895). On Bell Tones (1). The Pall Mall Magazine, Vol. VII, Sep-Dec, pp. 183 – 194

[3] E. Zwicker, G. Flottorp and S.S. Stevens (1957) "Critical bandwidth in loudness summation" J. Acoust. Soc. Am. 29: 548-557.

[4] H. Traunmüller (1990) "Analytical expressions for the tonotopic sensory scale" J. Acoust. Soc. Am. 88: 97-10