Acoustic analysis of sonority and discord of church bells

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Introduction

The sound of bells enchants us. Faulty manufacture and disadvantageous figuration of decorations may engender a dissonance. Ageing and cracks initiation affect the sound. The metrological analysis of the bell sound is used to document the result of the bell casting process. By analysing the time and frequency domain behaviour of the bell’s single tones, a musical fingerprint is generated. It comprises the measured harmony, the maximum sound level, rise time and decay as well as the beat of single bell tones. The approach to the musical fingerprint has been demonstrated with one particular bell that has been manufactured for the Dresdner Frauenkirche.

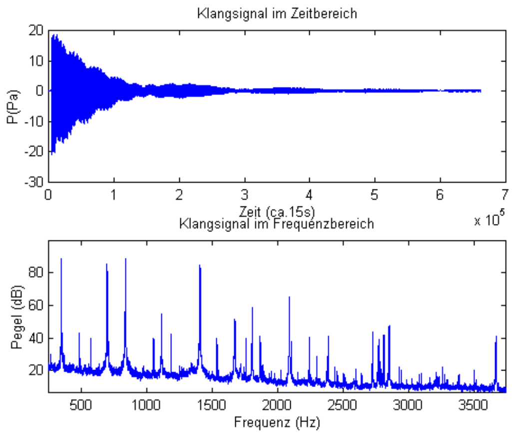

Figure 1: Representation of bell’s sound signal and spectrum.. The time domain behaviour and the level of the bell modes give information of sonority or dissonance.

The first casting result failed because of a dissonance and the second casting result has been accepted. Our duty was to compare two distinct bells made from the same spline. The one with a dissonance and the other with a good sound. The differences of the fingerprint data help us to identify clearly the cause of dissonance. The fingerprint also enables us to locate causes of dissonance and by routine measurements the longtime changing effects.

Continuous control measurements allow precocious detection in changes in material and bell structure.

These methods can also be applied for the testing of products in industrial production environments. The use of acoustic resonance analysis for product testing is well established in many applications.

Sonority

What is the meaning of sonority when we are talking about bells? Bell founders and other specialists talk about harmonic matching of bells, the duration of the bells sound. They talk about colour of sound and find a lot of adjectives to describe what they hear.

As numerous as these adjectives may be, as different the opinions about one bell may appear. In some cases, the specialists agree – most often if the bells have a dissonance. But even in agreement about the dissonance, the description of the sound effect appears to be very different.

So what is sonority? Which measures allow to give an objective and impartial representation of the bells sound?

The measures we found (can also be seen in Figure 1):

- eigenfrequencies and harmonic matching
- sound level
- beat
- attack
- duration of sound / damping

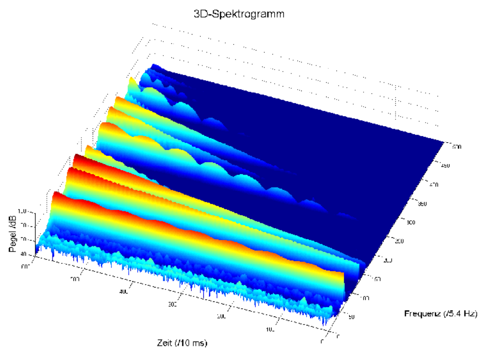

Figure 2: This is a bell sound spectrogram. Different duration, different level and different beat at different eigenfrequencies.

After the definition of the most important measures of a bell sound, measurements have to be taken and values to be calculated.

Measurements

In our measurements, we decided to vary the direction of the exciting impact. We marked 20 equally spaced positions around the half circle. This variation is advantageous because it not only allows to avoid static interference of sound waves and sound reflections, but it also inspects the measured object in different points of “view”.

Thus, the geometrical asymmetry of a bell and even a crack can be determined. This would not be possible while exciting the same place and changing the position of sound acquisition.

Frequency, symmetry and beats

Frequency analysis with high frequency resolution is one of the first analysis to be done. Exciting the bell by a mechanical impact at different places at the bells circumference shows the differing frequencies of two neighboured bell modes with identical shape but different direction.

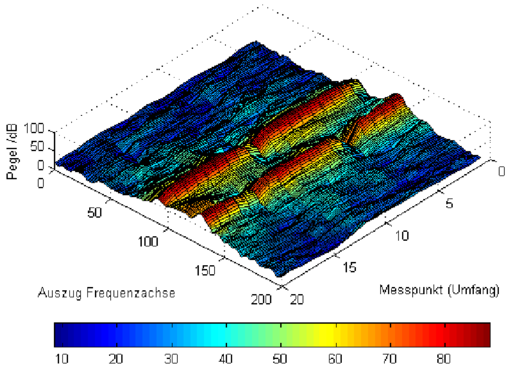

Figure 3: Exciting the bell by an impact at different locations lets us detect slightly different frequencies for one mode leading to beats

These differences lead to the beat of single tones within the bell harmony. Depending on the bells symmetry and shape of pictures, any single tone may be more or less affected.

Beats of around 1 Hz are nice to hear. More than about 3 Hz lead to jittery impression of sound, more than 10 Hz lead to a very rough impression.

Maximum level and damping

Figure 2 shows that different bell modes have different maximum level and different damping. By spectral analysis with high time resolution, we get the rise time, the highest level and the half-life-period for any bell mode (figure 4).

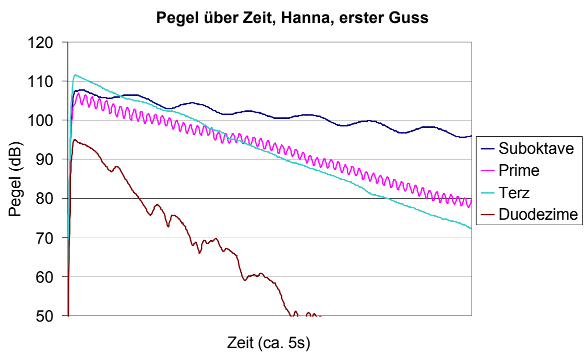

Figure 4: Rise time, maximumlevel and damping of a bell. Also visible fast beat of the prime (55 periods in 5 seconds)

Musical Fingerprint

The computed values are part of the musical fingerprint of a church bell.

In Table 1, a reduced fingerprint of the bell "Hanna" from the Frauenkirche in Dresden (second casting). Note that the standard pitch for bells is 435 Hz and not 440 Hz as for common musical instruments. The number behind the tone is its difference of frequency in 16th halftones.

	Sub-octave	Prime	Terz	Octave	Duo-decime
nominal	f'' + 6				
max level / dB	103,0	107,7	106,5	104,0	89,8
risetime / s	0,34	0,20	0,12	0,11	0,09
damping / s/6dB	2,58	0,92	0,77	0,71	0,45
F1 / Hz	349,3	697,4	836,9	1407,6	2089,5
F2 / Hz	349,9	700,5	837,3	1408,1	2090,0
beat / Hz	0,6	3,1	0,3	0,4	0,5
tone	f' +3 (4)	f'' +3 (4)	gis'' + 5	f''' +5	c'''' + 3

Table 1: Musical fingerprint for "Hanna" (second casting) one of the bells for the Frauenkirche in Dresden

References

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