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# ACOUSTIC INVESTIGATION OF THE CARILLONS IN POLAND

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The carillons existing in Poland are described. Three carillons have been recently investigated acoustically: that as Jasna Góra Sanctuary in Częstochowa, installed in 1905, that one at St. Catherine Church in Gdańsk, built in 1989, and the one at the Gdańsk Main-City town-Hall, rebuilt, yet unsatisfactorily, in 1970. Results of the computerized spectral sound analysis of those carillons are presented, compared and discussed.

## 1. Introduction

Carillons are specific musical instruments, composed of bells tuned to consecutive steps of a musical scale, serving as sound sources while excited into vibrations by hammer strokes. Thus carillons may be classified as percussional idiophones. The number of bells in a carillon should not be smaller than 23, i.e. its scale should reach at least two octaves. This condition comes from a definition accepted, among others, by the Carillon Guild in U.S.A. [6]. However, many carillons have 36 or more bells, thus reaching a scale of three or more chromatic octaves.

A less numerous set of bells, usually less than ten, playing a simple melody is called a chime. Hence, some ambiguity arises how to denominate instruments composed of e.g. sixteen or twenty bells. They may be denoted as big chimes or as incomplete carillons. The decision may depend on other features of an instrument. On the other hand, the word 'chime' is being used for denoting tubular bells rather [16] than traditional ones of a campanoidal shape [15]. Thus, those and other terminological problems are still not solved within the topic [12].

Acoustic investigation on a carillon should, obviously, contain investigations on particular bells of the instrument, and then on the entire instrument. A study of the bell sound is more difficult than that of other musical instruments, first, because bell-sounds are of transient type, second, because they have a very complex temporal and spectral nature, where harmonic relations among partials are only crude approximations, third, because the sound spectrum depends on the way of excitement i.e. on the force, the velocity, and on the place of hammer stroke, as well as, on the position of a recording microphones within a belfry space. More detailed dependences are considered in the specialized literature [1], [2].

Bells were studied by many outstanding scientists including Lord RAYLEIGH [20]. Classical papers on bells were collected by Rossing in Benchmark edition [16]. Main interest was devoted to analyses of bell sound complexity and to interdependences between bell dimensions and its sound spectrum. Carillon bells were mostly investigated as examples. However, further comparative investigations on various carillons seem to be desirable now, when measurements followed by computerized methods of analysis, are quicker and easier to be compared. Thus, objective comparisons of various carillon sounds are justified. They may be supported by the subjective assessments of sound quality.

The investigations on carillons in Poland, reported below, were considered by the authors as particularly important, because the carillon built recently in Gdańsk attracts great public attention due to its historical role in German–Polish relations. Another Gdańsk carillon only partly saved from war destruction presents also an interesting example. The third carillon, existing in Poland since XVIII century and rebuilt in 1905, gives good opportunity for comparisons, being approximately of same size as the first one.

It should be added here that may be more carillons or chimes existed in the past within the Polish territory, however, most probably, they were destroyed during the wars. For the three carillons investigated, more detailed data are given below.

## 2. Carillon data

The three investigated carillons are characterized here according to information either contained in the literature or collected during measurements and recordings made by the authors in situ. The carillons are described in chronological order of their construction or reconstruction.

### *2.1. The Jasna Góra Carillon*

Jasna Góra ("The Bright Mountain") is a traditional name of the famous Our Lady Church and Monastery in Częstochowa. This Sanctuary numerously visited by pilgrims was outfitted in the XVIII century with a carillon situated in the upper part of the eminent main church tower.

The actually existing instrument was imported in the year 1905 from a Belgian enterprise Jos. Conthier et C-ie, Malines, and installed in the tower, rebuilt at that time after the big fire of 1900, which destroyed totally the old carillon together with the upper part of the XVIII-century tower [5].

The carillon has 36 bells, in chromatic scale ranging from $C_4$ to $B_6$. The bells are hung on supporting steel frames in the uppermost part of the tower in four floor-stages. The four biggest bells, provided with clappers are hung swinging, while all the bells have outside hammers. Some of the bells have double or triple hammers. The cabin with a keyboard is situated one floor below. Bells are played therefrom through a mechanical action with the use of transmission bars and levers.

### 2.2. *The Town-Hall carillon*

A chime in a Town-Hall tower of the Gdańsk Main-City existed already in XVI century. The chime had fourteen bells and a clock-bell [14]. The instrument was destroyed during the Second World War in 1944. Only three damaged bells were recovered after the destruction [21].

After the War, sixteen chime-bells dismounted from a former youth-center in a Gdańsk suburb, called Biskupia Górka (Bishop's Hill), have been installed in the rebuild Town-Hall tower in 1970 [3]. A seventeenth bell installed later on, came from those recovered from the old pre-war instrument. A XVI century clock-bell coming from the ruined St. John's Church nearby [4], is also installed in the tower as a present clock-bell [10].

The existing carillon, though incomplete, may serve, due to its automated driving mechanism, to play melodies. Actually, only one melody (part of Nowowiejski's "Rota") is repeated every hour, following the beats of the clock-bell. The sound quality of the carillon is not satisfactory, because of numerous bullets and splinter damages to bells, and due to difficulties in retuning the bells.

The carillon now has seventeen bells ranging at not fully chromatic scale from $A\#_4$ to $E_6$.

### 2.3. *The St Catherine carillon*

St. Catherine carillon is the newest and the best from such instruments existing in Poland. Its history is noteworthy in the past period, and especially in recent years. The first chime in St. Catherine Church was built in XVI century. In 1738 it was replaced by a big carillon having 35 bells. It was destroyed in a big fire in 1905. The next carillon, with 37 bells, was installed in 1910. It existed until the Second World War, when in 1942 its bells, except one, have been dismounted and sent to be melt down as material for armaments. Two years later the St Catherine Church and its characteristic belfry-tower were almost totally destroyed. After the War the 28 luckily saved bells of the dismounted carillon have been found in Germany, and later on, in 1954, installed in Our Lady Cathedral in Lübeck [10].

Thank to the initiative of a pre-war Gdańsk citizen Mr Hans Eggebrecht, a foundation was created in order to rebuild the St. Catherine carillon [9]. The main idea of the foundation was to reconcile German and Polish nations after the tragedy of War. The new set of 37 bells was ordered by German foundators from the renowned Dutch foundry Koninklijke Eisbout in Asten, which mounted the carillon in St. Catherine Church [11]. Earlier, Polish foundators rebuilt the monumental belfry-tower, see Fig. 1.

The new St. Catherine carillon has been solemnly installed at the belfry-tower in 1989. Since that time it plays melodies every hour automatically, thanks to a digital steering system and electromagnetic hammers. Up to 99 melodies can be stored in digital memory of the system. The instrument may be played from an electronic keyboard through a MIDI system interface. A foreseen mechanical keyboard and action has not yet been installed, so far.

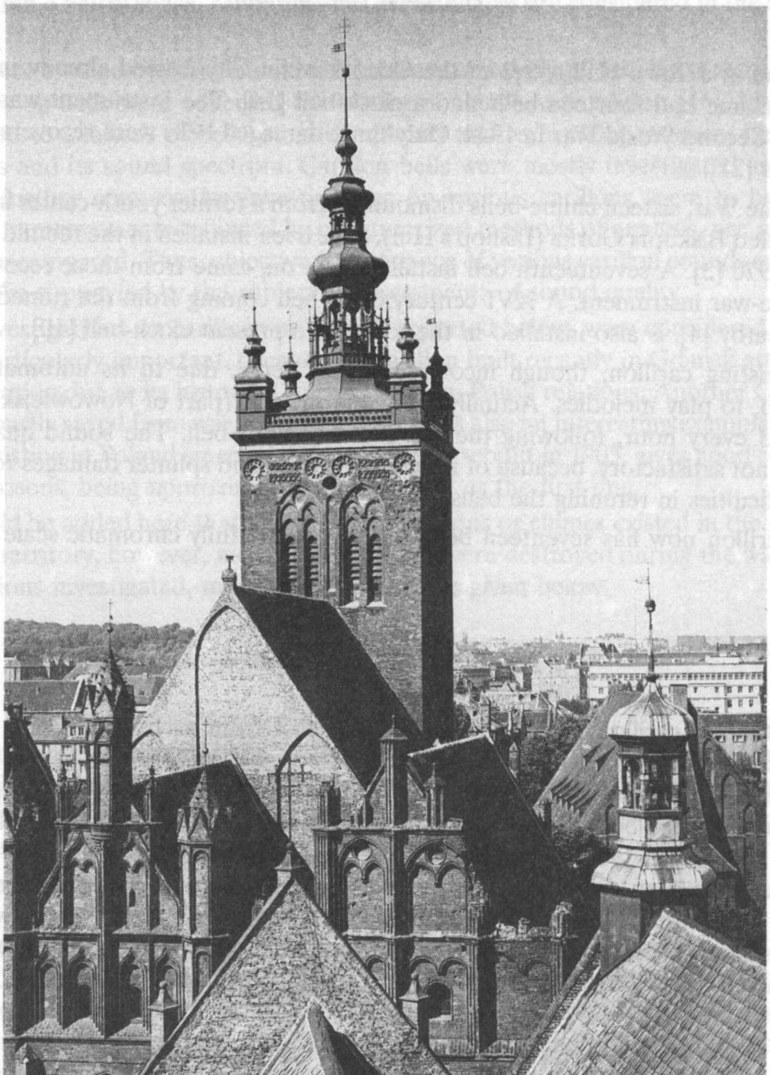

FIG. 1. The St. Catherine belfry-tower in Gdańsk.

The four low-note bells can be pealed either by clappers, when swung by wheel mechanisms, or by hammers, as are all remaining bells hung fixed. The largest of the bells serves also for striking hours. A part of the carillon bells mounted on a steel rack situated in the middle of the upper part of the rectangular, spacious, made of brick, belfry-tower is shown in Fig. 2.

The bells are tuned to chromatic scale reaching from $C_4$ to $C_7$.

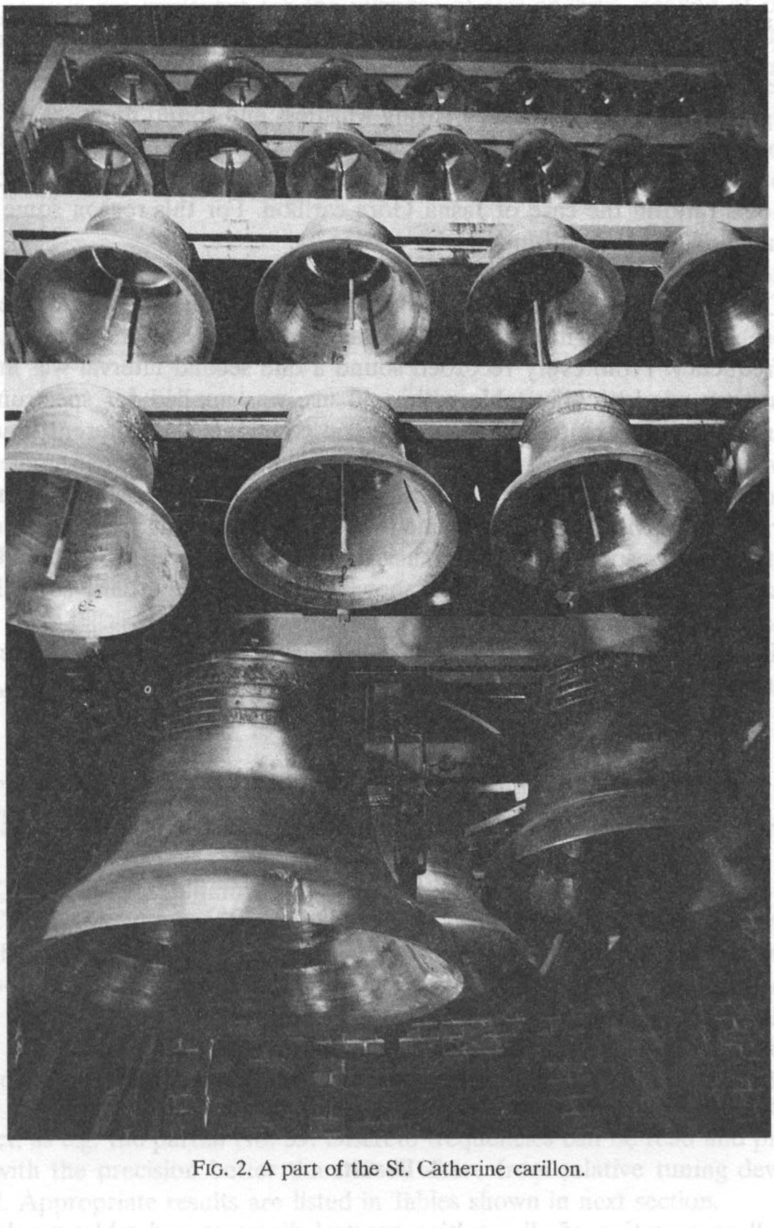

FIG. 2. A part of the St. Catherine carillon.

## 3. Acoustic investigation

Sounds of all carillon bells were recorded, using Nagra IV tape recorder with Neumann condenser microphone. Microphone distance varied for particular bells, which was inevitable because of difficulties in access to proper microphone positioning inside a belfry. However, the acoustic field at microphone positions although near to sound source was reverberant, especially in case of St. Catherine, due to sound reflections from inner belfry walls. To suppress excessive field irregularities sounds were recorded also stereophonically with a pair of microphones and then the sum of those recordings analyzed.

Bad weather conditions were pungent difficulties encountered at recording carillon sounds. High force gusty wind caused strong whistless and sound impulses at both cases of recording made in the Town-Hall tower and in St. Catherine belfry-tower. Heavy rain pattering on the tin roof of the tower-helmet, caused noise interference, which diminished signal to noise ratio in the case of Jasna Góra carillon. For this reason some particular results of analysis had to be disqualified.

Recorded sounds were analyzed at the laboratory by means of a system composed of an IBM PC AT computer outfitted with a special board card and a software elaborated for that purpose. The 12 bit digital presentation was due to A/D conversion made at 24 kHz sampling frequency. From every recorded sound a one second interval was analyzed. A rectangular time window, adjustable within 40 ms, was applied for spectrum analysis. Multiple analyses were excuted for every spectral component at different time intervals adjusted with resampling, in order to achieve an integral number of samples within a chosen time window length. Its final selection depended on the choice of the most stable phase characteristics within a selected time interval. The resulting frequencies of spectral components were transposed onto the musical, equally tempered scale, based on $A_4$ = 440 Hz diapason. Spectra for every bell showing subsequent partials, as well as tables displaying relative tuning in cents, were printed as results.

The printed short-time spectra, taken at maximum sound power, have discrete spectral components numbered along the abscissa scale. The component number $N$, shown in Fig. 3 to 6 above locally maximum ray values, stems from the ratio:

$$N = \frac{f_{\text{sampling}}}{2^n} = \frac{24000}{1024} \cong 23.4\ \text{Hz} \quad \text{per ray}$$

The whole process of analyses for a carillon including the printing of results lasted about two hours.

A part of the recordings was analyzed using a NeXT computer, with an A/C converter AD64x, where sounds were introduced at 44.1 kHz sampling frequency. NeXT software programs were also applied to digital editing of sound samples. Resulting duration of analyses in time-domain, filtered for chosen sound partials, was limited to about 1.3 s, in order to eliminate components due to unwanted sounds.

Replaying of the recorded bell sounds allowed to assess subjectively the quality of particular bells and compare them in favourable listening conditions at the laboratory.

## 4. Results

As a full presentation of all resulting spectral diagrams and tables would take too much volume, so only selected results given as examples are quoted here.

### *4.1 Jasna Góra carillon*

Fig. 3 depicts the short-time spectrum of the largest bell, i.e. $C_4$. Abscissae scale in Hertz is linear for easier search of harmonic relations; only a range to 3 kHz is shown, as higher partials are irrelevant for the purpose of this analysis. Scaling of ordinates is relative, as amplitudes depend much on the selected moment of the time window, and also on the signal to noise ratio of the sound recording. Partials numbered are those of local maximum amplitude.

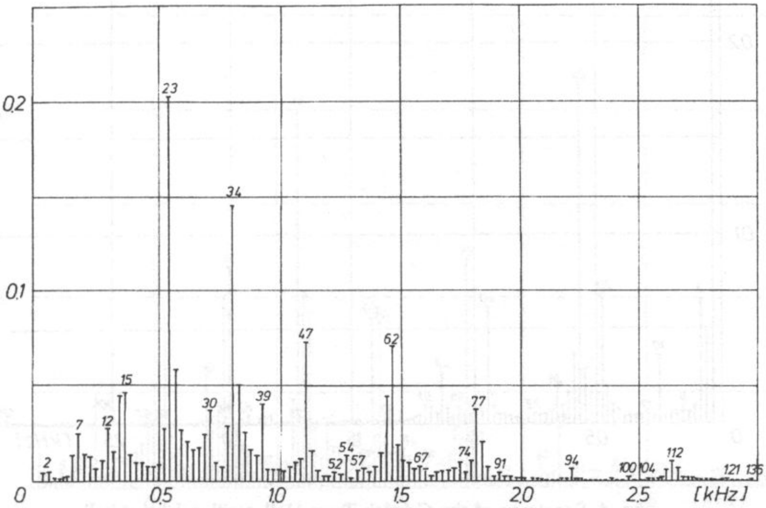


FIG. 3. Spectrum of the largest bell from Jasna Góra carillon.

The following partials among the numbered ones may be easily identified as relevant to the inner tuning harmony of the bell:

No. 7 — the Lower Octave (Hum tone),
12 — the Prime,
15 — the Minor Third,
23 — the Octave,
30 — the Tenth (Octave + Major Third),
34 — the Twelfth (Octave + Fifth),
47 — the Double Octave.

The Fifth and the Eleventh are missing in this case, while some irrelevant frequencies are distinct, as e.g. the partial No. 39. Discrete frequencies can be read and printed from analyses with the precision better than 10–4, where from relative tuning deviations are calculated. Appropriate results are listed in Tables shown in next section.

### *4.2 Town-Hall carillon*

Figure 4 gives the short-time spectrum of the largest bell ($A\#_4$), while the Fig. 5 shows that one of the clock bell. The last example may be interesting because of the lower than usual height to diameter ratio of that old bell, and noticeable difference in timbre.

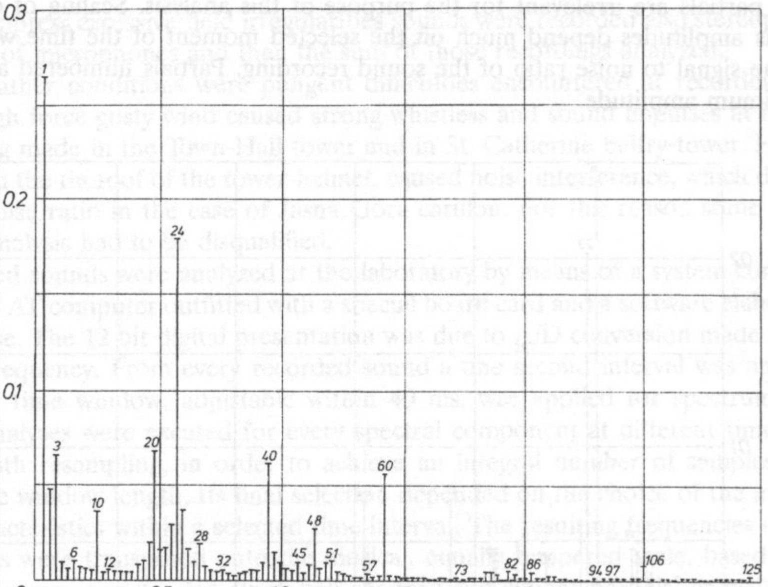


FIG. 4. Spectrum of the Gdańsk Town-Hall carillon largest bell.

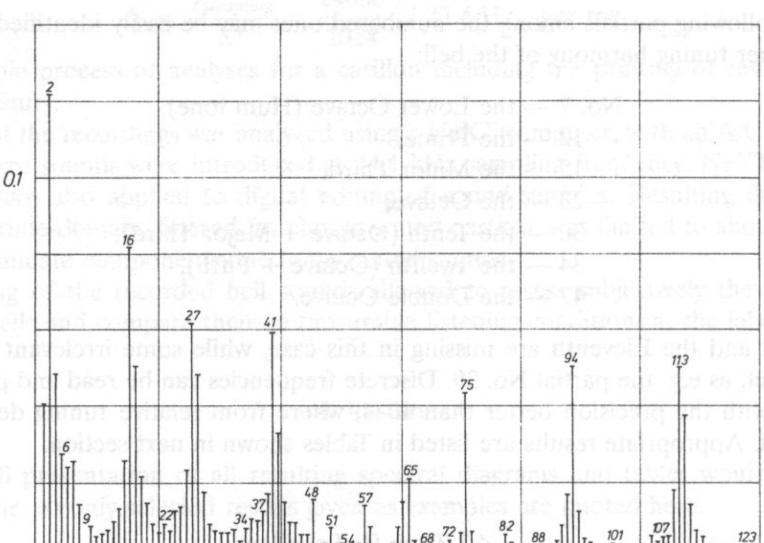


FIG. 5. Spectrum of the Gdańsk Town-Hall tower clock bell.

### 4.3. St. Catherine carillon

Figure 6 shows the short-time spectrum of the largest bell ($C_4$) when pealed with its clapper. Hammer excitation gives similar result; only amplitudes of partials differ slightly.

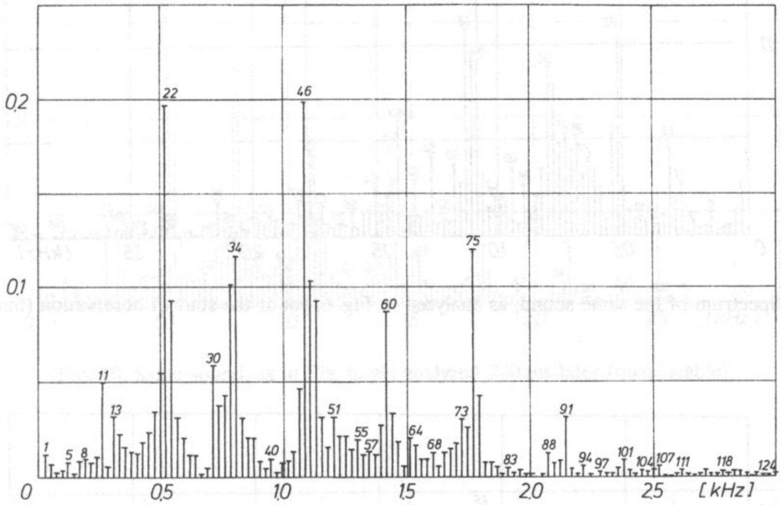


FIG. 6. Spectrum of the St. Catherine largest bell sound (analyzed at the moment of maximum sound power).

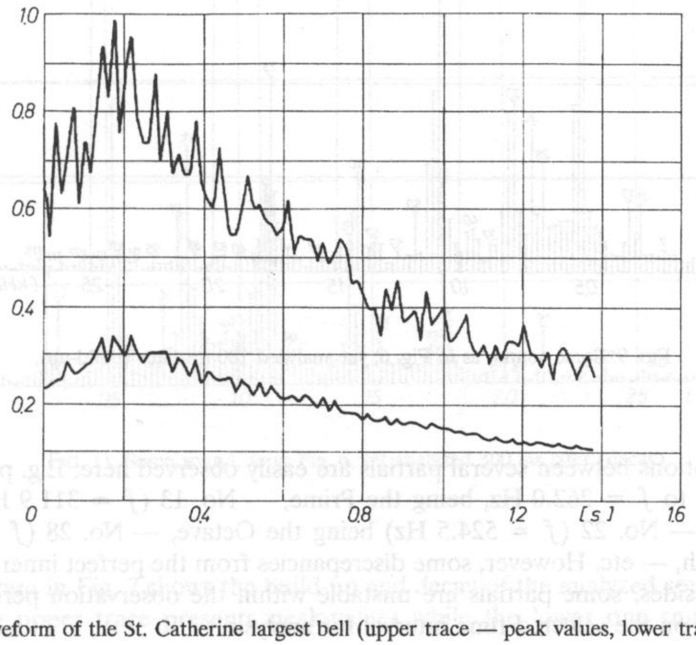


FIG. 7. Sound waveform of the St. Catherine largest bell (upper trace — peak values, lower trace — rms values).

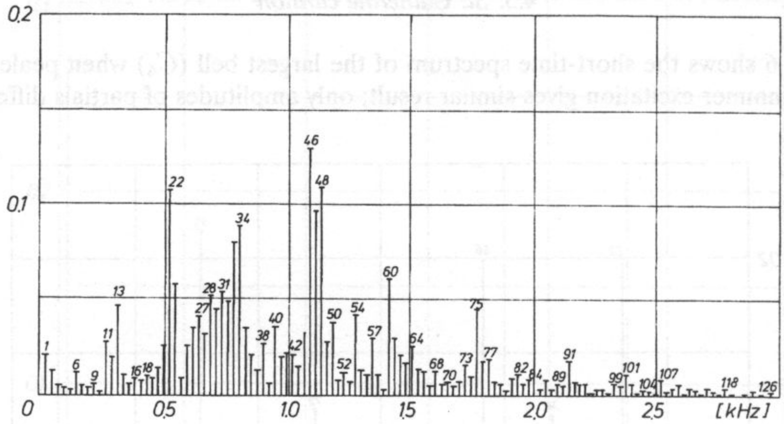


FIG. 8. Spectrum of the same sound, as analyzed in Fig. 6, yet at the start of observation (build-up).

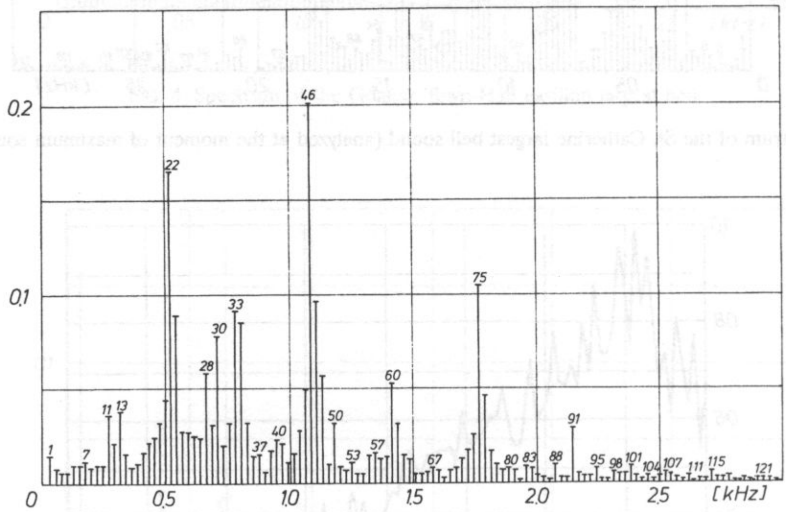


FIG. 9. Some sound, as in Fig. 6, yet analyzed 100 ms later (build-up).

Harmonic relations between several partials are easily observed here. E.g. partial No. 11, corresponding to $f = 262.0$ Hz, being the Prime, — No. 13 ($f = 311.9$ Hz) being the Minor Third, — No. 22 ($f = 524.5$ Hz) being the Octave, — No. 28 ($f = 655.8$ Hz) being the Tenth, — etc. However, some discrepancies from the perfect inner harmony are noticeable. Besides, some partials are unstable within the observation period and their values depend on the selected time interval for analysis.

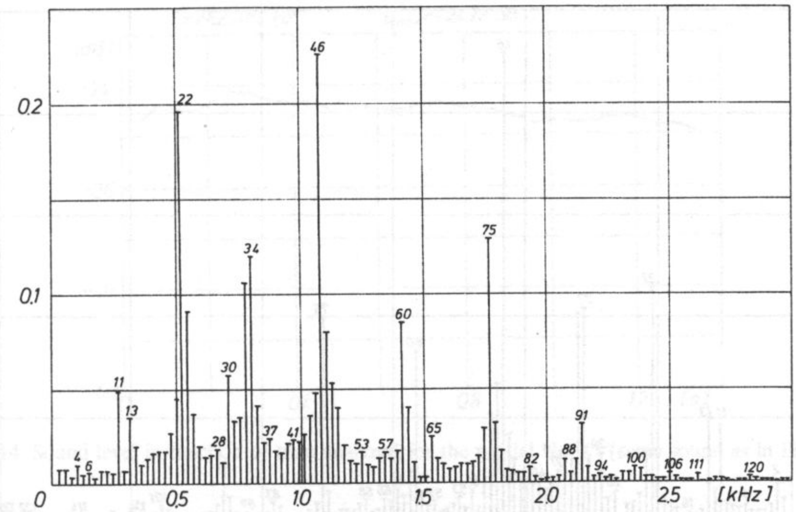


FIG. 10. Same sound, as in Fig. 6, yet analyzed 200 ms later (quasi-stable).

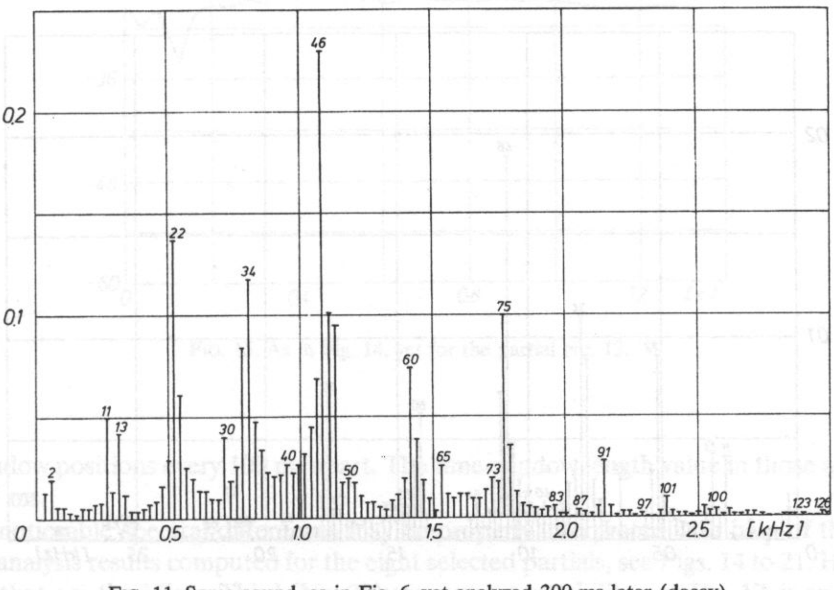


FIG. 11. Some sound, as in Fig. 6, yet analyzed 300 ms later (decay).

The diagram in Fig. 7 shows the build-up and decay of the analyzed sound as function of time. The upper trace presents peak-values while the lower one rms-values of the

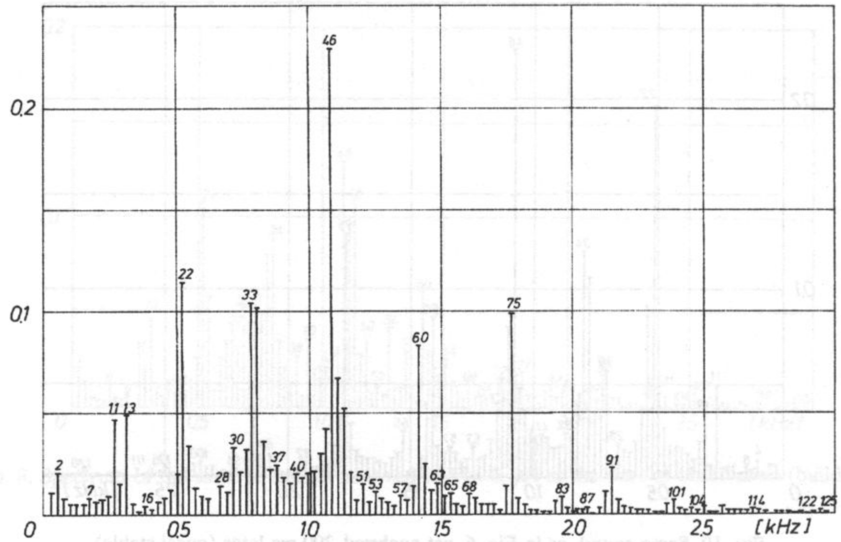


FIG. 12. Same sound, as in Fig. 6, yet analyzed 400 ms later (decay).

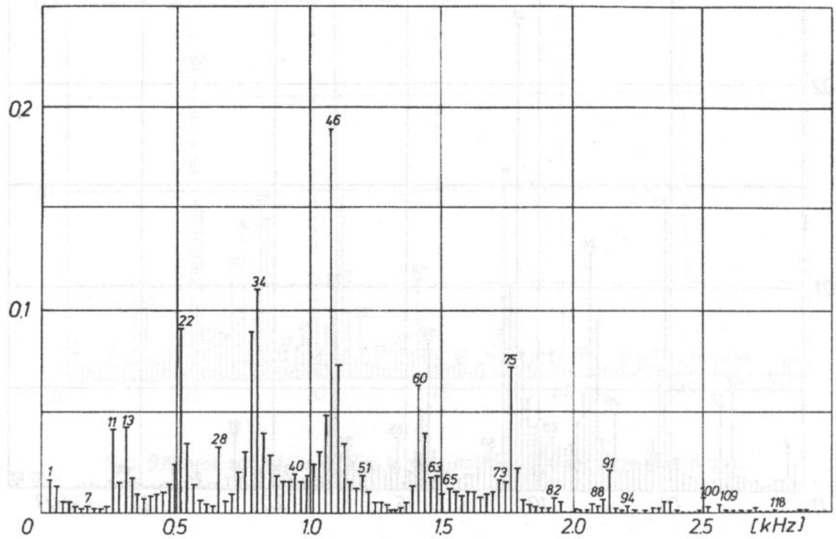


FIG. 13. Some sound, as in Fig. 6, yet analyzed 500 ms later (distinct decay).

function. In order to show the dependence of the short-time spectral on the selected observation time the following six spectrograms are presented, see Figs 8 to 13, taken at

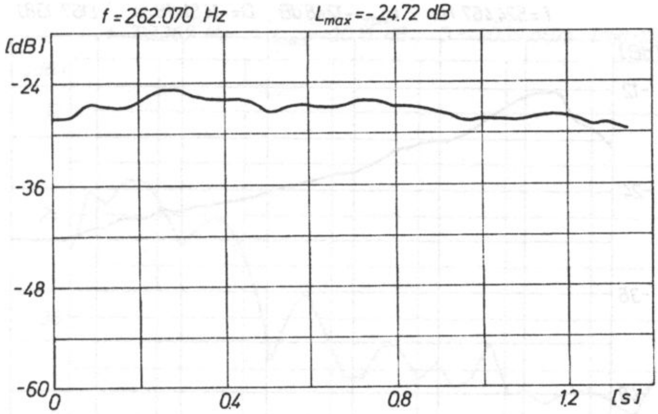


FIG. 14. Sound level in function of time analyzed for the partial No. 11 (same sound as in Fig. 6).

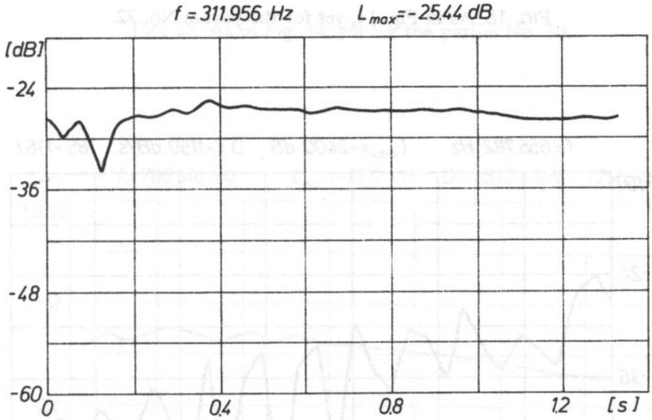


FIG. 15. As in Fig. 14, yet for the partial No. 13.

time-window positions every 100 ms apart. The time-window length value in those analyses was 42.5 ms.

The noticeable spectral differences may be properly interpreted with help of the time domain analysis results computed for the eight selected partials, see Figs. 14 to 21. Hence it appears that e.g. the Minor Third (No. 28) component instability, see Fig. 17, is caused by warble beats at a frequency of about 8 Hz, produced between two close situated vibration modes of the bell. A similar instability shows the Eleventh (No. 30), see Fig. 18, although considerably out of tune. It is worth noticing that those two warbling partials are both decaying faster than the majority of other more stable component, e.g. the Prime (Fig. 14), the Third (Fig. 15), the Twelfth (Fig. 19), and the Double Octave (Fig. 20). Decay rates

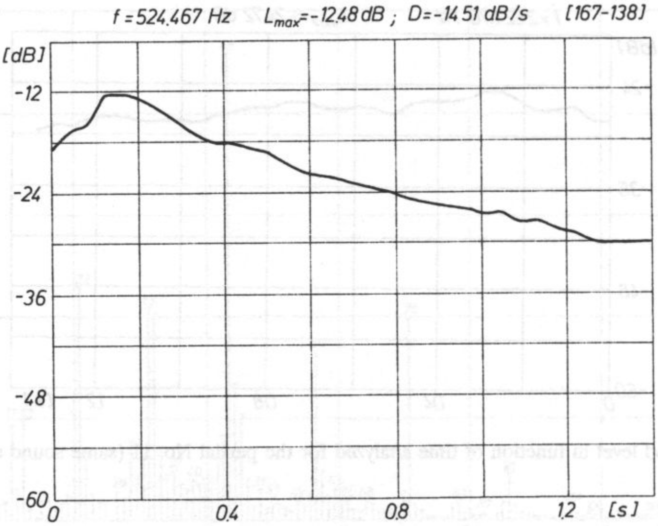


FIG. 16. As in Fig. 14, yet for the partial No. 22.

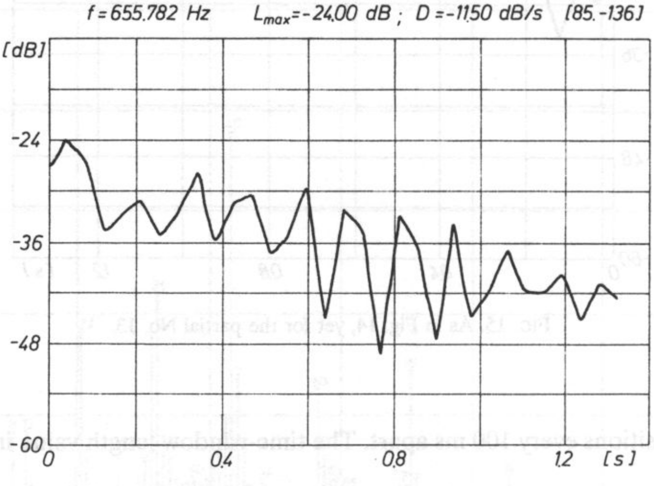


FIG. 17. As in Fig. 14, yet for the partial No. 28.

$D$ [dB/s], averaged within the observed time interval, computed for every analyzed partial, are quoted above diagrams rim.

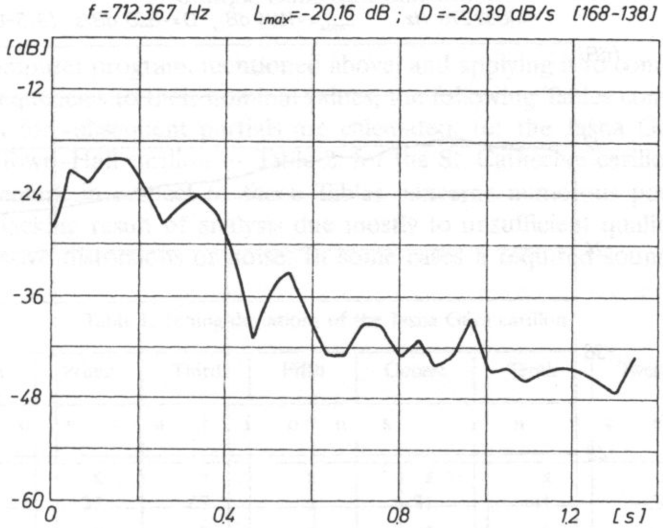


FIG. 18. As in Fig. 14, yet for the partial No. 30.

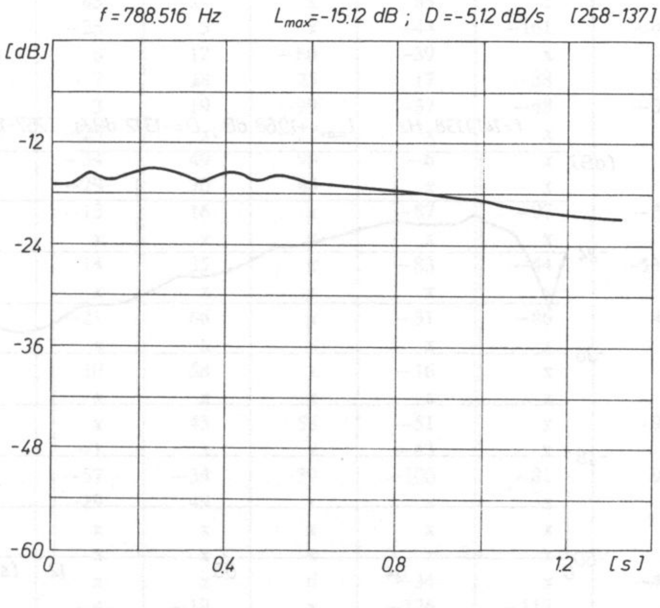


FIG. 19. As in Fig. 14, yet for the partial No. 33.

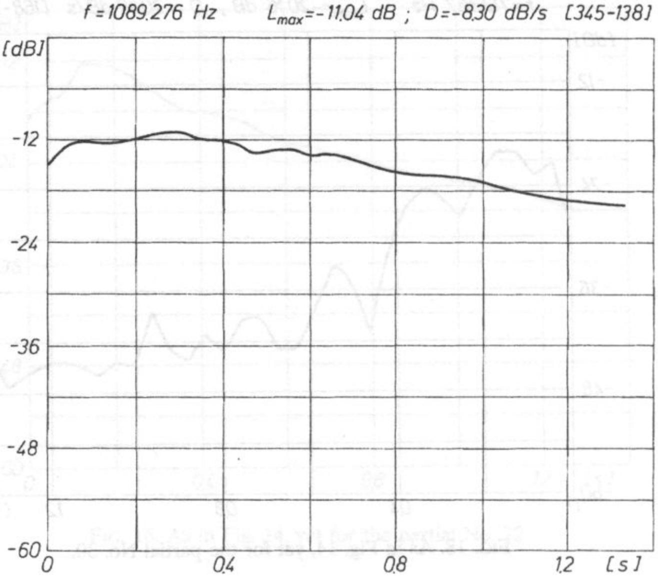


FIG. 20. As in Fig. 14, yet for the partial No. 46.

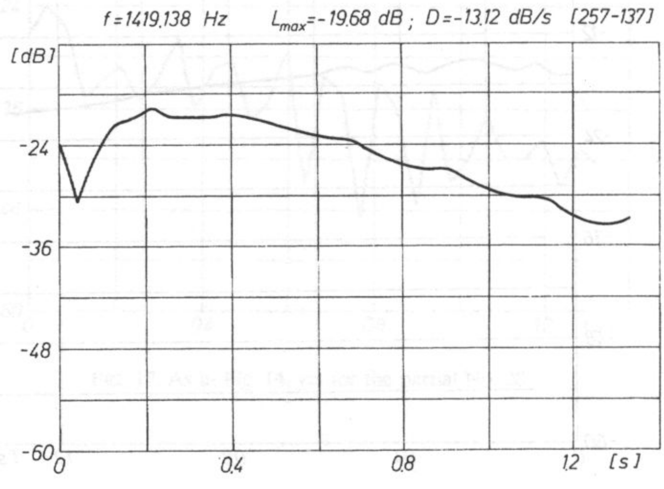


FIG. 21. As in Fig. 14, yet for the partial No. 60.

## 5. Comparisons and discussion

Using the computer program, mentioned above, and applying it to comparisons of analyzed partial frequencies to their nominal values, the following Tables containing relative tuning deviation for subsequent partials are calculated: for the Jasna Góra carillon — Table 1 for the Town–Hall carillon — Table 2, for the St. Catherine carillon — Table 3.

A general remark in respect to those Tables concerns numerous positions marked "x". It denotes lacking result of analysis due mostly to unsufficient quality of recording made with excessive distorsions or noise. In some cases a required sound could not be

**Table 1.** Tuning deviations of the Jasna Góra carillon

| Partials: | Hum tone | Prime | Third | Fifth | Octave | Tenth | Twelfth | Upper Octave |
|---|---|---|---|---|---|---|---|---|
| | Deviations in cents | | | | | | | |
| Bell: | | | | | | | | |
| $C_4$ | x | x | x | x | x | x | x | x |
| $C\#_4$ | x | 37 | 67 | x | −31 | 41 | −56 | −1 |
| $D_4$ | x | x | x | x | x | x | x | x |
| $D\#_4$ | 87 | x | 6 | x | −18 | 24 | 144 | 46 |
| $E_4$ | 76 | 84 | 64 | x | −34 | 5 | 35 | −24 |
| $F_4$ | 81 | x | 2 | −26 | −18 | −10 | −27 | 27 |
| $F\#_4$ | 58 | −25 | 14 | −66 | −61 | −8 | 34 | −22 |
| $G_4$ | x | x | x | x | x | x | x | x |
| $G\#_4$ | 1 | 48 | −24 | x | 85 | x | x | x |
| $A_4$ | 30 | −25 | 5 | x | −44 | −161 | −48 | x |
| $A\#_4$ | 23 | 6 | 12 | −80 | −39 | x | x | x |
| $B_4$ | 102 | −7 | 48 | 25 | 17 | −38 | 32 | x |
| $C_5$ | 6 | 3 | 19 | −99 | −37 | −48 | −33 | 31 |
| $C\#_5$ | 7 | −23 | x | −21 | x | x | x | x |
| $D_5$ | x | −34 | 49 | 99 | −6 | x | x | x |
| $D\#_5$ | 89 | −29 | 70 | 43 | x | x | x | x |
| $E_5$ | 90 | −13 | 16 | x | −87 | −97 | −33 | x |
| $F_5$ | x | x | x | x | x | x | x | x |
| $F\#_5$ | 1 | 14 | 35 | x | −83 | −44 | −116 | x |
| $G_5$ | x | x | x | x | x | x | x | x |
| $G\#_5$ | 31 | −21 | 66 | x | −31 | −86 | 40 | −44 |
| $A_5$ | x | x | x | x | x | x | x | x |
| $A\#_5$ | 45 | 10 | 58 | x | −16 | x | x | x |
| $B_5$ | x | x | x | x | x | x | x | x |
| $C_6$ | 30 | x | 43 | 58 | −51 | x | −90 | 45 |
| $C\#_6$ | x | −1 | x | x | −43 | x | x | x |
| $D_6$ | 33 | −57 | −34 | −39 | −100 | −81 | 94 | 42 |
| $D\#_6$ | 38 | −29 | 49 | x | x | x | x | x |
| $E_6$ | x | x | x | x | x | x | x | x |
| $F_6$ | x | x | x | x | x | x | x | x |
| $F\#_6$ | 32 | x | x | 6 | −34 | x | −44 | x |
| $G_6$ | x | −4 | −19 | x | −126 | −118 | x | x |
| $G\#_6$ | x | x | x | x | x | x | x | x |
| $A_6$ | −66 | 9 | −15 | x | −67 | x | x | x |
| $A\#_6$ | 15 | 65 | −22 | x | −126 | x | x | x |
| $B_6$ | −6 | −55 | 51 | x | 17 | x | x | x |

recorded due e.g. to a damaged hammer etc., so a few bells were passed over. However, the number of positively made analyses seems being sufficient to discuss the tuning quality of the investigated carillons.

It may be noticed, by inspection of the figures and comparisons among the Tables, that the new St. Catherine carillon is the best tuned. Deviations with negative values denote frequencies lower than nominal values.

The listed deviations are mostly within the limits calculated theoretically by SCHAD [18] and those found empirically by other investigators [6], [19]. Only values at a few positions in the Table 3 require verification, namely concerning the bells $D_4$, $F\#_4$, and $B_5$. A human error can not be excluded as the process of time interval selection for the analysis depends, as mentioned above, on operator's skill. At any rate, the most important five partials which decide upon strike note and upon tonal sound sensation are tuned so well that their deviation are unnoticeable for the listener. Next four partials are more deviated, e.g. for double octave deviations are more than half of semi tone, however, levels of those partials is mostly very low, so if theoretically audible they do not influence the sound quality. Besides, there are no available data from the literature, giving opportunity to compare respective deviations to those at other carillons of quality.

**Table 2.** Tuning deviations of the Town-Hall carillon

| Partials: / Bell: | Hum tone | Prime | Third | Fifth | Octave | Tenth | Twelfth | Upper Octave |
|---|---|---|---|---|---|---|---|---|
| | Deviations in cents | | | | | | | |
| A#$_4$ | 14 | −3 | 47 | −107 | 26 | −74 | 20 | −15 |
| B $_4$ | 0 | 1 | 22 | −98 | −10 | −63 | −25 | 19 |
| C $_5$ | −83 | 18 | 17 | −58 | −15 | −93 | −22 | 26 |
| C#$_5$ | −15 | −41 | 3 | −131 | −28 | 0 | −32 | 11 |
| D $_5$ | −40 | 18 | 17 | −48 | −23 | −65 | −36 | 7 |
| D#$_5$ | −51 | 4 | 22 | 17 | −4 | 21 | 2 | 45 |
| E $_5$ | −34 | −11 | 7 | −125 | −23 | 35 | −33 | 7 |
| F $_5$ | x | x | x | x | x | x | x | x |
| F#$_5$ | −43 | 80 | 5 | x | −19 | −12 | −17 | 19 |
| G $_5$ | −7 | −15 | 0 | −88 | −37 | −62 | −54 | −16 |
| G#$_5$ | −55 | 33 | −25 | −115 | −55 | −69 | −85 | −22 |
| A $_5$ | −18 | −7 | 4 | x | −26 | 27 | −36 | 7 |
| A#$_5$ | −54 | 32 | 41 | x | 7 | 22 | −12 | 30 |
| B $_5$ | −56 | 9 | 6 | x | −29 | −62 | −39 | 6 |
| C $_6$ | −36 | −22 | −91 | −44 | 49 | −21 | 35 | 89 |
| D#$_6$ | −18 | 12 | −54 | −16 | 24 | x | x | x |
| G $_6$ | −83 | 15 | 29 | −6 | −36 | x | −69 | x |

The Table 2 shows the most values of deviation negative, in particular for Upper Ocatve partials in nine bells, their average value is — 27,2 cents. It shows clearly that those bells were tuned to diapason $A_4$ = 435 Hz, which is 19.8 cents below the actual diapason of 440 Hz. Higher values of deviation found for that carillon are easy to explain, because of the aforesaid war damages to bells, and because of their provenience from different instruments. Those deviations are audible as distinct mistuning when listening to a played melody.

**Table 3. Tuning deviations of the St. Catherine carillon**

| Partials: | Hum tone | Prime | Third | Fifth | Octave | Tenth | Twelfth | Upper Octave |
|---|---|---|---|---|---|---|---|---|
| | Deviations in cents | | | | | | | |
| Bell: | | | | | | | | |
| $C_4$ | 7 | 1 | 3 | −2 | 1 | −10 | 9 | 68 |
| $C\#_4$ | −2 | 2 | 4 | 23 | 4 | −21 | 11 | 73 |
| $D_4$ | 14 | 0 | 3 | 50 | 3 | 21 | 12 | 75 |
| $D\#_4$ | x | 6 | x | 29 | 4 | −28 | 9 | 75 |
| $E_4$ | 1 | 5 | 5 | 4 | −9 | −19 | 16 | 80 |
| $F_4$ | x | 5 | 0 | 7 | 8 | −60 | 16 | 82 |
| $F\#_4$ | 9 | 1 | 4 | −42 | 3 | 6 | 10 | 73 |
| $G_4$ | −1 | 3 | 5 | −63 | 3 | −41 | 18 | 86 |
| $G\#_4$ | −3 | −1 | 4 | 17 | 3 | 43 | 14 | 72 |
| $A_4$ | x | x | 4 | 26 | 3 | 43 | 14 | 78 |
| $A\#_4$ | 5 | x | 6 | 17 | 5 | 49 | 18 | 86 |
| $B_4$ | x | 7 | 4 | 12 | 3 | x | 18 | 86 |
| $C_5$ | 4 | 3 | 5 | 13 | 4 | 47 | 12 | 55 |
| $C\#_5$ | 3 | 3 | 3 | 19 | 4 | 62 | 9 | 67 |
| $D_5$ | 3 | x | 4 | x | 4 | 62 | 14 | 77 |
| $D\#_5$ | 2 | 4 | 2 | 5 | 5 | −31 | 13 | 75 |
| $E_5$ | 5 | 4 | 5 | −2 | 6 | −58 | 13 | 74 |
| $F_5$ | x | 3 | 5 | 13 | 4 | −14 | 10 | 70 |
| $F\#_5$ | x | 4 | 4 | x | 3 | −26 | 7 | 64 |
| $G_5$ | 4 | 7 | 6 | 0 | 6 | x | 11 | 67 |
| $G\#_5$ | x | 3 | 3 | 4 | 5 | −27 | 14 | 77 |
| $A_5$ | 2 | 4 | 5 | 16 | 5 | −36 | 12 | 72 |
| $A\#_5$ | x | 4 | 6 | x | 6 | −29 | 13 | 82 |
| $B_5$ | x | x | x | x | x | x | x | x |
| $C_6$ | 2 | 3 | 3 | x | 4 | x | −1 | 11 |
| $C\#_6$ | 3 | 4 | 9 | 27 | 5 | 15 | 1 | 52 |
| $D_6$ | 4 | 3 | 4 | x | 6 | 27 | 2 | 79 |
| $D\#_6$ | 3 | 4 | 4 | x | 6 | −35 | −6 | 40 |
| $E_6$ | 3 | 6 | 5 | x | 6 | 42 | −3 | x |
| $F_6$ | 3 | 4 | 6 | x | 4 | −10 | −10 | 32 |
| $F\#_6$ | 3 | 4 | −7 | x | 2 | −66 | −26 | x |
| $G_6$ | 5 | 4 | 6 | x | 6 | x | −14 | 21 |
| $G\#_6$ | 6 | 3 | 11 | x | 4 | 44 | −23 | 3 |
| $A_6$ | 5 | 5 | 6 | x | −4 | x | −22 | 3 |
| $A\#_6$ | 5 | 6 | 8 | x | 4 | x | x | x |
| $B_6$ | 5 | 4 | 15 | x | 4 | 6 | −36 | 76 |
| $C_7$ | 3 | 2 | 14 | x | 5 | x | x | x |

The large deviations found for Jasna Góra carillon require further investigation. A possible explanation lays in the fact that due to then damaged mechanical system of excitation the bells were excited with their hammers raised by hand, so hammer travels might have been inadequate to excite properly bell partials, and were at any rate unequal. Most of measured deviations being negative, they show that the carillon was also tuned to the old diapason value, what is evident considering the year of its founding.

It may be added, that recordings at Jasna Góra were made only once, while those at Town–Hall and St. Catherine were repeated, after earlier investigations [8], [17], so an eventual error probability is far less for those last carillons.

Beside of the examples shown in presented Figures and Tables the elaborated software permits to compute, show, and print several other kinds of characteristics e.g. quasi-threedimensional evolutive spectra, time characteristics for selected partial, their decay time, etc. It may be added that the employed method is developed from a similar one employed earlier at Gdańsk Sound Engineering Department for investigation of organ sounds.

Following the results obtained further investigations are planned. Among others a psychophysiological study of listeners' preference between carillons with the Minor- versus Major-Third bells [13]. Such evaluation made recently by HOUTSMA and THOLEN [7] should be followed by many others executed in various conditions, before any initiative to build a whole "Major Third" carillon could be undertaken.

## 6. Conclusions

The abridged report on carillon investigations, presented here, is rather a preliminary attempt to gain a full information concerning those unique musical instruments in Poland. A dedicated software for IBM AT computer was elaborated and a complete method of investigation implemented, using also NeXT computers. It permits for easy and quick repeating and verifying measurements. Thus, comparison to other carillons in the World, well known and precisely investigated and described in the literature, will be possible. Besides, it may be expected that thanks to the discussion on methods of computerized bell sounds analysis among interested acousticians and sound engineers, a degree of standarization of such methods will be achieved, which will facilitate an exchange of information and accelerate fruitful comparisons.

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