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The Dynamic and Timbre of Restored Janáček's Grand Piano

How They May Have Influenced his Compositions?

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Abstract
What are the acoustic properties of the grand piano on which Leoš Janáček wrote most of his compositions? The paper describes the analysis of *2* instruments: renovated Janáček's Ehrbar and the Bösendorfer 185 VC. The double decay time was measured only at the Ehrbar, dynamic ranges and spectra of both instruments were measured and compared with each other. For the analysis, individual tones but also excerpts from the cycle *On an Overgrown Path* played by the pianist were selected. For accuracy, the room reverberations, where grand pianos were recorded, were also measured.

Key words
acoustic roughness, analysis, Bösendorfer, double decay time, dynamic levels of attacks, dynamic range, Ehrbar, grand piano, inharmonicity, Leoš Janáček, mechanical properties of grand piano, *On an Overgrown Path*, partials, spectrum, spectral centroid, Václav Syrový, timbre, zones in spectrum

The Motivation of the Analysis

There are two reasons for analysing the restored grand piano which Janáček had in his study. The first is to collect acoustic data for a deeper dive into the compositional process of this exceptional musician. Leoš Janáček can be put into categories such as expressionism, folklorism, impressionism, etc. He was a musically synthetic personality, naturally combining musical styles. As the composer he was known for capturing and writing down ideas from his hearing and imagination, without help or influence from any harmonic or melodic instruments. He wrote down human utterances and the sounds around him. He was able to use these sources as material for his compositions and decide, from memory and by imagination, which musical instrument they would be played on. And he was often stubborn about his unique instrumentation, which, in the context of the late 19th and early 20th centuries, was very innovative and unusual. So why analyse the parameters of his piano when it did not play a major role in his composing process?

The sources, on the contrary, show that he played his chamber, operatic, and orchestral compositions at the piano in his study. "*I also received a new piano, an Ehrbar, which Leoš chose himself. Later he wrote many of his compositions on it.*"[1] "*While Olga was still young, her room was the family bedroom and Ehrbar piano stood in dining-room. Janáček composed at it during the day; at night he worked in the bedroom...*"[2] "*Janáček was used to composing at the piano, not by playing long passages but chords and various harmonies which he would constantly repeat.*"[3] "*Leoš Janáček was faithful to the piano all his life, he did not buy another one, this instrument accompanied him from the age of 27 until the end of his life. He played it and composed most of his compositions on it...We can assume that the specifics of the sound of this Viennese grand piano also influenced the composer's work. The piano has a unique tone timbre, a long decay in the pianissimos and even a harsh sound in the forte.*"[4]

The real sound of this piano probably influenced some of Janáček's decisions and at the same time, it may have inspired him. This piano may have been an important tool when Janáček decided in which position to place melodies, chords, figures, characteristic thickening figures ("*sčasovky*"), whether to leave the musical structure in so-called open or close harmony, how to use the pedal, etc. It could have been especially important when he was writing the piano cycle *On an Overgrown Path*. For this reason, excerpts from this piano cycle were selected for our analysis. Therefore, we wanted to record this instrument and to perform a basic acoustic analysis, even though its sound may have been altered to some extent, so that this "hard" data could be used for further acoustic and psychoacoustic research.

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1 JANÁČKOVÁ, Zdenka. *My life with Janáček,* London: Faber and Faber, 2003, p. 19.

2 TYRRELL, John. *Janáček: Years of a life. Volume I, (1854-1914.) The lonely blackbird*. London: Faber and Faber, 2006, p. 408.

3 ZAHRÁDKA, Jiří. *Guided video-tour of Leoš Janáček memorial in Brno,* time 3:30-3:55 [online]. Dostupné z: https://www.youtube.com/watch?v=n7riq9eLMb8&t=229sthe [cit. 2024-06-15].

4 SELUCKÁ Alena – ŠINDLÁŘOVÁ, Simona. Klavír Leoše Janáčka – průzkum prostředí a restaurování. *Fórum pro konzervátory a restaurátory*, 2020, Vol. X, No. 1, p. 25.

This was not our only motivation. The second reason was for us to be able to make a timbral comparison of grand pianos from the 19^{th} and early 20^{th} centuries to pianos constructed in the 21^{st} century. Modern pianos can offer wider tone, a larger dynamic range, and a scale of *88* keys without obvious timbral breaks between registers. However, such smooth and unified parameters can lead to a universally uniform piano sound without uniqueness or the distinctive poetics of older, "imperfect" pianos. We would therefore like to find an answer to this question: How much has the original timbre changed compared to the newer and more perfect grand pianos?

Our analyse was focused on 3 parameters: total dynamic range (from ff to pp), on dynamic envelopes over the course of time (i.e. the relative dynamic range at the peaks of attacks[5]), and on the quality of the spectra[6]. The tones in our analyse were generated by hand, i.e. by classical pianistic technique. For the measurement of grand pianos, a play-bench[7] with mechanical fingers is normally used. This is, for example, how we measured Petrof grand pianos in an anechoic room in Hradec Králové. But it was not possible to transport and install this kind of the bench in Janáček's study inside the museum. Nevertheless, the co-author of this article, Ondřej Jirásek, tried his best to follow Janáček's dynamics, i.e. to play a given note as pp, mf, f, ff as strictly as possible. Eventually he played tones several times and calculated the average value.

Mechanical Properties of the Friedrich Ehrbar op. 7911 and the Bösendorfer 185 VC

Unlike modern instruments with their *88* keys, the grand piano Ehrbar has only *85* keys, with a range from A^0 to A^7. It contains two bridges: the first, short bridge holds the strings from A^0 to D^2, and the second, longer one holds the strings from Es^2 to A^7. The length of the 1^{st} string A^0 from the front duplex bridge to the beginning of the short bridge is *179* cm, the length of the last string D^2 kept by short bridge is *134* cm. The length of the 1st string Dis^2 kept by the long bridge is *158.5* cm, the length of the last string A^7 is only *2.5* cm. This creates a difference between the tension of the strings, which can manifest itself in a different timbre. The biggest break in the length and thus the tension of the strings was found between both bridges, keys D^2 and Dis^2. Both duplex bridges are in the shape of an exponential curve (Fig. 1). The Ehrbar was tuned about *36* cents lower than the Bösendorfer.

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5 LEVITIN, Daniel J. – NUZZO, Regina – VINES, Bradley W. Quantifying and analysing musical dynamics: Differential Calculus, Physics, and Functional Data Analysis Techniques. *Music Perception: An Interdisciplinary Journal*, 23, 2, pp. 137–152.

6 MCADAMS, Stephen – GIORGANO, Bruno L. The Psychology of Music. In *The Psychology of Music*, Diana Deutsch, 2008, p. 49.

7 URBÁNKOVÁ, Jana. Objective evaluation of upright and grand pianos by measuring play-bench. *ACC Journal*, 2018, Vol. 24, Issue 1, Dostupné z: https://dspace.tul.cz/server/api/core/bitstreams/5ec69180-11fc-4ef7-892d-604180ddf362/content [cit. 2024-06-15].

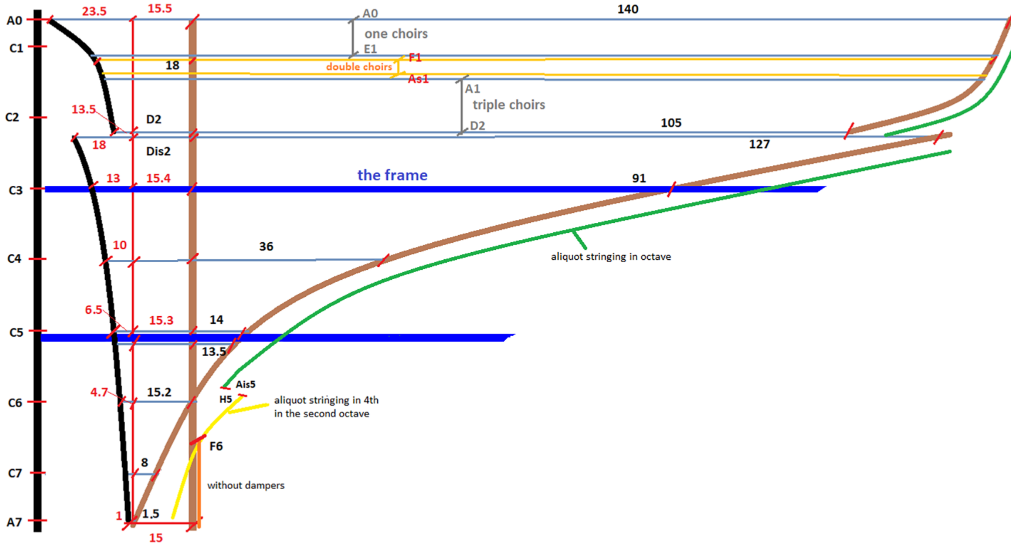

Fig. 1 The Ehrbar: string arrangement (cm).

We have also discovered differences between choirs of strings. The Ehrbar contains only *8* one-string notes (una corda), from A^0 to E^1. Even the choir of double-strung notes is minimal, on only *4* keys – F^1 to Gis^1. The rest are already provided with three strings. This disposition affects the registers of the instrument. An important feature of this piano is a long aliquot stringing. Unlike modern instruments, it boosts the fundamental note an octave higher (not a 2^{nd} octave or any other consonant interval over multiple octaves). During our measurement, the grand piano was in a condition where the aliquot stringing of the basses was muted by a woven fabric, whereas the stringing of the descants was exposed and functional.

The location where the hammer hits the string has a major influence on breaks in the spectrum, and on this instrument, this is mainly manifested in the bass. We therefore calculated the ratio (multiple) for where the hammers are directed within individual octaves. The Ehrbar hammers strike in subbasses into points between *1/7* and *1/8*. As we will see in following chapters, these results in some partials are missing in the spectrum (Tab. 1)

the string	length total (cm)	length to hammers (cm)	strike in multiply
A0	*179*	*23.5*	*7.6*
D2	*134*	*13.5*	*9.9*
Dis2	*158.5*	*18*	*8.8*
C3	*119.5*	*13*	*9.2*
C4	*61.5*	*10*	*6.2*
C5	*36*	*6.5*	*5.5*
A7	*2.5*	*1*	*2.5*

Tab. 1 The Ehrbar: hammer strike locations.

We chose Bösendorfer 185 VC for the comparison with the Ehrbar, because it belongs to a similar category: “*can be a wonderful practice instrument for the home, but equally a great concert instrument for a small hall*”.[8] Dimensions are L *185* cm, W *151* cm, H *120* cm. The producer emphasizes its special qualities: “*the integrated spruce components become acoustically active, forming a complete resonating body that allows the whole instrument, a steel core string is the basis for one or two layers of copper.*

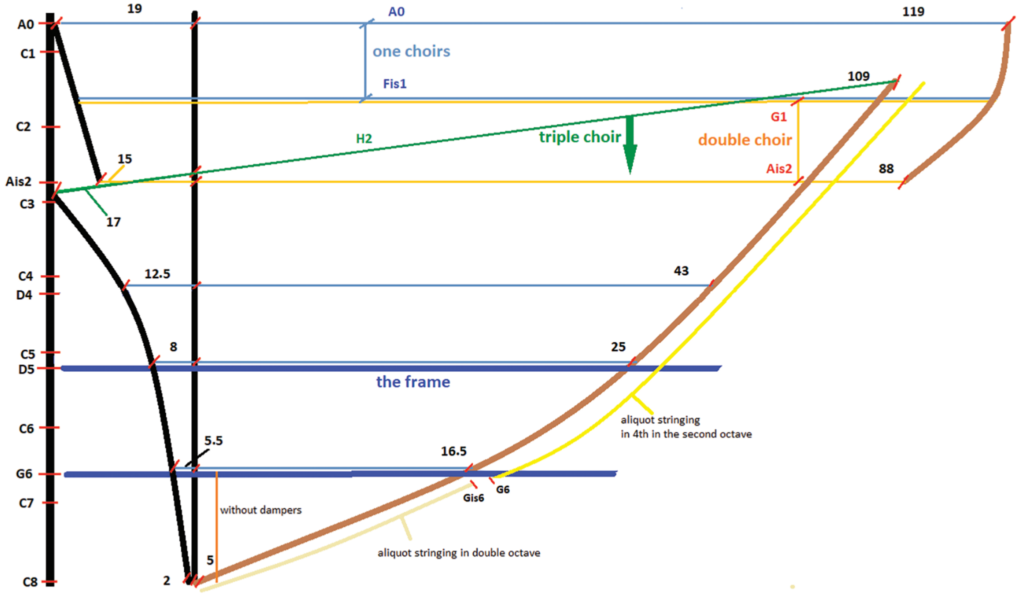

Fig. 2 The Bösendorfer: string arrangement (cm).

The carefully spun strings are a substantial element of the warm and sonorous Bösendorfer bass.”[9] It contains the traditional 2 bridges inside, with a full range of *88* keys divided:

the string	length total (*cm*)	length to hammers (*cm*)	strike in multiply
A0	*138*	*19*	*7.3*
AIS2	*103*	*15*	*6.,9*
H2	*126*	*17*	*7.4*
D4	*55.5*	*12.5*	*4.4*
D5	*33*	*8*	*4.1*
G6	*22*	*5.5*	*4*
C8	*7*	*2*	*3.5*

Tab. 2 The Bösendorfer: hammer strike locations.

8 Bösendorfer, *Bösendorfer Grands and Uprights, Grand Piano 185VC* [online]. Dostupné z: https://www.boesendorfer.com/en/pianos/pianos/grandpiano-185VC [cit. 2024-06-15].

9 Ibid.

A^0–Fis^1 single strings, G^1–Ais^2 double strings, H^2–C^8 triple strings; the aliquot stringing from H^2 to C^8 is tuned in 4^{th} over multiply octaves (Fig. 2).

As we see in the table, in the bass the hammers of a Bösendorfer are directed to nearly *1/7,* not to *1/8*. This influences various breaks in the spectrum (Fig. 3).

The Reverberation of Rooms

The reverberation time is defined as a *60* dB decline in the level of sound energy from the silencing of the excitation source. In order to reduce the required signal-to-noise ratio, a decline time of *20* dB or *30* dB is measured, and the measured time is then multiplied by *2* or *3* to obtain a *60* dB decline.

Reverberation time measurements were made in third-octave bands from *50* Hz to *10* kHz. Measurements were made at a total of *8* different microphone/speaker positions, averaging four individual measurements at each position. RT60 was measured using the integrated impulse response method employing an omnidirectional loudspeaker combined with a subwoofer for frequencies below *150* Hz and an omnidirectional microphone.

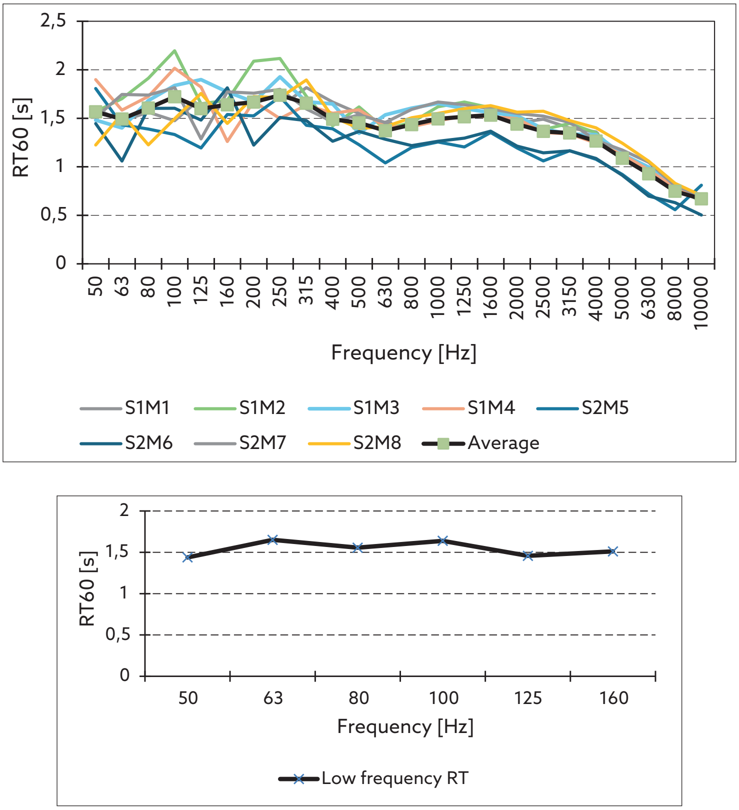

Fig. 3 The room reverberation RT60 of Janáček´s study.

The room containing Leoš Janáček's piano measures *12.25* m × *5.45* m × *3.35* m and is divided into two parts. In the front part there is a piano, around which an exposition is created in the form of period furniture and decoration. The other half of the room, on the other hand, lacks any furnishing and is merely bare. This can be clearly seen in the RT60 values measured for S2M5 and S2M6, where both the source and receiver were located in the piano section. Since a *20* dB drop is measured, the longer reverberation from the part of the room without equipment has not yet had time to assert itself and the measured values are thus approximately *0.3* s lower than for the other measurements.

The room that contains the Bösendorfer piano serves as a classroom and has small RT60 variations between positions. The frequency dependence of the RT60 is slightly unbalanced, with an increase at high and low frequencies.

Below *160* Hz, the modal characters of rooms become apparent, resulting in differences among measurements at low frequencies. For this reason, a separate measurement was made at low frequencies, with the microphone placed in the same position as when the piano was measured with the bass loudspeaker placed under the piano to mimic the radiation from the piano.

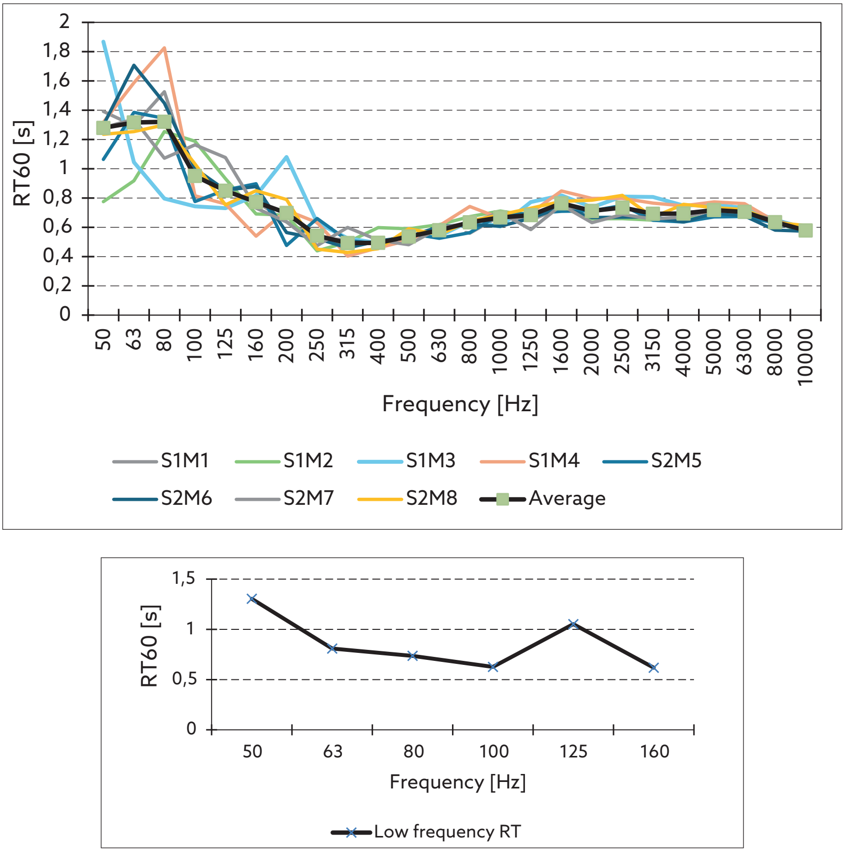

Fig. 4 The room reverberation RT60 of the lecture hall 205 at Janáček Academy.

The Analysis of Dynamic

The recording of the Ehrbar for measuring DDT45 (with double decay time representing the time it takes for the sound energy of an instrument to decrease by *45* dB) was made on 20.05.2024 from 16:00-19:00. To eliminate as much as possible the room reverberation, the microphone was placed at a distance of *30* cm from the bass strings, and the same from middle and treble strings. An AUDIX TM1 with omni-direction sensitivity was used. The recording set also contained an audio converter Presonus STUDIO 26c, and samples were recorded to DAW Studio one at a sample rate of *48* kHz and a bit-rate of *32* bits per sample. The microphone was calibrated at level *94* dB SPL.

The DDT 45 dB was chosen, because the grand piano is unable to generate a higher dynamic range. From the curve DDT45, a curve DDT60 was calculated. All 85 samples (the full chromatic keyboard) were recorded at dynamic f, cut to single tones. Every sample was normalized at level *0* dB, its stronger peak was identified by MATLAB, and this was marked. Next, a threshold of *-45* dB was set in the program and the drop point was found using an RMS calculation. A tolerance of *300* ms was set, but even so it was necessary to check each tone to make sure it did not "breathe" in acoustic beats or increase in volume again after *300* ms. Where this had occurred, the location of the dip was manually corrected. The section from the loudest peak to the threshold was marked and written in ms.

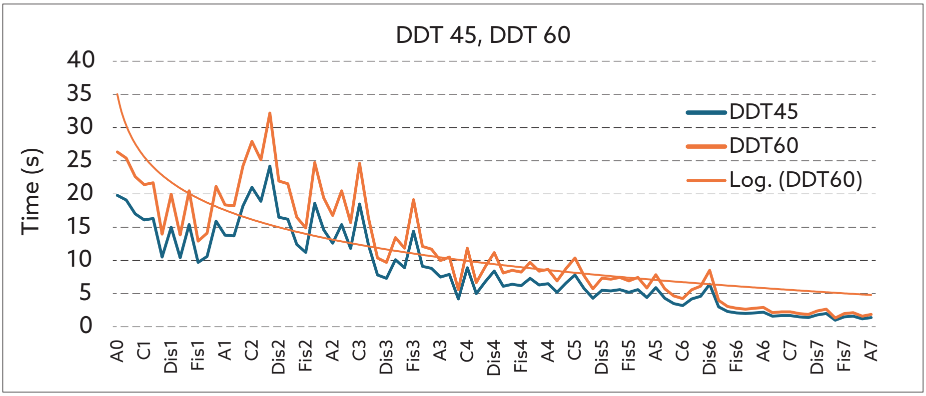

Fig. 5 The Ehrbar: DDT45, DDT60.

DDT 45 gradually decreases in the register A^0-D^1 (approx. the area of the single-string choir), remains shorter and stagnates in the register Dis^1-A^1 (double choir), and gradually rises starting from the tone H^1 (triple choir). This corresponds to the stringing. In the triple choir, double decay behaves similarly to other grand piano brands and gradually shortens. Even so, in comparison with more modern pianos, it perseveres in the treble octaves for quite a long time (somewhere between 1 and 2 s versus 0.5 s on modern grand pianos). This could be due to the short distance of the microphone from the strings or due to aliquot stringing in some octaves supporting a longer decay of the descants.

Note: Modes of the room with peaks on 80-120 Hz (E^2-H^2) and 200-270 Hz (G^3-C^4) are not reflected in the double decay, the curves here have the opposite dip. It will probably be due to the close microphone and the piano lid shading the larger room without furniture (absorption).

Two measurements for the relative dynamic levels and range between attacks were made. The recording of the Ehrbar was made on 18.03.2024 from 09:00-11:30 in the Leoš Janáček Museum, while the Bösendorfer was recorded on 18.05.2024 from 09.00-12:00 in the lecture hall no. 205 at the Faculty of Music of the Janáček Academy of Performing Arts. Again, to eliminate room reverberation but to obtain balanced energy from all strings, the microphone was placed *1*m from the centre of the instrument and *40* cm over the upper edge of the rim. An AKG C 480 with omni-capsule CK 92 was used. The set also contained an audio converter Presonus STUDIO 26c. Samples were recorded again to DAW Studio at a sample rate of *48* kHz and a bit-rate of *32* bits per sample. As this was only a relative dynamic range, the microphone was not calibrated. Four representative tones were recorded from every octave, at a symmetrical interval distance of a minor 3rd, i.e. the diminished chord C Dis Fis A. In order to obtain complex information about the dynamic range, we decided to analyze levels pp, mf, f and ff. We did not measure the total range of the dynamic envelope between the loudest peak in attack and the quietest level in the 2nd decay, but we focused on a dynamic range between the loudest peaks of attacks in pp, mf, f and ff. The recorded events were cut into samples, and for every sample the loudest peak was identified by MATLAB and entered into the table. Dynamic curves were calculated from the data thus obtained.

We see (Fig. 6) that the curves pp, mf, f, ff of Ehrbar are rather broken, the instrument is not very dynamically consistent and is characterized by a strong common dynamic increase around the note C^6. The largest dynamic space was found between the pp and mf levels.

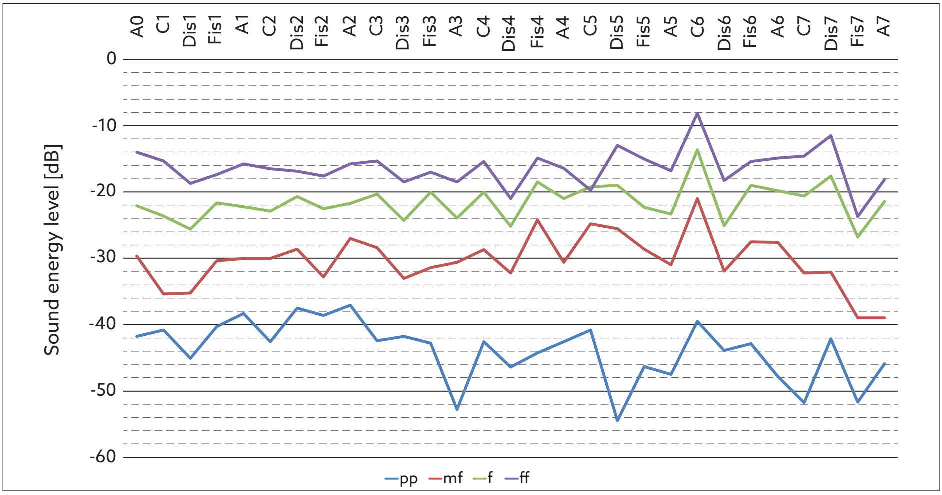

Fig. 6 The Ehrbar: levels of attacks in pp, mf, f, ff.

Note: Here too, there were no increases in the curve identical to the room modes.

The identical curves of the Bösendorfer are slightly more balanced. Nevertheless, this instrument is also characterized by dynamic increase, here around C^5. The largest dynamic space available to pianists is between mf and f. The dynamic range of Bösendorfer between f and ff is, on the contrary, very flat (Fig. 7).

Note: Only one peak that coincides on the curves of RT60 and dynamic levels of attacks is located around the tone B^2 (*125* Hz).

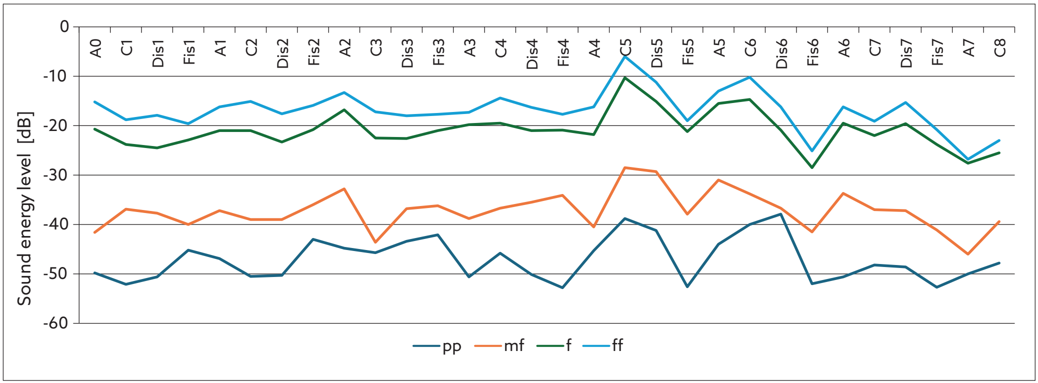

Fig. 7 The Bösendorfer: levels of attacks in pp, mf, f, ff.

The comparison of both pianos in relative total dynamic range was calculated. If we subtract the values of the pp curve from the values of the ff curve,

$$D_{total} = D_{ff} - D_{pp} \quad (1)$$

we will obtain full dynamic ranges among attacks (Fig. 8).

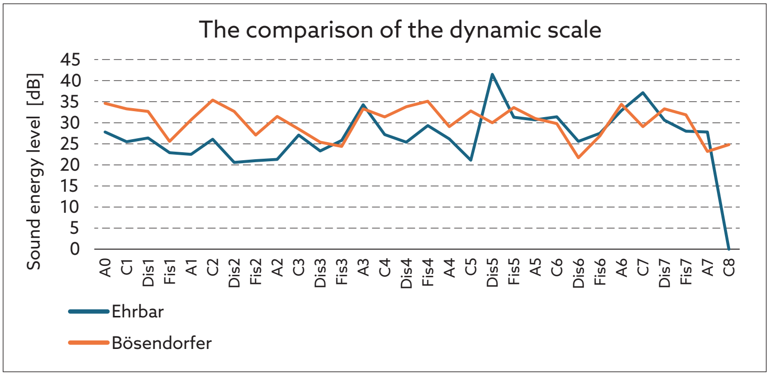

Fig. 8 Both pianos: total dynamic range among attacks.

The curves show that Bösendorfer features a much wider range in the basses and middles, while the Ehrbar is little bit wider in the descants (the beginnings of octaves 6, 7).

Note: To what extent could the restoration have changed the original properties of the instrument? The restorer Gert Hecher states that „all components were replaced with the original ones, so the piano returned to the form in which Janáček had received it.“[10] It can therefore be assumed that the measured quantities (the double decay time and the dynamic ranges) are relatively close to the original.

The Timbre

The samples recorded for measuring dynamic levels and dynamic ranges, i.e. 4 tones from each octave, were also employed to calculate the timbre. For this purpose, they were played as quavers. Of the four sound parameters: timing, dynamic, pitching and timbre, timbre is the most complicated to measure and classify. For our analysis of spectra we use the system of Václav Syrový, the Czech acoustician and experienced organist, expert in dealing with instrument registers and timbre. He divided the harmonic spectrum containing only partials (not inharmonic aliquots or noise) into 4 zones.[11] The classification is based on the logic of the harmonic structure, but also on the psychoacoustic human abilities to perceive the timbre. The 1st zone begins on the 1st partial and ends on the 8th partial. Syrový's term for this is the "interval zone". Because the human ear is still able to recognize single intervals within it (although there can be problems with 7th partials and in the dissonant ratio of the major 2nd to the 8th partial, as well as with the Helmholtz in the minor 3rd to the 6th partial[12]). Every partial in the 1st zone has an exceptional function: the even ones strengthen timbre power; odd ones create timbre. The 1st zone is relatively gentle and since it contains all partials, it has a homogenous timbre.

The 2nd zone from 9th to16th partial is perceived by the human ear as a diatonic cluster, for this reason it is called as diatonic. We hear it as a blend, we are not able to recognize single intervals inside timbre, but we perceive the quality of the covered-up chord (for ex 7sus4 chord). This zone makes the final timbre much wider and sharper and rough. Here the important role is played by so called formants. The 3rd zone, from 17th to 32nd partial, is built up by micro intervals which brings an element of ringing or buzzing to human ears. The 4th zone, from 33rd to 64th partial, contains such narrow micro intervals, although they are in harmonic proportions, that we perceive them as a various kind of noise (pink, brown, blue, purpure). The 3rd and 4th zones tend to be present mainly in brass instruments, partly in strings and in the case of pianos rather exceptionally (and then only in the bass). The grand pianos with this wider timbre are very aggressive in sound and harmonies in 0th, 1st and 2nd octave are "pasted and illegible“.

In our analysis, we mainly use spectrograms for visualisation of the spectra. These were calculated by Short-Time Fourier Transform in MATLAB, for more tones with the

10 HOFMANNOVÁ, Karla. Janáčkův klavír je zrestaurovaný. *Opera PLUS.* Published online 23. 11. 2019. Dostupné z: https://operaplus.cz/janackuv-klavir-je-zrestaurovany-krasny-zvuk-probudil-janackova-ducha/.

11 SYROVÝ, Václav. *Hudební zvuk.* V Praze: AMU, 2014, pp. 133-135.

12 SYROVÝ, Václav. *Hudební akustika.* 3. dopl. vyd., V Praze: AMU, 2013, p. 161.

window length = *2500,* overlap = *2400,* the Hamming window smoothing and dynamic range of *130* dB.[13] If we needed a more detailed resolution, we would work with window length = *5800,* overlap = *5600,* dynamic range *100* dB. The frequency range was usually cut on borders where modules of partials were lower than *-60* dB.

Let's go through notes played on the grand piano Ehrbar in dynamic ff. Fig. 9 displays a selection of 29 selected tones as the spectrogram.

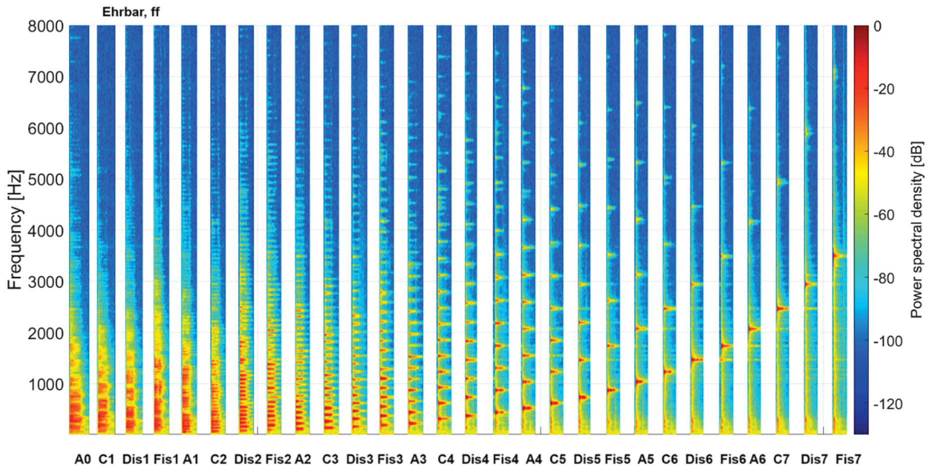

Fig. 9 The Ehrbar: tones in ff.

The 1st six bass tones were not rendered in enough resolution, therefore Fig. 10 with their detailed spectra is attached below.

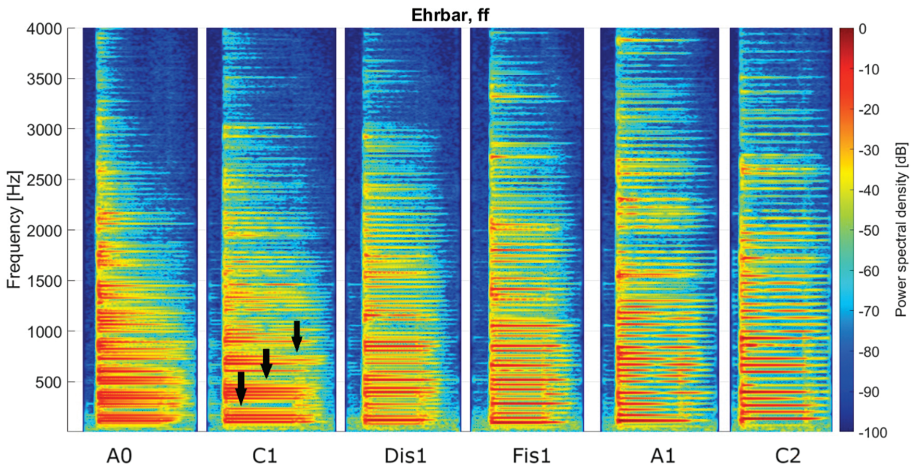

Fig. 10 The Ehrbar: details of bass tones in ff.

13 MATLAB, *Spectrogram, Input Arguments* [online]. Dostupné z: https://ch.mathworks.com/help/signal/ref/spectrogram.html#bultmx7-window [cit. 2024-06-15].

The spectrograms show that the lower octaves contain more partials than the higher octaves, which corresponds to the known facts about the spectra of grand pianos. Breaks between partials (see black arrows) are especially important in bass timbre. These are caused by the hammer beating the knot of the string, which was not enough to oscillate the appropriate multiple/anti knot of the strings. For the Ehrbar grand piano, there are significant fractures with missing first and second partials, whereas sometimes the spectrum lacks only the 8^{th} one (if we consider the classification of Syrový, this tone with a missing 8^{th} partial loses its force but does not lose the 7th partial, which creates harshness), and sometimes the spectrum lacks both the 7^{th} and 8^{th} partials (in which case the tone loses both force and harshness). The loss of up to 2 partials probably occurs due to the larger size (and thus the bigger area) of the hammer striking at *1/7* to *1/8* the length of the string. The whole phenomenon is then repeated in the harmonic series at multiples of *8*, i.e. a missing sixteenth partial, 32^{nd}, etc.

Only those partials with a module from *0* to *-40* dB (to the yellow or orange in spectrograms) were entered in the following table. Here we put them in zones according to Syrový's classification.

octave	tone	total		interval zone		diatonic zone		micro interval zone		noise zone	
		partials	interval range	partials	int. range	partials	int. range	partials	int. range	partials	int. range
7	A7	*1*		*1*	unis.						
6	Fis6	*3*	oct. + 5th	*3*	1 oct.+ 5th						
5	Fis5	*5*	2 oct. + 3rd	*5*	2 oct. + 3rd						
4	Fis4	*8*	3 oct.	*8*	3 oct.						
3	Fis3	*15*	3 oct. + 7th	*8*	3 oct.	*7*	maj 7th				
2	Fis2	*24*	4 oct. + 5th	*8*	3 oct.	*8*	oct.	*8*	aug4		
1	Fis1	*54*	4 oct. + 7th	*7*	3 oct.	*7*	oct.	*15*	oct.	*25*	min 7th
0	A0	*64*	5 oct. + min 2nd	*7*	3 oct.	*7*	oct.	*14*	oct.	*30*	oct.

Tab. 3 The Ehrbar, ff: partials and interval ranges of zones.

We see that contra octave extends to beginning of the noise zone, and the bass octaves 1 and 2 cover all or half of the micro interval zone. Octave 3 reaches only a part of the diatonic zone and the descant octaves 4-7 occupy only the 1st interval zone. The total number of partials ranges from *1* to *64*.

For the analysis of the Bösendorfer in dynamic ff, we used a selection of the same tones as with the Ehrbar. The only difference is the inclusion of the key C^7, so the total number of keys is *30*. All were played, again, at the dynamic ff (Fig. 11).

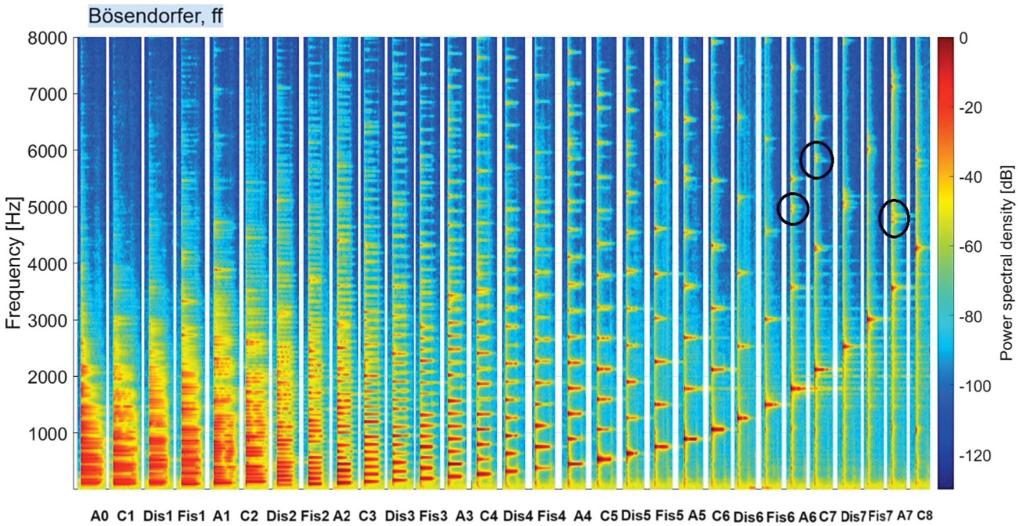

Fig. 11 The Bösendorfer: tones in ff.

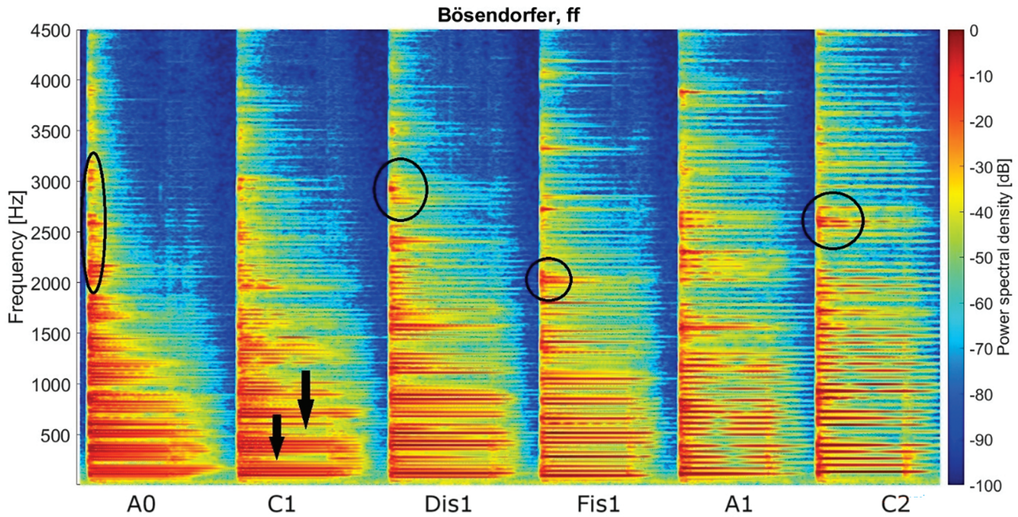

Fig. 12 The Bösendorfer: details of bass tones in ff.

The *Y* axis had to be enlarged to *4500* Hz (Fig. 12). The fundamentals are bland, again, in all 6 bass notes. (Is this due to the short resonance board not supporting the long waves of the first partials?) What is different, when compared to the Ehrbar, is the location of the breaks in the spectrum. They were found only in multiples of 7, muting only the first partial. Probably, this is due to the narrower width and thus the smaller area of the hammer striking at only *1/7* the length of the string. This phenomenon is valid for the keys A^0, C^1, Dis^1 and Fis1, not for higher and discontinuous spectra. The muted 7th partial is a good timbral solution, because this way only the harshness is limited. On the other hand, the narrow hammers, like all sharp tools for striking, generate a wider and more inharmonic spectrum.

With the Bösendorfer's partials, only those reaching *-40* dB were considered and entered into the Syrový's table.

octave	tone	total		interval band		diatonic band		micro interval band		noise band		
		partials	interval range	partials	int. range	partials	int. range	partials	int. range	partials	int. range	over
7	C8	*2*	1 oct.	*2*	1 oct.							
6	Fis6	*4*	2 oct.	*4*	2 oct.							
5	Fis5	*9*	3 oct. + maj 2nd	*8*	3 oct.	*1*	maj 2nd					
4	Fis4	*14*	3 oct. + maj 7th	*8*	3 oct.	6	maj 7th					
3	Fis3	*22*	3 oct. + 4th	*8*	3 oct.	*7*	oct.	*7*	4th			
2	Fis2	*36*	4 oct. + min 3rd	*8*	3 oct.	*8*	oct.	*14*	oct.	6	min 3rd	
1	Fis1	*80*	5 oct. +	*8*	3 oct.	*8*	oct.	*16*	oct.	*32*	oct.	16
0	A0	*88*	5 oct. +	*7*	3 oct.	*7*	oct.	*16*	oct.	*32*	oct.	26

Tab. 4 Bösendorfer, ff: partials and interval ranges of zones.

The Bösendorfer's spectrum is much fuller. The bass octaves 0-2 have partials extending to the end, half, or beginning of the noise zone, while octave 3 covers the majority of the micro-interval zone. Octaves 4-5 reach the diatonic zone, and descant octaves 6-7 are situated only in the 1st interval zone. The number of total partials is much higher, ranging from *2* to *88* partials. The timbre of the Bösendorfer sets the human ear ringing with its buzzing ingredients.

It is not the only difference. There is much importance in the high number of inharmonicities from the Bösendorfer throughout the spectrum. For example, we see it in tone A^1 (Fig. 13) by the red ovals. This phenomenon manifests itself across all octaves and even in the highest voices, e.g. keys Fis^6, A^6, C^7 (Fig. 11, black ovals).

Note: Inharmonicities in the piano spectrum are referred to as phantom partials, and even at low dynamics (for example in a *1:4* ratio against adjacent harmonic components) they add ringing elements to the timbre, which can be desirable (e.g. highlighting a melody) or undesirable (if components in the spectrum do not mingle well, in which case they clash and mask each other). In the case of the Bösendorfer, where the dynamic ratios of two adjacent harmonic-inharmonic components are *10:9*, inharmonicity is prominent – see the red ovals, Fig. 13.

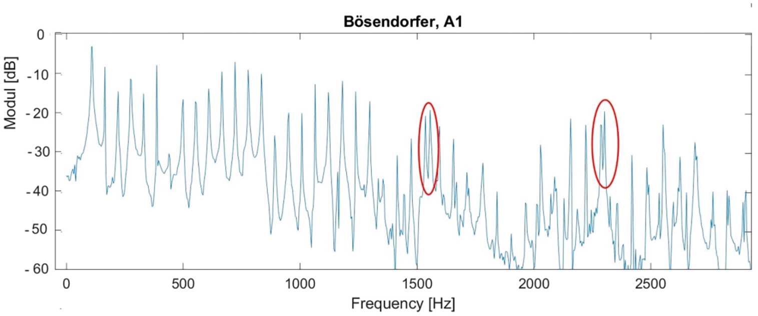

Fig. 13 The Bösendorfer: inharmonicities.

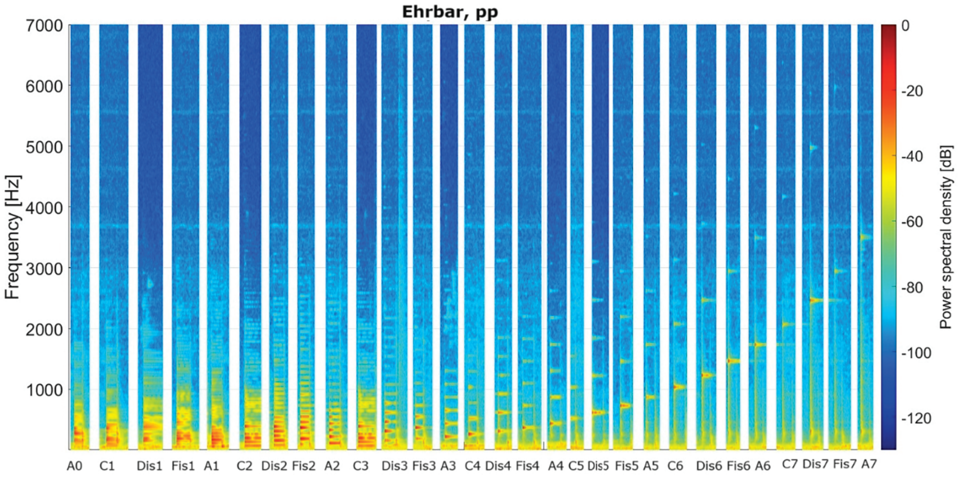

Fig. 14 The Ehrbar: tones in pp.

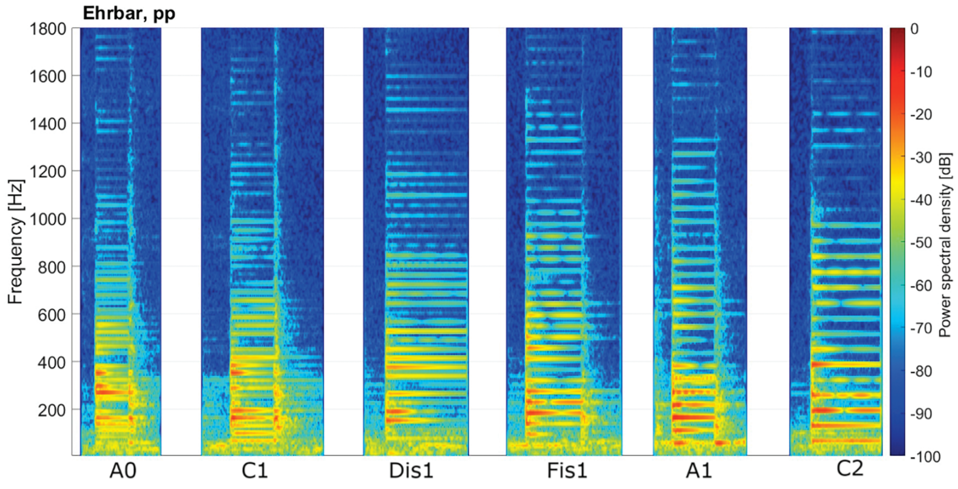

Fig. 15 The Ehrbar: details of bass tones in pp.

As we mentioned above, we analysed samples of both pianos at pp, mf, f and ff. At the softest dynamics, their differences blur, the timbres become less consistently distinct, and the sound differs less. For that reason, for pianissimo we only present graphs of the Ehrbar and compare them with the Bösendorfer in the text.

For notes played in pp on the Ehrbar, the partials decreased by a third to a half. For lower basses, the 8th partial and its multiples still miss. The partial modules do not maintain the same level over time, and the course of the spectrum over time is thus much more inconsistent.

Octave	tone	total		interval zone		diatonic zone		micro interval zone	
		partials	Interval range	partials	int. range	partials	int. range	partials	int. range
7	A7	*1*	unis.	*1*	unis.				
6	Fis6	*1*	unis.	*1*	unis.				
5	Fis5	*2*	oct.	*2*	oct.				
4	Fis4	*3*	1 oct. + 5th	*3*	1 oct. + 5th				
3	Fis3	*6*	2 oct. and + 5th	*6*	2 oct. + 5th				
2	Fis2	*15*	3 oct. and + 7th	*8*	3 oct.	*7*	maj 7th		
1	Fis1	*14*	3 oct. and + 7th	*7*	3 oct.	*7*	maj 7th		
0	A0	*19*	4 oct. and + 3rd	*7*	3 oct.	*7*	1 octave	*5*	min 3rd

Tab. 5 The Ehrbar, pp: partials and interval ranges of zones.

In the sub-bass, the partials reach only to the beginning of the micro interval zone (whereas at ff it was to the noise zone), and in the basses to the diatonic zone (whereas at ff it was to the micro interval zone). In the higher octaves they cover only the interval zone (at ff they also cover only the interval zone but with more partials). The spectra of the Bösendorfer played at pp show a very similar number of partials and a similar spread into the various zones. Since the Bösendorfer shows a wider spectrum in ff than the Ehrbar, it follows that Bösendorfer has a much wider timbral range (e.g. in the subbass from *19th* to *88th* partial against the Ehrbar's *19th* to *64th*, in basses from *14th* to *80th* against Ehrbar's *14th* to *54th*).

On an Overgrown Path, Selected Excerpts

Technical analysis was supplemented by 3 excerpts from the piano cycle *On an Overgrown Path* [Po zarostlém chodníčku]. The 1st is a representative passage of octaves 4 and 5, the

1st nine bars from *A blown-away leaf* placed in the soprano. This was recorded at a slow tempo (for rendering details) even though the prescribed metronome marking is BPM *66*, first the right hand alone, then the left hand alone, and finally together. In addition to the spectrogram, this time we also used the spectral centroid displayed against time. The spectral centroid is calculated as

$$Centroid = \frac{\sum_{k=b_1}^{b_2} f_k s_k}{\sum_{k=b_1}^{b_2} s_k} \quad \text{(Hz)}, \qquad (2)$$

where,
f_k is the frequency in Hz corresponding to bin *k*,
s_k is the spectral value at bin *k*.
b_1 and b_2 are the band edges, in bins, over which to calculate the spectral centroid."[14]

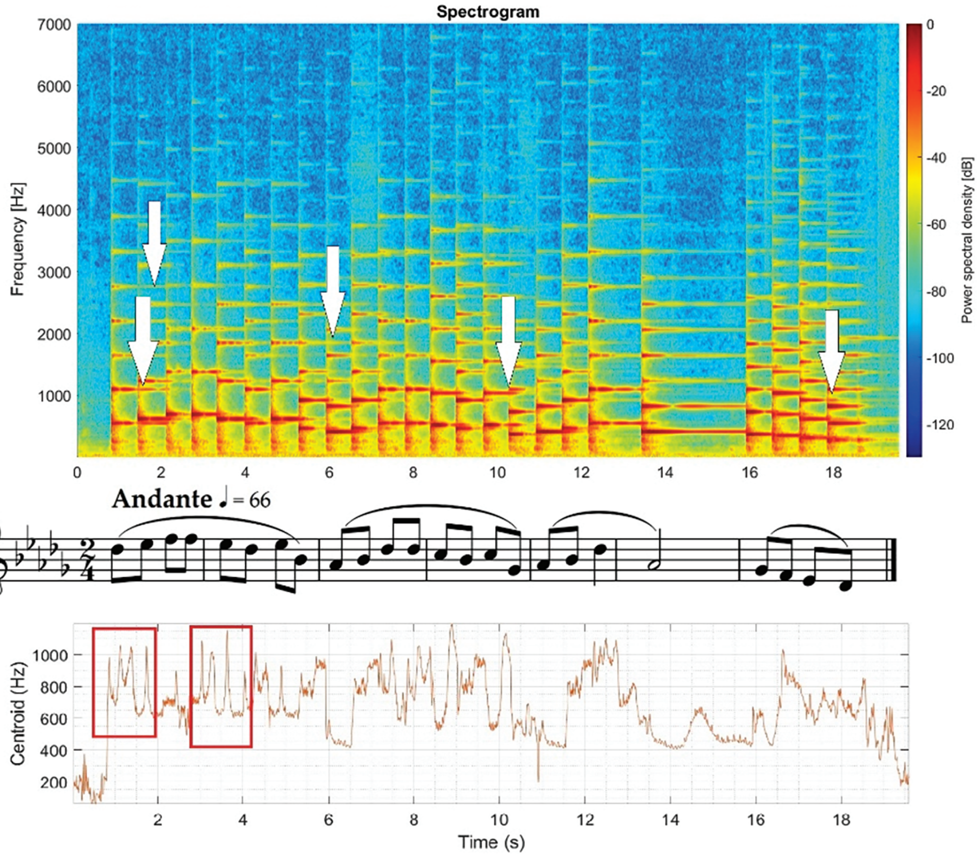

Fig. 16 The Ehrbar: right hand of *A blown-away leaf*[15]- the spectrogram and spectral centroid.

14 MATLAB, *Spectral Centroid, Algorithms,* [online]. [cit. 2024-06-15].

15 JANÁČEK, Leoš. *Po zarostlém chodníčku.* 2. ed., Praha: Bärenreiter, 2022, p. 6.

In the case of the right hand played on the Ehrbar, the graphs show three interesting phenomena. The spectrum is purely harmonic, with partials only moving within the interval zone. Modules of the partials keep the decline balanced (deeper partials are longer, higher partials are shorter and steeper, which corresponds to the curve of the spectral centroid in the red rectangles, Fig. 16). We discover the so-called reverb effect in the spectrogram – the previous partials blend into the upcoming tone even after the key is lifted. This is due to the Viennese mechanism slowly closing the damper.

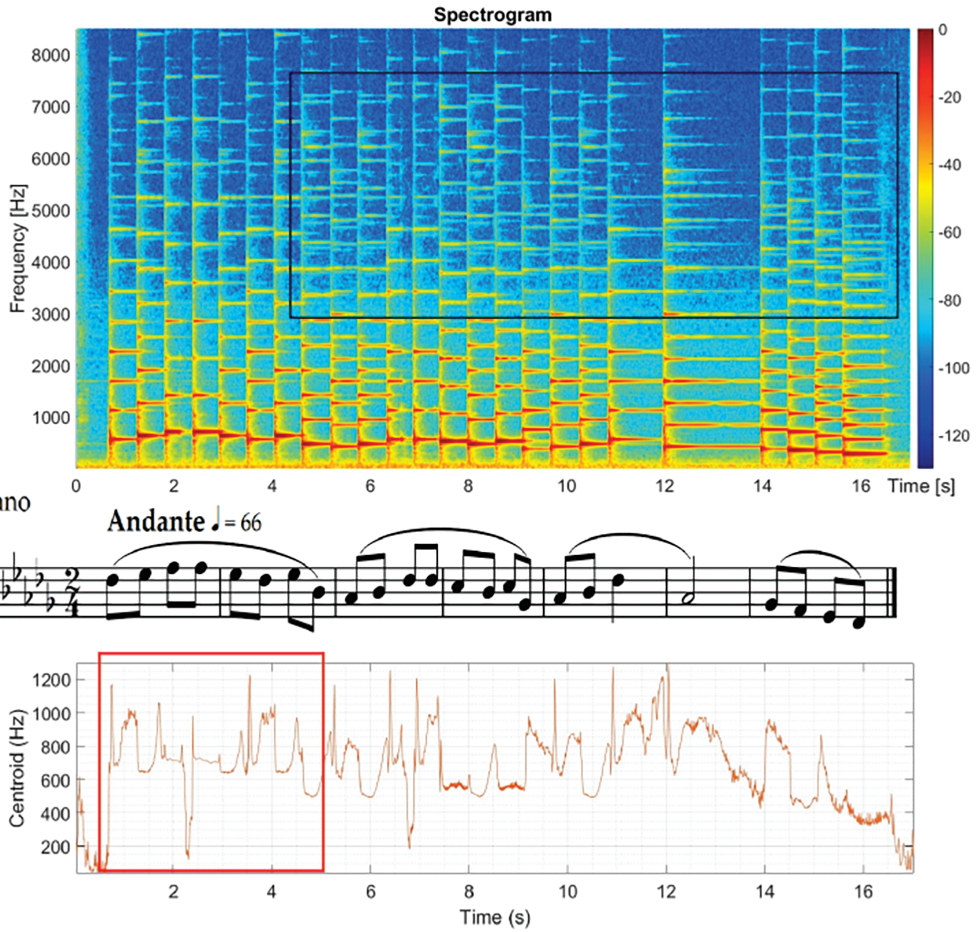

Fig. 17 The Bösendorfer: right hand of *A blown-away leaf*[16] – the spectrogram and spectral centroid.

The right hand of the Bösendorfer was measured in the same way. These centroids are located above those of the Ehrbar, and the spectrum is wider than the Ehrbar's (Fig. 17). The decline of the Bösendorfer's partial modules fluctuates greatly. Due to

16 Ibid., p. 6.

inharmonicities, the timbre is not balanced from tone to tone, nor even within the descending timbre of the same tone. The Ehrbar holds the centroids much longer on the same level. We could thus compare the Ehrbar's tones to well-played tones from woodwinds or strings, more like singing, since they conserve the same timbral formula.

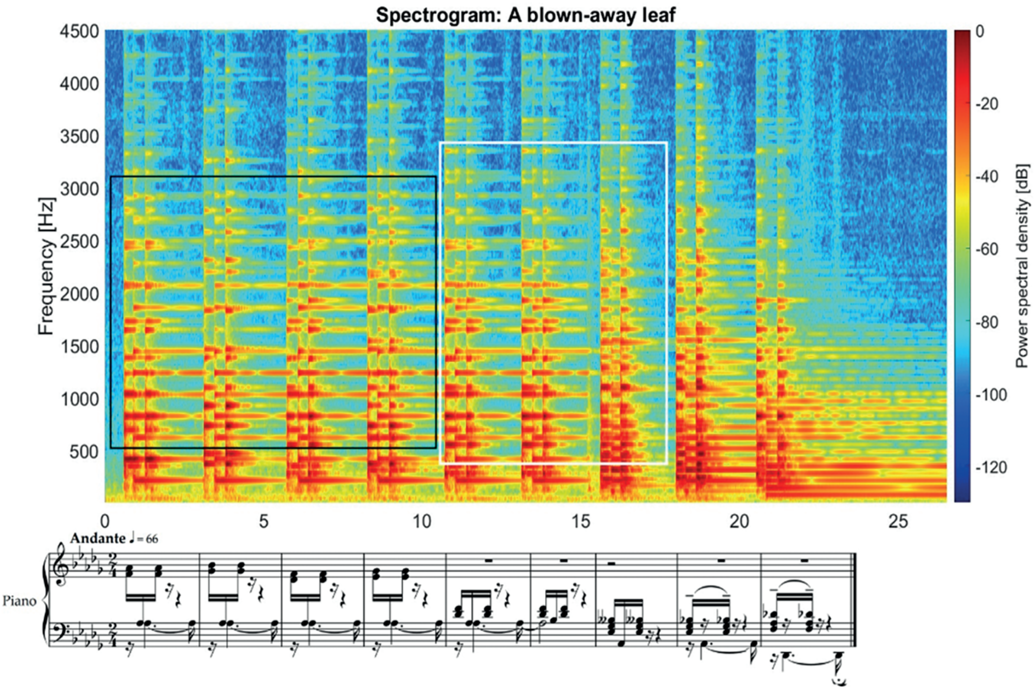

Fig. 18 The Ehrbar: left hand of *A blown-away leaf.*[17]

In the case of the right hand, we only display the spectrogram of the Ehrbar (Fig. 18). Here the voices are led in close harmony, the upper voice close to the accompaniment, so that the chord spectrum reaches into the lower partials of the soprano – see the white and black rectangles above *500* Hz. However, since the spectrum of the Ehrbar is purely harmonic, even in tempered tuning, the partials will be well combined and will not mask each other much.

Our Evenings

The eleven bars (having two voices) from *Our Evenings* [Naše večery] were selected as the second representative passage. The left hand only is played first (Fig. 19).

17 Ibid.

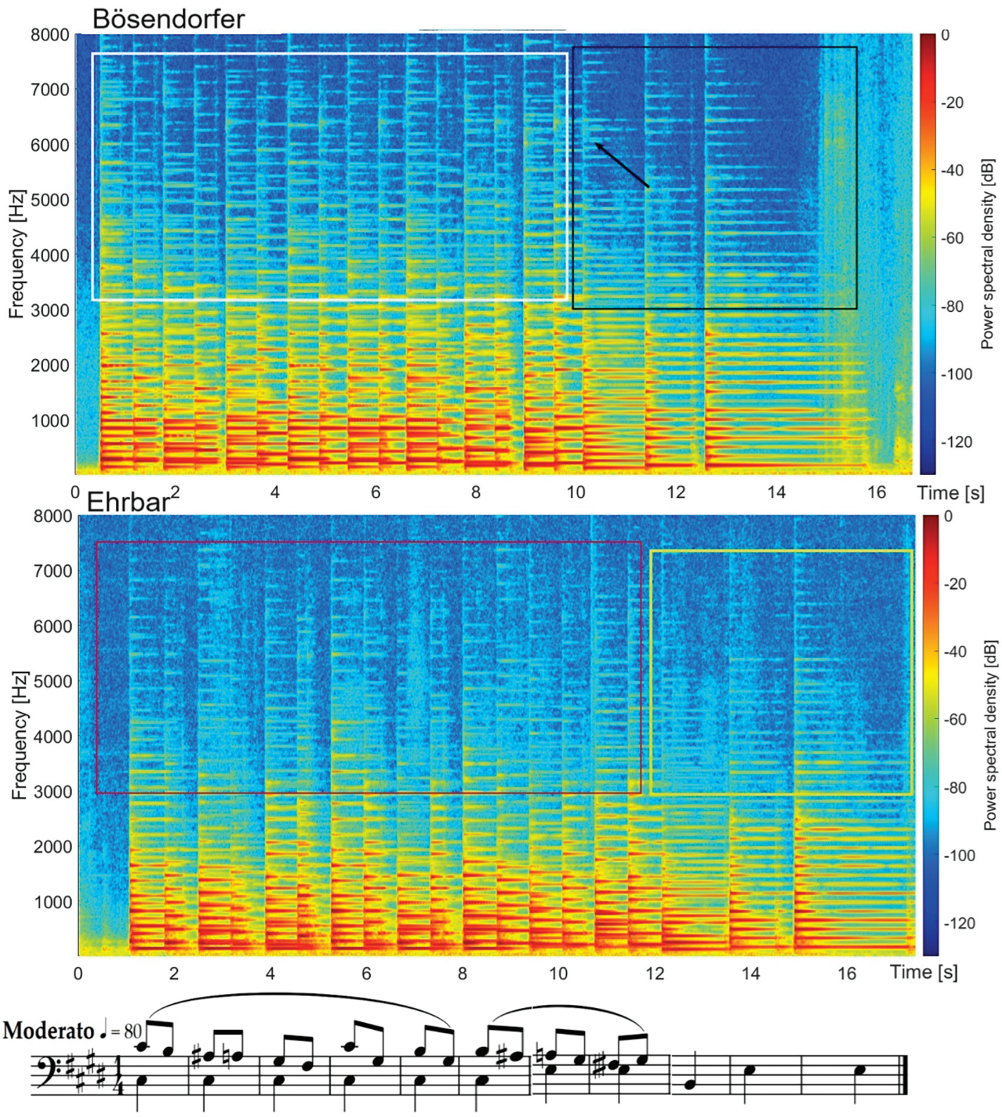

Fig. 19 Both pianos: left hand of *Our Evenings.*[18]

There are 2 voices here, so the spectra are denser with more partials and more dissonant clashes. Even so, the Ehrbar shows a narrower spectrum and more uniformity over time. These 2 voices played with the left hand on the Ehrbar occupy the spectrum in the range of approx. *3-4* kHz, above which they do not create significant disturbance (see the yellow and red marking). With the Bösendorfer, the sound up to *7.5* kHz is quieter, but there are polluting aliquots (the white and black marking). These will then collide with the timbre (3rds, 6ths, and chords) from the right hand.

18 Ibid., p. 3.

Next, both hands were recorded and measured (Fig. 20). Let's focus only on the spectrogram of the Bösendorfer. Not only is the band from *140-3000* Hz, where the basic timbre of the voices from both hands collides, polluted by partials and inharmonics, but the band above *3* kHz (in the white rectangle) is filled with ringing aliquots. We can verify these by using the so-called sweep filter.

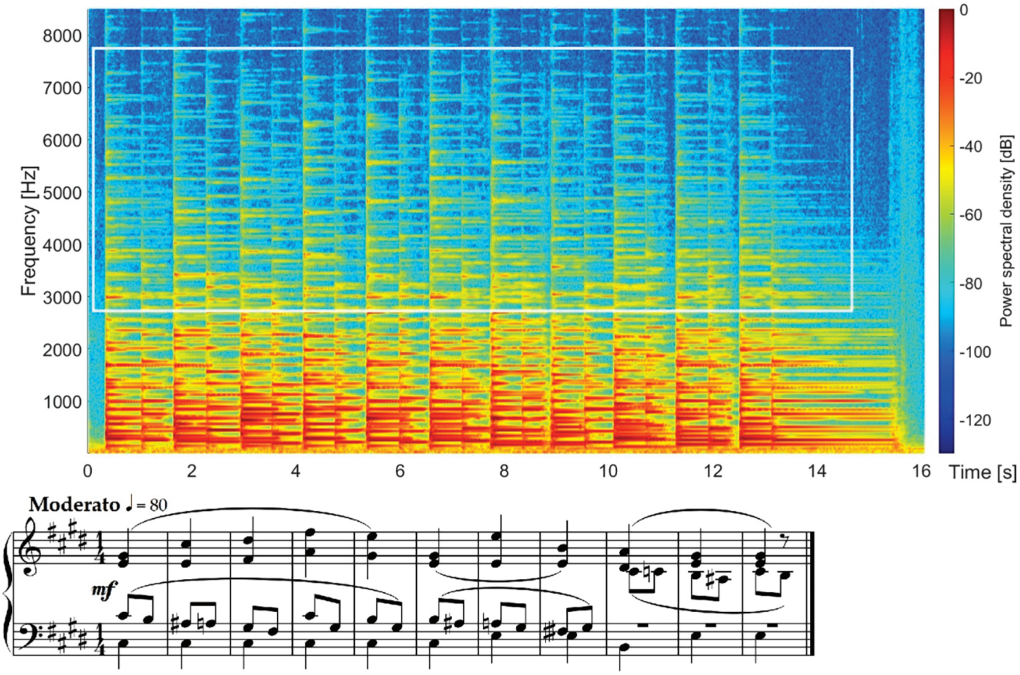

Fig. 20 The Bösendorfer: both hands of *Our Evenings*.[19]

The Frýdek Madonna

As the 3rd excerpt were selected bars 1-4 from *The Frýdek Madonna* [Frýdecká Panna Maria] played by both hands in basses, in octaves 1, 2 and 3 (Fig. 21). Here we measured the parameter of acoustic roughness in asper. The formula to compute the roughness is:

$$Roughness = cal \int_{z=0}^{24} f_{mod} \Delta L \, dz \text{ (asper)}, \qquad (3)$$

where

f_{mod} is the detected or known modulation frequency,

cal is a constant ensuring unity roughness of the reference signal,

19 Ibid.

ΔL is the perceived modulation depth,"[20]
z is the number of the bark band.[21]

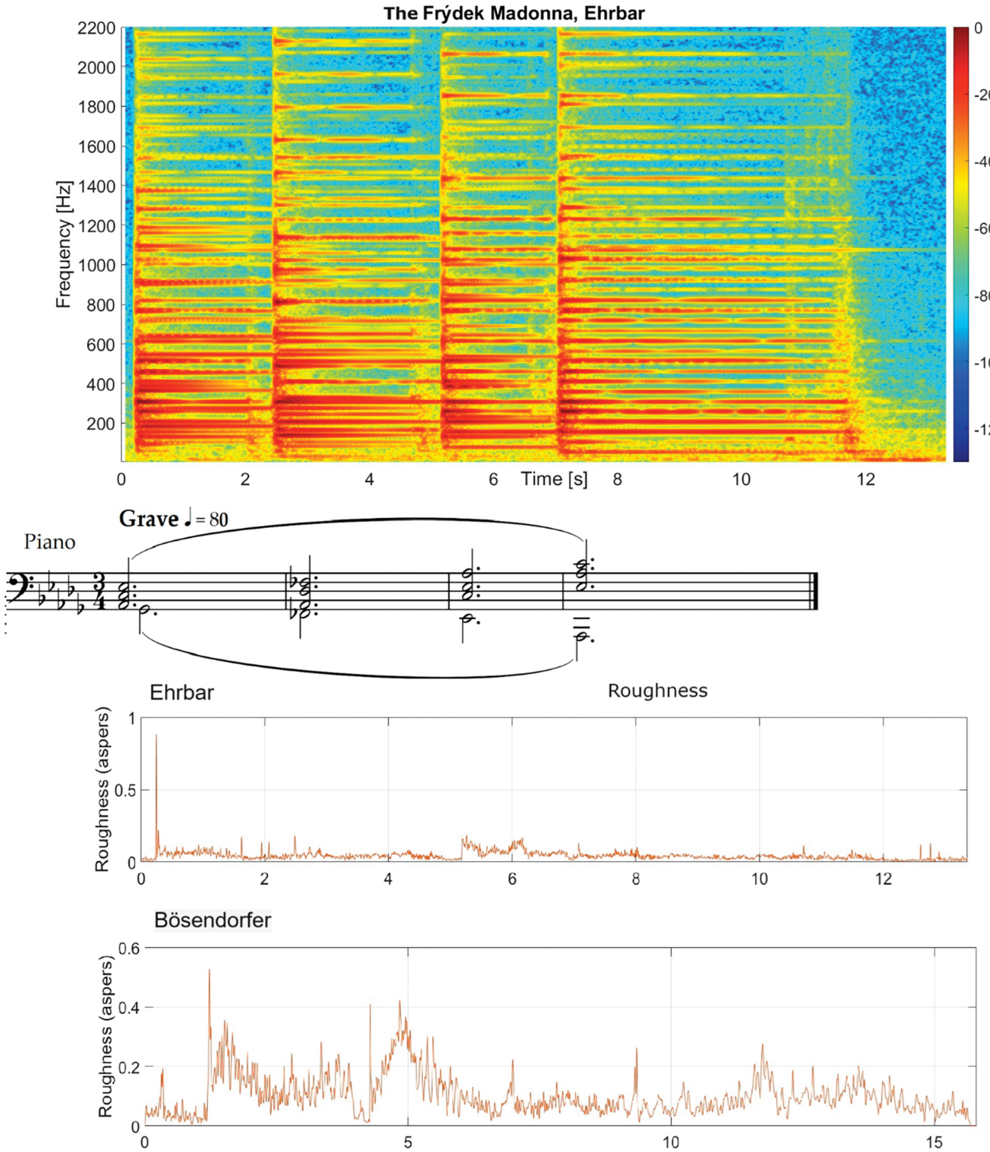

Fig. 21 The Ehrbar: both hands of *The Frýdek Madonna*[22] – spectrogram and roughness (both pianos).

20 MATLAB, *Acoustic Roughness, Algorithms.* [online]. Dostupné z: https://ch.mathworks.com/help/audio/ref/acousticroughness.html [cit. 2024-06-15].

21 MELKA, Alois. *Základy experimentální psychoakustiky.* Praha: AMU, 2005, p. 252.

22 JANÁČEK, Leoš. *Po zarostlém chodníčku,* op. cit., p. 10.

The spectrum of the Bösendorfer (*0.2–0.4* asper) turned out to be much rougher than the Ehrbar's (*0.1* asper), Fig. 21. This corresponds, again, to the wider and more inharmonic timbre of the Bösendorfer, where among inharmonic elements, much stronger acoustic beats result in greater roughness.

Note: In terms of timbre, lowering about -36 cents (ratio $f2/f1$ =1.02) opposite 440 Hz or only -16 cents (ratio $f2/f1$ =1.009) opposite tunning 435 Hz, can cause softer tension of strings and narrowing spectrum of the restored Janáček's Ehrbar. Experiments measured mainly on guitars[23] show that a slight difference in timbre occurs, but not so significant as to change the character of the instrument. This is confirmed by our comparison with recordings of other Ehrbars constructed around 1880 with 440 Hz tuning obtained from the Internet. The number of overtones and their contours are almost identical.

Discussion

A question for the discussion is our selection of the modern grand piano for comparison. The Bösendorfer, with the maximum length of its deepest string being *138* cm, is not in the same category as the Ehrbar with *162* cm. It would be useful to compare the Ehrbar with a grand piano with nearly identical frame and resonance box dimensions. One could also supplement the analysis with samples from other brands, perhaps of other dimensions, such as Steinway, Foerster, Kawai, Yamaha etc.

So, to what extent did the timbre of this Ehrbar grand piano affect Janáček's compositional decisions? It is generally known that Janáček, as a folklorist, often approached the piano as if it were a dulcimer. In his piano compositions he preferred timbral purity and rhythmical figures. For this reason, 3 excerpts from the piano cycle *On an Overgrown Path*[24] were recorded. In accordance with the results from the tones recorded individually, the soprano melodies played on Janáček's Ehrbar are more homogenous in timbre in close harmony and emerge much more legibly from the accompaniment of the left hand. They are not as masked as on the Bösendorfer. We could describe the Ehrbar's tones as being more like singing, extending the same timbral formula, supporting the purity of the melodies.

This unadulterated purity may have impressed Janáček, philosophically and compositionally. When Janáček constantly repeated various harmonies on the Ehrbar, he could probably be looking for the best compositional solution. Co-resonating strings create a latent harmony and can influence the composer where to proceed. Thanks to its narrower spectrum, Ehrbar could thus navigate him (if Janáček was influenced by the resonance of the strings), for example to closer tones in the harmonic series, rather than to more distant (non-resonating) ones.

23 BROADBENT, Curtis – JAIN, Armaan. Analysis of patterns in the harmonics of a string with artificially enforced nodes. *Journal of Emerging Investigators*, Vol. 3/7. 28 January 2021.

24 Ibid.

Our acoustic graphs and individual listening and the hypotheses or assumptions related to it should, however, be further verified by listening experiments and research with an appropriate number of participants. For example, it also opens up the possibility of comparing older brands of pianos, which could indicate why Janáček chose Ehrbar.

The gentle timbre of the renovated Ehrbar can be further explored in connection with psychoacoustic phenomena[25], that the instrument's narrow but well-balanced spectrum reduces its roughness and overall dissonance such as the augmented 4th, of course, but also 7^{ths} and 2^{nds}.[26] And whether this phenomenon could have shaped Janáček's handwriting, manifested itself in the semantics of the compositions, etc.

Conclusions

The analysis of two grand pianos was performed: Janáček's Ehrbar and the Bösendorfer 185 VC. The double decay time was measured only at the Ehrbar, dynamic ranges and spectra of both instruments were measured and compared with each other. For the analysis, individual tones but also excerpts from the cycle *On an Overgrown Path* played by the pianist were selected. For accuracy, the room reverberations, where grand pianos were recorded, were also measured. The obtained data were sorted and compared. Other research was also proposed and discussed, which should confirm or refute new hypotheses regarding the influence of the Ehrbar tone on Janáček's poetics.

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25 LOTS, Inbal Shapira – STONE, Lewi. Perception of musical consonance and dissonance: an outcome of neural synchronization. *J. R. Soc. Interface,* 2008, 5, 1429–1434. Published online 11 June 2008.

26 SYROVÝ, Václav. *Hudební akustika*. 3. dopl. vyd. V Praze: AMU, 2013, pp. 88–89.

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