Material-Dependent Sound and Vibration of a Harmonica Reed Block

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Introduction

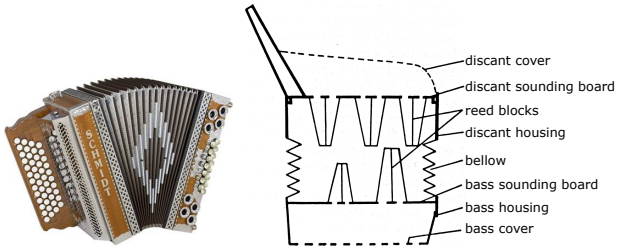
Reed blocks are the central elements of all hand-held bellows-driven free reed aerophones (squeeze box), such as the accordion or the Styrian harmonica, cf. fig. 1. The latter is a local variant of the accordion, important to the alpine folk music, and the subject matter of the research project this work is emerging from.
Traditionally, reed blocks are hand-crafted and made of wood, or more recently partially CNC-milled. 3D-printing offers new possibilities, such as manufacturing in one piece, advanced geometries, and rapid prototyping, but requires different materials. Our contribution investigates suitability of typical 3D-printable materials for manufacturing reed blocks in terms of radiated sound and surface vibration.

Harmonica structure and characteristics

The Styrian harmonica basically consists of descant part, a bass part and a bellow connecting these, see fig. 1. Both, descant and bass part, consist of a number of reed blocks which are mounted on the sounding board. This board has wholes coinciding with the holes in the reed blocks and these are covered by pallets, which are lifted when the corresponding button on the fingerboard is pressed. The lever mechanism connecting the buttons with the corresponding pallets are protected by a perforated, sound transparent cover.
The sound generating element of the harmonica is an oscillating free reed. The reed interrupts periodically the air flow, which is created by manually pushing or pulling the bellow. The interrupted air flow results in sequence of compressed and rarefied air pressure, i.e. sound. The self-excitation mechanism of the reeds starts only for one direction of airflow. Therefore each reed plate carries two reeds. For each of these reeds a thin sheet of leather or plastic foil prevents air flow in the non-excitable direction. Typically one pallet on the descant side closes three holes in the sound board.
Hence by pressing one button, i.e. playing one tone, involves three reeds. Thereby one reed is in tune, and the other two are intentionally tuned to slightly higher and lower frequency. This leads to an acoustic beat (in this context also called *Tremolo*), which is characteristic for the instrument. Such instruments are termed 3-voice (*3-chörig*) and 2-voice (*2-chörig*) if only two reeds are involved when playing one tone, see fig. 2.

Reed block

The purpose of the reed block is to provide firm support for mounting the reed plate as well as guiding the airflow to the reed. Pressure and flow conditions within the reed chamber are determined by its form and dimensions. And these parameters have an impact on the attack and oscillation amplitude of the reed. Due to the typical dimensions of the reed chambers, their resonant frequencies of are not effective and can be neglected, except for the four-line octave, see [1, ch. 5.3].



(a) Schmidt Harmonika-Erzeugung GmbH **(b)** from [1]

Figure 1: Styrian Harmonica.

As shown in [2, ch. 3], the different parts of the housing are vibrating when the instrument is played, but the sound radiated from the housing does not contribute significantly and has no influence on the overall level and timbre of the instrument. This implies that the reed blocks do not radiate by themselves significantly and the structure-borne sound transmitted from them to housing is also marginal compared to sound generated by the air flow modulated by the reeds.

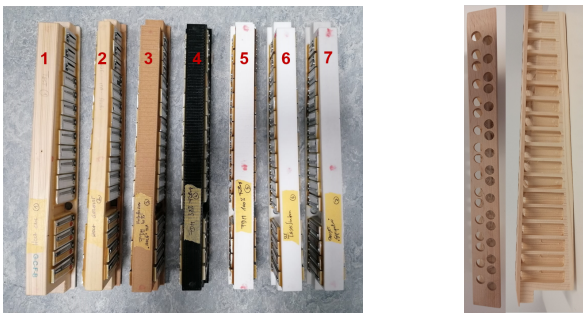
Thus, the reed block material is relatively unimportant in contrast to vibrating parts in other instruments, like e.g. string instruments. However, Richter in [1, ch. 5.3] suggests not to use materials with much less density than wood, the conventionally used material. A high reed block mass is expected to have a favorable impact on the reed oscillation as the amplitude of the reed will be higher if less energy is consumed by vibrations of the reed block.

Within this work we investigate reed blocks with different mass concerning generated sound and surface vibration. Therefore seven geometrically identical reed blocks have been manufactured, equipped with identical reed plates, but made of different materials. These reed blocks are shown in fig. 2, and the materials as well as the manufacturing method are listed in table 1.

[a] Material abbreviations: *polylactic acid* (PLA), *polyamide* (PA), *acrylonitrile butadiene styrene* (ABS).
[b] Manufacturing abbreviations: *computer numerical controlled milling* (CNC), *fused deposition modeling* (FDM), *selective laser sintering* (SLS), *material jetting* (MJ).

id	abbrev.	material	manufact.	mass
1	wCNC	wood	CNC	151 g
2	wGLUE	wood and glue	hand-crafted	103 g
3	wPLA	PLA with 40 % wood	FDM	153 g
4	ABS38	ABS 38% infill, black	FDM	216 g
5	ABS100	ABS 100% infill, white	FDM	272 g
6	PA	PA, white	SLS	278 g
7	Gyp	gypsum with binder	MJ	451 g

Table 1: Reed block materials[a], manufacturing[b], and total mass without reed plates.



(a) (b)

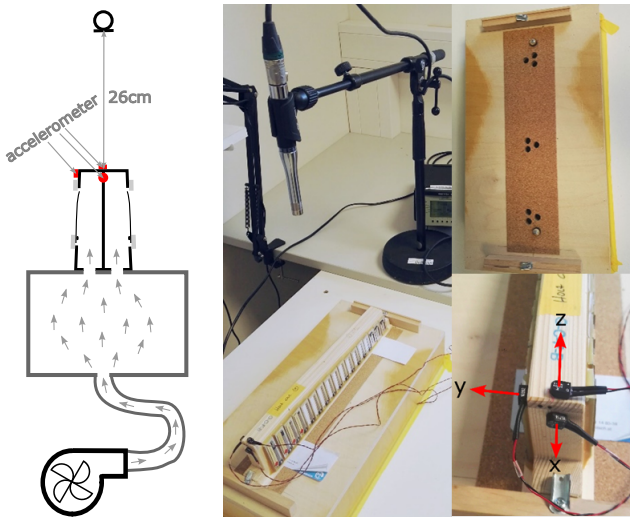
Figure 2: Reed blocks: (a) geometrically identical reed blocks with attached reed plates, (b) CNC milled wooden reed block without reed plates, bottom view (left) and side view (right).

Measurements

The different reed blocks were measured isolated, i.e. removed from the instrument. Therefore, each reed block was clamped on a leak-tight, box-shaped jig. This jig is usually used for tuning the reed plates and can be excited with a controlled air-flow. The measurement setup is sketched in fig. 3 (a) showing a cross-section of the jig with a reed block attached, and pictures of the setup are depicted in fig. 3 (b).
For each reed block 3 different tones (low, medium, high) have been measured. As mentioned in the introduction, one tone is generated by 3 intentionally mistuned reeds. Hence for each tone, 3 reed chambers have to be excited by the airflow. The upper right picture in fig. 3 (b) shows top-view of the jig with no reed block attached. Each group of closely spaced holes belongs to one tone. During the measurement of one tone the airflow through the holes belonging to the other tones was blocked by a sheet of paper, see left picture in fig. 3 (b).

The sound pressure was captured by a measurement microphone 26 cm above the reed block and the surface accelerations in x-, y-, and z-direction were recorded on three different positions. These three positions comprise both ends and the middle of the reed block, which were measured in 3 consecutive measurement runs. Figure 3 (b) shows the accelerometer placement at the low-tone end of the reed block. In the middle of the reed block only accelerations in y- and z-direction were captured.

In each measurement run 7 s of signal were recorded for the microphone and the accelerometers, whereby the start of the recording was timed such that the generated sound has reached steady state, after switching on the airflow.



(a) (b)

Figure 3: Measurement setup, (a) sketch of the reed block attached to the jig (cross-section) and location of microphone and accelerometers, (b) overall measurement setup (left), top-view of the jig without attached reed block (top-right), detail view of accelerometer placement (bottom-right).

Evaluation

First of all, a lowpass filter with a cut-off frequency of 100 Hz was applied to all recorded signals to reduce ambient noise. In a second step, a snippet of 2 s duration was selected from each recording due to the irregular (time-varying) acoustic beat of each tone. The snippets where selected such that the beat within the 2 s is as constant as possible. This was done based on the envelope of the time signal. The selection is illustrated exemplarily in fig. 4 (a), where the blue line shows the full-length time signal, the orange line shows the calculated envelope, and the vertical black dashed lines indicate the start and end of the selected snippet. In a third step, for each snippet the frequency spectrum was calculated and smoothed by applying a Gaussian window, which has a standard-deviation of 12^{th} of an octave.

Figure 4 (b) shows exemplarily the original frequency spectrum (blue) and the smoothed spectrum (orange) for one microphone recording. The vertical black dashed line indicate the frequencies of the first 15 harmonics. The smoothing was applied to avoid errors due to mismatches of the harmonic frequencies as the tuning of the reed blocks might deviate slightly. Finally, the spectral energy at the frequencies corresponding to the first 15 harmonics was taken from the smoothed spectrum, to facilitate the comparison of the different reed block materials.

Results

Sound pressure

Figure 5 shows the sound pressure level of the first 15 harmonic components for the different reed blocks, whereby subfigure (a) depicts the values for the low tone, (b) for the medium tone, and (c) for the high tone. In addition to the labels of the harmonic components, the corresponding frequencies are denoted above the x-axis.

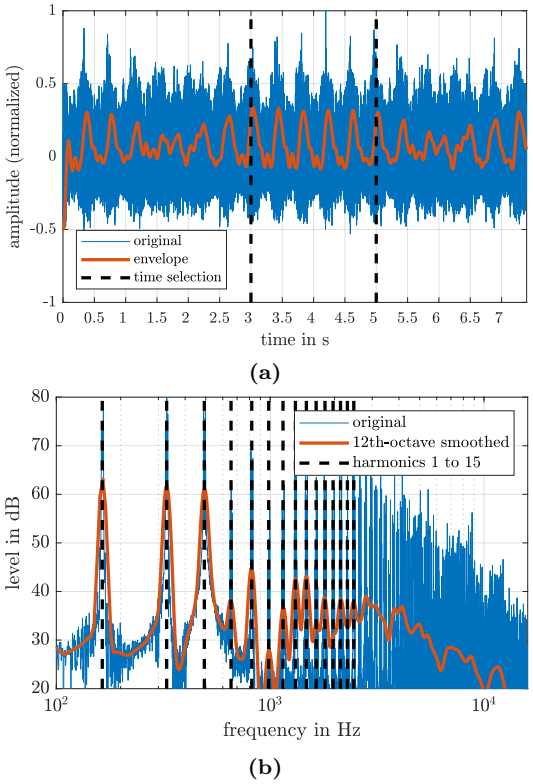


Figure 4: Exemplary illustration of time selection (a) and frequency smoothing (b) of the recorded signals.

The plotted lines show the median values computed as described in the previous section and the transparent patches indicate to the range of the pressure levels measured for the different accelerometer positions. The latter seem to have a negligible influence of around 1 dB on the measured pressure levels resulting in reproducible measurements.

For the low tone, see fig. 5 (a), the deviation of the reed block made of wood/PLA-mixture from the rest is most prominent. Especially, the 6^{th} and 7^{th} harmonic component show a significantly higher level. All but the wood/PLA-mixture are relatively similar compared to the measurement uncertainty. Only the CNC milled wood and the ABS with 38% infill show slightly higher values at the 3^{rd} component.

For the medium tone, see fig. 5 (b), there is a large difference for the 3^{rd} component. Again, the wood/PLA-mixture shows a significantly higher level and the Gypsum as well as the ABS with 38% infill are on the lower end. Interestingly, this is in a similar frequency range of about 1 kHz as the 6^{th} and 7^{th} component for the low tone. At the 6^{th} harmonic component, there is also a larger spread over the different materials. For the higher components, the levels are relatively similar, only the glued wood shows slightly higher levels than the rest. Compared to the low and medium tone, the sound pressure levels of the different materials are most similar for the high tone, see fig. 5 (c). Only for the glued wood, the difference between the 6^{th} and 7^{th} component is striking. In general, the level of the fundamental frequency decreases towards the higher tones. Moreover, the high tone exhibits a lowpass characteristic starting from the 10^{th} harmonic component.

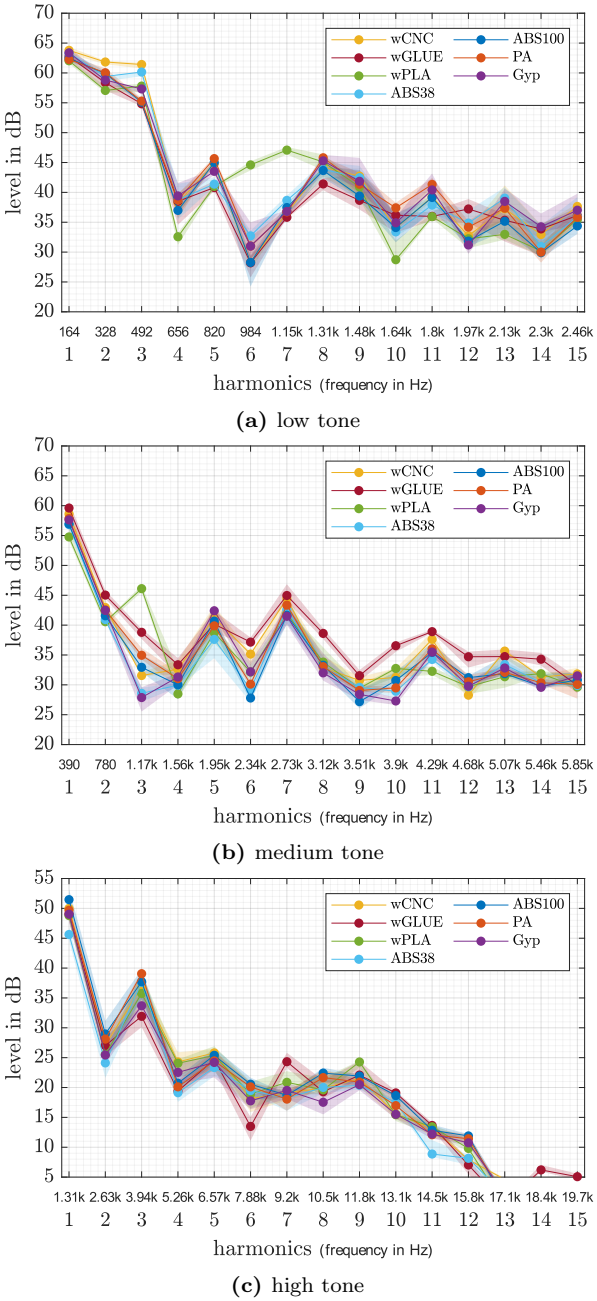


Figure 5: Sound pressure level of the harmonic components measured 26 cm above the reed block for the 3 different tones. The plotted lines show the median values and transparent patches correspond to the range of the pressure levels of 5 repeated measurements.

Surface acceleration

For the investigation of the surface acceleration the identical time sections of the accelerometer signals are used as for the sound pressure measurements. As for the pressure measurement, the repeatability was checked by control measurements for one of the reed blocks (wCNC). These results showed a similar variability as the pressure measurements. As might be expected, it showed that the acceleration levels are highest for the measurement position which is closest to the active reed chambers.

Due to the space limitations of this publication, only the results for the low tone with the accelerometers located at the low-tone end of the reed block are shown in the following. The low-tone results are chosen as there are the largest differences in the sound pressure levels concerning the different materials. For the medium and high tone there are similar tendencies as for the low tone. However in contrast to the sound pressure, the acceleration differences are significantly higher for the medium and high tone.

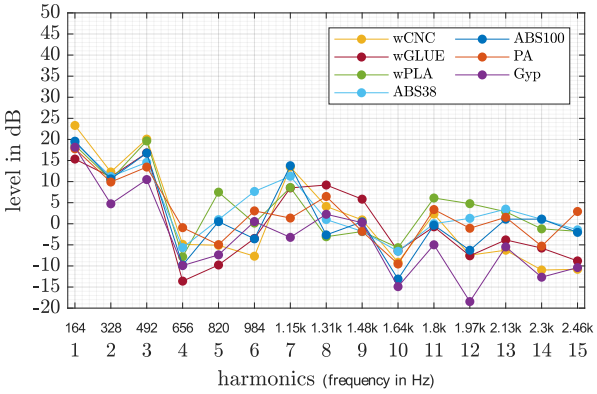
For the low tone, the measured surface acceleration levels of the different reed blocks at the first 15 harmonic components are shown in fig. 6, whereby subfigure (a) depicts the acceleration in x-direction, (b) the y-direction, and (c) z-direction. The sensor positions and axes conventions are shown in fig. 3 (b). As might be expected, the highest acceleration levels are observed for the y-direction, probably since the reeds are deflecting in this direction. In x-direction the acceleration is lowest.

In general, the lowest material dependency is observed in z-direction, especially for the first 4 harmonics. In the y-direction, the differences are clearly higher, whereby the largest differences exhibit at the 3rd harmonic component. For the acceleration in x-direction, the level differences are in a similar range, whereby here the 12th component shows the largest differences. For all 3 directions, the level differences of the first component (fundamental frequency) are relatively low. On average, the heaviest material (Gyp) shows the lowest acceleration levels for all 3 directions. Comparing the two reed blocks made of ABS, it shows that also the heavier version with 100% infill (ABS100) exhibits lower acceleration levels than the lighter version with 38% infill (ABS38) for almost all harmonic components in all 3 directions.

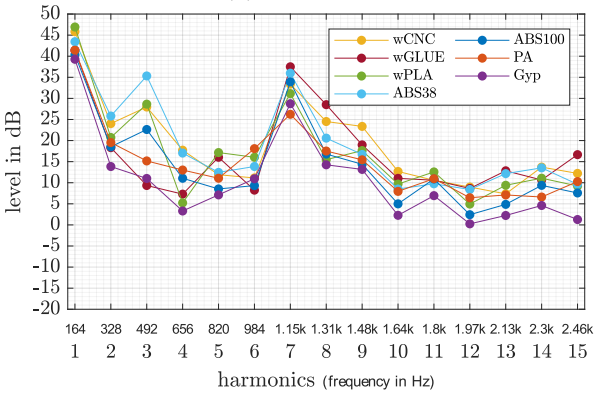
Conclusion

In general, the differences in sound pressure for the different materials are surprisingly small, except for the wood/PLA-mixture, and to a minor extent for the glued wood. The reed block made of glued wood is hand-crafted and hence slightly differs geometrically from the other reed blocks. The wood/PLA-mixture differs from all other materials concerning the surface texture. Due to the wood fibers in the filament, the surface of the 3D-print gets relatively rough and fringy. This supports the assumption that the surface texture of the reed block has a significant influence the radiated sound.

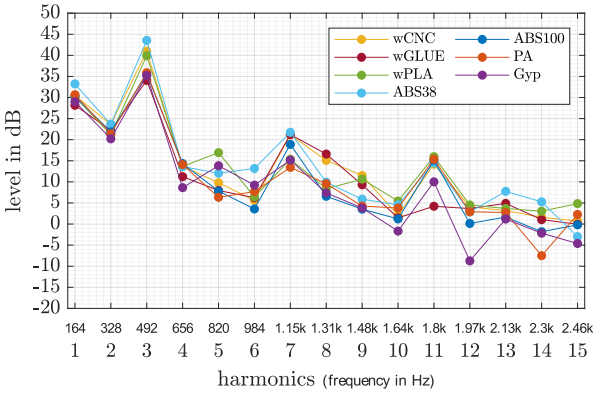
There are larger differences for the different materials concerning the surface acceleration, especially in x- and y-direction. These differences are connected to the density of the respective material, whereby the heavier materials tend to show less surface vibrations than the lighter ones. However, these differences have no obvious relation to observed differences in sound pressure for the various materials. This fact supports the assumption that the vibrating surface of the reed block does not contribute significantly to the radiated sound.



(a) x-direction



(b) y-direction



(c) z-direction

Figure 6: Surface acceleration levels of the harmonic components measured for the low tone on the low-tone end of the reed blocks.

Acknowledgments

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References

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