Analysis of Uncertainty in Input Impedance Measurements on Woodwind Instruments

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Introduction

The interpretation of input impedance curves of woodwind instruments with respect to their tuning, playability and sound color is vague: It was found, that individual instruments greatly differing in their musical performance can have very small differences in their input impedance curves [1]. In order to employ impedance curves in a musical instruments workshop for quality control purposes, the precision of a measurement has to be determined. We adapted the "ready-to-use" impedance measurement system for brass instruments "BIAS" [2], to measure the input impedance of bassoons. To imitate the measurement situation in a workshop, we carried out repeated measurements under varying surrounding conditions. The result of this study is a comparison of input impedance maxima of 4 different bassoons, including dispersion measures.

Experimental Setup

The Brass Instrument Analysis System "BIAS" is a commercially available servo-controlled capillary-drive impedance head as described by Benade [1]. Since it is suited for brass instrument mouthpieces, an adapter as shown in Figure 1 (c) is needed to connect a bassoon bocal to the impedance head. In the post processing, the effect of this cavity can be eliminated numerically [3]. Regarding the deviations in some preliminary measurements of one and same woodwind air column with this setup, the following influencing factors were obvious:

- Noise
- Temperature/humidity (measurement room, instrument body, impedance head),
- Tiny leaks (imprecisely fitted joints, badly closing pads)
- Force applied to the keys.

Some of these sources of trouble are more easily to avoid than others in a musical instruments workshop. To imitate the non-ideal measurement conditions hypothetically found there, we chose the measurement surrounding for the study to be a quiet but not climatized room.

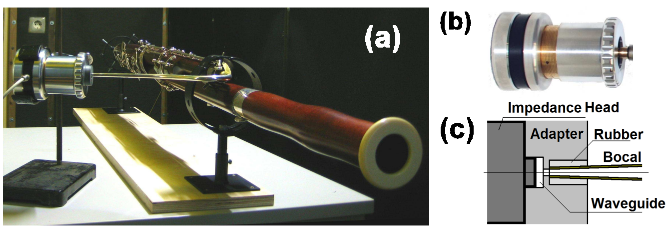

Figure 1: Experimental setup, (a) overview of setup (b) impedance head (c) illustration of adapter to connect the head and instrument

Temperature of the air column

The speed of sound depends on the temperature of the air and will clearly affect the result of an impedance measurement. To assure repeatability, it is important, that there are no temperature gradients along the air column under study. Regarding a bassoon, the wall thickness of body greatly varies: Thick wooden pieces as well as thin metal tubes are used. The tone hole configuration will have a great effect on the spatial temperature distribution.
Therefore, the time span, after which a constant temperature along the air column can be assumed, has to be determined. Several PT 100 temperature sensing elements were placed in a bassoon and the temperature was measured repeatedly after a quite extreme jump of the air temperature of the surrounding from 12.5 to 25 °C. Figure 2 shows the results for two tone hole configurations, where (a) all holes are closed, and (b) most holes are open. Temperature equilibrium at all measurement points was reached approximately 2.5 hours after the temperature change.

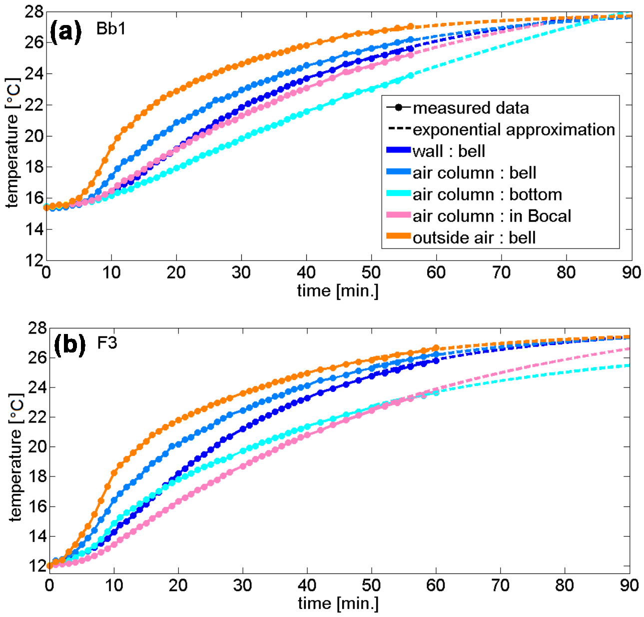

Figure 2: Experimental setup, (a) note Bb1: all tone holes are closed (b) note F3: without fingerings

Systematic Errors – Air Temperature

The result of impedance measurements on a bassoon during a change in the surrounding air temperature are shown in Figure 3 (a). The frequency shift of the impedance maxima is linearly related to the air temperature measured in the bocal (b). The damping of the resonance frequencies rises with temperature. In our measurements the temperature also had a great effect on the impedance magnitudes, especially for the first maximum(c).

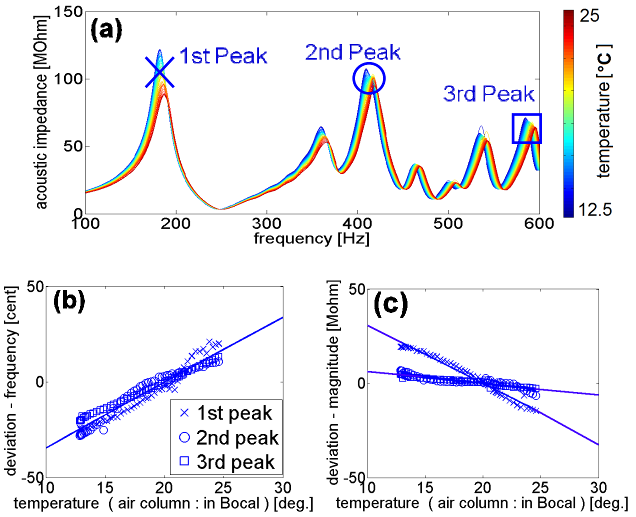

Figure 3: Effect of temperature on the impedance curve (a), deviation in frequency (b) and magnitude (c)

Random Errors – Reproducibility of the measurement

Throughout a period of 2 months, impedance measurements of 3 fingerings on 4 bassoons were performed repeatedly at different random climates after temperature equilibrium, which was assumed to be reached within 2.5 hours. For all bassoons, the same bocal (Heckel CC1) was used. After each of more than 50 measurement sessions, the bocal was disconnected from bassoon the under study and from the impedance head. From the measured curves, extrema were obtained using a parabolic fit on the logarithmic magnitude of impedance near a peak or dip. After removing outliers and the linear temperature trend, the variability of frequency and magnitude of the impedance peaks was analyzed. Figure 4 shows empiric probability density functions of the frequency and magnitude data of a typical measurement (Fundamental peak on B^b1). The variability observed was large and the data did mostly not follow a normal distribution.

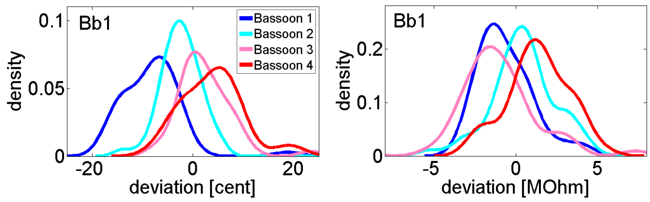

Figure 4: Probability density of 50 measurements of the fundamental impedance peak (B^b1, 58 Hz) in frequency (left) and magnitude (right)

Comparison of four Bassoons

The observed large variability is thought to arise mostly form the non-ideal measurement situation, which we consider to be typical in an instrument makers' workshop. Thus it is interesting, if the data obtained in this manner can be related to differences in the bore and tone hole design of bassoons from 4 different manufacturers. In Figure 5 the results of the harmonic impedance maxima from 0 to 600 Hz on note B^b1, F3 and F4 are shown. Regarding the dispersion measures, the obtained differences of the impedance mean values between these bassoons are very small for the lowest note. Ascending the frequency scale, the differences become more important. Figure 6 shows the standard deviations of both frequency and magnitude of the impedance maxima vs. frequency. From this we estimate the precision of the impedance measurement under the conditions described above to be within 10 cent in frequency and 10% in magnitude.

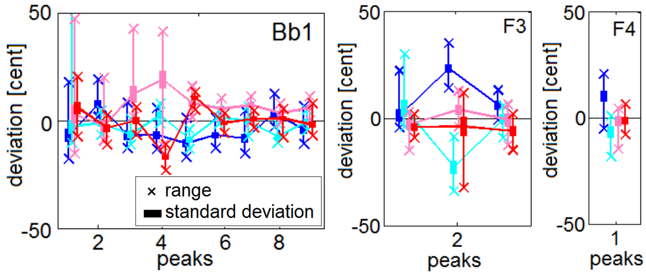

Figure 5: Comparison of 4 Bassoons on notes B^b1, F3 and F4

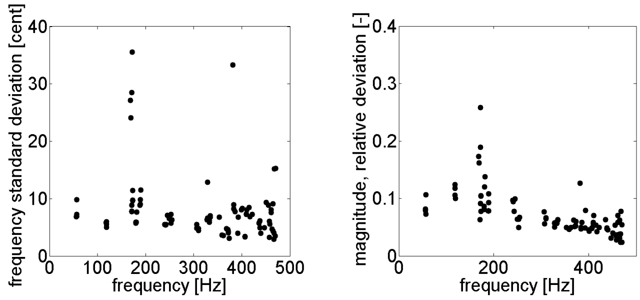

Figure 6: Standard deviation of impedance maxima

Conclusion

In this paper we studied the uncertainty in input impedance measurements on bassoons with a commercial impedance head under conditions typically found in an instrument makers workshop. In order to obtain valuable data, the instrument to be tested should be stored at a constant temperature for at least 2.5 hours. Great care has to be taken of tight fittings (joints, tone holes, connection to impedance head). The differences in impedance maxima between four bassoons observed in this study were rather small, but might be significant. Further studies with an artificial mouth are planned to relate these small differences in the impedance curves to playability features of the instrument in a musical performance.

Acknowledgement

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