Input Impedance Measurement of Bassoons

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Introduction

The linear acoustical properties of a wind instrument resonator are described by the impedance at the input end. Woodwind instruments usually have a complicated geometry with diameter changes, sharp bends and tone holes. To measure the input impedance of the bassoon, we built a remake of an impedance measurement device from John Backus [1], and measured the input impedance of all fingerings on three bassoons from different manufacturers. These curves show some basics of the acoustical performance of the bassoon such as the function of the octave key and auxiliary fingerings. Furthermore we studied the effect of the length and the volume of the double-reed mouthpiece on the input impedance.

Principle

The acoustic impedance is measured indirectly by means of two microphones. Figure 1 shows the equivalent electric circuit of the measurement technique.

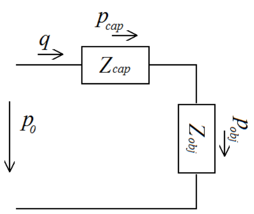

Figure 1: Equivalent electrical circuit for the impedance measurement technique.

The value p_0 is the exciting pressure of the setup, Z_{obj} is the impedance of the measurement object and Z_{cap} is the impedance of the capillary tube. The acoustic flow though the system is given by

$$q = \frac{p_0}{Z_{cap} + Z_{obj}} = \frac{p_{obj}}{Z_{obj}} = const. \quad (1)$$

If q is constant and $Z_{cap} >> Z_{obj}$, the formula can be re written.

$$Z_{obj}(f) \approx Z_{cap}(f) \frac{p_{obj}(f)}{p_0(f)} \quad (2)$$

The impedance of the measurement object can be thus obtained by the ratio of two pressure measurements when the value Z_{cap} is known.

Experimental Setup

Figure 2 shows the measurement setup to measure the input impedance of the bassoon. The speaker (Beyerdynamic DT48 A.0) is used as the sound source, the two microphones (Brüel and Kjaer Type 4938 and Type 4190) are mounted at the speaker and the input end of the instrument to measure the exciting pressure p_0 and the resulting pressure p_{obj}.The input signal is swept sine from 20 to 2000 Hz that was computed by MATLAB and processed via a soundcard (EDIROL UA-25). The capillary tube has a 0.1 mm annular gap to decouple the speaker from the measurement object and thus assure a constant flow through the system. The measurement is carried out in an anechoic room to assure a quiet surrounding.

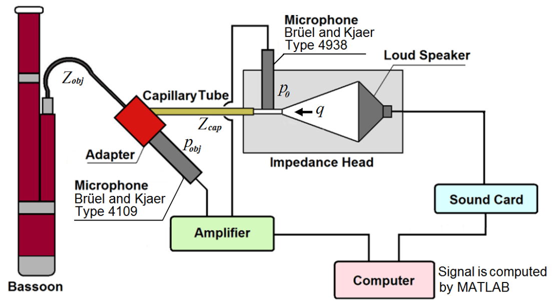

Figure 2: Experimental setup for impedance measurement

Calibration

To determine the impedance of capillary tube Z_{cap}, the impedance curve of a 3 m closed cylindrical tube is used. The quantity is obtained from matching the peaks of the theoretical [2] and the experimental curve.

Results

The impedance curve shows the frequency dependent feedback of the resonator, and some principles of the acoustical performance such as overblowing and the influence of the reed can be demonstrated.

Overblowing

To play the note B^{b}3, the player uses the fingering of B^{b}2 and additionally hits the octave key. Figure 3 shows impedance curves of B^{b}2 and B^{b}3. The first peak shifts down in impedance and up in frequency, and it is not harmonic any

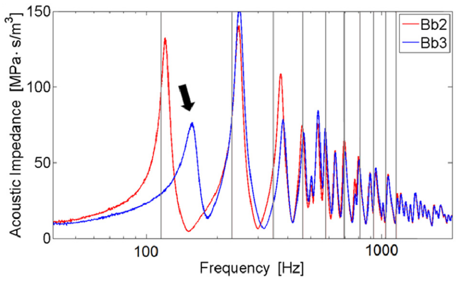

Figure 3: Influence of octave key on impedance curve. The note B^{b}2 shows in red and B^{b}3 shows in blue.

more. The reed catches up the second mode and vibrates at twice the fundamental frequency. This regime of oscillation is very stable, so the sounding pitch will remain, even if the player releases the key.

Alternative fingering: E^b key

Bassoon players usually know more than one fingering for certain notes to compensate for intonation problems or to achieve different timbres. There are two fingerings to play the note G3, with and without the E^b key. Figure 4 shows impedance curves of two fingerings. The opened E^b hole changes the impedance spectrum from 500 Hz to 1000 Hz and slightly lowers the fundamental frequency by 6 cents. Figure 5 shows the sound spectrum of these fingerings. The 2nd and 5th harmonic is increased, and the sounding pitch is strongly lowered by 20 cents.

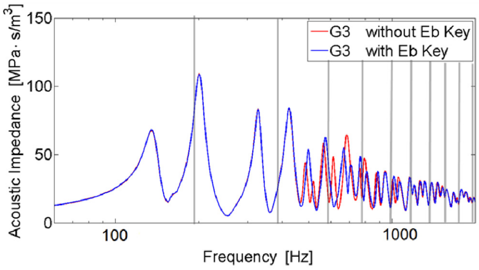

Figure 4: Influence of the E^b hole on the impedance curve. Fingering G3 with opened E^b key shows in blue, without E^b key shows in red.

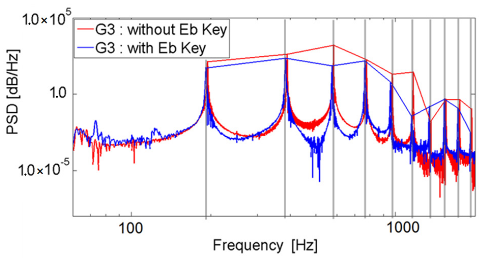

Figure 5: Influence of the E^b hole on the sound spectrum.

Impedance and tuning

Figure 6 shows the comparison of the fundamental frequency of the air column and the sounding frequency with the equally tempered scale. (A4 = 443Hz) The fundamental frequency of the air column (without reed) is higher than the sounding frequency especially for the notes higher than $G^{\#}2$, and this discrepancy rises with pitch. The first impedance peak of highest note is about 1.5 semitones higher than the sounding frequency.

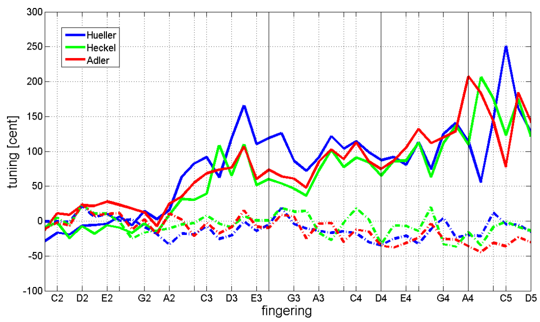

Figure 6: The comparison of the impedance and tuning. Solid line shows the fundamental frequency of air column, and dashed lines show the sounding frequency while playing the instrument.

Effect of the Reed Volume

To examine the effect of the reed volume, a cylindrical adapter of the same length as double reed is mounted between bocal and measurement head. The volume can be increased by a piston that is mounted orthogonally to the axis of the main bore. Figure 7 shows the frequency of the first impedance peak for several added volumes. Increasing the volume lowers the fundamental frequency. Figure 8 shows impedance curves for several volumes. The added volume has a little effect on the magnitude of impedances up to 400 Hz, however damping of the impedance peaks can be seen as higher frequencies.

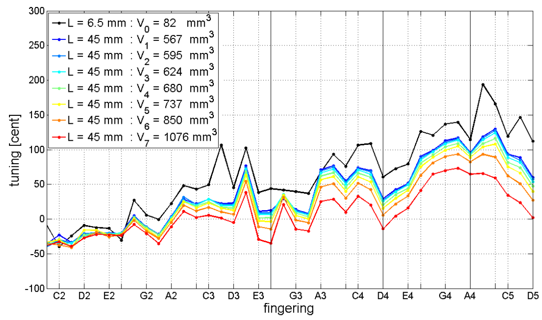

Figure 7: The frequency of the first impedance peak for several added volumes.

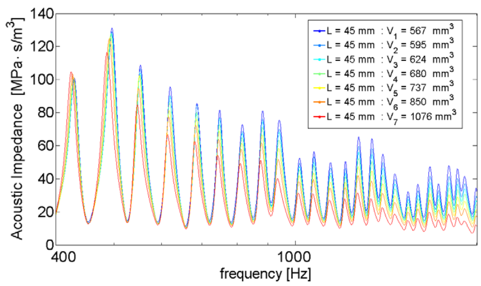

Figure 8: Impedance curves for several volumes on the lowest note B^b1 (f_0 = 58 Hz).

Conclusion

In this paper we investigated the acoustic impedances of the bassoon with an experimental approach. The basic acoustic properties of this instrument such as overblowing and alternative fingerings can be understood by the impedance curve. Between the fundamental frequency of the air column and the sounding frequency caused by player there are large discrepancies especially for higher notes. Increasing the volume at the mouthpiece lowers the fundamental frequency of the air column and damps the impedance peaks above 400 Hz.

References

[1] Backus J., Input impedance curves of reed woodwind instrument, JASA, 56 (1974), 1266 – 1279

[2] Plitnik G.R., Strong W.J., Numerical method for calculating input impedances of the oboe, JASA, 65 (1979), 816-825