AN ACOUSTICAL ANALYSIS OF WAVE-LINE FLUTE TUBE JOINTS

Michael Lind, Alexander Mayer

Institute of Music Acoustics
University of Music and Performing Arts Vienna, Austria
`michael_lind@gmx.at, mayer@mdw.ac.at`

ABSTRACT

The object of this paper is the acoustical research of the Waveline flute. For an overall length reduction of this special children instrument, an omega-shaped joint instead of a straight tube is placed between the flute's head and the main tube. For this analysis the flute is alternately combined with four joint prototypes varying in bore. These different flute setups are compared using two measurement methods. The distinctions in intonation are determined by using an adapted Brass Instrument Analysis System (BIAS). For a sound comparison an artificial embouchure system has been developed. High-speed video recordings of the emerging jet supported the design. The results of the obtained data indicate distinctive differences in the acoustical behaviour in terms of intonation, sound and response.

1. INTRODUCTION

Learning musical instruments often starts in childhood. Some instruments are available in smaller sizes to fit to the proportions and make it easier to be played by children. To allow an early start learning the transverse flute, a reduction of the overall length would be necessary - but this would also change the tune. One solution provides a setup of the Waveline flute [1] (see Figure 1). Here an omega-shaped tube is inserted between the barrel and the head-joint (see Figure 2). The approach of this setting is, that the mouthpiece and flute body will still be arranged on the same axis. As this type of Instrument is already sold, the inventor still tries to optimize and improve the omega bow in terms of better acoustical characteristics, like intonation and response.

Figure 1: The ergonomic approach of the Waveline patent ([1] and [2]); comparison of spine bending while playing standard flute (left) and the Waveline flute (right).

The head-joint terminates with a different inner diameter as the bodyjoint starts. Therefore the Waveline joint represents a transition piece to fit to both dimensions. Three of the four prototypes tested vary in the arrangement of bore alteration (see Figure 3).

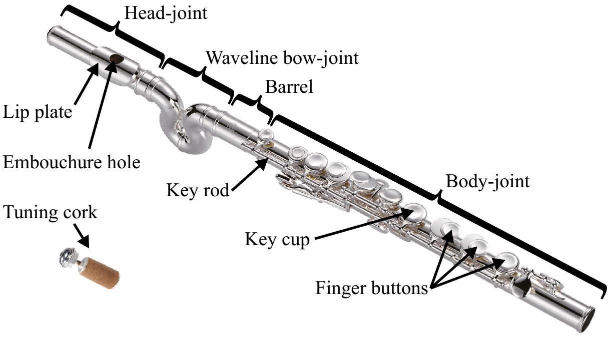

Figure 2: The Waveline flute and its components. As in all flutes the tuning cork is inserted into the head-joint.

2. THE PROTOTYPES

For a better intonation the bore of a standard flute is not shaped strictly cylindrical. Measured from the tuning cork inside the head-joint till the inner ending of the barrel, the head-joint diameter expands from about 17 mm to 19 mm. If the resulting cone is transferred to the Waveline flute, the bore of the bow-joint will also have to increase. The production of step-less conical and bent tubes (especially for small radii) will turn into an expensive process. Because of this high effort the currently sold bow-joint is manufactured with a stepped expanding bore (Figure 3, Type I).

2.1. Prototype bore configuration

As prototyping is much easier using synthetic material the joints where made out of glued-together half-shell parts. The desired bore was milled out by an CNC-Mill. As reference and comparison an additional plastic prototype was milled out having the same bore as the original metal Waveline joint (Type I).

Type I (Figure 3, left): The transition from the diameter of the end of the head-joint (17.8 mm) to the diameter of the main tube (19 mm) takes place in two steps. The first step is positioned at the start of the bow-joint, where the head-joint ends with a diameter of 17.8 mm and the bow-joint starts with a diameter of 18.3 mm. The position of the second step is on half way of the second bow: The diameter changes from 18.3 mm to the final diameter of 19 mm.

Type II (Figure 3, middle): This prototype features one step of rising in diameter at the start of the bow-joint: from 17.8 mm mm to 18.3 mm. The transition to the diameter of 19 mm at the position half way of the second bow happens continuously.

Type III (Figure 3, right): The rise of diameter from the end of the head-joint (17.8 mm) to the terminal diameter of 19 mm happens step-less. The diameter of 19 mm is reached at the position half way of the second bow.

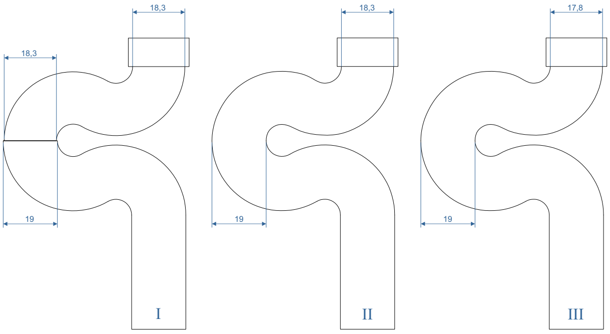

Figure 3: Bore of joint prototypes, from left to right: Type I, Type II and Type III

3. ARTIFICIAL MOUTH

Playing the flute a large variety of parameters have to be considered ([3] and [4]). These are:

- distance from the lip opening to the sharp edge
- embouchure angle
- vertical displacement to the sharp edge
- coverage of the embouchure hole
- shape and cross section lip opening
- air pressure inside the oral cavity and the resulting flow rate
- capacity of the oral cavity

While playing the flute, musicians tend to vary the embouchure parameters mostly unconsciously to match the flutes sound to their expectation. Differences of the acoustical behaviour of flutes can be equalized by most musicians in a wide range. As the influence of the analysed bow-joints on the acoustics of the flute is expected with only subtle distinctions, human playing tests have been taken out of consideration [5].

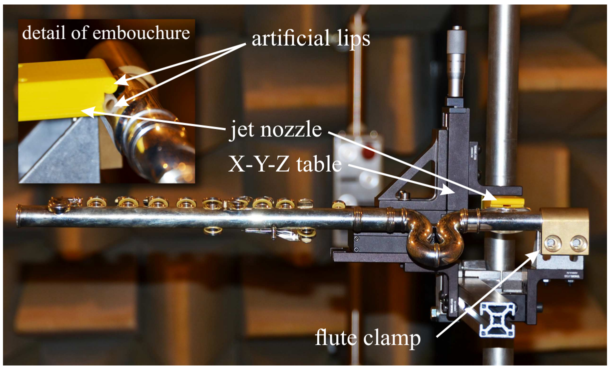

Figure 4: Setup of the artificial mouth system. The yellow plastic jet nozzle with its artificial lips presents the center piece of the artificial mouth.

To ensure an objective and reproducible analysis an artificial mouth was developed (Figure 4). The basic setup links the head-joint and jet nozzle to allow repeatable adjustments in the embouchure angle and the vertical and horizontal distance from the lip opening to the sharp edge. The head-joint is hold by a special flute clamp. An attached angle meter provides a readout of the current angle setting. The artificial mouth sits on a x-y-z table, micrometer screws allow fine adjustments on the desired distances. The air pressure needed to enforce a jet is generated by an air compressor. A digital air pressure sensor attached to the artificial mouth monitors the actual pressure setting.

3.1. Jet nozzle design

While a human player changes the lip gap depending on the desired note and loudness [6], the jet nozzle design should be as simple as possible. Still the artificial excitation should provide a wide range of possible notes including overblowed tones. First attempts were done by using a rectangular brass profile (5.4 mm by 2.25 mm). Although the excitation of the instrument was a success, the sound was poor in quality with a focus on the first harmonic. In general the response was insufficient for this analysis. Changing the nozzle cross section into an elliptical shape did not solve the problem. In the next step, high speed video recordings were done, to investigate jet formation.

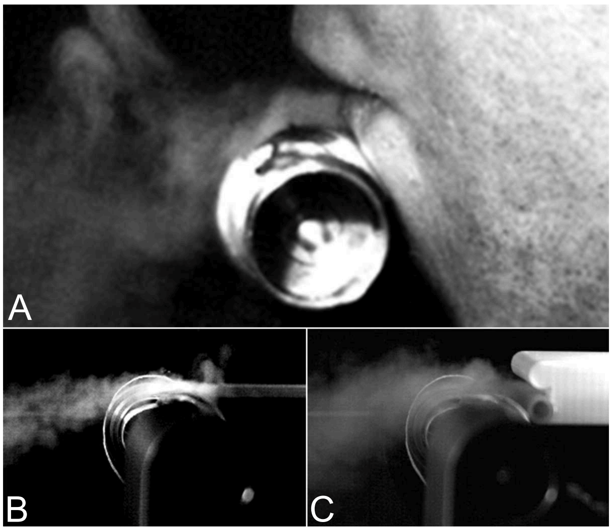

Figure 5: Three excitations in comparison: Jet formed by a human player (A), a rectangular brass profile (B)and by the final nozzle setup (C).

Smoke was used to ensure the visibility of the jet formed (see Figure 5). Although the examination of the recorded videos will show the differences very clear, the pictures shown, can indicate just a tendency. The slow-motion recordings of all constructions can be watched via the website `http://iwk.mdw.ac.at/am`. The jet formed by a human player (Figure 5/A) features a more diffused and swirled flow than the flow stimulated by the brass tube (Figure 5/B). The assumption that the musicians lips are causing a deflection, leads to the jet nozzle design drawn in Figure 6. As the bore of the construction is more complex, the final nozzle arrangement was created using rapid prototyping technology.

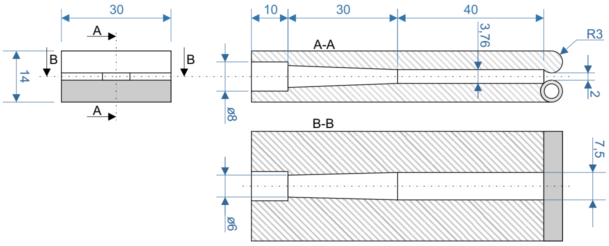

Figure 6: Technical drawing of the 3d plotted plastic jet nozzle (all measures in mm), for an airtight closure at the lip plate the lower artificial lip is made out of silicon tubing.

3.2. Final settings of the artificial mouth system

Following settings where chosen to excite the flute with the artificial mouth:

- angle between the center-axis of the jet nozzle and the upper side of the Embouchure hole: 50°
- distance from the narrowest spot of the nozzle to the sharp edge of the embouchure hole: 8.73 mm
- vertical offset of the center of the nozzle to the sharp edge of the embouchure hole: 1.07 mm
- air pressure: from d4 to d#5: 350 Pa; from e5 to g5: 1000 Pa

4. ADAPTED BIAS

The Brass Instrument Analysis System (BIAS) [7] has been used to determine the resonance frequencies of the flute. This system consists of a measuring head and the BIAS 7 control and analysis software package. To allow a measuring of the impedance at the position of the stopper, the head-joint had to be prepared. To enable the attachment of the BIAS measuring head on the correct position the head-joint had to be shortened. A special silicon-ring ensures an airtight connection. While playing the instrument, a musician partly covers the embouchure hole with his/her lip (embouchure hole correction) [8]. For the measurement a fixed embouchure hole masking has to be applied to ensure a constant coverage (see also Figure 7).

Figure 7: Flute with trimmed head-joint connected to BIAS.

5. DISCUSSION OF THE MEASUREMENTS

The bow-joints had to be measured under the following aspects:

- Intonation of resonances
- Sounding intonation
- Maximum pressure for playing in the low register
- Normalized spectral centroid
- RMS of the amplitude

For each bow-joint connected and each measurement the flute was tuned at a4 with 440 Hz.

5.1. Intonation of the resonance frequencies:

At the low pitches of the first register (lowest note d4), the intonation proved to be lower than zero cents. At pitches above a4 in the first register (to the c#5) the intonation measures values above zero cents. This results in an overall stretch in intonation from d4 to c#5 (deepest possible to highest possible fingering in the first register). The highest stretch rate can be observed evaluating the measurements of the metal bow-joint (see Figure 8). Bow-joint II feature the lowest stretch of intonation. It is remarkable, that the differences between bow-joint I and the metal bow-joint are relatively high, though they are constructed having the same dimensions in bore.

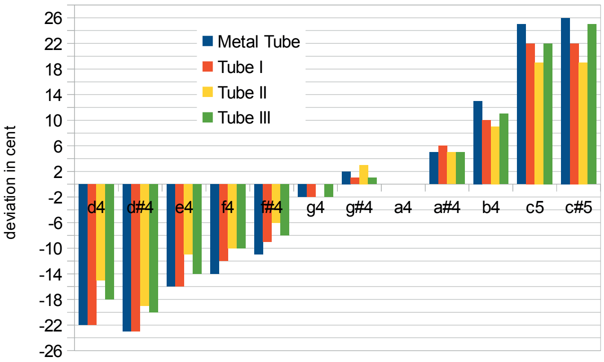

Figure 8: Resonance

5.2. Sounding intonation

Due to the edgetone-mechanism, the sounding intonation compared to the resonance gets lower with rising pitch [9]. The above mentioned stretch in intonation of the resonance frequencies counteracts this tendency. The lowering of intonation with higher pitch is even bigger than the counteracting rising intonation of the resonance-frequencies. The effect is an overall shrinkage of intonation from the deepest to the highest fingering in the first register (d4 to c#5).

As pictured in Figure 9 the original bow-joint (Metal Tube) features the lowest values of intonation shrinkage. Conversely bow-joint II shows the biggest amount of shrinkage. The differences between the metal bow-joint and bow-joint I are again significant despite their same construction-features.

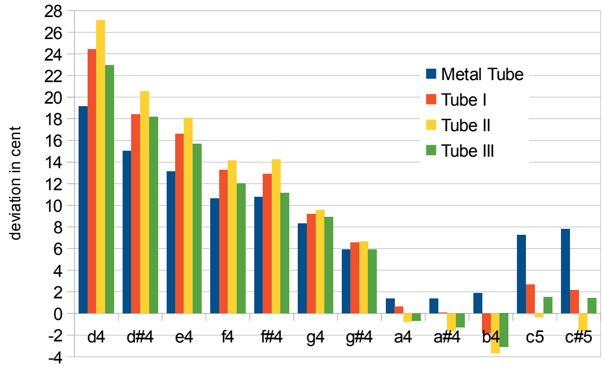

Figure 9: Sounding Intonation

5.3. Maximum pressure for playing in the low register

For musicians it is desirable, to have the possibility to play the flute with high blowing pressure without overblowing to the next register. In the bar-graph of Figure 10 the results of such measurements are presented. In general the maximum values are depending on the chosen fingerings corresponding to the excited note. Comparing the four bow-joint types no significant differences can be identified. In average bow-joint II indicates the widest pressure range. Therefore it can be played in most measured notes with the highest possible pressure, before changing to the second register.

5.4. Normalized spectral centroid

To discriminate the timbre of sounds, the difference of the normalized spectral centroid related to the fundamental frequency

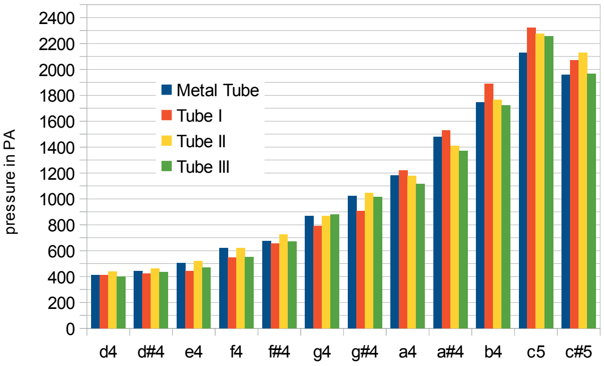

Figure 10: Maximum pressure for playing in the low register.

has to be at least at a value of 0.2 [10]. These differences are present at about one third of the measured fingerings: d4, d#4, c#5, d5, e5, f5, g5 in Figure 11. The values have been determined by using the soft-ware MQAN [11]. Referring to the calculated results, a continuous grading of the bow-joints is not discernible. At most fingerings bow-joint III features low to lowest values. This leads to the assumption, that the use of bow-joint III will result in the overall warmest and darkest sound.

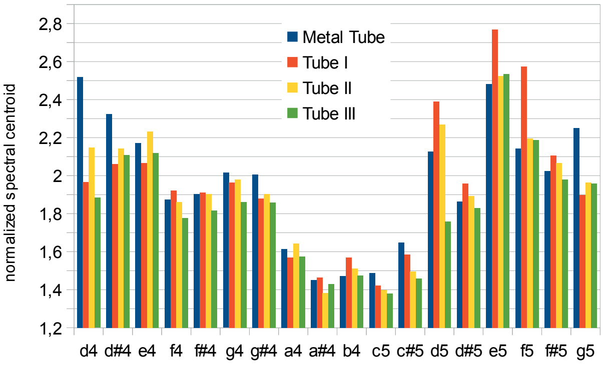

Figure 11: Normalized spectral centroid

5.5. RMS of the amplitude

As plotted in Figure 12 there is no bow-joint configuration, which RMS Amplitude measures the highest values over all fingerings. The y-axis of Figure 12 displays the unweighed values of the Amplitude in dB. The values have been related to the measured sound-level at 1000 Hz in dBA. The Microphone was placed at one meter in front of the center of the flute.

6. CONCLUSIONS

The setup of the artificial mouth proved to excite the flute reproducibly. The comparison of slow-motion videos of the jet exiting the human lips and different artificial nozzles lead to a special jet-nozzle design, which fits to the demanded specifications.

The results of the analysis of the different types of bow-joints clearly yield the high sensitivity of the instrument on small bore changes. A direct comparison of the values measured of the original metal- and type I bow-joint diverge more than expected. Tolerances in production or the influence of material can have caused this variations, and will be a main aspect in further analysis.

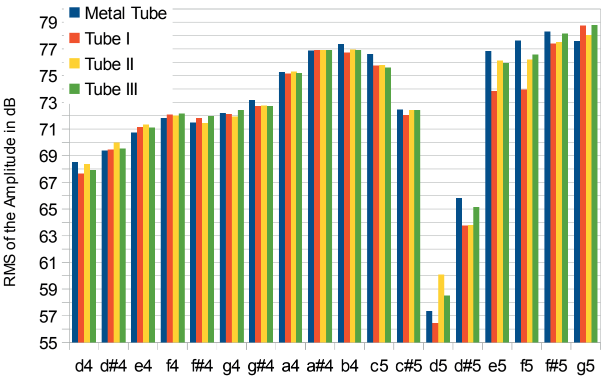

Figure 12: RMS of the amplitude

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