BRIDGING INSTRUMENT CONTROL ASPECTS OF BRASS INSTRUMENTS WITH PHYSICS-BASED PARAMETERS

Matthias Bertsch

Institute for Musical Acoustics (IWK), University of Music Vienna, Austria

Bertsch@mdw.ac.at

ABSTRACT

Is there a connection between what we feel when playing an instrument and what we can measure? Physical models and measuring tools have been developed to provide a better understanding of brass instruments and objective physical documentation of their acoustics.

Musicians and instrument makers still criticize the enormous gaps between the physics-based parameters and the empirically reported feelings of brass players on quality aspects of their instruments. Deviations between played and measured parameters like intonation and their variability have already been focused on in earlier studies. Attempts at finding a theoretical explanation of these deviations using physical modeling continue.

For musicians, one of the most important quality factors of a brass instrument is its response. A new series of playing tests has been designed to correlate empirical data with objective physical parameters (impedance measurements). International instrument makers provided special test instruments (modular trumpets). This paper will examine the difficulties in defining response and setting up suitable playing tests.

1. INTRODUCTION

Brass instrument makers produce and customize their brass instruments for players who have many different requirements and expectations of their ideal instrument. The manufacturing knowledge has developed through the centuries. Today, there are many good instruments on the market and the selection is large. One can choose between “rather similar” instruments built in large series by factories and custom-made smaller series or even handmade or adjusted “singular instruments”. So how can one find his optimal instrument without testing all of them? For beginners it is usually the advice of the teacher or the dealer, which narrows the choice. Those who start to test instruments usually quickly realize how difficult this procedure is. There are many criteria. On the one hand there is the sound quality and on the other hand there are the many aspects of instrument control parameters. The main criterion for the musician in choosing his instrument is the specific sound and timbre. Preferences about sound quality are individual and hard to describe with verbal attributes. It also depends on the specific interaction with the input of the player. Instrument makers’ descriptions of instrument parameters are for the most part very similar: perfect intonation, easy speaking, full sound, good response and more or less resistance. Of course, there are differences between those instruments, but there is little experience in labeling the parameters. You cannot simply look at a table and compare features as you do when you shop for a car or loudspeaker. Quality control of brass instruments is still chiefly done through subjective criteria of test players. Reproducibility is difficult to control.

1.1 Measurement tools and previous studies

Since the 1980s, acousticians have been asked to deliver objective quality control tools. Meanwhile there are hardware and software systems that can measure the input impedance of brass instruments, which are easy to use [1]. The impedance measurement data represents an acoustic fingerprint of the total behavior of an instrument. One curve corresponds to one physical geometry of an instrument. But what do these curves tell the musician?

One feature of the impedance curve had almost immediately been translated into musical terms. The positions of the peaks correspond with the intonation of the notes. The measurement allows the detection of deviations to a reference intonation. The Brass Instrument Analysis System (BIAS) developed at the Institute for Musical Acoustics (IWK) at the Music University in Vienna can accurately show the intonation of all playable notes of a brass instrument. Earlier studies by the author have been done to determine the intonation properties of trumpets [2]. Empirical data of played trumpets have been compared with different theoretical tuning systems and with the intonation, which was calculated by means of input impedance measurements. The results showed great differences amongst players even playing the same reference instrument. The arithmetic mean over all trials correlated best with the calculated objective intonation. This information is already a big help for both makers and players in evaluating instruments. Additionally, new optimization tools can already help to correct problems of existing instruments by bore profile modifications and they can be used in developing new instruments by calculating the intonation with computer models before the instrument is built.

1.2 More questions remain

So what about other instrument control aspects? Do they also correspond to physics-based parameters? Acousticians expect that they do. Thomas Moore wrote in his article for trumpet players: “the sound and feel of every horn is definitely determined by its impedance spectrum” [3]. But how can you measure the feel of the horn? The language of musicians describing instrument properties is not easily translated into physical terms. Even when they use the same words, the meaning can be different. So far, it is not clear that what all players label “good response”, “easy speaking” or “low resistance” are the same. Also, most players have little theoretical understanding about tone production. Our approach is to find a common language for players to report tone control parameters and to translate them into acoustical terms. The objective is to find an answer for a simple question: which factors make a trumpet speak well? What does the player, the mouthpiece, the bore, the shape or even the material have to do with it all? What can be changed to improve the response of a given instrument? The following example of practical relevance can show the need for these answers: While writing this introduction I received a phone call from an instrument maker. There is an almost perfect horn played by professional musician. The intonation is perfect; except that one note does not speak well if played piano. He asked what he should change on the instrument. I gave an answer, but I hope that we find a better answer as the ongoing project progresses.

1.3 Aims

The aims of the trumpet research project (TRP) are to define what 'response' can mean (there are many varying meanings), and to find physical parameters that can be used in further calculations and measurements. Preferences of different player types (classical, jazz, etc.) for these physical parameters are searched. This would allow computerized optimization of real instruments. Bridging the languages of musicians ("this trumpet feels good"), acousticians ("how much impedance is at this frequency") and instrument makers ("I could use a wider bore or different material") will help to create tools for developing better instruments.

2. METHODS

Several methods are used in this ongoing study. The planned methods include playing tests, input impedance measurements, bore reconstructions and finally the correlation of all data.

2.1 Playing tests setup

Blind performance tests and regular playing tests with outstanding professional trumpet players and with groups of musicians in Austria, Finland and the USA will deliver empirical data on specific test instruments. Different international instrument makers provide the test instruments. Playing tests are made with Bb trumpets with Périnet valves and German system trumpets with rotary valves. Some instruments are built modularly, such that the leadpipe, tuning slide and the bell can be changed. Information about makers is kept confidential during the playing tests so that players do not know what brand, model or setup of modular instrument they are playing. Tests are performed in a dark room (or with blindfold) and a questionnaire for each setup is answered. Information on the experience and preferences of the players are also requested. All data are organized in a database with search, sort and export functions.

2.2 Playing test questionnaire

Instrument control aspects are highly trained competence of musicians, but the knowledge is developing without unified verbal attributions. This is a well know problem of acoustician to deal with. Earlier tests by Wogram [4] have been taken into account. A new approach in this study is to proceed with the support of "images" and visualization. The player gives answers and the tester fills out the questionnaire. Sometime this includes translating expressed feelings. A typical difficulty is to quantify the value of a given aspect. In this questionnaire the player has five possible values ("-2","-1","0","+1","+2"), but he can use his own personal reference. The answer "0" corresponds to "neutral, normal" Answers of "+1" indicate more, "+2" much more of a given aspect (respectively "-1" is less and "-2" is much less). During testing the player develops his own scale.

Questions about the subjective sound preference and description of the sound quality:

- Dynamic range: small - normal - large
- Timbre: dark - neutral bright
- Timbre: dull - neutral - brilliant
- Small sound - normal - full sound
- Boring, hard to modulate, - normal - rich colors
- I don't like it - Don't know - I like it
- Sound volume: small - normal - large
- Sound projection: poor - normal - good
- Tendency to sound brassy: low - normal – high

Questions about the starting phase of a note: (The question focus specifically on g4 and g5 as open series and with valve 1 and 3 engaged):

- How fast is the attack (soft versus quick onset)
- Ease of staccato and repetitions, How quickly can you repeat very fast notes pp and ff
- Soft versus abrupt slurs (B4-C5, C5-Eb5)
- Easy to play ppp? How much effort do you need to play a note? How easy does it speak?

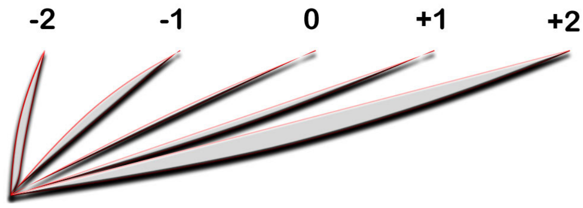

Figure 1: *Schematic representation to ask for the attack*: *"How fast do you get feedback when you start blowing"*

Question about the control aspects of a sustained note:

- Blowing resistance (forte)
- Air volume: Amount of energy (air) needed to sustain a note.
- Intonation of given notes
- Slotting pitch: enough or too much flexibility (how easy can you "lip up" and "lip down"?)

Figure 2*: Schematic diagram to ask for slotting pitch. The deepness and shape represents the flexibility of the pitch center.*

Classification of the instrument. The players are asked to judge about:

- Adequate user player level (beginner, student, pro),

- The type of music this instrument is best suited for (classical, jazz/pop or both)
- The applicability for all ranges, high or low register

Additional questions on mechanical and optical aspects (not in blind tests) are asked (Fast valve action... lightweight / heavyweight, Conception and assembly; finish) Finally the total preference is asked.

2.2 Measurements

All instruments and combinations of modular parts are measured with the BIAS system [2]. Several physics-based parameters are extracted from the input impedance measurement. Besides the peak frequencies, the shape of the peaks and the "0" phase position are taken into account. For each peak, the following values are calculated:

- **Offset**: Intonation given by the impedance peak center frequency. Intonation error related to the equal temperature in Cent. Tuning reference frequency is adjusted in order to minimize the overall intonation error of all playable notes.
- **Envelope**: Absolute peak height of impedance peak in MegOhm
- **Curvature**: Absolute value of the 2nd derivative of impedance curve at peak center in MegOhm/Hz^2. Calculated as parabolic fit using the Savitzky-Golay convolution.
- **Low3dbLimit**: Distance of left peak edge (-3dB) from peak center in Cent.
- **High3dbLimit**: Distance of right peak edge (-3dB) from peak center in Cent
- **Bandwidth**: Low3dbLimit plus High3dblimit. (Inverse Q factor in Cent)
- **Phase**: Phase value at peak center in Rad. Should be close to zero at least for prominent peaks.
- **Groupdelay**: Group delay, 1st derivative of impedance phase at peak center in Rad/Hz.
- **ZeroPhase:** Intonation given by zero phase frequency. Intonation error related to the equal temperature in Cent. Tuning reference frequency is adjusted in order to minimize the overall intonation error of all playable notes.

For a detailed analysis of input impedance peaks, the shift of the position and of the amplitudes of all higher peaks has to be taken into account. Weighting Functions in the BIAS system allow considering the sum function of the excitation spectra of the lip.

2.3 Bore reconstruction:

Different impedance curves correspond to different bore profiles. Recent studies of Kausel [5,6,7] in calculating the profile from input impedance measurements demonstrate a further development in this technique. To compare these data with special leadpipes used for playing tests, digital X-RAY measurements have been done to document their geometrical difference. Small changes in the bore and mouthpiece have strong impact on difference "response" parameters.

2.4 Correlation:

The main step is to correlate the data of the playing tests to those of the input impedance, and to the bore profiles. The questionnaire delivers values, which can be used for calculations. First, it will be necessary to find dependent and independent variables. As documented in earlier studies, reasons for variability in trumpet sounds are enormous [8].

3. PRELIMINARY STUDIES

3.1 Three leadpipes

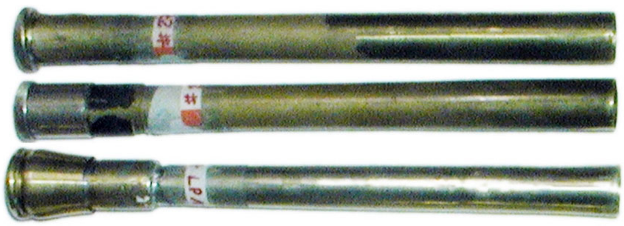

Figure 3: Three different leadpipes for a rotary trumpet.

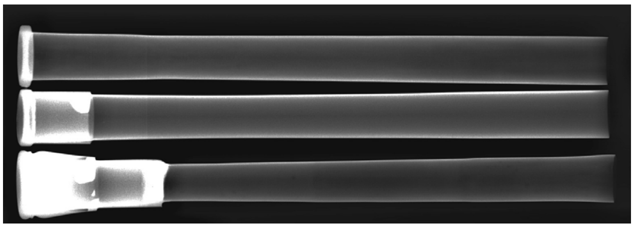

Figure 4: X-RAY images of above leadpipes

Different leadpipes can influence many aspects of a given instrument. Timbre, intonation, and several response factors are changed together with the input impedance. Figure 5 shows the impedance of trumpet #27 with the three leadpipes shown in Fig. 3 and 4. The absolute height and the shape of the peak that corresponds to the note g4 are different. This note can also be played with valve combination 1+3. The impedance peaks for this fingering is also plotted in Fig. 5. Musicians testing these instruments feel and hear differences, and more tests are necessary to find dependent and independent variables. A large number of tests repeated without knowledge of the players will determine the reproducibility of the tests.

3.2 Extra keys for response support

Some professional players and students in Vienna use rotary trumpets with additional keys (see Fig. 6) to support the response of tones in the high register. As can be seen in Fig. 7, the keys have a similar function to those on (non-original) historic trumpets. When the additional key is engaged, e.g. the "C" key, the impedance at this note is similar, while those at the neighbor's frequencies are much more changed. For this instrument, the peak height of the played note increased with two keys and decreased with two other keys. More tests should be done to find to what extent these keys help psychologically for the "high note syndrome", or if they actually improve the response. (The keys are pressed only to start a note and not to sustain it!)

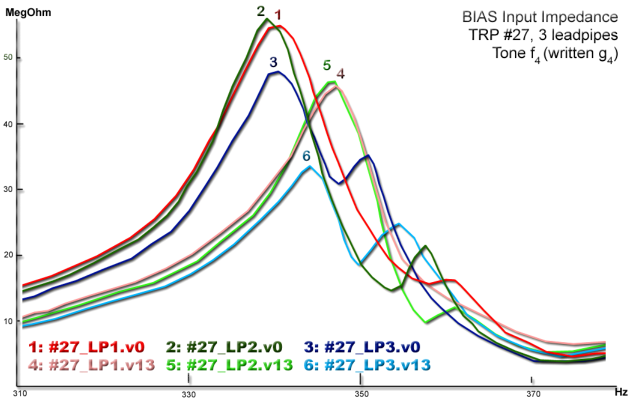

Figure 5: *Impedance peaks for g4 (written f3) at 340 Hz. of one trumpet with three leadpipes. The peaks 1-3 are without valves and peaks 4-6 are with valve 1+3 engaged.*

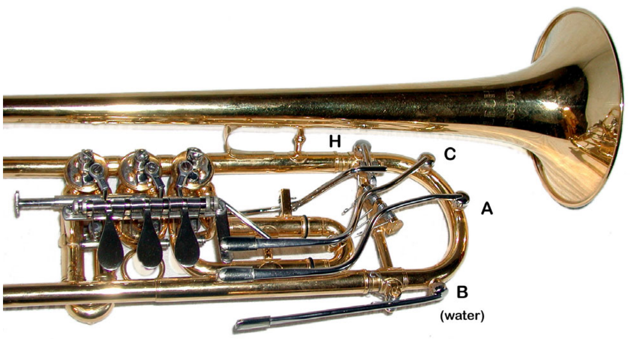

Figure 6: *rotary trumpet with additional keys to support the response of higher tones. The regular water key is used for "Bb5" and "D6", additional ones for "A5" "C6" and "H5".*

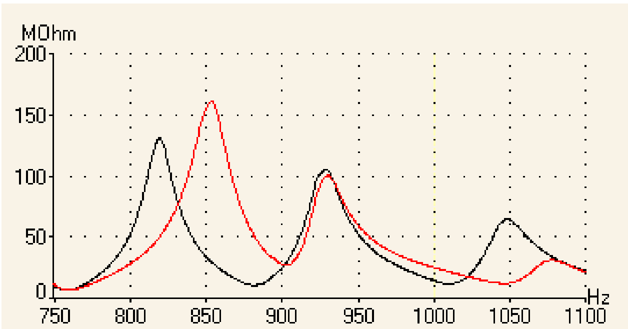

Figure 7: *Impedance for the written c5 (sounding Bb4) at 930Hz with (red) without (black) the addition C-key engaged. The peak at this frequency changes slightly compared to dramatically changes of the total curve. The shift of the position and amplitude of all higher peaks has a significant influence on the played note.*

4 SUMMARY

Preliminary studies have been done in 2002 for setting up the large-scale tests. The playing tests are being performed from March to June 2003 in Vienna and further tests with the same instruments are planned in other countries (Finland, USA,) to evaluate regional preferences and variations of schools. Playing tests are very difficult sensory evaluation tests, which depend on many aspects. Several psychological aspects have to be taken into account. Therefore, the tests will be performed without seeing the instrument and knowing about brand names; otherwise the expectations about brands and visual impressions can easily dominate the "feeling" of the musician. The expected results will help musicians to find their individual ideal instrument and deliver new tools for instrument makers.

5 REFERENCES

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Further information can be found through the website of the Institute for Musical Acoustics:

http://www.bias.at/TRP