IMPROVING A G-HIGH CLARINET USING MEASUREMENT DATA AND AN ELECTRONIC CIRCUIT ANALYSIS PROGRAM

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ABSTRACT

Electromechanical and electroacoustical analogies are widely used in mechanics and acoustics. Highly developed theories for electric networks, including sources, inductive, capacitive and resistive elements, as well as resonating circuits, electrical lines, etc. can thus be directly used to simulate the behaviour of musical instruments [1].

There exist special Circuit Analysis Programs, such as Micro Cap [2], that are useful for simulating complex electrical networks. Applying the above mentioned analogies, these tools can be used in different ways to simulate characteristics of wind instruments, such as input impedance, transient behaviour, spectra, etc.

The authors have developed special so called “macros” that allow a convenient application of the software tool for mechanical and acoustical systems.

A method was developed to simulate a complete clarinet body (without reed and mouthpiece). This method was then used successfully to develop a new G-high clarinet, a special Viennese instrument, called Picksuesses Hoelzl and used in Schrammelmusik. How this was done, also with the help of BIAS [3] will be described in detail in the article.

The purpose of this paper is to show the possibilities that exist, using software-based models of wind instruments, especially of clarinets. It is not meant to be a recipe for instrument manufacturers. Intensive training would be needed to use the described method in practice.

1. INTRODUCTION

1.1 The software model

The model of the clarinet comprises a combination of electrical elements. Some of these elements are part of the original software package of the Electronic Circuit Analysis Program, others are specially developed macros (electric circuits with inputs and outputs that are building blocks for the software model). Examples for the originally available elements are electric wires, current sensors (ampere meters), current and voltage sources and measuring points (nodes).

The specially developed macros include tubes, holes radiators, etc.. The macros have special shapes, so that the structure of the model can be understood intuitively.

An example of a macro is a lossy cylindrical tube of freely definable length, diameter and number in parallel (Fig. 1). All physical dimensions used are in SI-units and not explicitly given in the schematics. Therefore 11.2m in Fig. 1 means 11.2mm, 11 alone would stand for 11 meter. Several tubes of the same length and diameter could be connected in parallel. For a single tube N has to be set to 1 (the only case needed for a wind instrument). These physical dimensions are the numerical input to the macros.

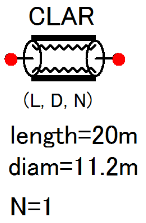

Fig. 1, Representation of a tube macro

Inside the macro there are several electrical elements and formulae to describe its detailed function (Fig. 2). The physics of the needed elements can be found in the literature, see [4] as an example.

The complete circuit of the G-high clarinet, including impedance sensor and radiator is shown in Fig. 3. This is meant to show the overall view of the model and to demonstrate its structure. The macros for sideholes can be seen, including the values for diameter, depth, diameter of the pad and pad-opening. Additionally the macro for lossy conical tube and cylindrical tubes is shown together with the lengths and diameters. The fingering for this clarinet is the same as for all German-type instruments.

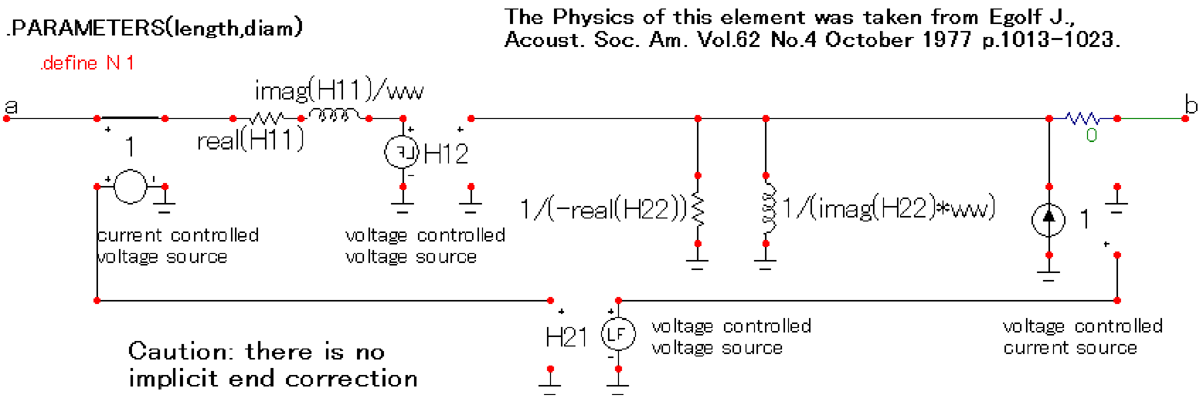

Fig. 2, Circuit inside a macro

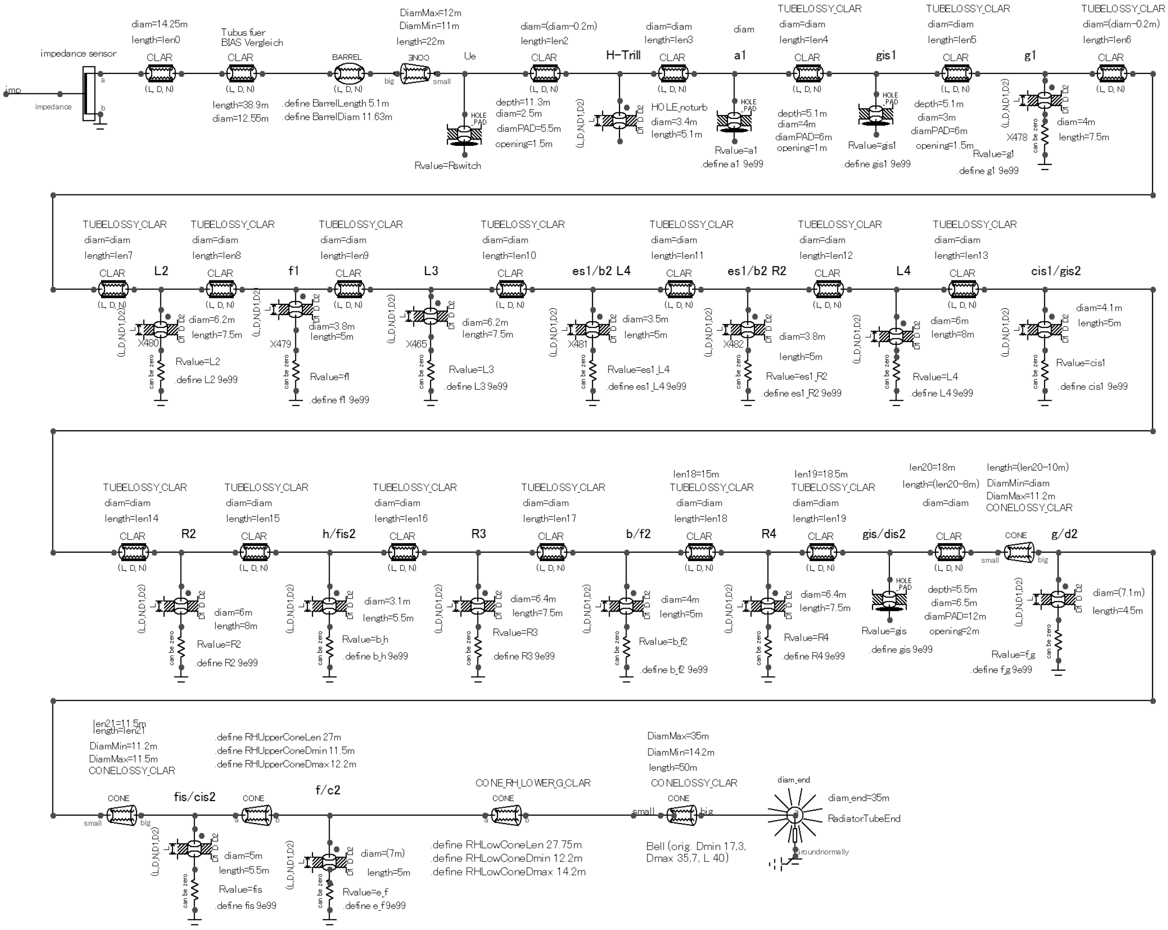

Fig. 3, Circuit diagram of a complete clarinet

Fig. 4 shows the result of the simulation for the impedances from B5 to C6 (fingered tones). Similar graphs also exist for the other playing registers of the clarinet. While the analysis is running, a so called stepping procedure is operational. That means that the opening or closing of side-holes is simulated, according to the correct fingering of each tone.

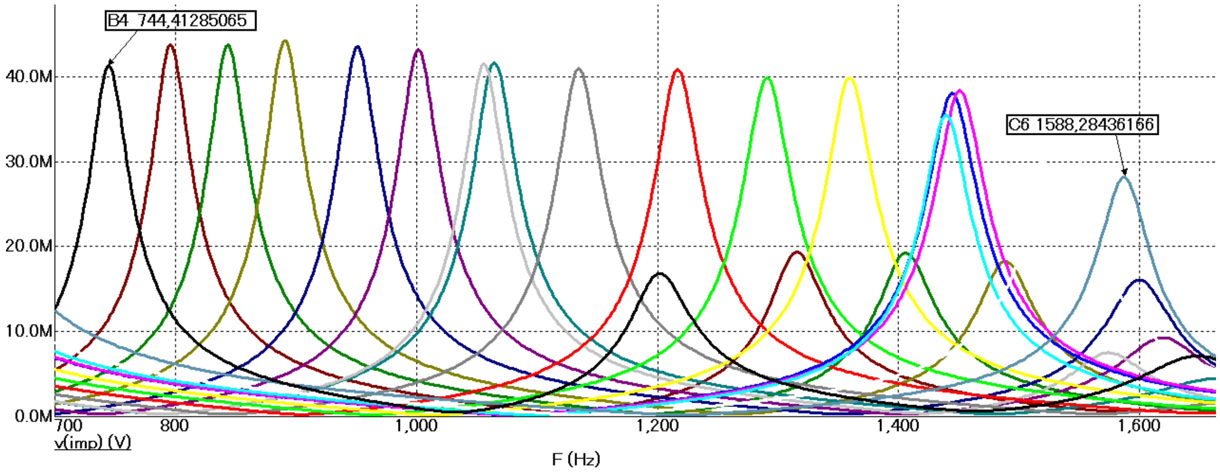

Fig. 4, Simulated frequency response of the impedance, stepped for various fingerings

1.2 Limitations of the model

There are several simplifications that limit the accuracy of the model. We neglect nonlinear effects and the inner and outer open-hole interactions. The sum effect of the tube losses is combined in an empirical factor that effectively increases the shear viscosity. This factor is in the range of 2 to 4 to give optimum results. Further down it is shown how these inaccuracies are compensated using BIAS and a music tuner.

2. FROM A PROTOTYPE TO AN IMPROVED DEFINITIVE INSTRUMENT

2.1 Main idea

The primary quality criterion for a musical instrument is good intonation. The player should be in a position to produce correct pitches fitting to either pure intonation or equal temperament. That means that the tones offered by the instrument are in a range of +/- 5 cent compared to the values for the tempered scale. The player is then able to adjust the pitch to the musically correct value by adapting the embouchure.

The aim of the software simulation is to develop a list of geometrical parameters suitable for producing a good clarinet. These parameters are diameter of the bore, conical elements in the bore, tone hole positions, diameters, depth, pad diameters and pad openings dimensions of the barrel and the bell. The simulation is not suited for developing a clarinet from scratch. A working prototype is needed first.

Fig. 5 shows the simple prototype that was used as a starting point. It has only two rings, no correction holes at all and no F#3/C#5 fork mechanics (special extension of the German-type clarinet, included in every modern clarinet).

2.2 Geometrical dimensions of the prototype

First of all the geometrical dimensions of the prototype are measured and documented. The bore and its profile along the axis is measured using a bore gauge. The other dimensions are measured using slide calipers.

2.3 Simulating the prototype

The mechanical dimensions are now fed into the circuit diagram of the model. This is time consuming and has to be done very carefully. After that a so-called AC (alternating current) analysis is started. The analysis for all common fingerings runs automatically. A diagram of resonances as shown in Fig. 4 is the result. For practical reasons the registers of the clarinet are simulated separately. These are the low (chalumeau) register from E2 to E3, the “throat-tones” F3 to Bb3, and B3 to C5 (clarin register). In this article the tones are always to be understood in written notation (if not otherwise mentioned).

The impedance sensor needs to be connected to the clarinet model via a special adapter-tube, as such a tube is also needed for the BIAS-measurement. In the simulation its dimensions must correspond to the adapter used for the BIAS-measurement (see below).

It is practical to use a spread sheet to collect and compare the intonation data. The results of the simulation, namely the frequency of the peaks and the magnitude (in acoustic Ohms S.I.) are entered into the third column of the spread-sheet. In the first column are the names of the tones (E2 to C5) including lines for alternative fingerings (e.g. fork fingerings). In the second column are the respective frequencies of the tones for equal temperament based on the concert pitch (in our case 443Hz). The cent deviations between second and third column are shown in the fourth column. There are several reasons for the deviations: The simulation is not perfect due to the limits of the model, the tube does not act like the mouthpiece-reed combination and there might be some measuring errors in the mechanical dimensions of the clarinet. But the main reason of course is, that the instrument is not yet optimised.

Fig. 5, Prototype used as a starting point

Fig. 6, BIAS measuring setup

2.4 Measuring the prototype using BIAS

The clarinet (the barrel) is connected to the BIAS measuring head not directly, but via a cylindrical tube (adapter). Its volume is chosen to be approximately equal to the volume of the mouthpiece. The diameter of this adapter has to fulfil two requirements: It should be similar to the bore-diameter of the clarinet and it has to be big enough to slip over the measuring cylinder of the BIAS head (diameter 14mm). Therefore in practice the adapter has two parts. One part of diameter 14mm and a length of about 10mm. This part slips over the BIAS-cylinder. The longer part of the tube has a diameter of 11mm (depending on the bore of the clarinet). And its length is chosen such that the mouthpiece volume is equal to the volume of the whole adapter. The values are not critical.

The clarinet is mounted together with the BIAS head on a special setup, including a spring and a tripod. (see Fig. 6, showing a Bb-clarinet). The same fingerings as used in the simulation are measured and the results are entered into the spreadsheet. Now a comparison of the BIAS measurement and the simulation in cent-difference is available. This comparison is also done for the height of each peak.

The differences between the frequencies of the resonance peaks are used for detecting measuring errors of the mechanical dimensions and incorrect values in the circuit diagram. Care must be taken that the room temperature in the simulation is the same as when making the BIAS measurements.

The basic model needs to be corrected by a loss factor. This is done by multiplying the shear-viscosity eta = 1.86 x 10-5 kg/(ms) by this factor. It is determined in such a way that the impedance of the peaks is approximately the same in BIAS and in the simulation. A value between 2 and 4 is the result.

After resolving obvious errors and finding a suitable loss factor this part of the procedure is completed (see Fig. 7). As can be seen, it was not possible to bring the difference down to an acceptable level for the C6 (fork fingering at the German clarinet). The reason remains unclear for the moment. Only the values of the simulation are used for the next steps. BIAS will later be used again to check the performance of the final model after its realisation.

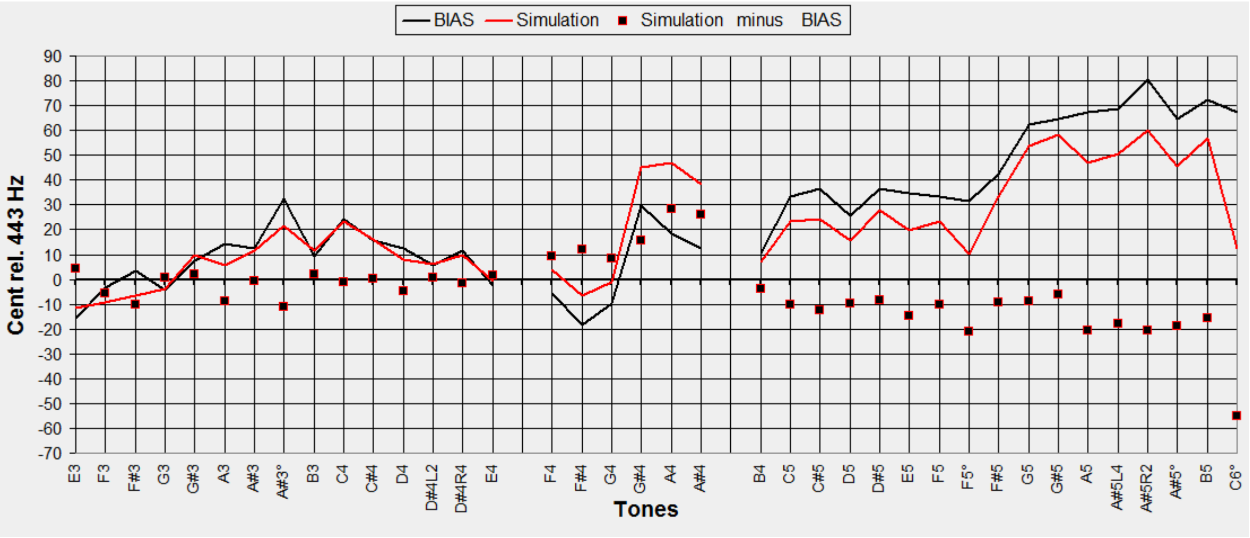

Fig. 7, Comparison BIAS versus simulation for all three registers up to C6

2.5 Pitch determination by blowing the prototype

So far the actual performance of the clarinet has not been considered. The mouthpiece-reed combination has a great influence on the intonation of the instrument. The aim of the whole procedure is to get an instrument which is suitable for playing each note in the desired intonation. This means that every tone should be adjustable (by the embouchure) in a range of about minus 15 to plus 15 cent referred to the equal tempered scale. This presumes that the intonation ”offered” by the instrument does not deviate too much from the tempered scale. If this is fulfilled it is possible to play also with pure intonation.

Thus the existing prototype needs to be blown with a medium mouthpiece-reed combination. “Medium” in this sense means firstly that the reed is not too soft and not too hard. Secondly the mouthpiece should be similar to one intended for the final instrument. Ideally there should be several mouthpieces available, from which one with average or best performance can be chosen.

After warming up the instrument, the whole chromatic scale is played, including any alternative fingerings. For each tone three intonation values are measured with a tuner and recorded in the spread-sheet. One is the minimum frequency that can be achieved with normal tone quality, one the highest, and one the frequency that is achieved with a medium, comfortable embouchure (optimum). Additionally an average value is computed for the maximum and minimum value to detect possible errors in reading the tuner.

If the prototype is not yet good enough, there will be some tones that do not fulfil the requirement of the playing range as mentioned above. This situation is shown in Fig. 8, taken from the prototype that was to be improved.

There are several imperfections to be seen in Fig. 8. For example it is impossible to play A#3° (fork fingering) and C4 in tune. Both are too sharp. A#5L4 (special fingering on the German clarinet with the ring finger of the left hand) is too low. Another problem is that there is a jump of more than 20 cent between the A#3 and the A#3° (fork). But the corresponding two tones (twelfths) in the clarin register (F5 and F5°) are not far apart. So any change in the tone holes that would improve the relation A#3 to A#3° would worsen the situation for F5 and F5°. This is because the prototype is a simple instrument lacking a special correction hole needed to bring all the four pitches A#3, A#3°, F5, F5° close to the zero-line. Using the simulation it was possible to place this correction hole at the right place with the right diameter and length.

It should be mentioned that also a correction of the bore was necessary to compensate for the above mentioned imperfections of the prototype. An article by Krueger [5] and a spread-sheet trial-and-error method was used to determine the conical parts of the bore. How this was done in detail is outside of the scope of this publication.

2.6 Calculation of correction factors

Now there exist two pitch values for each tone on the clarinet. One value comes from the simulation and one from actually playing the original prototype (optimum, as described above). The idea is that any correction of the tuning should bring the optimum (in the sense of blowing) value to zero cent (as compared to the tempered scale). Thus if y is a certain tone of the chromatic scale, we call the pitch of the played tone opt_proto(y) and the pitch of the simulation sim_proto(y). Then, expressing everything in cent:

$$\text{opt\_proto}(y)-\text{sim\_proto}(y)=k(y)$$

It is assumed that k stays roughly the same when simulating and blowing the instrument to be developed, so that

$$k(y)=\text{opt\_new}(y)-\text{sim\_new}(y)$$

As opt_new should be zero, the result is simply

$$\text{sim\_new}(y) = -k(y)$$

The reason for the pitch differences between the simulation and of playing the clarinet are mainly:

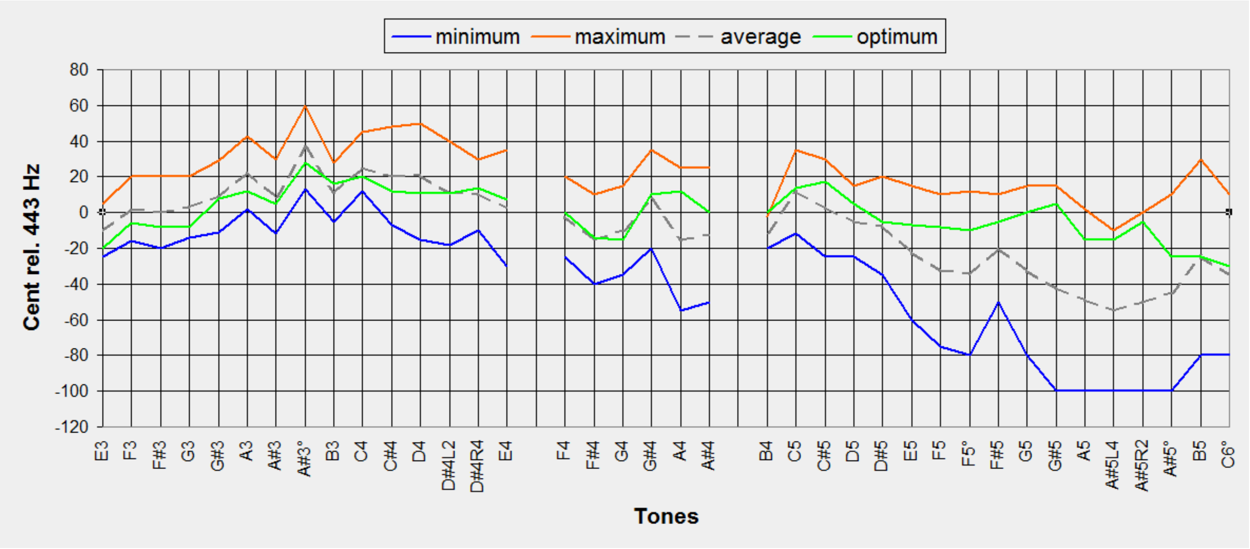

Fig. 8, Result of the tuner reading

At present the SW-model is not yet sufficiently developed for simulating the influence of the mouthpiece, reed and player on the intonation. This is because: first, the clarinet is simulated with a short cylindrical tube, whereas in reality a mouthpiece-reed combination is used. Second, the model does not fully take into account nonlinear effects (turbulence) and does not distinguish between the different kinds of losses, but uses a single factor (see above) to approximate reality.

At the connections of the side holes to the main tube, the flow lines have a complicated form that cannot be simulated perfectly by a simple T-connection as done in the model. Information about such effects can be found in the literature [6].

2.7 Adapting the simulation model to improve intonation

From the correction factors (see above) the necessary improvements can be deduced. Much creativity is needed to find the new dimensions. But - as the simulation takes only some minutes on an average computer - the trial and error procedure soon leads to a usable result.

Several experiments with the simulation model showed that it is not possible to obtain satisfactory intonation for the normal and fork-fingerings of A#3 and F5 (see above) by just altering the positions, diameters and depths of the corresponding tone holes or the bore diameter. Therefore an additional correction hole was introduced (see also 2.5). This kind of correction hole is a standard device in good German-type clarinets. The prototype, being a very simple model, also lacked the hole and mechanics for F#3 and C#5 fork fingering. The first choice of dimensions and positions of the two new holes was found by studying an ordinary Bb-clarinet. After several attempts suitable values for the new holes could be found. Of course the dimensions of neighbouring holes had to be modified too. Again this was a trial and error procedure. The following simple rules were applied: To increase the frequency of a certain tone the corresponding hole (namely the one which mainly influences the pitch) needs to be shifted towards the barrel. It can also be widened or reduced in depth. This takes several attempts: one run of the simulation of a complete register (E3 to E4, F4 to A#4, and B4 to C6) takes a few minutes.

2.8 Building the final model based on the simulation

The dimensions found to be optimal with the help of the simulation were sent to a professional instrument maker (Foag). This maker operates a CNC (Computer Numeric Controlled) milling machine and is able to reproduce the required dimensions with an accuracy in the order of 10 microns. Fig. 9 shows the final result. The newly introduced two holes turned out to have the correct dimensions, giving a satisfactory result (see Fig. 10).

3. FUTURE WORK

The main focus of the method described was to find mechanical dimensions that allow the clarinet to be played perfectly in tune. There are many solutions to achieve this goal. A different combination of hole distances, diameters and depths, as well as different bore characteristics could also lead to a good instrument. In the work done no special focus was laid on other factors, such as sound quality, balance of tones or attack characteristics. Presumably the software model would have to be refined if such characteristics should be taken into account.

For standard A- and Bb-Clarinets there exist so many good models that it is usually sufficient for instrument makers to copy an existing instrument. Nevertheless even such instruments could be improved using simulation software. For example it is not possible nowadays to play a fork-fingered F4 on the German-style clarinet with good intonation (it is much too sharp). The simulation could be used for finding an additional correction hole. This hole

Fig. 9, G-high clarinet, new model

would be open for the C6 (normally a fork fingering on the German clarinet), but closed for the F4. This could be achieved by introducing a lever that is combined with the speaker vent mechanism. Before building an actual instrument, the dimensions and position of such a hole could be found with the help of the model.

Fig. 10, Detail of the right hand side, showing the two additional holes

4. CONCLUSION

The aim of the project, namely to develop a new clarinet based on a working prototype and using software simulation was fulfilled. This method is especially advantageous for rare types of instruments, such as the G-high clarinet. Instead of building several prototypes and each time hoping for the best, one needs only to change the dimensions of an existing software model. This efficient approach saves time and material. It also motivates to explore new ground in clarinet development.

5. REFERENCES

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