The use of the input impedance for characterising historical serpents

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ABSTRACT

This article describes how the input impedance is used as a descriptor to classify and characterise the corpus of serpents from the Musée de la Musique. The study focuses on the products of a family of craftsmen (Baudouin father and son) with the objective to find a trace of the knowhow transmission. Input impedance measurements highlight small differences between serpents made by Baudoin and serpents from other craftsmen but do not distinguish between the instruments made by the father or the son.

1. INTRODUCTION

The Musée de la musique keeps in its collection more than five thousand musical instruments. Among them, only five percent are in a playable state. Indeed, a musical instrument is an information bearing - historic, aesthetic, cultural, technic and musical - and curators have to evaluate their cultural values in order to favour some of them in the context of an exhibition. For wind instruments, the general conservation rules are not to play them, to avoid a quick and huge hygrometric variation. When the musical value is interesting, and to allow the public to have a chance of listening a proposition of historical sound, the Musée orders a facsimile. The facsimile is a copy of an original musical instrument, using historical techniques and the same materials. The collection of serpents in the Musée de la musique includes thirty five instruments and one facsimile.

The serpent is described in the Dictionnaire Technologique written by Francoeur in 1831 [1] as a wind instrument of low register. It is made of several pieces of wood joined together thanks to proteinic glue and maintened with a thin layer of leather. It is played with a mouthpiece, and can reach 2.4 meter long. Only six fingerholes are made and, according to the available methods, its fundamental is D1 and many fingerings exist to produce the same note. The pitch of the notes was still not normalized at that time, but a spread value was the A 392 Hz, which will be used in that article.

Very few information about this corpus is available. For example, without any historical documentation, it is impossible to date the instruments. Nevertheless, some of them are signed by the maker Baudouin. Paris archives [2] show that George Antoine Baudoin claimed to be a serpent maker early in the 19th century. He died in 1816 and his son, Antoine Gabriel Baudoin, took over the family business. One of the curator's goal is to distinguish the instruments made by the father from those made by the son.

The input impedance helps characterising the acoustical response of a musical instrument at different frequencies. It depends on the geometry of the bore and small bore variations lead to different impedances [3, p. 65-67]. Impedance measurement can be used by craftsmen to evaluate the reproducibility of wind instruments making process [4–6], or to charaterise the influence of a process step, as the bending for example [7]. It is more difficult to use the input impedance with ancient instruments, mostly owing to the presence of leaks. This article proposes to describe the advantages and the limitations of the input impedance measurement of a historical musical instruments' corpus.

2. PROTOCOL

2.1 Impedance measurement

Many techniques are used to measure the input impedance [8, 9]. The difference between these methods consists in the measurement of the acoustical flow. Using one or two couples of microphones is the most popular technique [10, 11]. In this study, the experimental set up developed jointly by the LAUM [1] and the CTTM [2] has been used [12]. In this system, one microphone is positioned in a cavity behind the source which allows an estimation of the flow. The source is a piezo electric buzzer. The instrument is connected in front of the buzzer via a small cavity in which a second microphone is placed to measure the acoustic pressure. The transfer function between the two microphones, taking into account their sensitivities, allows the estimation of the input impedance.

The absolute uncertainty of the resonance frequencies measurement with this sensor is estimated to be 0.3%, which is 5 cents [13]. However, when comparing different resonances of the same instrument, the relative error is estimated to be ±3 cents, as systematic errors, such as those due to temperature or sensor geometry, are partially compensated.

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Figure 1. Experimental set up used to measure the input impedance of historical Serpents.

The input impedance measurement is sensitive to the air temperature and to the airtightness between the device and the instrument. Silicone adaptors are made for each instrument (Figure 1). These adaptors allow a perfect contact between the device and the serpent and respect the conservation rules (silicone is non corrosive both metal and wood). Moreover, the measurements are carried out in a climate-controlled room.

2.2 Measured serpents

Five of the nine instruments studied were made by Baudouin from 1812 to 1827. It is actually the most reprensented maker in the collection. Some of those serpents were most likely made by the father, and other ones by the son. The curator's hypothesis is to attribute to the father the serpents on which there is only one mark, and to the son, the instruments which have two marks (see Figure 2): first, because serpents with one mark are rarer than the one with two marks and second, because serpents with two marks seem to have been provided with keys from the outset [2]. Another serpent from the same period but made by another craftsman, Degalle, is also presented in this article. Finally, the three last studied serpents are contemporary. One is a facsimile by Berger (leather) and Wetter (wood) of a serpent made by Coeffet around 1830. The other two are made by Ribo and one of them is a copy of a serpent kept in the MIM (Musée des Instruments de Musiques) in Bruxelles. All these serpents are showed in Table 1.

Serpents kept in the Musée de la musique are identified with their inventory number. The input impedance is measured on the entire instrument, i.e with the crook and the mouthpiece (which are kept with the instrument, but it is not always possible to be sure that they come from the same instrument), positioned according to traces of use. Another measurement is also taken on the resonators only.

3. RESULTS

3.1 Precision of the measurement

To have reliable and repeatable measurements, it is necessary to strongly fix the instrument flat on the impedance

(a) 2 marks attributed to Baudoin son

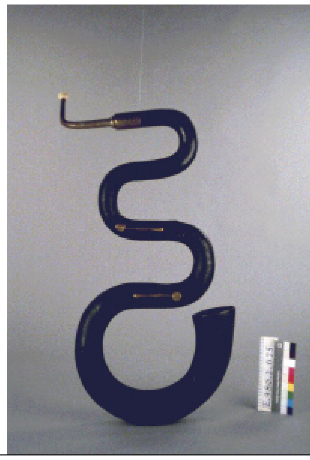
(b) 1 mark attributed to Baudouin father

Figure 2. Baudouin's signature on his serpents.

sensor in order to avoid any leak and to prevent it from moving. The silicone adapters guarantee a good airtightness but do not stand for a rigid mounting. Moreover, the presence of leaks in the instrument, the difficulty to open or close some keys, etc. make the measurements difficult to repeat with a same result. So, in the case of serpents measurements, it is not possible to reach the level of precision indicated in the previous section. Measured amplitudes of a same instrument can differ by 10% whereas the frequency varies by 2%. Hopefully, frequency gives more informations on the acoustics of the instruments than the amplitude, especially regarding the tuning. It could seem delicate to compare several instruments with that low reproducibility. Nevertheless, even with instruments that are supposed to be identical, differences can be highlighted by the input impedance. For example, Mamou-Mani et al. [5] compared five Howarth S10 student model oboes and found that the peak amplitudes can vary by as much as 30%, while the peak frequencies differ by no more than 2%. Therefore, it is consistent trying to distinguish different instrument craftsmanship with the input impedance measurement, especially when it is possible to have an estimation of resonance frequencies with a 2% accuracy.

3.2 Serpent impedance and the EFP

A typical serpent input impedance, as in Figure 3, shows several peaks which correspond to the eigenmodes of the

Inventory number	Type	Photo	Inventory number	Type	Photo
E575	Baudoin 1 mark 6 holes		E980.2.675	Baudoin 2 marks 8 holes 2 keys	
DAD32046	Baudoin 1 mark 7 holes 1 key (missing)		E1292	Baudoin 2 marks 6 holes	
DECL19193	Baudoin 2 marks 6 holes		Facsimile	Berger and Wetter 6 holes	

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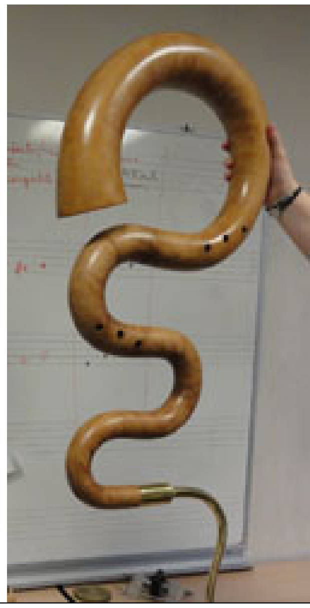
Inventory number	Type	Photo	Inventory number	Type	Photo
E2011.14.1	Degalle 6 holes		Ribo-6holes	Ribo 6 holes	
Ribo-10holes	Ribo (copy MIM) 10 holes 4 keys	 © KMKG-MRAH (photo of the original)			

Table 1. Photos and features of the nine studied serpents.

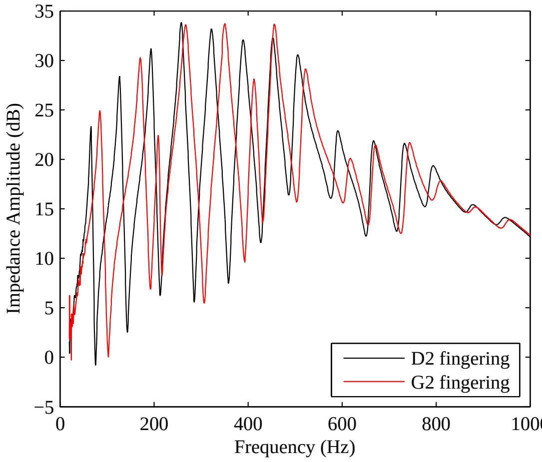


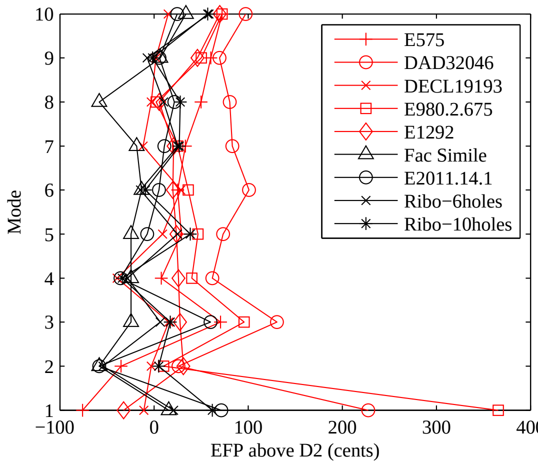
Figure 3. Input impedance of the E2204 facsimile for two fingerings: D2 fingering with all the holes closed (in black) and G2 fingering with the last three holes open (in grey).

instrument. The notes playable by the musician are supposed to have a frequency close to the resonance frequencies of the impedance. Figure 3 shows that, when all the holes are closed, the resonances are in a quite harmonic relationship, but when the holes are open this is not the case anymore. It is possible to observe the instrument harmonicity using the input impedance by plotting the equivalent fundamental pitch (EFP) [14]. It is defined as follows:

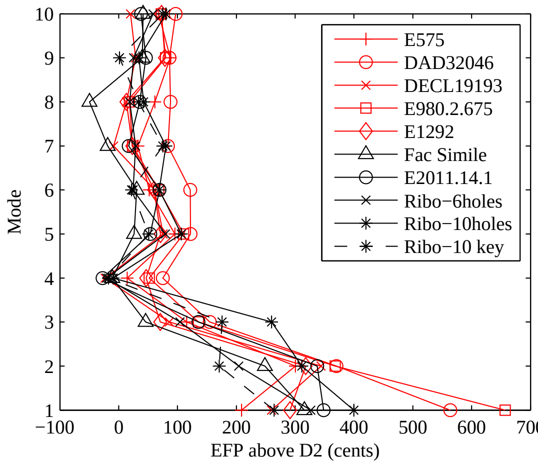
$$\mathrm{EFP}(n) = \frac{1200}{\log 2} \log \left(\frac{f(n)}{n f_0} \right), \quad (1)$$

where $f(n)$ is the frequency of the n$^{\text{th}}$ peak and f_0 is the frequency of a reference tone. The EFP represents the interval (in cents) between the frequency of each mode and the frequency of the corresponding mode for an ideal conical instrument of fundamental frequency f_0. EFP(n) is the pitch of the harmonic series whose n$^{\text{th}}$ member has frequency $f(n)$. Most of the methods give D2 as the fundamental frequency of the serpent, which corresponds to a frequency of 65.4 Hz, since the diapason was A 392 Hz at the time.

Figure 4 shows the EFP of the nine serpents for two fingerings: D2 fingering, where all the holes are closed, and E2 fingering where the last hole is open and the other are closed (for the Ribo serpent with 10 holes there are two options: opening the last two holes to be in the same configuration as the other serpents, or opening just the last hole with the key in order to have a longer air column). Regarding the EFP of the D2 fingering, four serpents have, except for the first mode, an identical behaviour: serpents E575, E980.2.675, DAD32046 and E2011.14.1. Indeed, the four have an EFP that increases by around 100 cents from the second mode to the third, then it decreases by approximately 50 cents from the third mode to the fourth and finally, for the superior modes it keeps more or less constant. Since there are a lot of leaks in these old serpents, it is often difficult to measure the first impedance peak, this is why there are that much differences. DAD32046 and



(a) All holes closed (D2 fingering)



(b) The last hole open (E2 fingering)

Figure 4. EFP of the six serpents for two fingerings: D2 fingering where all the holes are closed and E2 fingering with the last hole open. Baudoin's serpents are given in red and the others in black.

E980.2.675 have a too high first resonance. That should not be taken into account, this is in all likelihood due to leaks. It can also be observed that the facsimile has lower resonances than the others and serpents E1292 and DECL19193 are the more harmonic. Moreover, the two serpents made by Ribo have really similar resonances. This is because Ribo used the same shape for his resonators, which was copied with a machine shown in Figure 5. This first figure therefore shows that it is possible to distinguish the work of one factor: Ribo. With modern tools it is indeed easier to reproduct identical instruments. Moreover, it is possible to classify Baudoin's serpents into two groups: E575, DAD32046 and E980.2.675 in one group and DECL19193 and E1292 in another. That might prove the work of two different persons, the father and the son, but in that case, it is not the number of marks that can help classify them.

The second plot in Figure 4 can show if the last hole is set up differently in some serpents. It is possible to measure the position directly on the instrument, which can seem

Figure 5. Machine used by Ribo to copy the shape of his resonators.

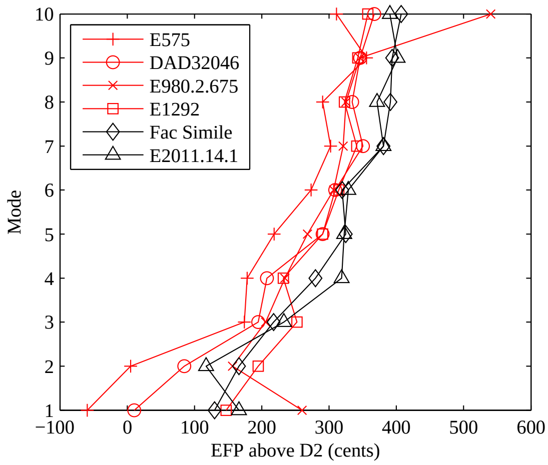


Figure 6. EFP of the resonators of six serpents with all their holes closed. Baudoin's serpents are given in red and the others in black.

easier than doing an impedance measurement, but the advantage of the impedance is that it directly shows the impact of the holes on the air column of the instrument. In this figure, without considering the first mode, all the instruments, except the two made by Ribo, have a quite similar behaviour. This to say, a huge decrease of the EFP of about 200 cents between the second and the third mode and then an EFP more or less constant. It is therefore only possible to distinguish the work of Ribo from the one of other artisans. Regarding the relation between the two first resonances it is however possible to highlight the work made by Baudoin. Indeed, for E575, DECL19193 and E1292, the second mode is higher than the first one, whereas it is the contrary for all the other serpents. When plotting the EFP for other fingerings, the results have similar behaviours.

In Figure 4, the EFP is plotted for the entire serpents (with mouthpiece and crook), which is interesting to know the notes that can be played with the instrument. Nevertheless, it is not possible to be sure if the mouthpiece is original, and the crook can have different positions, which significantly modifies the input impedance. All these elements add a lot of uncertainty in the comparison of the instruments. This is why it is interesting to plot the EFP [3] of the resonator alone, in order to only characterise the work of the craftsman on the wood.

Figure 6 shows the EFP of the serpents resonators. Unfortunately, for the serpent DECL19193 it was impossible to remove the crook which was stuck into the resonator. Moreover, measurements of Ribo's serpents were taken rapidly at an exhibition and only the entire serpents, which were more interesting for the craftsman, were measured. This is why only the EFP of six serpents are plotted in this figure. In Figure 6, higher modes can be separated into three groups: 1) DAD32046, E1292 and E.980.2.675, 2) Facsimile and E2011.14.1 and 3) E575. These results show the importance of the embouchure and the crook on the acoustics of the instrument. Indeed, the serpent DAD32046 whose resonator acoustics is very close to the E1292 at high frequency behaves in a completely different manner when it is provided with a crook and a mouthpiece. Moreover, in Figure 6 the serpent DAD32046 does not have its first impedance peak much higher than the others, as in Figure 4. This seems to indicate that the mouthpiece found with the instrument is not suitable or that there is a problem with its crook. At low frequency, behaviours are different and serpents can be discriminated into two groups: 1) E575, DAD32046, E1292 and Facsimile which have a second mode higher than the first, and 2) E980.2.675 and E2011.14.1 for which it is the contrary.

[3] We keep the EFP diagram to simplify, even if there is no musical interpretation that can be done on it.

4. CONCLUSIONS

The input impedance is useful to characterise musical instruments that cannot be played for conservation reasons. It gives informations about the notes that can be played by the instrument and it can help reconstruct the shape of the bore. This is why it was used to try to understand the work of the craftsmen Baudoin. Measurements are sometimes difficult to conduct since instruments are old, have a lot of leakages and are difficult to strongly mount on the impedance probe. Nevertheless, it is possible to obtain repeatable measurements, especially regarding the frequencies. By looking at the entire serpents, it is possible to distinguish the work of a contemporary craftsman, as he uses a machine that can reproduct similar shapes. Some distinctive features of Baudoin's work have been highlighted but they do not differ much from the work of other craftsmen. Moreover, those features are not the same for entire serpents or for only resonators.

This shows the limits of the input impedance for answering this kind of question. No explanation can be given on the number of marks since some 1 mark serpents are acoustically closer to serpents with 2 marks than others with 1 mark. The input impedance gives some clues but a part of mystery remains... Radiographies of the serpents resonators will be done, but it should only confirm the results obtained with the input impedance.

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5. REFERENCES

[1] L.-B. Francoeur, *Dictionnaire technologique ou nouveau dictionnaire universel des arts et métiers, et de l'économie industrielle et commerciale; par une société de savants et d'artiste*. Thomine et Fortic, Paris, 1831, ch. Tome 19, pp. 300–303.

[2] T. Maniguet, "L'usage du serpent et de ses formes dérivées dans la première moitié du xixe siècle," *Musique, Images, Instruments*, vol. 14, in press.

[3] P. Eveno, "L'impédance d'entrée pour l'aide à la facture des instruments de musique à vent : mesures, modèles et lien avec les fréquences de jeu (the input impedance for the support of the musical instruments making: measurements, models and link with the playing frequencies)," Ph.D. dissertation, Univ. Pierre et Marie Curie (Paris VI), 2012. [Online]. Available: http://goo.gl/RvujY

[4] V. Gibiat and J. Selmer, "Impedance comparison of high-quality alto and soprano saxophones," *J. Acoust. Soc. Am.*, vol. 112, no. 5, pp. 2292–2292, 2002.

[5] A. Mamou-Mani, D. B. Sharp, T. Meurisse, and W. Ring, "Investigating the consistency of woodwind instrument manufacturing by comparing five nominally identical oboes," *J. Acoust. Soc. Am.*, vol. 131, no. 1, pp. 728–736, 2012.

[6] A. Mamou-Mani and D. B. Sharp, "Evaluating the suitability of acoustical measurement techniques and psychophysical testing for studying the consistency of musical wind instrument manufacturing," *Applied Acoustics*, vol. 71, no. 7, pp. 668–674, 2010.

[7] J.-P. Dalmont, M. Curtit, and F. Yahaya, "Bore reconstruction from input impedance," *Proceedings of Forum Acusticum, Aalborg, Denmark*, 2011.

[8] J.-P. Dalmont, "Acoustic impedance measurements, part i : A review," *Journal of Sound and Vibration*, vol. 243, no. 3, pp. 427–439, 2001.

[9] A. H. Benade and M. I. Ibisi, "Survey of impedance methods and a new piezo-disk-driven impedance head for air columns," *J. Acoust. Soc. Am.*, vol. 81, no. 4, pp. 1152–1167, 1987.

[10] V. Gibiat and F. Laloë, "Acoustical impedance measurements by the two microphone-three-calibration (tmtc) method," *J. Acoust. Soc. Am.*, vol. 88, no. 6, pp. 2533–2545, 1990.

[11] M. van Walstijn, D. M. Campbell, J. Kemp, and D. Sharp, "Wideband measurement of the acoustic impedance of tubular objects," *Acta Acustica United with Acustica*, vol. 93, pp. 435–446, 2005.

[12] J.-C. L. Roux, J.-P. Dalmont, and B. Gazengel, "A new impedance tube for large frequency band measurement of absorbing materials," *Proceedings of Acoustics'08*, 2008.

[13] C. A. Macaluso and J.-P. Dalmont, "Trumpet with near-perfect harmonicity: design and acoustic results." *J. Acoust. Soc. Am.*, vol. 129, no. 1, pp. 404–414, 2011.

[14] D. M. Campbell, "Cornett acoustics : some experimental studies," *Galpin Society Journal*, vol. 49, pp. 180–196, 1996.