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Forum Acusticum 2011 - Aalborg - Denmark

Mechanical response characterization of saxophone reeds

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Summary
The subjective quality of single cane reeds used for saxophone or clarinet may be very different from a reed to another although reeds present the same shape and the same strength. In this work, we propose an experimental system in order to try to classify reeds in different families which could represent the musician feeling. In the long term, this measuring would enable to enhance the quality of the reed classiffcation during the manufacturing process. The aim of the measurement is to estimate the equivalent mechanical parameters of the reed. The reed is mounted on a tenor saxophone mouthpiece which cavity is excited with a loudspeaker is the frequency range 500 Hz - 6 kHz. The acoustic pressure is measured in the mouthpiece and the reed displacement is measured using a optical sensor near the reed tip. The frequency Response Function is analyzed using a modal analysis technique (MDOF) and the equivalent reed parameters are estimated (mass, stiffness and damping) for each mode. Different reeds chosen for their subjective differences (rather difficult and dark, medium, rather easy and bright) are characterized with the measuring system and by measuring the mouth pressure and the spectral centroid of the acoustic pressure radiated at the saxophone horn. First results show that differences between spectral centroid of the radiated pressure could be explained by differences in the equivalent mass of the vibration mode estimated by means of the measuring system.

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1. Introduction

The musical quality of woodwind instruments such as clarinet or saxophone depends strongly on the reed quality. Quality of single cane reed may vary from a reed to another. Using our own experience of musician, we consider that 30 % of reeds are good reeds in a box, whereas 40 % are mean quality reeds and 30 % are considered as bad.

Usually, the experimental characterization of mechanical properties is performed by measuring the mechanical stiffness of the reed submitted to a static force at a particular location from the tip. This measurement enables to estimate the strength of the reed which is indicated for the clarinet or saxophone player. It appears that this method is necessary to sort out the reeds for different strength and to indicate the musician if the reed can be played with a particular mouthpiece. However this approach can not explain the great differences observed between reeds with the same strength and the same cut.

The characterization of physical properties of reeds has been studied using different approaches such as vizualisation of cane cells, mechanical measurement of vibration response or optical holography to identify the vibrational modes of the reed.

Kolezik [1] studies the anatomical characteristics of cane using confocal laser scanning microscopy. Mukhopadhyay [2] proposes to characterize the quality of saxophone reeds using planar electromagnetic sensors. Obataya [3] studies the effect relative humidity on the dynamic Young's modulus of the reed using a free-free beam flexural vibration method and by measuring small plates made with cane. Pinard *et al.* [5] observe the vibrational modes of 24 clarinet reeds in both dry and wet conditions using holographic interferometry. Picart [4] observes the modes of a clarinet reed using holography and measures the displacement of the reed tip during auto-oscillations created in an artificial mouth.

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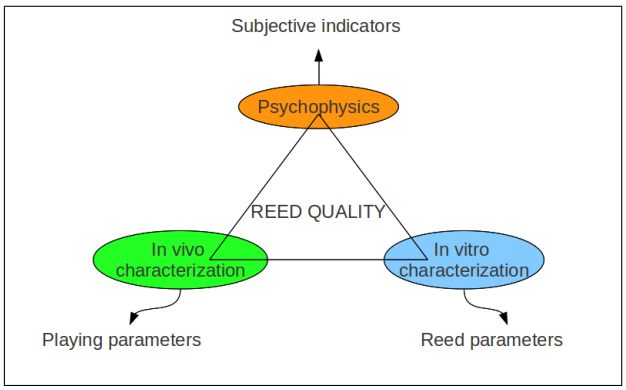

Figure 1. View of the structure of the work.

In our view, the analysis of reed quality can be divided in three parts as shown in figure 1. First axis concerns the psychophysics of the reed and should determine how many subjective dimensions characterize the reed musical quality. Second axis deals with physical measurements performed on a player ("in vivo measurements"). Last part deals with the "in vitro" measurements. It concerns the mechanical or optical characterization of the reed. In this paper, we present a work using the "in vivo" and "in vitro" measurements for characterizing the reed quality. Reed quality is not presented in terms of subjective indicators.

The aim of this work is try to explain why particular reeds produce different sounds (more or less bright) and different feeling for the player. On the one hand, vibroacoustical responses of reeds are measured using a experimental system which generates a sound inside a mouthpiece at low levels (compared to the the levels observed during the playing). The reed response is estimated by measuring the acoustic pressure inside the mouthpiece and the displacement of the reed tip. On the other hand, the pressure inside the mouth player and the acoustic pressure emitted at the saxophone horn are measured using the same reeds. For each reed and for different notes, the mean mouth pressure and the spectral centroid of the acoustic pressure are calculated.

The paper is organized as follow. First part presents the experimental system which enables to estimate the mechanical parameters of the reed. Second section presents the "in vivo" measurement system. Finally, the comparison between the two experiments are presented and the results are discussed in section 3.

2. Characterization of the reed mechanical response

The aim of this section is to present the experimental used for characterizing the vibroacoustical response of single cane reeds. Physical parameters describing the reed are also presented.

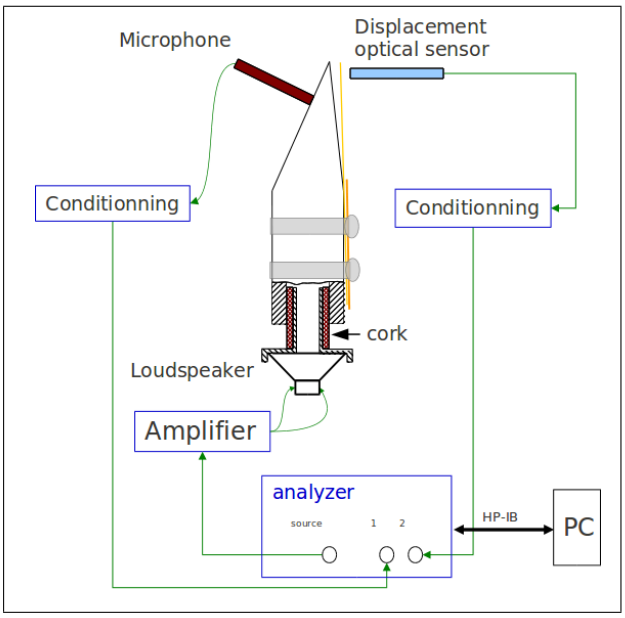

Figure 2. Principle of the measuring system used for the characterization of the reed vibroacoustic response.

The experimental system is based on the system presented by Gazengel *el al.* [6]. The system is presented in figure 2. The reed is mounted on a tenor saxophone mouthpiece using a cap. The mouthpiece cavity is excited with a small loudspeaker. The acoustic pressure exciting the reed is measured using a electret microphone (Sennheiser KE4) at 5 mm from the tip of the mouthpiece. The reed displacement is measured using an optical sensor (Philtec RC 25) having a measuring area of about 1 x 4 mm. This sensor is mounted on a traverse system which enables to set precisely the distance between the reed and the sensor. As the optical sensor response is non linear, the distance between sensor and reed must be known and determines the functioning point. For all the experiments, the response of the reed is charactized by measuring the Frequency Response Function displacement over acoustic pressure at the middle of the reed (in the transverse direction) and at 2 mm from the tip.

This experimental system is very simple compared with other experiments using holography. It does not enable to perform easily a modal analysis of the reed as the system presented for example in [5]. If the physical parameters estimated from this measuring apparatus can explain (even partially) the reed quality, it could be used in the future for industrial applications.

The Frequency Response Function (FRF) is measured using a Stanford analyser SR875. An example of FRF obtained is shown in figure 3. This result shows that the first flexural mode is predominant. Other modes are torsion mode, second flexural model and modes combining flexion and torsion as shown in [5].

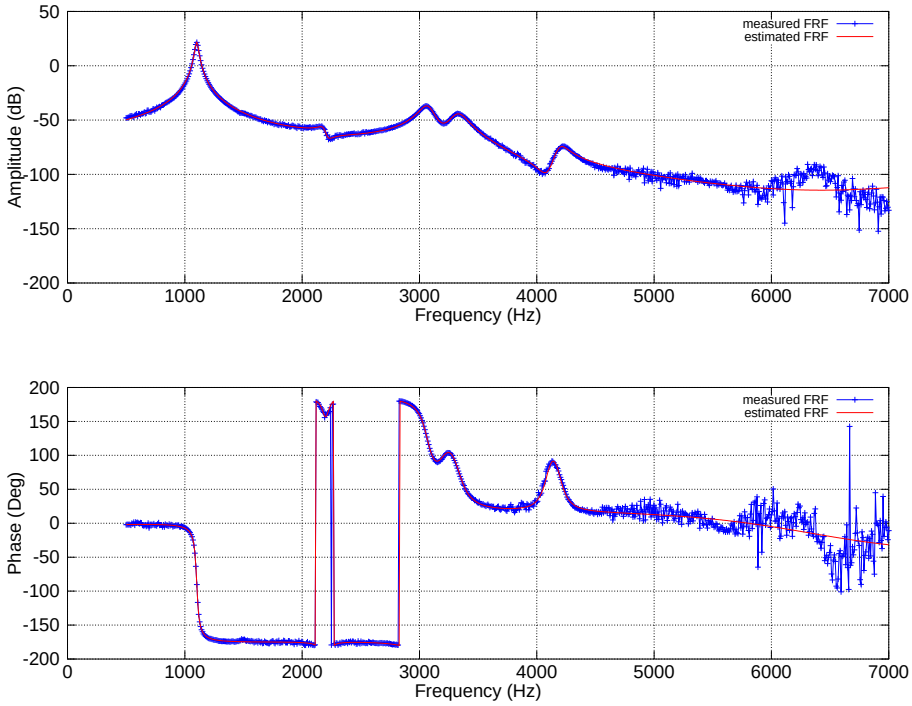

Figure 3. Frequency response Function of a reed. The displacement sensor is located at 2 mm from the tip and at the center of the reed.

The estimation of the reed parameters is done using a modelling of the reed response and a least mean square method as given in [7]. An example of the reconstructed function is shown in figure 3. This enables to deduce the reed parameters, compliance, mass, resonance frequency and quality factor for each mode.

3. "In vivo" measurements

In this section, we present the experimental system used for measuring the acoustic pressure at the saxophone horn and the pressure in the musician's mouth. These two physical parameters enable to deduce the spectral centroid of the emitted sound and the mean pressure in the mouth for a particular note played by the musician.

The mouth pressure is measured using a differential pressure sensor Endevco 8507-C2 connected to a small tube introduced in the mouth of the player during the test. The acoustic pressure is measured using a microphone placed in front of the saxophone horn (figure 4). The signals are connected to an acquisition board National instruments BNC-2110 using a sampling frequency $F_s = 50$ kHz.

An example of measured signal is shown in figure 5.

The estimation of the spectral centroid is performed as follow. The different notes are manually detected.

Figure 4. View of the "in vivo" measuring system.

For each note, the stationnary part of the signal is estimated by calculating the energy of the signal $p(t)$

$$E(t) = \int_0^t p^2(\tau) d\tau. \quad (1)$$

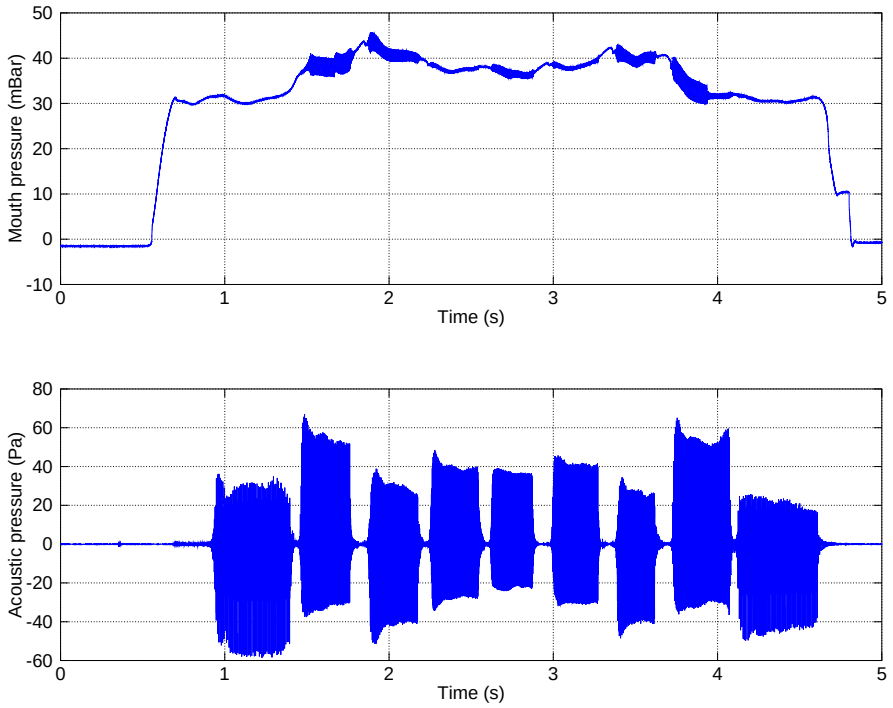

Figure 5. Example of signal measured when the musician is playing. (top) Mouth pressure. (bottom) Acoustic pressure at the saxophone horn output.

The stationnary part of the signal is defined for $E(t) \in [0.050.95]E_{max}$, where E_{max} is the maximum energy obtained at the end of the note. The spectral centroid $SC(n,r)$ is estimated for each reeed r and each note n by using 45 harmonics of the signal for each note using

$$SC(n,r) = \frac{1}{f_1}\frac{\sum_{k=1}^{k=45} A_k f_k}{\sum_{k=1}^{k=45} A_k}, \quad (2)$$

where f_k is the frequency and A_k is the amplitude of the spectral component k.

This enables to use the same number of harmonics for each note, the number of harmonics being limited by the maximum frequency (25 kHz). The mouth pressure is estimated as the mean pressure measured in the mouth during the stationnary part of the signal.

4. Results

4.1. Experimental configuration

The tests have been performed by a single tenor saxophone player using a Reference 54 Selmer saxophone and a Vandoren V16 T8 mouthpiece. 14 reeds have been tested. Three different trademark have been used with different strengths (Vandoren Jazz 3 and $3^{1/2}$, Vandoren Java $2^{1/2}$, Rico Royal 3 and $3^{1/2}$, La Voz medium and medium hard). All these reeds were played before doing the test and were not completely new. All the reeds were considered to be playable (not too hard, not too soft) The musical phrase used for the test is a arppegio of 9 notes (C 130.8 Hz, G 196 Hz, C 261.6 Hz, G 392 Hz, C 523.3 Hz, G 392 Hz, C 261.6 Hz, G 196 Hz, C 130.8 Hz).

For each reed, the arppegio has been first played five times in order to estimate the average and the standard deviation of the spectral centroid and the mouth pressure. Once the musical phrase are recorded, the vibroacoutical response of each reed is measured five times using the experimental system describedd in §2 and the equivalent parameters of the first mode are estimated.

4.2. Discussion

4.2.1. "In vivo" measurements

The estimated values of the spectral centroid (SC) and mouth pressure (MP) obtained in the "in vivo" configuration are presented in figure 6 and 7. Both parameters show a significative dependance on the played note. SC values are symetric around the highest note (high C), whereas MP is asymetric, showing greater values at the beginning of the phrase corresponding the notes of the low register of the saxophone (low C).

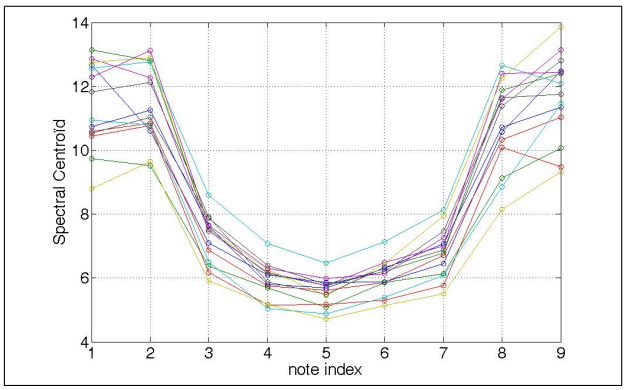

Figure 6. View of the estimated spectral centroid as a function of the note number.

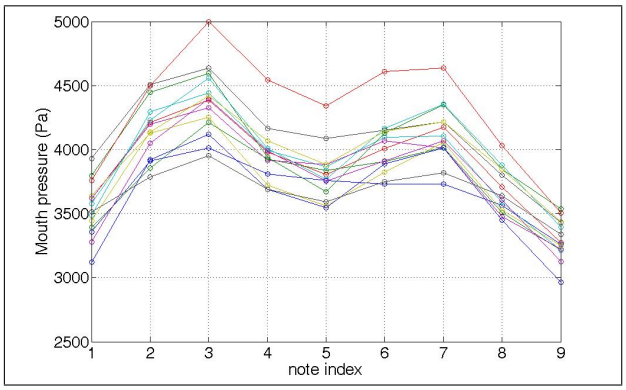

Figure 7. View of the estimated mouth pressure as a function of the note number.

In order to ignore the relation between SC, MP and the note number, we use relative parameters. The relative spectral centroid (RSC) is defined as

$$RSC(n,r) = (SC(n,r) - ASC(n))/ASC(n), \quad (3)$$

where $ASC(n) = \frac{1}{N_r}\sum_{r=1}^{r=N_r} SC(n,r)$ is the average spectral centroid for N_r reeds , n is the note number, r the reed number and N_r the number of reeds. The RSC is presented in figure 8 and shows that great differences appear for different reeds whereas smaller differences appear for different notes.

The relative mouth pressure is defined in the same manner

$$RMP(n,r) = (MP(n,r) - AMP(n))/AMP(n), \quad (4)$$

where $AMP(n) = \frac{1}{N_r}\sum_{r=1}^{r=N_r} MP(n,r)$.

Finally, we calculate a single parameter depending only on the reed number. The Mean Relative Spectral Centroid (MRSC) is defined as

$$MRSC(r) = \frac{1}{N_n}\sum_{n=1}^{r=N_n} RSC(n,r), \quad (5)$$

where N_n is the total number of notes. The Mean Relative Mouth Pressure (MRMP) is calculated using the same approach.

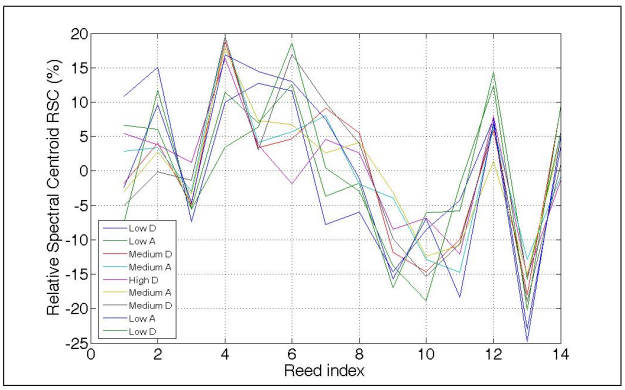

Figure 8. View of the RSC as a function the reed index for different notes.

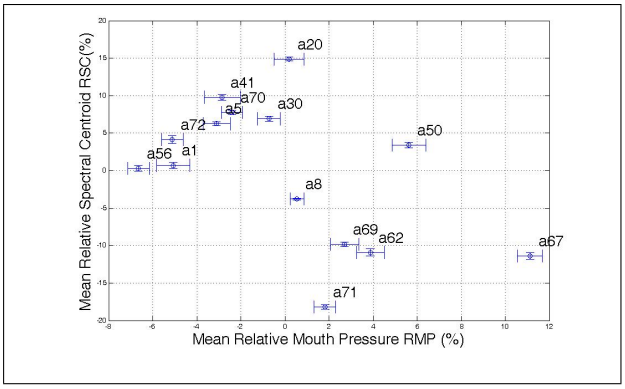

Figure 9. View of the values of RMSC and RMMP for the 14 reeds.

The uncertainty u in the MRSC and MRMP is calculated as

$$u = \frac{\sigma}{\sqrt{N_n}}, \quad (6)$$

where σ is the standard deviation in the parameter estimation. Using these two indicators (MRSC and MRMP), the reeds can be sorted in a two dimensions plane as shown in figure 9.

4.2.2. "In vitro" measurements

The estimated values of the relative parameters (stiffness, quality factor, mass) obtained by "in vivo" measurements are calculated by comparing the measured parameters to the mean value of these parameters. The uncertainty in the parameters p is calculated as

$$u_p = \frac{\sigma_p}{\sqrt{N_{mes}}}, \quad (7)$$

where σ_p is the standard deviation in the estimated values of the parameter and N_{mes} is the number of measurement (5 in our case). The error bar are shown on figure 10.

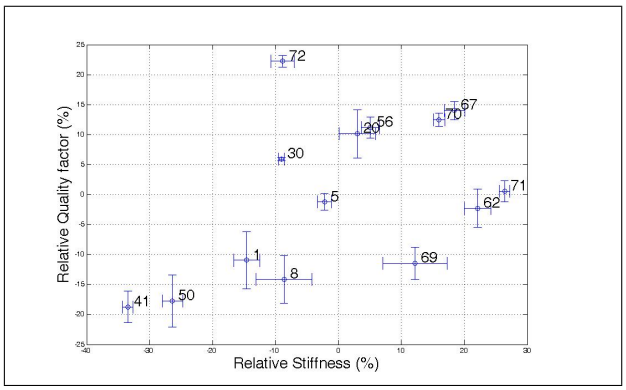

Figure 10. View of the values of stiffness and quality factor for the 14 reeds.

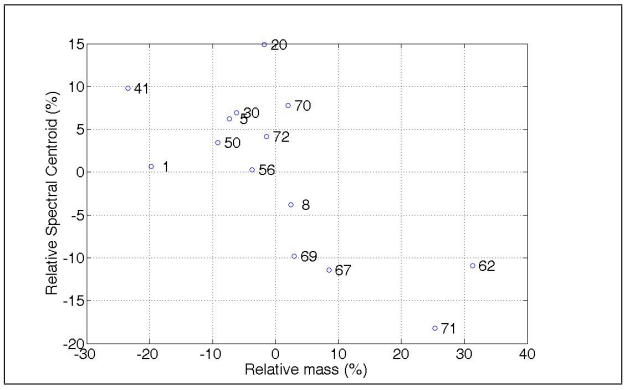

Figure 11. View of the values of equivalent mass of first vibration mode and spectral centroid for the 14 reeds.

4.2.3. Analysis

In both experiments (in vivo and in vitro), the uncertainties values enable to distinguish the different reeds. The uncertainties are greater for the experiments performed "in vitro" when mounting and unmounting the reed on the mouthpiece (typically less than 10 %) than for experiments performed "in vivo" (typically less than 3 %).

"in vivo" results show three reed families. First family corresponds to reeds which need a high pressure mouth and which produce a dark sound. Second family correspond to reeds which need a low mouth pressure and which produce a bright sound. Third family could characterize the "average" reeds (a8, a50). Although no subjective test has been performed, these families seem to represent the musician's feeling concerning the reed quality.

The comparison between "in vivo" and "in vitro" shows that the Mean Relative Spectral Centroid (figure 11) is globally inversely proportionnal to the relative equivalent mass of the first vibration mode. This result tends to show that light reeds enables to produce a brighter sound. However, it is difficult to see other relations between parameters measured "in vivo" and parameters measured "in vitro".

5. Conclusion

In this paper, we have studied the quality of 14 tenor saxophone cane reeds using experimental approaches leading to objective indicators. On the one hand, the reed is characterized "in vitro". The vibroacoustical response of the reeds are characterized using a specific bench which enables to measure the displacement of the reed at a point and the acoustic pressure generated in the mouthpiece with a loudspeaker. The stiffness and quality factor of the first vibration mode have been deduced from this measurements. On the other hand, the acoustic pressure at the saxophone horn and the mouth pressure are measured "in vivo". Specific indicators are proposed in order to take account the relation between the spectral centroid, the mouth pressure and the played note.

Comparisons between results obtained "in vitro" and "in vivo" show that the spectral centroid seems to be related to the equivalent mass of first vibration mode of the reed. Future work will consider the effect of high acoustic levels and of the lip on the reed mechanical behaviour to try to explain the differences observed during the playing.

Acknowledgement

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