Scraping technique for clarinet reeds derived from a static bending simulation

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Reed scraping is an art mastered only by a few clarinettists. The published empirical methods do not agree on how to determine where to scrape. In order to understand the problematic more clearly, a purely mechanical and simplified approach is attempted. The reed is modelled by finite elements and a simulation of free static bending shows that the longitudinal flexural stress dominates the problem. By targeting a stress field on different areas of the reed, it is observed that the strain is mainly longitudinal and only slightly lateral, due to the strong anisotropy of the cane (*Arundo donax*). Thus, a bending moment imposed on the axis of the reed causes almost no translation of the edges of the reed. A local decrease in thickness causes a localized increase in curvature, when the stress field remains constant. With this result, a series of Claripatch™ was developed to impose a localized decrease in curvature on the mouthpiece's lay. Using these patches and assuming some hypotheses based on observations, simulations and on the viscoelastic properties of the reed, one can deduce how to scrape it, according to the musical preferences of the clarinettist.

1 Introduction

Commercial reeds need often to be adjusted by scraping to suit the musical requirements of the clarinettist, but this art is really mastered only by a few players. The corresponding techniques are described in numerous documents, for instance [1,2,3,4,5,6]. Unfortunately they rely principally on subjective judgments and there is often no consensus about the musical effect of scraping on different surfaces of the vamp. We suppose that the reeds work better when the stiffness of both sides is well balanced. Nevertheless, some authors claim that quality reed needs to be slightly asymmetric [7]. P. Wagner summarizes the problem as follow: "*Nobody really knows… and if someone tells you otherwise, you'll know they know even less than you do*" [6].

This paper analyses the feasibility of the development of a scraping technique based on more objective scientific elements. The basic idea is to simulate the effect of scraping by inserting a thin wedge of plastic (Claripatch™, Patent US6921853) between the mouthpiece and the reed, to modify locally the curvature of the lay (the lay is the surface of the mouthpiece in contact with the reed). If the musical playability of the reed is improved by this local reduction of the curvature, the clarinettist scrapes the reed in the corresponding area in order to obtain the same effect, when the Claripatch wedge is removed.

This paper examines how such a wedge can be designed according to numerical simulations by the Finite Elements Method (FEM). For a given pressure field (exerted on the surface of the vamp of the reed), scraping modifies the deflexion of the reed (stain). In a static approach, this pressure field results as the sum of 3 components: lip, air and reaction of the lay. We consider the situation where the reed is laterally full in contact with the lay, supposing that the reed sides are periodically deformed this way. This is usually the case, for a duration of about half a period, when the clarinettist plays *forte*. We hypothesize that the quasi-static bending behaviour influences considerably the musical playability of the reed. Reasoning by perturbation, our approach considers the variation in the pressure field which is necessary to maintain the same deflexion when the thickness of the reed is modified. For small deflexions, we admit that the problem is essentially linear. The shape of the Claripatch wedge is approximated according to the lateral deflexion of the reed, when a pressure field corresponding to this difference is applied on an undeformed and unscraped reed. With this linear hypothesis, the actual shape of the lay and the pressure field exerted on the vamp do not need to be exactly known for drawing useful conclusions about scraping.

2 Method

A clarinet reed of model Vandoren V12 is measured and its thickness is approximated after a 2D polynomial fit. The reed is modelled in 3D as an orthotropic material. The reed is clamped on two rectangular surfaces 23 × 1 mm, spaced laterally by 5 mm, 38.2 mm from the tip of the reed, simulating the contact surfaces on the ligature. Otherwise the reed is free. For the simulations, the "Generative Part Structural Analysis" module by Catia v.5.17 (Dassault Technologies) is used, with mesh Octree3D, size 2 mm, absolute sag 0.1 mm, parabolic tetrahedrons. The generated mesh involves 5927 points, allowing both a good accuracy and a reasonable computing time. The details of the computation are described in [8].

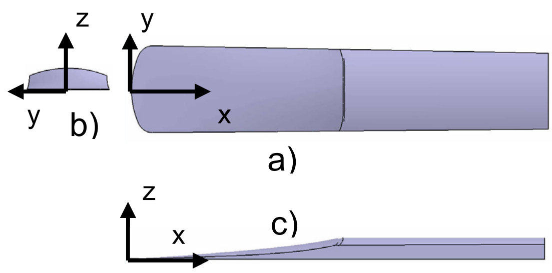

Figure 1: The clarinet reed: coordinates x, y and z. (a) top view, (b) front view, (c) side view.

For a discussion of the results, a comparison with the 2D Kirchhoff-Love theory for thin plates [9] may be useful, because the radial stain is negligible.

The axes are: x (longitudinal), y (transverse) and z (radial, see Fig. 1). By default, the dimensions are expressed in millimetres. The thickness of the plate is h and the stress tensor has the components: σ_{xx}, σ_{yy} and σ_{xy}. The bending moments are:

$$M_x = \int_{-h/2}^{h/2} z\sigma_{xx} dz \; ; \; M_y = \int_{-h/2}^{h/2} z\sigma_{yy} dz \; ; \quad M_{xy} = \int_{-h/2}^{h/2} z\sigma_{xy} dz \tag{1}$$

We assume that the longitudinal stress σ_{xx} computed with the 3D simulation on the external surface of the reed is approximately proportional to M_x The deflection w of the plate is described by the linear product:

$$\begin{pmatrix} M_x \\ M_y \\ M_{xy} \end{pmatrix} = -h^3 \begin{pmatrix} D_1 & D_2/2 & 0 \\ D_2/2 & D_3 & 0 \\ 0 & 0 & D_4/2 \end{pmatrix} \begin{pmatrix} \frac{\partial^2 w}{\partial x^2} \\ \frac{\partial^2 w}{\partial y^2} \\ \frac{\partial^2 w}{\partial xy} \end{pmatrix} \quad (2)$$

where D_1, D_2, D_3 and D_4 are the bending stiffnesses. In the simulations, these coefficients were set respectively to: 1170, 18, 40 and 367 MPa. This corresponds to the reference values cited in [8]: Young moduli E_L=14GPa and E_T=0.48GPa, shear modulus G_{LT}=1.1GPa and Poisson coefficient ν_{LT}=0.22.
With these values, Eq. (2) reduces essentially to a 1D Euler-Bernoulli beam equation:

$$M_x \cong -h^3 D_1 \frac{\partial^2 w}{\partial x^2} ; \qquad M_y << M_x \; ; \; M_{xy} << M_x \quad (3)$$

Moreover, from preliminary analyses, we observed that the von Mises yield criterion σ_v is always strongly dominated by σ_{xx}. This provides a very useful simplification: since M_x depends exclusively from the stress σ_{xx}, the problem can be approximated essentially in term of M_x. Additionally, the computational burden can be lightened for the following reason: the effect of a modification in thickness can be approximated from a modification of the bending moments, because the bending moments are proportional to h^3 (or more explicitly to $h(x,y)^3$, since the thickness is variable), according to Eq. (2): the stiffness and mass matrices need thus to be computed only once with FEM. A second substantial simplification can be operated for a mathematical reason: the deflexion of the reed and the distribution of bending moments are necessarily bandlimited functions. On the surface of the vamp, the air pressure is essentially constant and the lip pressure exerts by nature only smooth variations of the pressure field. However, the pressure field caused by the reaction of the lay can present sharp transitions, especially in the transverse direction. In the longitudinal direction, sharp variations in the pressure field are naturally smoothed by 2 mechanisms:

- If a strong pressure is applied on a small area, the cells tend to collapse and the pressure is transferred on neighbouring cells. This plastic deformation can be observed on old reeds: the contour of the window of the mouthpiece is clearly impressed on the back of the reed.

- If a strong bending moment is applied on a small area, the viscoelastic relaxation probably spread out this stress on the neighbouring areas (until eventually the sides of the reed enter in contact with the lay).

Moreover, even if the pressure field exhibits strong local variations, the distribution of bending moments presents necessarily smoother variations, because it depends from a double integration of the pressure field. The deflexion itself is even smoother, because of the quadruple integration.

The inverse problem is greatly simplified by these 2 main considerations: the deflexion depends essentially on M_x and M_x is necessarily a bandlimited function. Therefore $M_x(x,y)$ can theoretically be approximated as a weighted sum of bidimensional Gaussians [1] :

$$M_x(\bar{x},\bar{y}) \cong \sum_{p=1}^{P}\sum_{q=1}^{Q} a_{pq} Exp\left(-\frac{(\bar{x}-p)^2}{2s^2}\right) Exp\left(-\frac{(\bar{y}-q)^2}{2s^2}\right) \quad (4)$$

where P and Q are the dimensions of the grid, a_{pq} the weights for each bidimensional Gaussian and s is the standard deviation (set to: s=0.5). The variables x and y must be translated and scaled adequately to correspond to those of the dimensionless grid $\bar{x}$ and $\bar{y}$.

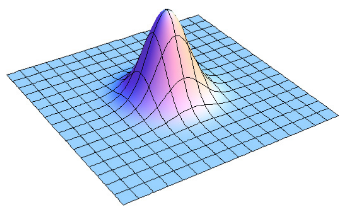

Figure 2: Bidimensional Gaussian

Eq. (4) is however of little merit for calculating w after Eq. (2) for 2 reasons:

- The bending moments M_y and M_{xy} are small but not negligible: Eq. (2) cannot be simplified as a 1D beam equation such as Eq. (3).

- The boundary conditions impose that some of the bending moments are vanishing near the free edges, therefore a perfect Gaussian distribution is impossible to achieve near the boundaries.

Consequently, a nearly Gaussian distribution ("as Gaussian as possible") of M_x is approximated from a pressure field. This ensures that M_y and M_{xy} can be computed correctly and that the boundary conditions are respected.

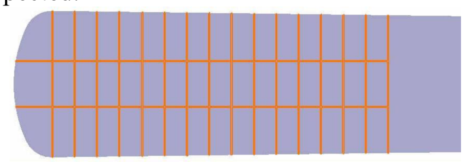

Figure 3: Division of the vamp of the reed in 16X3 surfaces

For solving this inverse problem, we adopt a rather crude approach. This is justified because our concern is to sketch general guidelines about the static bending of the clarinet reed, in relation with the problem of scraping.

[1] According to the Shannon theorem, the Sinc function should be the optimal function for this task. This requires however an infinity of terms. If the computing domain is truncated, the Sinc should be regulated by multiplication with a Gaussian, to limit the consequences of the truncation [10,11]. When the computing domain is very tiny (here we have a grid 3X4), the standard deviation of the Gaussian must be small in order to inhibit the phenomenon of ripple, so the Sinc function reduces essentially to a Gaussian.

We proceed in the following way: the surface of the vamp is divided according to a grid of 16X3 surfaces (see Fig. 3) and the effect on w, σ_v and σ_{xx} of the application of an uniform unitary pressure on each of the 48 surfaces (actually only 32 computations were made, because of the symmetry of the problem) is computed by Finite Element Method. As a second step, we searched by a least square fit how to approximate each bidimensional Gaussian as a linear combination from a discrete pressure field distributed over these surfaces. The operation is repeated 8 times, targeting the summit of each Gaussian on a 4X3 grid located at x=8, 16, 24 and 32 mm and y=-4, 0 and 4 mm.

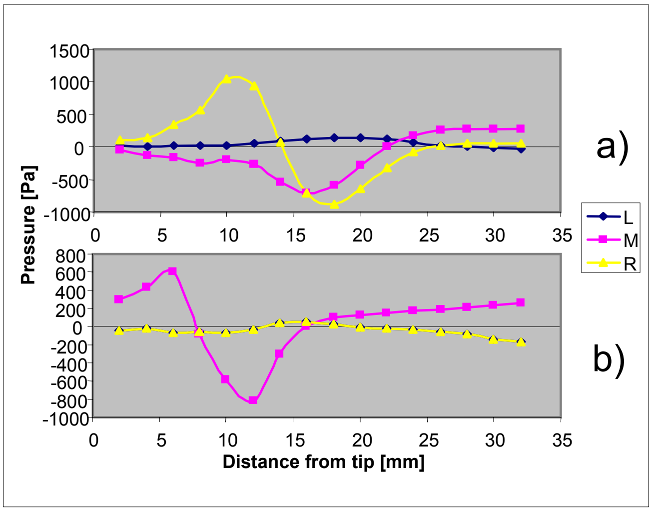

Figure 4: Discrete values of the pressure exerted on each rectangular surface depicted in Fig. 3 (L: left, M: middle, R: right column), for targeting a Gaussian stress distribution: **a)** laterally (x=16, y=4), **b)** in the axis (x=8, y=0).

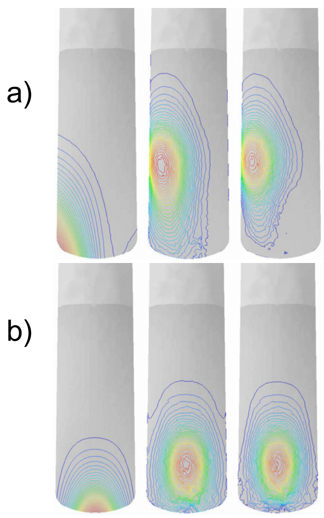

Figure 5 : Bidimensional Gaussian targeted: **a)** laterally (x=16, y=4), **b)** in the axis (x=8, y=0). From left to right, deflection w, von Mises yield criterion σ_v and stress σ_{xx}. The colour scale is identical for both σ_v and σ_{xx}. The scaling is linear from dark blue (nearly 0) to red (1).

The Fig. 4 depicts the distribution of the pressure field necessary for constituting a nearly Gaussian distribution of stress on the side or on the axis of the reed. The corresponding distributions of w, σ_v and σ_{xx} are depicted on Fig. 5. Notice that σ_v and σ_{xx} are always approximately equal, confirming our assumption, that the problem is largely dominated by the longitudinal bending moment M_x. This is approximately true for all fitted Gaussians. As expected, the boundary conditions do not allow building exact Gaussians. The obtained distributions are however quasi-orthogonal bandlimited functions, respecting the boundary conditions, and this is the most important point.

When the Gaussian is targeted in the axis of the reed, the sides exhibit only a rotation, but no translation at all. Notice this on Fig. 5 b) left: the first dark blue fringe goes up to the tip of the reed. The lateral displacement of the reed is therefore nearly zero. This observation simplifies considerably the problem, since the bending moment M_x in the axis has no influence on the lateral contact of reed with the lay. This implies that the translation of the lateral edges is exclusively a function of the lateral distribution of bending moments. The lay acts as a limiter of bending moments: when the reed is laterally full in contact with the lay, the lateral bending moments are known.

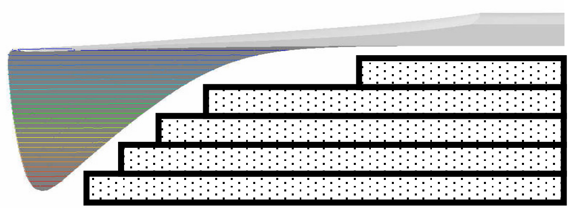

Figure 6: Side view of the deflexion of the reed (massively exaggerated), when the Gaussian stress is targeted on the side (x=16, y=4); Shape of the corresponding Claripatch. The height of each step is about 15 µm.

Figure 7: Top view of the Claripatch for a local reduction of the stress on the right side only. The clarinettist scrapes the reed approximately in the red area, if the playability of the reed is advantageously improved by this patch.

The lateral deflexion of the reed gives the shape of the Claripatch wedge. Fig. 6 shows the profile of such a convex wedge, for increasing locally the curvature of the lay. A concave Claripatch for decreasing locally the curvature is sketched on Fig. 7. On the left, the steps are of equal length. The curvature is therefore unmodified. On the right, the steps are longer near the tip (especially the first one, between the tip of the reed and the patch). When this Claripatch is applied on the mouthpiece, M_x is reduced in the red area, when the right side of the reed is in contact with the patch (or with the lay, near the tip). If the clarinettist considers that the playability of the reed is improved by this patch, he obtains approximately the same effect by scraping the reed in the red area. The bending moment M_x can be reduced in the same way in both cases, because it is proportional to $h^3 \dfrac{\partial^2 w}{\partial x^2}$, according to Eq. (3).

Table 1: Relative lateral deflexion of the reed for a unitary Gaussian stress, targeted on the line y=4.

	Target of the Gaussian			
	x=32	x=24	x=16	x=8
x	Lateral deflection of the reed			
4	0.967	0.973	0.921	0.510
6	0.897	0.865	0.755	0.325
8	0.827	0.757	0.595	0.192
10	0.756	0.652	0.447	0.105
12	0.686	0.548	0.316	0.056
14	0.616	0.447	0.207	0.029
16	0.547	0.351	0.125	0.016
18	0.478	0.261	0.070	0.009
20	0.411	0.181	0.038	0.005
22	0.346	0.114	0.020	0.003
24	0.284	0.065	0.011	0.002
26	0.226	0.033	0.006	0.001
28	0.173	0.014	0.003	0.001
30	0.128	0.005	0.002	0.001
32	0.090	0.002	0.001	0.000
34	0.060	0.002	0.001	0.000
36	0.039	0.002	0.000	0.000
38	0.024	0.002	0.000	0.000

3 Discussion

Our aim was principally to analyse the feasibility of a scraping technique based on scientific criterions. Our approach eludes all dynamic aspects of the reed in playing situation and focus the attention exclusively on static aspects. This may seem strange for musicians used to approach this problematic in terms of vibration. It was however clear in our minds that the inertial forces involved in dynamic situations can also be expressed with the help of bandlimited functions and can therefore be assimilated *de facto* as a dynamic application of a pressure field. Indeed, our model allows expressing quite correctly the first vibration modes of the clarinet reed and may thus be a useful tool for a sparse representation of all aspects of the mechanics of the reed. A modal approach has proved less useful in this context, because of the strong pressures exerted by the lip and the lay.

Despite of our "do it yourself" approach (detouring a sophisticated FEM software for solving an inverse problem), the essence of the mechanical problem could be decomposed as the sum of quasi orthogonal bandlimited functions of the bending moment M_x. This was possible because of the strong anisotropy of the reed material (*Arundo donax* L.). The drastic data reduction in the model from 5927 to 12 dimensions destroys certainly many important details of the mechanical problem, but we are convinced that the most important aspects are maintained. A division of the surface of the vamp in only 12 surfaces rends the musical problem certainly more tractable for a scientific analysis, than with a more refined model.

Our hypothesis, that the quasi-static bending behaviour influences considerably the musical playability of the reed, remains to be demonstrated. This seems plausible, since the playing frequency is generally much lower than the frequency of the first mode of vibration of the reed (associated with the lip of the clarinettist) and this fact seems corroborated through our musical tests. It must be however verified, that the reed remains indeed laterally in full contact with the lay, periodically, during *fortissimo* playing.

If this has proven true, then the problem of designing the mouthpiece's lay of all instruments with single beating reed is considerably simplified: the shape of the lay can be expressed as the lateral deflection of a given reed subject to the application of a lateral, bandlimited distribution of bending moment M_x. This means for instance, that the lay of all clarinet mouthpieces designed for the V12 reed by Vandoren can probably be expressed as a linear combination of the deflections given in Table 1. We verified that this assessment is true for the models M30, B40, B45, B45lyre, 5JB, M13, 5RV and 5RVlyre by Vandoren, with a maximal absolute error less than 6 μm (about 0.5% of the maximal opening; This correspond approximately to our measurement error). The arbitrary division of the longitudinal axe in 4 surfaces is then probably sufficient for a musical analysis of the problematic. These deflections can be considered as a basis of quasi orthogonal vectors and it is possible to establish interesting correlations between these vectors and the musical properties of the mouthpieces, but this is beyond the scope of the present paper.

Practical tests show that our scraping technique works rather well. Differences in the playability of clarinet reeds by modifying locally the curvature of the lay on the left or on the right are not difficult to notice and we verified with a few clarinettists that the effect of scraping is approximately equivalent to the effect of the Claripatch. It is often reported that the improvement of the playability by scraping is superior.

Systematic musical tests remain however to be carefully conducted and confirmed by multiple retests. We observed that misjudgements sometimes occur, especially when the reed is quite hard. The clarinettist often prefers to reduce the thickness on the weak side of the reed, because this reduces the required air pressure in the short term. In the long term, however, a better practice seems to balance the stiffness of the sides.

An experimental study of the modifications of the non-linear characteristics with the method described in [12] could be valuable. The technique of the "popping sound" [6] (sudden aperture of the reed after a static closure of the reed channel when an underpressure is applied in the bore of the mouthpiece) should also be investigated, since it could offer an easy and full objective test for our scraping technique.

4 Conclusion

Practical evidence proves the feasibility of our approach of the scraping technique and this shows that our hypotheses are probably correct. The most important aspects of the mechanics of the clarinet reed can be obviously addressed in terms of bandlimited distributions of longitudinal bending moments.

In the future, a musical and psychoacoustic study of our scraping technique should be conducted and the acoustical mechanism generating the perceived differences should be investigated.

Acknowledgments

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