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Influence of strain-gauge sensors on the vibrational behaviour of single reeds

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Abstract

Experimental measurements are often used in conjunction with physical modelling to characterise sound generation in musical instruments. Focusing on single-reed woodwind instruments, such analyses have provided accurate descriptions of the coupling between the sound excitation mechanism and the resonator during steady-state regimes. For note transients however, more detailed measurements of the reed vibrations under real playing conditions are required. Therefore, strain gauge sensors haven been placed on a series of clarinet and saxophone reeds, in order to capture the vibrations without interfering with the player. Different ways of attaching the sensors to the reeds are considered and the resulting influence is quantified by means of Laser Doppler Vibrometry and Electronic Speckle Pattern Interferometry.

Keywords: woodwinds, single-reed, strain-gauge sensors

Influence of strain-gauge sensors on the vibrational behaviour of single reeds

1 Introduction

The musician-instrument interaction is a topic that has recently attracted great attention within the field of music acoustics [1]. In the case of single-reed woodwind instruments, a major part of this interaction takes place at the mouthpiece. Of particular interest in this study is the possibility to characterise various articulation techniques that musicians use by adapting their embouchure in order to control the oscillations of the instrument. This requires subtle measurements regarding the vibrations of the reed, especially in the case where a tongue-reed interaction takes place. Such measurements can be used to validate existing physical models that are used to resynthesise transient phenomena in woodwind instruments. Even though such models have been used to both analyse and resynthesise steady-state woodwind sounds, the analysis of transients still poses several difficulties, due to their short duration and the difficulty to obtain measurements under real-playing conditions.

In an attempt to obtain a better understanding of the reed vibrations, while the instrument is played by a human performer, strain gauge sensors have been attached to a series of clarinet and saxophone reeds. The non-intrusiveness of these sensors, although confirmed by professional players, also needs to be experimentally tested. Therefore the effect of the sensors on the resonance frequency of (isolated) cane and synthetic reeds is quantified in this study. This allows to verify whether the proposed approach is suitable for analysing (and subsequently modelling) articulation during woodwind performance.

Musicians use a variety of articulations techniques in order to structure a tone sequence. These may include various actions of the tongue [2], which usually involve a direct interaction with the reed [3]. The influence of tongue strokes to the vibrations of the reed have recently been under investigation [4]. Based on considerations by Bates [5] and Sullivan [6], the present authors tried to quantify tonguing by measuring and simulating both the mouth- and mouthpiece pressure and the reed oscillations [7, 8]. Subsequently, based on the same considerations by Bates and Sullivan, Li et al. [9] used an analogous experimental setup to correlate tonguing with blowing pressure, while only considering a binary tongue action and without measuring the reed oscillations.

Quantifying the reed displacement, while measuring the mouthpiece pressure, allows a more detailed understanding of the way the player's tongue may affect the reed vibrations. Furthermore, access to these signals may be advantageous in terms of formulating and validating an inverse modelling approach that could yield valuable information on the excitation mechanism. Given pressure and flow in the mouthpiece and using a two-step optimisation routine, an inverse model of clarinet tones has been successfully applied during steady-state regimes [10]. But the rapid variation of model parameters during transients adds more complexity to such an inverse modelling approach, which could benefit from the measurement of a further signal (in this case reed displacement). The difficulty of measuring such a signal under real playing conditions has been recently pointed out in an attempt to characterise saxophone reeds [11].

Capturing the reed vibrations while a musician is playing the instrument is no trivial task [12]. Strain gauge sensors mounted on synthetic reeds have turned out not to disrupt experienced woodwind instrument players [2]. Therefore, the construction of such sensor reeds is currently being pursued for research purposes, but alternative applications in terms of live-performance and education are also foreseen [13]. The next section describes the experimental setup that is used to estimate the effect of the sensors on the resonance frequency of the reeds. The results and a short discussion of the outcomes of this study follow in sections 3 and 4.

2 Experimental Setup

All reeds used in this study are Fiberreeds made by Hartmann[1]. These are made of multiple layers of fibre-reinforced polymers. Therefore strain-gauge sensors can be integrated in the reeds during production (see [13] for details). Such sensors have already provided fruitful information on the vibrational behaviour of single-reeds [14]. In order to quantify the effect of the sensor placement, three types of clarinet and saxophone reeds are used; with one sensor, two sensors and no sensors at all (see Figure 1 (right) for the clarinet sensor reeds). The use of two sensors is required in order to capture torsional modes which may be present in the reed oscillations [15].

In this work the aim is to qualitatively analyse whether mounting strain-gauge sensors on single reeds may significantly alter their frequency response. Therefore an analysis is carried out based on isolated reeds, which allow more direct and precise measurements.

Two different experiments are carried out in order to visualise the reed vibrations. First, the frequency response of the reeds is measured, and then the vibration patterns at the reed

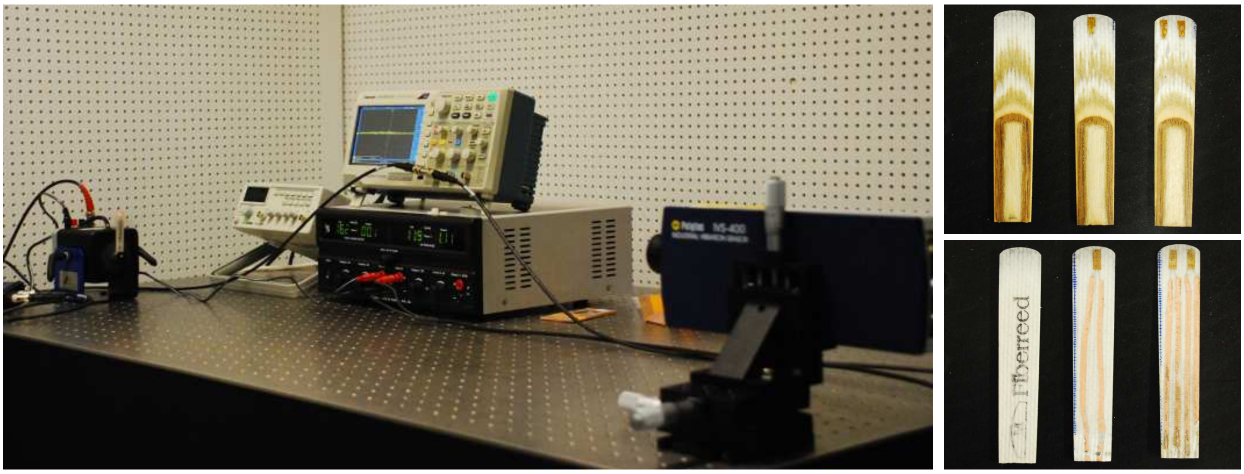

Figure 1: **The LDV measurement setup (left) and the clarinet sensor reeds (right).**

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[1] www.fiberreed.com

resonance frequencies are imaged. The former measurement (see Figure 1 (left)) involves the reed being excited by a shaker (TMS/PCB K2007E01) using a frequency sweep while a Laser Doppler Vibrometer (LDV, Polytec Laser Vibrometer IVS–400) pointing at the sensor position measures the velocity of the reed. In the second experiment, in order to obtain a better understanding of how the sensors might affect the reed vibrations, Electronic Speckle Pattern Interferometry (ESPI) is used to visualise the reed motion. The experimental setup is depicted on Figure 2.

ESPI is a nondestructive optical technique generally applied in a full-field surface deformation analysis. It uses properties of coherent light reflected from a rough surface and captured by a camera with a superimposed reference beam created by the same source. The formed image is called a subjective speckle pattern [16]. In general, phase-shifting techniques may be applied in order to recover the phase information of the vibrating object [17]. In the present study a simpler setup is used for the detection of the out-of-plane displacement with a continuous wave laser and a conventional CCD camera, as described in [18]. If the response of the object to a harmonic stimulation is linear, the intensity difference between two adjacent captured images during the excitation by a shaker (Brüel & Kjær, type 4810) provides information about the operating deflection shapes (ODS) of the surface and the amplitude of vibration through correlation fringes. Several subtraction images are recorded for each frequency, filtered and processed using the algorithm presented in [19]. Compared to other optical methods, e.g. holography, ESPI is more efficient in terms of post-processing applications, such as extracting displacement amplitudes via phase reconstruction.

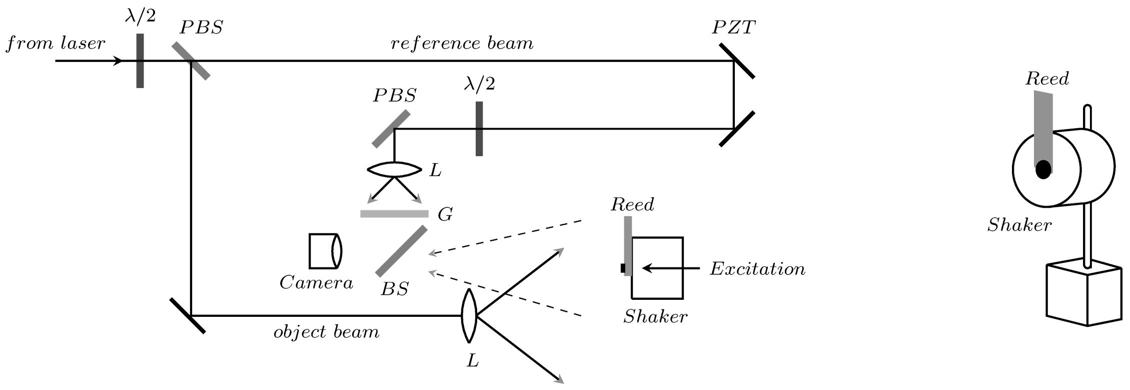

Figure 2: **Sketch of the ESPI arrangement (see [19] for details). The laser light is divided into two beams, using a polarizing beam splitter (PBS). The intensity of the beams is controlled by half-wave plates (λ/2) and lenses (L) are used to expand the beams. A PZT-driven mirror is introduced in the reference arm in order to produce a varying optical path difference [18]. The reference beam passes through the ground glass (G) and a beam splitter (BS) is used to combine the beams.**

3 Results

The measurements show that integrating strain-gauge sensors in the reeds has a small effect on their resonance characteristics. The fact that woodwind instrument players were not disrupted may be explained by analysing the resulting variations. Figure 3 shows the frequency response of clarinet and saxophone reeds with and without integrated sensors. It can be observed that the presence of the sensors lowers the resonance frequency of the first mode of vibration, while the second mode remains almost unaffected. Furthermore, the vibration amplitudes at both first and second resonance frequencies are only slightly affected by the presence of the sensors (with the exception of the saxophone reed with two sensors, which exhibits lower amplitudes).

Note that the measured frequency response in that case corresponds to an isolated reed. When mounted on the mouthpiece, the effective stiffness of the reed (and thus its resonance characteristics) changes; its vibrating length decreases, leading to an increase in stiffness. A decrease in the reed opening also has a similar (dynamic) effect, with the reed “beating” on the mouthpiece lay. To approximate this behaviour models with non-constant stiffness have been proposed [20]. Using a constant reed stiffness and a collision term to model reed beating [10] has been shown to be sufficient for sound resynthesis applications [21, 14].

Furthermore, under real-playing conditions the player’s lower lip pressure results in a smaller portion of the reed vibrating. Hence the resonance frequency of isolated reeds is actually much lower than that during performance. For instance, the first clarinet-reed mode is measured at 706 Hz, whereas under real-playing conditions it is expected to lie at around 2000 Hz (see, e.g., [22]). This should be taken into account when considering how a change in the reed resonance due to sensor placement may significantly affect the performer.

Further insight on the reed vibrations is obtained using ESPI, which enables to visualise the pattern of the reed motion. As shown in Figure 4 the ODS of the reeds are not significantly modified by the sensors. At the first reed resonance the whole reed is moving as a clamped bar and the extra mass presented by the sensor(s) lowers the resonance frequency. However, the playing frequency in woodwind instruments is much lower than the reed resonance [23]. Therefore, small variations in the frequency of the first resonance, as those observed in Figure 3, do not directly influence the reed vibrations under real playing conditions. The same vibrational pattern holds when the reed is mounted on the mouthpiece (see [17]) with resonance frequencies shifted upwards due to a smaller portion of the reed being free to vibrate. As such, the alteration of the resonance characteristics of the reeds by the sensors is hardly noticeable by the player, as has been already confirmed in a subjective evaluation study [2].

It should be noted here, that in the present study the effect of the player’s lower lip has not been considered. This results in a much smaller vibrating reed surface, with ODS similar to those identified with the second resonance frequency of the free reeds. The design of an artificial mouth that would allow measurements under more realistic conditions is envisaged. However, this would obstruct the view of the camera for interferometry purposes. This study is thus limited to extracting information from the vibrations of isolated reeds, regarding the intrusiveness of the sensors.

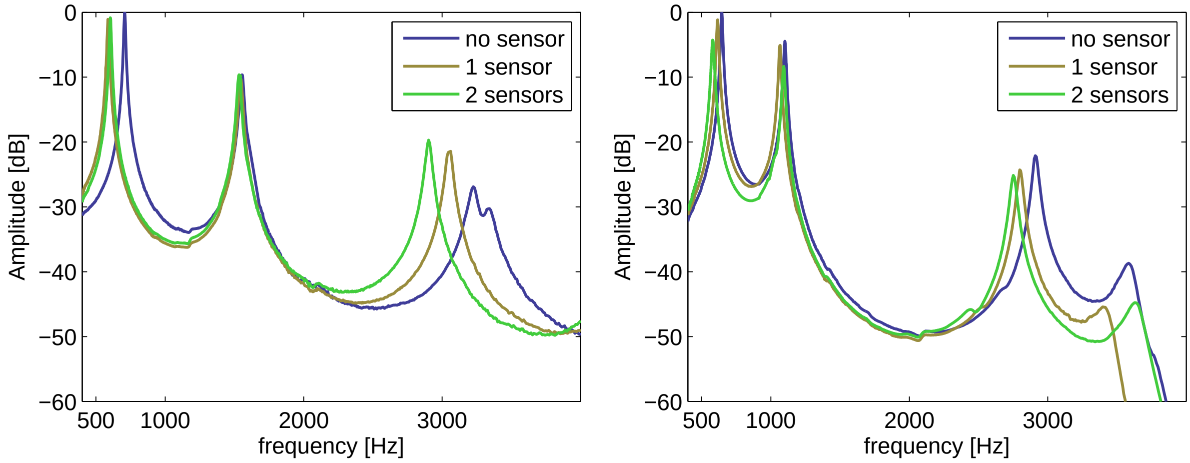

Figure 3: **Frequency response of clarinet (left) and saxophone sensor reeds (right).**

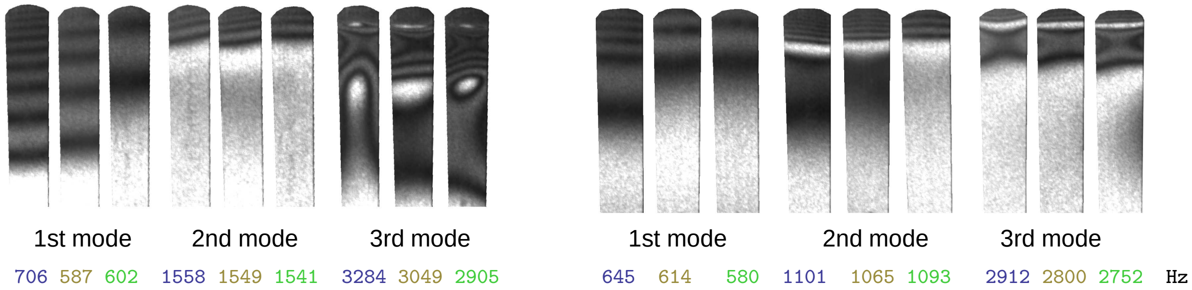

Figure 4: **Decorrelated electronic speckle pattern interferograms of clarinet (left) and saxophone sensor reeds (right) oscillating at their first three resonance frequencies. At every mode the operating deflection shapes are shown from left to right corresponding to no sensor, one sensor and two sensors mounted on the reed. Nodal lines are represented by white regions and moving areas by correlation fringes.**

4 Discussion

Under real playing conditions, and hence below the first reed resonance the reed is expected to mostly behave as a vibrating bar (with amplitude dependent stiffness, as explained in Section 3). Therefore a strain-gauge sensor on the tip of the reed can capture valuable information regarding the reed-tip displacement. This parameter is usually present in physical models of woodwind instruments and directly related to the flow into the mouthpiece. The low intrusiveness of these sensors renders them suitable for measurements under real playing conditions, where alternative measurement techniques may be impossible. Such a construction of sensor reeds presents a very flexible measurement tool, which in combination with a pressure measurement can provide enough information to extract the physical characteristics of the single-reed excitation mechanism.

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