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INFLUENCE OF THE SURFACE CONDITION IN THE BORE OF WOODWIND INSTRUMENTS ON THE ACOUSTIC IMPEDANCE

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Introduction

Woodwind players typically play next to the bore resonances. The playability and the quality of woodwind instruments strongly depend on the frequencies, amplitudes and bandwidths of the bore resonances. The input impedance of woodwind instruments, which allows estimations of these characteristics, has been extensively studied [e.g. Backus, 1974; Wolfe, 2001]. The influence of the bore geometry on the impedance peaks is well known [Chaigne & Kergomard, 2008]. However, the playability of woodwind instruments is also affected by the surface condition inside the bore. Indeed makers and players typically use oil to seal the pores of the inner wall. Recently, at the Musée de la Musique in Paris, the input impedances of a historical (not played) serpent made by Baudoin and of an oiled facsimile of same geometry in a playable state have been measured. Their comparison revealed significant differences of Q-factors and amplitudes in the impedance peaks.

This study investigates the influence of the surface condition of wooden pipes on the characteristics of their impedance peaks.

Materials and methods

A corpus of six pipes was provided by maker Pierre Ribo. Three are made of maple, three of chequer tree. Each pipe is composed of two pieces, cut lengthwise, parallel to the trunk, and glued together. For each species, one pipe was immersed in oil; another was immersed twice, and dried for one week between both baths, and one pipe was not immersed. The bores of the pipes are approximately cylindrical of diameter between 24.05 and 24.25 mm and length between 338.5 and 339.5 mm.

Many methods of acoustic impedance measurement have been previously developed and reviewed [Dalmont, 2001a]. The one used in this study was developed by Le Roux et al. [2008]. For each measurement, one end of the pipe is placed in the plane of the open face of the measuring device, so that their axes coincide. The contact between the pipe and the sensor is sealed with silicone and petroleum jelly. The setup measures dimensionless impedances on this plane: $Z/(\rho_0 c_0/S)$, Z being the input impedance of the pipe, c_0 and ρ_0 the speed of sound and the density of air and S the area of the cross section.

For each pipe the impedance spectrum is measured twice, between 20 Hz and 6 kHz, allowing estimations of the amplitudes, frequencies and Q-factors of the 12 lower resonances. The Q-factors are estimated by the quotient between the frequencies of the impedance peaks and their bandwidths at -3dB. These estimations are reproduced within 0.11% for the resonance frequencies, 1.9% for the Q-factors and 0.1 dB for the amplitudes.

Results

Among the pipes considered, the characteristics of impedance peaks undergo significant variations, as shown by the measurements of Fig.1.

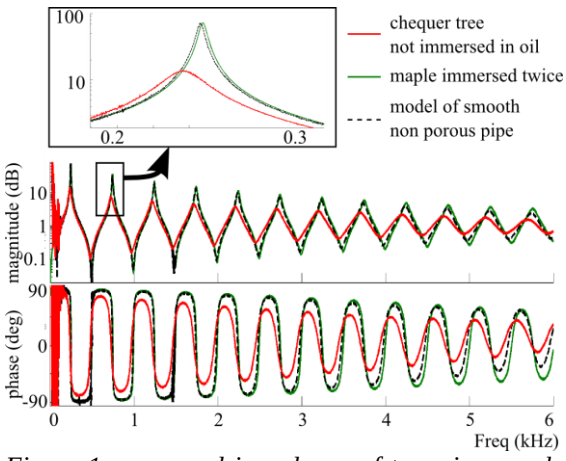

Figure 1: measured impedance of two pipes made of different wood species and with different surface conditions and theoretical impedance of a model of pipe. Each pipe has a diameter equal to 24.1 mm and a length equal to 339 mm

For the 12 first peaks, the standard deviations of these variations are 0.6% for the resonance frequencies, 32% for the amplitudes, and 32% for the Q-factors. These values are compared with a simple model of uniform cylindrical pipe, open at its far end, with length correction [Dalmont, 2001b] and viscothermal losses [Fletcher & Rossing, 1991], see black curve in Fig.1. When the diameter and length sweep the same range as those of the real pipes, the resonance characteristics of the model undergo much smaller variations than the measured ones: the standard deviations are 0.1% for the resonance frequencies, 0.2% for the amplitudes and 0.2% for the Q-factors.

For both wood species considered, the measured amplitudes and Q-factors of the impedance peaks increase when the pipe has been immersed in oil, as shown in Fig.2. However the effect of a second immersion is relatively bigger on the resonance characteristics of the chequer tree pipes while it is negligible on the maple pipes.

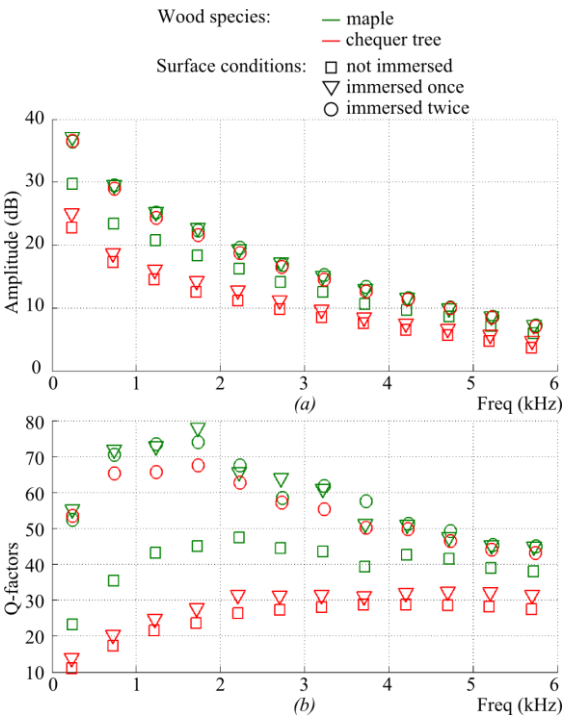

Figure 2: amplitudes (a) and Q-factors (b) of the impedance peaks of maple and chequer tree pipes having different surface conditions.

As a result, immersing a wooden pipe in oil increases its resonance amplitudes and Q-factors significantly. Further, the number of immersions has different effects, depending on the wood species. Further studies show that the deviation of amplitude and Q-factors of the impedance peaks when the surface condition of the pipes is changed are linear functions of their frequency deviations. A model of acoustic propagation in a porous medium using Biot's theory [Allard & Atalla, 2009] is introduced to discuss these results.

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