Can wall vibrations alter the sound of a flue organ pipe?

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The prediction of changes in the perceived sound of a blown pipe due to wall vibrations is made difficult by the multitude of interactions. Excitation, shape, and sound radiation of structural modes depend on a number of parameters like material, voicing technique, geometry and fixing of the pipe. This article presents experimental work on comparison of vibrations and sound radiation from a tin-rich pipe in two cases: with damped and undamped wall vibrations. It was found out that changes in sound pressure level at certain frequencies in the spectrogram coincide with eigenfrequencies of both air modes and structural modes and thus support the assumption of mode coupling being responsible for sound changes.

INTRODUCTION

Although most organ builders agree to organ pipe vibrations being audible, this is in contradiction to many experiments that were carried out on modern organ pipes (for an overview, see [1]). A reason why this question is not easy to answer is the multitude of parameters (e.g. foot pressure, voicing) and boundary conditions (e.g. pipe support, temperature) that are difficult to control during an experiment. In addition, modern flue organ pipes are rather thick-walled compared to pipes of the 17^{th} or 18^{th} century.

This work presents some measurement results indicating that eigenmodes of the air column, further called *air modes*, and eigenmodes of the pipe body, *structure modes*, are likely to interact at some frequencies.

METHOD

Several experiments have been carried out (for details, see [1, 2]) for measurement of the air modes and structure modes of the same pipe under two different conditions. For detection of the structure modes the pipe was investigated either with walls covered by a removable, heavy damping layer or without layer. The air modes were identified by insertion of a paper covered stick into the air column inside the pipe. In both cases damping of the resonances by 10 dB could be achieved.

Transient sound

At first the pipe was blown and the sound pressure was recorded.

Figure 1 shows the spectrograms of the pipe in two cases. For sake of better visualization, the harmonics have been removed. To the left the undamped case is shown. Clearly several clouds are visible during the build-up of the sound. The sound of the damped pipe is shown to the right. In this spectrogram, the clouds are still present but the sound pressure level at certain frequencies has been reduced by approx. 10 dB at 1250 Hz, 1550 Hz and 1800 Hz in the first 100 ms of the sound. Smaller differences between the damped and the undamped pipe sound can be observed in the stationary part of the sound at those frequencies.

Stationary sound

As a second approach the pipe was mechanically excited with a shaker at the labium (c.f. Fig. 2). The sound pressure at the upper (passive) end of the pipe has been recorded and the ratio to the applied force has been calculated. For this frequency response functions (FRF) four cases have been investigated: damped/undamped walls and damped/undamped air column.

In a 3rd experiment, the eigenmodes of the pipe body have been determined from laser velocimetry on the body of the mechanically excited pipe and subsequent modal analysis. The results are compared to finite element calculations (FE). The measurement results are listed in Table 1.

Table 1. Comparison of resonance frequencies (in Hz) from calculations (calc.) and measurements (meas.).

	Structure modes			**Air modes**
	FE calc.	**Laser meas.**	**FRF meas.**	**FRF meas.**
A	829	841	850	896
B	1226	1241	1263	1209
C	1514	1500	1516	1524
D	1863	1853	1865	1840

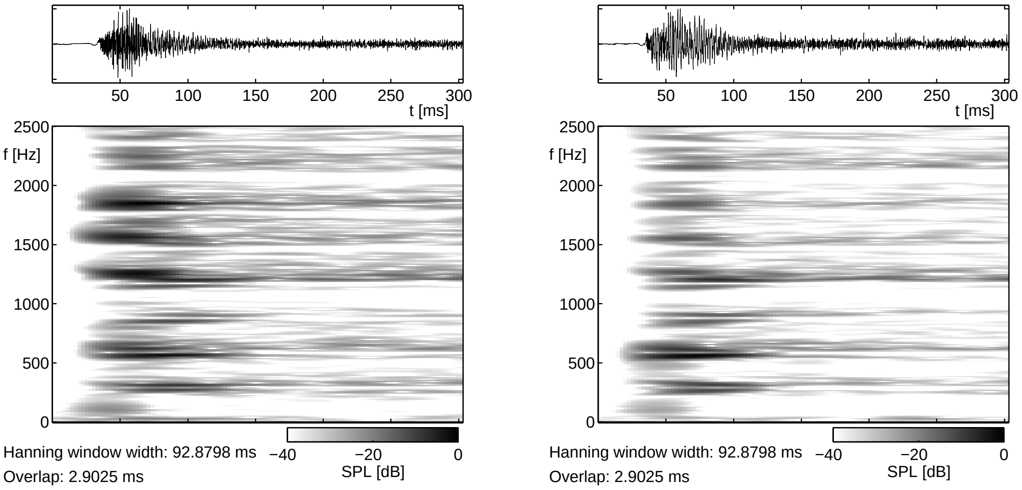

FIGURE 1. Spectrograms of the undamped (left) and damped (right) pipe without harmonics.

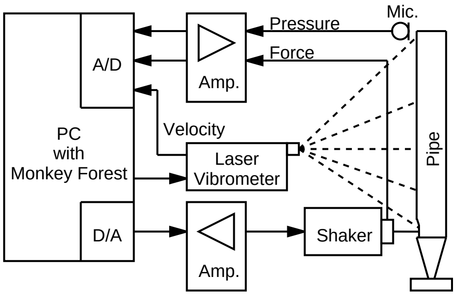

FIGURE 2. Set-up for the FRF measurements.

DISCUSSION

The wall vibrations appear to affect only a small frequency range (Modes A-D between 800 Hz to 1900 Hz, as presented in Table 1). Since the resonance frequencies of the structural modes are similar to the eigenfrequencies of the air modes, the coupling theory is supported. Perceptually, the differences are very small[1].

In the last two years, some more experiments have been carried out that seem to support the organ builders. Effort has been made to explain the nature of the coupling between air modes and structure modes and the hypothesis of pipe vibrations being audible. In [3] a mathematical approach to the theory of coupling in a simplified musical instrument is presented. Nederveen [4, 5] explains the coupling as a change of the compliance of the air that is bounded by an elliptical tube, vibrating in a twisting mode. Miklos and Angster [6] observed subharmonics in the spectrum and deduced periodic wall stiffening from the non-linear effect caused by pressure fluctuations inside the pipe. However, more experiments should validate these coupling theories.

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REFERENCES

1. M. Kob, *ACUSTICA – acta acustica* **86**, 642-648 (2000).
2. M. Kob, *ACUSTICA – acta acustica* **86**, 755-757 (2000).
3. F. Gautier and N. Tahani, *Journal of Sound and Vibration* **213**, 107-125 (1998).
4. C. N. Nederveen and J.-P. Dalmont, “Experimental investigations of wall influences on woodwind instrument sound”, in *ACUSTICA – acta acustica* **85** Suppl. 1, 1999, S76.
5. C. N. Nederveen and J.-P. Dalmont, “Influence of Wall Vibrations on Organ Pipe Sound Level and Pitch”, in *Abstract book of The Physics Congress 2000 – Physics of Musical Instruments (POMI),* Brighton, 2000, 54-55.
6. A. Miklos and J. Angster, “Linear and Nonlinear Wall Vibrations of Organ Pipes”, in *Abstract book of The Physics Congress 2000 – Physics of Musical Instruments (POMI),* Brighton, 2000, 54.

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[1] Sound examples and color pictures can be found on the Internet at http://www.akustik.rwth-aachen.de/˜malte/pipe.