THE INFLUENCE OF NICKS ON THE SOUND PROPERTIES AND THE AIRFLOW IN FRONT OF FLUE ORGAN PIPE

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ABSTRACT

Nicking is a well-known voicing technique of metal flue organ pipes widely used by Czech organ builders in history. Its effect is investigated in this paper. The sound analysis results and the PIV images of the airflow in front of the mouth were studied to achieve more advanced state of the art in organ pipe diagnostics. Both measurements were performed in steady state part of pipe sound. The results of the sound analyses are in accordance with organ builders experience – the depression of higher harmonics was observed in the frequency spectrum after pipe nicking. Airflow analysis shows significant differences in vector velocity maps – decrease of vector lengths near the flue.

1. INTRODUCTION

The sound of organ in baroque era has represented certain sound quality ideal of the period. Later, the sound of organ varies through the history. In the baroque era the clear and resolute sound timbre was required, in the romantic era more delicate sound was preffered. Hence the need of existing instruments modification (wind pressure elevation, pipes re-voicing). One of the commonly used methods of metal flue organ pipes voicing was creating (or enlarging) nicks on the languid (see Figure 1). The organ builders say the nicks makes pipe sound "more cultivated" or "less aggressive" which is equivalent to depression of higher harmonics in technical language. Also it is known, that the nicks should make flow more uniform and ordered. The aim of this paper is to document the differences in the sound quality and in the airflow in front of the pipe mouth before and after nicking.

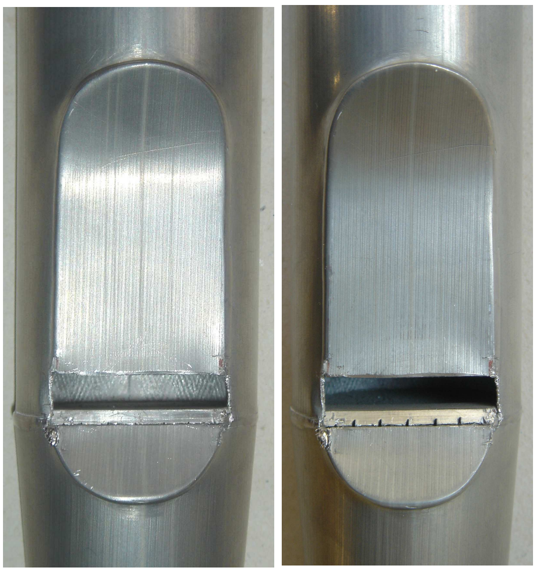

Figure 1: detailed view of pipe mouth; languid with small baroque nicks (left), and with large romantic nicks (right)

2. METHOD

2.1 Measurement setup

The Principal 8’ pipe B3 was documented. Measurements were taken in an anechoic room. The pipe was installed on an experimental windchest with electro-magnetic valves and small bellows supplied by electric ventilator. The wind pressure was 83 mm water gauge (≈ 814 Pa). Sound recordings (and subsequent airflow measurements) of the pipe in the original baroque state was taken. Then the large romantic nicks were made on the languid and all measurements were repeated. Acoustical and airflow measurements were done separately because of noisy optical measurement devices.

2.2 Acoustical measurement

Sound of the pipe was digitally recorded using 4 microphones. Two microphones were placed far from the pipe and two microphones near the pipe, one of them in the vicinity of mouth and the second one in the half length of pipe body. A schematic diagram of the microphone arrangement is shown in Figure 2.

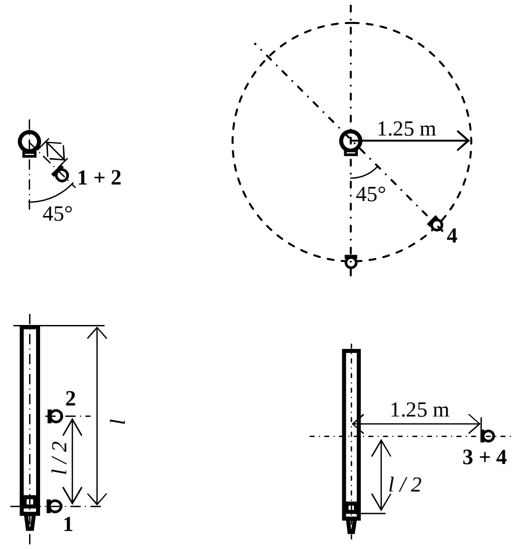

Figure 2: microphone arrangement during pipe sound recording

The recorded sound signals were analyzed. For each signal the standardised sound pressure level (SPL) and the frequency spectrum was computed, the fundamental frequency was identified and then the harmonic spectrum was computed. For each computed spectrum the frequency center of gravity (FCG) and frequency center of gravity of harmonic spectrum (FCGh) was computed.

Frequency center of gravity of harmonic spectrum (FCGh) is defined as

$$f_{cg} = f_1 \left(\sum_{k=1}^{N} kA_k \bigg/ \sum_{k=1}^{N} A_k \right) \qquad (1)$$

where
N … total number of harmonic partials in spectrum
f_1 … fundamental frequency
A_k … amplitude of k^{-th} partial

FCG of FFT spectrum is defined similarly using FFT bins instead of harmonics.

2.3 Airflow measurement

2.3.1 Particle image velocimetry (PIV)

The airflow in front of the organ pipe mouth is closely tied with generated sound and physical characteristics of pipe [1, 3], which can be very helpful while diagnosing pipes. Airflow was investigated using phase-locked Particle Image Velocimetry (PIV) – a non-intrusive optical measuring technique. PIV experiments on flutes were earlier conducted e.g. by Bamberger [3] and Yoshikawa [1]. Principle of this technique is illustrated in Figure 3 [2]. The method obtains instantaneous velocity vector maps in a cross-section of a flow. The particle seeded flow is illuminated by a thin light sheet which is formed by laser beam passed through cylindrical lens. Double-pulsed laser flashes twice in an arbitrarily short time interval, which freezes particles in the flow. Snapshot pair is captured for each flash by a high-speed camera. The obtained image pair is then divided into sub-sections (interrogation area) and particles movement $\vec{v}$ is computed

$$\vec{v} = \frac{\Delta \vec{X}}{\Delta t} \qquad (2)$$

where $\Delta \vec{X}$ is the movement of particles in the specific interrogation area and Δt is the time delay between the flashes in the pair.

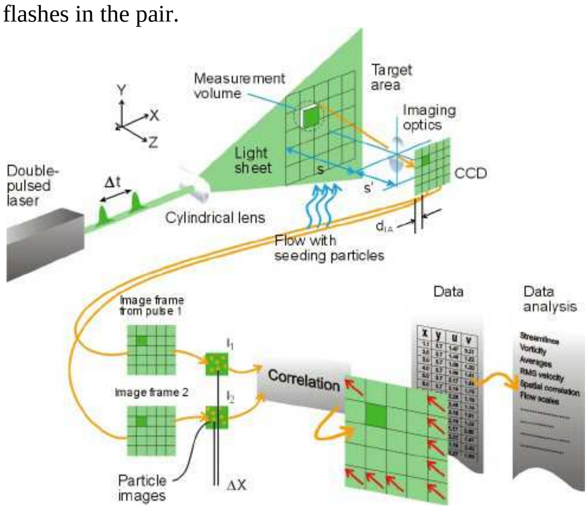

Figure 3: principle of Particle Image Velocimetry [2].

2.3.2 Planes of interest

Airflow was investigated in front of the pipe mouth. Measurements were conducted in two perpendicular planes: parallel to mouth (front view - 8 mm in front of the front labial edge) and perpendicular to the mouth center – side view. Graphical representation of investigated planes is shown in Figure 4.

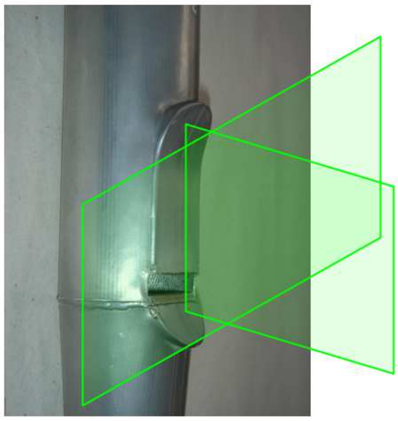

Figure 4: the planes of interest of the airflow measurement

2.3.3 Phase-locked PIV

Maximum repetition rate of used double-pulsed laser (Litron Nano-L 200-15) was 15 Hz. Since the measured pipe was tuned on 248 Hz it was not possible to directly acquire time-resolved data using this equipment. Phase-locked technique was used instead. Velocity maps were obtained repeatedly at the same phase of generated sound and resulting vector maps derived from image-pairs taken at this specific phase were then averaged. This method allows only investigation of steady state airflow.

2.3.4 Optical measurement setup

Optical measurement setup is shown in Figure 6. Sound of the pipe is captured using condenser microphone (SENNHEISER KM-6P) located at the specific position. The signal is pre-amplified and then filtered by the narrow band-pass filter (Brüel & Kjaer Spectrum shaper 5612) which passes only a signal of the fundamental harmonic. This signal is then processed by a shaper (Lindos L102) which produces a square-wave-like signal. The negative to positive zero crossings of this signal are used as the trigger events for camera (Phantom SpeedSense v611) and the laser. In order to obtain image pair in the desired phase of the generated sound delay is set via controlling PC. The PIV system (manufactured by Dantec Dynamics A/S) is synchronized via 80N77 Synchronizing box. The PIV system is controlled using Dynamic Studio software by Dantec Dynamics.

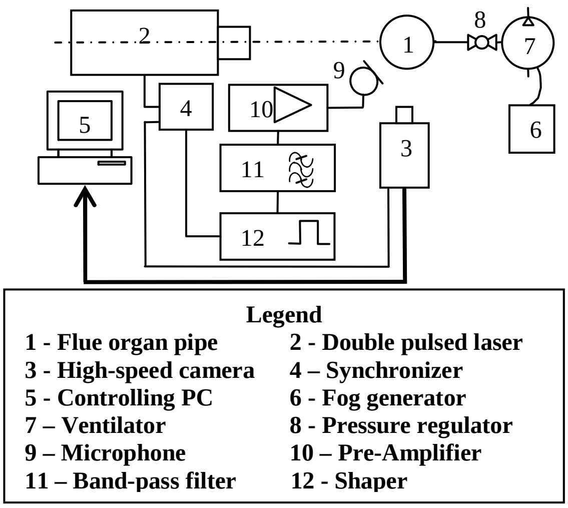

Figure 5: optical measurement setup

Figure 6: experimental setup of airflow measurement

2.3.5 Results computation

Velocity vector maps were obtained using Adaptive correlation analysis implemented in the software Dynamic Studio 3.41 [5]. Vorticity maps (Figure 12) in *z*-plane were also computed using Dynamic Studio according to the formula:

$$\omega_z = \frac{\partial V}{\partial x} - \frac{\partial U}{\partial y} \qquad (3)$$

where **V** is the scalar map with vertical values of vectors, **U** is the scalar map with horizontal vector values and *x*, resp. *y* is horizontal, resp. vertical coordinate.

3. RESULTS

3.1 Acoustical measurement

The fundamental frequency of the tone was 248.7 Hz. The fundamental frequency shift after nicking remains in the range of measurement uncertainty. The SPL of the sound recorded by individual microphones is summarized in Table 1. Changes of SPL values are very subtle, only the signal captured at the mouth showed slightly larger decrease of ca. 1.3 dB. The results of frequency analysis shows that languid nicking decreases amplitudes of higher partials (see Figure 7). This phenomenon is also documented by noticeable decrease of harmonic spectrum centre of gravity values (FCGh, see table 2). The decrease of corresponding value (FCG) is more than three times smaller. This implies that the noise part of the sound remains unchanged.

Table 1: standard sound pressure levels of the pipe with baroque and romantic nicks

	SPL [dB]	
mic No.	baroque	romantic
1	84.8	83.5
2	84.0	84.2
3	75.7	75.3
4	76.8	76.4

Table 2: frequency spectrum centre of gravity (FCG) of the pipe with baroque and romantic nicks and change ratio of its value (upper part); harmonic spectrum centre of gravity (FCGh) of the pipe with baroque and romantic nicks and change ratio of its value (lower part);

Frequency centre of gravity (FCG) [Hz]			
mic No.	baroque	romantic	rel. change
1	1602	1584	0.99
2	1587	1463	0.93
3	1554	1513	0.97
4	1394	1353	0.97
Centre of gravity of harmonic spectrum (FCGh) [Hz]			
mic No.	baroque	romantic	rel. change
1	568	506	0.89
2	483	412	0.85
3	512	457	0.89
4	482	434	0.90

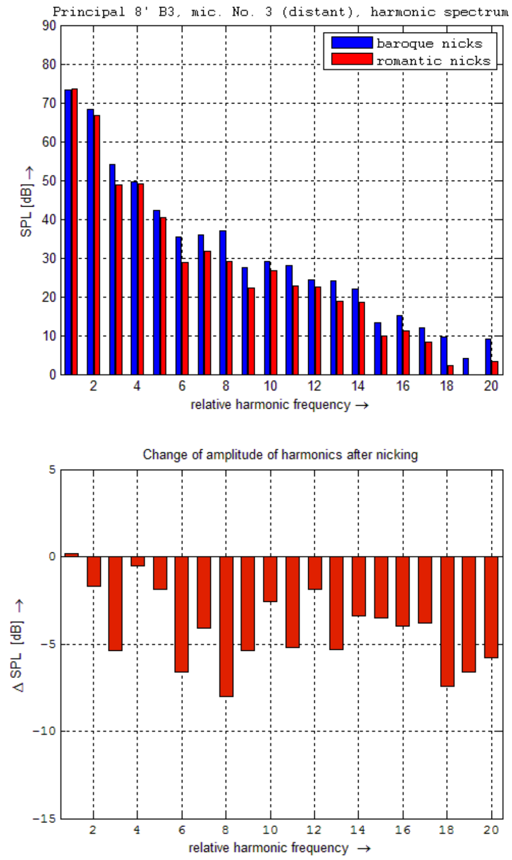

Figure 7: harmonic spectrum of sound of the flue pipe with baroque nicks and with romantic nicks (up), change of the amplitude of harmonics after nicking (down).

3.2 Airflow measurement

Images obtained while investigating airflow from side and front view are shown on Figure 8 and 9 respectively. Red rectangles mark areas for which resulting velocity maps are shown in the following images.

Vector maps were created by averaging of 250 maps for each of 12 phases. Only the maps in several crucial phases are shown to achieve better readability of results.

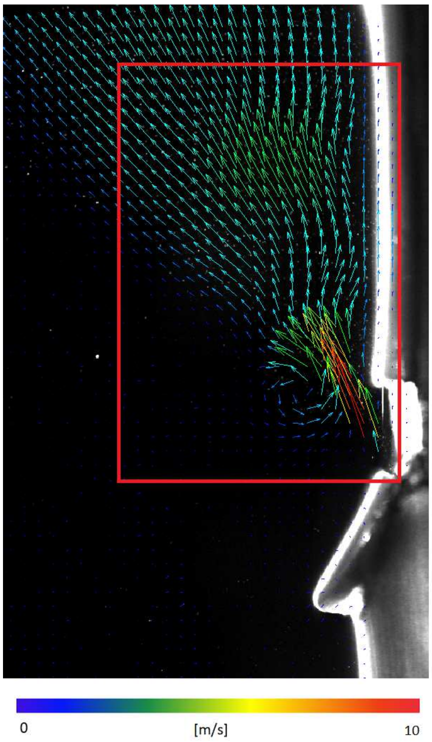

Figure 8: The area of interest in front of the mouth from the side view with averaged velocity vector map in 0°.

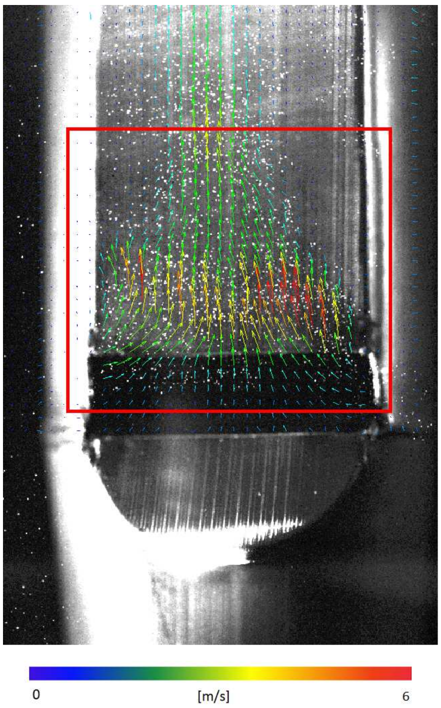

Figure 9: The area of interest in front of the mouth from the front view with averaged velocity vector map in 0°.

On Figure 10, resp. Figure 11 are shown velocity maps obtained from side, resp. front view. Blue velocity vectors correspond to baroque nicks, red vectors to romantic nicks. Color scale represents the relative difference of vectors lengths in the pair in the specific position (the greener area, the greater difference between vectors). It is evident that the velocity near the languid was decreased after creating romantic nicks.

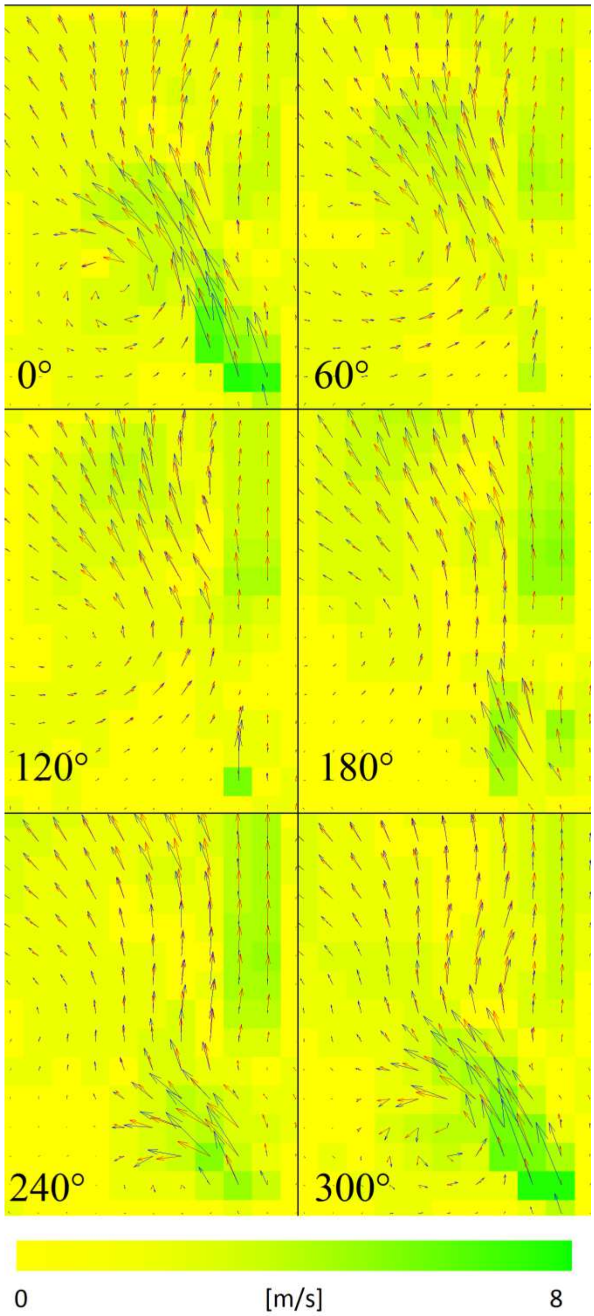

Figure 10: velocity maps in front of the mouth observed from side view in specific phases of generated sound, underlying color corresponds to the local velocity difference between baroque and romantic nicks

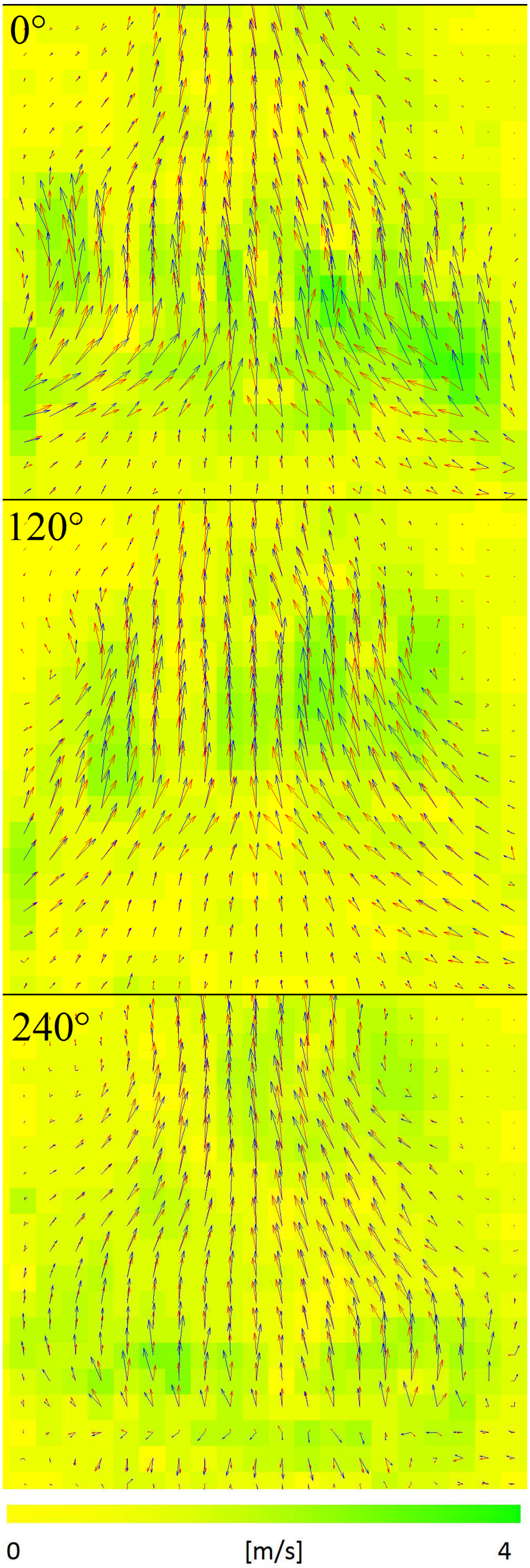

Figure 11: Velocity maps in front of the mouth observed from front view in specific phase states of generated sound.

3.2.1 Vorticity

Vorticity maps were computed by Dynamic Studio according to equation 3. On Figure 12 there are shown vorticity maps derived from averaged velocity maps at 0° (which corresponds to the most outward striking jet state) of generated sound for baroque nicks (left) and romantic nicks (right). Original velocity maps are also shown for better clarity.

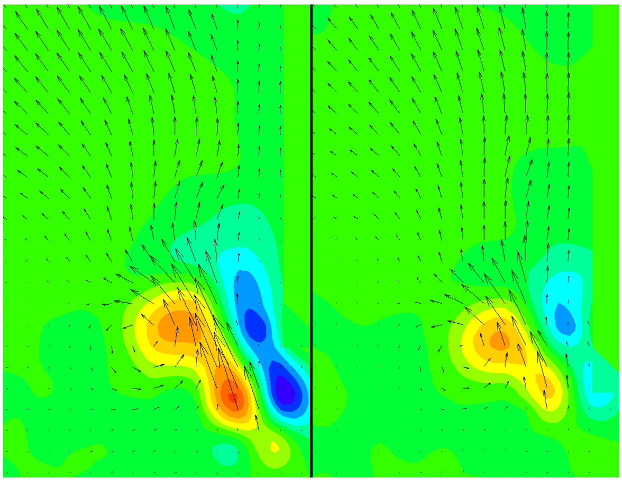

Figure 12: vorticity maps in front of the mouth observed from side view. Baroque mouth (left), romantic mouth (right). Blue, resp. red colors represent negative, resp. positive values.

4. DISCUSSION AND CONCLUSION

Changes in the sound frequency spectrum as a consequence of metal flue pipe languid nicking were documented. Also the changes in the airflow in front of the pipe mouth and the vortex layer creation were shown.

Given the usual values of the flow speeds in wooden and metal organ pipes, the air could still be considered incompressible. Therefore a good approximation from simple continuity equation U_0A = const., where U_0 is the mean flow velocity and A the area of the slit, is obtained. Nicks slightly extend the flue cross-section without removing the flue edge completely so the tone production at the languid remains unchanged. Then from the continuity equation results the decrease of U_0 without destroying any of sound producing mechanisms (see Figure 10 and 11).

The fundamental frequency shouldn't be affected by nicking, because the pipe and its eigenfrequencies are still the same. On the other hand audible and measurable differences in the acoustic spectra were expected. Excitation of higher harmonics is associated with nonlinear behavior of the jet (vortex-layer formation among others - for further discussion see [4]). This is documented in amplitude decrease in obtained vorticity maps after creating nicks (see Figure 12) - jet-vortex layer formation is less significant with nicks, which suppresses the tone production mechanism documented by Yoshikawa et al. [1].
On top of that it is considered a stronger attenuation of higher frequencies as a result of mainly inertive (inductive) pipe impedance, which can affect the signal to noise ratio in the less excitated higher harmonics. Acoustic measurements (see Figure 7) confirmed these asssumptions – nicking decreased amplitudes of higher partials of the tone.

5. ACKNOWLEDGMENTS

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6. REFERENCES

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