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Aero-Acoustic and Vibration Characteristics of Self-Oscillating Artificial Vocal Folds

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Abstract: The study presents in vitro measurements of phonation characteristics performed on developed 1:1 scaled replica of human vocal folds. The measured aerodynamic, vibration and acoustic characteristics are in good agreement with the values found in humans.

Introduction

Voice production is a complex physical process, which involves airflow coming from the lungs, self-oscillating vocal folds and acoustics of the resonance cavities of the human vocal tract. The vocal folds, excited by the airflow, generate a primary sound which propagates in the airways of the vocal tract modifying its spectrum and producing the final acoustic signal radiated from the mouth. Understanding basic principles of voice production is important for detection of laryngeal pathologies and treatment of laryngeal disorders. The physical models of voice production are important tools for experimental verification of developed theoretical models of phonation and in the development of the vocal folds prosthesis [1].

Method

The vocal folds made of silicon rubber were excited by airflow with synchronous measurement of the flow-induced vocal fold vibrations using laser vibrometer, two high speed cameras, the subglottic dynamic and mean air pressures and the radiated sound. A general scheme of the measurement set up and the used experimental techniques were described in detail in [2]. The airflow coming from the model of trachea was increased step by step from the phonation onset up to the airflow rate and subglottic pressure, which are in the range of physiologically relevant values for a normal human voice production.

Results and summary

The vocal folds model created by a silicon cover filled by a liquid phonated in the interval of the airflow rate $Q \cong 0.08 - 0.6$ l/s and subglottic pressure $P_{\mathrm{sub2}} \cong 0.28 - 1.7\,\mathrm{kPa}$ having realistic maximum vibration amplitudes, so-called glottis opening $MaxGO \cong 0 - 2.6\,\mathrm{mm}$. Corresponding to a bass voice, the fundamental frequency increased with the flow rate from 80 Hz at the phonation onset up to $F_0 \cong 103\,\mathrm{Hz}$ while the peak sound level of the generated acoustic signal at the distance 20 cm from the vocal folds increased from 62 dB up to $L_p \cong 90\,\mathrm{dB}$.

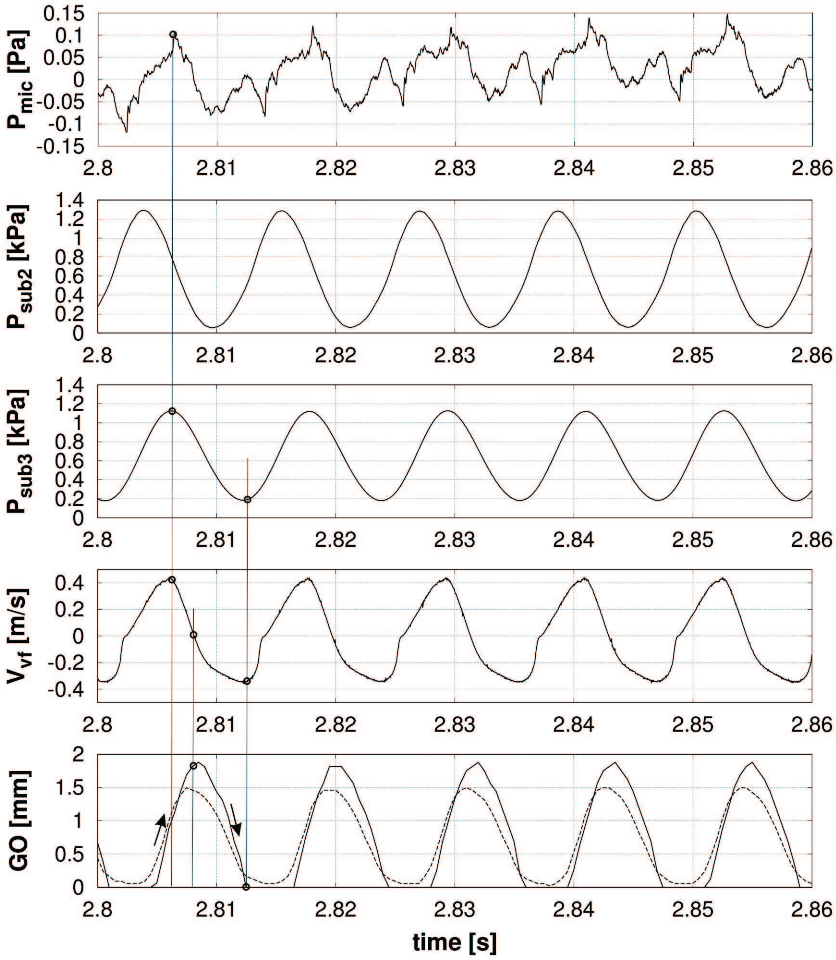

Fig. 1: Measured and evaluated signals for the vibrating vocal folds model for the flow rate Q=0.15 l/s, mean tracheal subglottic pressure P_{sub2}=0.67 kPa and F_0=86 Hz.

Fig. 1 shows the example of the measured signals during phonation. The peaks of the microphone signal (P_{mic}) correlates with the peaks of the vocal folds surface velocity in the vertical direction (V_{vf}) as well as with the subglottic pressure measured just before the glottis entrance (P_{sub3}), which is delayed after the subglottic pressure measured in the trachea (P_{sub2}). The signals of the glottis opening (GO) show that the closed time of the glottis, i. e. when GO=0 for the glottis motion in the horizontal direction (full line), is nearly 0.4 of the vibration period, and that the maximum displacement of the glottis in the vertical direction (dashed line) is slightly phase shifted and corresponds to zero of the vocal folds velocity (V_{vf}=0). The negative maximum of the velocity ($V_{vf}\cong$ -0.35 m/s) is just before the glottis closer where the minimum of the subglottic pressure P_{sub3} exists.

In summary, the results show that the maximum energy from the airflow is transferred to the acoustic energy during the opening phase of the glottis where are the maxima of the subglottic pressure P_{sub3}, the vertical vocal folds velocity V_{vf} and the peak sound level L_p of the sound (P_{mic}).

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