

## Experimental investigations on human voice generation

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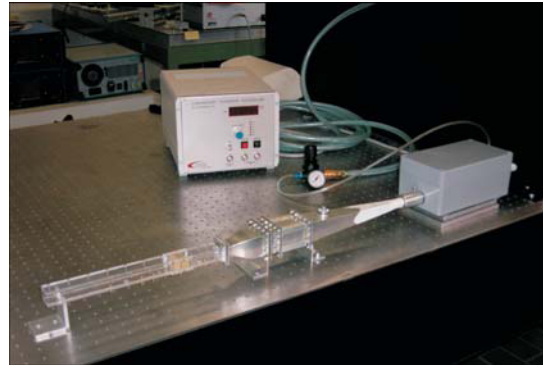
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Normal human voice production arises from oscillations of the two opposing vocal folds within the larynx. The opening between the vocal folds is called glottis. Increased sub-glottal pressure causes an airstream through the glottis and excites vocal fold oscillations. Hence, the airstream is modulated and forms the primary voice signal. Subsequently, the voice signal is filtered by the vocal tract and emitted as acoustic signal through the mouth.

The medical treatment of laryngeal cancer may require a total laryngectomy, i.e. a total excision of the larynx. In such a case, the vocal folds as the sound producing element get lost. Due to the surgical intervention, the trachea and the esophagus are separated in order to prevent uncontrolled mixing of breathing and swallowing. While the connection of the esophagus to the pharynx is not affected, breathing is maintained by suturing the stump of the trachea to the skin of the neck (tracheostoma). As the lung is no longer connected to the pharynx and the oral cavity, it is not possible to emit a modulated airstream and thus an acoustic signal through the mouth. For the aim of voice restoration, a substitute voice generating element has to compensate the function of the excised larynx. With the implantation of a shunt valve, the separated trachea and esophagus are reconnected. An unidirectional connection is built up between trachea and esophagus. During exhalation, while closing the tracheostoma with a finger, the airstream is conducted through the shunt valve into the esophagus. The soft tissue of the upper esophagus sphincter, i.e. the pharyngeal-esophageal segment (PE segment), is set into vibrations. Thus, the airstream is modulated and a primary voice signal is provided (tracheoesophageal voice production). As in normal voice production, the voice signal is filtered by the vocal tract and emitted as acoustic signal through the mouth.

In comparison with normal voice, the quality of the tracheoesophageal voice is significantly reduced. In recent works, the tracheoesophageal voice production has been investigated. To get a better understanding of the physically mechanism of the voice production a special test facility has been constructed. Fig. 1 shows the design of the self-oscillating model of the vocal folds. It was cast into an idealized shape of the vocal folds on a 1:1 length scale with human vocal folds.

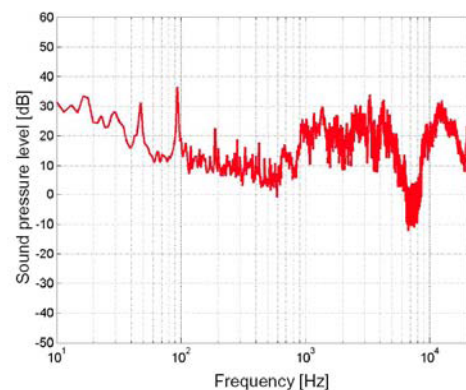
The vocal fold model was constructed using a three part polyurethane rubber compound. The stiffness of the cured rubber could be varied by adjusting the mixing ratios or the different compounds. Tensile tests on the different rubbers used in the experiments yielded modules from about 30kPa to 6.5kPa. These modules are similar to that, which can be found in vocal fold tissues.



**Fig 1** Test rig

For the experimental investigations different measurements techniques were used. At first the experiments started with visualization experiments. It shows the vortex distribution behind the vocal folds. Flow separated upstream in the glottis from the vocal fold on the right just passed the minimum glottal cross section. The flow remained attached to the glottal wall of the other vocal fold until reaching the glottal exit expansion.

To get information about the complex fluid – structure – acoustic interaction in the glottis the instationary flow field and pressure field were correlated with structure movements and the acoustic sound signals. The velocity measurements were done by Particle Image Velocimetry (PIV) and Hot Wire Anemometry (HDA). For getting information about the structure oscillating a Laser Scanning Vibrometer was used. The results show that the aerodynamics and vocal fold dynamics were fully coupled. The regular self-sustained vibrations were analyzed (Fig. 2) for different vocal fold configurations. Finally the capabilities and limitations of the models are discussed and the areas for future developments are identified.



**Fig. 2** Frequency spectrum of sound field