

SOURCE VOICE CHARACTERISTICS OF THE ARTIFICIAL VOCAL FOLDS

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Abstract: Specialised literature presents a number of models describing the function of the vocal folds. In most of those models an emphasis is placed on the effect of Bernoulli's air underpressure during the air passage through the glottis. The author defines a principle of the vocal folds function with a working version name „principle of the compressed air bubble“. The paper deals with the experimental analysis of these artificial vocal folds and, first of all, with the properties and characteristics of the source voices generated by them. The main forces acting on the vocal folds during phonation are as follows : subglottal air pressure, elastic and inertia forces of the vocal folds structure.

I. INTRODUCTION

There have been several modified versions of the vocal folds function described in literature – [1], [2]. Most of them are based on the principle of the myoelasto-dynamic theory. They share a common predominant view whose central idea is that of an expressive effect of what is called Bernoulli's underpressure (negative pressure) produced within the space of the glottis at an increased speed of the airflow which passes between the vocal folds in motion.

Due to the numerous weak points found in the principles as defined by different authors in the literature there has been another principle defined and developed, preliminary called „compressed air bubbles“, in short „bubbles“ - [3]. The paper deals with the experimental analysis of these artificial vocal folds and, first of all, with the properties of the source voices generated by them [6].

II. DEFINITION OF THE „COMPRESSED AIR BUBBLES“ PRINCIPLE

The transport of the compressed air bubbles (air column, small air volume) through the glottis from the subglottal to the supraglottal space are the fundamental idea of this principle. The air bubbles with the higher subglottal pressure should be shifted as soon as possible to the upper part of the glottis. After the glottis opening the bubbles expand from the higher subglottal air pressure so that the acoustic pressure amplitude to be

source voice generated has the highest value in this case. This condition is very important for a higher intensity of voice generation.

According to this principle of the vocal folds function, the main forces acting on the vocal folds during phonation are as follows :

- the subglottal air overpressure acts on the relatively large inner subglottal surface, producing a considerable higher force opening the vocal folds,
- resilient forces of the vocal folds muscles which act against the opening of the vocal folds,
- forces of inertia of the vocal folds structure.

The forces of inertia of the air bubbles cannot play a significant role with regard to the low value of air density, a small size of the moved bubbles and also to small changes of the airflow speed.

The driving phenomenon for the vocal folds during phonation is the compressed air in the subglottal space, which always reaches a higher resulting air pressure value here than within the supraglottal space, and is the function of the glottis opening g . So that the basic characteristics of the vocal folds motion and the model function is the relation of the resulting subglottal air pressure and the opening between the vocal folds in the form defined by relation $p_{RSg}(g)$ – [6].

III. EXPERIMENTAL ANALYSIS OF THE ARTIFICIAL VOCAL FOLDS

Based on the compressed air bubble principle there have been artificial vocal folds developed for speaking aloud [4], [5]. Their design allows for changing the fundamental frequency of the source voice to match the male or female voice.

In order to test and verify the above defined principle of the bubbles there were some experiments carried out. Fig.1 represents a diagram of experimental analysis of a specific type of artificial vocal folds (geometry, arrangement, frequency tuning). The substitute vocal folds are placed inside the vocal folds box in the way dividing its space into two areas : the subglottal area – 1, the supraglottal area – 2. Into the subglottal area 1 is taken compressed air from the pressure vessel. In each area, a required acoustic pressure is measured with an appropriate microphone $M1, M2$.

IV. MEASUREMENT RESULTS

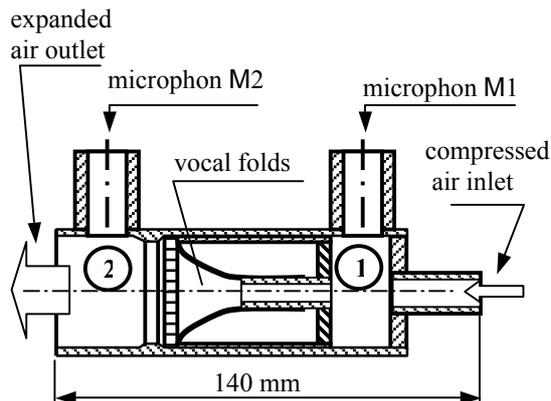


Fig.1 Diagram of the vocal folds location in the vocal folds box

The general measurement set is shown in Fig.2. In addition, a static mean value of the subglottal air pressure p_{SGS} is measured in the subglottal area, using a water column height, h . By setting of its mean value, the intensity of the source voice during phonation may be simulated by means of artificial vocal folds.

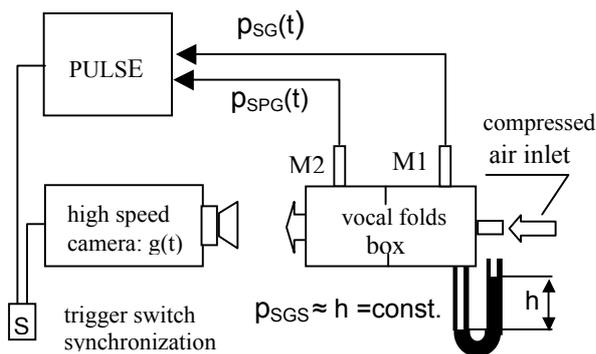


Fig.2 Measurement set of the vocal folds experimental analysis

The following variables were recorded during the phonation measurement - Fig.2 :

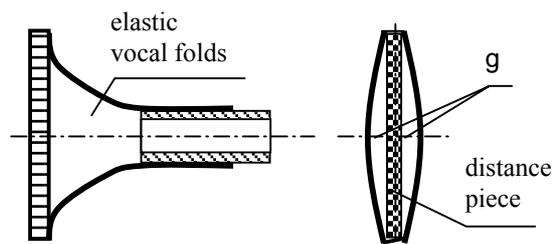
- water column height, h , characterizing the set mean value of the subglottal air pressure, p_{SGS}
- microphone M1 recorded variable air pressure in the subglottal space (measured by PULSE), $p_{SG}(t)$
- microphone M2 recorded acoustic pressure in the supraglottal space (measured by PULSE), $p_{SPG}(t)$
- the course of the opening $g(t)$ between the two vocal folds during their phonation (recorded by a high-speed Olympus camera).

The synchronization of all variables to be measured was ensured by means of trigger switch, S.

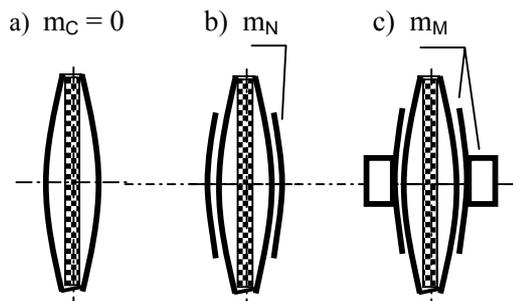
The characteristics of the artificial vocal folds vary, of course, depending on the type of the vocal folds measured. The individual types are distinguished by capital letters : C – basic type, M, N. They differ in geometry and in their additional masses, m_j ($j = C, M, N$) which in turn also changes their fundamental frequency tuning F_{0j} .

The parameters of the individual vocal folds type :

- type C – basic type: $m_C=0$, $F_{0C}=240$ Hz
- type M : m_M , $F_{0M}=132$ Hz
- type N : m_N , $F_{0N}=144$ Hz.



A. Scheme of the vocal folds



B. Additional masses of vocal folds

Fig.3 Types of the artificial vocal folds measured

Fig.4 represents the course of variable subglottal air pressure $p_{SG}(t)$ of a type C vocal folds, measured at a water column height of $h = 119$ mm, which corresponds to value $p_{SGS} = 1120$ Pa.

Fig.5 represents the spectrum of supraglottal acoustic pressure $p_{SPG}(t)$ behind the vocal folds. This acoustic pressure presented is the source voice generated by the type C vocal folds. The spectrum contains significant discrete components, which are harmonic components to the fundamental phonation frequency ($F_0 = 240$ Hz) of the vocal folds. All those harmonic components together form the „source voice“ of a given artificial vocal fold type.

Through the analysis of the high-speed camera recordings we shall obtain the course of the openings between the vocal folds as a time function - $g(t)$. Fig.6 represents the evaluation of the course of opening $g(t)$ based on the high-speed camera recordings.

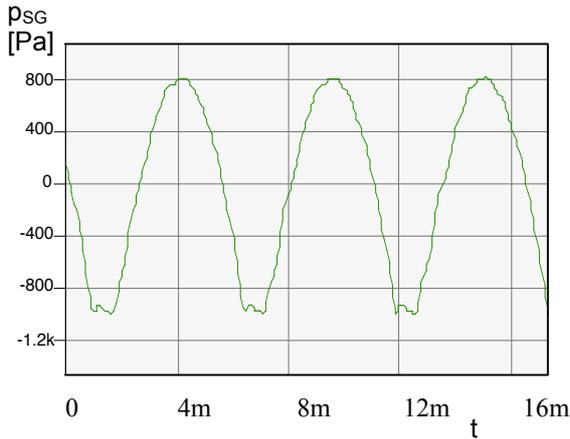


Fig.4 Variable subglottal air pressure course $p_{SG}(t)$

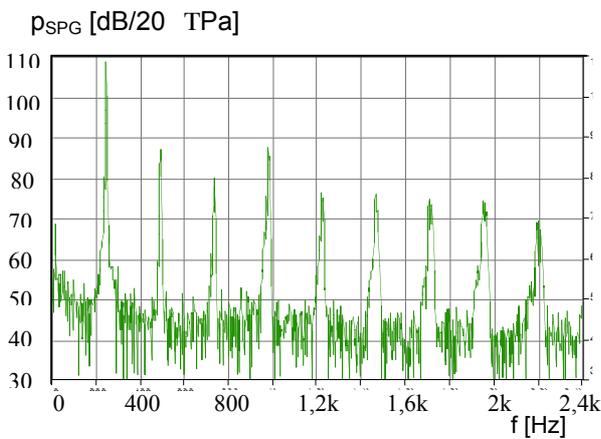


Fig.5 Spectrum of the artificial vocal folds source voice

It also specifies a volume of air $V_{SG}(t)$ passing through the specific value during phonation. A total volume of air passing through the vocal folds (volume of the bubble) during one period can then be obtained by means of integrating the course of $V_{SG}(t)$ in time.

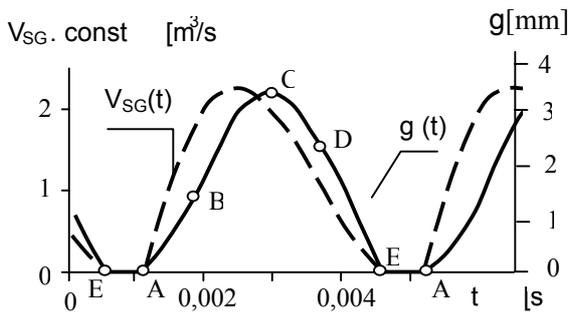


Fig.6 Course of the glottis opening $g(t)$ and of the air passing volume of $V_{SG}(t)$.

Based on the known courses $p_{SG}(t)$ – PULSE and $g(t)$ – camera, a $p_{SG}(g)$ relation needs to be established,

whereby we shall obtain a hysteresis loop characterizing the vocal folds motion. In Fig.7 this relation is shown for a type C vocal folds along with the mean value of $h = 119$ mm and it means $p_{SGS} = 1120$ Pa subglottal air pressure to be given.

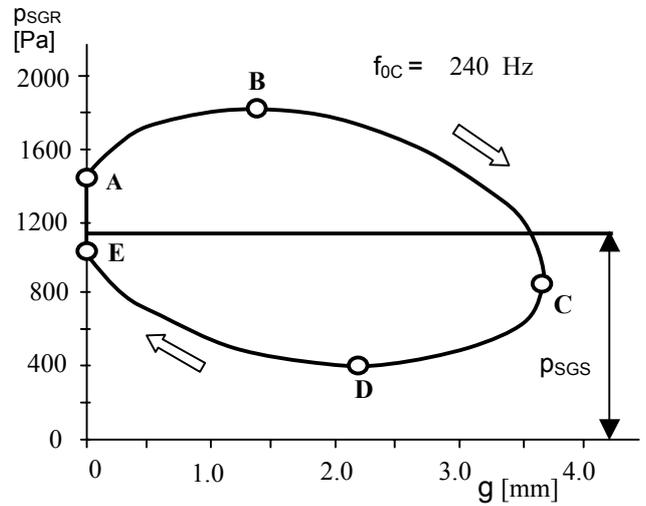


Fig.7 Course of $p_{SGR}(g)$ for p_{SGS} value

V. DISCUSION

The phonation period starts at point E with the increase of the air subglottal pressure continuing up to point A, with the vocal folds closed during this phase. At point A the vocal folds start opening and due to the increased subglottal air pressure begin to move away from each other. At the point where the elastic forces of the vocal folds prevail over the air pressure forces, the vocal folds start to come closer again at point C.

During part of ABCDE cycle the vocal folds are open. The vocal folds opening occurs at a higher air pressure $p_{SGR}(t)$ while their closing happens at lower values. As a result we obtained a loop whose area characterizes the energy supplied to the vocal folds by the changing air subglottal pressure which causes the vocal folds motion and consequently the acoustic supraglottal pressure origin. So that the phonation and generation of the source voice is created in this case.

The high-speed camera can also evaluate the flow of air through the vocal folds. To make the air visible a cigarette smoke was used. The recording in Fig.8 shows that the air passing through the artificial vocal folds is in the shape of sets of independent small volumes – air bubbles.

The following conclusions result from the analysis of the experimental data and the relations evaluated :

- the flow of air through the vocal folds may be defined by means of the passing compressed air bubbles (small air volumes) from the subglottal to

the supraglottal areas,

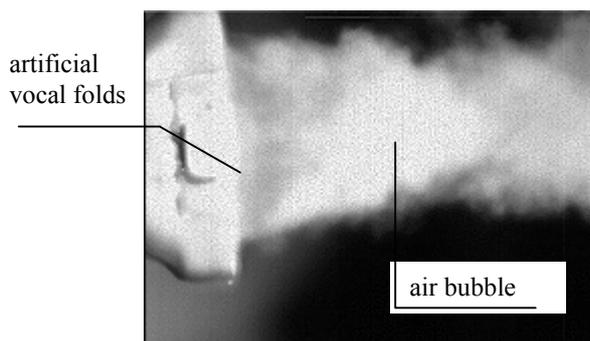


Fig.8 The bubbles expanding in the supraglottal space

- these bubbles expand in the supraglottal space beginning whereby generating acoustic waves, whose fundamental frequency and corresponding harmonic components define the source voice of the vocal folds,
- relation $p_{RSG}(g)$ is characterized by a loop of oval shape, which is abruptly ended during the contact of the vocal folds, i.e. at a $g=0$ value; during that time the subglottal pressure significantly increases as needed,
- as the value of mean subglottal pressure $p_{SGS,i}$ increases, the area of the loops is enlarging, i.e. the relevant subglottal pressures are growing (primarily the upper branches) and also the values of maximum opening of the vocal folds g_{max} are rising,
- this fact defines and explains the change to the intensity of the source voice; it is only through this parameter $p_{SGS,i}$ that the change of voice intensity may be achieved,
- the presence of bubbles (periodic action) is a necessary conditions for generating a sufficient number of harmonic components to excite formants of individual vowels,
- fundamental frequency of the vocal folds vibrations is given by their mass-elastic structural properties only,
- main forces acting on the vocal folds during phonation are as follows : subglottal air pressure, elastic forces of the vocal folds structure, and forces of inertia of the vocal folds system.

VI. CONCLUSION

The experimental analysis of the artificial vocal folds verifies the fact that the vocal folds function is based on the sequential flow of the compressed air bubbles through the phonating vocal folds – when

generating a loud voice. As a result of closing of the vocal folds the subglottal air pressure increases promptly, so that its value is high enough after the vocal folds opening. After expansion of such bubble in the supraglottal space there are acoustic waves generated with several harmonic components and with varied, however falling amplitudes. The correctness of the function of the artificial vocal folds is documented by the experimental verification of the spectra of several artificial vocal folds types.

The intensity of the generated source voice is determined solely by the mean value of the subglottal pressure whose value is set consciously by an individual by the lung activity. Humans also consciously set the height of their fundamental voice tones. Those represent the only two parameters that humans are able to define by will when speaking aloud.

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