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DESIGN OF FINITE ELEMENT MODELS OF MALE VOCAL TRACT

K. DEDOUCH*, J. HORÁČEK**, T. VAMPOLA*,
P. KRŠEK*** and J. G. ŠVEC****

Summary: *Two types of finite element (FE) models of male vocal tract are presented and compared in the paper. The geometry of male supraglottal space, which corresponds to the English vowels, was published by Story at al. in 1996. The files of data were obtained by using the magnetic resonance imaging (MRI) method. However, the design of mathematical model of the male vocal tract was very laborious. New, progressive procedure for direct transformation of the data file obtained by MRI technique to the finite element model was developed recently. Acoustic frequency-modal characteristics of both types of the FE models are compared.*

1. INTRODUCTION

The first two FE models for male vocal tract were designed by using the data published by Story *at al.* [2]. The FE models that correspond to the English vowels / a / and / i / are composed of 43 narrow truncated cones. The total length of the models is, in accordance with Story, 174.58 mm. The length of the vocal tract is assumed from the lips to the glottal end (see - [7-9]).

Other two FE models which correspond to the Czech vowels / a / and / i / were designed by using a direct method developed by P. Kršek [4-6]. The FE models correspond to the real male vocal tract. The method for direct transformation of the MRI data files to the FE model enables to develop optimal mesh of finite elements. It is almost impossible to design the FE model of the real male vocal tract without application of such procedure for MRI data direct transformation. The authors appreciate the very original MRI data obtained recently for the vocal tract during phonation for all Czech vowels, because for the Czech vowels only X-ray images of the upper part of the vocal tract had been taken and published by Hála and Polland [10] in 1926.

The analysed FE models of the male vocal tract are composed of only acoustic finite elements. The boundary areas of the acoustic spaces are considered as acoustically hard for all models analysed.

* Doc.Ing. Karel Dedouch, CSc., Dr.Ing. Tomáš Vampola, Czech Technical University Prague, Faculty of Mechanical Engineering, Institute of Mechanics, Technická 4, 16607 Prague 6, Czech Republic, E-mail : dedouch@fsik.cvut.cz ; vampola@fsik.cvut.cz ;
** Ing. Jaromír Horáček, DrSc., Institute of Thermomechanics, Academy of Sciences, Dolejškova 5, 180 00 Prague 8, Czech Republic, E-mail : jaromirh@it.cas.cz
*** Ing. Přemysl Kršek, PhD., Brno Technical University, Faculty of Mechanical Engineering, Department of Design, Technická 2, Brno, Czech Republic, E-mail : krsek@iris.fme.vutbr.cz
****Dr. Jan G. Švec, Medical Healthcom, s.r.o., Řešovská 10, 180 00 Prague 8, Czech Republic E-mail : svecjan@mbox.vol.cz

2. FINITE ELEMENT MODELS

The distribution of acoustic pressure inside a closed space is described by the wave equation

$$\nabla^2 p = \frac{1}{c_0^2}\frac{\partial^2 p}{\partial t^2}, \tag{1}$$

where c_o is the speed of sound. The boundary condition belonging to the acoustically hard area is

$$\frac{\partial p}{\partial \mathbf{n}} = 0, \tag{2}$$

where $\mathbf{n}$ is the direction of the normal to the boundary area. At the open end of the acoustic space the boundary condition is given by

$$p = 0. \tag{3}$$

The finite element method applied to investigation of acoustic fields requires a discretization of the wave equation. The equation of motion for acoustic pressure in the nodes of acoustic finite elements can be written in the matrix form in global co-ordinate system as

$$\mathbf{M}\ddot{\mathbf{P}} + \mathbf{B}\dot{\mathbf{P}} + \mathbf{K}\mathbf{P} = \mathbf{0}, \tag{4}$$

where **M**, **B**, **K** are the mass, acoustic boundary damping and stiffness matrices, respectively, and **P** is the vector of nodal acoustic pressures.

The modal analysis was applied on the all developed FE models and the calculated natural frequencies and acoustic mode shapes of vibration were compared. The FE code ANSYS 5.5 was used for the modal analysis. The acoustic space was modelled by acoustic 3D finite elements FLUID 30. In the case of FE models of English vowels / a / and / i / the brick elements were used. The FE models for the English vowels / a / and / i / are presented in the Fig. 1. The FE models for the Czech vowels / a / and / i / designed by the direct method using the MRI data sets are presented in the Fig 2. For the FE models created directly from the MRI data the tetrahedral finite elements were used.

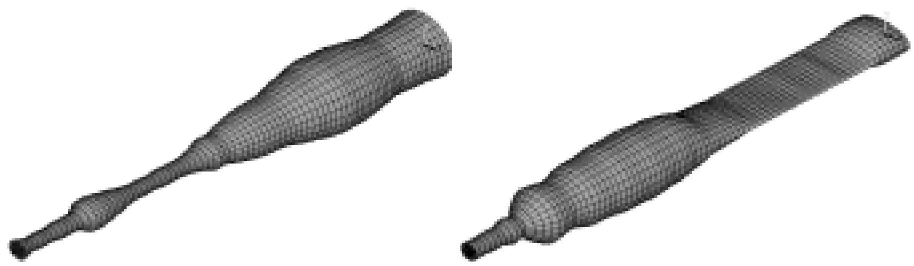
3. RESULTS OF NUMERICAL SOLUTION

The numerical results of modal analysis were used for comparison of the developed FE models, and especially for testing of the new models for Czech vowels, which correspond to the real male vocal tract. The computed natural mode shapes of vibration of all investigated FE models for first three formant frequencies are shown in the following Figures:

a) for English and Czech vowels / *a* / in Figures 3 - 5,

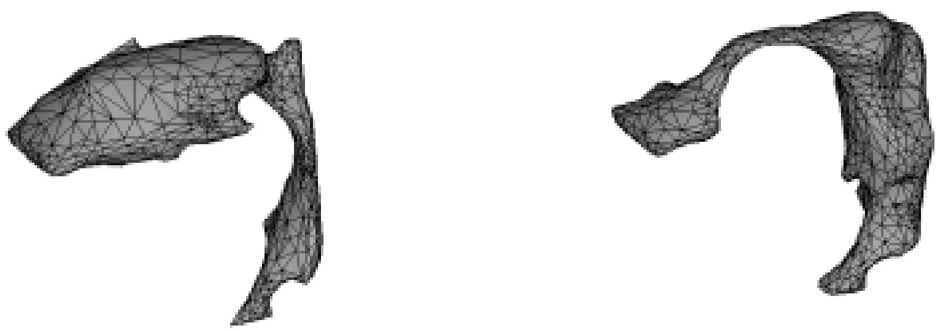
b) for English and Czech vowels / *i* / in Figures 6 - 8.

Corresponding natural (formant) frequencies are summarised in Tables 1 and 2. No absorptive boundary areas of the acoustic spaces were considered in the numerical calculations. The formant frequencies F1 – F4 for the vowel / a / are presented in Tab. 1 and the formant frequencies for the vowel / i / in Tab. 2.



a) b)

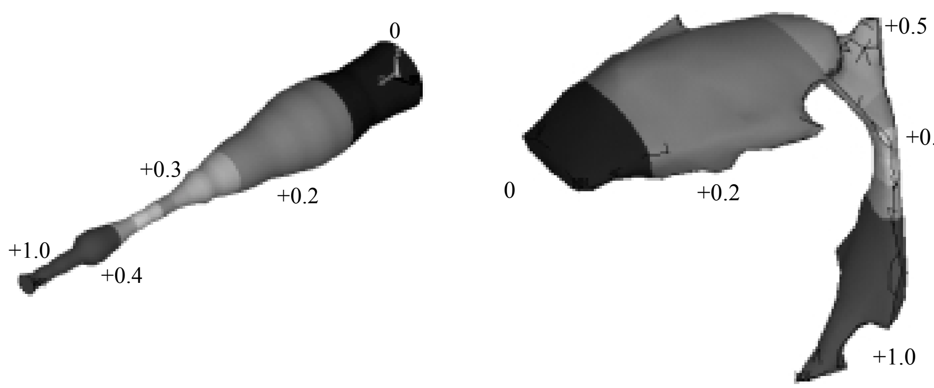
Fig. 1 FE models of the human vocal tract for English vowels according to Story [2]:
a) / *a* /, b) / *i* /.



a) b)

Fig. 2 FE models of male vocal tract for Czech vowels according to MRI data set [4, 5]:

a) / *a* /, b) / *i* /.



a) b)

Fig. 3 Acoustic mode shapes of vibration for the vowel / *a* / and for1st formant F1:
a) according to Story F1 = 789.80Hz, b) for Czech vowel F1 = 670,19 Hz.

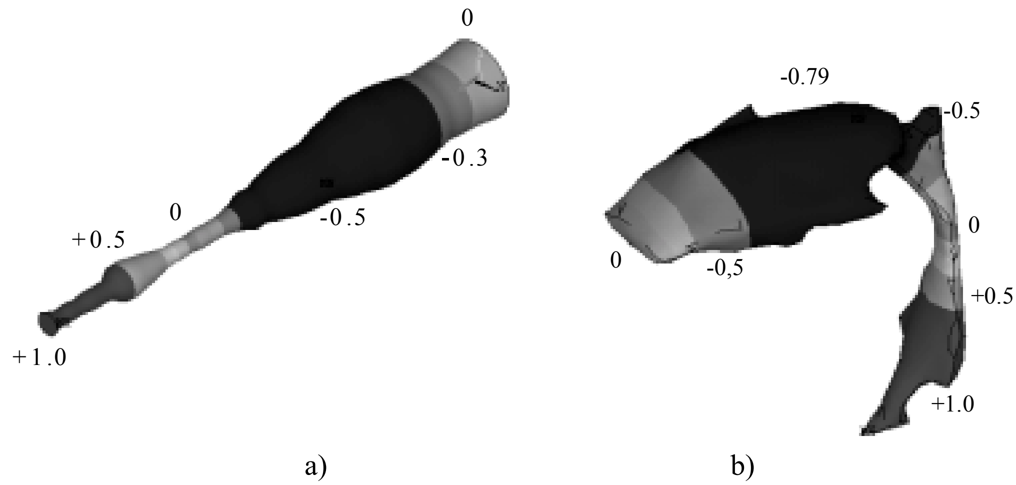


Fig. 4 Acoustic mode shapes of vibration for the vowel / *a* / and for 2nd formant F2:
a) according to Story F2 = 1 183.80Hz, b) for Czech vowel F2 = 1 138.99 Hz.

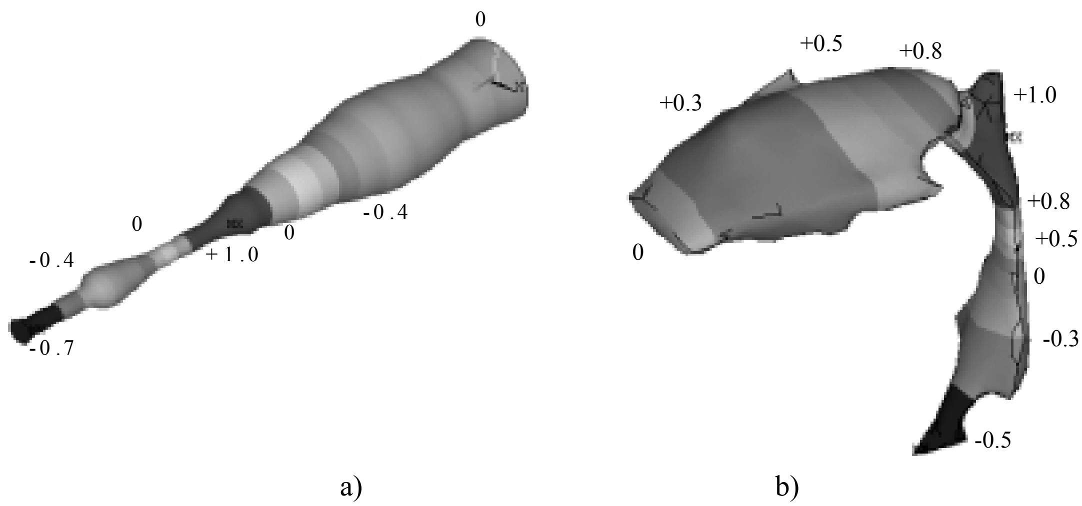
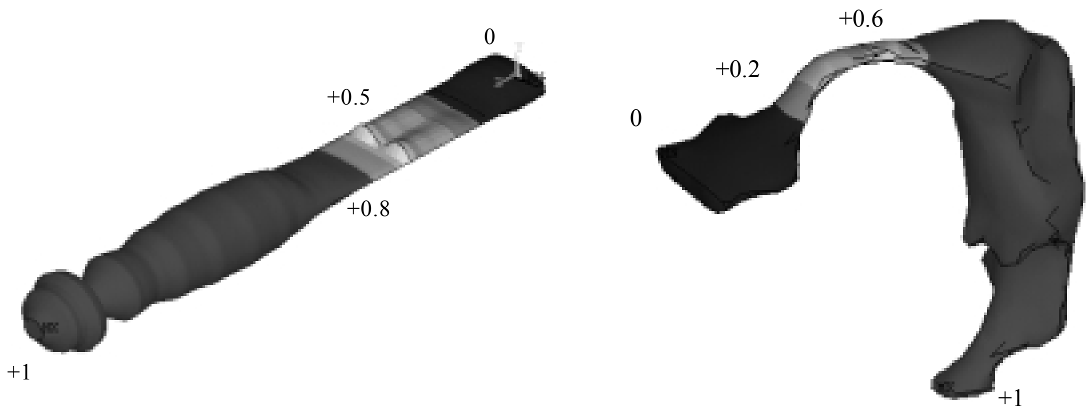
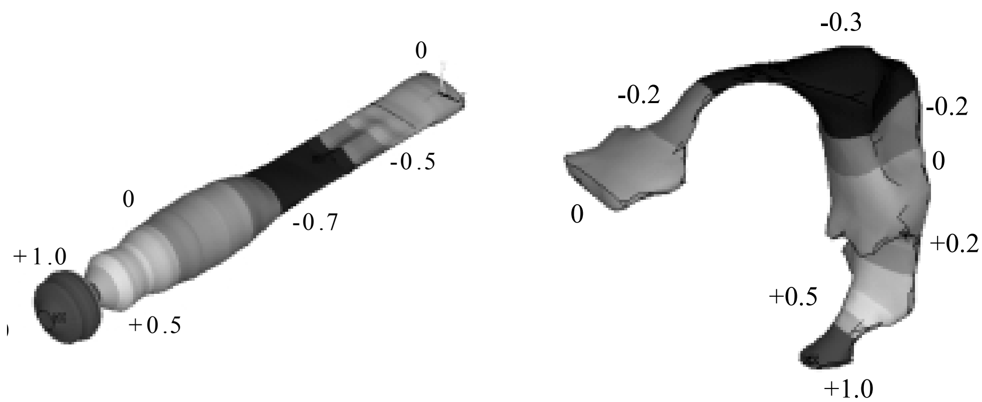


Fig.5 Acoustic mode shapes of vibration for the vowel / *a* / and for 3rd formant F3:
a) according to Story F3 = 2 788.86 Hz, b) for Czech vowel F3 = 2 874.84 Hz.



a) b)

Fig. 6 Acoustic mode shapes of vibration for the vowel / *i* / and for 1st formant F1:
a) according to Story F1 = 204.40 Hz, b) for Czech vowel F1 = 207.76 Hz.



a) b)

Fig. 7 Acoustic mode shapes of vibration for the vowel / *i* / and for 2nd formant F2:
a) according to Story F2 = 2 290.30 Hz, b) for Czech vowel F2 = 2 273.80 Hz.

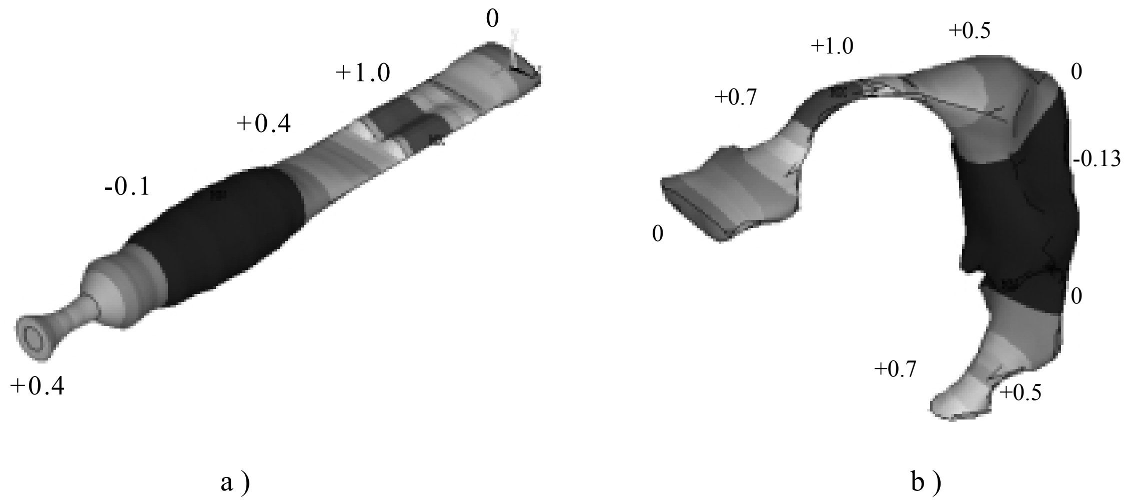


Fig. 8 Acoustic mode shapes of vibration for the vowel / *i* / and for 3[rd] formant F3:
a) according to Story F3 = 3 349.97 Hz, b) for Czech vowel F3 = 3 192.52 Hz.

Tab. 1 Formant frequencies of the FE models for vowel / *a* /

FE model	FORMANT FREQUENCIES			
	F1 [Hz]	F2 [Hz]	F3 [Hz]	F4 [Hz]
According to Story	789,80	1 183,80	2 788,86	3 631,45
Direct method from the set of MRI data	670,19	1 138,99	2 874,84	3 970,10

Tab. 2 Formant frequencies of the FE models for vowel / *i* /

FE model	FORMANT FREQUENCIES			
	F1 [Hz]	F2 [Hz]	F3 [Hz]	F4 [Hz]
According to Story	204,40	2 290,30	3 349,97	3 804,12
Direct method from the set of MRI data	207,76	2 273,80	3 192,52	3 425,89

4. CONCLUSION

The results of modal analysis of two types of finite element models of human vocal tract for English and Czech vowels / *a* / and / *i* / are presented in the paper.

The first group of FE models for English vowels / *a* / and / *i* / was designed in accordance with the data published by Story [2]. Computed formant frequencies F1 – F4 correspond to the data refereed in literature [3] very well.

The second group of FE models for Czech vowels / *a* / and / *i* / corresponds to the FE models of real male vocal tract. These FE models were designed by a direct method for MRI data transformation to the mesh of finite elements. The computed formant frequencies F1 – F4 are in a reasonable agreement with the FE models developed according to Story data, and the frequencies correspond to the data refereed in literature as well.

5. ACKNOWLEDGEMENT

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