FEM model of middle ear prosthesis with pseudo-elastic effect

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Abstract

This paper is devoted to modelling of shape memory prosthesis made of Nitinol which will be used to reconstruct the human middle ear. The pseudo-elastic model of the prosthesis material is developed in FEM in order to check vibrations modes. Next an implementation of the prosthesis in the model of damaged middle ear is planning.

Keywords: shape memory alloy, middle ear prosthesis, pseudo-elasticity

1. Introduction

The human middle ear consists of three small ossicles: the malleus, the incus, and the stapes. The ossicles create a sound conduction system that transmits sound from the external ear to the fluids of the inner ear. The ossicles are connected to each other by the incudo-mallear and incudo-stapedial joints and supported by two muscles: the tensor tympani muscle, attached with its tendon to the handle of the malleus, and the stapedius muscle, attached to the stapes neck or posterior crus. The malleus is also firmly connected to the tympanic membrane, whereas the stapes is attached to the bony walls of the oval window by an annular ligament. This biomechanical system of the middle ear can move in 3D space in complex manner. Therefore, the Finite Element Method (FEM) is often used to study spatial vibrations of the ossicles [1-8]

It sometimes happens, the ossicular chain is partially destroyed by inflammatory diseases such as chronic suppurative otitis media or cholesteatoma. For patients with middle ear dysfunctions, the medical practice called ossiculoplasty (reconstruction of the middle ear ossicles) can improve the hearing process. Variety of middle ear prostheses are commercially available. The classical TORP (Total Ossicular Replacement Prosthesis) and PORP (Partial Ossicular Replacement Prosthesis) are made of titanium or titanium alloy. The TORP and PORP connect the tympanic membrane to the stapes head (PORP) or the stapes footplate (TORP). The classical prostheses length can be modified (by cutting) only once during a surgery operation. If a prosthesis is too short, it cannot be used again. Therefore in this paper the prosthesis made of shape memory alloy (SMA) is proposed. The shape memory prosthesis could be fitted to individual patient during operation and reused again if the prosthesis length is fitted improperly. However, an analysis of shape memory prosthesis and predicted results are not easy because of pseudoelastic behaviour of SMAs. Therefore, natural vibrations of the prosthesis are investigated in order to verify possibility of implementation the prosthesis into the human middle ear.

2. Numerical model of prosthesis

The proposed middle ear prosthesis is a very small element (4-6mm length) made of Nitinol. The numerical model of the prosthesis is built in ABAQUS using tetrahedral elements C3D10 is divided into 8147 elements. The pseudoelastic effect of SMA is modelled by user's procedure giving the hysteresis loop presented in Fig.**??**.

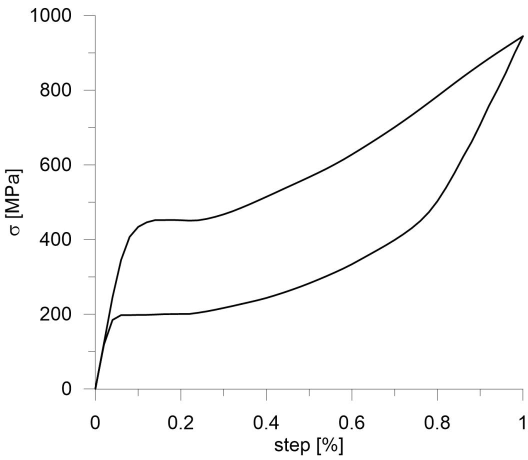

Figure 1: Characteristic of loading and unloading of the shape memory prosthesis

3. Dynamical analysis

An analysis of the prosthesis natural vibrations is important from practical point of view because the shape memory prosthesis is planning to be implemented into the human middle ear. Therefore, the natural vibration frequency of the prosthesis should be enough far away from the natural vibrations of the total middle

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ear system. Our analysis focuses on frequencies and mode of vibrations which are presented in Tab.**??** and Fig.**??**, respectively.

Table 1: Frequencies of the prosthesis natural vibrations

Mode	Frequency [Hz]
1	102.45
2	114.37
3	135.12
4	164.85
5	263.32
6	283.63
7	299.41
8	341.37

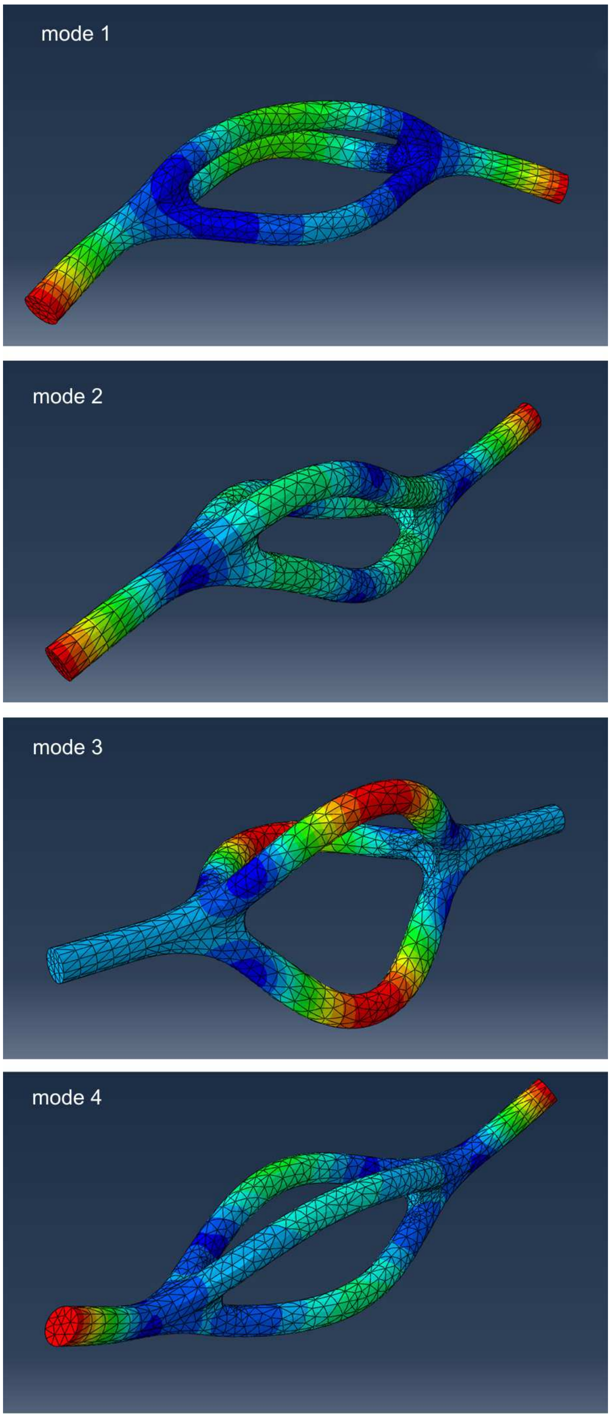

Figure 2: Modes of the prosthesis natural vibrations

The prosthesis natural frequencies are lower than the characteristic value for the middle ear system. That guarantees its adequate behaviour in the ear.

4. Conclusions

The presented new design of shape memory middle ear prosthesis is analysed under the angle of its future applicability in the human middle ear. The natural vibrations analysis is the first step which helps us to match the prosthesis geometry to have the proper natural frequencies and modes. The pseudo-elastic effect can be important when the prosthesis will be implemented in the middle ear system. Therefore, we are planing to extend the numerical model and introduce the prosthesis into middle ear system. Then, the system response on harmonic excitation will be analysed.

References

[1] Bornitz, M., Zahnert, T., Hardtke, H. J., and Huttenbrink, K. B. Identyfication of Parameters for the Middle Ear Model. *Audiology & Neuro-Otology 4* (1999), 163–169.

[2] Dai, C., Cheng, T., Wood, M. W., and Gan, R. Z. Fixation and detachment of superior and anterior malleolar ligaments in human middle ear: Experiment and modeling. *Hearing research 230*, 1-2 (2007), 24–33.

[3] Eiber, A. Mechanical Modeling and Dynamical Bhavior of the Human Middle Ear. *Audiology & Neuro-Otology 4* (1999), 170–177.

[4] Gan, R. Z., and Sun, Q. Finite element modeling of human ear with external ear canal and middle ear cavity. *Second Joint Embs-Bmes Conference 2002, Vols 1-3, Conference Proceedings* (2002), 264–265.

[5] Gan, R. Z., Sun, Q. L., Dyer, R. K., Chang, K. H., and Dormer, K. J. Three-dimensional modeling of middle ear biomechanics and its applications. *Otology & Neurotology 23*, 3 (2002), 271–280.

[6] Sun, Q., Gan, R. Z., Chang, K. H., and Dormer, K. J. Computer-integrated finite element modeling of human middle ear. *Biomechanics and Modeling in Mechanobiology 1*, 2 (2002), 109–122.

[7] Sun, Q. L., Chang, K. H., Dormer, K. J., Dyer, R. K., and Gan, R. Z. An advanced computer-aided geometric modeling and fabrication method for human middle ear. *Medical engineering & physics 24*, 9 (2002), 595–606.

[8] Taschke, H., Weistenhofer, C., and Hudde, H. A full-size physical model of the human middle ear. *Acustica 86*, 1 (2000), 103–116.