EXPERIMENTAL MODE CHARACTERIZATION OF A TYMPANIC MEMBRANE FROM TIME DOMAIN HIGH SPEED DIGITAL HOLOGRAPHIC TESTS

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ABSTRACT

This works is part of a research line focused on the generation of a finite element numerical model of the tympanic membrane (TM) based on experiments carried out on a cadaveric human temporal bone. A high-speed digital holographic (HDH) system was used to obtain the acoustically-induce transient displacement of TM surface of eight specimens during a transient test in the Eaton-Peabody Laboratory.

We are developing a methodology to generate the complete model of the TM system by validation of numerical and experimental data. This study will help to better understand the mechanisms of transmission of sound in the ear, where TM plays an important role in the transmission of sound energy to the inner ear through the excitation of the ossicular chain.

Displacement measurements were obtained by an HDH method based on correlation interferometry capable of measuring almost instantaneously the full field of view of the displacements of the visible face of the TM (>200.000 points at 67.200 camera frame rate) [1–3]. The shape measurement is based on the Multiple Wavelength Holographic Interferometry (MWHI) system, by means of lighting variations with a constant optical path length (OPL) [4,5].

Based on the experimental data, the shape of the outer wall of the TM and the damping values are evaluated. Other parameters (Young modulus, thickness, etc.) will be obtain by numerical-experimental validation between test data and an iterative series of transient numerical simulations with ANSYS software. There is very little numerical work on the time-domain response of the human auditory system [6] and no one referred to a specific specimen. However, the authors have experience in harmonic and modal simulations of these mechanisms, which is a starting point in this study [7–9].

In this work, preliminary methodology for the determination of mode shapes obtained by experimental data is presented. A new routine is programmed based on the post-processing of transient data of full external face of TM during the test. The main objective is to have an accurate approximation of main frequencies and shape modes that we can use further in the numerical-experimental validation.

In this sense, the time response of the system is processed in two different ways. Fast Fourier Transform is applied to obtain the Frequency Response Function with different weighting window, one centred on the initial impulse function applied and another one centred on the long-term response of the system. In the first case, the FRFs shown the spectral distribution of the incident pressure wave. On the second case, the whole modal response of the system can be identified, and natural frequencies and mode shape can be estimated as well as damping values.

The methodology presented shows that we can obtained important information to characterize dynamic properties of the system directly from this kind of transient experiment. In addition, sets a range of starting values for some material properties that reduces the number of iterations in subsequent numerical transient simulations.

REFERENCES

[1] P. Razavi, J.T. Cheng, C. Furlong, J.J. Rosowski, High-Speed Holography for In-Vivo Measurement of Acoustically Induced Motions of Mammalian Tympanic Membrane, in: Conf. Proc. Soc. Exp. Mech. Ser., Springer New York LLC, 2017: pp. 75–81. doi:10.1007/978-3-319-41351-8_11.

[2] P. Razavi, H. Tang, J.J. Rosowski, C. Furlong, J.T. Cheng, Combined high-speed holographic shape and full-field displacement measurements of tympanic membrane, J. Biomed. Opt. 24 (2019). doi:10.1117/1.JBO.24.3.031008.

[3] H. Tang, P. Razavi, K. Pooladvand, P. Psota, N. Maftoon, J.J. Rosowski, C. Furlong, J.T. Cheng, High-speed holographic shape and full-field displacement measurements of the tympanic membrane in normal and experimentally simulated pathological ears, Appl. Sci. (2019). doi:10.3390/app9142809.

[4] C. Furlong, Absolute shape measurements using high-resolution optoelectronic holography methods, Opt. Eng. (2000). doi:10.1117/1.602355.

[5] I. Yamaguchi, T. Ida, M. Yokota, Surface shape measurement by phase-shifting digital holography with dual wavelengths, in: Interferom. XIII Tech. Anal., SPIE, 2006: p. 62920V. doi:10.1117/12.681970.

[6] J. Zhang, J. Tian, N. Ta, Z. Rao, Transient response of the human ear to impulsive stimuli: A finite element analysis, J. Acoust. Soc. Am. 143 (2018) 2768–2779. doi:10.1121/1.5026240.

[7] A. Gonzalez-Herrera, E.S. Olson, A study of sound transmission in an abstract middle ear using physical and finite element models, J. Acoust. Soc. Am. 138 (2015) 2972–2985. doi:10.1121/1.4934515.

[8] L. Caminos, J. Garcia-Manrique, A. Lima-Rodriguez, A. Gonzalez-Herrera, Analysis of the mechanical properties of the human tympanic membrane and its influence on the dynamic behaviour of the human hearing system, Appl. Bionics Biomech. 2018 (2018). doi:10.1155/2018/1736957.

[9] A. Gonzalez-Herrera, J. Garcia-Manrique, Numerical study of the mechano-acoustic coupled resonance of a tube-membrane system, Meccanica. 53 (2018) 3189–3207. doi:10.1007/s11012-018-0882-7