Applied Acoustics 129 (2018) 291–305

Contents lists available at ScienceDirect

Applied Acoustics

journal homepage: www.elsevier.com/locate/apacoust

# Contact parameter identification for vibrational response variability prediction ☆

Ester Creixell-Mediante [a,b,*], Jonas Brunskog [a], Jakob S. Jensen [a], Martin Larsen [b]

[a] Acoustic Technology, Department of Electrical Engineering, Technical University of Denmark, Ørsteds Plads 352, 2800 Kgs. Lyngby, Denmark
[b] Oticon A/S, Kongebakken 9, 9765 Smørum, Denmark

ARTICLE INFO

*Article history:*
Received 22 March 2017
Received in revised form 28 July 2017
Accepted 14 August 2017
Available online 19 August 2017

*Keywords:*
Contact modeling
Model updating
Vibrations
Structural acoustics
Linear modeling

ABSTRACT

Variability in the dynamic response of assembled structures can arise due to variations in the contact conditions between the parts that conform them. Contact conditions are difficult to model accurately due to randomness in physical properties such as contact surface, load distribution or geometric details. Those properties can vary for a given structure due to the assembly and disassembly process, and also across nominally equal items that are produced in series. This work focuses on modeling the contact between small light-weight plastic pieces such as those used in the hearing aid industry, where the vibrational behavior of the structures within the hearing frequency range is critical for the performance of the devices. A procedure to localize the most probable contact areas and determine the most sensitive contact points with respect to variations in the modes of vibration of the assembled plastic parts is presented. The procedure uses a gradient-based optimization strategy that updates the stiffness constants of a number of contact spring elements to match experimental data. By identifying the contact parameters for several sets of experimental data measured under varying contact conditions, the variability of the contact parameters can be characterized.



## 1. Introduction

Variability in the vibrational response of nominally identical devices is a well known problem that affects several industries with serial production. Studies on this variability have been published in the literature for generic products [1], and for specific industries, such as guitar manufacturing [2] and automotive vehicles [3]. This problem is also a matter of concern in the hearing aid industry, where controlling the vibrational response of the devices is critical, as unpredicted vibration transmission paths can become relevant causes of mechanical feedback between the loudspeaker and the microphones. As described in Ref. [4], smaller designs of hearing aids are desired from an aesthetic and practical point of view, while high amplification levels are required for performance. The strong acoustic-mechanical interaction results in complicated dynamic behavior and large sensitivity to structural details and variations [5], therefore predicting the variability of the vibrational response is a key point in obtaining a reliable model of acoustic-mechanical feedback paths, and to design products that will perform as desired.

The variability is observed in most complex systems that are composed of several parts, which suggests that the variation is partly generated when these parts are put together. In the hearing aid industry, each device is formed by multiple parts, such as those shown in Fig. 1, which gives rise to high variability in the vibrational response of nominally equal devices produced in series. Variability on the physical properties of the contact surface such as hardness, roughness and waviness, as well as the geometry and the material properties [6] have a strong influence on the coupling conditions, and hence on the transmission properties at the contact, and results in the observed variability in the vibrational responses of the structures. Those properties are also affected by the process of assembly and disassembly of the parts, due to small changes in the relative position and erosion effects. A simple experiment where the response of the two assembled plastic pieces shown in Fig. 4 is measured five times with the parts being dissassembled and assembled back between measurements (the conditions of the experiment are given in detail in Section 2), presents the vibrational responses shown in Fig. 2 (where the curves have been separated by 10 dB for a clearer visualization but would

☆ Part of this work was presented at NOVEM2015, Dubrovnik, Croatia.

* Corresponding author at: Acoustic Technology, Department of Electrical Engineering, Technical University of Denmark, Ørsteds Plads 352, 2800 Kgs. Lyngby, Denmark.

*E-mail addresses:* emed@oticon.com (E. Creixell-Mediante), jbr@elektro.dtu.dk (J. Brunskog), json@elektro.dtu.dk (J.S. Jensen), mnla@oticon.com (M. Larsen).

http://dx.doi.org/10.1016/j.apacoust.2017.08.011
0003-682X/

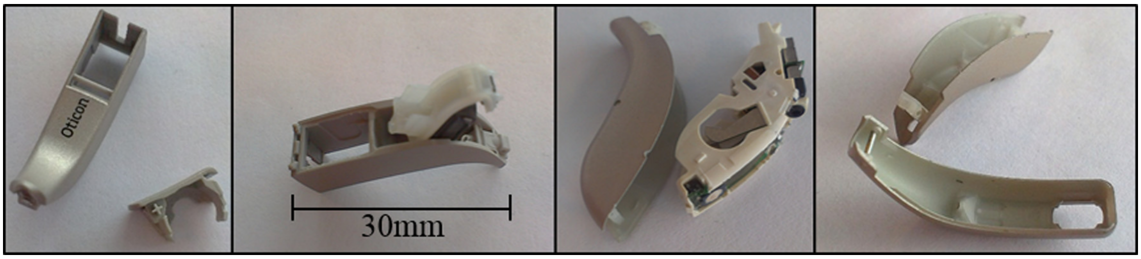


**Fig. 1.** Several hearing aid parts.

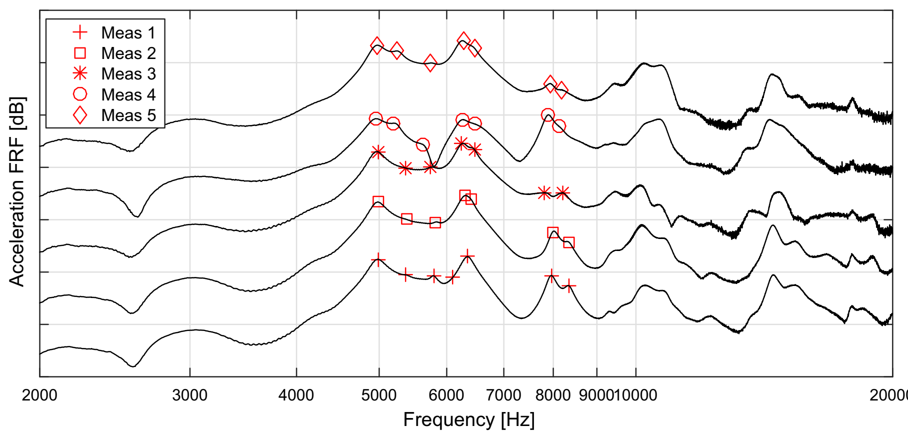


**Fig. 2.** Vibrational responses of the same assembly of plastic pieces with small contact changes due to disassembly and reassembly. The curves have been separated by a 10 dB offset for better visualization. The red marks indicate resonant frequencies, identified as described in Section 2. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

otherwise be on top of each other at the lower frequency range). The variation across measurements of five of the identified modal frequencies is shown in Fig. 3(b). When comparing to the variation due to measurement uncertainty (i.e. re-measuring the structure without disassembling), shown in Fig. 3(a), it is clear that the variation due to the disassembling and reassembling process is significant.

Studies of the uncertainty problem in large scale built-up structures have suggested the use of statistical energy methods for response prediction, given the probabilistic nature of the problem [1]. Statistical energy methods [7] are shown to be adequate for modeling the response at frequencies where the mode overlap is sufficiently high, which are also the frequency ranges where the variability due to contact uncertainties is most significant for large structures [8]. The variability problem in the hearing aid industry arises within the most critical frequency range; the audible frequency span. Here, the small light-weight structures that compose the devices often present their fundamental modes of vibration, which makes statistical energy methods unapplicable. An alternative is running a number of computations of deterministic Finite Element (FE) models for randomized parameters (Monte-Carlo simulations), for which the probability distributions must be esti-

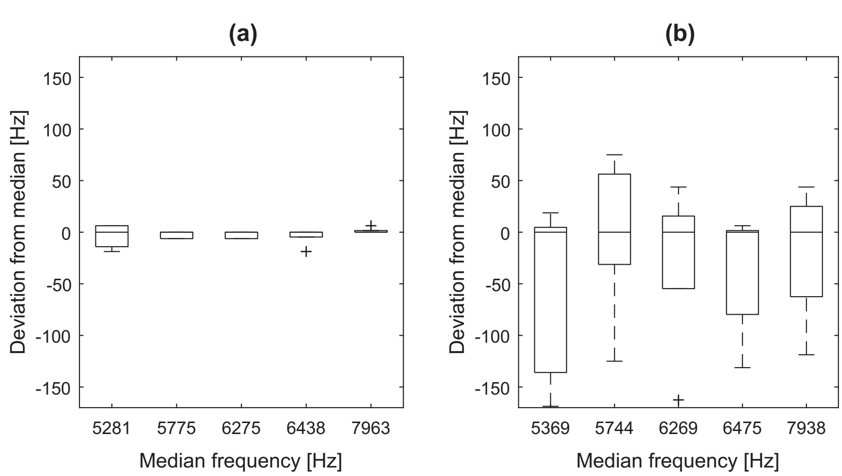


**Fig. 3.** Variations in resonant frequencies across five measurements of the assembly in Fig. 4 for (a) unchanged contact condition and (b) varying contact condition. On each box, the central mark is the median, the edges of the box are the 25th and 75th percentiles, the whiskers extend to the most extreme datapoints the algorithm considers to be not outliers, and the outliers are plotted individually.