Chapter 7
Membrane Micro Electro-Mechanical Systems for Industrial Applications

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ABSTRACT

The objective of this chapter is to provide the analytical-numerical tools for the simplified rewriting of the most important mathematical models of MEMS membrane devices for Mechatronics, exploiting advanced concepts and results in the theory of curves and surfaces. Moreover, when the solution in closed form could not be obtained (that is, it is impossible to obtain the membrane deflection analytically), some consolidated techniques will be described both to obtain conditions ensuring existence/uniqueness of the solution, and the most suitable approaches for obtaining numerical solutions in the absence of ghost solutions. Finally, some practical examples will illustrate the approaches presented.

INTRODUCTION

Mechatronics engineering studies mechanical, electronic and computer interactions for the analysis and design of fully automated control systems (Bolton, 2003), (Jouaneh, 2012). This term is composed of the words "mechanics" and "electronics", historically, the company that used this word for the first time was Yaskawa, in Japan, in the 1960s. The first works concerned the development of systems requiring knowledge on both domains. Since, the development of this discipline has been exponential, requiring analysis/synthesis techniques assisted and supported by constant technological innovation with the main purpose of creating devices on an increasingly smaller scale. At the same time, the most recent industrial guidelines direct both researchers and designers to the development of low-cost devices able to combine the physical properties of the problem with low-level machine languages. Hence, the need to design

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sensors and actuators able to meet the multiple needs required by the most widespread industrial, civil and biomedical applications. In such a context, static and dynamic Micro-Electro-Mechanical-Systems (MEMS) technology has matured, especially in all of those domains where modern miniaturized and integrated electromechanical systems are required. Specifically, in the general knowledge space, MEMS microsystems are considered as very important devices for mechatronics foundational and core knowledge (Habib, Mechatronics: A Unifying Interdisciplinary and Intelligent Engineering Paradigm, 2007), (Habib, Human Adaptive and Friendly Mechatronics (HAFM), 2008). Moreover, thanks also to modern numerical techniques capable of simulating extremely realistic industrial scenarios, MEMS represent one of the most important achievements of engineering on an industrial scale (Gad-el Hak, 2006), (Pelesko & Bernstein, 2003) (Phan & et al., 2018). Currently, the industrial applications of MEMS devices in mechatronics are extremely varied, from applications in the biomedical domain, such as surgical-diagnostic-therapeutic microsystems (Khoshnoud & de Silva, 2012), (Wang & Soper, 2006) to recent developments in the opto-electronic field (compact sensors systems, photodiode) (Warren, 2008); thermally driven MEMS actuator for mechatronics (Kimura, 2009) to modeling vibration elastic structures (Pelesko & Bernstein, Modeling MEMS and NEMS, 2003). Additionally, modeling MEMS has gained wide acclaim both coupled thermal-elastic systems (Pelesko & Bernstein, 2003) and electrostatic-elastic systems (Pelesko, 2004) making MEMS devices extremely attractive for mechatronics applications, due to the fact that their small size as well as the easy production with relatively low costs (Gad-el Hak, 2006) (Mistry & Nahapatra, 2012), (Warren, 2008). If on the one hand the demand for MEMS devices in Mechatronics is very strong, on the other hand, it is not always possible to formulate analytical mathematical models easily implemented. The MEMS technology makes it possible to integrate both electronic circuits and opto-mechanical devices on the same silicon substrate (Plander & Stepanovsky, 2017), employing manufacturing technologies similar to those used for the realization of integrated circuits. The dimensions of a MEMS device are generally variable between a few *μms* and 1 *mm*, while the individual components of which it is composed vary between 1 and 100 *μms*. The most widely used MEMS devices in mechatronics belong to the class of the general electrostatic-elastic systems. This is due to the biggest problem of the mass-spring model of the electrostatic actuators is the inability to capture real geometry and elastic effects as well. Usually, an electrostatic-elastic MEMS device consists of two parallel plates, one of which is fixed and the other deformable. A difference potential V is applied and the deformable plate moves. Often, however, many applications require that a membrane replace the deformable plate in order to reduce the inertial effects. Usually, the physical-mathematical models use the deflection of the membrane, u, as an independent variable. Furthermore, these analytical formulations hardly allow resolution in closed form (Angiulli, Jannelli, Morabito, & Versaci, 2018) (Di Barba, Fattorusso, & Versaci, 2017). As a result, one must be satisfied with obtaining conditions that guarantee both existence and uniqueness of the solution, often using techniques based on fixed-point theorems formulated in suitable functional spaces with evident aggravation in terms of computational complexity (Esposito, Ghoussoub, & Guo, 2010). The alternative, therefore, is the numerical approach, which, although of great practical interest, do not prevent us from being present for ghost solutions interest, do not prevent us from being present for ghost solutions (Angiulli, Jannelli, Morabito, & Versaci, 2018), (Esposito, Ghoussoub, & Guo, 2010). Thus, a viable path is the joint use of analytical approaches assisted by numerical techniques in order to obtain numerical solutions that respect the analytical conditions that guarantee existence and uniqueness of the solution by eliminating the possibility of obtaining ghost solutions. In this context, the experience of the authors in the field of modeling electrostatic MEMS membrane devices with strong non-linearity of interest to Mechatronics has matured. In particular, by combining the physics of the problem with important

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