Chapter 7
Modeling, Mathematical and Numerical Studies of a New Biventricular Model for Artificial Heart Powered by an Electromagnet Subjected to Sinusoidal and Square Voltages

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ABSTRACT

This paper describes and investigates the dynamics of a new model of biventricular model for artificial heart which consists of two ferromagnetic masses fixed on springs and subjected to a common electromagnet powered by sinusoidal and square wave voltage sources. The effects of the following control parameters are considered: the external voltage source frequency and amplitude, the ratio between the stiffness coefficients, and the one between the masses. As results in both cases of external excitations, subharmonic oscillations, hysteresis, coexistence of limit cycle and point attractor, permanent bounding are found. The optimal voltage and the ratio between the stiffness coefficients are obtained. Bursting oscillations usable for pulsatile pumping are observed for low frequencies under square wave voltage.

INTRODUCTION

Artificial organs are developed in order to give a solution to the growing surgery organ needs with reduced technical, moral, ethical, religious objections (Hench &Jones, 2005). They cover a wide range of organs (Hakim, 2009) and their ultimate aim is to obtain devices behaving as close as possible as native organs. This biologically-inspired engineering challenge can be approached in artificial organs research

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fields by taking into account the influences of external factors through sensors (Shichiri et al., 1998). This approach leads to hybrid scheme where both artificial and native organs can be used in conjunction or only the artificial organ is working. Based on different techniques, the synergy of artificial and native organ intends to prevent imminent deaths, relieve the native failing organs while promoting its recovery (Hench & Jones, 2005), and/or replace a damaged part of the organ (Abidian et al., 2012; Kol & Woafo, 2011; Nkomidio & Woafo, 2011).

As cardiovascular diseases stand for the first cause of death worldwide (WHO, 2011) and that some works have already been done in the area of the cardiovascular system, such as in arterial endoprosthesis (Kol & Woafo, 2011; Miwa & Matsuda, 1994), the still open topic of artificial heart that requires a new generation of devices (Fuchs & Netz, 2001) will be our focus.

Indeed, recently a new approach of Artificial heart, still in development, using two electro-hydraulic pumps and generating pulsating flow, with sensors and microprocessor, was studied (Mohacsi & Leprince, 2014); its challenge are fluid leakage and life duty. The most implanted device now (Copeland et al, 2012) serves as a bridge to transplant, with a mean support time of 87 days. In the third-generation of blood pump consisting mostly of mechanical non contact devices with continuous flow, the challenge of wear reduction through magnetic levitation is still open and lead to more complexity while in the second-generation consisting mostly of rotary pump, gyroscopic effects and wear are nuisances (Hoshi et al., 2006; Leprince, 2005). The main advantages and disadvantages of the available major pumping approaches are presented by Leprince (2005). So our main objective is to propose an approach which intends to reduce the drawbacks of the third and second-generation of blood pump able to pump blood in a pulsatile function, with extended life duty, in order to build a better bridge to transplant consisting of biventricular assist device or preferably permanent total artificial heart more suitable (Küçükaksu, 2013).

The native heart can be viewed as an electromechanical system, since it possesses an electrical activity that excites the cardiac muscle which by its movement assures the pumping function. Therefore our approach is based on an electromechanical system intended to perform the cardiac pumping function.

Electromechanical systems are useful in energy conversion typically from mechanical to electrical energy form and vice-versa. They can be used as actuators, and sensors (Busch-Vishniac,1999; Kamm, 1996; Leondes, 2006; Lyshevski, 2001; Pelesko & Bernstein, 2003; Preumont, 2006). Depending on the application size three categories can be considered: macroelectromechanical systems, microelectromechanical systems (MEMS), nanoelectromechanical systems (NEMS). From the dynamical point of view many systems of these categories can be analyzed and proved to have the same dynamical structures. In the literature, these systems have been broadly studied under sinusoidal excitation and self-sustained electrical circuits with the effects of nonlinearities taken into account. And as dynamical behaviors, resonances, anti-resonances, hysteresis, harmonic, sub and super-harmonic oscillations, multi-stability and transitions to chaos have been obtained (Yamapi & Woafo, 2009) with experimental investigations carried out (Kitio Kwuimy et al., 2010; Kitio Kwuimy & Woafo, 2010; Kitio Kwuimy & Woafo, 2007).

An Interesting class of electromechanical systems is that of system activated by ferromagnetic forces such as switches (Nasar, 1998; Lyshevski, 2001). Abobda & Woafo (2012) studied recently a macroelectromechanical system intended to be a new ventricular assist device, made of a ferromagnetic mass fixed on a spring and subjected to an AC electromagnet. They found subharmonic and bursting oscillations and analyzed their shape when varying the viscous damping coefficient, the number of turns of the coil, the frequency and amplitude of the AC voltage. Furthermore they observed pulse packages patterns and sharp burstings in the motion of the mechanical part.