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FLUTTER MEASUREMENT IN PROSTHETIC BIOLOGICAL CARDIAC VALVE

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Abstract. *Prosthetic heart valves had their projects improved over time, however an ideal valve that unites the advantages of long lifespan and no danger of calcifying or clotting is inexistent. The use of porcine or bovine pericardium biological valves has as main disadvantage a lifespan of 10 to 15 years, failing by calcification and fatigue, being a great challenge to increase this usage time. A not so much studied phenomenon is the effect of flutter, which is an oscillation of the leaflets that can cause regurgitation and accelerate calcification and fatigue. As a first step to study how to reduce the oscillations, a method was developed to quantify the frequencies of the flutter occurring at the time of full opening of the valve. In a testing bench that simulates the cardiac flow, the behavior of the leaflets was shot with a high-speed camera. With a motion capture software, it was possible to obtain the trajectory of one leaflet and its frequencies and amplitudes of the oscillations. This response is an important start to create a method for modifying geometric and material parameters to further reduce oscillations, improving hemodynamics and increasing the useful life of the valve.*

Keywords: *cardiovascular engineering, prosthetic cardiac valves, flutter, bioengineering*

1. INTRODUCTION

The first artificial heart valves were created in 1952, evolving from ball cage models to the pyrolytic carbon bicuspid valves. One of the major problems of the mechanical artificial valves is the modification of blood flow in the heart, changing velocities and stresses and, consequently, increasing the chance of clot formation. Thus, the patient needs to take anticoagulant drugs throughout his life to avoid future problems (Dasi *et al*., 2009). A major breakthrough in the technology of prosthetic valves was the use of biological porcine and bovine valves starting from 1969. The main advantage in using this type of valve is that it modifies less the hemodynamic and does not suffer any kind of rejection, not needing the use of anticoagulants. However, they have certain disadvantages as calcification of the leaflets and structural failures after around 10 to 15 years of use, having a shorter life than mechanical valves (Dasi *et al*., 2009).

A scarcely studied condition is the effect of the oscillation of heart valve leaflets during flow known as flutter. This oscillation is the resultant effect of the interaction between the blood and the leaflet, being associated with regurgitation, calcification and fatigue (Louie *et al*., 1988; Hsu., 2001; De Hart *et al*, 2004) and is considered more destructive than any another mechanism (Ionescu, 2014). This is a phenomenon already observed long ago in natural and artificial valves (Douglas *et al*., 1974; Mintz *et al*., 1982).

According to De Hart *et al*. (2004), it is believed that the oscillation of the leaflets is responsible for reducing the lifespan of heart valves by creating fatigue and subsequent structural failure. As a lower life is a frequent problem in biological prosthetic valves, oscillations during its functioning are undesirable.

Heart valves are studied for decades, either in vitro or in vivo formulations or different numerical methods. However the focus of the studies were always directed to the stresses in the leaflets of the valves (Yap *et al.*, 2012) or in the interaction of blood flow with their opening and closing (Dasi *et al*., 2007; Singh *et al*., 2008). Studies such as Condurache *et al*. (2009) discuss means to analyze the in vitro valve flutter, focusing on what would be the ideal forms of signal processing to measure the oscillation frequency. But still the works fail at showing no quantitative result of the oscillations, complicating efforts to compare the results of this research area.

Thus, the objective is to show a pilot study to quantify the vibration frequency of a cusp of the aortic valve in a test bench. Besides having an actual answer to the comparison between valves under the same conditions, a quantitative value is essential for using in future works when attempting to reduce the vibrations caused by flutter.

2. METHODOLOGY

2.1 Experimental Chamber

For the experiment, we used a test bench for heart valves that complies with ISO 5840-2005 standard. It can do three tests in forward continuous flow, reversed continuous flow and pulsatile flow. In the continuous mode it is possible to vary the flow rate from 5,0 to 30,0 l/min at intervals of 5,0 l/min. In pulsatile mode it's possible to change the frequency of the cardiac pulse from 30,0 to 120,0 beats per minute (bpm).

A schematic diagram of the bench in the continuous mode is shown in Fig 1. A fluid reservoir is connected to a centrifugal pump along with a frequency inverter; a Labview program controls the flow and receives data obtained by the pressure transducer installed downstream and upstream of the valve. The bench is made of acrylic to be able to observe the behavior of the fluid and valve into work. Due to a partnership with St. Jude Medical company, it is not possible to show photos of the bench.

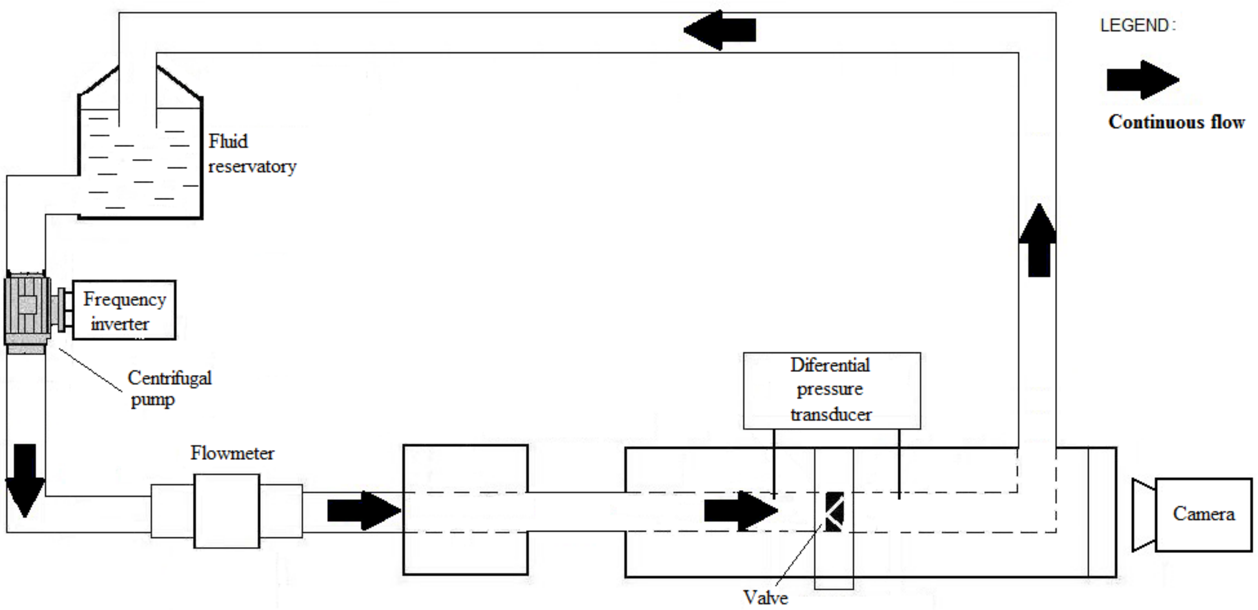

Figure 1. Schematic diagram of the forward flow of experimental chamber.

The fluid employed is a water solution with 0.2% glutaraldehyde commonly used to maintain the environment and testing valves sterile. The tricuspid valve used was a biological porcine valve from St. Jude brand SJM Biocor® with an internal diameter of 16,0 mm and external of 24,0 mm. It is coupled on the bench by a drawer system with a support for its perfect fit.

2.2 Data Acquisition

A video was made with a high-speed camera brand Phantom v7.3 positioned in front of the tested valve as shown in Fig. 1. A filming at a speed of 2000 frames per second and total time of 1.2 seconds was made. To obtain adequate lighting, four LED lamps that operate on 12 V were installed. LEDs are optimal illumination for the experiment for being a cold and continuous current light, not interfering with the experiment, since electric alternating current light of 60 Hz would affect shooting at high speed.

The cusp position was done manually for about 200 frames. Using the software Tracker, the valve outer diameter is marked and the distance is measured from the center of the circle to the point to be followed, as shown in Figure 2. Then, the obtained data are analyzed by a Fast Fourier Transform (FFT) through an algorithm in Matlab, and the frequencies of the oscillations are extracted.

The experiment was done with different flow rates to obtain a broader response. The flow rates employed were 10, 20 and 30 l/min. These flow values are physiological, with the systolic peak ranging from 20 to 30 l/min depending on the patient (Yap *et al*., 2012; Dasi and Moore, 2014).

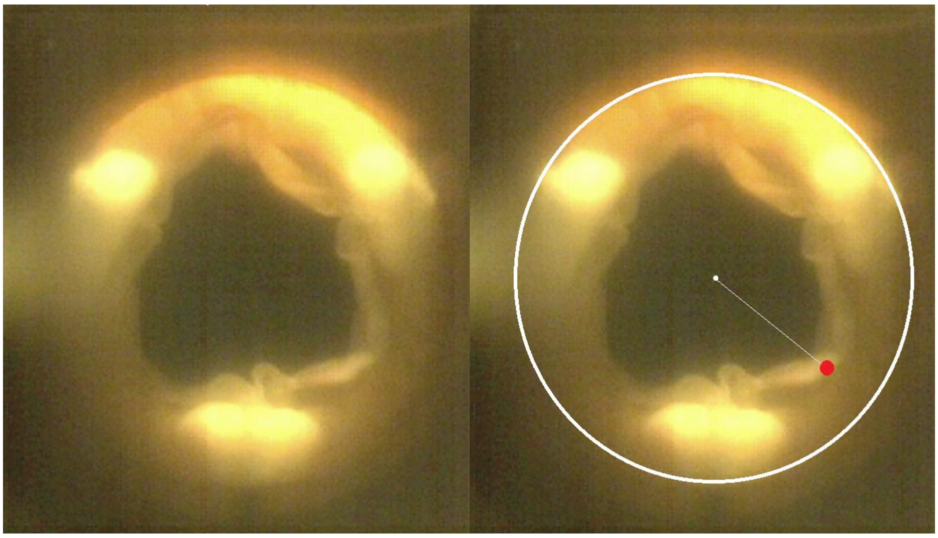

Figure 2. A) Valve image during test in direct continuous flow. B) Demarcation point to be followed and distance from the valve center.

3. RESULTS AND DISCUSSION

Figure 3 shows the leaflet position for the different flow rates of the experiments. It can be observed that although there is displacement of the point marked during flow rate of 10 l/min, the movement is largely disordered and of low amplitude. However, beginning from the flow of 20 l/min, the displacement of the cusp behaves as a high oscillation amplitude and orderly movement, showing that there is occurrence of flutter. For the flow of 30 l/min, there is no visible change in behavior of the leaflet, with the flutter also taking place in an orderly manner.

By analyzing the data by FFT, it was possible to obtain the frequencies of the cusp oscillations as shown in Fig. 4. It is possible to verify that for the flow of 10 l/min, low frequencies and low amplitudes are found, they can be considered as the natural frequency of the cusp, as mentioned by Condurache *et al*. (2009).

For the flow of 20 l/min a frequency of 238 Hz is noted with high amplitude, it being the dominant flutter oscillation. For the flow of 30 l/min, the dominant frequency of 271 Hz was measured by the FFT. In both flows a frequency of low amplitude of 10 Hz was also observed.

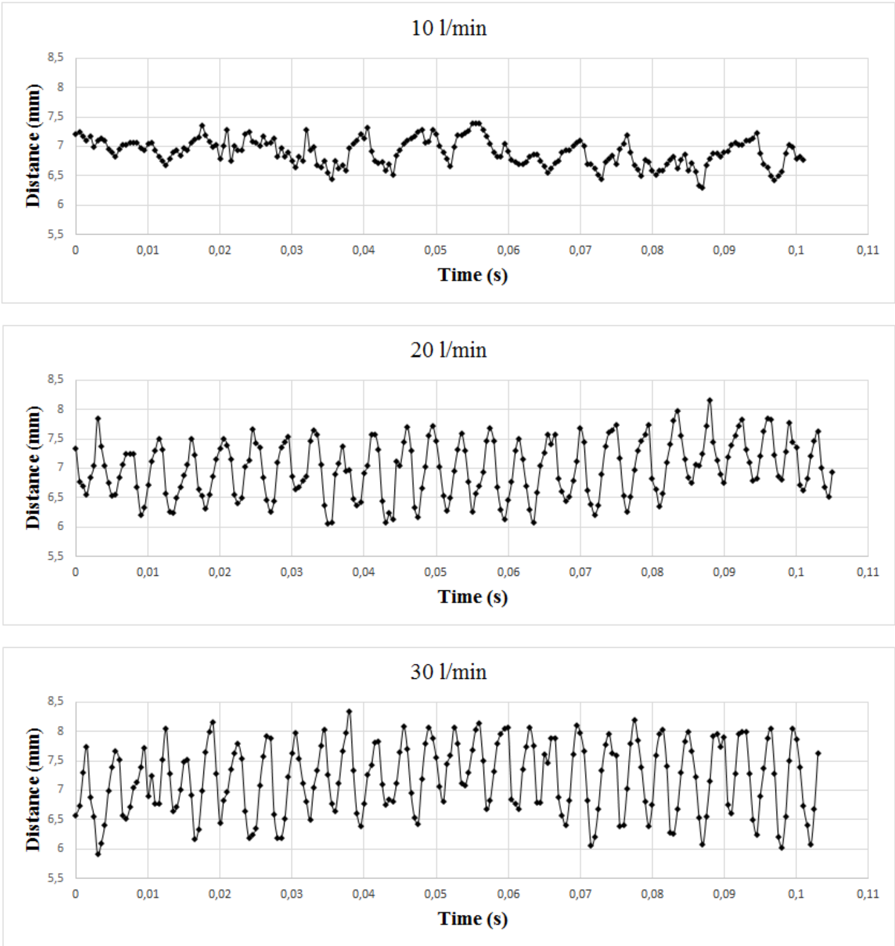

Figure 3. Position of the cusp by time for different flows.

The experiment shows that beginning from a critical flow, flutter begins with high frequencies and amplitudes. Although the frequency of oscillation increases with increasing flow rate, it remains of the same order of magnitude and the same amplitude. The change in the dominant frequency may have partly due to the methodology used to follow the leaflet position manually, adding an operator’s error to the system.

Considering that the structural fatigue caused by repetitive motion of opening and closing of biological artificial valves is a significant factor in their lifetime, the occurrence of flutter at a frequency of such magnitude can be regarded that its action contributes considerably to experience reduced useful life.

Although the value found is an important step in the study of flutter, it is important to improve the methodology for obtaining data of the leaflets. The current work only studied manually a single point in an one-dimensional direction; the improvement for a computational technique that reduces errors and follow various points in two dimensions is important to study several degrees of freedom to check for other dominant frequencies during flows.

By having a value quantified from the oscillations, the next step will be to find ways to change properties of the valves to reduce flutter, studying parameters such as the thickness of the leaflets, material and diameter of the valves.

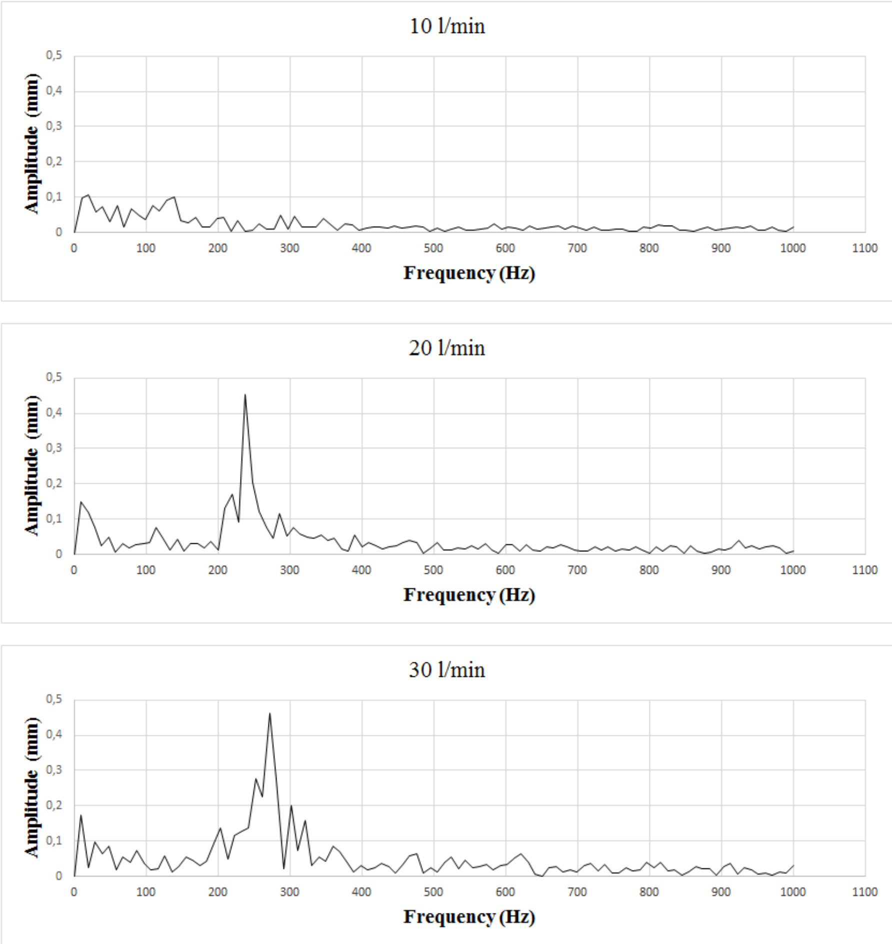

Figure 4. Amplitude by frequency of the oscillation of cusp for the different flows

4. CONCLUSION

Flutter is a phenomenon that occurs in natural and prosthetic heart valves, being harmful in cases such as biological valves, accelerating its calcification and consequent wear, reducing its useful life and forcing the patient to undergo new operations. Although the phenomenon is known for decades, there are few quantitative studies on it and little is known about what can be done to reduce the oscillations.

The methodology for quantifying flutter can be used for the testing of newly manufactured valves before they are implanted in patients, where the occurrence of vibrations could result on a disposal of the valve due to the chance of not reaching most of its life.

In this work the flutter of a cusp of a porcine valve was quantified for different flow rates. It was possible to verify that there is a critical flow rate that initiates oscillations in which the highest frequency occurs during the systolic peak flow.

This result is a first step towards an in-depth study of the flutter and its consequences on prosthetic valves in their performance and lifespan. The next challenge is to improve the methodology to measure the oscillations of the cusps to then study parameters and develop methods to reduce vibration without damaging the general operation of the valve.

5. ACKNOWLEDGEMENTS

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