Pulsatile Pump

Andrew McCahill '17, Alec Bunge '17

Advisor: Dr. Joseph Palladino

Department Of Engineering, Trinity College, Hartford, CT

Abstract:

The goal of this Capstone Senior Engineering Design project is to create a pump capable of mimicking the human heart's pulsatile flow in the left ventricle. Among many applications, this pulsatile flow is necessary for the prototype testing of a Left Ventricular Assist Device. This pulsatile pump is a positive displacement pump. The mechanism used for driving the fluid is the displacement of a rubber diaphragm attached to a piston rod to create hydrostatic force. The motion of the diaphragm is precisely controlled by a stepper motor programmed using pulse width modulation. To accurately mimic the flow of the heart, the diastolic base pressure of the flow should measure between 70-80 mmHg, with a pulse pressure raising the systolic pressure to 110-120 mmHg. The displacement of the diaphragm creates a measured pulse pressure of 38 mmHg, and by adding compressed air into the pumping chamber, the base pressure can be raised 75 mmHg creating a pump with a pulsatile pressure between 75-113 mmHg.

Introduction:

Pulsatile flow surrounds us in everyday life; it is found in several mechanical systems such as engines and hydraulic systems. Most importantly, it is an accurate model of the cardiovascular system of animals. Studies have shown that animals develop deficiencies if they are subjected to a continuous blood flow. When designing devices to assist with blood flow, it is important to see how the device handles a pulsatile flow similar to that of the heart. The human heart produces the following pulsatile pressure curve.

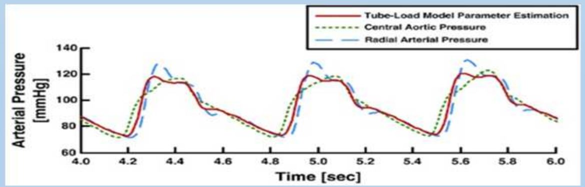

Figure 1. Theoretical graph of a human aortic valve's pressure www.journal.frontiersin.org

This curve has an average base pressure of 70 mmHg and a peak pressure of 110 mmHg. This human heart rate can range from 50-200 BPM whilst maintaining the same pressure range. This graph is for a heart rate of 100 BPM. To be a useful application the pulsatile pump must be capable of mimicking this curve with its measured pressure.

Design Process:

This Pulsatile Pump uses the rotation of a motor to cause a vertical displacement of a piston-diaphragm to create a hydrostatic force on the pumping fluid driving its motion. The direction of the fluid's motion is controlled via check valves and its pressure is measured via a pressure transducer located at the outlet of the pump.

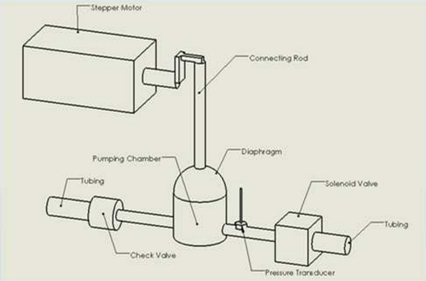

Figure 2: Pulsatile Pump schematic

The desired pulsatile pressure is determined by change of volume of the air pocket located in the diaphragm. Due to constant temperature, the necessary change in volume can be computed using Boyle's law.

$$\frac{P_1}{P_2} = \frac{V_2}{V_1} \quad (1a.)$$

$$\frac{70\ mmHg}{110\ mmHg} = \frac{V_2}{.273\ litres} \quad (1b.)$$

$$V_2 = 0.444\ litres \qquad \Delta V = 0.171\ litres \quad (1c.)$$

The maximum pressure that the diaphragm undergoes is 110 mmHg. This is the pressure used for calculating the size torque needed from the motor to assure the motor will be large enough.

$$\Sigma F_{diaphragm} = 0 \quad F_{motor} = F_{pressure} = P * A_{surface} = P * \pi(a^2 + h^2)$$

$$\tau = r_{rotation} \times F_{motor} \quad (2a\&b)$$

The diaphragm is the shape of a spherical cap, where *h* is the height of the cap and *a* is the radius of the largest cross section in the cap. The radius of rotation is one half of the measured vertical displacement to create the necessary change in volume. The required torque from the motor to drive the system 24 Nm. To determine the required diameter of the pump's tubing, Bernoulli's steady flow energy equation is evaluated at the surface of the fluid for several diameters.

$$\frac{P_1}{\rho g} + \frac{V_1^2}{2g} + z_1 = \frac{P_2}{\rho g} + \frac{V_2^2}{2g} + z_2 + f\frac{L}{d}\frac{V^2}{2g}$$

$$Q = AV = 8.3 \times 10^{-5}\ m^3/s$$

$$A_1 V_1 = A_2 V_2 \quad (3a,b\&c)$$

The average flow rate was calculated over the required range of pressure. This was done multiple times with different diameters. The size tubing that produced the correct flow rate was about a ½" in diameter.

Final design:

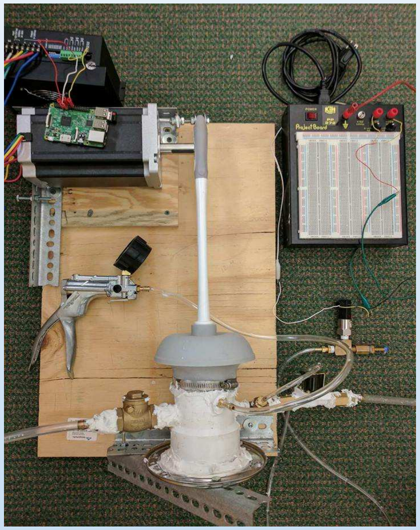

Figure 3: Pulsatile Pump Design

Results:

Our final results show that the pulsatile pump produces an average peak pressure of 105 mmHg and an average minimum pressure of 64 mmHg, resulting in an average pulse pressure of 41 mmHg.

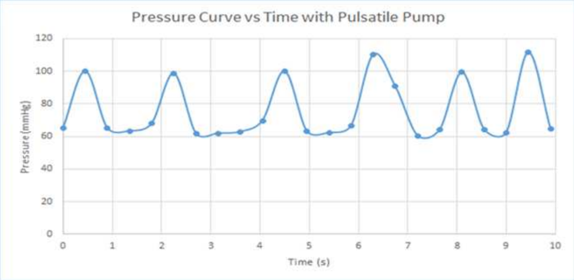

Figure 4: Pressure Curve (mmHg) using Pulsatile Pump

Acknowledgments:

Andrew Musulin

Professor John Mertens

Professor Joseph Palladino