Hemodynamic Simulator II

P09026

Detail Design Review

Invitees Reading Material

10/28/2008

Rochester Institute of Technology

Contents

Project Summary

Project Background:

Hemodynamic Flow Simulator is a modular system that replicates the flow and pressure related to the hemodynamic system. The long term goal of this project is to analyze and redesign some of the features of the module and make it fully compliant to customer's needs. The prototype designed by project P08026 team would be utilized in an attempt to achieve a final unit which is both self contained and aesthetically pleasing. In addition, the module should be able to perform in equally well, in educational and research applications.

Problem Statement:

The primary objectives of this project are to redesign the pump to its initial requirements, redevelop the data acquisition software and develop computer control for all system parameters. In addition, the final product must be self contained, and easy to transport from one classroom to another.

Objectives/Scope:

1. Initially, the pump must be redesigned in order to better replicate the pumping of the heart, which includes appropriate blood pressure and volume from the heart.
2. The final product must contain a data acquisition system that would monitor blood pressures, volumes, flow rates at desired locations. In addition, the measured data must be easily accessible to the user.
3. Furthermore, develop a computer system that would allow a user, access to all the parameters of the flow simulator. Hence, providing the user with a better control of the entire unit.

Deliverables:

- To have a portable, aesthetically appealing, and fully functioning re-modeled blood flow simulator that would appropriately replicate the operations of the heart (left-ventricle).
- To have a fully remodeled Graphical User Interface that would provide users full control of the unit, and is simple to operate.

Expected Project Benefits:

- The module would provide faculty members with a tool that may be utilized for instructional purposes.
- This will soon incorporate the testing of the school's LVAD prototypes to prove their effects of the circulatory system.

Assumptions & Constraints:

1. Simulate actual flow rates and pressures as produced by the human heart.
   (ie. Match pressure waves in aorta and left ventricle, other properties to be emulated by the system include proper system resistance and compliance.)

2. Must provide electrically and mechanically safe operation.
3. Must be portable, easy to transport from one class to another.
4. Heart chamber must be easily visible and data must be clearly displayed and recorded for use.

Issues & Risks:

- Redesigning the pump in an attempt to replicate the blood flow of the human heart.

Developing a GUI that would allow user to fully control the system, including flow rates, and blood volume

Specifications

Engr. Spec. #	Importa-nce	Source	Specification (description)	Unit of Measure	Ideal Value	Comments/Status
Fluid (Water)						
ES1	1	http://www.thermexcel.com/english/tables/eau_atm.htm	Volume	liters	5	Water will be used according to customer request
ES2	1	http://www.thermexcel.com/english/tables/eau_atm.htm	Viscosity	kg/m.s	0.001003	Room Temperature, T = 20°C
ES3	1	http://www.thermexcel.com/english/tables/eau_atm.htm	Density	kg/m3	998.29	Room Temperature, T = 20°C
Heart Chamber						
ES4	1	http://www.fi.edu/learn/heart/development/development.html	Normal Heart Rate	Beats per minute	120 - Infant 70 - Adult	Values used as reference on generating Pressure Curve
ES5	1	http://www.bbc.co.uk/science/humanbody/body/factfiles/heart/heartbeat.shtml	Max. Heart Rate	Beats per minute	220	With variation of +/- 5% - Values used as reference on generating Pressure Curve
ES6	1	http://gaps.anest.ufl.edu/palm/files/formulas/13.html	Systemic Vascular Resistance	MPa·s/m3	90–120	Normal - Values used as reference on generating Pressure Curve
Physical Dimensions						
ES7	1		Cart Size	inches	21.5 x 38.5	
ES8	1		Height	inches	72	Maximum Height
ES9	1		Location of the heart	feet	5	w.r.t the floor (eye level)
Overall System and Safety						
ES10	1	http://www.dangerousdecibels.org/faq.cfm#16	Noise Level	dB	60	Normal conversation level
ES11	1		Emergency Stop Button Response	sec	3	Actuator motion stops
ES12	2	http://www.grow.arizona.edu/Grow--GrowResources.php?ResourceId=188	Drainage Time	min	5	
ES13	1		Functioning Time	hours	8	

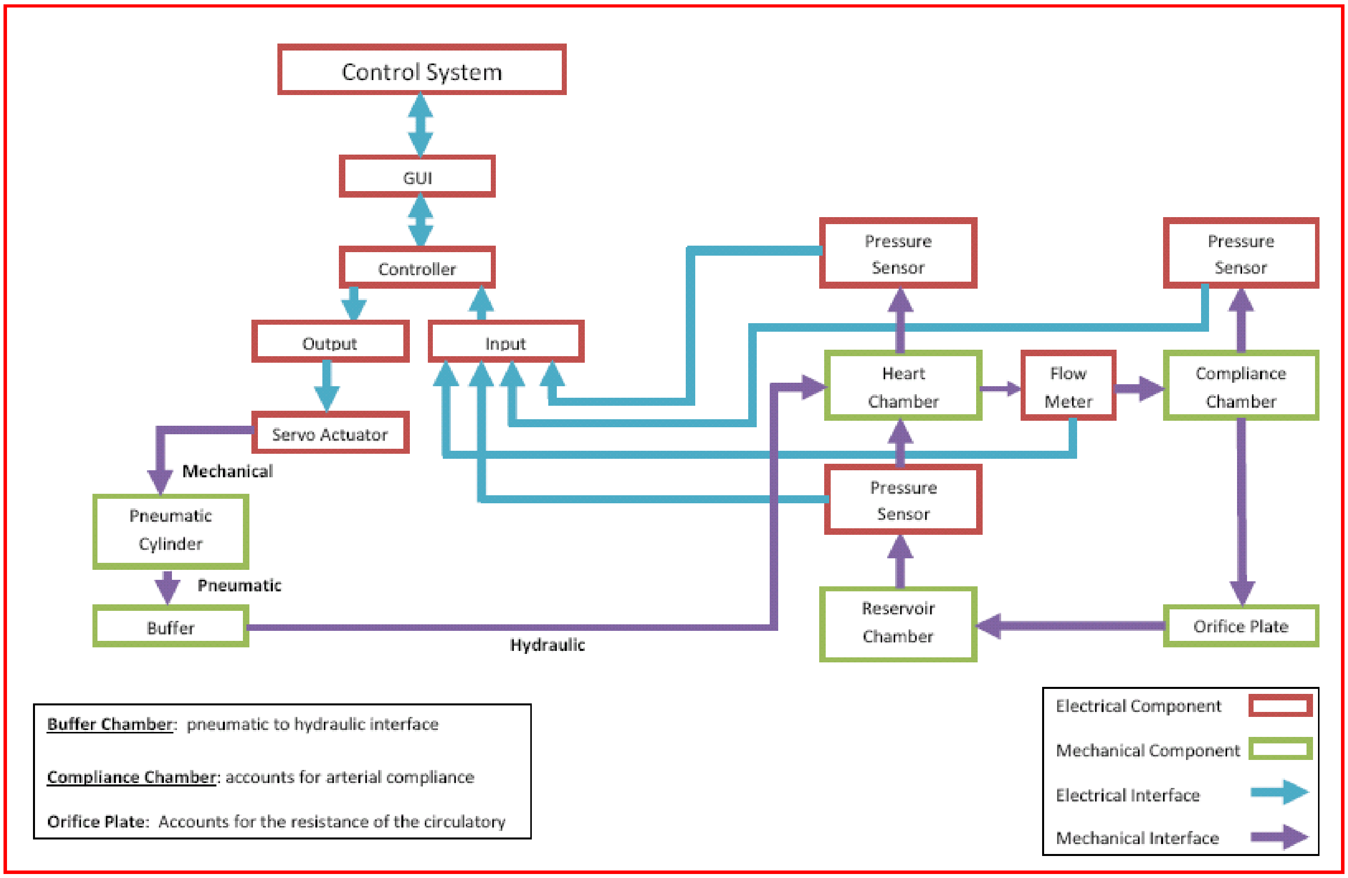
ES14	1		A/C Voltage supply	volts	120	Available in most classrooms

Specifications (Non-Quantifiable)

Engr. Spec. #	Importance	Source	Specification (description)		Desired Results	Comments/ Status
ES15	1		Control Software		Lab VIEW	
ES16	1		Aesthetic		Benchmarked by previous project and customer feedback	Aesthetically Pleasing - Polished, clean, enclosed, stainless steel (low maintenance), only thing exposed will the circulatory system and the heart chamber
ES17	1		Safety		Ground Default System	Like the ones in a bathroom

Reference Parameters						
Fluid (BLOOD)						
ES18	1	Cutnell, John & Johnson, Kenneth. *Physics, Fourth Edition*. Wiley, 1998: 308.	Viscosity	N-s/m²	0.0027	At 37°C
ES19	1	Cutnell, John & Johnson, Kenneth. *Physics, Fourth Edition*. Wiley, 1998: 308.	Density	kg/m³	1060	At 37°C
ES20	1	Taggart, Starr and Cecie Starr. *Biology: The Unity and Diversity of Life*. California: Wadsworth, 1989: 398.	Volume	liter	5	With variation of +/- 20%
ES21	1					
ES22	1	http://www.eie.polyu.edu.hk/~ensmall/eie448/EIE448/Notes_files/topic2.pdf	Circulatory System total length	meters	10^{8}	
Propagation Velocities of Blood in Human Body						
ES23	1	http://www.eie.polyu.edu.hk/~ensmall/eie448/EIE448/Notes_files/topic2.pdf	Atria	m/s	1	
ES24	1	http://www.eie.polyu.edu.hk/~ensmall/eie448/EIE448/Notes_files/topic2.pdf	AV Node	m/s	0.05	
ES25	1	http://www.eie.polyu.edu.hk/~ensmall/eie448/EIE448/Notes_files/topic2.pdf	Purkinje Fibres	m/s	3	
ES26	1	http://www.eie.polyu.edu.hk/~ensmall/eie448/EIE448/Notes_files/topic2.pdf	Ventricles	m/s	0.5	

Overall System Architecture



Control System Modeling

The operator of the Hemodynamic Simulator will have control over three parameters: Systolic Ejection Period, Heart Rate, and Left Ventricular Pressure.

The following explains how each parameter will function.

Systolic Ejection Period, SEP:

The SEP will be equivalent to the time it takes the cylinder to move forward. This forward movement in the cylinder will result in an increase of pressure in the system. The returning movement of the cylinder is equivalent to the Diastolic Filling Period. The DFP will not be explicitly controllable, but will change depending on the SEP and the HR.

Heart Rate, HR:

The HR will be proportional to the inverse of the RR interval. The RR interval is the sum of the SEP and DFP. In the cylinder, the RR interval will be equivalent to the time it takes the cylinder to move forward and return once.

Left Ventricular Pressure (LVP):

The LV Pressure will be proportional to the velocity of the actuator. The pressure in the system will be directly controlled by the displacement of the actuator, but the displacement will not be explicitly controlled. The change in displacement will be a result of the velocity of the actuator and the SEP.

Initial Conditions:

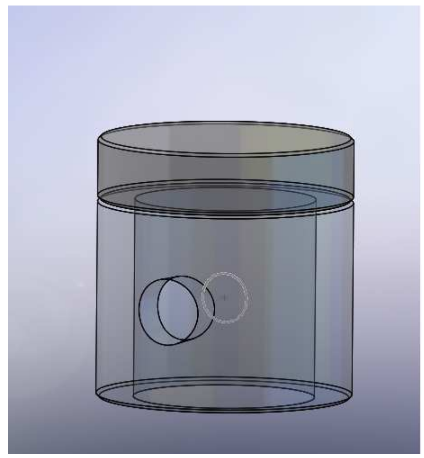
To displace 100 mL of water, the cylinder will need to move 125 mm. Ideally, the SEP will be 350 ms. To move the cylinder 125 mm in 350 ms, the cylinder needs to move at a speed of 0.357 m/s, which is well within the specs of our motor. This will be achieved by inputting a motion profile. The profile will be a piecewise linear function of position with respect to time. The cylinder will move from a position of zero to 125 mm at 0.357 m/s. The cylinder will then return to zero at a speed of 0.192 m/s. These will be set as baseline requirements, as they will meet the ideal values of SEP = 350 ms and HR = 60. At this speed, it is our educated guess that the LV Pressure will be 120 mmHg. If the pressure of the output is different, we will have to change the amount of water we displace with the cylinder.

The shaping of the curve will be controlled by the compliance and resistance of the system. The initial values of compliance and resistance have been calculated by the mechanical team. The resistance is an area of the globe valve that will be blocked, the amount that the globe valve is closed. The compliance will be a result of the ratio water to air in the compliance chamber.

Mechanical Pump Construction

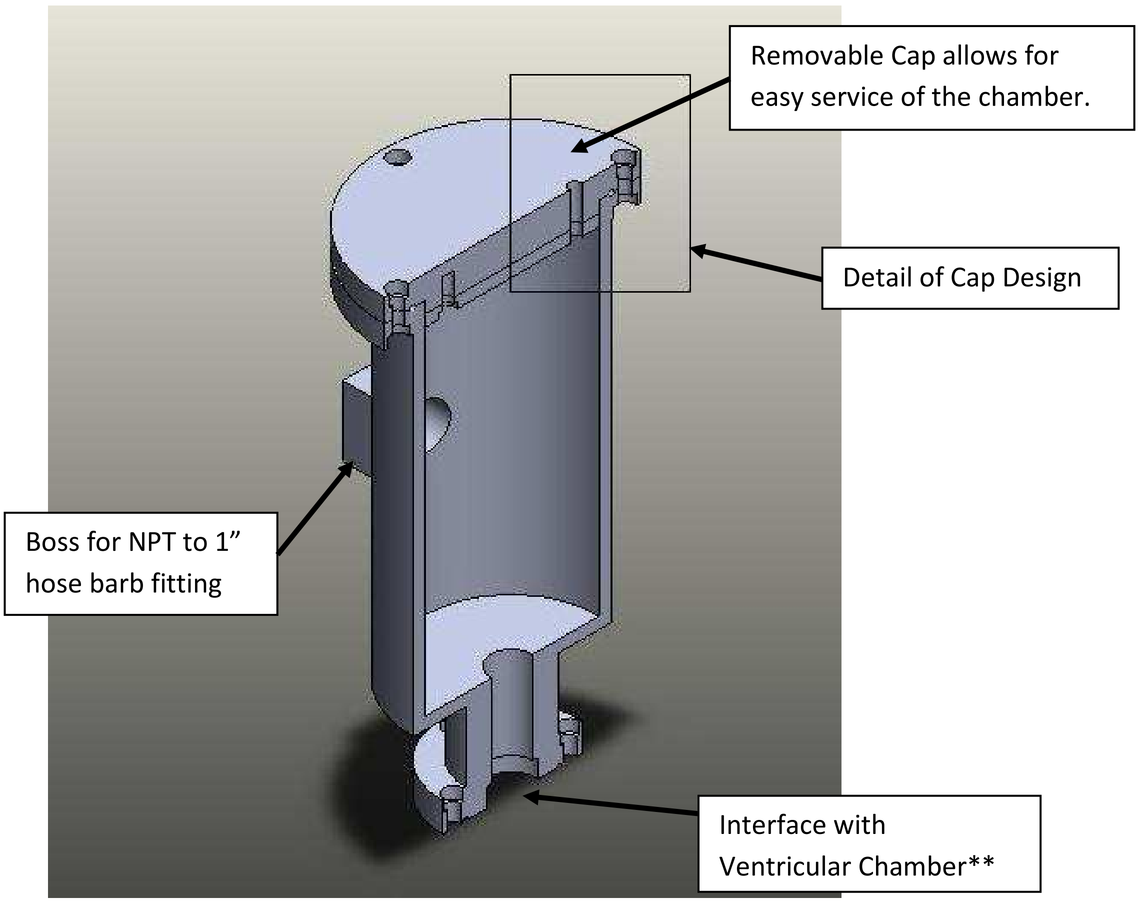
Buffering Chamber

a. The design built by Dr. Schwartz will be used and tested initially.
b. Risk has been Identified in 3 critical area's
    i. Too much compliance in the air column diving the heart chamber/ ventricle
    ii. Larger column of water creates greater fluid inertia and will cause system lag
    iii. Water column height above ventricle will cause pressure during diastole
    iv. All three can be mitigated by adjusting the cylinder length after testing.
c. This solution is shown in the following diagrams.

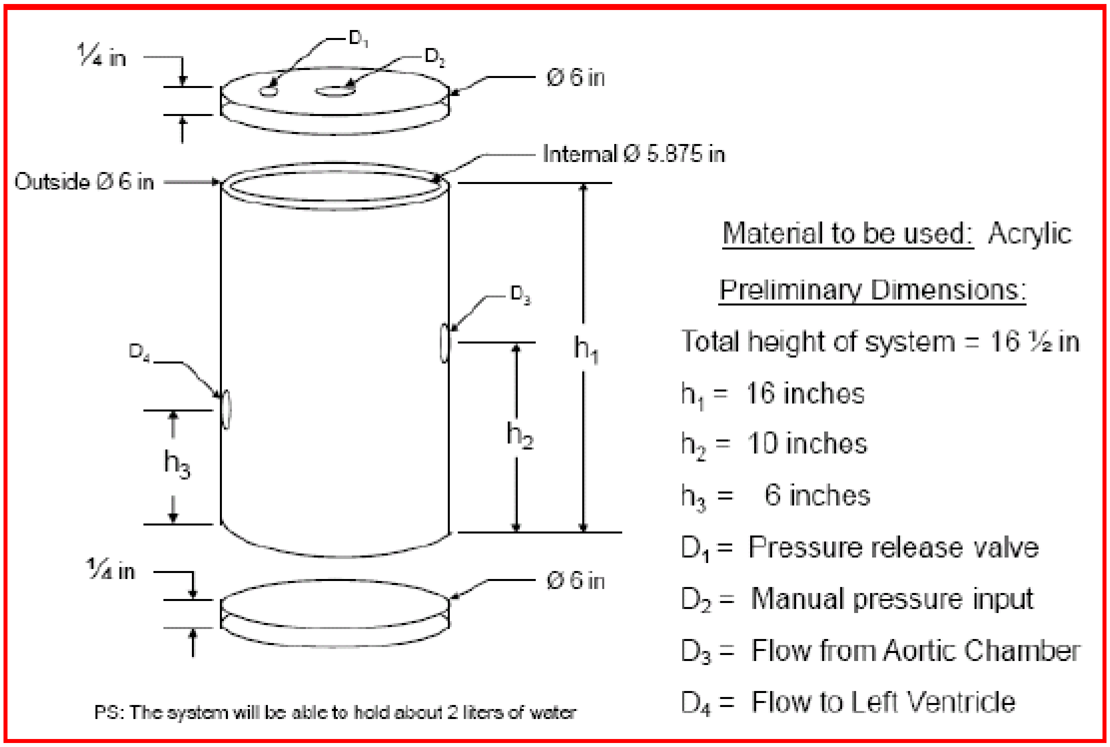
	
Taller Buffering Chamber to be used initially	Shorter proposed Buffering Chamber design

Aortic Chamber

a. Acrylic construction chosen for clarity, ability to machine and ability to chemically bond the material. (Polycarbonate would fit these criteria but would have to be clarified out of house.)
b. Cylindrical shape and plastic welding minimize the need of seals.
c. Designed to directly interface with the existing ventricular chamber.
d. Basic sizing of geometry guided by basic fluids analysis.



Atrial Reservoir



Actuator Selection

Required Actuator Specifications			
	Buffer Chamber Ratio (Air:Water)		
	All Air	1/2 Air, 1/2 Water	3/4 Water
Maximum Velocity (mm/s)	1600	1000	700
Average Velocity (mm/s)	800	500	350
Displacement (mm)	200	125	87
Force Required (N)	80	80	80

Selected Actuator Specifications	
THK	VLA-ST-60-12-0250
Maximum Velocity (mm/s)	1000
Average Velocity (mm/s)	600
Displacement (mm)	250
Rated Force (N)	134 (Maximum is 398)

Required Motor Specifications	
Motor Wattage (W)	50
Motor Rated Torque (N-m)	0.159

Selected Motor Specifications	
Yaskawa	In Process of Selection
Motor Wattage (W)	
Motor Rated Torque (N-m)	