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ME 415 – Senior Design
IOWA STATE UNIVERSITY

Four-Way Valve

A four-way bidirectional valve designed for energy-saving startup, Waters Hot Inc.

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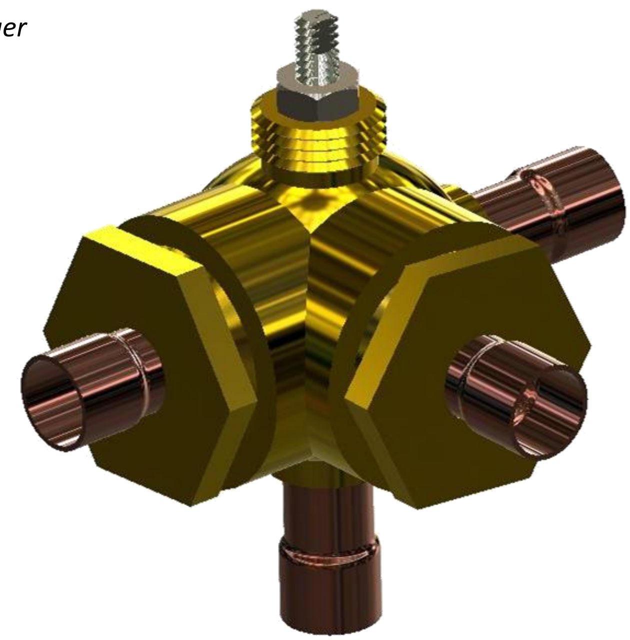

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EXECUTIVE SUMMARY

Purpose and Scope of Report

The purpose of this report is to provide background on Waters Hot Inc.; demonstrate understanding of the four-way valve design problem; show work researching and developing designs; provide the final design selection and justification; communicate material selections; provide a business case and cost analysis; and to give guidelines for future expansion.

Conclusions and Findings Summary

Overall, the fall 2009 semester design project was very successful. Initial research of current valve designs yielded three items of interest: a “4-Way Valve” not meeting the needs of Waters Hot (due to two lines being open at a single time); a spring valve used in pressure valve operations; and the ball valve. None of these designs completely solved the four-way valve problem, but served as a starting point for Team MachinE.

Initially five valve designs were created to fit the needs of Waters Hot: 1) the linear motion valve, 2) the funnel valve, 3) the camshaft valve, 4) the rotating plate valve, and 5) a ball-valve variant with three outlets. Out of these five valves, the ball-valve design was selected over the others due to its simplicity, low number of parts, and its extension of existing technology. The other designs were dismissed on basis of high-moving parts, high complexity, maintenance/fabrication issues, and/or sealing concerns.

Specific dimensions and geometry were developed to yield a final valve design the size of a baseball. The final design can open each line independently and completely shut off without opening an intermediate port. Special care was taken to make sure the design is easy to manufacture and assemble. Working drawings were created and dimensioned.

Materials were selected and manufacturing process was laid out. It was the recommendation of the team that the housing be cast out of brass and machined to specification—similar to other existing ball valves. The ball itself can be made from chromed brass to cut down on costs and machining time. The seals should be made from virgin Teflon to withstand the temperatures and pressures. The shaft can be made out of stainless steel to resist wear and survive the high turning torque.

A conservative cost estimate of the valve design ended up at $80 per valve including all labor costs, material costs, and tooling. At a retail price of $100, Waters Hot could deliver a 30% return on investment in under 5 years.

A prototype of the valve design was built using different materials and geometry to test the design’s function.

Background

In fall of 2009, Waters Hot teamed with an Iowa State University Mechanical Engineering Senior Design team, Team MachinE, to create a 4-way bidirectional valve. A 4-way bidirectional valve contains four inlets/outlets (or a combination, e.g. 1 inlet-3 outlets) and allows current to flow through the valve in both directions for every configuration. Four-way valves exist, but always allow two streams to be flowing at once. Waters Hot desired a 4-way valve with one inlet and three outlets (or vice versa) to direct flow of fluid into one of three circuits.

Engineering Process

In general, the design process had five main steps:

- Initial research and problem statement comprehension: Researching Waters Hot; visiting the company and installation site; understanding the problem statement; and doing research on valves where all elements in this step. It was critical the design process was understood.

- Brainstorm and Creation of Alternative Ideas: Ideas were compiled and compared. Over a few weeks, brainstorming sessions were held and five final design concepts were created. Care was taken to specifically meet design criteria.

- Design Selection and Specifications: After much discussion, a top choice was selected. The geometry was finalized with the aid of engineering calculations. Pressure and flow-rate values were calculated to ensure the design met project specifications. Durable materials were selected for the final design.

- Fabrication: A functional prototype was fabricated out of similar metals. Bronze was chosen for the ball instead of brass for easier machining. Despite its different appearance, the prototype still was operable to test the valve function.

- Conclusions: Plans for the future were developed and final presentation was given. A full report was composed to aid others in future expansion of this research and design. The business case was considered and analyzed. Recommendations to Waters Hot were made.

Final Recommendations

This valve design is easily expandable to a five-way valve simply by adding pipe through the closed port in the valve. It is also possible to increase this design to an n-way valve by adding more pipes and increasing the size of the ball.

Team MachinE recommends that the design be patented and Waters Hot sell the valve at $100/valve.

INTRODUCTION

In the fall of 2009, Waters Hot Inc. teamed up with the Mechanical Engineering Department at Iowa State University to create a semester design project for Mechanical Engineering senior design students. Waters Hot informed Iowa State University that a four-way valve, not seen on the market today, would be the perfect addition to their current energy-saving heating and cooling system. Such a valve would allow Waters Hot to channel fluid independently through three different lines and overall increase their bottom line.

After of survey of personal skills, Jason Boggess, Diana Gylling, Lee Harris, Ted Hotvet and Laurel McDonough were paired with the Waters Hot design project. Boggess had much leadership experience both through class projects and extracurricular activities and was selected to be team lead. Harris had much Solidworks™ experience through internships and had phenomenal design skills. All members of the group were high-achieving academic students who were willing to work hard.

Shortly after the group was formed, “Team MachinE” became the team name for its assonant rhyme and “M E” representation.

After the team was created, Team MachinE prepared to fully grasp the problem at hand. Travel arrangements were made and the team traveled to Orange City to visit the Waters Hot facility. The shop was toured and the team got to see firsthand a Waters Hot System in action. After the problem was sufficiently understood, the team was ready to start their work on solving the four-way valve design problem.

This report is a summary of four-way valve concept design evolution, team MachinE’s processes methodology, and the final solution complete with business analysis.

BACKGROUND

Waters Hot Inc. is a started startup company operating out of Orange City, Iowa. Founded in 2002 by Kevin Flammang, Waters Hot aims to save energy by combining refrigeration and power cycles into a single system.

Standard refrigeration cycles, like those found in a freezer or air-conditioning unit, cool air inside the unit and release heat to an outside environment. Heaters, like those which heat the air in your home or the water in you pipes, add energy to a cold mass of air or water. Similar cycles work against each other when paired in the same environment. For example, during the summer air conditioners work to keep your house cool, yet freezers keep your ice cream forzen. The refrigeration cycle in your freezer removes heat from the ice cream and then rejects it to the surrounding air in your home. The air-conditioning unit does a similar thing, yet ejects the heat to the outside of your house. In essence, the freezer heats your home as the air-conditioning unit cools it. Energy is wasted.

Kevin Flammang first realized the capacity of these redundant systems and pioneered a new technology to reclaim that energy. He invented the patented "R.A.S.E.R.S." System that combines the processes of rejection, cogeneration, and reclamation to deliver unparalleled energy savings. R.A.S.E.R.S. (Reverse Ambient Solar-Energy Reclamation System) can be installed in commercial or residential applications and reduces energy needs by up to 65%.

The R.A.S.E.R.S. system combines all heating and cooling processes through a single system for maximum efficiency. In the rejection mode, the R.A.S.E.R.S. system uses all the energy possible before "rejecting" the remaining energy out into the environment or back into the building (depending on whether the system is heating or cooling). The reclamation mode recycles energy from multiple sources to create more efficient heating/cooling processes. For instance, in a laundry facility, the heat from dyer vents could be collected and used to the heat water for washing clothes. This mode saves from 30-50% of all energy costs.

The final mode of energy savings is co-generation mode. In this mode, a single R.A.S.E.R.S. system provides both heating and cooling needs simultaneously. I.e. there is a single boiler/condenser and energy is piped where it needs to go. This form of energy saving is optimum with an average savings of 40-60%.

Today, the company has over 100 R.A.S.E.R.S. systems installed in commercial and private applications.

Figure 1: R.A.S.E.R.S System

DETAILED PROBLEM DESCRIPTION

From Waters Hot, inc.:

> *"Waters Hot R.A.S.E.R.S. system™ inherently uses multiple refrigeration circuits to perform two or more heating and cooling functions. Current industry valves are designed for single circuit operation which creates operational issues at various points in the vapor compression cycle. Thus we seek a valve to support multi-circuit refrigeration systems that will provide an open and close function to each circuit independently without leakage regardless of inlet or outlet pressure differential."*

Team MachinE Interpretation

Waters Hot would like a four-way bidirectional valve to improve the business of their R.A.S.E.R.S. system. Currently no four-way valves exist on the market that meet Waters Hot's specifications. The four-way valve they desire directs fluid flow from a simple inlet pipe into one of three outlet lines. The valve should be bi-directional—allow fluid to flow in and out in a single circuit (3-to-1 and 1-to 3)—and not open any intermediate lines while switching from one line to another.

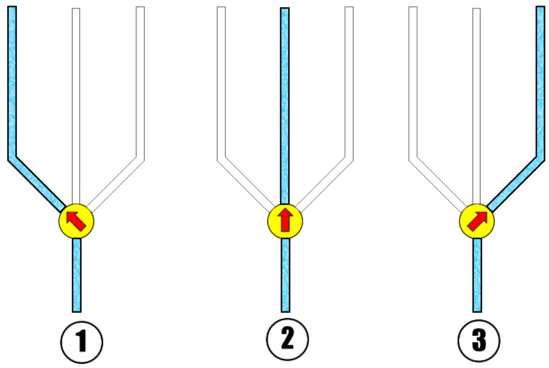


Figure 2: Flow Direction Diagram

OPPORTUNITY STATEMENT

Building such a valve will be a great opportunity to for Waters Hot to better serve their customers which will in turn, increase their business. This valve could also increase the efficiency of the R.A.S.E.R.S. system, create new jobs in the area of green energy, and build better connections between Iowa State University and the Waters Hot Company.

For Team MachinE, working on this valve design project helps team members gain industry experience; gain contacts with potential real-world employers; and overall helps the environment.

Constraints & Specifications

The following is a compilation of the constraints given to Team MachinE by Waters Hot representatives and more criteria compiled by Team MachinE.

Function

- Must open and close in under 5 seconds
- Must open and close without leaking to an intermediate circuit
- Lifecycle must be 10-15 years, or about 40,000-50,000 cycles
- Pressure drop must be less than 3psi
- 15 pounds per minute liquid/vapor flow rate
- 3 pounds per minute fluid flow rate
- 24V AC controller

Materials

- Body must be brass
- All other parts must be brass or stainless steel
- Teflon or Zytel seals
- Uses R-410A and POE
- Uses R-22 and Mineral oil

Operating Conditions

- Maximum operating pressure 650psia
- Maximum operating pressure differential 450psia
- Maximum safe pressure exceeds 3250psia
- Operating temperature ranges from -40° F – 300°F
- Handle both a liquid and a gas
- Scalable to different pipe sizes

Integration

- 3" copper pipe extensions off valve
- 1" minimum spacing between copper pipes/circuit lines for welding room
- Small footprint to fit inside unit (within 1 cubic foot)
- Costs less than $300
- Possibly: Non-pilot operated

As wells as design specifications, Team MachinE compiled a list of people impacted by this project.

Customers

- Waters Hot Inc.
- Waters Hot Inc. Investors
- Other fluid circuit design companies looking to purchase a four-way valve

PROJECT TIMELINE

There were five main sections to the project timeline:

- <u>Initial research and problem statement comprehension:</u> During this stage of the project, the team traveled to Waters Hot Inc to visit a working facility. The equipment and R.A.S.E.R.S. system was studied to develop the optimum working valve. The team rewrote the problem statement in their own words during this stage, and researched current valve types. Goals and stakeholders were indentified and numerical criteria and constraints were established.

- <u>Brainstorm and Creation of Alternative Ideas</u>: In the second project stage, the team developed their own valve ideas. After about two weeks of solid brainstorming, each member of the team had his own design to polish. Once all the designs were finished, the team spent hours debating the alternative designs.

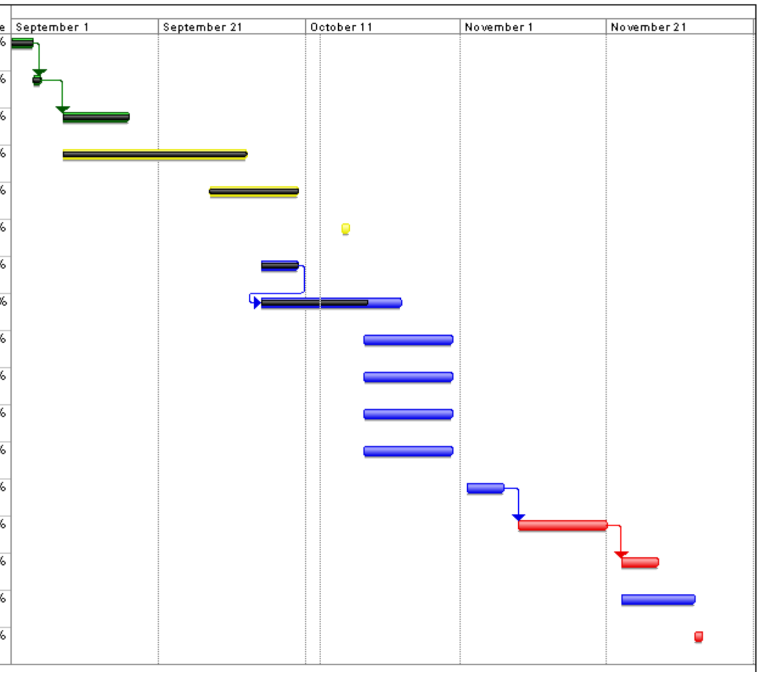
- <u>Design Selection and Specifications</u>: In this stage, the top choice was selected. The geometry of the final design was finalized. Pressure and flow-rate values were calculated to ensure the design met project specifications. Durable materials were selected to ensure long life-time and low costs.

- <u>Fabrication</u>: A functional prototype was fabricated out of different metals to test valve function. Bronze was chosen for the ball instead of brass for easier machining. Despite its different appearance, the prototype still was operable.

- <u>Conclusions</u>: Plans for the future were developed and final presentation was given. A full report was composed to aid others in future expansion of this research and design. The business case was considered and analyzed.

Table 1: Gantt chart

ID	Task Name	Start	% Complete
1	Develop Project Charter	ue 9/1/09	100%
2	Tour Water's Hot Facility	Fri 9/4/09	100%
3	Research Problem, Valves, etc.	ue 9/8/09	100%
4	Brainstorm Designs	ue 9/8/09	100%
5	Generate Alternative Designs	n 9/28/09	100%
6	Virtual Meeting with Water's Hot	10/16/09	0%
7	Design Selection	n 10/5/09	100%
8	Design CAD Modeling	n 10/5/09	70%
9	Functional analysis	10/19/09	0%
10	Cost Analysis	10/19/09	0%
11	Customer Analysis	10/19/09	0%
12	Quality Assurance (Virtual Testin	10/19/09	0%
13	Final Design/Bill of Materials	n 11/2/09	0%
14	Fabrication?	n 11/9/09	0%
15	Testing?	11/23/09	0%
16	Presentation Preparation	11/23/09	0%
17	Presentation?	u 12/3/09	0%



Design Evolution: Alternate Design Concepts

During the brainstorming process, Team MachinE developed five concepts for the four-way valve. The following is an overview of each of these five design concepts. Each design includes a description of the design followed by list of pros and cons. The four concepts have been named the "Linear Motion Design," "Funnel Design," "Rotating Plate Design," "Camshaft Design," and the "Ball Valve Design."

Linear Motion Design

The linear motion design consists of two metal rods oscillating inside of a metal housing. Each metal rod contains two holes specifically drilled at two different locations to create four combinations of paths through the metal housing. The housing self has six holes—three on each side. Using these four combinations, the fluid can be directed into one of three lines (or closed), and only one path can be open at any given time (See Figure 3)

Solenoids are used to move the rods back and forth to one of the four positions. The valve body has a manifold that feeds into the valve.

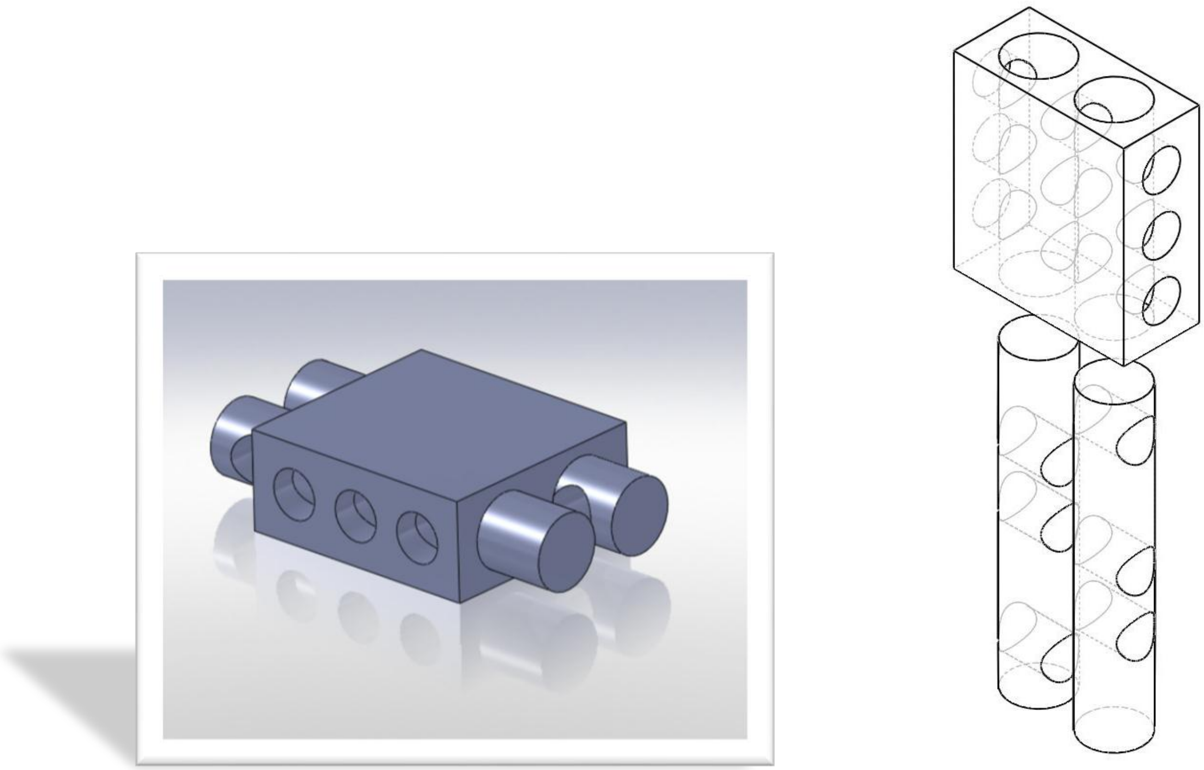


Figure 3: Linear Motion Design

Pros

- Simple—few moving parts to manufacture and maintain
- Easy to control (on-off controllers)
- Straight lines through housing (little pressure loss)
- Fast transition between lines

Cons

- Fluid flow passes over the seals
- Lines are open to the environment during actuation (which would leak)
- High power consumption while valve has a line open

Funnel Design

In the Funnel Design, fluid enters a large funnel and exits to one of the three exit ports. An AC motor attached to the housing via a control through the center of the funnel controls the funnel position. As the funnel is rotated around, fluid can be directed into and out of one of three exit lines (see Figure 4).

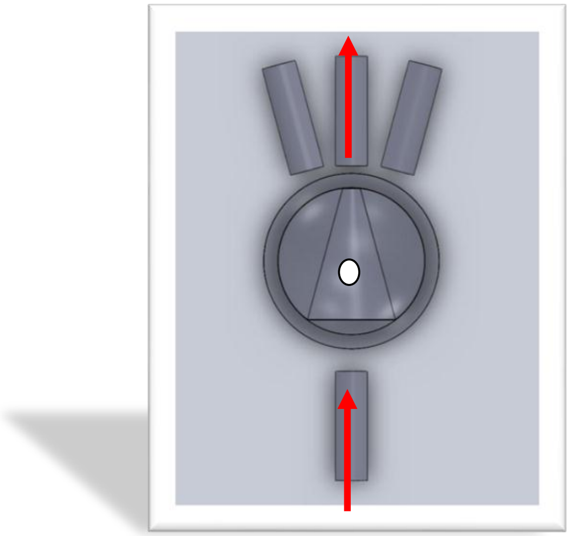


Figure 4: Funnel Ball Design

Pros

- Easy to seal due to round shape
- Fairly low number of moving parts

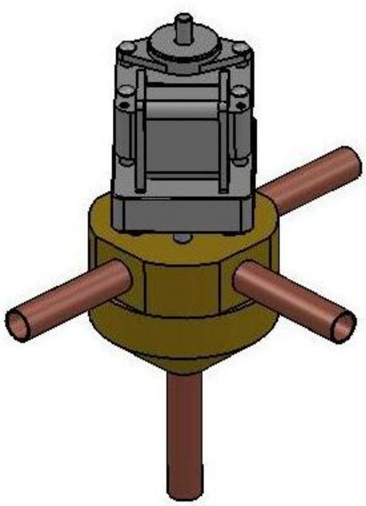
Cons

- Turbulent flow in funnel section increases pressure loss
- Could self-rotate due to angled flow
- Almost impossible to manufacture

- While operating, must pass through intermediate port to go from far left port to far right port
- 360° turns not possible without opening all three lines simultaneously
- Requires position control system

Rotating Plate Design

The Rotating Plate Design utilizes a circular plate with a single hole. The plate is rotated at 90° intervals to accpect fluid from one of three lines. The plate is tightened to the top of the valve housing sealing two lines while allowing flow from the third. The fourth 90° rotation is reserved for an all-closed configuration. At the bottom of the housing, there is a funnel which channels the fluid from the lines. This design works to provide the function of the four way valve with minimal parts as well as minimal machining and labor costs.



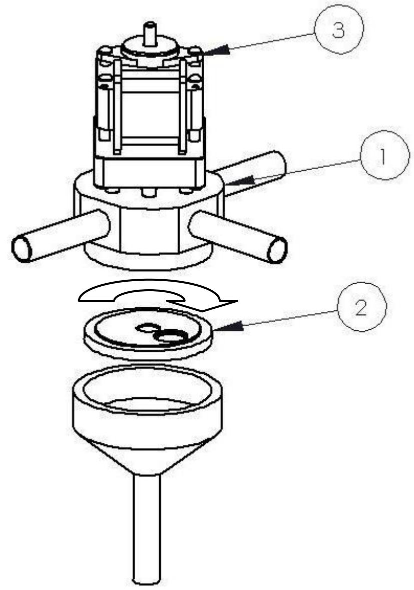


Figure 5: Rotating PlateDesign

Pros

- Simple—few moving parts
- Easy to manufacture and maintain
- Smaller size and weight
- No power needed to keep the valve open or closed

Cons

- Difficulty sealing due to constant pressure on the plate
- Fluid passes over seals
- Potentially high torque due to high normal force on plate
- Requires position control system

Camshaft Design

In the camshaft design, a single camshaft is used to open and close three independent spring valves in a single housing (Figures 6 & 7). Each 90° rotation of the camshaft opens a single valve while the fourth 90° rotation is an all-closed position. The camshaft is rotated in either direction to avoid opening any intermediate lines while opening and closing he valve.

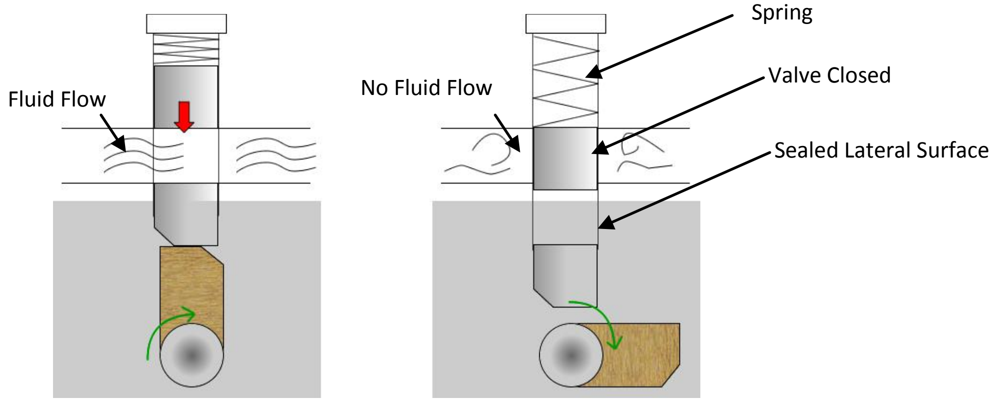


Figure 6: Side View of the Camshaft Design

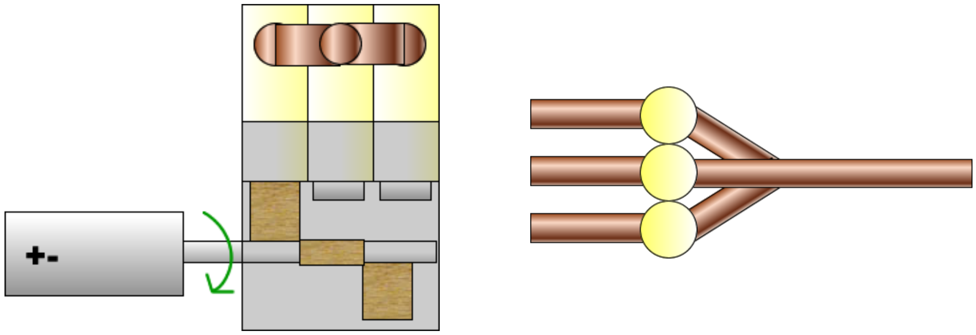


Figure 7: Front View and Top View of the Camshaft Design

The flow enters through three separate entrance pipes and exits through a single pipe. The spring valves are contained in a single housing while the camshaft has its own separate covering. The motor is outside the valve and visible to the user for easy maintenance and repair. The spring valves operate like normal spring valves with a single piston to close and open the flow. Since this valve operates using a camshaft and not pressure, fluid flow could occur in either direction.

Pros

- No power needed to keep the valve open or closed
- Automatic shutoff (all-closed) when the motor and camshaft are removed
- Valve seals are perpendicular to fluid flow for a tighter seal
- Motor and camshaft are easily removable for easy maintenance
- Spring valves are capped and allow easy access to springs and seals
- No forces on the camshaft when the valve is in its all-closed position
- Based on existing spring-valve technology

Cons

- High number of moving parts which increase likelihood of failure
- Higher cost from many parts
- Requires position control system
- Fluid could freeze in an off port which could cause valve failure

Ball Valve Design

In the Ball Valve Design, fluid flows through the bottom pipe into a brass ball where it can be directed into one of the three outgoing lines. The ball is rotated by a simple position-control motor attached to a shaft at the top of the ball. The ball can be rotated in either direction to avoid opening an intermediate pipe. The fourth position is reserved for an all-closed configuration.

This design is an adaptation of an existing three-way valve and has been modified to extend the rotation to four locations.

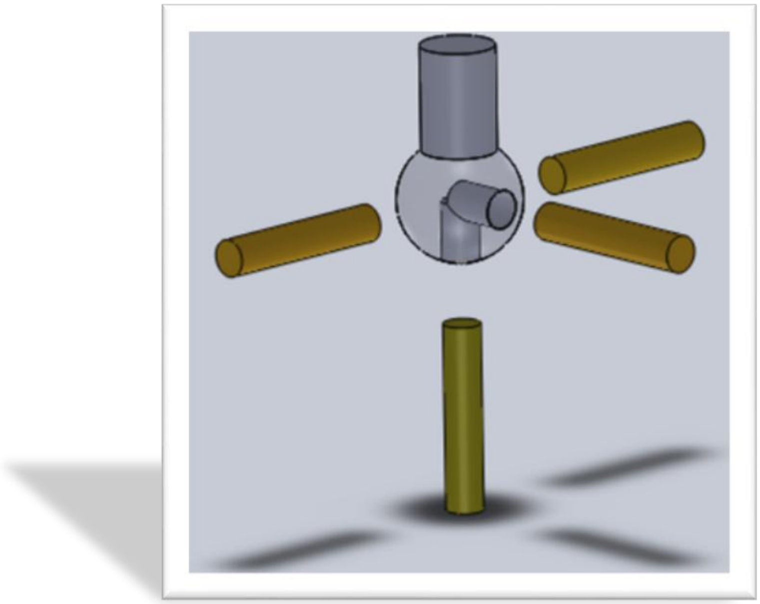


Figure 8: Original Ball Valve Design

Pros

- Simple
- Easy to seal due to round shape
- Based on an existing valve design/Existing ball valve parts could be used in design (i.e. seals)
- Low pressure lost

Cons

- Requires position control system

Decision Matrix

Once the alternative deigns were created they were compared through a decision matrix (Table 2). Each valve design was rated using the four criteria that could be easily calculated (or assumed) from the valve's geometry: size, complexity, technology, and power consumption. Designs could not share ratings, i.e. each design had a unique number for each category. Even though ratings could not be asserted through testing, engineering intuition was used to create an accurate rating system.

From the table, it is easy to see the ball valve is the clear winner. From the results of this decision matrix, Team MachinE decided to focus its efforts on the ball valve for its final design.

Table 2: Decision Matrix for the Five Designs

Design	Small Size	Least Complex	Proven Technology	Low Power Consumption	Total
Linear	2	5	4	1	12
Funnel	4	3	1	4	12
Rotating Plate	3	2	2	3	10
Camshaft	1	1	3	2	7
Ball Valve	5	4	5	5	19

FINAL DESIGN

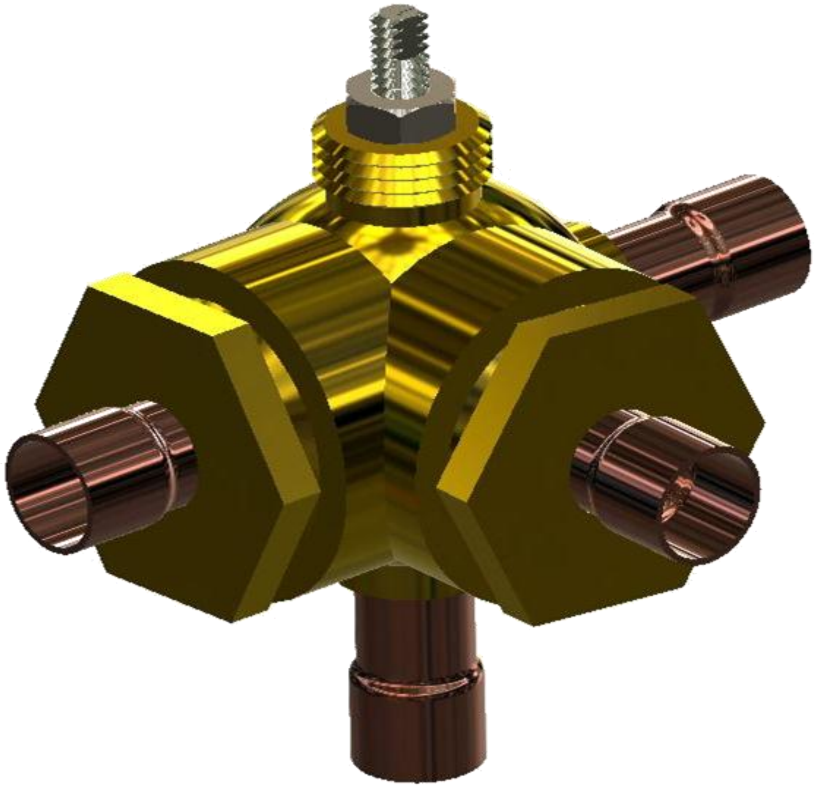


Figure 9: Ball Valve Design

A modified ball valve design was determined would be the most appropriate choice for the Four-Way Valve final design. The design consists of an inlet located on the bottom of the valve in a vertical orientation and three outlets located perpendicular to one another on a horizontal plane running through the middle of the valve. The flow is directed to one of the outlets, or an optional "off" position, via a ball with a 90° elbow machined into its center. *Diagrams of the valve can be seen in Figures 9-11 as well as the working drawings located in the appendix.*

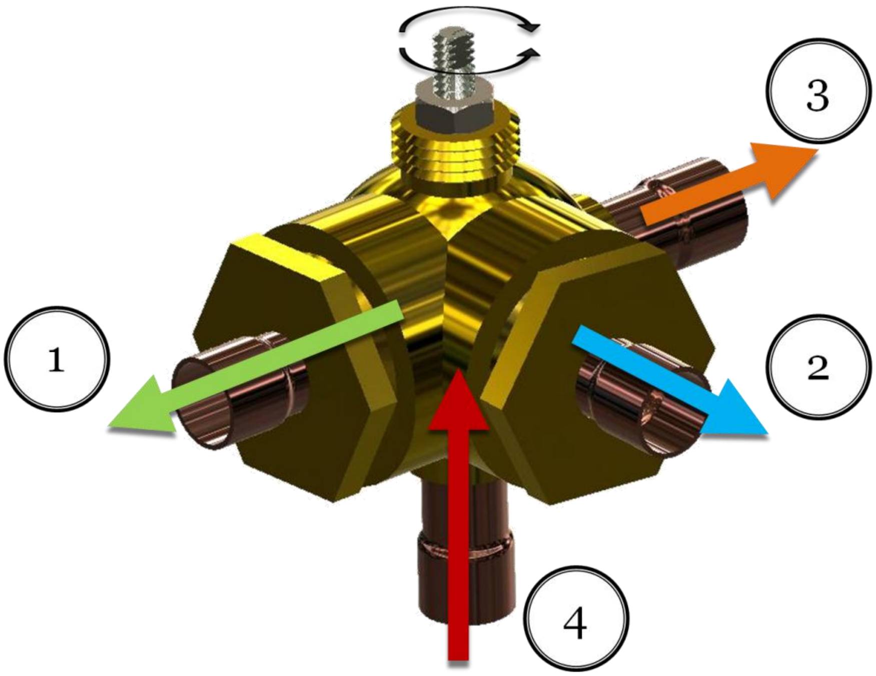


Figure 10: Ball Valve Design Function

More specifically, the design consists of five main components: the housing, the ball, the plugs, the seals, and the shaft. It also consists of a few minor components including a jam nut and copper refrigeration tubing. Each component was designed to be easily machined and to allow for quick and easy assembly of the final product. The following is a brief outline of the design of each of the major components (Shown in Figure 11).

1. Housing: The spherical shape of the housing will maximize its strength while minimizing the material used, and ultimately cost of the finished part. The threaded inserts for the plugs allow for insertion of the ball during assembly and access for machining inside the housing. The holes for the copper tubing are flanged on the inside to prevent inserting tubing too far into the housing during assembly. Seats for the seals are machined into two sides as well as the top of the housing. This provides for easy assembly while maintaining a degree of precision necessary to achieve a good seal between the housing and ball. Finally, the top of the housing around the shaft is threaded so a motor mounting plate could be attached.

2. Ball: The ball has a smooth 90° corner machined through its center. The diameter of this hole is equal to the diameter of the refrigeration tubing. This orientation and dimension allow for a minimal pressure drop in the valve. Also there is a keyway machined into the top of the ball which allows the shaft to mesh with the ball, yet still allow for easy assembly.

3. Plugs: The plugs become a necessary part of this particular design. As mentioned before, their large size allows for both easy insertion of the ball into the housing during assembly as well as accessibility to the interior of the housing during machining processes. They are also designed with the same seal seats and tubing hole flanges mentioned in the housing section. The plugs are threaded to be adjustable to a specific torque needed to achieve the proper force on the seal faces. The plugs are braised in place in order to prevent movement of the plug and leakage around the threads.

4. Seals: The mating surface of the seals are spherical to achieve and maintain a good seal with the ball. The fifth seal keeps fluid from leaking out of the top the housing around the shaft. The force on this seal is provided by a jam nut located on the shaft.

5. Shaft: The shaft contains a key which meshes with the keyway on the ball to turn it during operation. It also contains a seal seat to hold the seal properly. During assembly, the seal is slipped over the top of the shaft before the shaft is inserted into the housing. Then, the shaft is threaded to fit a jam nut required to seat the seal. Finally, the top of the shaft has two flat parallel sides to allow a plate to attach to the top on which a motor can be mounted. Depending of the particular motor and coupling, this design attribute could easily be changed to a keyway.

For use with the R.A.S.E.R.S system, the valve would most likely be controlled by a reversible, continuous feedback, 24 VAC motor via a shaft located vertically at the top of the valve housing. However, depending of the application this motor could also be controlled manually.

The materials chosen for the final design are shown in Table 3. These materials were selected based on three criteria: cost, tooling, and design criteria. The team determined that brass and stainless steel were appropriate materials for the housing and the ball because they are relatively cost effective and can withstand pressures five times 650 psi, as well as temperatures between -30 and 400 degrees Fahrenheit. These metals are relatively easy to machine which should reduce tooling and labor costs. Virgin Teflon® was chosen for the seal material because it was the only plastic that would withstand the high temperatures while maintaining its low coefficient of static friction.

Table 3: Materials for the Ball Valve Design

Item	Material
Housing	Brass
Ball	Stainless Steel
Seals	Virgin Teflon®
Threaded Plug	Brass
Tubing	Copper
Shaft	Stainless Steel

Figure 11: Ball Valve Design - Exploded View

For the final design, it was necessary for it to have the following constraints that were laid out from Water's Hot. Theoretically, the final design does follow all of the constraints laid out below.

Table 4: Design Constraints

Design Area	Details	Follow Design Constraints?
Actuator	uses either motor/solenoid	+
	need to actuate circuits in 0-5 sec	+
Circuitry	(1-3) 1 inlet 3 outlet operate independently (Bidirectional)	+
	(3-1) 3 inlet 1 outlet operate independently (Bidirectional)	+
Connections	3 in extended Copper ODF	+
	1 in minimum spacing between circuits	+
Cycle Life	10-15 years (about 40,000 to 50,000 cycles)	+
Flow Rate	15 lb/min options A, C, and D	+
	3 lb/min option B	+
Fluids	R410A & POE	+
	R22 & Mineral Oil	+
Materials	Bass & Stainless Steel Body and Parts	+
	copper for ODF connections	+
	Teflon or Zytel Seals for ball	+
Max Operation Pressure Differential	450 psia	+
Open?	must have an all closed position	+
Operating Pressure Drop	<3 psi at design flow for all but option B	+
Operation	no leakage between circuits	+
	non-piloted	+
Safety Certification L	able to withstand 3-5x pressure for ETL approval	+
size	still fit in unit	+
Temperature	-40 - 300 ° F	+

Implementation of Design

The most economical way to fabricate the ball valve is to sand cast the housing and machine the other parts. The ball and plugs can be purchased, along with the jam nut. Is it also possible to machine the plugs from hex stock, if purchasing plugs is not desired.

Even though sand-casting is the most economical way to create a low number of valves, as production increase, die casting becomes the better option to reduce machining time and labor costs. Below is a subjective comparison of sand-casting and die-casting.

Table 5: Subjective comparison of sand casting and die-casting.

	Sand Casting	Die Casting
Startup Time	A few days	Several weeks
Initial Expense	Inexpensive	Expensive
Labor Costs	Higher labor costs on long runs	Lower labor costs on long runs
Finish	Pebbly	Smooth
Wall Thickness	Thicker than die casting	Thinner than sand casting

Figure 11, the exploded view of the valve, shows the way the valve is to be assembled. First, the shaft and top seal must be slid through the bottom of the housing to mate with the top of the housing. Then, the jam nut can be placed on top to tighten the shaft.

Next, the far seals are inserted into the housing. Then the ball is inserted into either large hold. Even though only one large hole is needed in the housing to insert the ball, two are made available to duplicate as many parts as possible and allowing the inside housing to be machined. Note the slit in the ball will need to be aligned with the key in the shaft in order to fit property.

After the ball is in, the closer seals can be place, and the plugs tightened to a high enough pressure the valve does not leak. Finally, the copper tubing can be welded to the outside of the housing.

COST ANALYSIS

The final design is simple to manufacture and much of the material needed to produce the valve is readily available. However, a few components (such as the housing) are complicated and will be more expensive to produce. In Table 6, material costs and labor estimates were formulated for each part. These prices include raw material costs (market value) and labor costs estimated at $60/hr. The final cost of the valve is $80 per valve including manufacturing and assembly.

Table 6: Cost for the materials for the valve

	Item	QTY	Price ea.	Total Price
Initial Investment	Pattern/Tooling	1	$3,000	$3,000
Cost (Per Valve)	Housing	1	$25	$25
	Ball	1	$20	$20
	Ball Valve Seal	4	$1	$4
	Top Seal	1	$1	$1
	Threaded Plug	2	$10	$20
	Shaft	1	$2	$2
	Assembly		$8	$8
Total (Per Valve)				**$80**

The initial investment is largely for the housing mold. The sand casting was the assumed method of casting due to the low number of valves produced. The price of the ball itself is high due to the amount and type of material. The material for the seals only costs a couple of cents per seal, but machining costs will drive up the price closer to a whole dollar.

These prices were determined using the current market material prices, and then adjusted to match wholesale values.

Since the valve is inexpensive, profit can be realized quickly. The Internal Rate of Return (IRR) is 30% after five years at a sale price of only $100—low for a special valve such as this. Table 7, shows the annual sales estimates as well as the projected material costs. This table also takes into account all other expenses incurred manufacturing, selling, and developing the valve.

Table 7: Profit and Loss statement

	Year 1%	Year 1	Year 2	Year 3	Year 4	Year 5
Units Sold		25	50	100	200	500
Sales Revenues		2500	5000	10000	20000	50000
Returns	0.02	50	100	200	400	1000
Materials	0.4	1000	1900	3610	6859	16290
Manufacturing	0.4	1000	1900	3610	6859	16290
Depreciation	Simple	86	171	343	686	1714
Gross Profit		364	929	2237	5196	14705
R&D	0.03	75	150	300	600	1500
Sales & Marketing	0.15	375	390	406	406	406
Gen Admin	0.02	50	100	200	400	1000
Interest	0.1	300	300	300	300	300
NEBT		-436	-11	1032	3491	11500
Taxes	0.3	0	0	309	1047	3450
NEAT		-436	-11	722	2443	8050
Unit Price	100					
Initial Investment	3000					
IRR	0.3					
Depreciation	3.43					
Material cost reduction	0.05					
Material/unit	40	40	38	36.1	34.3	32.58
Manufacturing/unit	40	40	38	36.1	34.3	32.58
IRR Calculations	-3000	-436	-11	722	2443	8050
Cumulative cash flow		-3436	-3447	-2725	-282	7768

PROTOTYPE

The valve prototype is currently under production, yet will not be finished by the end of 2009. The prototype will be made with an aluminum housing and bronze ball instead of the original brass and stainless steel design. These design changes were made due to limited material availability and lack of tooling required to drill through a stainless steel ball. The seals will be made out of virgin PTFE—the same material specified in the design.

This valve will be a functional model to determine the torque needed to turn the valve and to show the ability of the valve to operate. This valve may not stand up to accurate pressure, temperature, or wear criteria due to the change of materials.

Also, the prototype will look nothing like the original design.

CONCLUSIONS

Remaining Work

The prototype has not been completed yet. After the prototype is finished it will be possible to run a functional test. It will also be possible to ensure the valve turns the way it is suppose to.

Safety

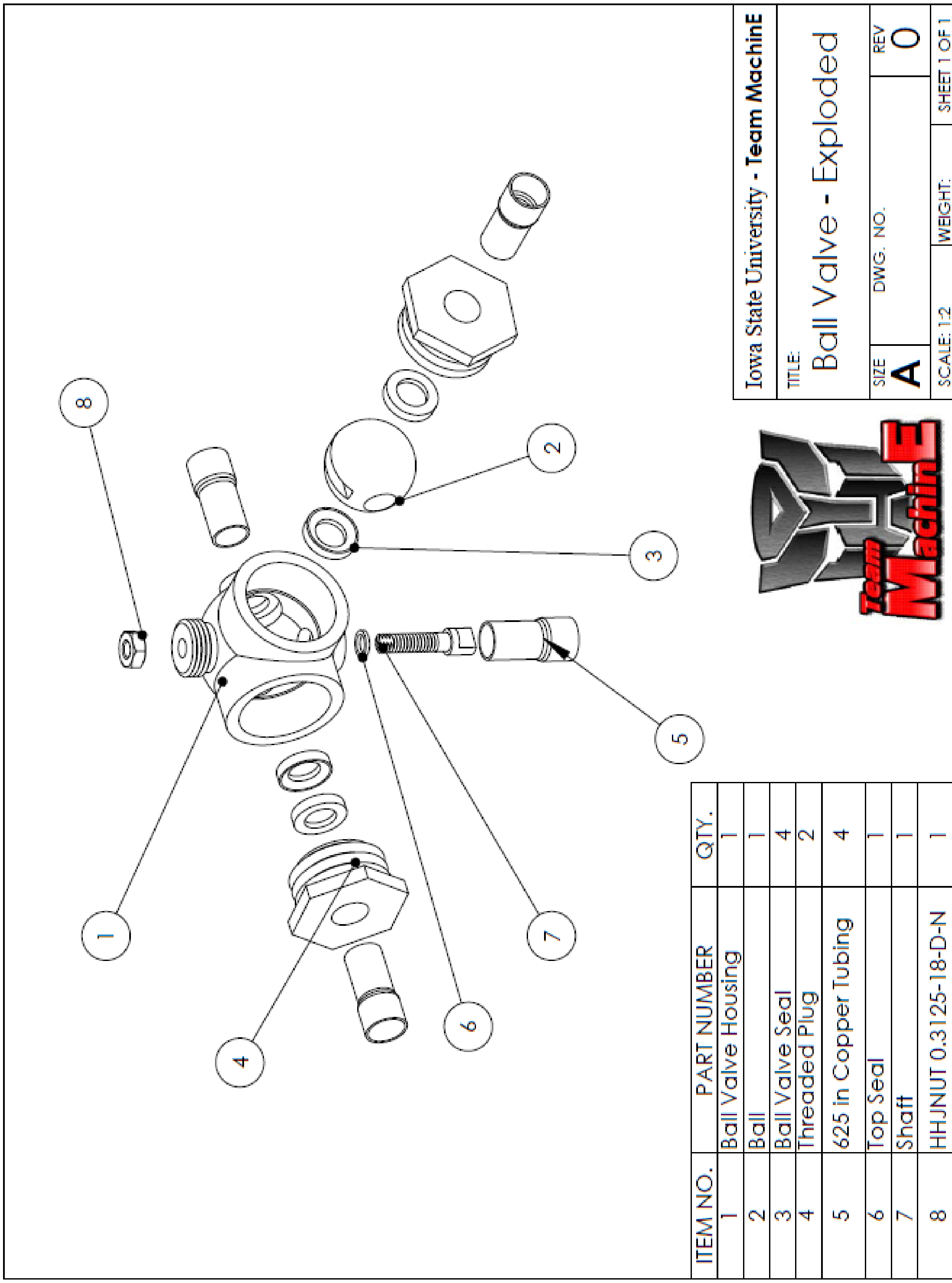
The biggest safety concern is the pressure in the valve. Since refrigerator valves need to go through testing using pressures that range from three to five times as high as what the valve is suppose to withstand, this valve will need to be tested to those safety standards.

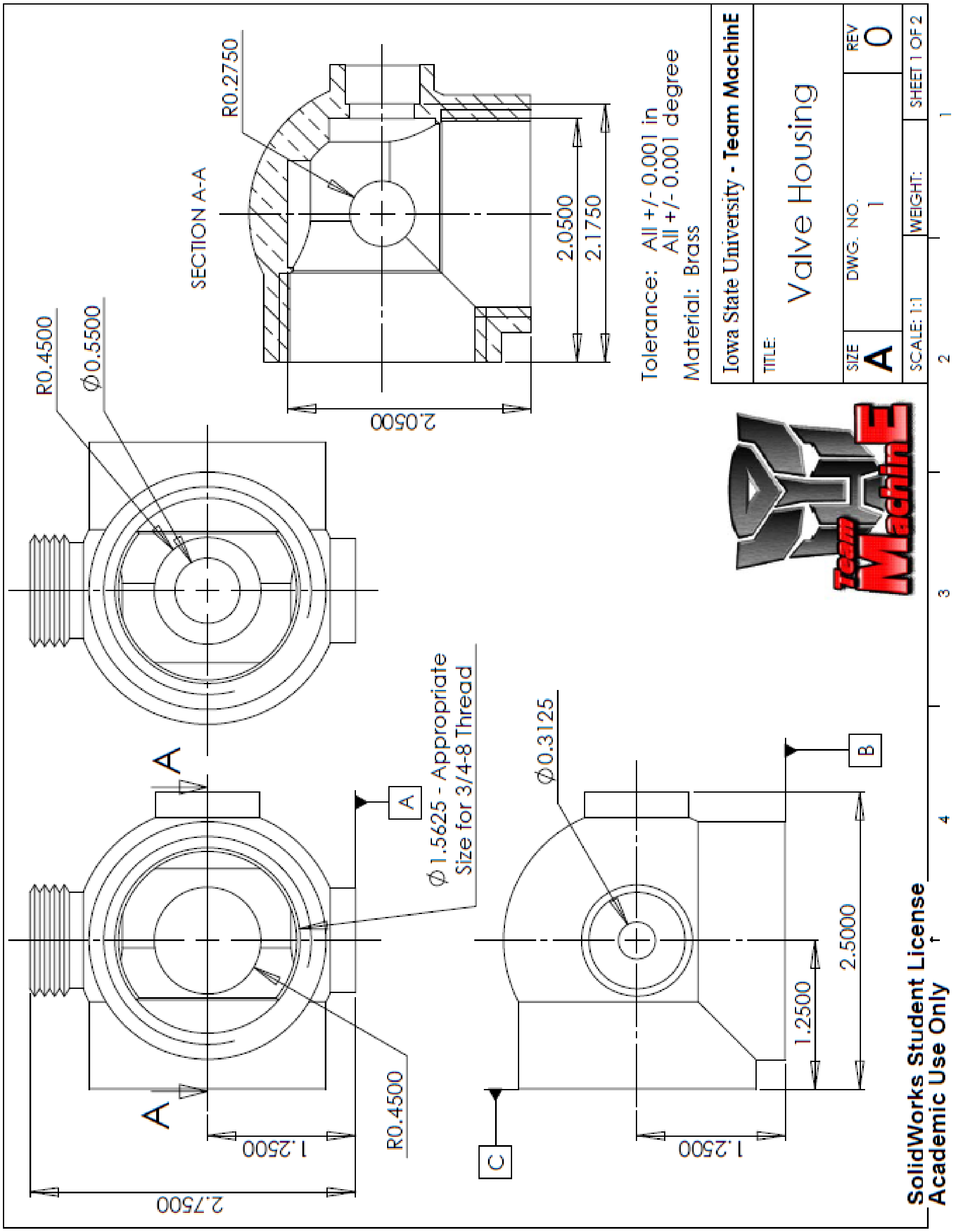
Future Expansion

With the current design it would be simple to expand the design to a five-way valve. With some simple changes in the design it could be expanded to be even more by making the ball larger or switching to a plate design and creating more exits from the housing, while still keeping the basic principles of the design the same. However by expanding the number of openings on the valve the ability to switch from outlet to outlet without opening up to one in the middle will be taken away.

This valve could also be sold on the commercial market for other heating and air conditioning systems where it would be beneficial to have a single valve rather than multiple valves. However this will undoubtedly be a very limited as to the small demand for a 4 way valves such as this one. In the long run this valve will need to be available to repair people for maintaining the R.A.S.E.R.S. system. Demand for the system should also increase when the efficiency of the system increases with the addition of this valve, which will then drive up the demand for the valve.

APPENDIX A: WORKING DRAWINGS




SECTION A-A
R0.2750
R0.4500
Ø0.5500
2.0500
2.1750
2.0500
Tolerance: All +/- 0.001 in
All +/- 0.001 degree
Material: Brass
Iowa State University - Team MachinE
TITLE:
Valve Housing
SIZE
A
DWG. NO.
1
REV
0
SCALE: 1:1
WEIGHT:
SHEET 1 OF 2
Ø1.5625 - Appropriate
Size for 3/4-8 Thread
Ø0.3125
A
B
C
R0.4500
1.2500
2.7500
1.2500
2.5000
1.2500
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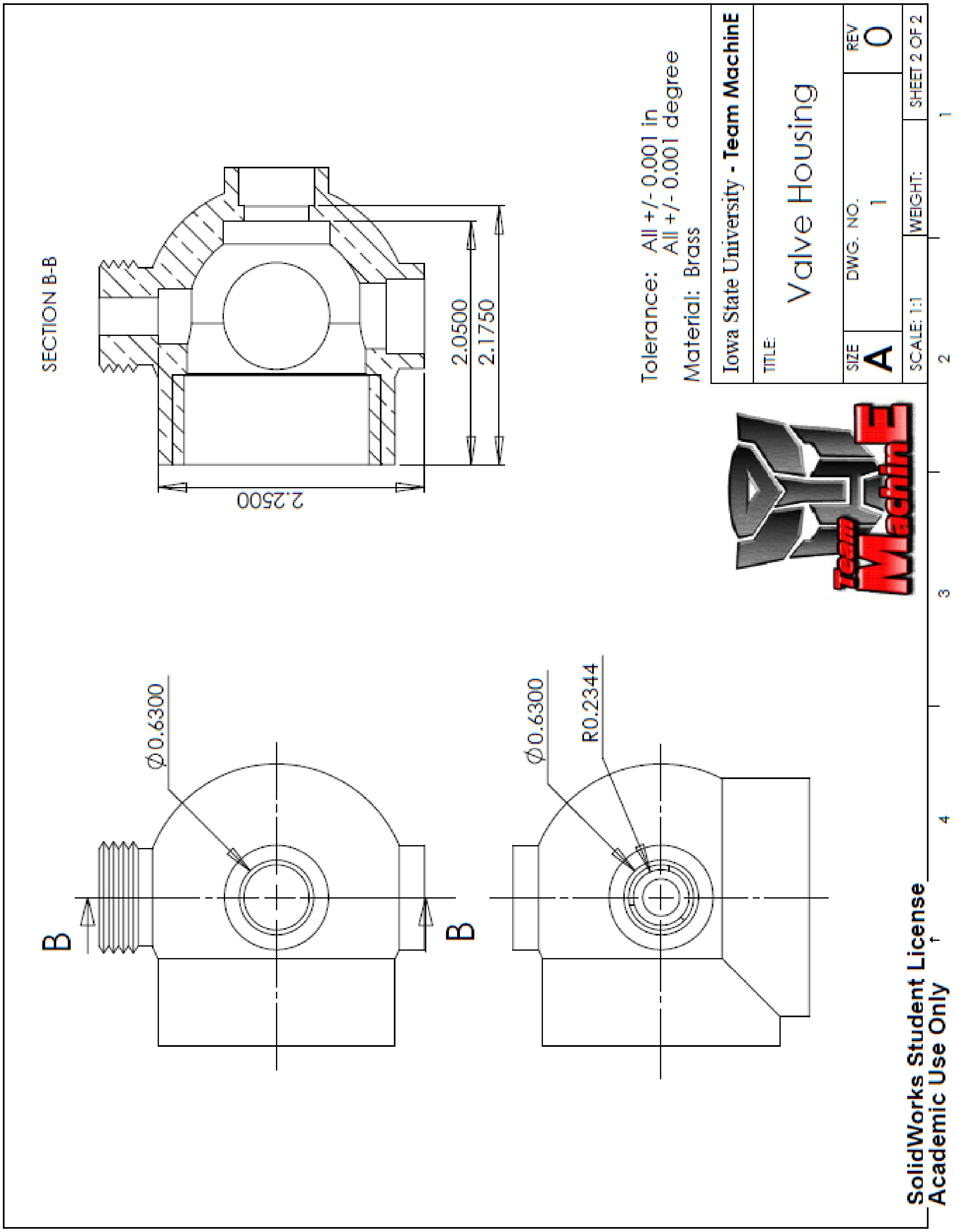
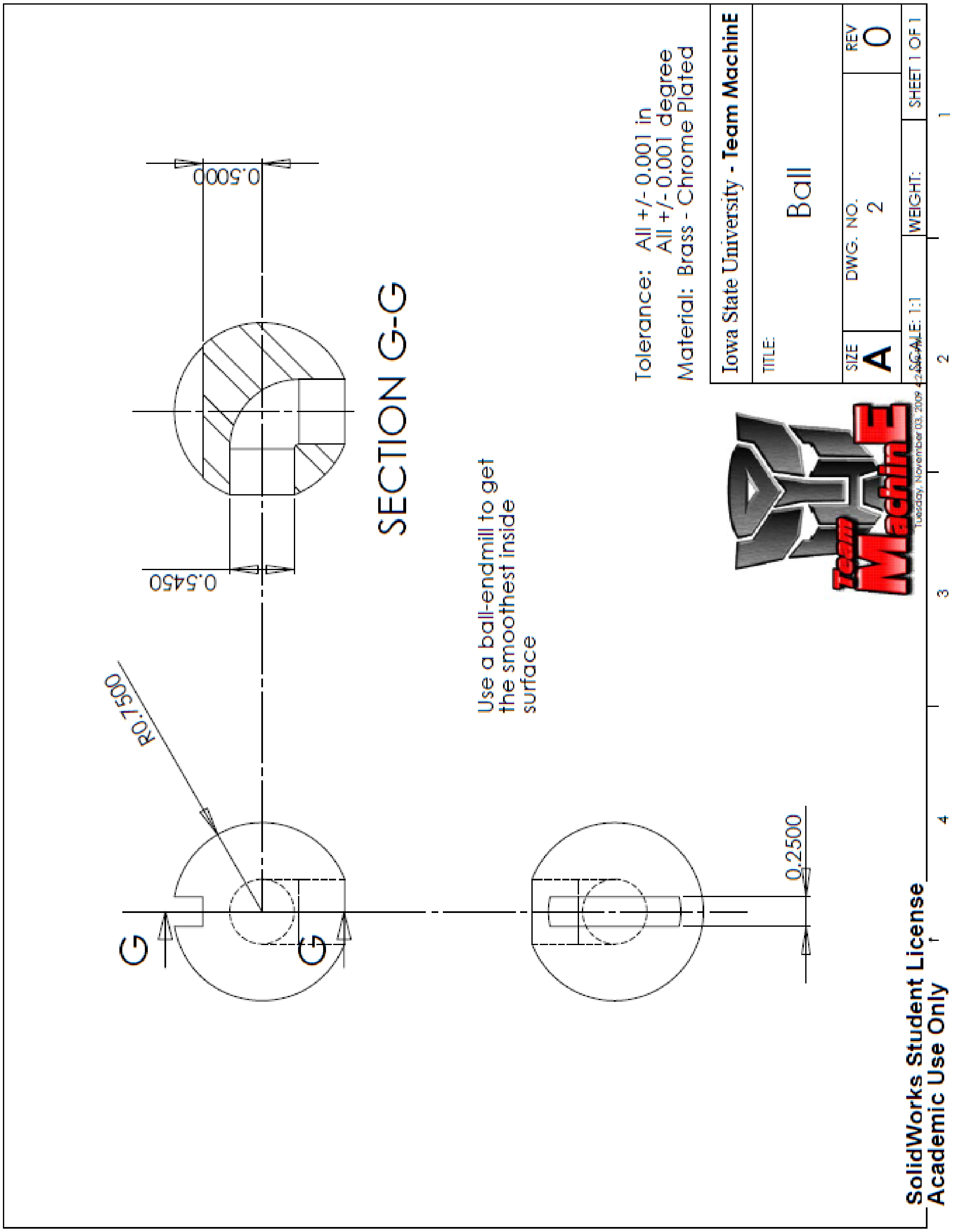
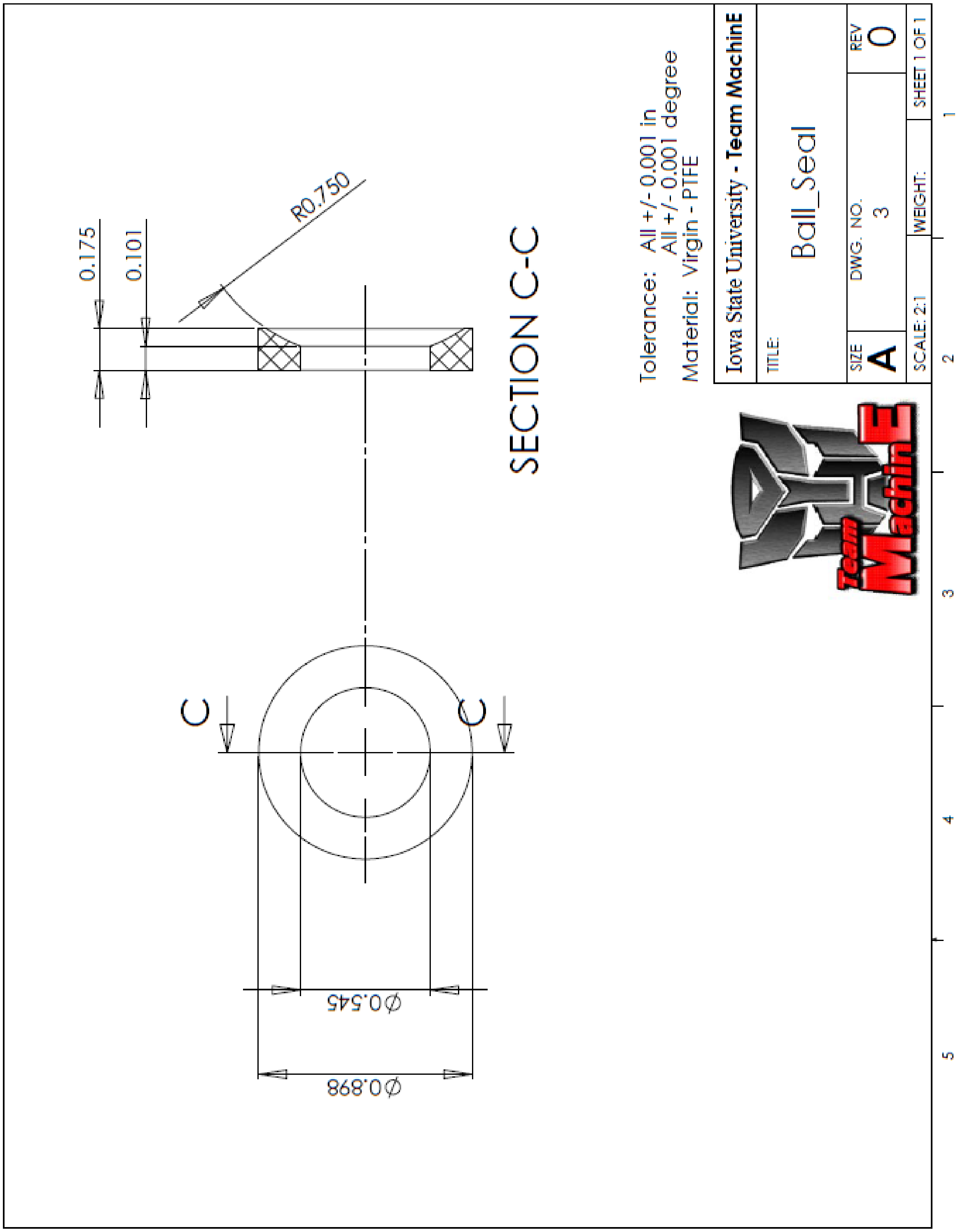
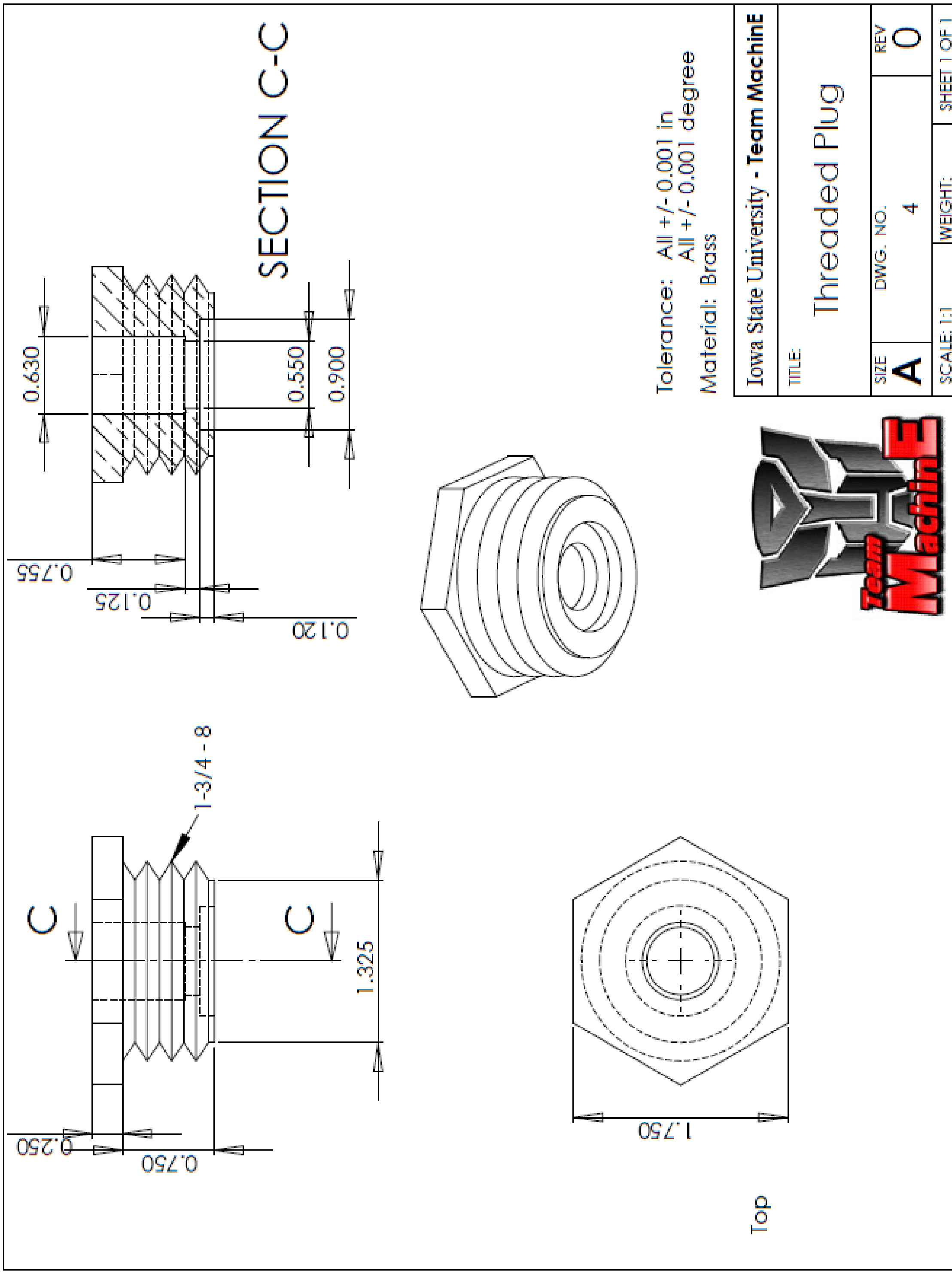
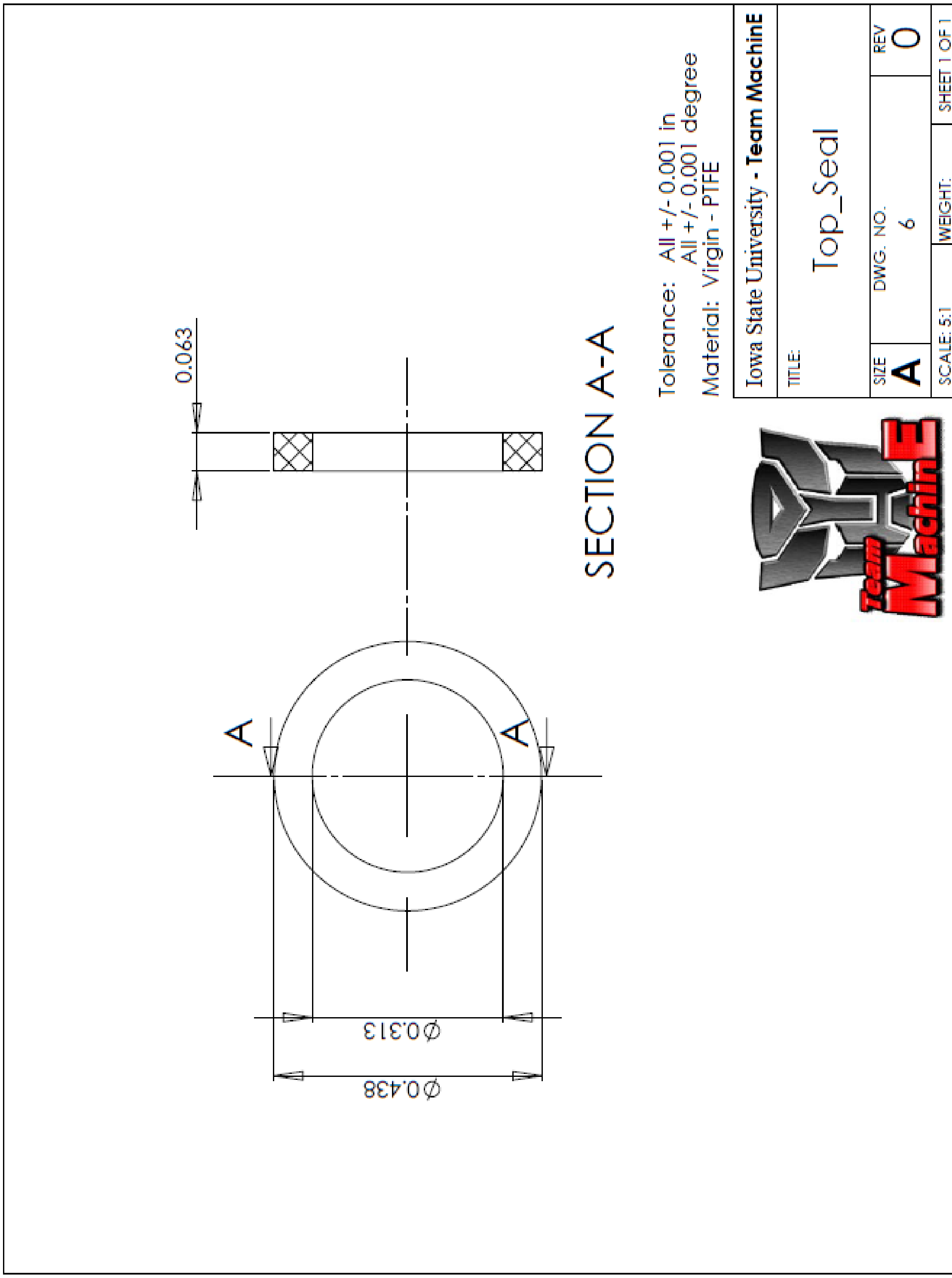
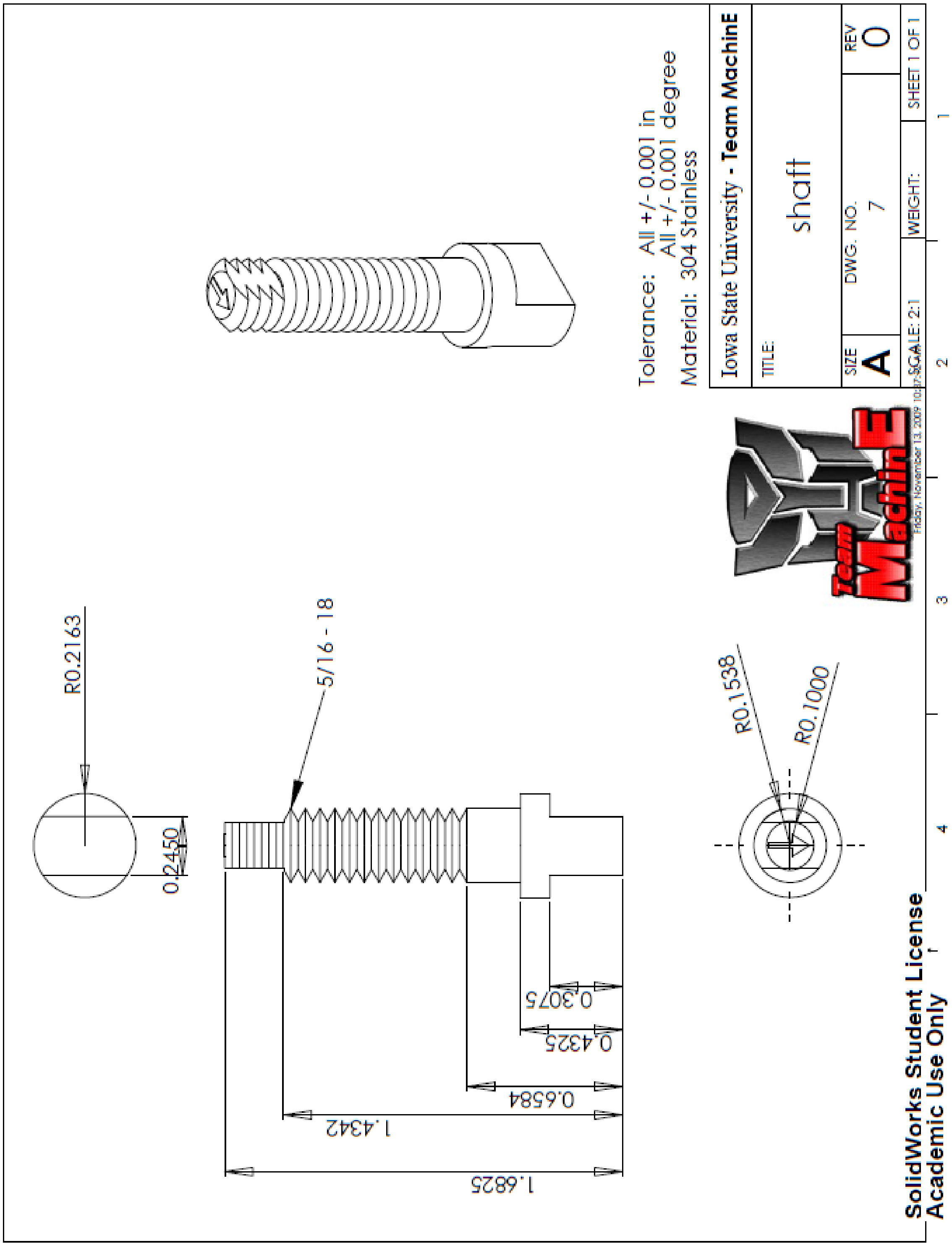

SECTION B-B
2.0500
2.1750
2.2500
Ø0.6300
Ø0.6300
R0.2344
B
B
Tolerance: All +/- 0.001 in
All +/- 0.001 degree
Material: Brass
Iowa State University - Team MachinE
TITLE:
Valve Housing
SIZE
A
DWG. NO.
1
REV
0
SCALE: 1:1
WEIGHT:
SHEET 2 OF 2
Team MachinE
SolidWorks Student License
Academic Use Only


R0.7500
0.5450
0.5000
SECTION G-G
G
G
0.2500
Use a ball-endmill to get the smoothest inside surface
Tolerance: All +/- 0.001 in
All +/- 0.001 degree
Material: Brass - Chrome Plated
Iowa State University - Team MachinE
TITLE:
Ball
SIZE
A
DWG. NO.
2
REV
0
SCALE: 1:1
WEIGHT:
SHEET 1 OF 1
SolidWorks Student License
Academic Use Only


0.175
0.101
R0.750
SECTION C-C
C
C
Ø0.545
Ø0.898
Tolerance: All +/- 0.001 in
All +/- 0.001 degree
Material: Virgin - PTFE
Iowa State University - Team MachinE
TITLE:
Ball_Seal
SIZE
A
DWG. NO.
3
REV
0
SCALE: 2:1
WEIGHT:
SHEET 1 OF 1
Team MachinE


SECTION C-C
0.630
0.550
0.900
0.755
0.125
0.120
1-3/4 - 8
C
C
1.325
0.250
0.750
1.750
Top
Tolerance: All +/- 0.001 in
All +/- 0.001 degree
Material: Brass
Iowa State University - Team MachinE
TITLE:
Threaded Plug
SIZE
A
DWG. NO.
4
REV
0
SCALE: 1:1
WEIGHT:
SHEET 1 OF 1


0.063
SECTION A-A
A
A
Ø0.313
Ø0.438
Tolerance: All +/- 0.001 in
All +/- 0.001 degree
Material: Virgin - PTFE
Iowa State University - Team MachinE
TITLE:
Top_Seal
SIZE
A
DWG. NO.
6
REV
0
SCALE: 5:1
WEIGHT:
SHEET 1 OF 1
Team MachinE


R0.2163
0.2450
5/16 - 18
R0.1538
R0.1000
0.3075
0.4325
0.6584
1.4342
1.6825
Tolerance: All +/- 0.001 in
All +/- 0.001 degree
Material: 304 Stainless
Iowa State University - Team MachinE
TITLE:
shaft
SIZE
A
DWG. NO.
7
REV
0
SCALE: 2:1
WEIGHT:
SHEET 1 OF 1
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APPENDIX B: DMADVR

Project Charter

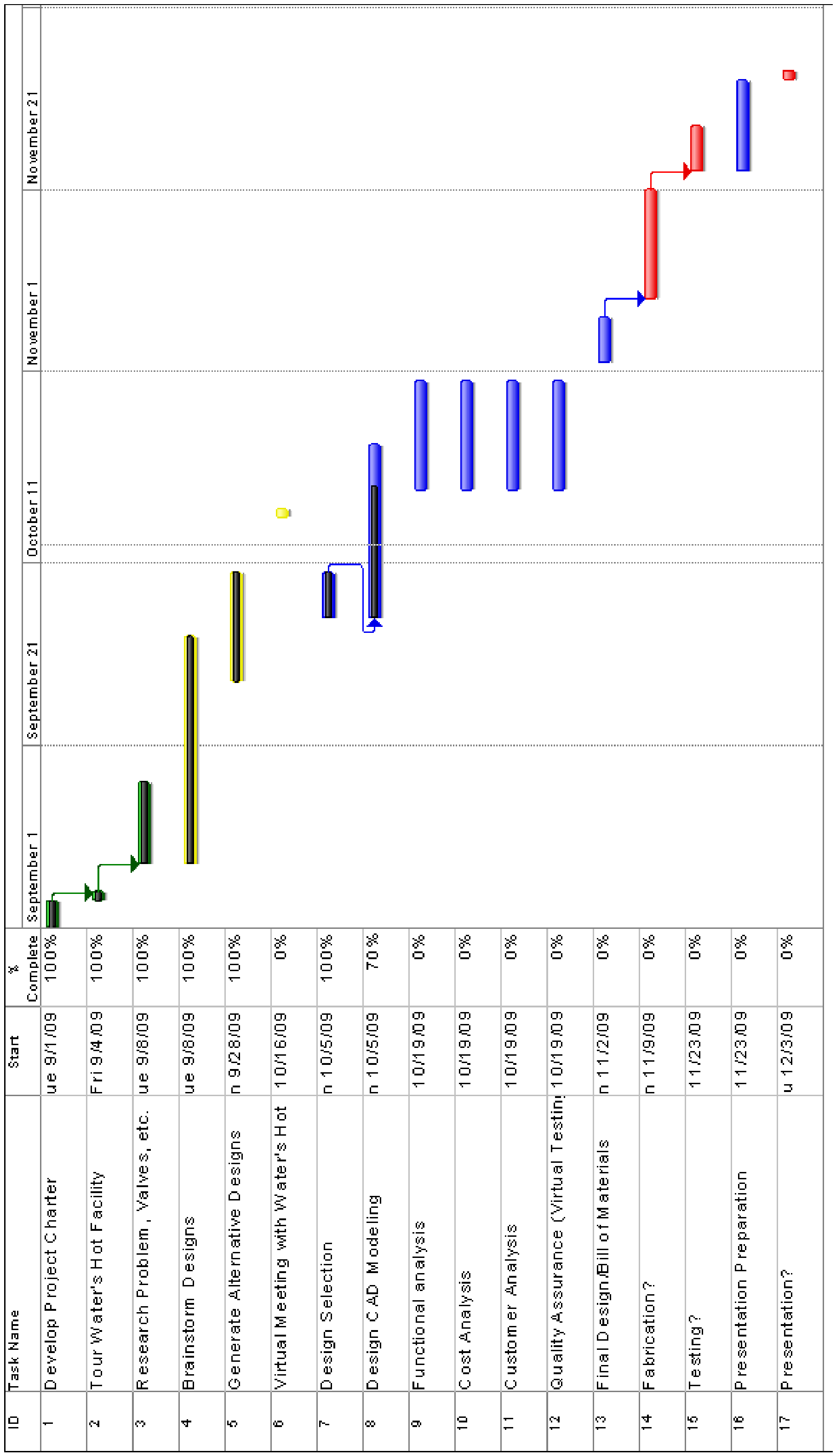
Project Name	Waters Hot		
Team Members	Jason Boggess, Diana Gylling, Laurel McDonough, Lee Harris, Ted Hotvet		
Section Instructor	Greg Luecke		
Faculty Instructor	Jim Heise		
Start Date	24 August 2009	**End Date**	14 December 2009

Element	**Description**	**Team Charter**
Problem Statement	Describe the situation and what is driving the need for a solution	Waters Hot, Incorporated manufactures an energy management system that leads the industry in efficiency for meeting residential, commercial, institutional, and industrial building applications. At the heart of this system is the R.A.S.E.R.S. system. The control valve is a critical component in this system. The system performance of the system could be significantly improved if the current 3-way valve could be replaced with the digitally controlled 4-way valve.
Opportunity Statement	Describe the market opportunities and the potential financial or social opportunities	Waters Hot: -New valve that is potentially patentable and marketable -Increases efficiency of the R.A.S.E.R.S. system -Create new jobs -Creates connections between students, Iowa State University, and Waters Hot For Our Team: -Gain industry experience -Gain industry contacts (potential employers) -Good job references/ Résumé builder -A chance to do something new/patent a new product
Importance of Project	Describe the priorities that make this project necessary. Describe benefits to customers for doing this project.	Makes the Waters Hot product more efficient Generates new business for Waters Hot

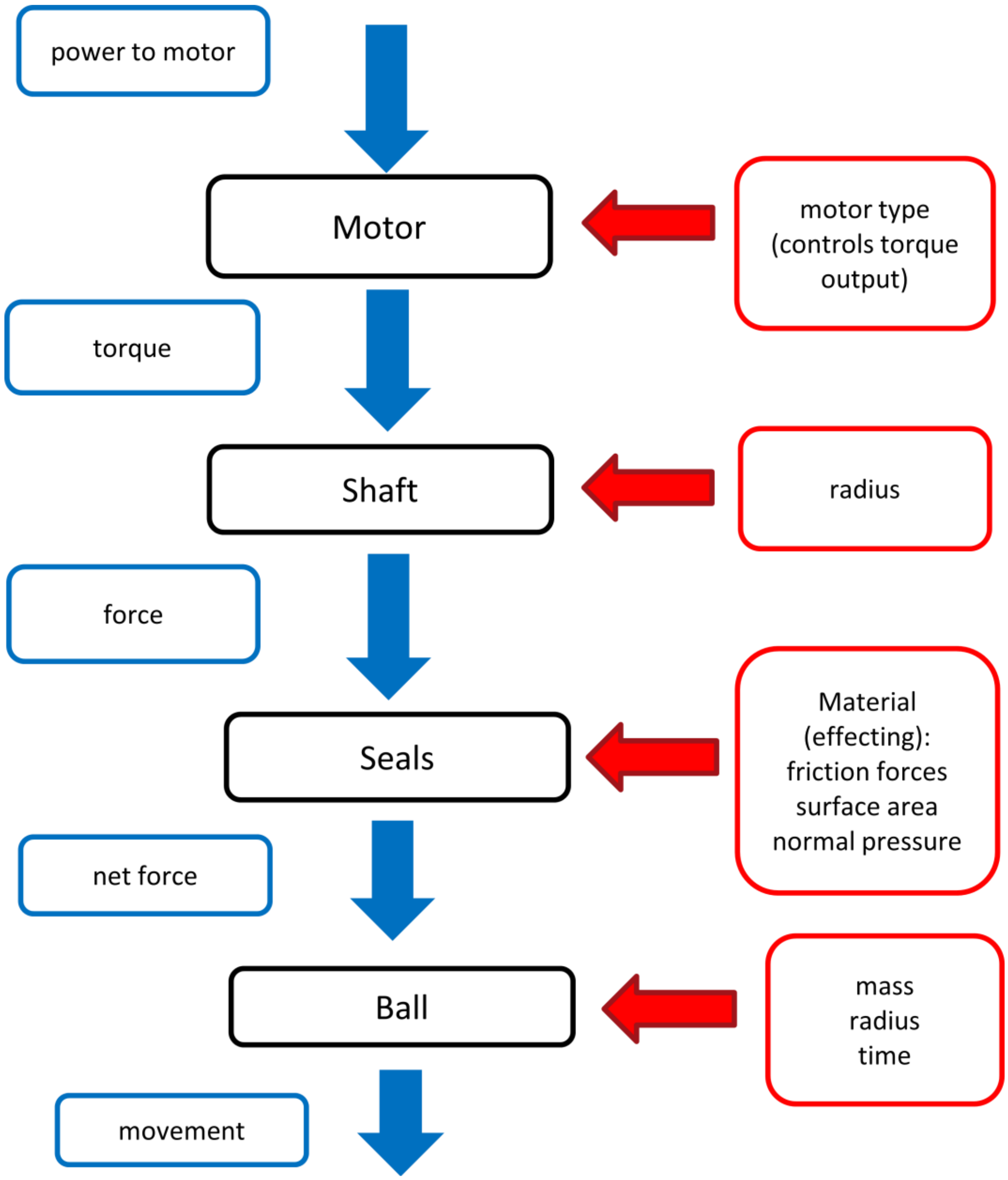
<table>
<tr><td>Primary Customers</td><td>Define the customers impacted by this project. Start with the end user, add all who are stakeholders.</td><td colspan="3">Waters Hot - Helps to make the R.A.S.E.R.S System to work more efficiently</td></tr>
<tr><td>cope:</td><td>Describe in a general sense what this will and will not deliver. What defines this project as being "done"? Use next section for definition of specific deliverables.</td><td colspan="3">Valve Design (CAD, Design Documents, Bill of materials, functional analysis, materials, cost, etc.)</td></tr>
<tr><td rowspan="3">Expectations / Deliverables</td><td rowspan="3">Specify the project metrics that are key to the customers</td><td>Project Metrics</td><td>Goal</td><td>Accomplished</td></tr>
<tr><td>Cost</td><td>$200</td><td>yes</td></tr>
<tr><td>Materials</td><td>brass, copper, stainless steel</td><td>yes</td></tr>
<tr><td rowspan="6">Team Resources</td><td>Team Members</td><td colspan="3">Contact Information (email/phone)</td></tr>
<tr><td>Jason Boggess</td><td colspan="3">jasonboggess@gmail.com, (515) 979-9784</td></tr>
<tr><td>Diana Gylling</td><td colspan="3">dlgylling@gmail.com, (605) 695-7637</td></tr>
<tr><td>Lee Harris</td><td colspan="3">free.lee.harris@gmail.com, (515) 231-2755</td></tr>
<tr><td>Ted Hotvet</td><td colspan="3">thotvet@gmail.com, (612) 558-6453</td></tr>
<tr><td>Laurel McDonough</td><td colspan="3">laurel.mcdonough@gmail.com, (402) 660-4085</td></tr>
</table>

Project Timeline

Gantt Chart



Functional Analysis



Process Step	Description of Process Step	Input Variables (from other Process Step)	Input KPP	Step Control Variables	Input KPP	Output Variables	Output KPC
Power	Input power to motor	AC power from R.A.S.E.R.S	x				
				motor type	x		
						torque	x
Shaft	Convert torque to the shaft force	torque	x				
				shaft radius	x		
						shaft force	x
seals	Using shaft force to determine the net force	shaft force	x				
				Coefficient of Static Friction	x		
				Normal Pressure	x		
				Surface Area (5 seals)	x		
						Normal Force	x
						Friction Force	x
						Net Force	x
Ball	Using Net force to determine movement	Net Force	x				
				Radius	x		
				Time	x		
				Mass	x		
						movement	x

Math Model

Motor	**Input**	Power		in-lbf/s
	Control	Motor Type		
	Output	Torque	271.44000000	in-lbf
			22.62000000	ft-lbf

Shaft	**Input**	Torque	271.44000000	
	Control	Ball Radius	0.75000000	in
	Output	Shaft Force	361.92000000	lbf

Seals	**Input**	Shaft Force	361.92000000	lbf
	Control	Coefficient of Static Friction	0.10000000	
		Normal Pressure	2600.00000000	psi
		Surface Area (4 seals)	1.39200000	in^2
	Output	Normal Force	3619.20000000	lbf
		Friction Force	361.92000000	lbf
		Net Force	0.00000000	lbf

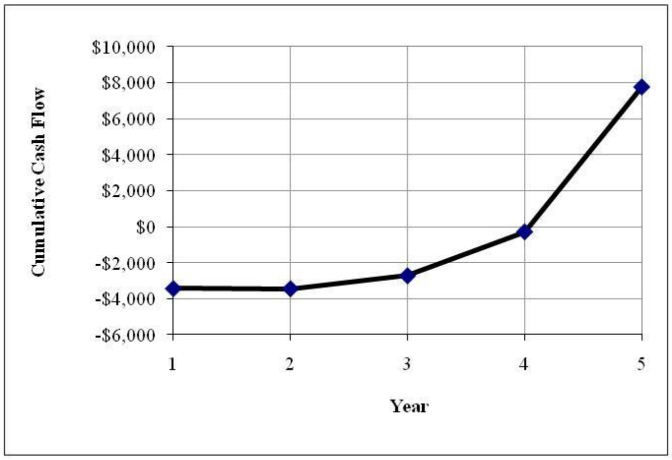
Head loss of 0.0888 in

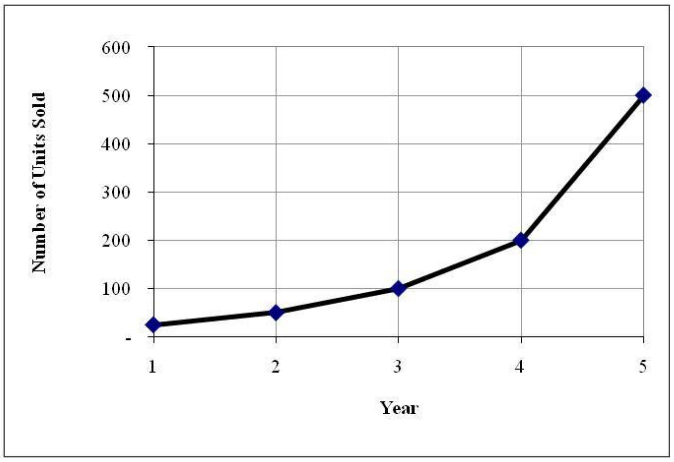
$$\dot{m} = \rho A V$$
$$A = \pi r^2$$
$$V = 15.12\ in/sec$$
$$\rho_{R410A} = 0.0375724\ {}^{lb}/_{in^3}$$
$$\dot{m} = 0.25\ lb/sec$$
$$kl\ for\ elbow = 0.3$$

$$A = \pi \left(\frac{3}{8}\right)^2$$
$$0.25\frac{lb}{sec} = 0.0375724\ {}^{lb}/_{in^3} * \pi \left(\frac{3}{8}\right)^2 * V$$
$$head\ loss = Kl * \frac{V^2}{2g}$$
$$head\ loss = 0.3 * \frac{(15.12\ in/sec)^2}{2 * 32.17ft/\sec^2 * 12in/ft}$$

Profit and Loss Statement

	Year 1 %	Year 1	Year 2	Year 3	Year 4	Year 5
Units Sold		25	50	100	200	500
Sales Revenues		**2,500**	**5,000**	**10,000**	**20,000**	**50,000**
Returns	2%	50	100	200	400	1,000
Materials	40%	1,000	1,900	3,610	6,859	16,290
Manufacturing	40%	1,000	1,900	3,610	6,859	16,290
Depreciation	simple	86	171	343	686	1,714
Gross profit		**364**	**929**	**2,237**	**5,196**	**14,705**
R&D	3%	75	150	300	600	1,500
Sales & Marketing	15%	375	390	406	406	406
Gen Admin	2%	50	100	200	400	1,000
Interest (% of Io)	10%	300	300	300	300	300
NEBT		**(436)**	**(11)**	**1,032**	**3,491**	**11,500**
Taxes (% of NEBT)	30%	0	0	309	1,047	3,450
NEAT		**(436)**	**(11)**	**722**	**2,443**	**8,050**
Unit Price		$100.00				
Initial Investment (Io)		$3,000				
IRR		30%				
Depreciation		$3.43				
Material cost reduction per year		5%				
Material / unit		40.00	38.00	36.10	34.30	32.58
Manufacturing / unit		40.00	38.00	36.10	34.30	32.58
IIR Calculations	**($3,000)**	**($436)**	**($11)**	**$722**	**$2,443**	**$8,050**
Cumulative Cash Flow		-$3,436	-$3,447	-$2,725	-$282	**7,768**





Appendix C: Information from Water's HOT

Problem Statement

Waters Hot R.A.S.E.R.S. System™ inherently uses multiple refrigeration circuits to perform two or more heating and cooling functions. Current industry valves are designed for single circuit operation which creates operational issues at various points in the vapor compression cycle. Thus we seek a valve to support multi-circuit refrigeration systems that will provide an open and close function to each circuit independently without leakage regardless of inlet or outlet pressure differential.

Specifications and Guidelines

Operation: Must have open/close capability without leakage on each circuit.

Fluids : R410A & POE (POLYOLESTER) oil - First Priority

R22 & Mineral Oil - Also desired but lower priority

Use 15 lb/min fluid flow rate (liquid or vapor) for design options A, C, and D below

Use 3 lb/min fluid flow rate (liquid) for design for option B below

Connections : 3" Extended Copper ODF, 1" minimum spacing between circuits

Circuitry : (1-3) 1 inlet to 3 outlets operate independently (Bidirectional Preferred)

(3-1) 3 inlets to 1 outlet operate independently (Bidirectional Preferred)

Construction: Brass & Stainless Steel Body and Parts, copper for ODF connections

Seals for ball : Teflon, Zytel, ???

Acutator: Electromechanical, must be powered by 24 VAC, can be controlled by another signal, low power consumption is desired,

Cycle Life : 10-15 years -> about 10 times a day so 40,000 to 50,000 cycles

Operating Pressure Drop: < 3psi at design flow for all but option B

MOPD (Max. Operating Pressure Differential) : 450 psia

Safety CertificationL: UL or ETL - must be pressure tested to 3 - 5x operating pressure for ETL approval

Valve Types:

A) 3/8" to 1/2" port (1/2" connections), 40°F to 150°F in and out (liquid), circuitry 1 to 3 and 3 to 1 MOP: 650 psi. One circuit will always be open while system is operating.

B) <0.1" (outlet) port (¼" connections), 40°F to 150°F in, (Reclaim: Liquid to Suction Gas), circuitry 3 to 1, MOP: 650 psi. This valve must have the ability to close all circuits while system is operating.

C) 1/2" to 5/8" port (5/8" Connections), 40°F to 300°F in and out (Hot Gas), circuitry 1 to 3, MOP: 650 psi. One circuit will always be open while system is operating.

D) 3/4" to 7/8" port (7/8" connections), -40°F to 300°F in and out (Suction Gas), circuitry 3 to 1, MOP: 650 psi. One circuit will always be open while system is operating.

Flexibility in these requirements:

Seals – materials, design; these can vary as long as it meets the rigors of the fluids, pressure, operation, life cycle and temperature ranges

Spacing between the circuits – must be wide enough to permit brazing on each circuit – 1" min.

Port Size – port can vary within the range given for each valve

Type of actuator – motor, solenoid,... need to actuate circuits in 0-5 seconds

Additional Requirements

Must have a small foot print as it must still fit inside our unit.

If possible, non-pilot operated (this is the style we had problems with in the past)