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HYDRAULIC SWITCH FOR DISHWASHERS
WITH BOTTLE BLASTER SYSTEM

By

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B.S., Florida International University, 2010

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HYDRAULIC SWITCH FOR DISHWASHERS
WITH BOTTLE BLASTER SYSTEM

By

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Masters of Science

A Thesis Approved on

April 15, 2014

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ABSTRACT

HYDRAULIC SWITCH FOR DISHWASHERS WITH
BOTTLE BLASTER SYSTEM

Lazaro Galban

04/15/2014

A dishwasher works by using water pressure to operate the Spray Arms. There are different types of wash systems with the most common being two spray arms, a lower and middle arm. These two spray arms operate independently from each other and can be powered individually. In this particular wash system, the subsystem of interest is the Mid Spray Arm which is connected with the Bottle Blaster where both operate simultaneously. The Mid Spray Arm is used to clean the upper dishwasher rack while the Bottle Blaster is used to clean bottles, also in the upper rack. In order to have proper cleaning performance in the dishwasher, the Mid Spray Arm needs to rotate with at least 20 revolutions per minute (RPM). Since the Mid Spray Arm and Bottle Blaster are connected together, the flow rate requirement is 12 gallons per minute (GPM); which is higher than a system that doesn't include a Bottle Blaster (approximately 8.5 GPM). In order to reduce the amount of water usage and flow rate, a new system was configured that will independently operate the Mid Spray Arm and Bottle Blaster. For that, three different designs were created and a Pugh Matrix was used to select the appropriate design. The selected design will operate using water pressure to block the Mid Spray Arm port or the Bottle Blaster port and is attached to the Main Conduit before the Mid Spray Arm. This new system reduced the water consumption of the entire dishwasher due to the fact that is able to operate with a smaller pump. The new system provides 8.53 GPM to the Mid Spray Arm and 6.48 GPM to the Bottle Blaster compared to 9.88 GPM and 7.32 GPM respectively with the current system. This new system has a better cleaning performance due to the increased in RPM's, now 25 RPM, on the Mid Spray Arm. Also, since a smaller pump can be used the new pump price will be $12.38, which is

approximately 17% less expensive than the current pump. Another advantage is the reduction in

noise by approximately 11% from an initial 21.3 dBa pump output.

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CHAPTER 1 - INTRODUCTION

1.1 Motivation

In the past couple of decades, much attention has been given to water conservation and energy usage, which is why products are becoming smarter and more efficient when it comes to water and energy savings. Using a dishwasher saves approximately 230 hours of personal time in a year and is able reduce the utility bill by $40 when compared with washing dishes by hand (Energy Star, 2012). The appliance companies are taking advantages of these savings in order to persuade customers to buy their products. A dishwasher is used by a consumer 0.1 to 0.2 times a day which becomes a saving of approximately 23 gallons of water a year over washing dishes by hand (Alliance for Water Efficiency, 2010). The current GE dishwasher that uses a Mid Spray Arm and Bottle Blaster system consumes approximately 30% more gallons per minute compare to a dishwasher without the Bottle Blaster System (Curtis, 2013). This increase in water consumption is due to the required pressurization of both of those components simultaneously. Since there is an increase in flow demand, the size of the pump needs to be larger than the current dishwasher pump which translates to more power and energy consumption. If the Mid Spray Arm and the Bottle Blaster could operate independently, it would reduce the flow necessary by the system for proper cleaning.

1.2 Synopsis

A dishwasher uses water flow/water pressure to operate the spray arms that cleans the dishes. In some GE models the Mid Spray Arm is connected with a Bottle Blaster in the same branch; both the Mid Spray Arm and the Bottle Blaster will get pressurized simultaneously. The operation of the two systems at once tends to require 12 GPM which is approximately a 30% increase in GPM over a system without a Bottle Blaster (Curtis, 2013). Due to this increase in flow rate, a higher flow rate pump is required which increases unit cost and energy usage. The

work herein describes a new system configuration that independently operates the Mid Spray Arm and Bottle Blaster. This new system will have comparable performance to current simultaneous system while reducing the flow rate requirement to operate the dishwasher. It will also help reduce the overall cost of the entire unit.

1.3 Hypothesis

The overall cost and noise of a dishwasher will be significantly reduced while increasing the performance of the wash system using a hydraulic switch that can independently operate the Mid Spray Arm and Bottle Blaster.

1.4 Literature Review

A Hydraulic Switch will follow the same principle as shuttle valve due to the way the switch operates. The basic structure of a shuttle valve consists of three openings with a ball or other blocking valve element moving freely within the valve structure. There are two types of shuttle valves, the first one is has a valve blocking piece, a ball or poppet, that moves freely inside the valve housing and blocks a port on the valve depending of the hydraulic fluid inlet location. The second one is a pressure shuttle valve and this one works by pressurizing two of the three side on the valve housing openings which in terms creates pressure to the third port and allow the fluid to move through the third port (Rabie, 2009). Figure 1a shows the regular shuttle valve and 1b shows a pressure shuttle valve.

(a)

(b)
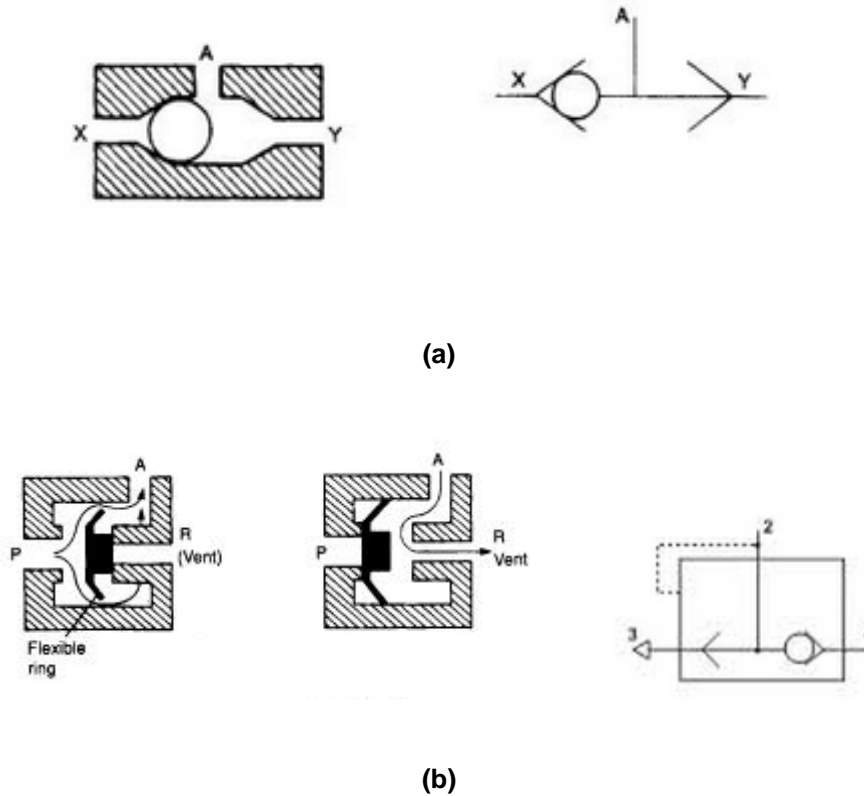
Figure 1: Different Shuttle Valve operation (a) regular shuttle valve (b) pressure shuttle valve (Valvias , 2009)

Shuttle valves accept flow from two different sources and divert the highest pressure to a single outlet port (Esposito, 2008). There are a number of configurations available which are small enough to fit into the envelope of the hydraulic system of a dishwasher. Those configurations include, but are not limited to, cartridge type, insert type, and an in-line version. The ball type or cartridge style, Figure 2, consists of a steel ball that can seal against one of two adjacent seats, providing a path from the highest pressure signal to another function. When one inlet port is pressurized, the ball or poppet is forced against the opposite seat, blocking that inlet and providing a flow path to the outlet port. This specific shuttle valve has different models and sizes where each one is rated differently. The flow experienced by the cartridge type valve can range between 1 to 13 GPM. These valves have a high inlet pressure in the upper 1000 psi, mainly used for large equipment hydraulic systems (PowerSolutions, 2007). The poppet type or

insert style, Figure 3, performs the same actions as the cartridge style, but allows for higher flow

rates due to poppet design. This type of valve have different ranges in terms of fluid flow, it can

vary between 2.5 to 10 GPM with a high pressure load of 6000 psi used in heavy equipment

industry (PowerSolutions, 2007). Lastly, in-line type, Figure 4, performs the same action as the

cartridge type in a in a self-contained body. It is mounted in an equipment/machine with a flow

rating of 3 to 6 GPM with a 3000 psi maximum inlet pressure (PowerSolutions, 2007). Currently,

most of the shuttle valves in existence are used in high pressure flow applications for hydraulic

system. A current part being used in a GE dishwasher that operates similar to one of the

previously mentioned valve is the diverter. The diverter, Figure 5, uses a ball powered by the flow

from the pump to block the port of the Main Conduit or the Lower Spray Arm. The ball blocking

the ports is moved back and forth by the water column that seeps around the ball and fills the

cavity being block at that specific moment. This valve is able to withstand the flow of a

dishwasher; 8 to 12 GPM with a pressure range of 4 to 8 psi (Boyer, 2013).
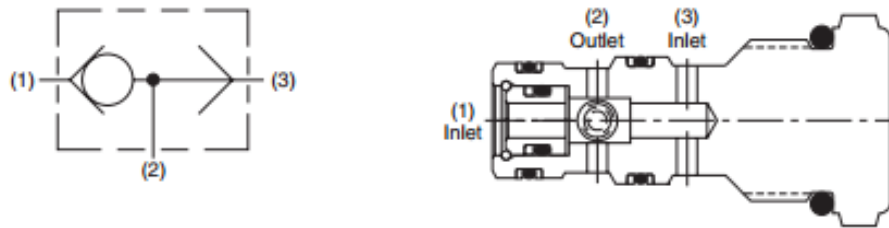
Figure 2: Ball Type - Cartridge Style Shuttle Valve (PowerSolutions, 2007)
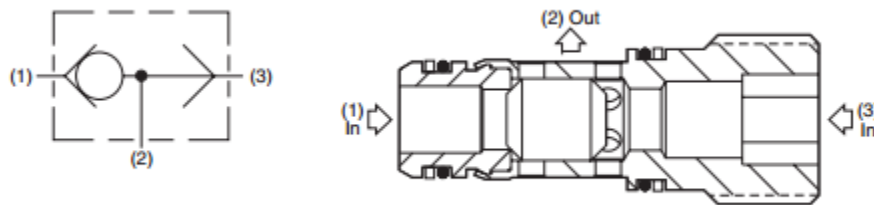
Figure 3: Poppet Type - Insert Style Shuttle Valve (PowerSolutions, 2007)
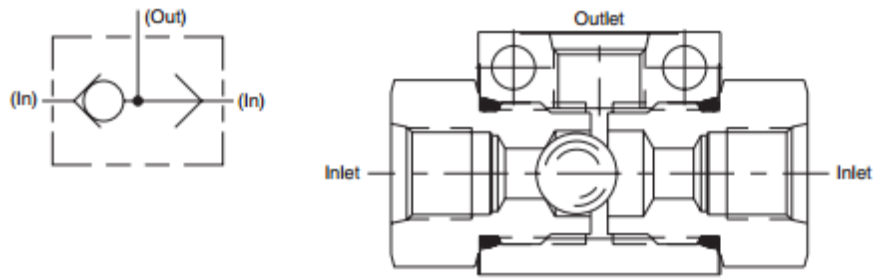
Figure 4: In-Line Type Shuttle Valve (PowerSolutions, 2007)
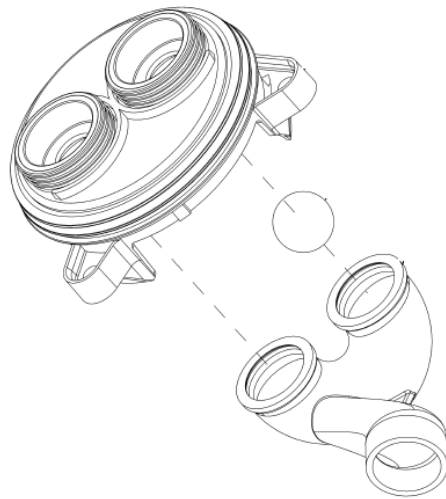
Figure 5: GE diverter valve (Boyer, 2013)

CHAPTER 2 – CURRENT SYSTEM

2.1 Current Design

In order to reconfigure the current system to allow the integration of a hydraulic switch, an understanding of the current components and their operation is required. Currently, water flows upward through a conduit called the Main Conduit. The Main Conduit (Figure 6) is of rectangular cross section with an interior dimension of 1.68 inches in width and 0.487 in thickness.
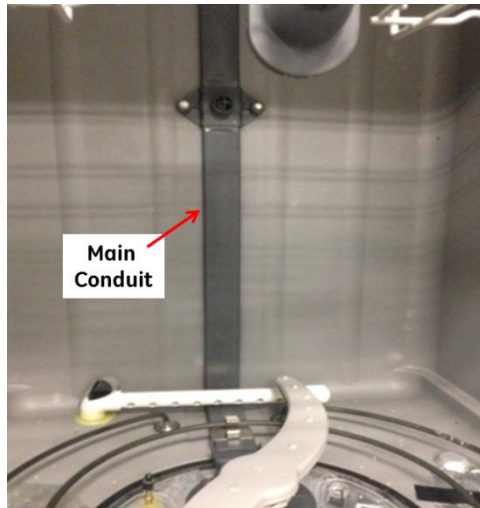
Figure 6: Interior of a GE dishwasher showing the Main Conduit. Water flows inside of the dishwasher though the Main Conduit.

The Mid Spray Arm and Bottle Blaster are shown in Figure 7 and both systems are attached to the Main Conduit which gets powered by the water flowing through it. The Bottle Blaster is connected to the Mid Spray Arm and operates at the same time hence, the need of a design/system that will power both of them individually. If this can be accomplished, water usage will be reduce for the same performance and the power necessary for regular operation will also be shortened.
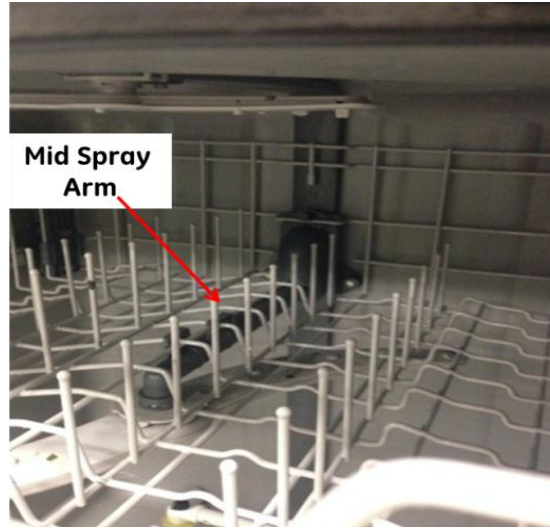
(a)
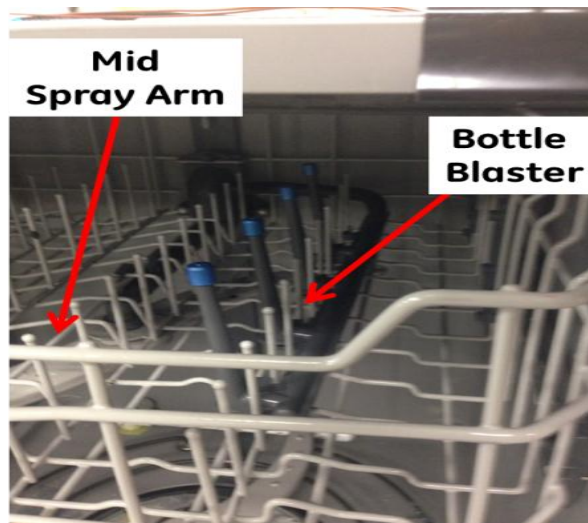
(b)

Figure 7: Location of Mid Spray Arm (a) attached to the Upper Rack in a GE dishwasher. Bottle Blaster (b) is also attached to the Upper Rack next to the Mid Spray Arm.

2.2 Concept Overview

In order to generate a new concept, an overview of the dishwasher current system is necessary and a Block Diagram will be used. A Block Diagram is used to describe the function between input variables and output variables. Figure 8 shows the Block Diagram for the current GE Bottle Blaster and Mid Spray Arm system. The outcome that needs to be achieved is shown in Figure 9 and it illustrates the Block Diagram for the new system which includes the Hydraulic Switch powering the Mid Spray Arm and the Bottle Blaster independently.
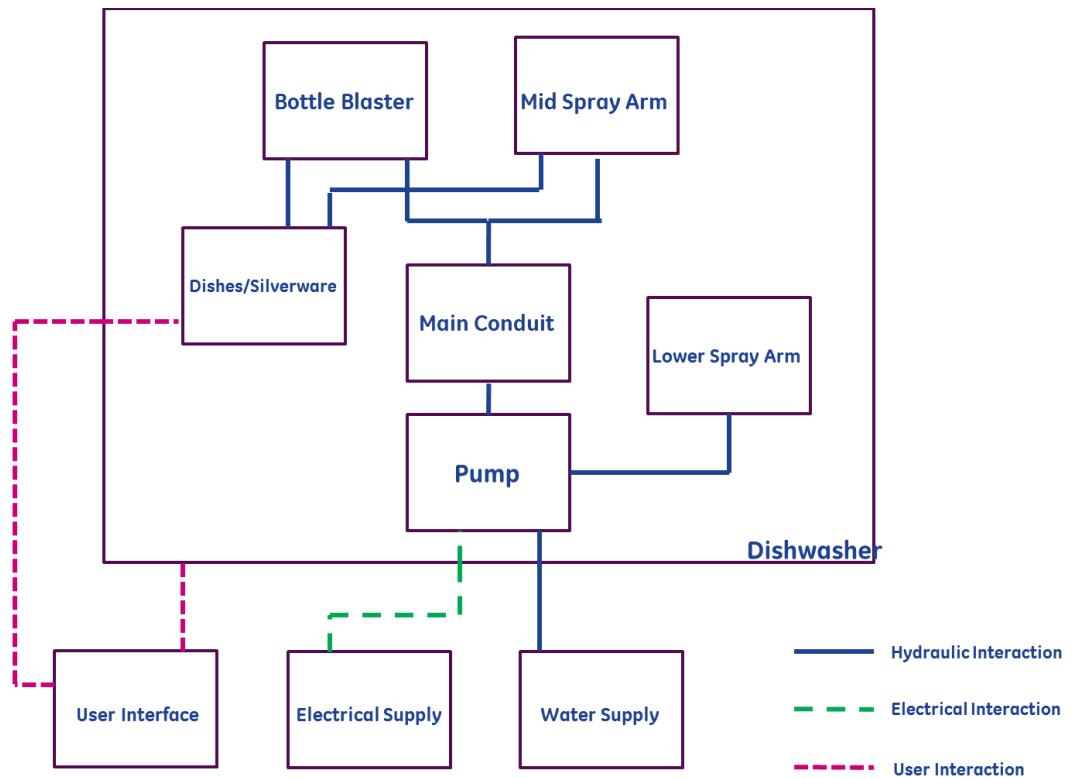
Figure 8: Block Diagram of the current GE Bottle Blaster and Mid Spray Arm system.
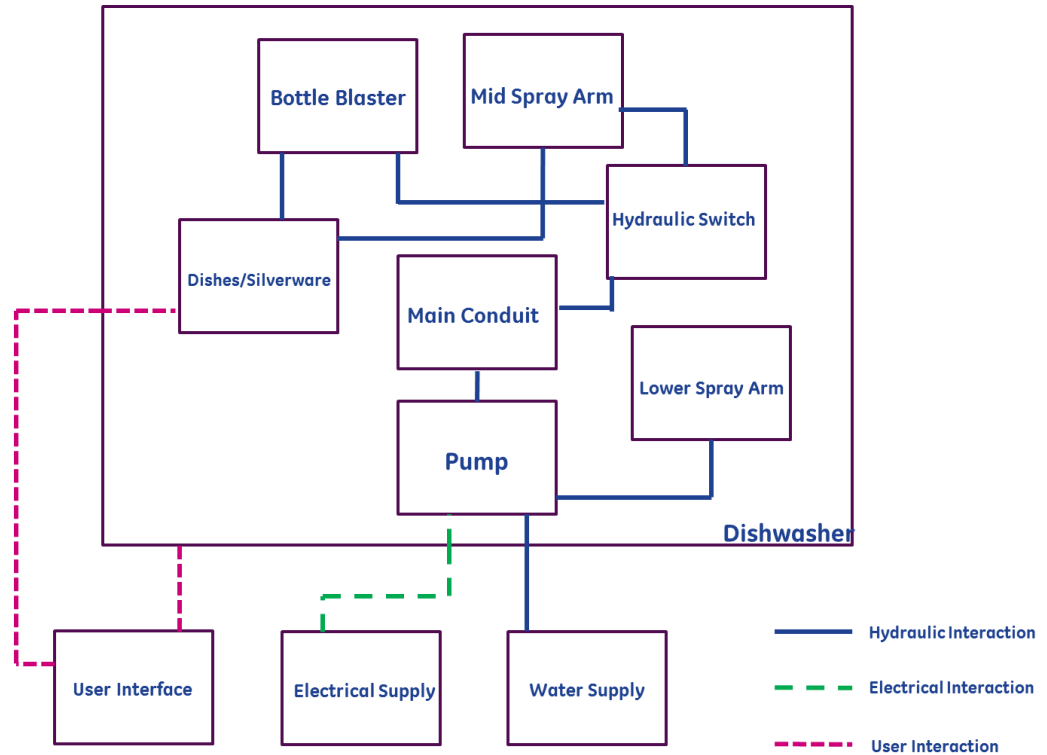
Figure 9: The new system concept Block Diagram and its interactions.

2.4 Concept Generation

Now that there is an understanding on how the current system works, different designs incorporating a Hydraulic Switch will be considered to improve performance and conserve water. Three possible Hydraulic Switches were considered (Figure 10 – 12). A Pugh Matrix was made to determine the most appropriate Hydraulic Switch for this application. Several concepts are evaluated according to their strengths and weaknesses and compared against a base concept (Mid Spray Arm and Bottle Blaster) operating simultaneously. The evaluated concepts were selected by understanding whether the consumer will be willing or able to perform the required operation of the system and whether it is manually or electrically activated by pressing a button in the dishwasher.
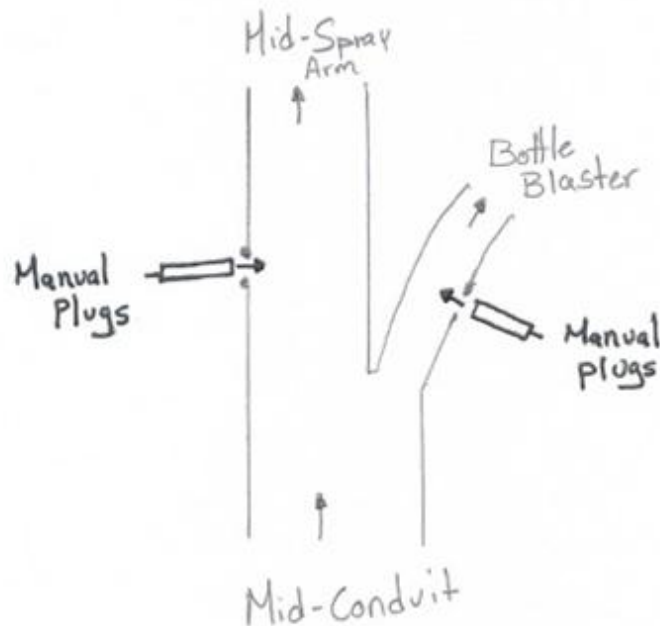
Figure 10: Manual operated concept where consumer chooses and activate which side of the dishwasher system to use by manually inserting a plug.

Concept 1 (Figure 10) shows a concept that would use plugs to be inserted or removed manually by the consumer. These plugs will be assembled inside of the conduit and operate using a sliding action. When the plug is fully inserted, it will create a seal against the other wall of the port. In this concept, the consumer will have to open the dishwasher door and modify the plugs in order to use either the Mid Spray Arm or the Bottle Blaster. If the consumer doesn't use the Bottle Blaster, they can leave the manual plug open for the Mid Spray Arm and closed the one for the Bottle Blaster. Plugs would be inserted/removed between cycles.

Concept 2 (Figure 11) shows a concept that operates by using water pressure to push a ball inside the conduit to either the Bottle Blaster port or the Mid Spray Arm port and blocking it. When the main pump starts, it will push the ball towards the Bottle Blaster side and direct the flow towards the Mid Spray Arm. At the same time, water is gradually seeping around the ball and filling up the Bottle Blaster conduit. When the pump stops, the ball is push down by the pressure

head inside the Bottle Blaster conduit, displacing the ball to favor the Mid Spray Arm conduit. When the pump starts again, the Mid Spray Arm will be block by the ball and the Bottle Blaster will be powered. The consumer will not have any direct or manual interaction with the operation of this mechanism; it will work seemly without their knowledge.
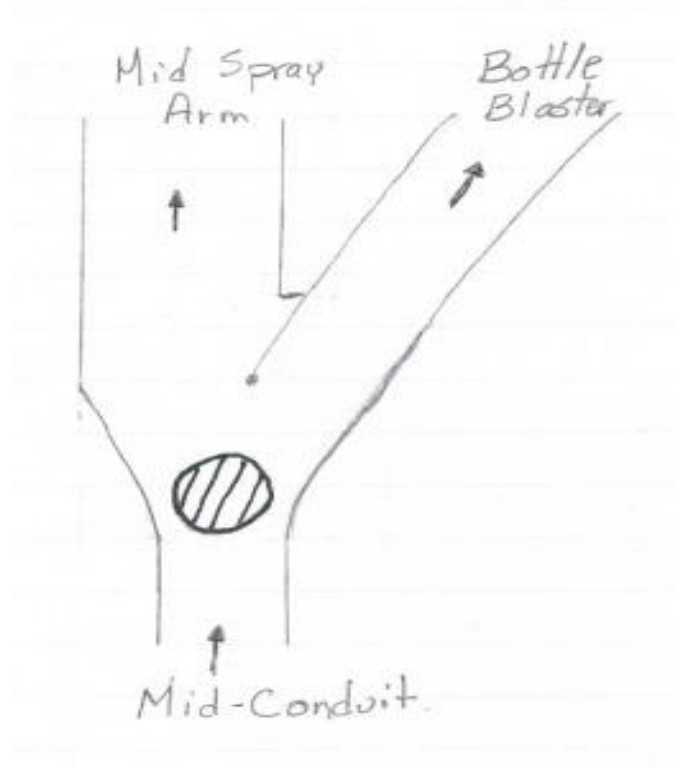
Figure 11: Water pressure operated concept which blocks the ports of the Mid Spray Arm or Bottle Blaster using a ball,

Lastly, Concept 3 (Figure 12) operates by using an electric motor that turns a wheel inside the conduit. This wheel controls the flow path to either the Mid Spray Arm or Bottle Blaster ports. This system was considered due to its automation (i.e. no consumer interaction) by using an algorithm in the main dishwasher board or the option of a manually-specified cycle selection by the user through the dishwasher's interface.

Figure 12: Electric motor operate concept to open/closes the Mid Spray Arm or Bottle Blaster.

Now that the three designs have been identified, they can now be used to fill up the Pugh Matrix where they will be compared to the current design. Table 1 shows the analyzed Pugh Matrix. In order to effectively rank the different concepts, a series of Key Criteria were ranked using three different levels of importance, 1 = lowest, 3 = medium and 5 = highest importance. The Key Criteria are taken from consumer's wants and needs (Emery, 2013). Each Concept is evaluated against the base line using three different values:

1 = design is better than current, 0 = same as current and -1 = worse than current.

Hydraulic Switching

Date of Analysis: __24-Aug__ **Analyst:** _

	Importance Rating	Design Concept 1 : Bottle Blaster/Mid-Spra pressurized at the same time	Design Concept 2: Manual Closure of each branch	Design Concept 3: Pressure activate switching	Design Concept 4: Motorized Wheel
Net Process Total		0	-8	4	-18
Weighted Sum of Better		0	10	10	0
Weighted Sum of Worse		0	-18	-6	-18
Sum of Better (1)		0	2	2	1
Sum of Worse (-1)		0	6	2	6
Sum of Same (0)		8	0	4	1
Key Criteria for Comparison					
1 Cost - Manufacturing	3	0	-1	-1	-1
2 Easiness of Use	5	0	-1	0	0
3 Manufacturing	3	0	-1	-1	-1
4 Assembly in Unit	3	0	-1	0	-1
5 Serviceability	1	0	-1	0	-1
6 Cost - Units	5	0	1	1	-1
7 Complexity	3	0	-1	0	-1
8 Overall Performance	5	0	1	1	1

Table 1: Pugh Matrix showing the comparison between the current system and the three different concepts.

The various criteria above were given the importance rating by a group of consumers (Emery, 2013). The ease of use and the cost is a major decision factor when a dishwasher is considered; therefore they are given a 5. The cost of manufacturing as well as the serviceability is not a factor that a consumer takes into account when buying a dishwasher though it is a factor for the company building them. The rating is done by the multiplication of the importance rating and the value associated to each concept when compared to the baseline design. The summation of the result from each category is displayed in the Net Process Total on the Pugh Matrix. Based on these results, the concept that was evaluated and performed better than the current set up is Concept 2 (Figure 11).

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A Behavior Diagram can be generated for the selected design obtained from the Pugh Matrix. A Behavior Diagram is used to depict behavioral features of a system and it will give an understanding of the interactions that the selected design will experience. Figure 13 shows the behavior diagram for design Concept 2. The Hydraulic Switch shows an interaction with the dishwasher which is affected by hydraulic power, whether it is low pressure, leaks and/or clogs. The switch will be mounted in the Main Conduit. It also shows that it will be controlled by water pressure and powered by the water pump. Figure 14 shows the mounting location of the Hydraulic Switch with respect to other system components.
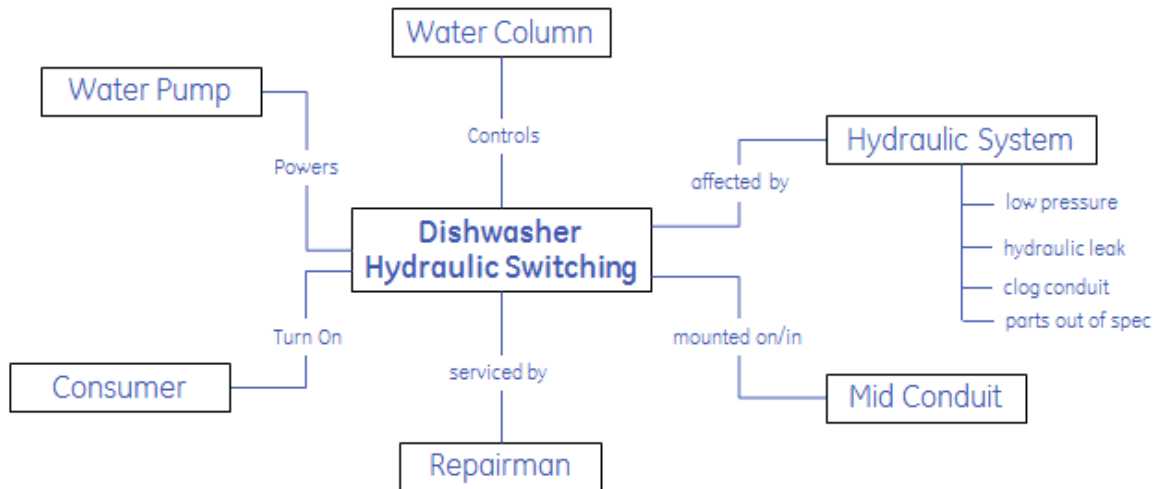
Figure 13: Behavior Diagram design Concept 2 and the interactions of the dishwasher system.
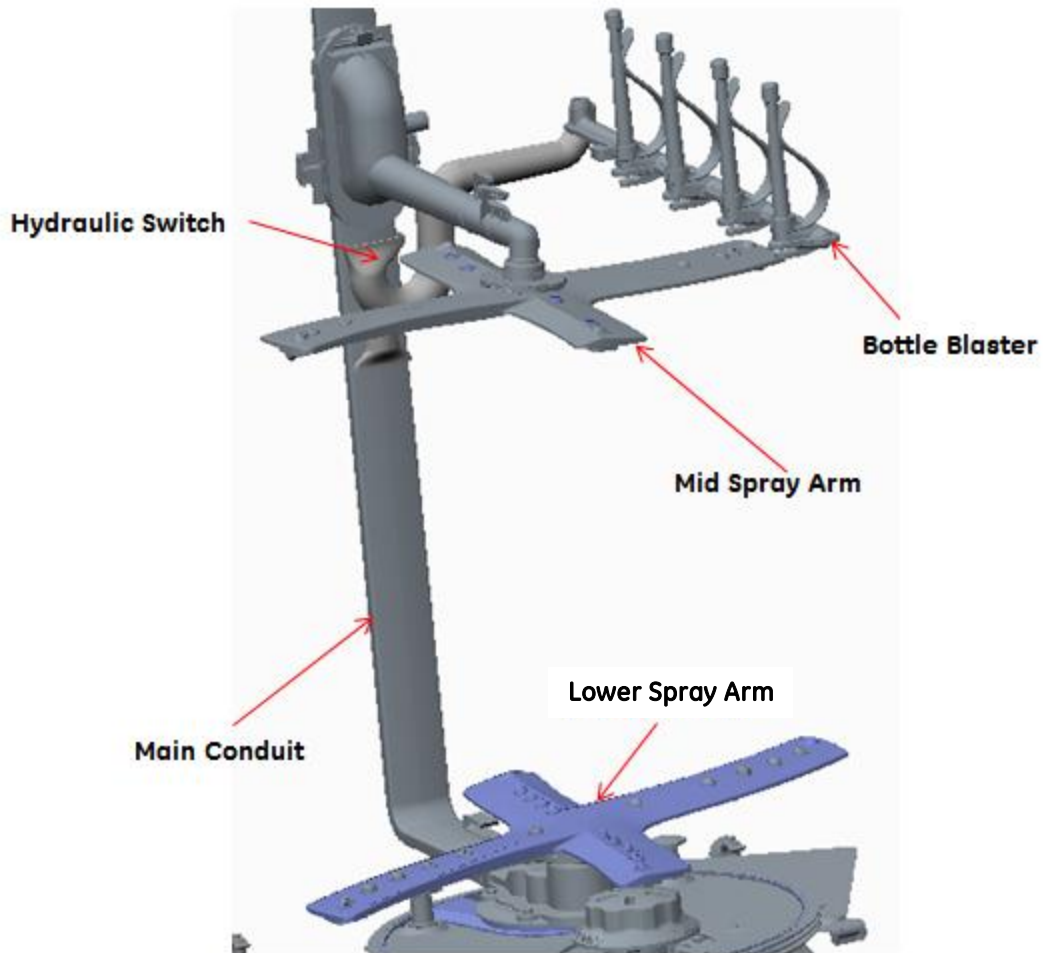
Figure 14: GE dishwasher Wash System with Hydraulic Switch mounting Locations

In order to accomplish the required operation, the new design (Figure 15a), has to fit the main conduit before the Mid Spray Arm in order to power either the Bottle Blaster or just the spray arm. The Hydraulic Switch needs to have a rectangular cross-section for its inlet and outlet; the main conduit will fit inside of the switch, which has an interior dimension of 1.68 inches in width and 0.487 inches in thickness. Since the conduit is made out of PVC, the switch will be made out of the same material. Figure 15b shows a section view of the switch with the ball inside.

(a)
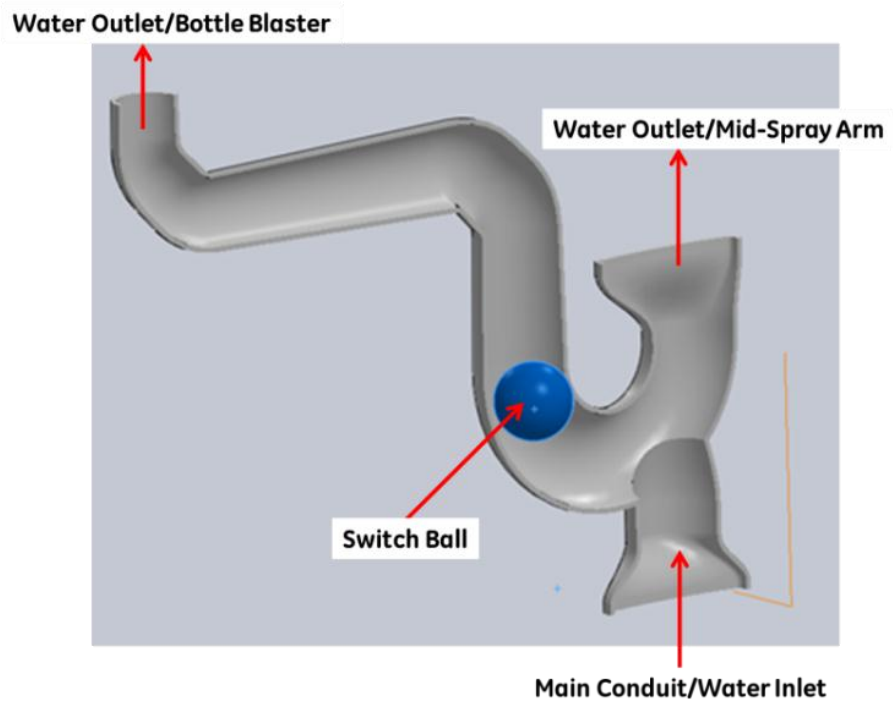
(b)

Figure 15: FDM prototype of the Hydraulic Switch (a) and cross-section showing interior components (b).

The Hydraulic Switch will be manufactured by molding the two halves of the part and then a hot plate will weld both sections together after the ball has been placed inside. This system will work as follow: 1) The dishwasher is not on and the pump is power off where the blocking ball is on its free state. 2) Water travels up the Main Conduit and enters the Hydraulic Switch pushing the ball inside towards the Bottle Blaster port, directing the water to the Mid Spray Arm. At the same time, water gradually seeps around the ball, filling up the Bottle Blaster conduit, which is at a higher elevation than the ball. 3) When the pump stops, the pressure head from the Bottle Blaster pushes the ball back through the switch towards the Mid Spray Arm. 4) As the pump is turned back on, the ball is pushed towards the Mid Spray Arm and the water is directed towards the Bottle Blaster. Figure 16 shows the different steps of the Hydraulic Switch.
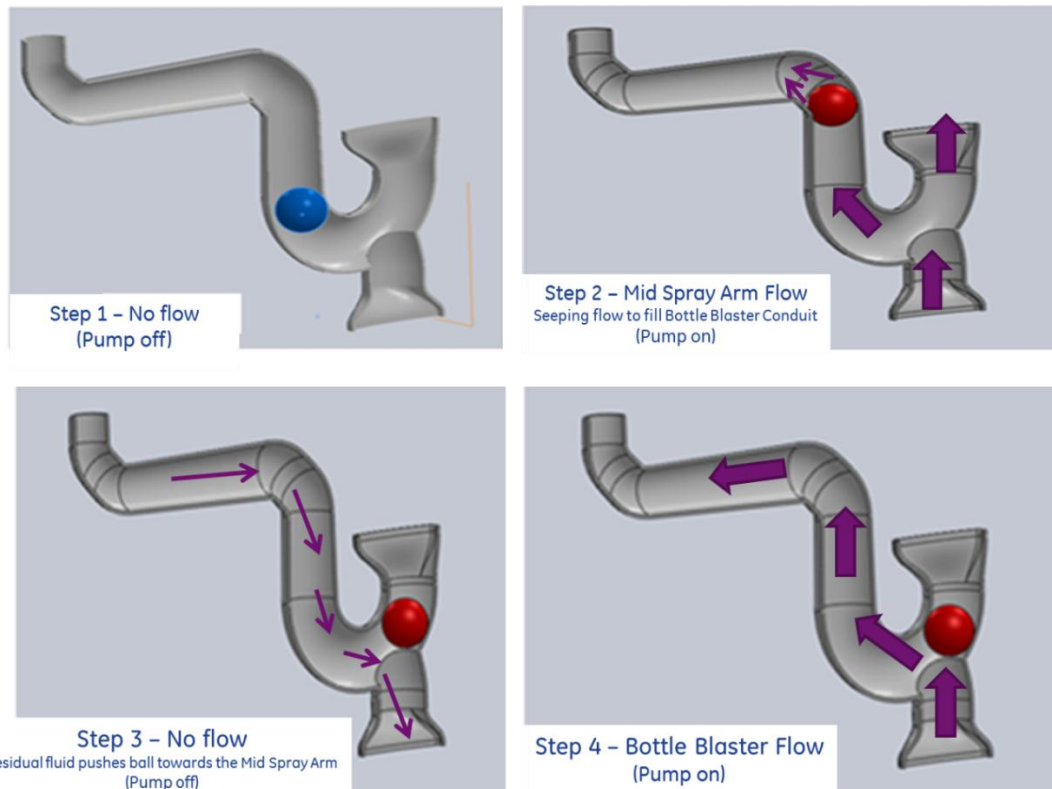
Figure 16: The four different positions of a Hydraulic Switch. Step 1: The ball position during no flow condition (pump is off). Step 2: The pump flow allows the bulk of the flow to power the Mid Spray Arm while a smaller amount seeps through towards the Bottle Baster. Step 3: The pump is turned off to allow accumulated fluid in the Bottle Blaster conduit to displace the ball valve. Step 4: The pump is turned on and the ball valve is now displaced to direct bulk flow towards the Bottle Blaster.

The Hydraulic Switch in Figure 16 works in principle similar to the three shuttle valves mentioned in Figure 3 -5. It uses fluid pressure to move a ball that blocks one of the ports allowing the flow to travel to a specific branch, but that is where all similarities ends. The Shuttle Valves observed are used in high pressure applications of up in the 1000 psi range, while the Hydraulic Switch will operate more in the 4.5 to 5.5 psi array. Also, most of the Shuttle Valves have more than one inlet, in order to use the same valve for multiple purposes; the Hydraulic Switch will not operate appropriately if the inlet port is changed. The closest that the Hydraulic Switch comes to an already existing part is with the GE diverter, Figure 6. In both cases, the pressure and flow rating are the same since their being use in the same system and both have the same operation principle.

CHAPTER 3 – EXPERIMENTATION WITH NEW DESIGN

The experiment was conducted using a rig composed of a water reservoir with a capacity of 10 gallons. There is a stationary pump, Flotec Model FP5172, able to provide up to 50 GPM. The flow rate going into the dishwasher is measured using a flow rate sensor in the water line. There are two flow rate sensors in the water line, one that measures from 0.5 to 3 GPM (GPI Meters, Model A109GMA025NA1), the other one measure 3 to 15 GPM (GPI Meters, Model A109GMA100NA1). Figure 17 shows the water delivery system for the testing rig and Figure 18 has the Block Diagram for the same test rig.
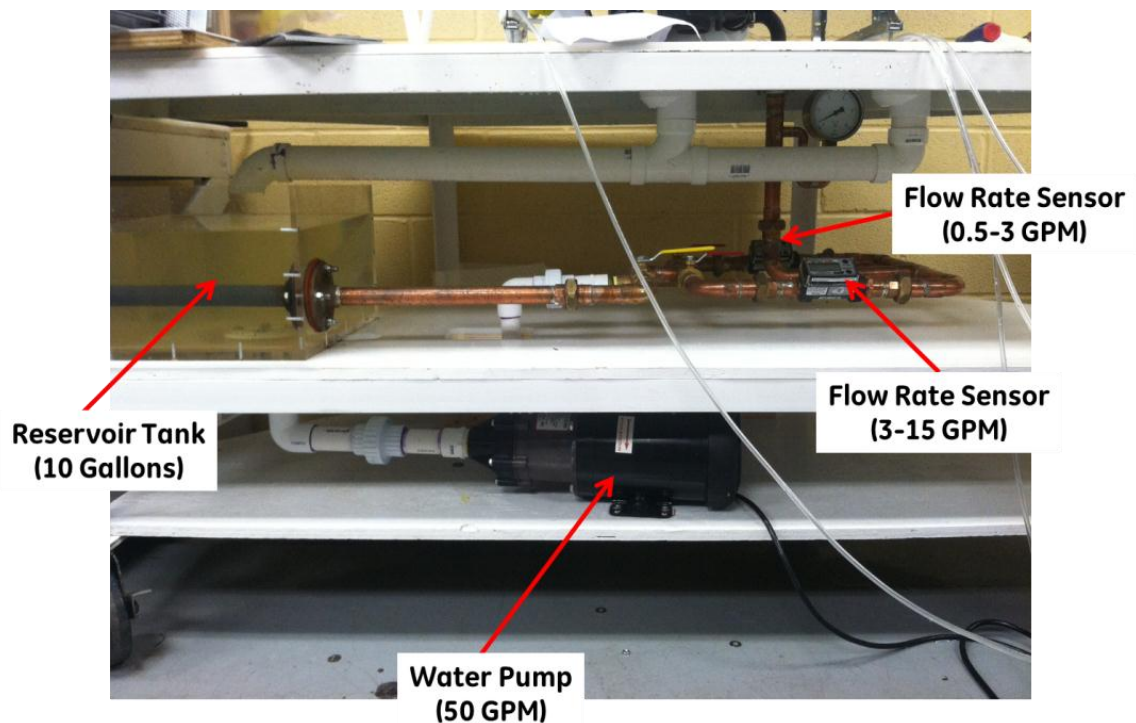
Figure 17: Water delivery and flow measuring rig
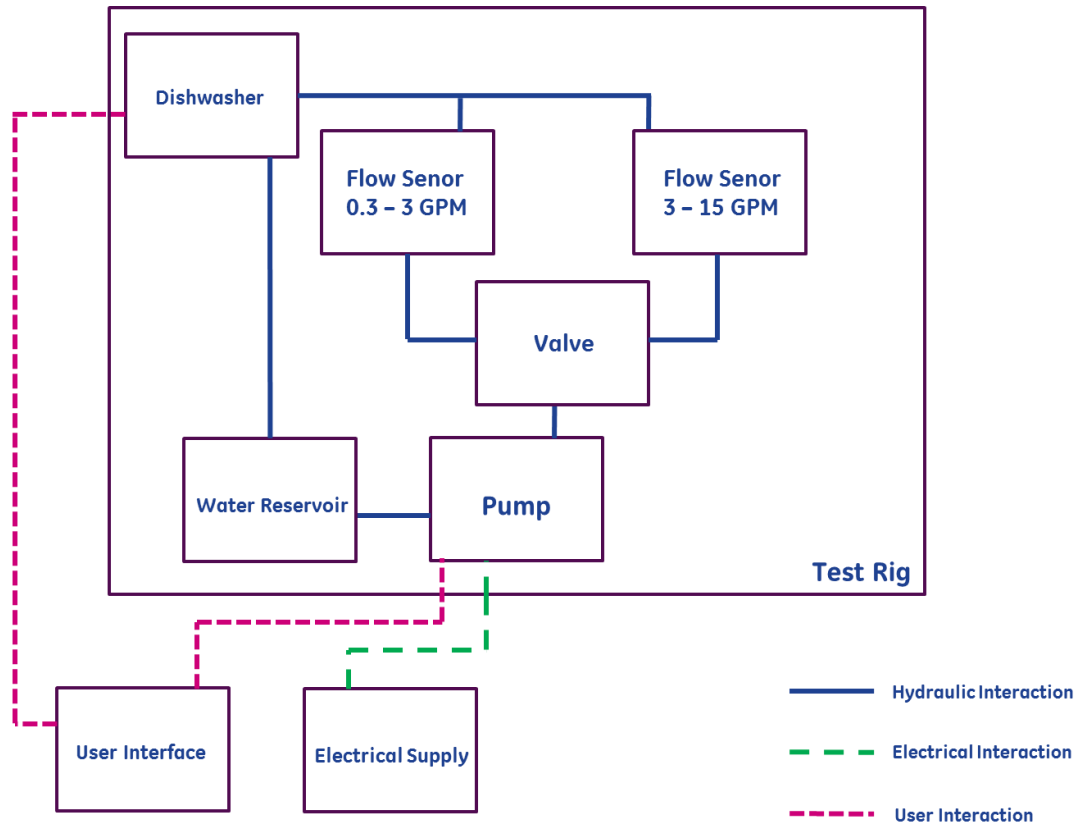
Figure 18: Water delivery and flow measuring block diagram for the test rig.

In order to test this new system, as well as obtaining baseline data, a dishwasher is necessary. In this case, a GE's plastic tub dishwasher unit was used and is shown in Figure 19.

Figure 19: GE plastic tub dishwasher used for data collection.

Five pressure collection points were set up in order to map the pressure difference throughout the entire system. 1) Sump area, just after the pump outlet, measuring pump pressure. 2) Base of Main Conduit, to measure flow pressure going up in the conduit and after the Bottom Spray Arm. Location (2) provides us with an understanding of the amount of pressure loss from the time water enters the sump to when it starts to travel up the Main Conduit. 3) The third point is half way up the Main Conduit, just before the connection for the Mid Spray Arm. 4) The fourth point is in the Mid Spay Arm branch obtaining the pressure differential between the Mid Spray Arm and the rest of the system. 5) The final point is located in the Bottle Blaster itself, which gives you the same information as point (4) but with respect to the Bottle Blaster. Figure 20a shows where the different pressure points where taken and 20b shows the block diagram of the different pressure points.
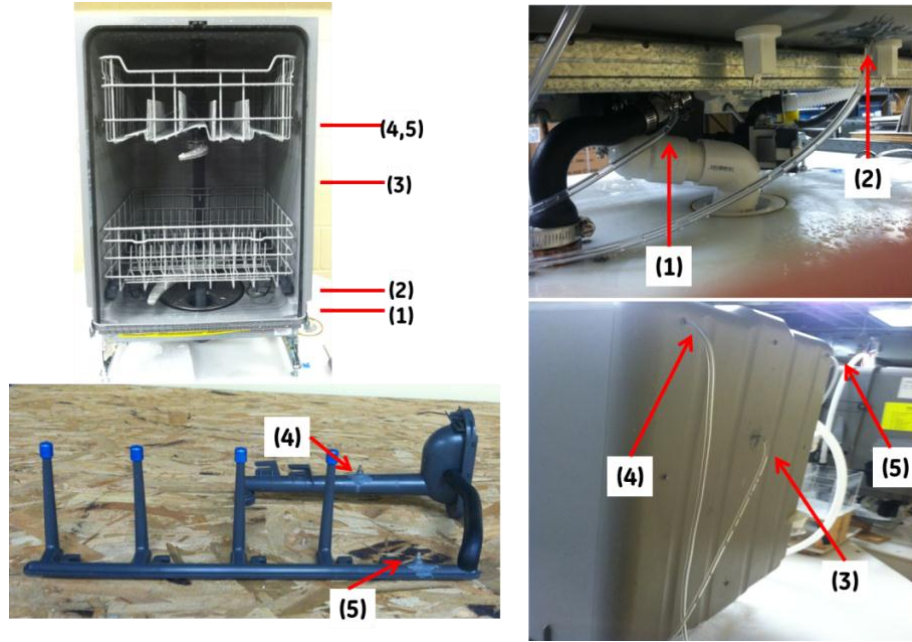
(a)
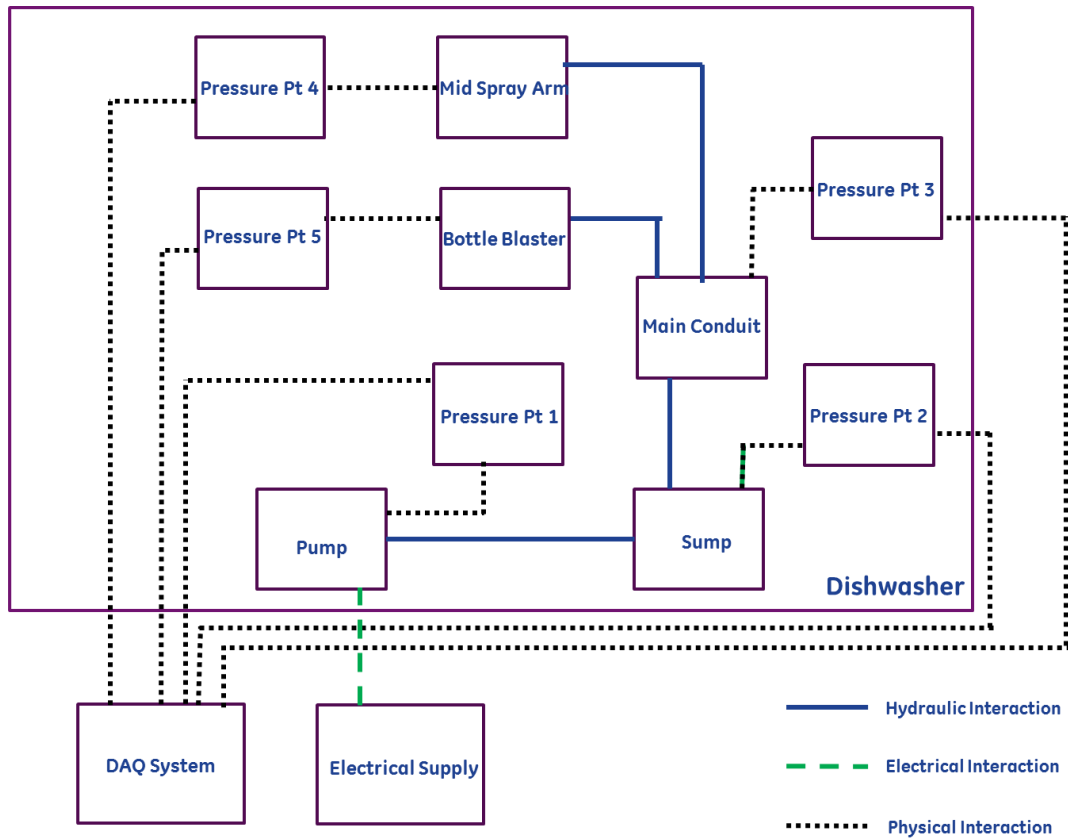
(b)

Figure 20: Pressure points locations along the dishwasher (a) and their corresponding block diagram (b)

The five pressure points were measured using five pressure transducers from Omega (Model Number: PX309); these transducers can measure a pressure range between 0 to 15 psi and translated into a 0 to 5 V_{dc} output signal. The output signal from the transducers is read by an Agilent Data Acquisition Unit (Model Number: 34972A) connected to a computer. The signal sent by the Agilent system is read using the Benchlink Data Logger 3 and the pressure change of the system is displayed, recorded on the computer and saved to a specific file. Figure 21 shows the transducers and Data Acquisition setup.
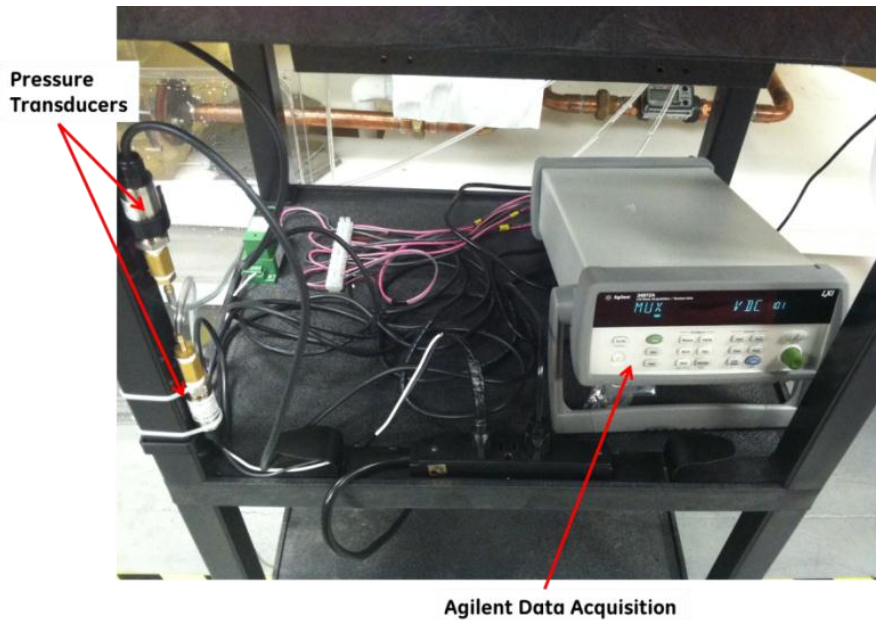
Figure 21: DAQ system for the different pressure sensors throughout the dishwasher.

Scan	Time	Bottle Blaster (PSI)	Upp Sp Arm (PSI)	Mid Conduit (PSI)	Lower Conduit (PSI)	Sump Inlet (PSI)
1	3:16:40 PM	0.1030	0.0054	0.0604	0.1083	0.3090

Table 2: Benchlink Data Output

Table 2 shows the Benchlink Data Output into an Excel file. The file is outputted with a time stamp that can be made to get recorded every 1, 5, 10, etc. seconds. In this case, the time

stamp is being recorded every 5 seconds. With the information obtained using Benchlink, the Flow Curve System for the current system is shown in Figure 22 below.
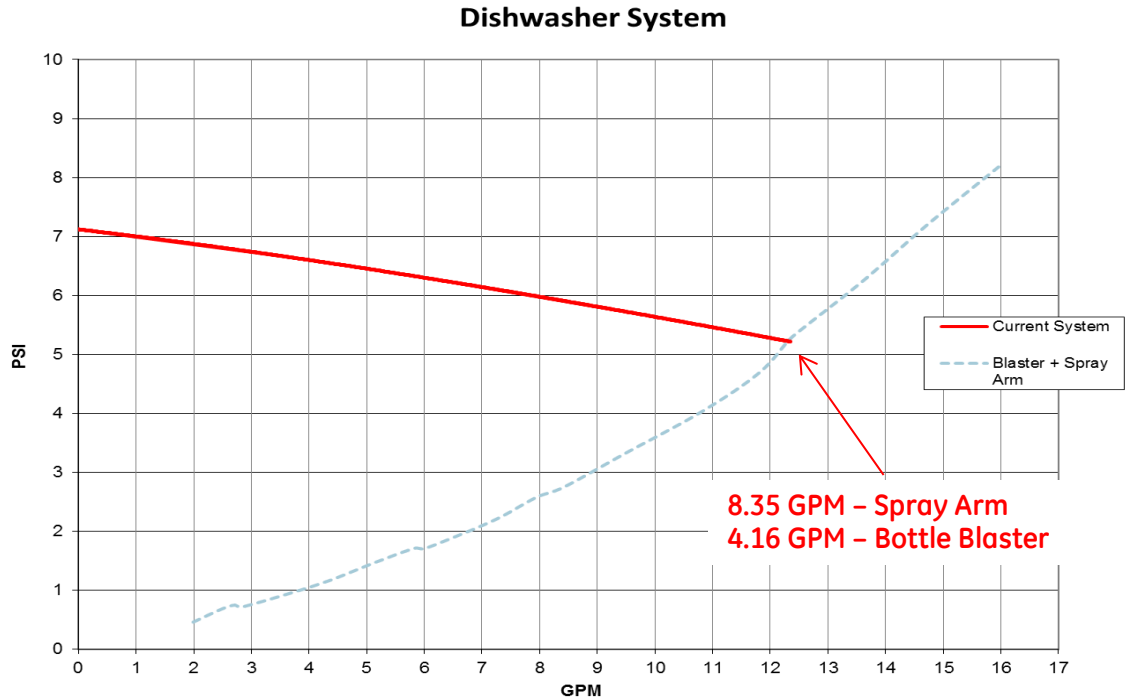
Dishwasher System

Figure 22: System curve for the current GE dishwasher with the Mid Spray Arm and the Bottle Blaster system as well as the pump pressure curve.

The graph above illustrates 2 different curves. The dash curve shows the relationship of the combined Bottle Blaster and Mid Spray Arm in the GE dishwasher; this curve is used to determine the flow rate through the current system. The horizontal curve (red curve) is the pump pressure curve overlaid on top of the system curve for the dishwasher. The data and graph determined that it takes approximately 12 GPM to operate the dishwasher Bottle Blaster and Mid Spray Arms for proper dishware cleaning with a system back pressure in-between 4.5 to 5.5 psi. If the current system is analyzed to determine the dedicated flow used by the Bottle Blaster and Mid Spray Arm, approximately 8.35 GPM is used to operate the Mid Spray Arm and approximately 4.16 GPM to operate the Bottle Blaster. The majority of the water tends to flow through the Mid Spray Arm following the path of least resistance. The spray arm alone has 11 ports for water to shoot out while the Bottle Blaster only has 4 ports, one for each bottle.

CHAPTER 4 – NEW SYSTEM

4.1 Analyzing Current Design

There are several different factors or failure modes that can affect a design. The design of the part or assemblies must be done to be robust enough such that if those failure modes occur, it will not damage the rest of the components nor cause injury to a consumer. For that, a Failure Mode and Effect Analysis (FMEA) was performed. The FMEA, Table 3, is done with a group of engineers and is supposed to determine multiple failures that could occur to a specific part (Turner, 2013). It is done in an Excel template that has a series of columns with a specific label that has to be filled. These labels include the potential Failure Mode of the design, the potential Cause of the Failure Mode. It also has any potential effects of the failure modes and an in-place detection system, if available.

Part or FBD Block	Function in FBD Block	Potential Failure Mode-- Results in a loss of function	Potential Cause of Failure Mode	Occurrence	Potential effects of failure mode on End Product and the End User	Severity	In-Place and Planned Cause Preventions or Detections	Detection	RPN
	What is the design function?	In what way can the component, subsystem, or system fail to meet the design intent?	What causes the Key Input to go wrong?		What is the impact on the Key Output Variables (Customer Requirements) or internal requirements?		What are the existing controls and procedures fail/safes, tests, mathematical studies...etc) that prevent either the cause or the failure mode?		

Table 3: Table showing the different fields necessary to complete a FMEA

In some cases, the design in question might have hundreds of possible failure modes which are why there is a ranking system in each FMEA. The first ranking is done in terms of Occurrence that could happen and is done after the potential Failures and Causes are discussed. The break down for Occurrences is shown in Figure 23 below. After the Potential Effects of the failure modes is determine, the severity of these effects has to be ranked as well. The breakdown is shown in Figure 24. Lastly, the Detection rating to determine each failure mode is ranked and shown in Figure 25.

Occurrence ratings

1	1/ 1,000,000	Likelihood of occurrence is remote
2	1/ 20,000	Low failure rate with supporting documentation
3	1/ 5,000	Low failure rate without supporting documentation
4	1/ 2,000	Occasional failures
5	1/ 500	Relatively moderate failure rate with supporting documentation
6	1/ 100	Moderate failure rate without supporting documentation
7	1/ 50	Relatively high failure rate with supporting documentation
8	1/ 20	High failure rate without supporting documentation
9	1/ 10	Failure is almost certain based on warranty data or significant DV testing
10	1/ 2	Assured of failure based on warranty data or significant DV testing

Figure 23: Occurrence Ratings for FMEA

Severity ratings

1 Customer will not notice the adverse effect or it is insignificant
2 Customer will probably experience slight annoyance
3 Customer will experience annoyance due to the slight degradation of performance
4 Customer dissatisfaction due to reduced performance
5 Customer is made uncomfortable or their productivity is reduced by the continued degradation of the effect
6 Warranty repair or significant manufacturing or assembly complaint
7 High degree of customer dissatisfaction due to component failure without complete loss of function. Productivity impacted by high scrap or rework levels.
8 Very high degree of dissatisfaction due to the loss of function without a negative impact on safety or governmental regulations
9 Failure results in violation of governmental regulations
10 Customer endangered due to the adverse effect on safe system performance

Figure 24: Severity Rating for FMEA

Detection ratings

1	100%	Likelihood failure will be found or prevented before releasing design
2	99%	Likelihood failure will be found or prevented before releasing design
3	95%	Likelihood failure will be found or prevented before releasing design
4	90%	Likelihood failure will be found or prevented before releasing design
5	85%	Likelihood failure will be found or prevented before releasing design
6	80%	Likelihood failure will be found or prevented before releasing design
7	70%	Likelihood failure will be found or prevented before releasing design
8	60%	Likelihood failure will be found or prevented before releasing design
9	50%	Likelihood failure will be found or prevented before releasing design
10	<50%	Likelihood failure will be found or prevented before releasing design

Figure 25: Detection Ranking for FMEA

Once the ranking has been completed and a number for each the three categories is given, then a RPN (Risk Priority Number) is calculated. The RPN is calculated by multiplying the three ranking categories (Occurrence, Severity and Detection) by each other. The higher the RPN, the higher the probability of an issue once the product is launched and therefore should address first. In this case, the FMEA for the Hydraulic System takes into account the ball not sitting properly, leaks due to non-sealing gasket thickness, etc. The results of the RPN indicated that the two highest failure modes, with a number of 120, will be:

1)   Leaks between the sealing surfaces which creates poor wash performance.

2)   Part misassembly caused by a leak at the weld lines which, in turn, creates poor wash performance.

Table 4 shows part of the Hydraulic System FMEA report.

Part or FBD Block	Function in FBD Block	Potential Failure Mode-- Results in a loss of function	Potential Cause of Failure Mode	Occurrence	Potential effects of failure mode on End Product and the End User	Severity	In-Place and Planned Cause Preventions or Detections	Detection	RPN
	What is the design function?	In what way can the component, subsystem, or system fail to meet the design intent?	What causes the Key Input to go wrong?		What is the impact on the Key Output Variables (Customer Requirements) or internal requirements?		What are the existing controls and procedures fail/safes, tests, mathematical studies..etc) that prevent either the cause or the failure mode?		
Hydraulic Switch	Diverts the water from wash pump to either the mid/upper sprayarms or the bottle blaster	ball gets stuck	friction in assembly	3	poor wash performance	6	design geometry	3	54
			inconsistant wall thickness	3	poor wash performance	6	guage balls used to verify correct w all thickness after molding	3	54
			food soil build up or trapped debris	3	poor wash performance	6	slat testing	3	54
			seating surface too large	3	poor wash performance	6	eFP and quality plan	2	36
			w eld melt interferes with travel	5	poor wash performance	6	eFP and quality plan	3	90

Table 4: FMEA report for the Hydraulic Switch design

In order to maximize the effectiveness of the Hydraulic Switch, a DOE (Design of Experiment) is necessary. The DOE will let us know which dimensions to increase, decreased or if an imperfection will be allowed on the part. This DOE has four variable factors which include conduit size, open area where water will enter. The ball size for the switch is another factor; if the ball is too small, it will not block a port. If it is too big, the necessary travel won't occur and the switch will not operate correctly. Food particles and assembly flash is the last two factors considered in the DOE. Assembly flash is similar to a burr in a metal part and is created when two plastic parts are joined together through a melting process; like a hot plate. The constraints of the DOE come from the upper and lower specifications of the four variables tested. These upper and lower specifications are taken from the parts that are already in use inside of the dishwasher, the values need to fall in-between those specifications to avoid any redesigned of the current components. Table 5 shows the respective specifications for the four variables tested.

Variables	Constraints		
Conduit Opening Size (in^2)	1.360	$\leq x_1 \leq$	4.000
Ball Size (in^3)	0.730	$\leq x_2 \leq$	0.932
Food Particles (in)	0	$\leq x_3 \leq$	0.020
ASM Flash (in)	0	$\leq x_4 \leq$	0.020

Table 5: Variable specifications for the DOE variable.

The DOE can start to be filled with the specifications from Table 5. The flow rate through the system is the output obtained from the DOE and is important because it powers the spray arms which, in turn, clean the dishes. The DOE was made using two operators and a software called Minitab v12.23; Table 6 shows the DOE and its flow rate values.

StdOrder	RunOrder	CenterPt	Blocks	Conduit Size Opening	Food Particle Present	Ball Size	ASM Flash	Flow Rate (Mid Arm)	Flow Rate (Bottle Blaster)	Mid Spray Arm Pressure	Bottle Blaster Pressure
3	1	1	1	Lower Spec	Food	Lower Spec	No Flash	4.2	1.67	4	5.8
10	2	1	1	Upper Spec	No Food	Lower Spec	Flash	4.93	2.4	2.68	4.3
9	3	1	1	Lower Spec	No Food	Lower Spec	Flash	4.26	1.73	1.85	2.45
14	4	1	1	Upper Spec	No Food	Upper Spec	Flash	8	5.47	4	5.8
8	5	1	1	Upper Spec	Food	Upper Spec	No Flash	6.57	4.04	2.68	4.3
1	6	1	1	Lower Spec	No Food	Lower Spec	No Flash	4.8	2.27	1.85	2.45
4	7	1	1	Upper Spec	Food	Lower Spec	No Flash	7.5	4.97	3.2	5.23
11	8	1	1	Lower Spec	Food	Lower Spec	Flash	3.16	0.63	0.86	0.75
6	9	1	1	Upper Spec	No Food	Upper Spec	No Flash	9.85	7.32	5.9	6.8
13	10	1	1	Lower Spec	No Food	Upper Spec	Flash	6.8	4.27	2.8	4.59
15	11	1	1	Lower Spec	Food	Upper Spec	Flash	5.98	3.45	2.4	4
12	12	1	1	Upper Spec	Food	Lower Spec	Flash	4.53	2	1.6	2.12
16	13	1	1	Upper Spec	Food	Upper Spec	Flash	7.04	4.51	2.94	4.39
2	14	1	1	Upper Spec	No Food	Lower Spec	No Flash	8.55	6.02	4.55	6.33
5	15	1	1	Lower Spec	No Food	Upper Spec	No Flash	7.39	4.86	3	5.15
7	16	1	1	Lower Spec	Food	Upper Spec	No Flash	6.05	3.52	2.42	4.13

Table 6: Flow rate results from the DOE analysis performed.

The DOE result from Table 6 shows a coefficient for each variable as well as a constant. The coefficients from the table can be used to generate an equation and maximize the flow rate through the system. Table 7 shows those coefficients for each variable from the DOE.

Term	Effect	Coef
Constant		6.2256
Conduit	1.7912	0.8956
Food Particle	-1.1938	-0.5969
Ball Size	1.9687	0.9844
ASM Flash	-1.2763	-0.6381
Conduit*Food Particle	-0.2288	-0.1144
Conduit*Ball Size	-0.4812	-0.2406
Conduit*ASM Flash	-0.7162	-0.3581
Food Particle*Ball Size	-0.4062	-0.2031
Food Particle*ASM Flash	0.3737	0.1869
Ball Size*ASM Flash	0.7663	0.3831
Conduit*Food Particle*Ball Size	-0.2912	-0.1456
Conduit*Food Particle*ASM Flash	0.3688	0.1844
Conduit*Ball Size*ASM Flash	0.5363	0.2681
Food Par*Ball Size*ASM Flash	0.3362	0.1681
Conduit*Food Particle*Ball Size*ASM Flash	0.0812	0.0406

Table 7: Coefficient of the different variables obtained from the DOE.

With the data above, a Paretto Chart can be created and is illustrated in Figure 26 below. The Paretto Chart is used to highlight the most important factors along a large set of factors commonly used in a DOE; more important, it represents the most common sources of flow rate variations.
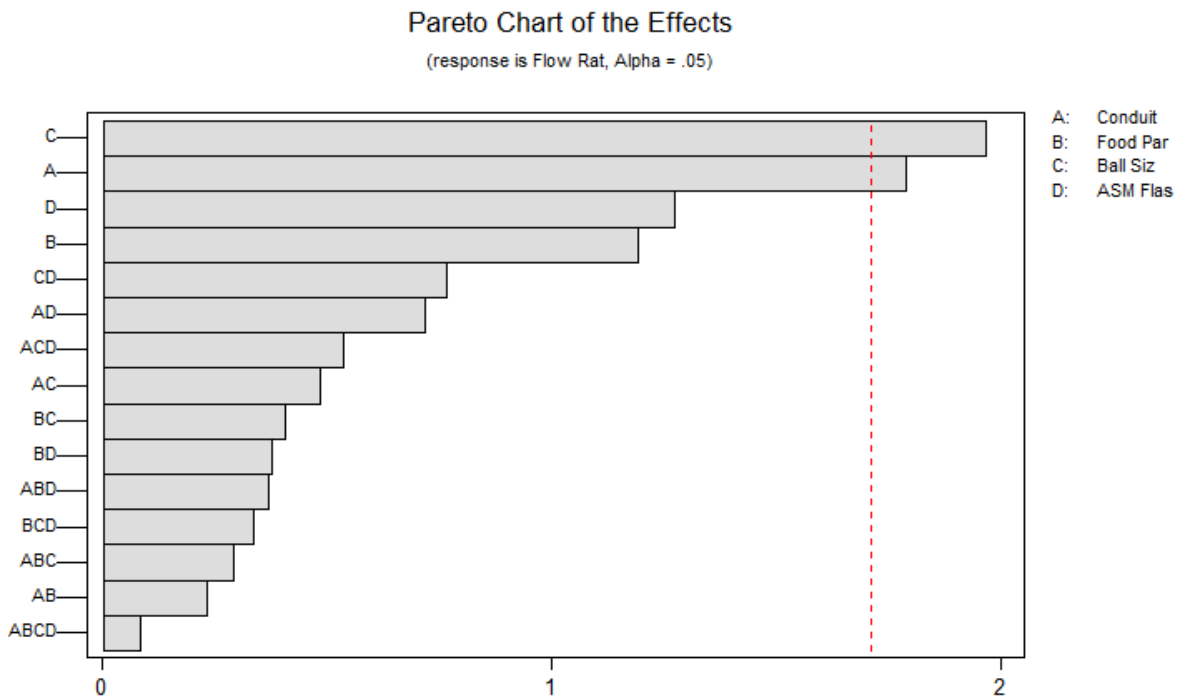
Figure 26: Paretto Chart showing the different effects of the DOE variables.

The factors for each variable can be selected from Table 7 and analyzed during the DOE. Using those variables, a function can be generated (Equation 1) which describes the flow rate seen through the system.

$$Flow\,Rate = 6.2256 + 0.8956(Conduit\,Size) - 0.5969(Food\,Particles) + 0.9844(Ball\,Size) - 0.6381(ASM\,Flash)$$

Equation 1: Flow Rate Equation obtained from the variables in Table 7.

Equation 1 shows the flow rate being mainly affected by the ball size and conduit size. This equation can be inserted into Excel and analyzed by using the constraints/dimensions in Table 5. Equation solver in Excel can be used to maximize the equation and obtain the highest flow rate through the system while staying inside the specifications. Table 8 below shows the new optimized values obtained from Excel equation solver using Equation 1 and Table 5 data. A new nominal can be obtained from the maximizing analysis for each of the variables in the DOE.

Variables	
Conduit Opening Size	3.085 in^2
Ball Size	0.850 in^3
Food Particles	0
ASM Flash	0

Table 8: Optimize Variable Values using Equation 1 in Excel equation solver with the specifications in Table 5.

4.2 Hydraulic System Design

An interface between the Hydraulic Switch and the Main Conduit has to be created since they will be connected to each other. A seal must be obtained which will prevent leaks at that interface and reduce/eliminate pressure loss, leading to flow rate reduction. In order to find an appropriate dimension for the new seal, a tolerance loop needs to be created. A tolerance loop analyzes dimensions and manufacturing tolerances in order to achieve a required dimension for proper operation of a part or assembly. The outcome is usually preferred to be at a Six Sigma level of tolerance of a 3 Z score value or grater. In a tolerance loop, a vector loop is the first thing that needs to be created. A vector loop is a 2D representation of the area that will be analyzed by the tolerance loop and is usually composed of two or more parts. Figure 27 shows the tolerance loop 2-D Vector Diagram.
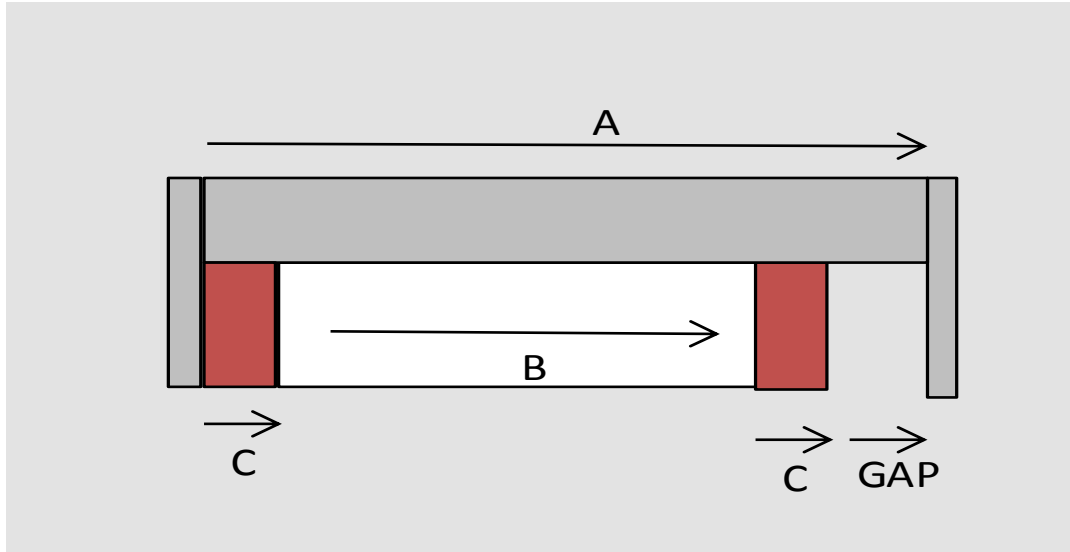
Figure 27: Tolerance Loop Vector Diagram of the Hydraulic Switch, Main Conduit and sealing gasket

The vector diagram above is composed of three different parts; part A is the width of the Main Conduit in the dishwasher, B is the Hydraulic Switch width and C is the gasket thickness in-between the Main Conduit and the Hydraulic Switch. The gap is the space that needs to be filled in order to have a proper sealing surface. The proposed design has the Main Conduit, A, being bigger than the Hydraulic Switch, B, and the corresponding gasket, C. Using simple arithmetic, an Ideal Mean Response equation can be generated and its shown in Equation 2 below.

$$A = B + 2C + Gap$$

Equation 2: Ideal Mean Response taking into account the 3 different parts that composes the system

Equation 2 does not show what needs to be solved since the dimensions for A and B are already known. The required thickness is what is necessary in order to fill the gap created by the Main Conduit, A, and the Hydraulic Switch, B. Rearranging Equation 2 to solve for the gap, the Ideal Mean Response Equation becomes:

$$Gap = A - B - 2C$$

Equation 3: Rearrangement of the Ideal Mean Response Equation

Equation 3 now gives a better understanding of the dimensions needed to design a gasket that will fill the gap between the Main Conduit and the Hydraulic Switch. Gaskets are designed to seal with compression, if there isn't any compression between the A and B surfaces a leak will show up. In this case, another equation determines the compression of the gasket (Equation 4).

$$\% \, Compression = (Gap / 2C) * 100$$

Equation 4: Gasket Compression necessary for proper seal

Gasket Compression is a factor of the gap that needs to be filled and the thickness of the gasket times two. The multiplication by two is the two sides in the 2D analysis where the gasket will be compressed. Using Equation 3 into Equation 4, the factors can be replaced on the equation to become:

$$\% \, Compression = \left[\frac{(A - B - 2C)}{2C} \right] * 100$$

Equation 5: 2-D Gasket Compression

Equation 5 has two unknown variables, the compression percentage and the gasket thickness. Based on previous work and designs, a gasket can have a compression percentage between 20% and 80% and still operate normally providing the adequate seal needed in a design (Boyer, 2013). The range for the percentage of compression (which will be used in the Tolerance Loop) is 80% for the Upper Specification Limit (USL) and 20% for the Lower Specification Limit (LSL). Equation 5 now becomes the Ideal Mean Response in the Tolerance Loop analyzing the design where a single variable is unknown, C.

Aside from nominal dimensions, the Tolerance Loop also requires tolerance for the USL and LSL. The standard deviations for those dimensions with a Short or Long Term Six Sigma selection must be known before running the loop. The gasket for this design hasn't been manufactured and a standard deviation must be obtained by measuring the thickness of at least thirty samples of a current production gasket. The standard deviation doesn't vary in excess when using the same manufacturing method and material, therefore, the value obtained from the measured samples is used as the standard deviation for the proposed gasket. The measured gaskets were made out of ePDM with a nominal gasket thickness of approximately 0.710 inches with a $\pm$ tolerance of 0.031 inches. A total of thirty one gaskets were measured and the standard deviation was obtained using Minitab. The use of basic statistic and normality test will give us an understanding of the data measured.

Normal Probability Plot

Average: 0.168167
StDev: 0.0055029
N: 30

Anderson-Darling Normality Test
A-Squared: 1.081
P-Value: 0.007
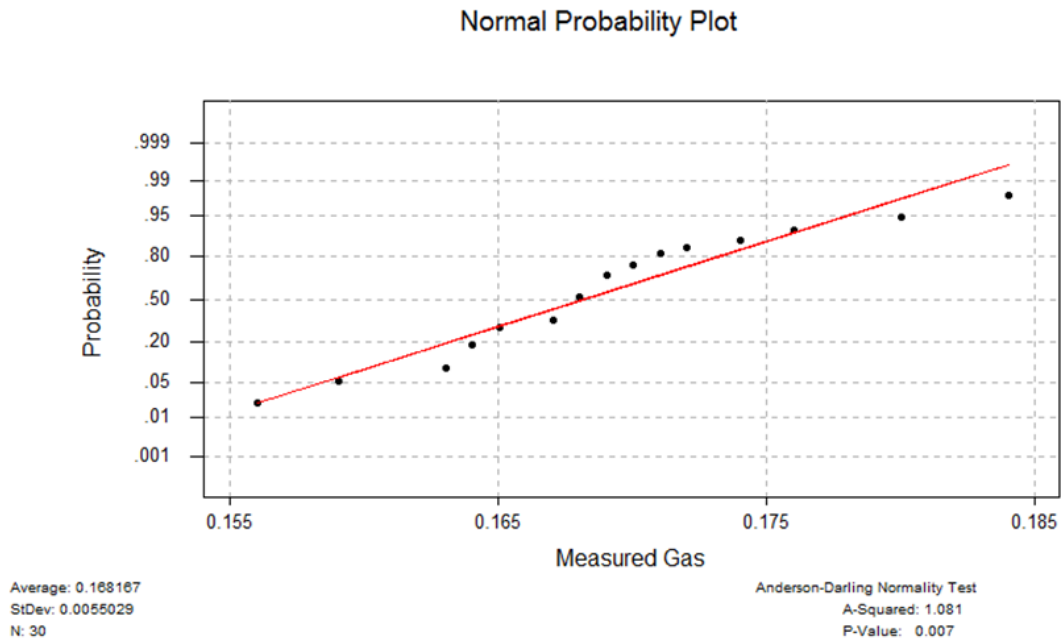
Figure 28: Normality Test on the measured gasket samples for obtaining standard deviation

The normality test (Figure 28) shows a linear trend in the measured gasket thickness. If a linear trend is not obtained with the normality test, a Tolerance Loop would not be able to be used. The equations behind the Tolerance Loop are linear and therefore a linear relationship is

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necessary in order for a Tolerance Loop to work. The standard deviation can now be found using basic statistics and clicking in descriptive statistic. Table 9 shows the 95% confidence level results from the descriptive statistics analysis.

Variable	Measured
N	30
Mean	0.168167
Median	0.16800
TrMean	0.16792
StDev	0.00550
SE Mean	0.00100
Minimum	0.15600
Maximum	0.18400
Q1	0.16400
Q3	0.1700

Table 9: Descriptive Statistics Results of the Hydraulic Switch gasket using 95% confidence level.

Since a standard deviation has been obtained for the gasket that will be used in the Hydraulic Switch design, the standard deviation of the Main Conduit and the Hydraulic Switch has to be found as well. The Hydraulic Switch will be made out of the same material as the Main Conduit (ABS). The standard deviation for ABS parts will be taken from GE's Entitlement and Capability database where multiple designs and materials have been cataloged and the capability has been recorded. The standard deviation and tolerances are achieved by filling multiple fields with the part characteristic. Figure 29 shows the result of the Main Conduit which has a tolerance of $\pm$ 0.005 inches and a standard deviation of 0.00125 inches.

Process	1	Molding ▼
Process Detail	1	▼
Material	11	ABS ▼

		▼
Entitlement Database		Surface-to-Surface ▼
Expert Tolerance	0.005	▼
σ st	.00125	Thickness ▼
		English ▼
Characteristic Range	1	in ▼
Additional Part Info	3	Wall Length < 3 in ▼
Business Source	1	IndSys/EDC ▼

Figure 29: Hydraulic Switch and Main Conduit Capability obtained from GE's Capability and Entitlement Database.

Since all of the required dimensions with their tolerance and standard deviation have been obtained, their values can be inputted into the Tolerance Loop to find the appropriate gasket thickness for the Hydraulic Switch system. The Tolerance Loop consists of four main sections and Table 10 shows the first table consisting of all the parts being analyzed: Main Conduit, Hydraulic Switch and gasket.

TABLE 1 — PARAMETER INFORMATION

Yellow cells are inputs

Part Name	Part number (or spec#)	Sheet	Zone	CTQ?	Factor Description	Widen Column / Shrink Column
Main Conduit Width	A			N		
Hydraulic Switch Wi	B			N		
Gasket Thickness	C			N		

Table 10: Table of Parameters in the Tolerance Loop

TABLE 2a — NOMINAL DESIGN INTENT

Yellow cells are inputs

Nominal Spec	Tolerance Lower	Upper	Term S/L	Entightlement Std Dev	Entightlement Data Source	(Z-bench) Z-It	Std Dev %Contr	notes
3.0850	0.0050	0.0050	S	0.0013		2.86	0.6%	
2.1300	0.0050	0.0050	S	0.0013		2.86	0.6%	
0.3200	0.0300	0.0300	S	0.0055		4.03	98.9%	

Table 11: Nominal Design Intent table for the nominal and tolerances of the different parts being analyzed.

The second section in the loop has the part's dimensional information including tolerance and standard deviations. This section includes a Six Sigma Z score value which is given to each dimension; the Z score value shows which part will cause the greatest variation on the final ASM; the lower the Z score, the largest contribution to variation. Table 11 shows the second section of the Tolerance Loop. The third section in the loop is where the Ideal Response Function equation obtained in Equation 5 is used. The Ideal Mean Response calculates the compression percentage and compares it against the USL and the LSL, 80% and 20% respectively. Table 12 shows the result from the Ideal Mean Response. The fourth and final section of the Tolerance Loop shows the calculation portion for the long term Z score value.

49.219	**IDEAL** Mean Response
80.000	Upper Spec Limit
20.000	Lower Spec Limit

Table 12: Ideal Mean Response and Specification Limits of the Tolerance Loop

TABLE 2b	Summary Table -NOMINAL DESIGN INTENT					Components	
	Response						
			(Z-bench)	Worst Case Limits			
Mean	Std Dev	DPU	**Z-lt**	Lower	Upper	Z-lt	DPU
49.219	3.353	3.58E-17	8.34	33.667	64.770	2.99	4.21E-03

Table 13: Tolerance Loop Output obtained from all the different dimensions and variables in the Tolerance Loop.

Table 13 shows the output results of the Tolerance Loop. The value of interest is the Long Term Z score which, for this design a value of 8.34 is obtained. Generally, for a design or dimension that is Critical To Quality (CTQ), a minimum Z long term score of 4.5 is necessary or a minimum of 3 for a non-CTQ dimension.

4.3 Final System Results

Based on the design tested and the pressure needed to run the spray arms at the necessary RPM's, a system was created which uses a lower volume of water. Figure 30 shows the result of the new design compared to the current system.
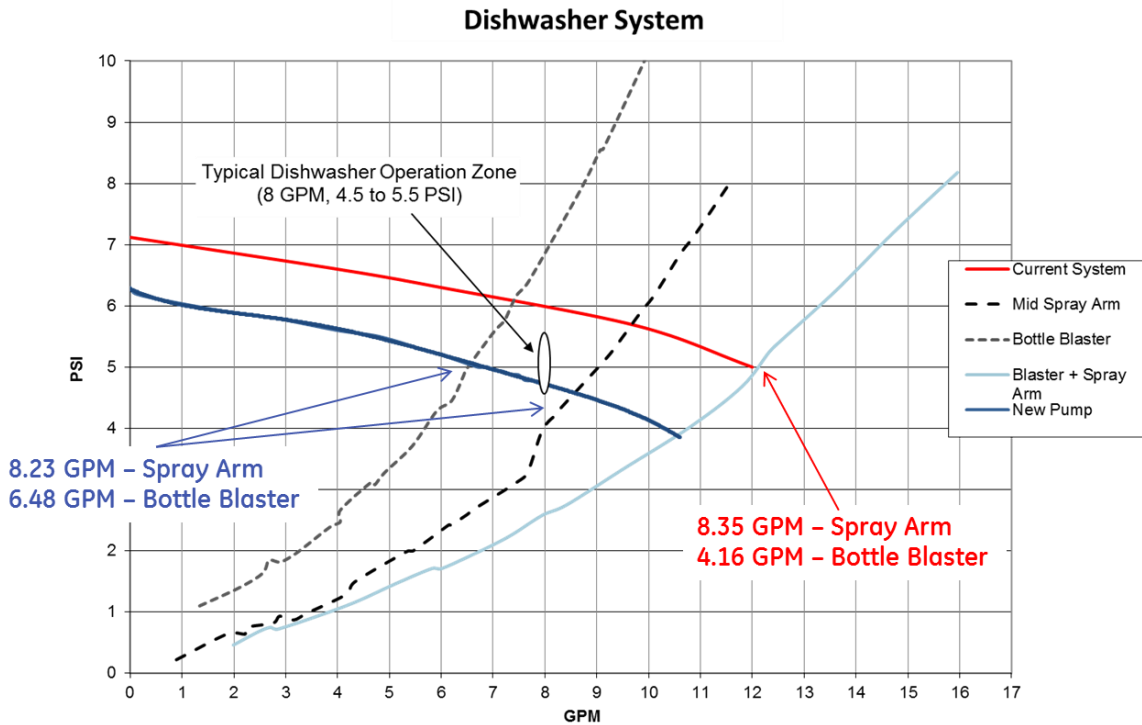
Figure 30: New System Curve for GE dishwasher with the Mid Spray Arm and Bottle Blaster with the Hydraulic Switch.

The figure above shows three curves from left to right. The first one is the Bottle Blaster system curve obtained by measuring the flow rate going through the Bottle Blaster alone. The mid curve is the Mid Spray Arms system curve and measures the flow rate against the pressure drop. The last curve shows the relationship of the combine Bottle Blaster and Mid Spray Arm in the GE dishwasher. This curve is used to determine the flow rate through the current system. The highest horizontal curve (red curve) is the pump pressure for the current system overlaid on top of the system curve for the dishwasher. The graph illustrate that it takes approximately 12 GPM to operate the dishwasher Bottle Blaster and Mid Spray Arms for proper dishware cleaning with a

system back pressure of 4.5 to 5.5 psi. The current system uses approximately 8.35 GPM to operate the Mid Spray Arm and approximately 4.16 GPM for the Bottle Blaster. The lowest horizontal curve (blue curve) is the new system pump pressure which uses a smaller pump and provides approximately 8.23 GPM to the Mid Spray Arm and 6.48 GPM to the Bottle Blaster. The new system also has better cleaning performance due a 50% increase in RPM's for the Mid Spray Arm, now 25 RPM. Also, since a smaller pump can be used, the new pump price will be approximately $12.38 which is 17% less expensive than the current pump. The power consumed by the system has been changed as well. Currently, the combined operation of the Mid Spray Arm and Bottle Blaster needs approximately 0.31 kW. The Hydraulic Switch has allowed a reduction of the system load, therefore reducing the power required by the system. The Mid Spray Arm now requires 0.017 kW and 0.014 kW by the Bottle Blaster for proper operation. This reduction in power has also allowed a decreased in pump noise by 11% from the initial 21.3 dBa output based on the pump's manufacturer specification. The cost savings and flow reduction proves the hypothesis that a Hydraulic Switch will reduce the overall cost and noise while increasing the performance through a dishwasher with a Mid Spray Arm and Bottle Blaster system. Price and noise reduction as well as an increase in cleaning performance are three items that are traditionally important to a consumer and helps them lean towards one manufacturer or another.

CHAPTER 5 – PROOF OF CONCEPT

To determine the flow that will be seen through the proposed concept, measurements were taken using FDM prototype of the Hydraulic Switch (Figure 31). The measurement was done with the water rig fixture shown in Figure 17 and using the five pressure transducers with the Data Acquisition System in Figure 21.

Figure 31: FDM prototype of the Hydraulic Switch with a quarter shown for scale

As the pump is turned on and water starts flowing through the system with the Hydraulic Switch design, a reading was obtained and shown in Table 14. The table shows the flow rate for both branches in the dishwasher as well as the pressure seen by the Mid Spray Arm and Bottle Blaster. The measured results are compared with the system's theoretical behaviors (Figure 30). The Hydraulic Switch had a maximum measured flow at the Mid Spray Arm of 7.55 GPM which is 9% lower than the predicted 8.23 GPM which operates the Mid Spray Arm and Bottle Blaster independently (blue curve, Figure 30). The 7.55 GPM seen by the Mid Spray Arm is also lower than the current 8.35 GPM in the current system. The flow rate through the Bottle Blaster with the Hydraulic Switch was measured to be 4.55 GPM. Although the flow rate through the Bottle Blaster increased by 9% from the predicted 4.16 GPM (red curve, Figure 30), it is still below the 6.48 GPM that this system should see. Aside from the flow rate, the back pressure of the system was also obtained. The Mid Spray Arm and Bottle Blaster had back pressures of 3.16 psi and 4.03 psi, respectively: both systems are still under the system performance specifications but can be improve by changing the geometry of the Hydraulic Switch to help lower the hydraulic losses due to bends in the conduit.

Flow Rate (Mid Arm) GPM	Flow Rate (Bottle Blaster) GPM	Mid Spray Arm Pressure psi	Bottle Blaster Pressure psi
0.46	0.36	0	0
1.5	0.9	0	0
1.56	2	0	0
1.83	1.23	0	0
2.1	1.5	0	0
2.23	1.63	0	1.5287
3.28	0.68	0	1.2287
3.35	0.75	0	1.3587
3.87	1.27	0	1.5287
4.1	1.5	0.0677	1.8187
4.34	1.74	0.2077	1.6187
4.69	2.09	0.2677	2.3787
4.8	2.2	0.4677	2.4587
5.3	2.7	1.2677	3.0287
5.85	3.25	1.8177	3.5587
7.15	4.55	3.1677	4.0287

Table 14: Hydraulic Switch concept data measurements

Another way to determine the flow through the system, especially through the Bottle Blaster since it experiences the lesser of the flow, is through the use of a theoretical equation relating flow through an orifice with nozzle geometry measured parameters, this equation is given by

$$Q = C_D A \sqrt{2 g \Delta h}$$
Equation 6: Flow through an orifice equation (Valvias, 2007)

where Q is the volumetric flow rate (m^3/s or GPM), C_D is the discharge coefficient, A is the cross sectional area of fluid constriction (m^2 or in^2), g is the gravitational constant (9.81 m/s^2), and Δh is the head loss difference. The discharge coefficient is assumed to be 0.6 which, in general, is taken as the standard though it varies with changes in area ratio and Reynolds number (Engineering Tool Box, 2009). This equation can be alternatively expressed as

$$Q = C_D A \sqrt{\frac{2 \Delta P}{\rho}}$$
Equation 7: Simplify flow through an orifice equation (Valvias, 2007)

where ΔP is the pressure difference (psi or N/m^2) across the orifice and ρ is the density of the fluid (kg/m^3).

The analysis of the above equation is done using the dimensions of the Hydraulic Switch; the Main Conduit attachment side has an opening of 3.085 in^2 and the Bottle Blaster has an opening of 0.238 in^2. Figure 32 represents the relationship between the inlet and outlet flow, which will be used in conjunction with Equation 7. The case will be studied where the ball is restricting flow to the Bottle Blaster (Figure 16, Step 2). For simplicity, the Mid Spray Arm will be assumed to be at the same pressure seen by the Main Conduit.
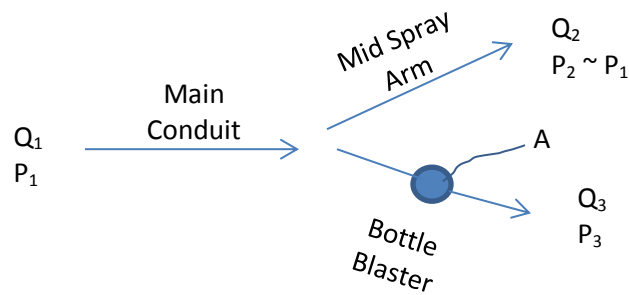
Figure 32: Flow representation for Equation 7

The calculation will focus on the comparison of the flow that will be predicted by the equation and the result obtained by the proof of concept evaluation. Equation 8 shows the known values from the experimental test into Equation 7.

$$Q=0.6\left(\pi*0.275^2\,in\right)\sqrt{\frac{2\left(4.0287-3.1677\,psi\right)}{1000\,kg/m^3}}$$

Equation 8: Inserting known values into Equation 7

Solving for the basic arithmetic and converting empirical units into SI units.

$$Q=0.6\left(1.824145x10^{-4}\,m^2\right)\sqrt{\frac{2\left(5.9364\,kPa\right)}{1000\,kg/m^3}}$$

Equation 9: Converting empirical units

$$Q=3.16891x10^{-5}\,m^3\!\!\Big/\!_s=5.0228GPM$$

Equation 10: Flow rate result for current orifice area

The resulting equation outputs a volumetric flow rate of 5.02 GPM which is 9% higher than the flow value obtained using the concept during experimental test. This difference can be accounted from the omission of friction losses due to material, surface roughness and the geometry of the Hydraulic Switch; this simplistic analysis provides a comparison between, theoretical and experimental results are when flow through an orifice is considered. The Hydraulic Switch is not meeting the flow rate value estimated by the system curve of 6.48 GPM (Figure 30). In order to determine the optimum size for the orifice area of the Bottle Blaster Size, Equation 7 will be used, with a known flow rate,

$$6.48\,GPM = 0.6 * A * \sqrt{\frac{2(4.0287 - 3.1677\,psi)}{1000\,kg/m^3}}$$

Equation 11: Substituting known values into Equation 7

$$\frac{6.48\,GPM}{\sqrt{\frac{2(4.0287 - 3.1677\,psi)}{1000\,kg/m^3}} * 0.6} = A$$

Equation 12: Rearranging Equation 11 to solve for orifice area

$$A = 1.9774x10^{-4}\,m^2 = 0.3065\,in^2$$

Equation 13: Using the area calculated in Equation 12 and solving for radius

The optimum area for achieving the 6.48GPM predicted by the system is 0.307 square inches. This area is the opening that the Hydraulic switch needs to have in the Bottle Blaster side for proper performance using the Hydraulic Switch and from it, the ball size can also be determined. In order to allow the ball to move from one end to the other inside the Hydraulic

Switch, the ball need at least 0.020 inches of clearance (Boyer, 2013). The area of the conduit end can be used to determine the diameter of the ball by knowing the clearance necessary for the ball to flow properly. Taking all of that into consideration, the ball must be at least 0.585 inches in diameter. The ball size is possible since it is smaller than the Hydraulic Switch conduit size. Figure 33 shows a linear relationship between flow rate and orifice area which demonstrates that as the area opening area increases the flow rate through the conduit will increase as well as long as Equation 7 is used with a constant density of the fluid, same pressure change and a constant discharge coefficient. Figure 33 can also be used as a quick guide as long as the conditions mentioned above are satisfied.
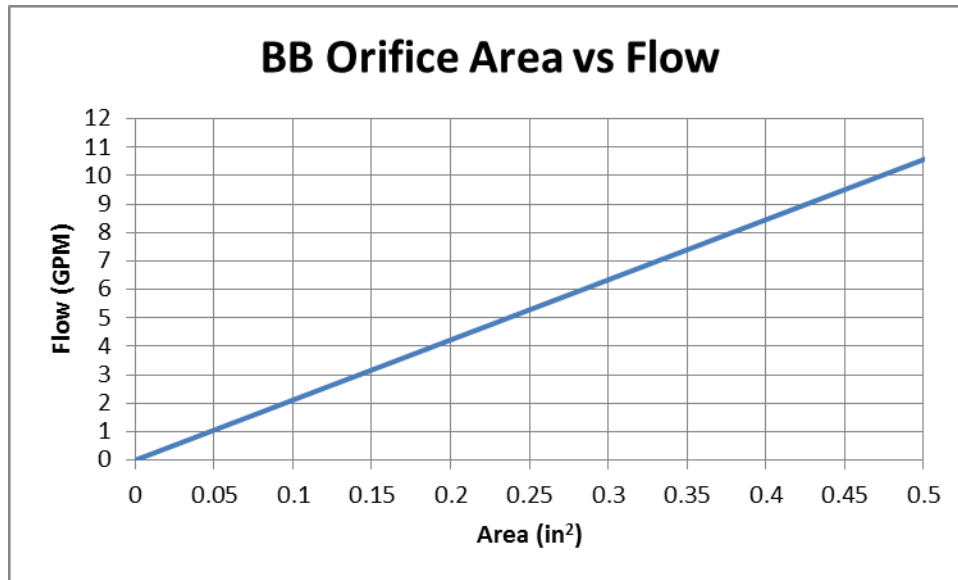
Figure 33: Relationship between orifice area and flow rate through the Bottle Blaster branch

CHAPTER 6 - CONCLUSION

6.1 Conclusion

The hypothesis was proven correct. The Hydraulic Switch lowered the overall unit cost by using a smaller pump which is 17% less expensive than the current $12.38 pump. The use of a smaller pump caused the noise level to drop by 11% to 18.9 dBa. This reduction in noise level is component wise only and does not represent the overall unit noise level. The Hydraulic Switch also caused the performance of the dishwasher to change. The revolution of the Mid Spray Arm has increased by 50% to become 25 RPM. The RPM of the spray arm is proportionally related to its cleaning performance; the higher the RPM, the faster and better cleaning of the dishes inside the dishwasher. The evaluation of the concept resulted in a maximum flow through the Mid Spray Arm of 7.55 GPM which is lowered than the 8.23GPM that a system which operates the Mid Spray Arm and Bottle Blaster independently. The 7.55 GPM seemed by the Mid Spray Arm is also lowered than the current 8.35 GPM in the current system. The Bottle Blaster experienced a similar condition allowing only 4.55 GPM. Although the flow rate through the Bottle Blaster increased by 9% from an initial 4.16 GPM, it is still below the 6.48 GPM that this system should see. When the concept experimental flow rate data though the Bottle Blaster branch is compared to theoretical results based on Equation 7, the theoretical calculation of flow through an orifice is 9% higher than the experimental results. The theoretical analysis predicts an area for the Bottle Blaster orifice of at least 0.3065 squared inches to achieve the predicted flow rate of 6.48 GPM. Aside from the flow rate, the back pressure of the system is also obtained. The Mid Spray Arm had a back pressure of 3.16 psi and 4.03 for the Bottle Blaster, both system are still under the system performance specifications but can be improve by changing the geometry of the Hydraulic Switch to help lowered the hydraulic losses due to bends in the conduit.

<u>6.2 Future Work</u>

The Hydraulic Switch still has limitations and more work is needed. The system must be used with a steady flow that provides constant pressure to the blocking ball. If the flow is insufficient during the cycle, the ball might drop down and block the other port without finishing the cycle that was initially desired. This unexpected blockage of the other port will leave dirty dishes and consumer dissatisfaction will occur. Overall, the Hydraulic Switch still is a viable option to reduce cost and noise levels in a GE dishwasher with a Mid Spray Arm and Bottle Blaster system. Future work should emphasize the cycle time of the dishwasher; currently the Mid Spray Arm and Bottle Blaster system takes approximately thirty minutes to complete a cycle. This cycle time is necessary to provide proper cleaning and sanitation while powering the Mid Spray Arm and Bottle Blaster at the same time. Even though using the Hydraulic Switch reduces the amount of water necessary to independently power the Bottle Blaster and Mid Spray Arm, it also increases the cycle time required for proper cleaning performance. This increase in time is due to the independent operation of the new system where the Mid Spray Arm will turn on to sanitize the dishes followed by powering the Bottle Blaster. Another future point that needs more research is in the field of energy usage. Energy usage for a dishwasher with the Bottle Blaster and Mid Spray Arm system is about 275 kilowatt-hours per year (kWh/yr) or 753 Wh/day. The use of a smaller pump alone under the same timing is approximately 8 Wh/day, however more work is needed to quantify power saving. Other than general performance, the Hydraulic Switch geometry can be optimized to reduce friction loss during operation.

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