Water Spray System

for Water Intrusion Testing

Final Design Report

Group 17

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Sponsored by:

Cummins Inc.

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I Executive Summary

The Water Spray System project, sponsored by Cummins, involves knowledge of many aspects of the Mechanical Engineering field. Properly combining these different aspects to create the desired final product would provide many challenges and limitations throughout the design process. In testing for something a potentially harmful to the engine as water intrusion in the electronic fuel system, it is readily apparent how imperative proper functionality of the resulting product will be.

Though it brings along its own challenges, this project demanded creativity and innovation on the part of our design team as the client had only a few requirements and constraints for the desired product. The main requirement to be addressed is the simultaneous spray coverage of a 6 ft wide by 3 ft high area that must be replicated on both sides of the engine being tested. The size of our system would largely be based off of the solution decided upon to fulfill this required spray coverage area. Apart from the various mechanical obstacles to attend to, we were also required to develop an automated control system that would accept user specified values for spray duration, spray frequency, and total number of cycles and run the system with little to no user interaction. Additional constraints of 1 gallon per minute for each nozzle as well expected ranges of values for the automated inputs mentioned above were also provided by our sponsor.

The initial stages of the concept generation and selection stage proved difficult. Taking what our team understood to be all of the product specifications into consideration, three initial design concepts were developed, some of which featured automated motion as well. However, after further discussion with our sponsor, additional design concepts needed to be conceived. This led to the design that was ultimately decided upon that features an array of six nozzles on each side.

The square spray pattern of the nozzles and manner in which they are arranged, adequately and uniformly covers the required spray area. In order to spray as desired, analysis on the piping system and the losses within the system had to be done. It was found that our system contained approximately 35 feet of total head. From this the appropriate nozzle was chosen. Also, the total flow rate requirements of the system forced our team, under the guidance of our faculty advisor, Dr. Kareem Ahmed, to include a reservoir in the system.

Upon assembly of our product, we will look to test the system experimentally to ensure that the system outputs as desired especially in regards to the spray coverage area.

II Introduction

Background

Water Intrusion is a very serious problem when dealing with engines of any kind. The term water intrusion can be used describe the problem in many situations concerning engines. This is the overriding problem involving vehicles after enduring a flood of some sort. In such instances, the submersion of the engine in water most likely caused catastrophic failure of many of the engine components. Also, water intrusion can be in reference to an engine inadvertently allowing water to enter and mix with the oil or even collect on top of the pistons in the cylinders. Running the engine under these conditions has the potential to cause irreparable damage. Water can even collect in the exhaust manifold resulting in a variety of problems in different environments.

Though these are all examples of the problems water intrusion can cause, the occurrence that is most relevant to this design project is with regards to the electronic fuel systems of the engines. Electronic fuel injection systems were developed to essentially improve upon and replace the carburetor. The numbers of functions these systems can perform are increasing as rapidly as technology is developing, however they are made up of three sub-systems: the fuel delivery system, the air induction system, and the electronic control system. This electronic control system is where water intrusion can cause significant damages. Its chief function is to determine precisely how much fuel should be injected by constantly monitoring various engine sensors. Water intrusion in these sensors can result in corrosion and short-circuiting, causing the sensor to send misleading signal data. In devices that rely on such precision, incorrect and misleading signals would pose a considerable problem for the engine and engine performance.

This problem of water intrusion is especially important to engine manufacturers such as Cummins. Considering the variety of applications and environments for which Cummins manufactures engines, from boats to emergency vehicles to the popular Dodge Ram, one can understand the need to test for and monitor any water intrusion. Cummins also specializes in related technologies such as these fuel systems so it is clear why ensuring these sensors are properly sealed is essential.

Problem Definition

Cummins employs a water spray system at their facilities to conduct various tests on engines. One specific test monitors the electronic fuel systems on engines for water intrusion. The water spray system is intended to simulate water splashing onto the engine from, for instance, a truck driving over a puddle. The system currently in use, while it does meet design requirements, is rather inefficient due to lack of automated controls and it is not as robust as they would like. A schematic drawing of this current system can be seen in Figure 1. Our task is to design a new water spray system that is more efficient and stable.

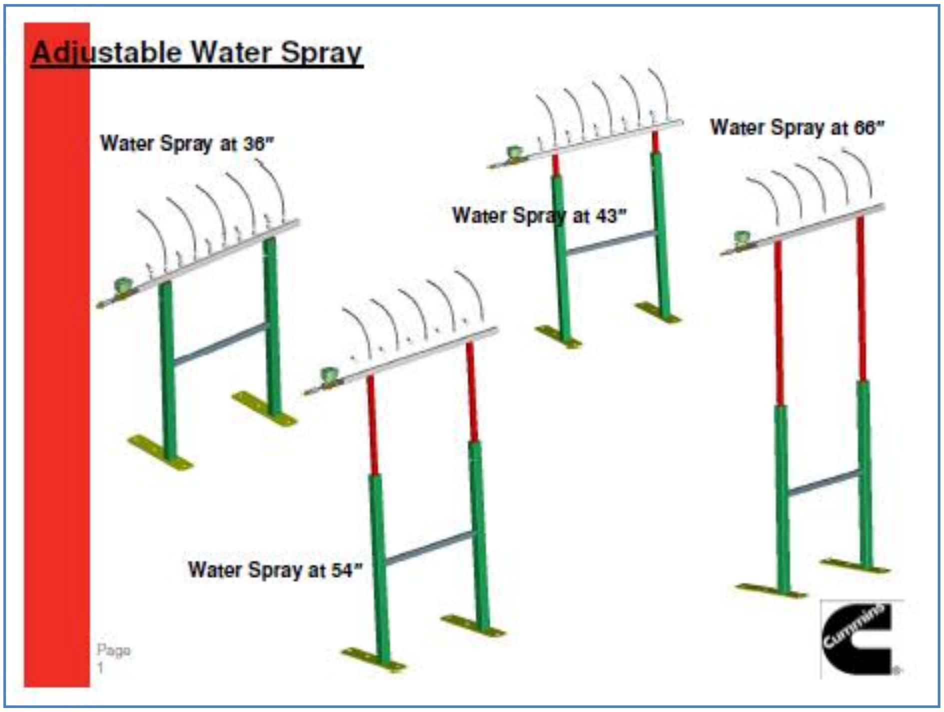

Figure 1: Current water spray system being used

Objective

The objective of this project is to "design, analyze, prototype, and test" a water spray system that includes automated, adjustable spray settings. This system is to be used in engine splash testing for water intrusion by Cummins Inc., a diesel engine manufacturer for applications ranging from automotive to industrial construction equipment and power supplies. The basic functionality of the system will be to spray for a set duration, wait for a specified time frame, then repeat for as many cycles as designated by the operator. The design will feature pipes and nozzles in an array such that every area on the engine can be sprayed simultaneously. It will also have an automation feature that allows for spray duration and frequency to be adjusted. The motivation behind this design project is to reduce the need for human-system interaction resulting in more efficient testing.

III Product Specifications

This project has involved many discretionary decisions on the part of the design team which was only furthered by the sponsor's limited requirements and constraints. However few they may be though, they must be addressed and held under consideration throughout the entire design process. The project description provided at the very beginning of this process detailed many of the design specifications that our group should plan for. However, it was through interaction and dialogue with our sponsor representatives', Alex Dugé and Andrew Zac-Williams, that these specifications were clearly communicated. We had many questions regarding the requirements. Do the engines need to be sprayed on both sides at once? Does the spray coverage area need to be simultaneous? What method of interfacing the spray system with the automated control system is preferred by the sponsor?

As mentioned previously, one of the chief requirements of the resulting product is that it must be capable of spraying a 6 ft by 3 ft area simultaneously. Additionally, this spray coverage must be replicated on both sides as both sides of the engine will be our target areas. Many of our design specifications do not have a concrete value associated with them but to appropriately design our system, a range of expected values was given. The structure had to be height adjustable from 3 ft to 6 ft as well. Also, in order to increase the efficiency of the testing, the client required that the spray settings, both the duration of the spray and the frequency with which it will spray, be automated and adjustable. Our group was instructed to anticipate and design for a spray duration of approximately 10-15 seconds. Also, the frequency mentioned above is in reference to the elapsed time between sprays. Our group was instructed to expect this value to be roughly 15 minutes. The final specification given to us by the sponsor was for there to be a volumetric flow rate of 1 gallon per minute for each nozzle. As a basis for design, the inlet water pressure is expected to be 40-60 psi.

The remaining variability in the system was up to the discretion of our design team. However, while these details and components were subject to our choice, their selection was typically dependent on their ability to satisfy the other design specifications. The mode of liquid supply was to be based on our control and flow requirements. The number of nozzles to be used was also at our discretion as long as the spray coverage requirement was satisfied. This was also the case with our spray pattern with the additional goal of obtaining an even spray coverage over the target area.

Below in Table 1, all of the design specifications and their respective requirements or expectations have been listed. Organizing the design specifications in such a way allowed our group to develop design concepts and easily determine if said concepts would be appropriate or even feasible. The importance of having a clear grasp of the each of the parameters around which to design and build our product is highlighted by this table.

Table 1: Summary of Design Specifications

Specification	**Requirement**
Spray Coverage	3 feet x 6 feet
Flow Rate	1 gpm per nozzle
Automation	Spray Duration/Spray Frequency
Height Adjustability	Between 3-6 ft
Structure Stability	Very Stable
	Expectation
Spray Duration	8- 15 seconds
Spray Frequency	15- 20 minutes
Inlet Water Pressure	40-60 psi
Nozzle Count	Enough to cover target area
Mode of liquid supply	Dependent on control /flow requirement

During subsequent teleconferences with our sponsor representatives, additional requests were made of the final product. One feature that requested was that portability be taken into account. This stems from the fact that once the final product is created, it must be shipped to Cummins' facilities in Indiana. By designing the system to be portable, both cost and space factors of shipping will be addressed. In addressing the space factor, another request of our sponsor will be met and that is ease of storage. Our representative expressed the need to be able to store the broken down system in a confined space when its use is not required. In the spirit of efficiency, the sponsor added that they would like the ability to turn off one whole side of the spray structure. If, for instance, only one side of the engine need be tested, the additional water waste from other side of the structure can be avoided. It was also asked of us to attempt to make our product able to be stored easily. The final request made was to design the system such that its re-assembly was relatively easy, a request that our design team had already anticipated and sought to fulfill. These requests are not quantifiable but must be taken into consideration when generating design concepts and selecting materials.

IV Design Concept

Concept Generation and Selection

The concept generation stage of the design process for this project was not as smooth as our group originally anticipated. Prior to understanding that the whole spray coverage area needed to be maintained simultaneously, our group developed a few initial concepts. These concepts had distinct differences but one feature they shared in common was the implementation of a single nozzle. A couple of the concepts moved the single nozzle using automated motion on the X-Y vertical plane. The motivation behind these two concepts was test repeatability and preciseness. The third initial concept was the most simplistic approach, using a rigid arm that could be manipulated into the desired position and orientation. Upon clarification of the simultaneity of the spray coverage area, these concepts were immediately discarded as they did not satisfy a vital design requirement. These three discarded concepts can be seen in the figure below.

Figure 2: Initial, discarded design concepts

Back at the proverbial drawing board, our group then began developing the concept that we would ultimately decide to use. This design features a fixed array of nozzles. The nozzles and pump supplying water to them would be operated via a control system to be decided upon as well. Due to our resulting time constraint and the understanding that modifications will be made to optimize our design throughout the design process, our group decided it would be prudent to select this concept as the basis for our final product. We were all in complete agreement that, with this design, we would be able to satisfy each of the design requirements given to us by our sponsor fully and effectively. The array of nozzles could be arranged such that it covers an 18 square foot area at the desired height with some adjustability permitted in the coverage height. The selection of the pump and nozzles could be such that a volumetric flow rate of 1 gpm can be attained. In order to be able to automate the spray settings, solenoid valves would be implemented and controlled in sync with the pump by some sort of control system. Also, with the removal of the automated motion aspect of our previous designs, our focus could be centered on the optimization of the mechanical and dynamic fluid transportation features of the project. The first generation of the design, a basis upon which modifications could and would be made, can be seen in the Figure 3. The transparent projections onto the block in the figure represent the expected spray coverage of each individual nozzle based on the system pressure and nozzle performance specification.

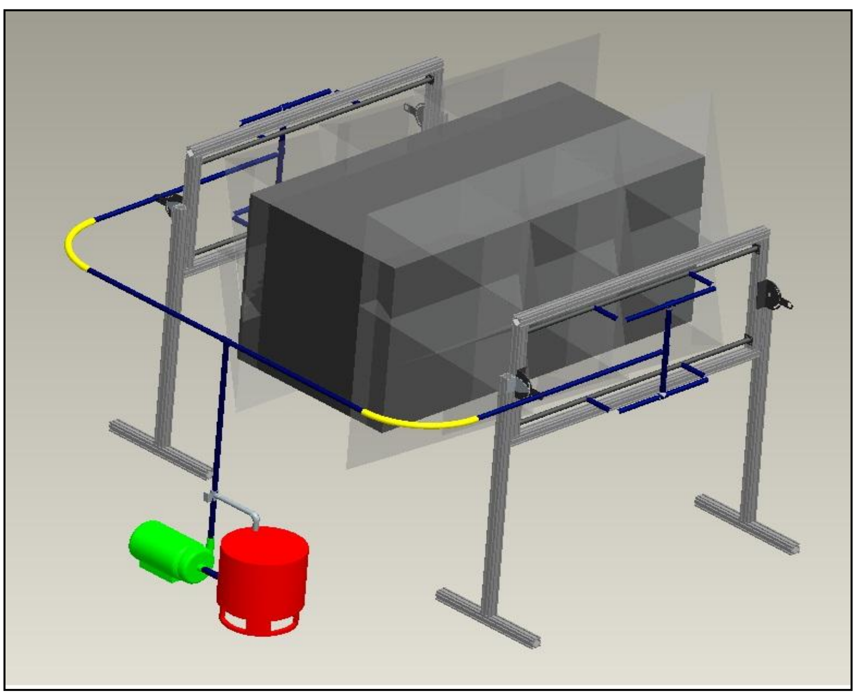

Figure 3: First generation of final design concept

Since the complexity of the automated motion feature had been removed from this concept, our group looked to increase the adjustability allowed in the system for a wider range of application. Originally, the individual rows of the arrays could be height adjustable by use of flexible tubing. Also, a custom tilting bracket was going to be created to be able to adjust the array to the different styles and shapes that Cummins engines come in. After continued talks with our sponsor, it was discovered that modifications could be made before arriving at the final product.

Final Design

Though we realized that some modifications were going to be necessary, our group was very pleased with the closeness with which our final constructed product resembled our 3D Pro-Engineer model created last October. This likeness can be seen in the figure below.

Figure 4: Initial construction of final product

As mentioned above, when discussing our first generation design with our sponsors it was found that, while increased adjustability was useful and convenient, the marginal benefit gained by the proposed adjustable features was not significant enough to incur the additional cost and loss in stability.

The tilting feature of the array was deemed to fall into this category. The intent behind this feature was to be able to conform to both inline and V-style engines. However, it was revealed to us by our sponsor that approximately 90% of the engines manufactured by Cummins are inline and therefore rendered the tilting feature unnecessary. Additionally, it was decided that the rows of the arrays should remain largely rigid. After calculating the spray coverage of each individual nozzle, incorporating an appropriate amount of spray overlap for design margin, and correctly positioning the nozzles, the rigid array more than satisfies the simultaneous spray coverage area requirement. Our sponsor encouraged us to attempt to reconcile simplicity with proper, required functionality.

After making these appropriate modifications to our design, our group arrived essentially at the design pictured in Figure 4. This final design consists of several features that all contribute to the performance of the system. Each of these features will be described in detail along with highlighting their contribution to both the system as a whole and to the individual design requirements as laid out by Cummins.

It seems reasonable to begin by detailing the structure chosen. For our beams that make up the bulk of the structure, we chose to use slotted extruded 80/20 aluminum. This selection was based on a variety of reasons. Firstly, the slotted feature of this material makes it ideal for construction and assembly. As a corollary, disassembly is also made easier due to the slots. Though the individual rows of the arrays are to remain rigid, the slots allowed for a bit of design margin in case the experimental spray coverage fell short of its expected theoretical coverage. Also, operating in such a moisture-rich environment demanded a material resistant to corrosion, a inherent quality of aluminum. Other inherent qualities, such as being lightweight and its high strength-to-weight ratio, of aluminum also contributed to its eventual selection. As shown in Figure 5, the extruded aluminum composes the base, vertical beams, and horizontal crossbar of the structure. The base was designed to be 2 feet wide. This wide base combined with the sturdiness of the material resulted in a rather stable, robust structure.

Figure 5: View of bare structure

Continuing on from the structure, the arrays of nozzles were carefully designed and constructed. The horizontal components of the arrays are made up of aluminum as well. In addition to the desirable qualities outlined above, the welding capabilities of aluminum contributed to its selection. The bars are hollow to allow the water to travel through. Aluminum caps were welded on to the ends of the hollow pipes to create a seal. The pipes were then fitted into custom-made sleeves that, in turn, connect to the slotted aluminum vertical beams. The sleeves were then each outfitted with set screws to restrict the hollow pipes from rotating due to torque caused by the weight of the piping hanging on the rear. Figure 6 shows a close-up view of one of these sleeves.

Figure 6: Aluminum pipe sleeve connection

To connect our nozzles, the aluminum pipes were notched and a custom-made attachment was welded on to reduce the outlet orifice to a threaded size that would fit our chosen nozzles. The nozzle choice was one that would affect many parts of the system; therefore the decision was an important one. Our first decision was to utilize spray nozzles with a full, square spray pattern. The full cone spray pattern would require more nozzles per side and additional overlap to account for the inherent gaps created by aligning circles together. With the square spray pattern, any overlap would result from desired design rather than necessity. The nozzles we chose are designed with a 75° spray angle and fit a pipe size of 3/8”. The calculations performed to determine the spray coverage of an individual nozzle and to properly position the nozzles so that the spray coverage area requirement is met for a given back pressure and flow rate can be found in the Appendix section of this report. Based on these calculations, we determined that we would need 2 appropriately spaced rows of 3 nozzles wide to satisfy our requirement. The nozzles are also made up of brass because of the relatively good corrosion resistance of brass. Stainless steel nozzles would offer a greater corrosion resistance than brass but the trade-off in cost would be incredibly significant. The following image shows the array as whole.

Figure 7: One of the two nozzle arrays

The piping design is a very integral part of the system. For the material, we chose chlorinated polyvinyl chloride (CPVC). This material exhibits excellent corrosion resistance and allows for more flexure than its counterpart, PVC. CPVC is commonly found in piping applications. Its ductile nature also allows for more design margin with which to construct the system. The shape of the piping structure attached to the back of the arrays serves a significant purpose. Originally, the single inlet to the hollow aluminum pipes was at the ends of the pipes. This resulted in successive activation of the nozzles. In an attempt to encourage even filling and activation of the nozzles, the piping meets in between the upper and lower hollow pipes and distributes the water to each through two evenly separated inlets. This H-style configuration, as we have come to refer to it as, effectively tries to equalize the local pressure behind each nozzle so that we can obtain as uniform and consistent of a spray pattern from each nozzle across the array. This configuration can be easily seen in Figure 7 above. From the H-style configuration, we decided to use 1” PEX flexible tubing to connect to the pump section of the system. The flexibility of this tubing reduces some of the rigidity in the system which, in this case, is helpful. Along with the rotating ability of the SharkBite fittings which will be described shortly, this flexibility would allow for some, yet limited, variability in the width of the two arrays. This would be useful if a slightly larger than expected engine was to be tested. The additional width that can be gained as a direct result of the PEX tubing could potentially be the difference in whether or not the engine can undergo this testing. The remainder of the piping is comprised solely of CPVC.

In order to address the sponsor’s request for the ability to completely shut off either side of the structure, we decided to implement ball valves which would attach near the other end of the PEX tubing. The ball valves are also made from CPVC for consistency and both the inlet and outlet will fit threaded 1” CPVC connectors. These specific ball valves can withstand a pressure of approximately 225 psi at room temperature which will be more than sufficient to handle the pressure of our system, introducing a sizeable factor of safety. The implementation of these ball valves in our system can be seen in Figure 8.

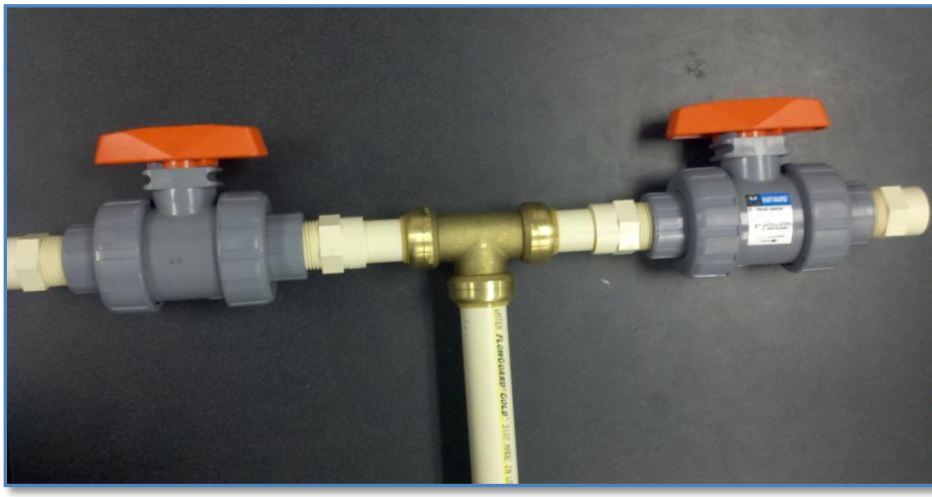

Figure 8: Ball valves used to shut off either side of the spray structure

As one may notice from the above pictures, the fittings chosen are not simple CPVC joints. Instead, at the suggestion one of our teaching assistants, we chose to use SharkBite fittings. The greatest benefit of using these fittings is demonstrated by the system's increased ease of assembly and disassembly. When inserted into place, these fittings provide a watertight, secure joint that can be removed in seconds by using the separately sold Disconnect Clip to push on the fitting's release collar. A diagram of one of these SharkBite fittings can be seen in Figure 9. The grab ring exerts a strong force on the inserted pipe, the strength of which is demonstrated by the cutting marks on the CPVC when it is removed. As was already mentioned, the pipes are free to rotate within the fitting while maintaining a secure connection. These fittings become extremely useful in providing a margin of error to the system.

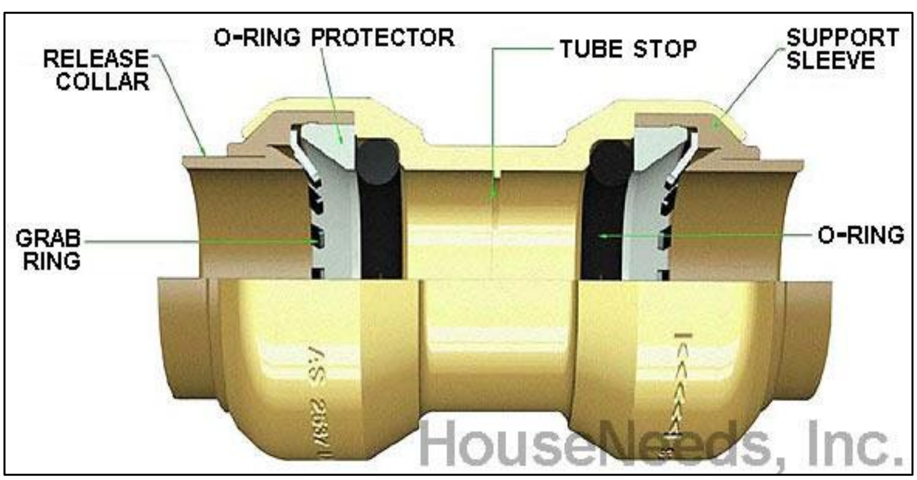

Figure 9: Schematic of SharkBite fitting

One feature that was added by our group to increase the ease of calibrating the system was a spring activated flow meter just before the system splits to the two sides. This flow meter is simple and made of plastic but serves its desired purpose. By attaching it directly to the outlet of one of the solenoid valves, the user can easily manually calibrate the system to either 6 gpm or 12 gpm by sight by adjusting the solenoid valve using the screw handle.

Solenoid valves were a necessary component in our system the way it was designed. These, along with the pump, are to be operated via our control system. We have incorporated two solenoid valves in our system. One, described above, releases the water to run to the two sides of the structure. The other, diverts the water to our water reservoir as a part of our recirculation system to be discussed shortly. These valves will alternate between open and closed opposite of the other, meaning while the recirculation solenoid valve is open, the other solenoid valve will be closed. The valve bodies are composed of glass-filled nylon which results in a lightweight, cost effective valve selection. Similar valves made of CPVC cost nearly 10 times their nylon alternative. The configuration of the two solenoid valves and flow meter can be seen in Figure 10.

Figure 10: Solenoid valves and flow meter configuration

Operating in synchronization with our valves will be our pump. To help determine the appropriate pump to be used, we employed the use of a pump performance graph for pumps of increasing horsepower that relates flow rate to total head in the system. This graph has been provided in Figure 11. We determined the total head in our system to be approximately 35 feet when you consider the length and diameter of piping traveled added to the pressure losses associated with our various valves and nozzles. Again, these calculations can be found in the Appendix section of this report. According to the graph, this value of total head along with our known maximum flow rate of 12 gpm indicates that a pump rated at 1/3 HP would be needed. We selected a 1/3 HP centrifugal pump which, according to its product specifications, will provide a flow rate of 11 gpm at 40 feet of head. Centrifugal pumps are useful for applications that involve low pressures and relatively high volume flow. Being that our flow rate requirement did not demand precisely 1 gpm, this pump is well suited for this application.

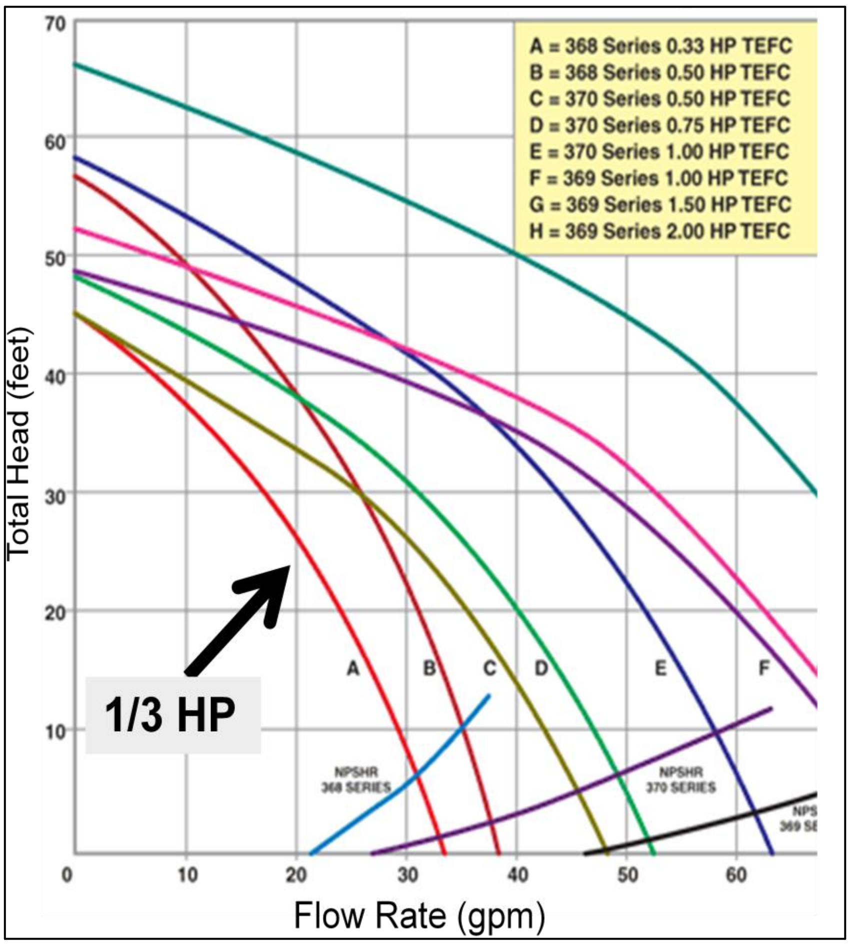

Figure 11: Pump performance graphs for pumps of varying horsepower

A quick comparison of the 12 gpm required at full spray and the flow rate provided by a city line raises cause for concern. While the volumetric flow rate from a city line varies from city to city, the potential for interruption in supply is something to take into consideration. The pump we have chosen will suffer serious damages if run dry, therefore an interruption in water supply could cause a failure in our system. It is for this reason that we have decided to implement a water reservoir in our system. By doing this, we can not only maintain a more consistent volumetric flow rate but also guarantee the user time to act accordingly in the event of an unexpected interruption in water service. We have also, as mentioned above, designed a recirculation system involving the pump, reservoir, and solenoid valves that will simply divert the water back to the reservoir while the pump is busy priming. To prevent overflow in the reservoir, which would be highly undesirable, the inlet hose will be attached to a space-saving nylon float valve that will be hanging near the top of the reservoir. When the water level reaches the valve, the float will be pushed up, restricting the water flow completely. This particular float valve was chosen due to space restrictions making the use of a rod and lever difficult and cumbersome. This recirculation system is depicted in Figure 12.

Figure 12: Recirculation system

This design group has learned throughout this design process to understand the need and importance of continual re-design for optimization. Sometimes adjustments and modifications to the design need to be made to account for the difference in theoretical expectations and what actually occurs. This is demonstrated by the changes made to the position of our recirculation system. The details of the testing will be outlined in the next section; however the pressure losses due to the water traveling vertically approximately 4 feet before splitting necessitated the elevation of our pump and reservoir by means of saw horses and a custom-made shelf. By doing this, we were able to increase the nozzle output performance much closer to what was desired.

Due to the moisture-rich environment and presence of electrical components, a method of shielding the pump and circuitry from the water spray was needed. We have chosen to use Plexiglas to perform this function. The transparency of the material will allow for continued viewing of structure and test bed.

Accordingly, one of the parts needing the most protection from water was the control system. Our control system consists of an embedded system, which for our case will be the computer, a control board, electromechanical solenoid valves, and our pump used in conjunction with a relay. We chose to use a Dragon 12-plus board due to familiarity and known functionality. We originally attempted to use a micro-dragon board. It has the same processor as the Dragon 12-plus board but it is much simpler. However, after developing the code for the micro-dragon board, there was an issue with the serial communication interfacing (SCI). Therefore, despite having far more capabilities than needed for our system, we chose to use the Dragon 12-plus board. The control board being used can be seen in Figure 13. Though our solenoid valves and relay are all rated at 24 VAC we explored the possibility of using a 12VDC power supply. Through testing, we were able to determine that each component reliably energized at an approximate voltage of 11.7 volts. This is lower than the RMS voltage which should reduce the possibility of overheating the coils. Calculations for the equivalent RMS voltage can be found in the Appendix section of this report. It was concluded that the results of this testing confirmed that a 12 VDC power supply would be sufficient for our use. The current necessary to power them all was less than 1 A which allowed us to use a single power supply. However, in order for this to work, we needed to construct a circuit on a proto board which would allow us to divide the voltage and current across all three. A zener diode was used to prevent back EMF and protect the circuit. The proto board was then connected to the three pins on the control board and to a common ground with the power supply. When the code is run on the control board, it sends a signal to the pin which allows the circuit to be completed to the power source for the valves and relay. The relay then allows the 120 VAC power supply to be completed, turning on the pump.

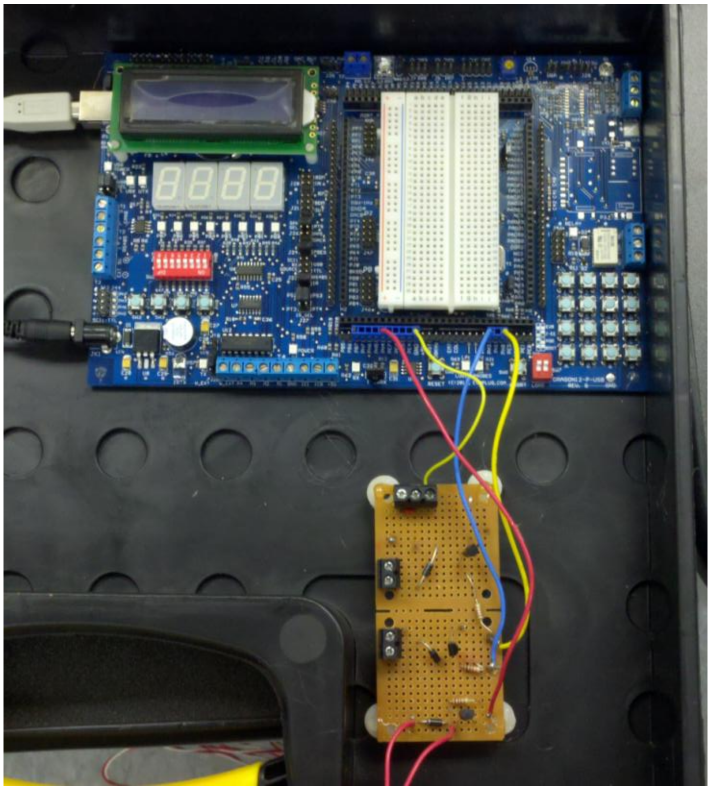

Figure 13: Control Board in protective box

At the suggestion of our sponsor, we initially considered the program LabView for the SCI. Unfortunately, after much research and experimentation, it was concluded that this was not a feasible option with our control board. As a solution to this issue, we decided to employ the use of a hyperterminal. Hyperterminal programs come standard on all Windows operating systems up to Windows XP and can be easily downloaded on the more recent operating systems. Though operation of the control system using the hyperterminal might require additional steps, it is very simple to use and it effectively performs the tasks required by our sponsor.

Once the board is reset, the code is programmed to prompt the user for spray duration (seconds), spray frequency (minutes), and total number of cycles. The code will then begin the test accordingly and output the current cycle the test is on. The source code is relatively simple. Once the test has begun, the program will first enter recirculation mode for a predefined prime time. After the pump has reached steady operation, the recirculation valve will close and the valve opening up the rest of the system will open. Accounting for the elapsed time needed to reach full blast from the nozzles in the source code, the system will spray for the specified duration. Once this operation has been completed, the pump will then turn off and the valves will return to the recirculation mode. This will last for the length of the specified frequency time. That will complete one cycle and the test will repeat for the designated number of cycles. A flowchart outlining and tracing the program's logic can be found in the Appendix section of this report as well as an example of the hyperterminal output interface. In addition to the protective Plexiglas, the control board and related components are housed in a water-resistant box.

V Testing and Analysis

The interesting nature of this particular project involved very little quantitative analysis in the design phase of the process. However, it was not completely void of some necessary analysis. Most important in this was the selection of the appropriate pump. An analysis of the pressure losses throughout the system provided us with a point of reference on the pump performance graph in Figure 11. This method certainly streamlined the pump selection process and resulted in an appropriate and relatively cost-effective pump. Analysis also needed to be performed on the nozzle selection to determine the arrangement and number of nozzles needed to fulfill the spray coverage area requirement. Again, these calculations can all be found in the Appendix section of this report.

Static testing of the system could be performed as well. These tests were directly related to the requirement that the system be very stable. The most effective test for this would be a tipping analysis. We were able to digitally measure the critical angle of tipping backwards to be 15°, as backwards would be the most likely direction of tipping given the weight distribution. The weight of the structure and connected components were all centered within the base of the structure increasing the stability of the system. During dynamic testing of the system, these results would be confirmed as the structure showed no signs of tipping potential. The greatest danger for tipping would result from someone forcing it themselves.

Beyond these initial calculations, much of the analysis was a direct result of the testing performed once the system was constructed. It is for this reason that devices such as a flow meter and adjustable flow valves are so useful. Manual calibration of the system is reduced to simply turning a handle until the flow meter reads the desired output.

Initial testing of the system, provided positive results considering it was, in fact, initial testing. This initial testing involved the mechanical system only. The valves were operated using their manual overrides. The first sub-system test was fittingly on the reservoir and float valve. The test yielded the expected result. The hose, attached to the top of the float valve, supplied water to the reservoir without issue and the flow did indeed cease once the water level in the reservoir reached the float valve. These results were certainly repeated in every subsequent test. The next test was used to validate that adjusting the solenoid valve would result in proportional changes to the flow rate. This could easily be done by monitoring the flow meter readings. According to our tests, the system had no problem outputting the 6 gpm flow rate for a test of half of the system. However, under full operation, it seems that the system was only able to output a flow rate just short of the desired 12 gpm. While it was discussed that an exact flow rate of 1 gpm was not necessary, it is the standard upon which we based much of our design and component selection. Our group did notice a slight drop in our maximum flow rate from day-to-day. The first tests achieved approximately 11 gpm, then, despite little change to the water transportation system, this value dropped to 10gpm. We are still searching for both the cause of this and a potential solution. Moving along the system, the next test involved the effectiveness of the ball valves. They both operated as anticipated without any leaks. This leads to our next test and that is verifying that there are no leaks in the system. The SharkBite and other fittings all seemed to seal well with the use of special cement for the CPVC to CPVC connections and nylon tape for the threaded components. There was one noticeable leak at the outlet of the water reservoir. As with a hose connected to a spigot, these connections are difficult to seal completely. Our group will continue to employ different methods to obtain a tighter seal, however a small leak might be conceded.

All of these previously described tests seemed to confirm what our group was expecting. The remaining testing would be that which will determine if our system meets the client's needs or not. A few items were to be monitored in this phase of the testing. Firstly, is the elapsed time between opening the system valve to reaching full, steady spray a reasonable amount of time? It is expected that once the system opens, it will take time to be filled and begin spraying at full blast. It is also expected, due to gravity, that the bottom rows of the arrays will begin to spray well before the top rows. Our goal as a design group is to minimize this lag time as best we can. We have incorporated a check valve leading the upper rows of the arrays that will prevent the top from draining which will streamline the spray activation from all nozzles. Additionally, once the spray has reached full blast, the anticipated spray pattern of the individual nozzles will be evaluated. In our mechanical testing, the spray pattern looked precisely as desired during operation of half of the system at 6 gpm. However, due to the flow rate being not quite 12 gpm, operation under fully open conditions yielded a spray pattern that was not as full and complete as desired. Despite this possible setback, the system still covers an 18 square foot area rather completely and evenly. Therefore, while our group will continue to look for ways to reduce the pressure losses in the system in hopes of raising the maximum flow rate slightly, it does operate as required by our sponsor.

Electrical and computer testing had to be conducted as well. Before even connecting the control system to the components to be controlled, the source code and hyperterminal method was tested and positively validated using LED lights to represent the separate controlled components. Also, our two solenoid valves and relay for the pump all operate at a nominal voltage of 24 VAC. Rather than purchasing a 24 VAC power supply which seems to be relatively uncommon, we calculated the RMS voltage to be 16.9 volts. To prevent overheating of the coils, a 12 VDC power supply was desired. We tested each device using a DC power supply. They all seemed to activate reliably at an approximate voltage of 10.7 volts. Therefore, a slightly higher 12 VDC power supply would be appropriate.

VI Expenses

For this project, our budget was set at $2000. Due to the nature of the project, no fundraising was necessary as $2000 would turn out to be an ample amount. Upon first glance at the project, it was expected that the most costly item to be purchased would be our chosen pump. It is for this reason that it was imperative to find the appropriate pump at the most cost-effective price. Fortunately, we were able to purchase a pump for under $400. We were also extremely fortunate to have all of the extruded aluminum donated by Dr. Oscar Chuy from the surplus in his Mechatronics lab. This donation saved our group a significant amount of money, without which we might not have remained within budget. The table below shows a condensed form of our purchases.

Table 2: Condensed expense report

Part	Quantity	Price
1/3 HP Centrifugal Pump	1	$374.55
Valves (Solenoid and Ball)	4	$226.73
Piping/Tubing (CPVC and PEX)	48 ft	$97.40
3/8" Brass square spray nozzles	12	$119.04
SharkBite fittings	23	$333.67
MicroDragon Project Module	1	$55.00
Flow meter	1	$64.23
Brackets for extruded aluminum	16	$98.88
Water reservoir	1	$20.00
Saw horses, shelf, and plexiglas		$45.00
Additional Electrical Components	3	$29.35
Misc Pipe fittings		$200.00
Protective box for electronics	1	$8.00
	TOTAL	$1,671.85

The most important fact to highlight is that we have managed to remain within our designated budget of $2000. With a surplus of more than $300, our group has considered including with the shipment of our system to Cummins a complete set of smaller nozzles. The higher pressure build up due to the smaller outlet orifice could potentially result in a more full and desirable spray pattern. This option has only been discussed and no alterations have been made to the system to accommodate these smaller nozzles.

VII Safety/Risk Assessment

As with any design project, it is important to assess potential risks or safety hazards and address as best as possible. The fact that these tests run for an extremely long time, fatigue is of immediate concern with regards to the pump. Given a choice to run the pump continuously or intermittently, our group agreed that considering the length of time between sprays, we would be best suited to turn the pump off during the time between spray cycles. We firmly believe that this will result in a longer pump lifetime. Also, regarding the pump and the other electrical components, we face the same problem our system is meant to test the engines for, water intrusion. This project operates in a moisture-rich environment creating a high potential for water contacting any of the electrical components in our system. To combat this, we have taken a number of precautions. Firstly, we will ensure that the wiring from both solenoid valves and the pump is securely insulated. Also, we have purchased a box in which to house our control board and associated parts. This box can be sealed to prevent any water intrusion. In order to protect the pump from the nearby spraying, we have installed Plexiglas to stand between the spray structures and the pump. Housing the pump in some way could also be considered. From a safety standpoint, there is a risk for shock by contacting the electrical components when plugged in especially in such a wet environment.

Fortunately, the pressures in the system do not reach very high values. Each component of the water transportation system, including the CPVC and SharkBite fittings, is rated well beyond the pressures encountered in the system providing a significant factor of safety. SharkBite fittings are also useful in that, in the event that one does fail, they are relatively cheap and easily replaced by use of the Disconnect Clip.

There are also a couple of environmental risks to be assessed. The first arises from the application of the system. In spraying engines, water could potentially mix with oils. This water-oil mixture must be run through a separator to be properly dealt with. Fortunately, Cummins employs its own separators in their facilities. The most prevalent environmental concern is the water waste accumulated in this testing. It was calculated that for a 1000 hour test that sprays for 15 seconds every 15 minutes, 284 gallons would be used per day over the course of about 42 days. As it was not a specified requirement of the system and due to budget constraints, a water collection and recirculation system would not be feasible. However, as outlined in the next section of this report, this could be the focus of continued work on this project.

VIII Future Work

With the design process coming to a close for this particular project, it is useful to identify areas in which further work and testing could be done. One simple modification that could be tested and analyzed was the incorporation of varying size nozzles mentioned in the Expenses section of this report. The nozzles we chose were based off of theoretical calculations and simple testing on different individual nozzles. While this resulted in an effective nozzle selection for the purpose of our system, it can be seen that further optimization can be performed. Once the structure was fully constructed, the nozzles experienced a slight degradation in expected performance due mainly to the losses in the system and gravity. Furthermore, this nozzle optimization could include a quicker and simpler method of attachment and detachment.

Further testing of different nozzles could certainly improve upon our system; however our group feels that the focus of future work should be on a means of water collection and possible incorporation of a water-oil separator. This was a suggestion made to us by our sponsor representative only if our budget would permit the additional costs. Unfortunately, our group did not feel our remaining funds would support the costs of such an endeavor. This is not to say that a method of water collection and recirculation to the system would not be useful. As described above, the water waste from a generalized test reaches approximately 284 gallons per day. This is a significant amount of water waste that could be greatly reduced or even eliminated with the implementation of such a device.

IX Conclusion

This project certainly offered many challenges and was a great learning process for this group. We discovered the importance of staying in constant contact with our sponsor at a very early stage. The main purpose of this is to gain a firm grasp and understanding of each and every need and requirement of the sponsor. Our group found that the key to gaining such a thorough understanding depends a lot on asking the proper questions, especially on any issue over which there might be some confusion. With the chief requirements being the large simultaneous spray coverage area and the automated control system, our solution of the arrays of nozzles seemed to be the most logical approach. We would then be able to control the flow through the nozzles by use of our pump which could then be operated via a control board.

Many of the challenges we face concerned the numerous components that would comprise the system in order to satisfy all of the sponsor's specifications. Not only were we faced with selection decisions for each of these system components, but also the choices on the manner with which they would cooperate with each other. To fulfill the spray coverage area requirement, it was easy to see that a nozzle featuring a spray pattern would be most appropriate. Using the provided spray angle of our selected nozzle, we were able to perform the necessary calculations to design our array. We found that, theoretically, a 2x3 array design would spray the desired area with an included overlap for design margin. Knowing our flow requirement, we were able to select an appropriate pump corresponding to the head loss calculated in the system. Through incorporation of different valves, both mechanical and electromechanical, we were able to successfully satisfy additional requirements of our system. The control system proved challenging as well since our group members had little experience with electronic hardware and programming. Through much dedicated effort and assistance from more knowledgeable sources, we were able to develop a solution to this requirement as well. Despite the developmental challenges, the control system was still able to be simplistic in operation making it very user-friendly.

Our group is quite pleased with the final product of our project. However, that is not to say that there could not have been improvements in each phase of the design process. One tendency of our group was to overcomplicate things. We were so quick to think of complex designs that we did not realize that a more simplistic design could more feasible and even complicated enough in its own right. As mentioned above, the control system, even though somewhat complex in development, turned out to be rather simple in operation. This group believes that was the direct result of lessons learned throughout this design process. One strength of this design group has been its ability to adapt. This became especially important in bridging the gap between theoretical design and actual design. The fact is that parts just never seem to match up as perfectly as one would like. When this occurred, rather than panic, our group methodically developed new and efficient solutions to the arising problems.

As far as the design is considered with regards to the final product, this group would concede that improvements could certainly be made. One situation that was discovered involved to consistency of the nozzle direction. Due to having to hand tap the threaded connection for the nozzle, a couple nozzles tilt just slightly. A new method of attaching the nozzles in a more consistent fashion would certainly add to the final product's performance. Also, though the product effectively covers an 18 square foot area, the spray pattern performance of the individual nozzles could be improved upon. A slightly more powerful pump might result in a more defined square spray pattern from the each nozzle. It would also counteract the force of gravity on the water being sprayed more effectively. This was mentioned in the Future Work section of this report but a water retrieval and recirculation system would also result in more efficient performance while at the same time being more environmentally conscious.

X References

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XI Appendix

Additional Images

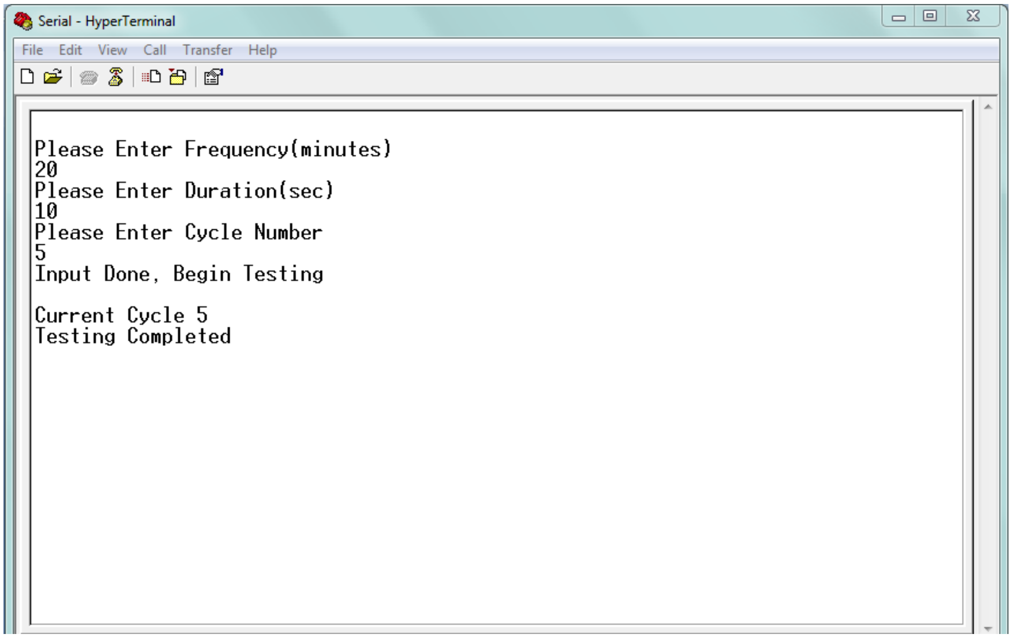

Figure 14: Example of hyperterminal interface

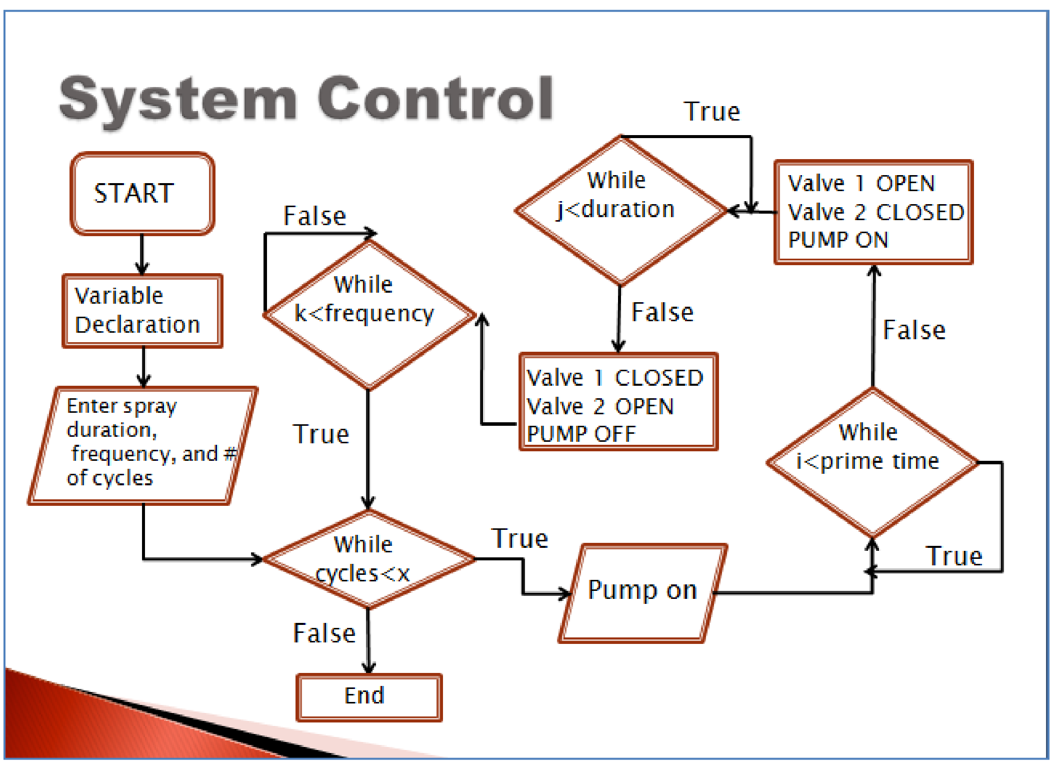

Figure 15: Flowchart representation of control system's program logic

Calculations

Individual Nozzle Spray Area

$$A_{per\ nozzle} = 4 * d^2 * tan^2(\alpha)$$

Where

d: perpendicular distance from nozzle to desired plane of spray

α: spray angle specified by manufacturer for nozzle

Total Head loss in system

$$\boldsymbol{P_1 \ = \ P_2 + \left(\frac{\rho}{2g_c}\right)({v_2}^2 - {v_1}^2) + \left(\frac{\rho g}{g_c}\right)(z_2 - z_1) + \left(\frac{fL_P}{D_h}\right)\left(\frac{\rho {v_1}^2}{2g_c}\right) + \sum K\left(\frac{\rho {v_1}^2}{2g_c}\right)}$$

Where

$$\sum K \ = K_{nozzle} + K_{90} + 3 * K_{Tee} + K_c = 5.265$$

$$K_{nozzle} = 0.1\left(1 - \frac{d_2}{d_1}\right) = 0.075$$

Equivalent RMS Voltage

$$V_{RMS} = \frac{V_{AC\_peak}}{\sqrt{2}}$$