Aquamatic Technologies

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Simon Fraser University
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March 8, 2010

Dr. Andrew Rawicz
School of Engineering Science
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Re: ENSC 305/440 Design Specifications for the *Spa Commander*

Dear Dr. Rawicz,

Enclosed is a copy of Aquamatic Technologies' design specifications for the *Spa Commander,* including but not limited to electrical, mechanical, and control aspects. The *Spa Commander* is a pool and spa water testing and treatment control system that ensures a safe water balance.

Aquamatic Technologies holds paramount the safety of the user. The design of the *Spa Commander* aims at creating a safe and intuitive automatic home spa chemical treatment system as an alternative to traditional manual testing methods. The design enclosed aims at being economically friendly by using readily available off-the-shelf parts. The cost benefits allow Aquamatic Technologies to target the *Spa Commander* towards the residential market.

The design specifications attached apply to the proof-of-concept model that will serve as a prototype for our *Spa Commander*. Possible improvements and changes for future iterations of the Spa Commander are outlined in this document, but will not be implemented at this stage of development.

If you have any questions or concerns please contact Matt Bergsma by email at: mjb4@sfu.ca.

Sincerely,

Dan Latuszek

Chief Executive Officer

Aquamatic Technologies

Enclosed: Design Specification for the *Spa Commander*

Aquamatic Technologies

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March 8, 2010

Executive Summary

The details for designing and developing our spa maintenance system are outlined in the design specifications (this includes only our proof-of-concept model). The specifications of the *Spa Commander* include, but are not limited to, the intake of spa water, the correct and continual testing of this water for pH levels and contaminants, and the administering of chemicals back into the spa. Possible problems and design improvements for future iterations of the *Spa Commander* are not discussed in this document.

Each chemical, pH Plus, pH Minus, Chlorine/Bromine, will be administered from the hoppers by DC motors driving gate valves. A PIC will control this function as described below and general software program process flow is also included. These chemical adjustments will then be pumped back into the spa to maintain clean and clear water at all times. The plumbing design is fully described in the document. The display panel will allow the user at-a-glance information about the pool water and chemical levels. Three LEDs (one for each chemical hopper) will turn on when the chemicals are running low, two LEDs will show if pH or Chlorine/Bromine is imbalanced, and one LED will turn on when the pool is safe for use. There will also be an LED to indicate power. The *Spa Commander* will need detailed testing, and a description of this test plan (for the system and the system components) is provided at the end of the design specification.

Since our team is having troubles obtaining a cost effective sensor for chlorine, and the one we ordered (analog) may not arrive in a timely fashion. We will leave the design option open for possible use of an ORP sensor – digital or otherwise. This possible change will not affect our design, outlined below, significantly.

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Glossary of Terms

Chemistry:

[x] – concentration of x

pH – measure of the acidity or alkalinity of a solution. It is equal to p[H], the negative logarithm (base 10) of the molar concentration of dissolved hydrogen ions (H^+).

Cl – chlorine (an element, atomic number 17), Cl^- refers strictly to chlorine ion(s)

Br – bromine (an element, atomic number 35), Br^- refers to bromine ion(s)

ORP – oxidation reduction potential, the oxidative capacity of a solution

Electrical and Electronics:

AD – analog-to-digital

DA – digital-to-analog

DC – direct current

VAC – Volts Alternating Current

P&ID - process and implementation diagram

PIC – programmable integrated chip, a type microcontroller

MOSFET – Metal Oxide Semiconductor Field Effect Transistor

Associations:

CSA – Canadian Standards Association

ANSI – American National Standards Institute

NSF - National Sanitation Foundation

NSPI – National Spa & Pool Institute

Process:

AO – Analog Output

AI – Analog Input

DI – Digital Input

DO – Digital Output

1. Introduction

The *Spa Commander* is designed for residential spa users who do not want to waste time testing and adding chemicals manually. The spa water will be automatically tested by our system and chemicals will be administered to adjust the water to maintain a safe standard in regards to pH and sanitizer. Considering the widespread use of home hot tubs it is surprising that there are no feasible options on the market to maintain water safety and clarity without hand testing and constant chemical additions. This document specifies the design of the *Spa Commander* to a high level of detail and will be used in the development of our proof-of-concept model.

1.1. Scope

The design specification outlines the detailed design of our chemical testing/delivery system. This document shows how the design meets the functional requirements as presented in the *Functional Specification*. All the requirements for our prototype system are considered in this report.

1.2. Intended Audience

This document will be used by Aquamatic Technologies to create our *Spa Commander*.

The design specification is intended for use as a design guideline to ensure that no requirements are left out of our final prototype system, as well; it will be used to familiarize the ENSC 305/440 markers with our product.

2. System Specifications

The *Spa Commander* will automatically detect the pH and the level of contamination in the water source of a spa or pool. The system will then analyze the readings and display whether the water is considered safe and sanitized. If the water is not adequate then the *Spa Commander* will adjust the chemical balance of the water to restore safety.

When the water is detected as unsafe, the *Spa Commander* will notify you if the pH level is out of the safety range and/or the water is not sanitized. In addition, it will adjust the chemical levels in order to restore balance in the water. The *Spa Commander* will also display a notification if the chemical supply is low.

Theoretically, by the use of an ORP sensor as will be described in this document, any type of sanitizer can be used. However, we will only consider the two most common sanitizers: Chlorine (Cl) and Bromine (Br).

3. Design Overview

This section covers the electrical and mechanical design of the *Spa Commander* home spa water treatment system. Also included are details regarding pool chemistry and the overall control system.

3.1. Control Specification

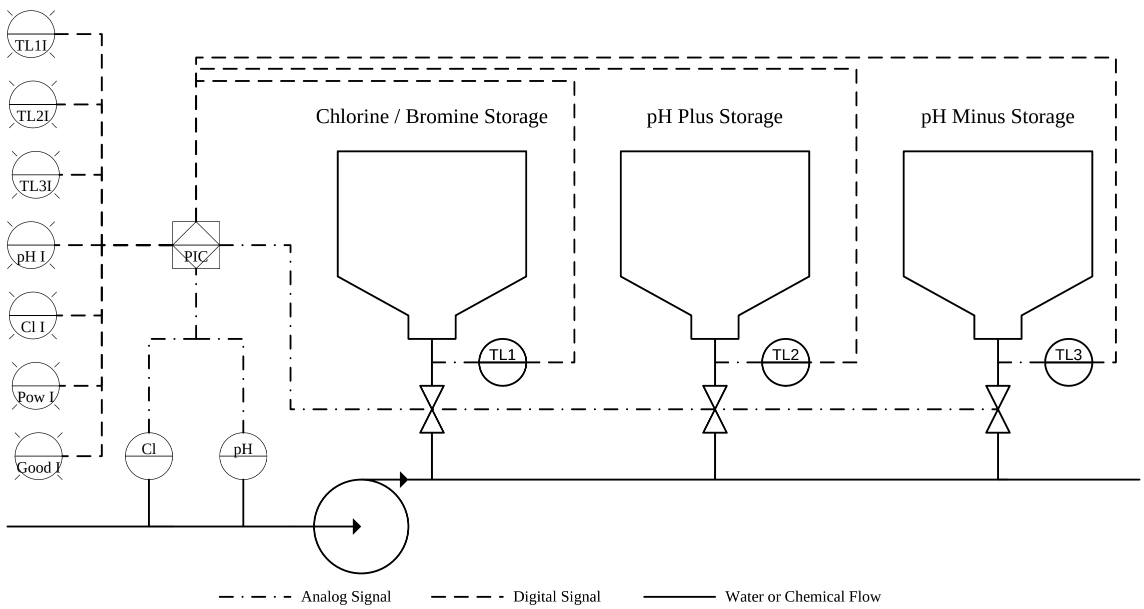

Figure 1 - P&ID of Spa Commander

A P&ID of the control design is shown in the figure above. As water flows through our system, two sensors convert the chlorine/bromine concentration and pH level into an electronic analog signal which feed into our PIC controller. Once there an integrated AD converts both signals to a digital equivalent. The Tank level is implemented using a binary switch and spring, which is also fed back into the PIC. The PIC control logic itself is explained in more detail below, but essentially it uses the chemical measurements and tank level measurements to determine if the current pool chemistry is safe for people to be in the pool, and if not takes the appropriate corrective action. As well, if the tank levels drop below a certain point, a light will be illuminated to allow the user to know to add more of the applicable chemical to the storage tanks. All necessary lights will be mounted to the system in an obvious way to allow the user to see at a glance the current state of the pool. When the levels are out of bounds, the PIC will send an analog signal to the applicable valve to open it up and allow a flow of the appropriate chemical to be added to the pool.

3.1.1 PIC Implementation and Flowcharts

The PIC drives the primary display and the chemical delivery systemof the Spa Commander. The Spa Commander utilizes a PIC manufactured by MicroChip capable of analog to digital conversion with an internal oscillator. The number of I/O pins of the PIC is not as important because the tank level indicators can be implemented on a separate PIC if there are not enough I/Os. Splitting the sensor signals is possible but not recommended because the amplitude of the two signals are directly related to the pH and chlorine or bromine concentration. Below is a schematic of the inputs and outputs of the PIC.

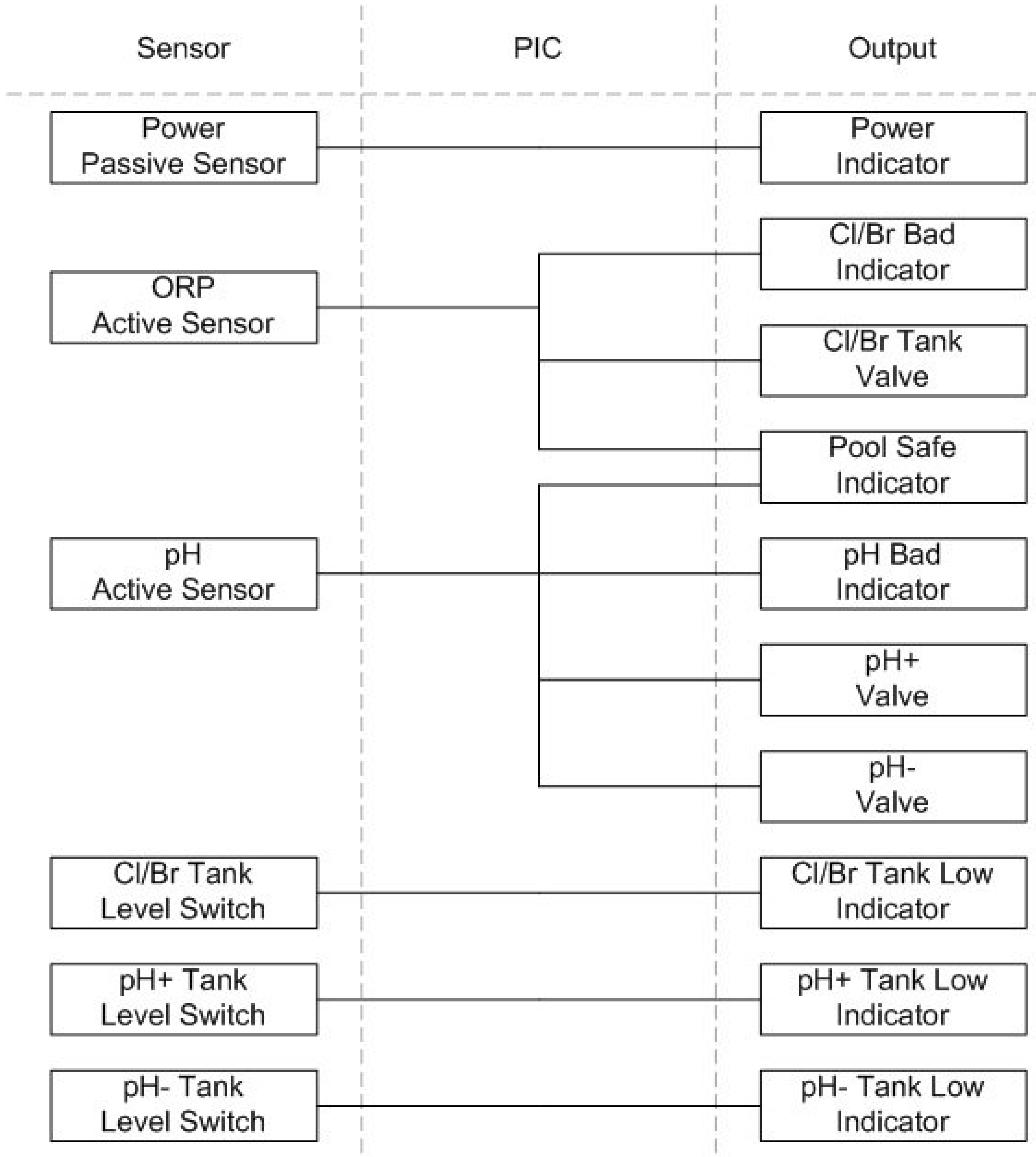

Figure 2 - Process Flow Chart

When the microcontroller determines that the pH is out of the desired range it immediately turns on the pH bad LED. It then determines how far away the current pH of the water is from the optimal value and adjusts the rate of either pH Plus or pH Minus is released. Because the container openings are controlled by analog gate valves, the outputs to the gate valves also have to be analog. Therefore, the system utilizes a PIC microcontroller capable of analog output. The output passes through an amplifier circuit to produce a value within the specifications of the motor controlling the gate valve to adjust its aperture size.

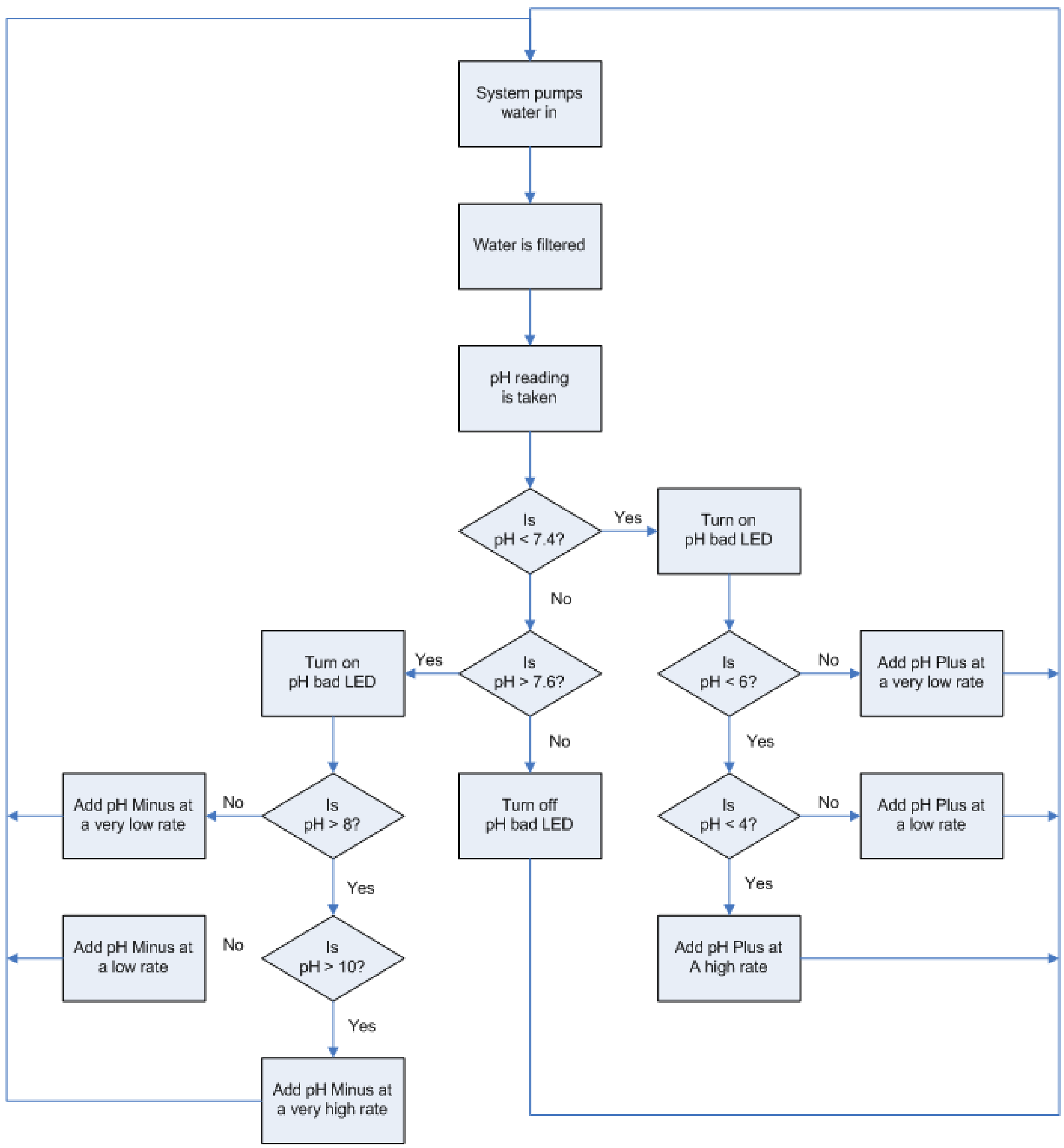

Figure 3 - PIC pH Control Scheme

The optimal pH is set as the range between 7.4 and 7.6. If the pH is between 6 and 7.4 then pH Plus is released at a very low rate (i.e. a low gate valve voltage to the pH Plus container is outputted). A low gate voltage is outputted when the pH is between 4 and 6 and a very large voltage is outputted when the pH is less than 4. A similar scheme is used when the pH is above the optimal value. The rationale for this implementation is not that the system reaches the desired pH faster but because pH is much more sensitive to small changes in acids and bases at neutral pH (close to 7). If the pH is determined to be between 7.4 and 7.6 then no action is taken and the pH bad LED is turned off. The logic for detecting sanitization levels are similar as shown in the figure below.

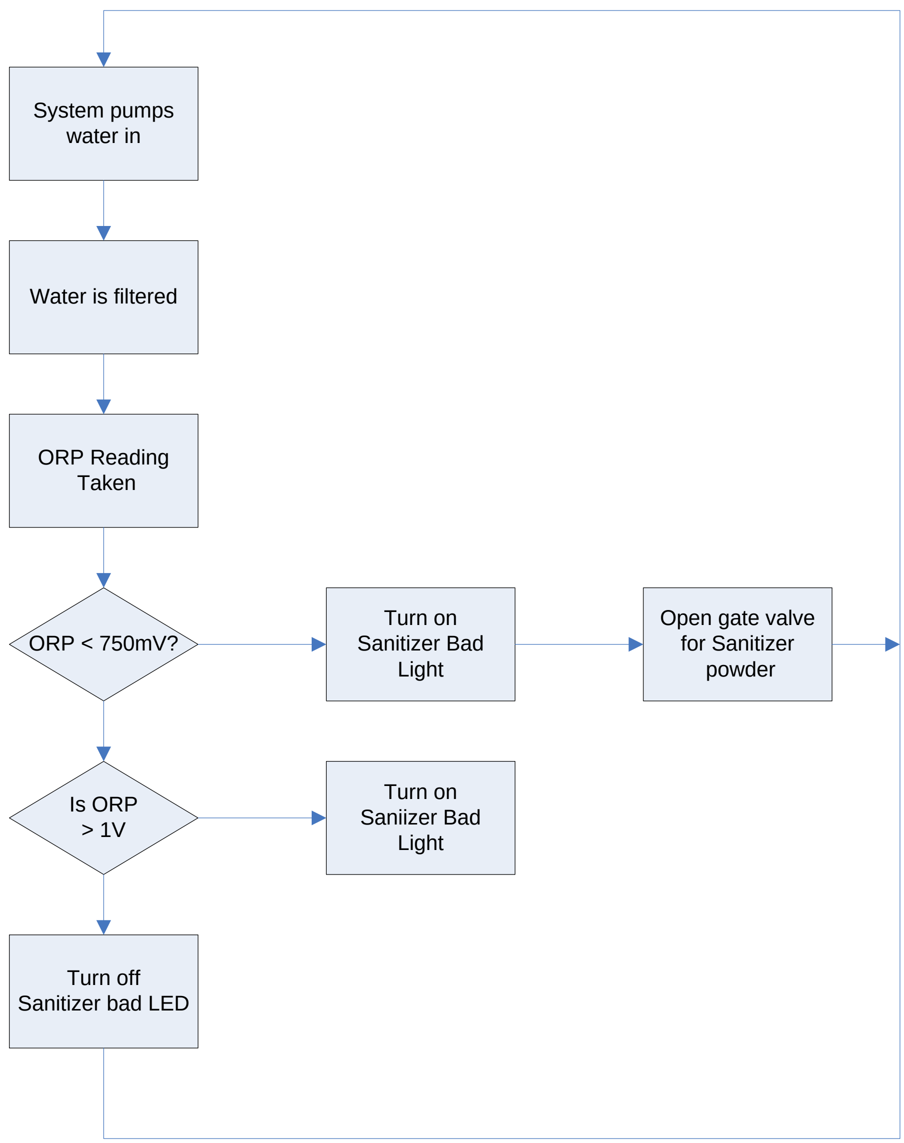

Figure 4 - PIC Sanitizer Control Scheme

Since there is only one LED to indicate that the pool is safe, this Pool Safe LED turns on only when both the pH bad LED and Sanitizer bad LED turn off. This can be easily implemented in the microcontroller using basic logic by storing the status of the pH and Sanitizer LEDs.

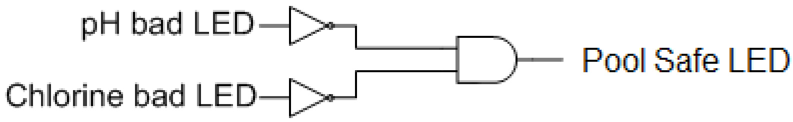

Figure 5 - Pool Safe LED logic

3.2. Sensors

This system will require a few sensors, some such as the chemical level switches will be made manually by Aquamatic Technologies due to their relative simplicity, while both of the chemical sensors will have to be purchased or acquired from a supplier due to their complexity of design. In general 2 chemical sensors will be needed to get an accurate pH level and Cl/Br level in the spa, since both need to be controlled and the Cl/Br level is useless without knowing the pH of the tank itself due to the acid/base buffer properties of the solutions.

3.2.1. pH

Acidity is a result of hydronium ions (H_3O^+) in solution and pH is a measure of the concentration of H_3O^+ in solution. H_3O^+ exists in a slight buffer with hydroxide ions (OH^-), which provide alkalinity in the solution, the governing equation of the two chemicals is

$$H_3O^+(aq) + OH^-(aq) \leftrightarrow H_2O(l)$$

With $[H_3O^+][OH^-] = 10^{-14}$ being the actual mathematical balance of the two chemical concentrations. The formula for pH is

$$pH = -\log([H_3O^+])$$

pH sensors themselves work by using an electrochemical cell and a semi-permeable membrane. The membrane allows only H_3O^+ ions to pass through it, giving a solution by the electrodes whose conductivity is directly proportional to the concentration of H_3O^+ in solution. As the spa's pH level varies, a concentration gradient between the sensor and the spa itself causes a H_3O^+ to diffuse across the membrane resulting in a change in the output voltage of the sensor. Due to the nature of the balance between H_3O^+ and OH^- and the formula for pH this is a non-linear change. This is accounted for in the control strategy for the PIC.

3.2.2. ORP

For sanitizer measurement, there are two main choices. The first choice is more expensive and works on a similar principal as the pH sensor with a semi-permeable membrane used to control chemical access to an electrochemical sensor. One potential problem associated with this the fact that they typically allow the hypochlorous ion through, in the case of chlorine or its bromine equivalent, and not the active oxidizer. This requires the PIC to handle additional code and also adds complexity.

The actual sensor that the system uses is an ORP sensor. An ORP sensor measures the oxidizing potential of a solution which is more beneficial from a control and health standards perspective.[5] Moreover, since ORP sensors are standard for pool and spa control in more expensive systems they are significantly less expensive. ORP sensors operate by comparing a voltage generated by a solution to a known standard (built into the sensor or hardcoded and replaced by a voltage inside of the sensor). The standard as adopted by the NSPI in 1988, is a minimum of 650 millivolts when chlorine or bromine are used as primary disinfectant.[6] However, we will be using a minimum of 750 millivolts due to the larger introduction of bacteria in pools and spas and also to account for any de-calibrations of the ORP sensor over time. The subsequent output voltage is proportionate to the oxidizing potential of the solution being measured. For more accurate control, the Nernst equation can be used to retrieve the precise concentration. However, since ORP sensor usage in pools and spas is well documented, it is possible to retrieve previously calculated values to simplify our implementation.

3.2.3. Chemical Level Switch

The chemical level switches are implemented by hand to create a simple spring loaded switch. While the chemical level is above a certain point, the mass of the chemicals and the container depresses a spring causing the contacts of the switch to open and generate a logical low signal. As chemicals are dispensed into the spa the spring decompresses, at a certain mass the switch closes to produce logical high signal which triggers a low tank level indicator. As the springs degrade, the mass required to change the logical low signal to logical high decreases. By setting the level at a reasonably high level (i.e. 10-25 grams of chemical weight) the indicator light is triggered before the container is completely emptied.

3.3 Mechanical System Design

The main feature of the mechanical system is the ability to control the amount of chemical that will be dispensed from the containers. The things that needed to be considered are:

- The size of the chemical containers
- The type of valves

Figure 6 illustrates how the various physical components of the Spa Commander are set up. In the diagram, the DC pump would causes water to flow into the pump from the left hand side. The pH and ORP sensors are located to the left of the pump and the three containers are located side by side to the right of the pump. The containers hold the chemicals required to adjust the pH and sanitizer concentration in the water: pH Plus, pH Minus, and Cl/Br.

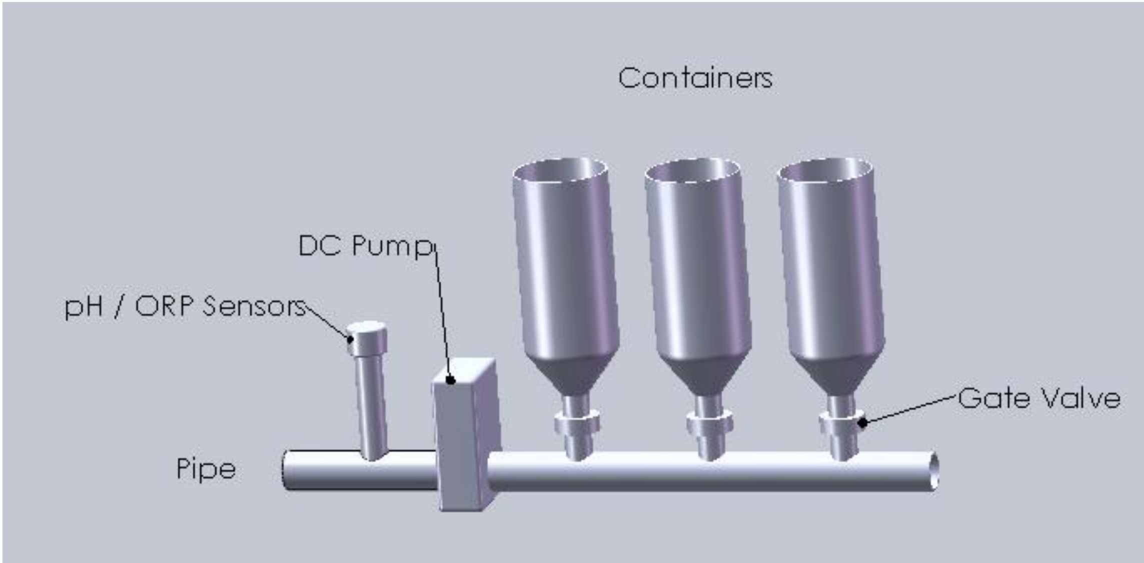

Figure 6 - Sensor, pump, and chemical containers

3.3.1 Chemical Container Design

The main considerations when it came to the design and size of the containers was deciding how much chemical should be stored. As described in the Functional Specifications, the system has three chemical containers: one for increasing the pH, one for decreasing the pH, and one for the chlorine/bromine disinfectant chlorine. It was decided that the device would store enough chemicals to last at least 3 months without refilling. We also wanted a container that would be easy to refill, meaning it will not be too narrow or too shallow. Hence our final design is a cylindrical container that is 5.1 cm in diameter and 12.7 cm in height made out of PVC piping. This allows the system to hold 500 grams of each chemical that will be used at a typical rate of 30-40 grams per week, thus giving it a period of at least 3 months between refills. The containers have a lid that prevents the chemicals from accidentally spilling out in case the system tips over. The lids close tightly but are not completely air tight as such an implementation would inhibit the delivery system which is dependent on gravity.

3.3.2 Valves

The valves must be able to operate under the load of the chemicals. They also needs to prevent water from seeping into the container from the pipe. The two designs that have been considered were a paddle wheel system that rotated and dispensed chemicals and a sliding gate valve that could be adjusted to deliver different amounts. After some research, the sliding gate valve was chosen because it would be more reliable and easier to implement.

The valve is built into the PVC pipe that connects the containers to the outflow. A small slit is made into the side of pipe and a thin but strong sheet of metal is inserted to seal the inside. The sheet of metal will be attached to a small DC motor that slides the metal in and out, effectively opening and closing the valve. To prevent any contamination from air or water, the sliding gate valve will be placed further from the outflow and the slit in the pipe will be sealed. By adjusting how much the valve opens or closes we can control the amount of chemical that will be dispensed. This design meets our requirements of simplicity and cost constraints.

3.4. Power Supply

Power is supplied to the system by an AC/ DC transformer. The Spa Commander is being designed for usage in North America so the power source will be the standard of 110 to 120 volts at 60 hertz and converted to a DC voltage as required by the electronic components sourced for the *Spa Commander*, most notably the pH and chlorine sensors. As well both sides of the source (AC and DC) will be fused with fast blow fuses to prevent damage to components in the case of any electronic failure or breach of the exterior case by water.

3.5. Safety Requirements

Safety and fail safe requirements are of major importance in the design due to health concerns and electrical hazards. It is important to ensure that chemicals are not accidentally released because they pose health risks. A fail-close safety mechanism will be implemented for the chemical gate valves to prevent the system from chemicals being released while the system is not operating. During an unexpected failure such as a power outage, the valves will automatically close to prevent chemical addition.

The *Spa Commander*'s central unit including all electrical components should be placed away from the water source to prevent any accidental water contact. A noticeable caution label is clearly placed on the unit's front cover instructing safe placement of the unit. However, this is only implemented in final production as it is unnecessary for a prototype. In addition, the water intake and outtake tubing connected to the central unit is lengthy (at least 2 metres) allowing the unit to be placed a reasonable distance away from the water source. However, the length of the tubing for the prototype may differ for convenience.

3.6. Chemicals

Three different soluble chemicals are required in order to raise pH, lower pH, and sanitize water. The chemicals must be in solid granular form to facilitate chemical diffusion as well as to keep costs to a minimum. However, slight variations in the chemicals are possible as long as they are in solid granular form. Development and optimization of the *Spa Commander* will be done using these chemicals: Sodium Hydrogen Sulfate ($NaHSO_3$), Soda Ash (Na_2CO_3), and Calcium Hypochlorite ($Ca(HClO)_2$) to raise pH, lower pH, and sanitize water respectively.

3.7. Pump

A small 35 gph (gallons per hour) flow fountain pump will be required in order to pump water into and out of our Spa Commander. Spa water will be forced into the tank by the pump for chemical sampling to take place. Then when chemicals are added to the tank, the saturated water is then pumped back out into the spa to balance it. The pump's physical size is 2" by 2" with a 0.75" valve. This will be small enough to keep our unit compact, while large enough to keep up with the water demands. The pump has an adjustable flow of at maximum 35 gph, this maximum flow is sufficient for the Spa Commander's needs.

3.8. Exterior Casing

The exterior case of the *Spa Commander* is constructed out of Plexiglas. Plexiglas was chosen because it is relatively inexpensive and malleable. It is also non-conductive which is important since the system will be used in the vicinity of water. Plexiglas also allows labels to be easily engraved during prototyping. The casing is made waterproof by use of silicon sealant although it can be substituted with another sealant as long as it is capable of preventing water from entering the system. The sealant is applied around the opening where the power supply enters and along any edges where two pieces join.

The main body of the system is 20 cm tall, 30 cm long, and 20 cm wide. A wider base is implemented to reduce the chance of the system from tipping on its side since it is dependent on its orientation to operate (gravity pulls chemicals out of the containers when the valves open). The prototype is a simple rectangular prism constructed out of Plexiglas mounted on a much larger Plexiglas base while the final production model is a much more aesthetic trapezoidal prism. A general idea of the shapes is illustrated in the figure below.

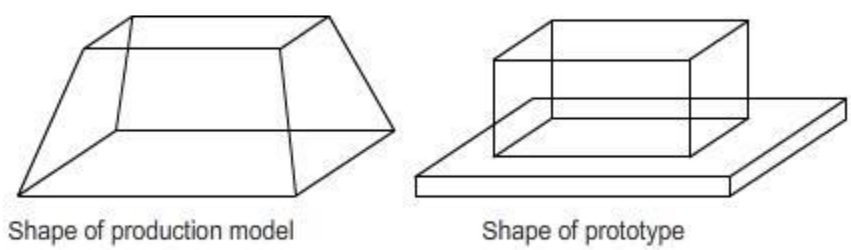

Figure 7 - Shapes of production model and prototype of the *Spa Commander*

4. Display

The *Spa Commander* has a main faceplate with a set of status LEDs. There may be design changes made to display of the final prototype depending on needs that arise. Section 4.1 explains the fundamental design of the faceplate of the *Spa Commander*.

4.1. Faceplate

The figure below shows the basic design of the faceplate of the *Spa Commander*. The LEDs are coded in three different colours: green indicating good, red indicating bad, and yellow as a warning.

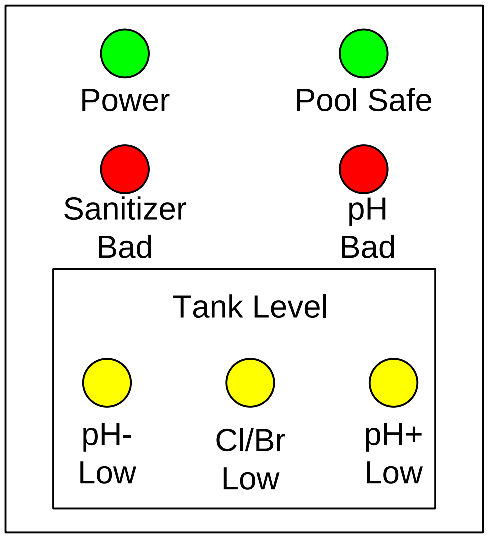

Figure 8 - *Spa Commander* Faceplate Design

The faceplate for this system is setup intuitively so the user can at a glance tell if the system is running correctly and if the pool is safe or not. If the water is not safe (i.e. chlorine or bromine concentration and pH are not at the optimal levels for pool and spa operation), the appropriate red LED will become illuminated to allow the user to know what is causing the unsafe conditions. Two green LEDs (Power and Pool Safe) indicate that the water is safe to enter and a single red LED prevents the green Pool Safe LED from turning on. The tank level indicators will be placed near the bottom which allow the user to know which tanks need to be refilled before the chemical containers are completely emptied.

4.2. Labels

The final production model of the Spa Commander must have functional labels and electrical warning labels. This does not include the LED labels already mentioned on the faceplate in the previous section. These labels are necessary to further insure the safety of the user and, where possible, should utilize symbols or designed in a manner which prevents misunderstanding and bridges language barriers.

4.2.1. Container Labels

The system contains labels on the containers indicating where to add chemicals. It is important that these labels remain visible for as long as the Spa Commander is in service. These labels are therefore either etched into the exterior casing of the Spa Commander or painted on glazed over in a high contrast colour. The requirements for the labels on the prototype are not as important as the final production model because the prototype is strictly limited to internal usage by the developers. The final production model will most likely use the latter implementation for improved readability and aesthetics.

4.2.2. Warning and Safety Labels

Because the Spa Commander is an electrical system operating in the vicinity of water, it must have appropriate safety labels instructing proper usage of the system despite the fact that the system is waterproof. The labels must be printed in high contrast colours to ensure readability.

Warnings:

- Do not operate this device if the exterior casing is cracked or broken
- Do not operate this device if the power cord sheath is broken
- Power supply input: 120V, 60Hz (North American standard)

5. Electrical

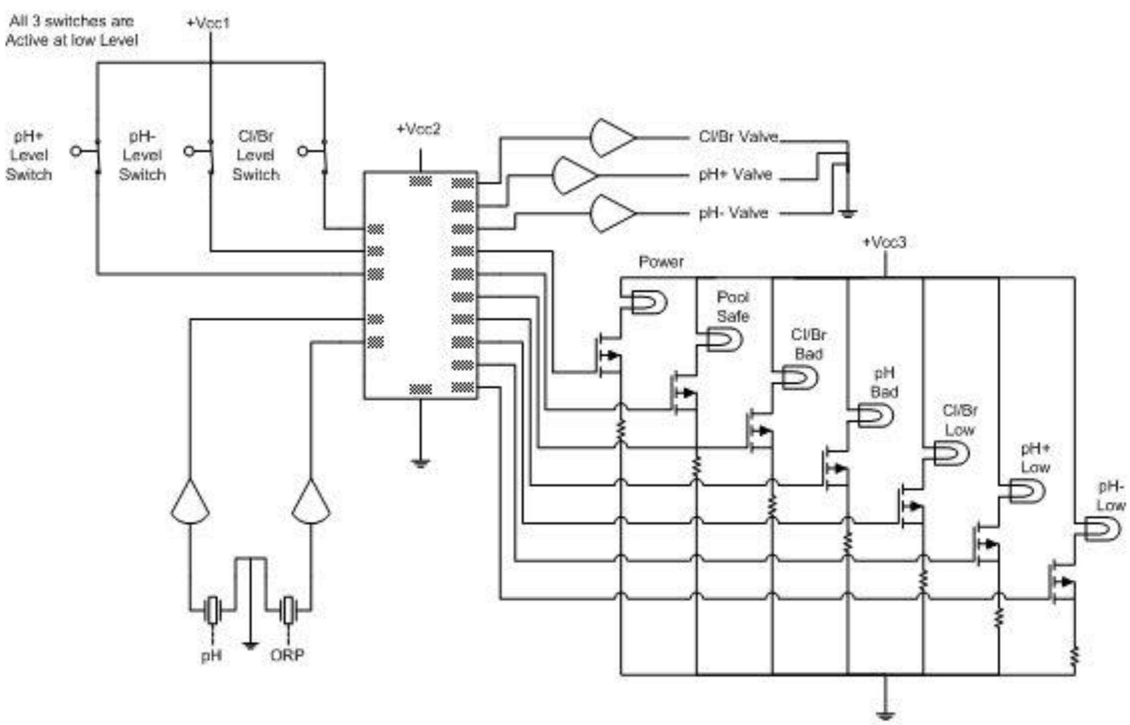

Figure 9 - Electrical Schematic

Above is an idealized electrical schematic of our system. Starting at the top left, a set of level switches connected to the dry chemical storage tanks. These are simply connected to a voltage source with a current limiting resistor if needed to provide a binary signal which is fed directly into the PIC. For simplicity of design, low level active switch and spring assembly are implemented.

Below the switches in the diagram are two chemical sensors. Each sensor provides the necessary voltage to allow them to run properly, and their outputs run through separate amplifier circuits and feed into integrated AD converters in the PIC. On the output side of the schematic are valve control circuitry, this circuitry takes the output of the integrated DA converters and amplify the signal through either a single stage or multistage amplifier. This process generates the necessary voltage and current levels needed to power the gate valves controlling the dry chemical flow from the tanks.

In the bottom right portion of the schematic is the faceplate circuitry, this consists mostly of LEDs attached to MOSFETS run in saturation to act as switches or relays and is attached to a current limiting resistor. This enables a binary signal to be fed directly to the MOSFET allowing current to flow, which in turn limits the current supplied by the PIC while still allowing enough current to flow through the LED to get the desired output brightness.

6. System Test Plan

The test plan is divided into several major sections. The first section consists of testing the pH meter and ORP sensors. Focus is shifted towards the system’s chemical administering functions once the sensors are determined to be in working order. Upon completion of diagnostic testing of the sensors and chemical delivery mechanisms, the entire system will undergo grey box and then black box testing. The system test plan includes as many test cases and corner cases as possible. The current list is subject to change upon finalization of the prototype as certain design changes may occur.

6.1. Unit Testing

To verify that the pH meter and ORP sensors are working properly, the two components are tested separately. To confirm that each sensor works properly:

1. Use hand testing procedures to test a sample of spa water (for pH and Cl/Br).

    - Fill the cells of a test kit with spa water taken from a depth of 18" and away from the return line.
    - Add the specified number of drops (depends of the volume of the cell) of the pH solution (phenol red) into the pH test cell.
    - Add the specified number of drops of the OTO solution to the Cl/Br test cell (orthotolidine and hydrochloric acid).
    - Mix and then compare the color of the water to the respective color standards.

2. Test the pH meter and ORP sensor separately, each time allowing the pump to push water through the system.

3. Monitor the sensor as the system operates with only a single sensor and verify that each are capable of sending a signal to the PIC.

When sensors are verified to be operating properly, the next step is to verify that the chemical delivery control system is also working properly with the system.

1. Allow the sensors to measure the pH and concentration of Cl/Br of water without chemicals separately. Since there both the pH and concentration of Cl/Br will be below the optimal values, the control systems should begin releasing chemicals into the water.

2. For both the pH and the Cl/Br, perform manual tests and then calculate the amount of chemicals to be added to bring levels to optimal levels.

3. Monitor the actuators and verify that chemicals are added to the water and the system is able to operate continuously.

4. Record the time required to bring the volume of water to optimal chemical levels and determine whether it is reasonable.

6.2 Standard Test Cases

Standard test cases are operating conditions and scenarios that will frequently occur. These are the most important test cases and the Spa Commander should be able to continue operation under the following circumstances. Depending on the final design of the prototype, standard test cases include but are not limited to the following scenarios.

6.2.1 Long Term Operation

The user will set up unit on side of pool and turn unit on.

Conditions:

The spa chemicals are reasonably balanced already and *Spa Commander* is full of chemicals is tested to be operating properly (Section 6.1. Unit Testing).

Expected Observation:

After a day or two the chemicals can be rechecked by the user to ensure that the chemical levels in the pool remain balanced and the Spa Commander is still operating properly.

After an extended period the pool continues to balance chemical levels and the LEDs on the faceplate operate correctly. The power LED remains on and the bad pH and bad Sanitizer LEDs turn on when the chemical levels are not at optimal levels. When the chemical containers are close to depletion, the fill chemical LEDs need to turn on.

6.2.2. No Chemicals

The user will set up unit on side of pool and turn unit on.

Conditions:

Plain tap water is used with no chemicals are added to the water, hand tests are performed to verify. The chemical containers in the *Spa Commander* are full and the system is tested to be operating properly (Section 6.1. Unit Testing)

Expected Observation:

The LEDs on the faceplate for “Sanitizer bad” and “pH bad” are turned on because the system does not sense any sanitizer and the pH reading is neutral (7.0, optimal is 7.4-7.6). The motor controlling the gate valve to the Cl/Br container opens and releases the chemicals into the spa. The sequence repeats until the concentration of Cl/Br is balanced so that the LED indicating unbalanced Cl/Br turns off. The results are then verified with hand testing.

6.3. Corner Cases

During development of the *Spa Commander*, it is important to ensure that the device will continue to operate when presented with unexpected operating environments. There are a large number of corner cases that can be tested, the list includes but is not limited to the following scenarios.

6.2.1. Corner Case 1: No Cl/Br

The user will set up unit on side of pool and turn unit on.

Conditions:

The spa has a low sanitizer reading when manual tests are performed and the chemical containers in the *Spa Commander* are full and the system is tested to be operating properly (Section 6.1. Unit Testing).

Expected Observation:

The system senses low sanitizer and the LED on the faceplate that indicates unbalanced Cl/Br turns on. The motor controlling the gate valve to the Cl/Br container opens and releases the chemicals into the spa. The sequence repeats until the concentration of Cl/Br is balanced so that the LED indicating unbalanced Sanitizer turns off. The results are then verified with hand testing.

6.3.2. Corner Case 2: Very High pH

The user will set up unit on side of pool and turn unit on.

Conditions:

The spa has a pH reading that is too high to conform with water safety standards when hand tests are performed, and the chemical containers in the *Spa Commander* are full and the system is tested to be operating properly (Section 6.1. Unit Testing).

Expected Observation:

The system senses a high pH reading and an LED lights up on the display panel which is for “pH unbalanced”. The motor that adjusts the flow of pH minus which opens the hopper and adds chemical to be pumped into spa. This repeats until pH is in a safe range and the LED turns off. This will be verified with hand testing.

6.2.4. Corner Case 3: very low pH

The user will set up unit on side of pool and turn unit on.

Conditions:

The spa has a pH reading that is too low to conform with water safety standards when hand tests are performed. The chemical containers in the *Spa Commander* are full and the system is tested to be operating properly (Section 6.1. Unit Testing).

Expected Observation:

The system senses a low pH reading and an LED lights up on the display panel which is for “pH unbalanced”. The motor that adjusts the flow of pH plus which opens the hopper and adds chemical to be pumped into spa. This repeats until pH is in a safe range and the LED turns off. This will be verified with hand testing.

7. Conclusion

The *Spa Commander*’s design specifications as outlined above meet the functional requirements of our system. These details will be used in the development of our proof-of-concept model. The spa water will be automatically tested by our system and chemicals will be administered to adjust the water to maintain a safe standard in regards to pH and sanitizer (Cl/Br). The testing is as outlined above and will be used to ensure all functionality of the *Spa Commander*. This document provides all the objectives for the development of the spa chemical maintenance system’s prototype.

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Appendix A – Exploded view of schematic