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Paper

AN EVALUATION OF RESPONSE TIMES FOR EXISTING AND POTENTIAL FUTURE PRESSURE RELEASE SAFETY DEVICES IN WATERBLASTING SYSTEMS

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ABSTRACT

Pressure release devices are an integral part of waterblasting best practices and are mandated by contractors, asset owners and industry. These devices, commonly known as dump valves, are used as an operator's primary control to release pressure in the system, sometimes in response to a hazardous event. The design and response of these devices has a direct impact on the safety of persons in the vicinity of a waterblasting operation. The immediate response to a dangerous event not only depends on the operator's ability to react, but also on the equipment's response time and ability to reduce system pressure. The purpose of this research is to evaluate reaction times to an event by pairing operators with the most common pressure release devices including handheld pneumatic pilot operated valves, foot actuated pneumatic pilot operated valves and electronic pilot operated valves. The potential utility of automated responses will also be explored.

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1. INTRODUCTION

Pressure release devices, commonly referred to as dump valves in industry, are a critical component in waterblasting systems. The dump valve is responsible for giving the operator a quick and easy way to divert flow from the cleaning nozzle while also lowering the system pressure to a safe level. While pressure is not the only factor when classifying a waterjet to be in a safe state, skin simulants have shown to be penetrated by water jets at less than 500psi (Wright, 6).

A common style of dump valve is pneumatically piloted. A pneumatically piloted valve uses air pressure to shift the valve from one state to another, open to closed or vice versa. Tubing inner diameter (ID) and length are critical characteristics to consider when setting up a pneumatic circuit for use with a pressure release device. Different tubing ID's and lengths will lead to different valve response times. Generally, a larger volume of air in the pneumatic circuit will take more time to dissipate than a smaller volume. These dissipation times have a direct effect on the overall reaction time of the pressure release device. The dissipation time also depends on the initial pilot line pressure, commonly around 100psi, and the minimum pressure to shift a valve or allow a valve to spring return upon discharge.

An additional consideration is the energy stored in the high-pressure hoses. The larger ID hoses and lengths will release more energy in the event of a pressure release than a small ID and short hose for the same pressure.

Along with tubing ID, length, minimum pilot pressures and stored high pressure water energy, the means in which you initiate, or trigger, a change to the pilot signal is another variable of a pressure release device. Common triggers for pressure release devices are foot pedals, hand actuated levers or electronic control systems like Estop buttons or dead man levers. Each trigger design and implementation have pros and cons when considering reaction intuition, response time and reliability.

Lastly, the overall response time of a waterblasting system ultimately relies on the human reaction. The human reaction time has been a deeply researched field for different applications. For instance, a human automotive reaction-time study reported an average reaction time of 0.627 seconds (Nagler, 261). To determine reaction times in a waterblasting environment, operators of varying experience levels were paired with different dump valve triggers to perform a reaction-time study of a waterblasting event. In addition, the benefits of using computerized reactions to the same event were explored.

2. TEST ARRANGEMENT

2.1 Pneumatic Pilot Pressure

2.1.1 Threshold Pilot Pressure Determination

This testing was designed to determine at what pneumatic pilot pressure a standard 20kpsi dump valve would shift from a closed state, sending water to the nozzle, to and open state, allowing water to divert from the nozzle and lower the system pressure to a safe level. To determine this, the pneumatic pilot pressure was adjusted using a regulator and measured using a ProSense 0-200psig SPTD25-20-0200H pressure transducer. With the valve shifted to the closed state, the water pressure was brought up to 20kpsi, using a 325hp diesel pump and measured using a Core Sensors 0-44kpsi CS10-2A44000PS5A000-03 pressure transducer. The pneumatic pilot pressure was then slowly decreased to zero using the regulator. The data from the water pressure transducer and pneumatic pilot pressure transducer could then be correlated to determine the pilot threshold pressure of the dump valve.

2.1.2 Discharge Time

This testing consisted of pairing different tubing diameters and lengths with an industry standard dump valve. The dump valve used was a spring return style piloted by a pneumatic cylinder. Air pressure in the pilot signal was measured using a ProSense 0-200psig SPTD25-20-0200H pressure transducer. Discharge times from 100psi to the threshold pressure described above in section 2.1.1 Threshold Pressure Determination were recorded for each ID and length combination. The tubing sizes tested had IDs of .125”, 156” and .250”. Each tubing size was tested at lengths of 5’, 10’, 15’, 20’, 50’ and 100’. All tubing ID and length combinations were discharged and recorded three times.

2.2 Water Discharge Impact and Pressure

To evaluate the energy stored in different high-pressure systems, conditions on the bypass or diversion outlet of an industry standard dump valve were measured. To do this, the bypass outlet of the dump valve, normally a free flowing, large diameter orifice, was restricted using a .165” inner diameter nozzle. Pressure just upstream of the nozzle was measured using a Core Sensors 0-44kpsi CS10-2A44000PS5A000-03 pressure transducer. In addition, the discharge impact force was evaluated by orienting the nozzle normal to a target at an approximate 2” standoff. Impact force on the target was measured using an Omega 0 -1000lb LC1103-1K load cell. 50’ lengths of high-pressure hose ID’s of 3mm, 5mm, 8mm and 13mm were tested at operating pressures of 5, 10, 15 and 20kpsi. The bypass event was initiated by manually releasing a pneumatic foot pedal trigger. All hose ID and pressure combinations were discharged and recorded a minimum of five times.

2.3 Human Reaction

To simulate a safety concerning event in which the operator felt a need to react by using the dump valve, rupture disc failures were used. The idea behind using a rupture disc bursting is that it closely emulates visual and auditory characteristics of a safety concerning failure such as fitting failures or the nozzle coming off the end of a high-pressure hose.

Unbeknownst of the startling rupture disc event, operators of different skill levels were asked to clean a heat exchanger with automated equipment. This is shown in the left image of Figure 5. While the operator was focused on positioning and feeding the high-pressure hose, the pump pressure was slowly increased above the rupture disc rating. The rupture event is shown in the right image of Figure 5. The different automated equipment and dump valve trigger configurations used in this testing are shown below.

Automation Control	Trigger for Dump Valve	Automated Equipment
StoneAge CBX Control Box	Control Box Lever	StoneAge Compass
StoneAge CBX Control Box	Foot Pedal	StoneAge Compass

StoneAge CTRL-100 with AutoMove* and AutoFeed*	Automation Lever or Estop	StoneAge Compass with Sentinel Technology
StoneAge CTRL-100 with Mapping*	Automation Lever or Estop	StoneAge Compass with Sentinel Technology

*AutoMove – Automated positioning to the next tube location with just a toggle of the CTRL-100 joystick.
*AutoFeed – Automated feed in and feed out with just one click of the CTRL-100 forward feed button.
*Mapping – One click of the X/Y positioner joystick on the CTRL-100 to clean the entire exchanger. User simply acts in an overseer capacity.

Layouts of the controls systems for the CBX Control Box and CTRL-100 can be seen in the left and right images of Figure 6, respectively.

2.4 Computer Reaction

Based on the consistent water pressure trends found during a rupture event, automated computer reactions were tested against the rupture disc failure condition. Similar to the human reaction testing, water pressure was slowly increased above the pressure rating of the rupture disc. Timing of the computer response was captured by comparing the falling edges of the water pressure and pneumatic pilot pressure. The computer reacted by changing the state of a relay which the Estop signal passed through.

3. DATA ANALYSIS

3.1 Pneumatic Pilot Pressure

3.1.1 Threshold Pilot Pressure Determination

To correlate the pneumatic pilot pressure to water pressure, timestamps of each data set were compared to synchronize the data points shown in Figure 1. The threshold pressure was determined by the pilot pressure which corresponded to a water pressure less than 500psi.

3.1.2 Discharge Time

The discharge time for each tubing ID and length pair was determined by averaging three discharges events. The discharge time is defined by the time it takes to go from the initial pilot pressure, 100psi, to a pilot pressure less than the threshold pilot pressure of the system defined in 4.1.1 Threshold Pilot Pressure Determination. More specifically, these values are the difference between the falling edge of the pilot pressure data to the first data point less than the threshold pressure. This time window is represented between the two dashed vertical lines in Figure 2.

3.2 Water Discharge Impact and Pressure

The impact force and pressure for each high-pressure hose ID and operating pressure pairing was determined by finding the maximum force and pressure that occurred over a minimum of five discharge events per high-pressure hose ID and operating pressure combination.

3.3 Human Reaction

To determine how long it took each person to react to the rupture disc event, timestamps of the water pressure data and pneumatic pilot pressure data from the dump valve circuit were compared.

Timing of the rupture event could be determined by the falling edge of the water pressure data and a reaction event could be determined by the falling edge of the pneumatic pilot pressure. An example of this reaction time determination is shown in Figure 7 by the spacing between the two dashed vertical lines.

3.4 Computer Reaction

With the data compiled from the 18 human reaction tests, it was determined that the slope of the decaying water pressure due to a rupture event is a condition that could be used to trigger a reaction by the computer. The 18 rupture events produced an average water pressure decrease of 44kpsi per second with a standard deviation of 6.83kpsi. Using an exclusion of two standard deviations the threshold for a reaction trigger was set to a water pressure decrease of 30.34kpsi per second. With an average sample rate of .026 seconds, the computer performed a rolling least-squares linear regression on the last N data points in time. If the slope of the linear regression dropped below -30.34kpsi per second, the computer changed the state of the relay to trip an Estop condition. Determining the computer reaction times used the same method outlined above in 3.3 Human Reaction and can be seen in Figure 8.

4. TEST RESULTS

4.1 Pneumatic Pilot Pressure

4.1.1 Threshold Pilot Pressure Determination

Shown by the data in Figure 1, the valve does not have binary states of on and off. Due to the characteristics of a spring return valve assembly, there exists a pilot pressure range between states of flow being directed to the nozzle or directed to the bypass or diverted state. Between the approximate pressures of 7-13psi, some of the water is going to the nozzle and some is being diverted, still maintaining a certain amount of system pressure at the tool. Based on the safe operating pressure of 500psi mentioned above, the threshold pilot pressure of this system was determined to be any pressure less than 7psi.

4.1.2 Discharge Time

A consistent trend across all pneumatic pilot circuits is that discharge time increases with volume. With the initial pressure and size of the pressure release orifice held constant, the larger the air volume present in the tubing, the longer it will take to discharge to atmosphere. However, if there exists a long length of tubing combined with a proportionally small inner diameter, the effects of pressure loss could start to dominate the discharge timing. This is represented in Figure 3 where the 100’ of .125” ID tubing had a longer discharge time than the 100’ of .250” ID tubing.

4.2 Water Discharge Impact and Pressure

As demonstrated in this test, both impact force and discharge pressure increase with system pressure for any given hose ID, as shown in the left and right images of Figure 4, respectively. In addition, the ID of your high-pressure hose has a significant impact on the potential energy stored in the high-pressure system. As the high-pressure hose ID increases, so does the potential energy in that system. This is supported by the increase in impact force and discharge pressure for the larger ID’s relative to the smaller ones at a given pressure.

4.3 Human Reaction

The 18 human reaction tests produced an average response time of 1.14 seconds with a standard deviation of 0.83 seconds.

4.4 Computer Reaction

Using a rolling sample of five data points, the computer produced an average reaction time of 0.11 seconds with a standard deviation of 0.04 seconds across six tests. Changing to a rolling sample size of three data points produced an average response time of 0.07 seconds with a standard deviation of 0.01 seconds across four tests.

5. CONCLUSIONS

- When possible, trending towards smaller tubing ID's and lengths in pressure release pilot circuits will help maintain a reasonable dump valve response time. If small tubing ID's and lengths are not feasible due to job characteristics, consider having all persons a further distance away from any high-pressure hoses or connections. Results of this paper in conjunction with EN ISO 13855 can be used as references for reasonable operator standoff distances.
- When working with larger volumes of high-pressure water (i.e., larger ID hoses and lengths or multiple hoses) it is recommended that the pressure relief valve be rigidly mounted, and all connections be tethered by whip checks. As the volume of high-pressure water increases, so does the energy released by that system during a failure or pressure release event. Lastly, the orientation of the dump valve bypass or diversion orifice should be considered as dangerous water velocities and volumes can be released here.
- Pneumatic foot pedals and control boxes are still great options as they are intuitive for users.
- Electronic triggers offer an avenue for future growth. Computerized reactions to sudden drops in system pressure can be used to respond to a safety concerning waterblasting event quicker and more consistently than a human.

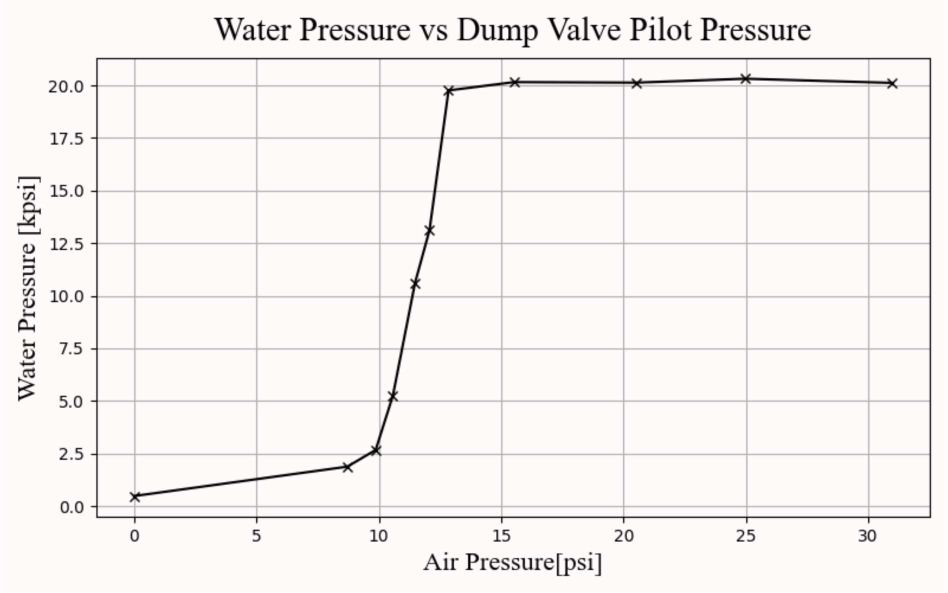

Figure 1

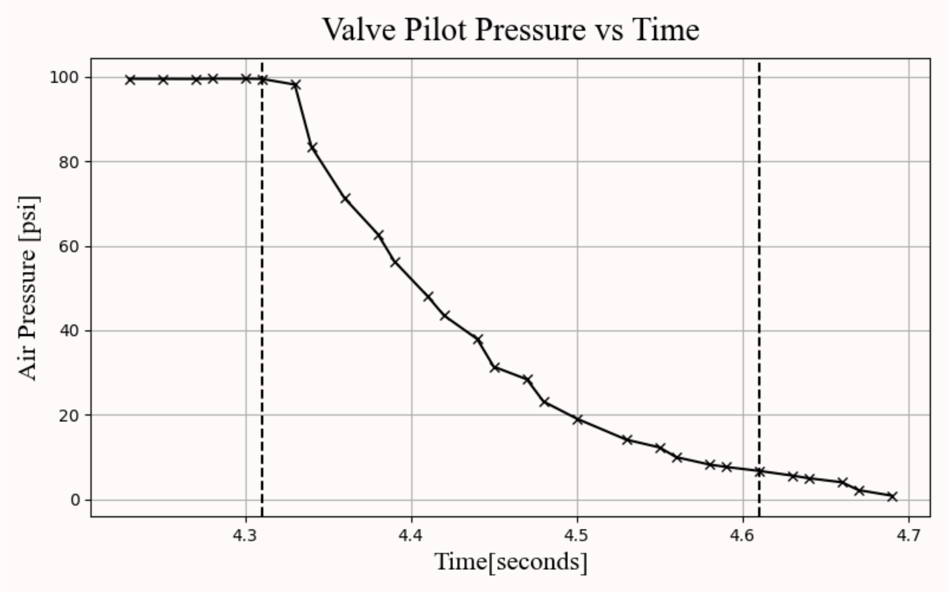

Figure 2

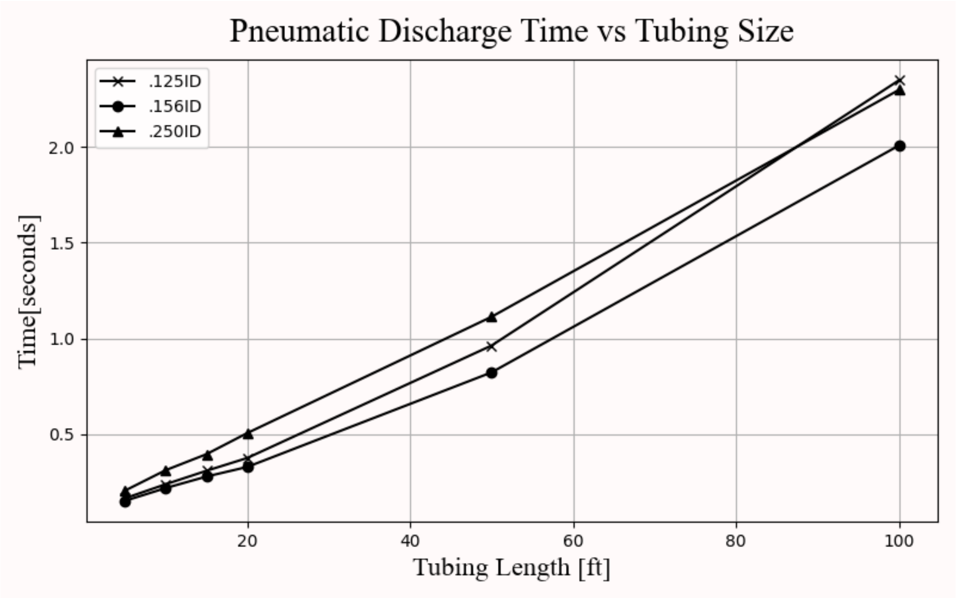

Figure 3

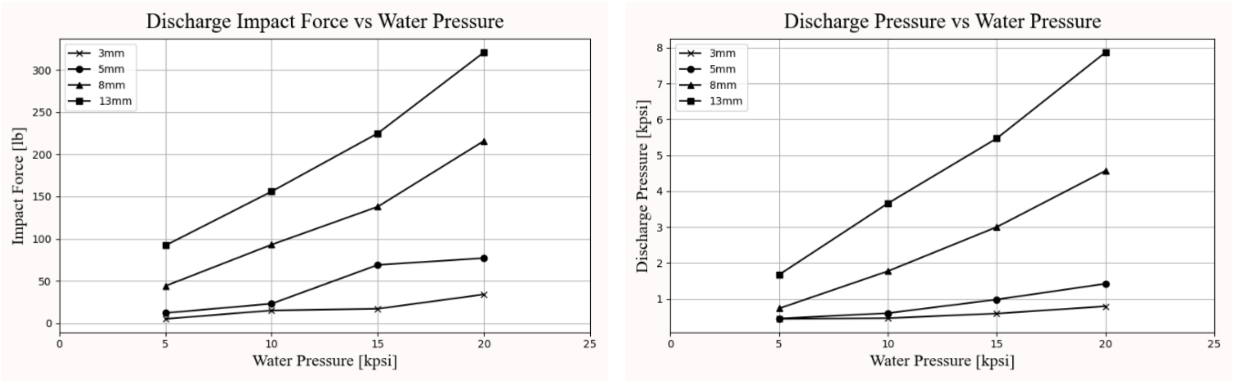

Figure 4

Normal Operation

Rupture Event

Figure 5

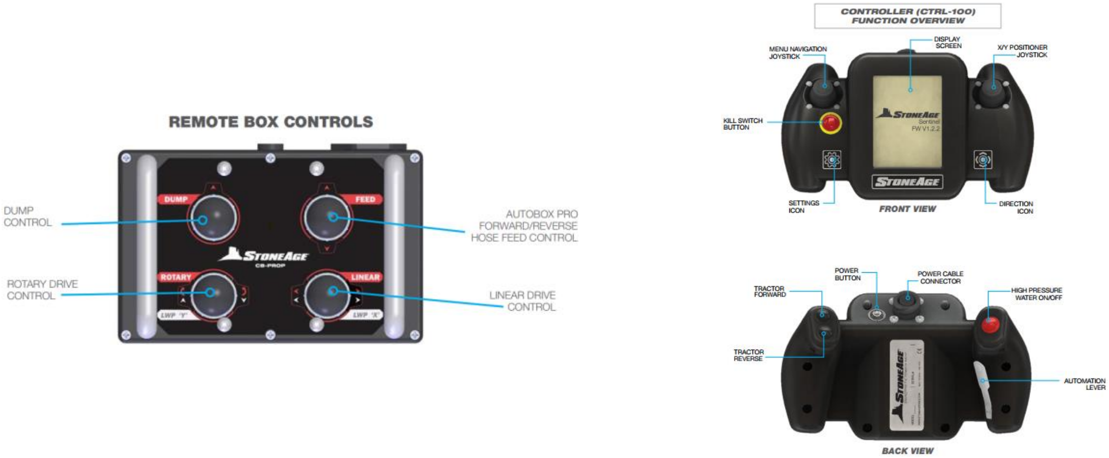

Figure 6

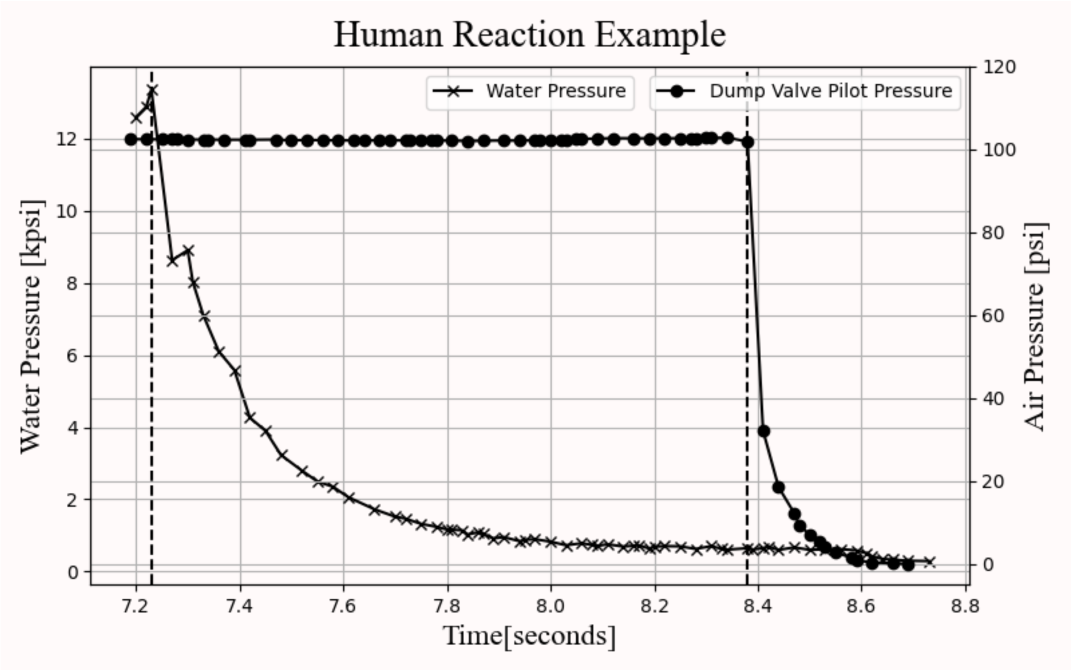

Figure 7

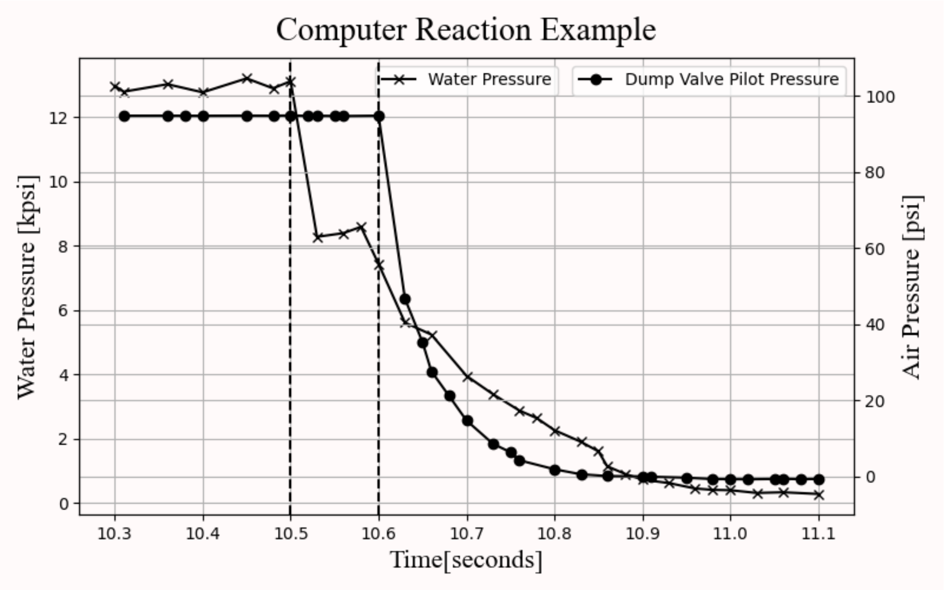

Figure 8

6. REFERENCES

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