SMART VALVE Engineering Report

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Abstract

This report focuses on the testing and analysis of the SMART VALVE family of valves, for Automatic Flow Control, LLC. The goal of the testing was to originally refine the SMART VALVE's variable flow control characteristic through calibration of the product's spring loaded piston. After beginning with Computational Fluid Dynamics, physical testing validated the results. Subsequent C.F.D. testing approximates the spring data of the 1.5", 2", 3", 4", and 6" valves. This report will also present the testing of SMART VALVE's claims of water meter error reduction and backflow protection.

Objective

To first refine the variable flow control quality of SMART VALVES, and then to validate the claims of said variable flow control along with claims of water meter error reduction and backflow protection.

Introduction

The following report serves to summarize the refinement and testing process, results, and analysis of the SMART VALVE variable flow control product.

Claims to be addressed:

- *Variable Flow Control*
- *Water Meter Error Reduction*
  - *Air Bubble Volumetric Reduction*
  - *Absorption of High Pressure Waves due to Intermittent Supply*
- *Backflow Protection*

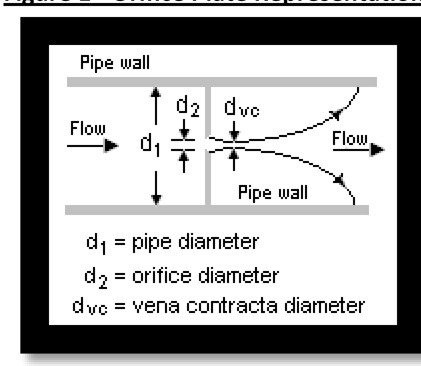
As a variable flow control, SMART VALVE works on several basic principles that will be briefly developed in the following paragraphs:

A flow controller is a device designed to limit the amount of fluid flowing through a supply line. A common application of flow control is found on the tap of a kitchen sink or in a shower head.

The most basic flow control, an orifice plate, is also used to measure flow rate. Pressure is measured on both sides of the plate and along with some geometric parameters, the flowrate can be calcualted.

$$Q = \frac{C_d}{\sqrt{1-(\frac{d_2}{d_1})^4}} A_2 \sqrt{\frac{2(P_1 - P_2)}{\rho}}$$

Figure 1 - Orifice Plate Representation



Where:

Q = volumetric flow rate, m^3/s
C_d = Coefficient of discharge, dimensionless
A_2 = cross-sectional area of the orifice hole, m^2
d_1 = diamter of the pipe, m
d_2 = diameter of the orifice hole, m
P_1 = fluid upstream pressure, Pa
P_2 = fluid downstream pressure, Pa
ρ = fluid density, kg/m^3

The SMART VALVE is a variable flow controller, ideally restricting the flow of the fluid across a pre-specified range of flow rates. The cutaway of the SMART VALVE as seen in Figure 2 illustrates how the flow controller *geometry changes under different conditions. At different flow rates, the piston will depress a calibrated amount. This change in geometry retards the flow of water by creating a back pressure in the line. The piston is supported by a simple spiral spring that operates under the equation:*

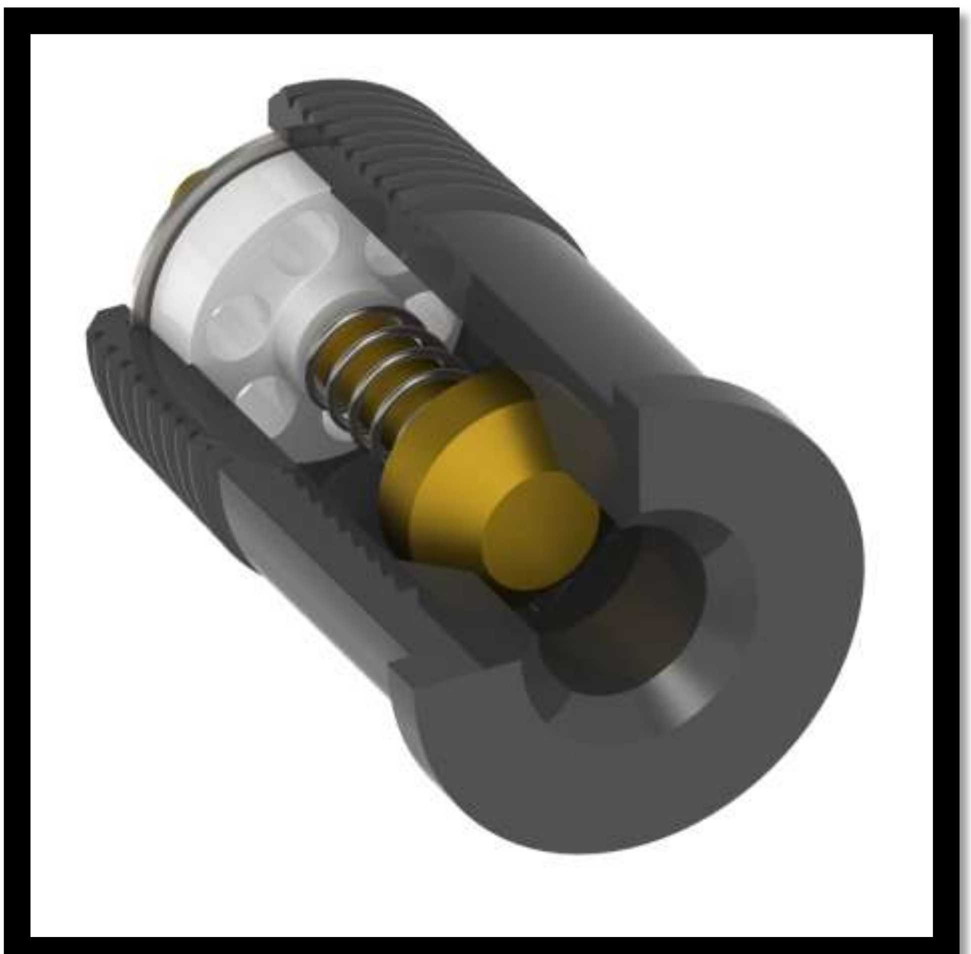
$$F_s = k\ x$$

Where:

F = Force of Spring, lb
k = Spring Rate, lb/in
x = Deflection of the Spring, in

It is important to note that the refinement of SMART VALVE's variable flow control will be limited to calibration of the spring that supports the piston, as seen if Figure 2. Testing began with Computational Fluid Dynamics of the 0.75" SMART VALVE to get an approximate of the ideal spring rate for this application. This was followed by a series of physical tests. With validation of the simulation data, further C.F.D. was completed to approximate the ideal springs targeting a 20% > flow rate savings for the 1.5", 2", 3", 4", and 6" models.

Figure 2 – Cut Away Rendering of 0.75" SMART VALVE



Procedure

Computational Fluid Dynamics Simulation Testing Procedure

Overview:

- Controlled Variables: Water, Temperature, Static Pressure at Inlet
- Dependent Variable: Force of Piston Head
- Independent Variable: Position of Piston and Flow Rate

Assumptions and Boundary Conditions:

1. Internal Flow Analysis
2. Incompressible Flow
3. No change in elevation
4. Static Environmental Pressure: 14.69595 lbf/in^2
5. Temperature: 68.09 F
6. Laminar and Turbulent ; intensity: 2.00 % ; length: 0.01 in
7. Pressure Inlet: 55 lbf/in^2
8. Volumetric Flow Outlet: Look at Table 5 in the appendix of this report.

Goals:

1. Piston Surface Goal
   i. This a force goal in the direction of flow that includes all faces of the head of the piston, to include the sides and the back face.

1. Using the regressed Flow Rate vs. Piston Position data found in the Appendix of this report, along with the above Assumptions, Boundary Conditions, and Goals test 5 positions of the piston for each size SMART VALVE with their respective flow rates.
   i. Position 1 = 10 % of total deflection
   ii. Position 2 = 50 % of total deflection
   iii. Position 3 = 90 % of total deflection
   iv. Position 4 = 33.333 % of total deflection
   v. Position 5 = 66.667 % of total deflection
2. Record the results in a table.
3. Take Screen Shots of a section view of the Valve with a pressure plane plot parallel to the direction of flow.

Flow Control Physical Testing Procedure

Overview:

- Controlled Variables: Water, Temperature, Static Pressure at Inlet
- Dependent Variable: Flow Rate at the Outlet of the System
- Independent Variable: Spring Rate and Preload of Spring

1. Use a testing bed similar to the one in Fig 3 and 4 in the appendix of this report.
2. Record all of the following testing data in a table.
3. Measure the water pressure at the water source.
4. Connect your water supply and prepare your drainage hose.
5. Flush the system.
6. Run the water with Valve 3 closed and Valve 2 open, as seen in Fig 3. This will be the control of the experiment. Run water for 15 second intervals into a volumetric measuring container. Do this three times, recording the data and emptying the volumetric flask each time the test begins.
7. Run the water with Valve 2 closed and Valve 3 open, as seen in Fig 3. Now the water will flow through the SMART VALVE. Make sure to flush and pressurize the system before continuing testing. Run water for 15 second intervals into a volumetric measuring container, in the case of this report, with a resolution of 1 fluid ounce. Do this three times, recording the data and emptying the volumetric container each time the test begins.
8. Repeat test 7 as many times as you wish, only changing the spring of the SMART VALVE, and ensuring to Flush the system after every setup.
9. It is also possible to measure the flow rate by allowing the water to fill a volumetric measuring container to a certain volume while measuring the time it takes to do so. (Both methods are used in the following testing)

Backflow Protection Physical Testing Procedure

Overview:

- Controlled Variables: Water, Temperature, Static Pressure at Inlet
- Dependent Variable: Flow Rate at the Outlet of the System, (regularly the inlet of the SMART VALVE)
- Independent Variable: Direction of the Flow

1. Use a testing bed similar to the one in Fig 3 and 4 in the appendix of this report, but with the "Backflow Test Apparatus" found in Fig 5, in the appendix of this report, installed at the outlet of Fig 3's rig.
2. Install the SMART VALVE into the Back Flow Test Apparatus.
3. Pressurize the line with water
4. Record the presence, if any, of water droplets, or of any water leaking from the SMART VALVE's throat.

Water Meter Error Physical Testing Procedure

Overview:

- Controlled Variables: Water, Temperature, Static Pressure at Inlet
- Dependent Variable: Recording of Air Bubbles by the water meter
- Independent Variable: SMART VALVE vs. No SMART VALVE

1. Use a testing bed similar to the one in Fig 3 in the appendix of this report. It is important to this test that the tubing of the bed is made of clear piping in several areas before and after the water meter.
2. Introduce no more than 10 psi of compressed air into the system.

3. As in the Flow Control Physical Test, run a control with the water going through Path A and the Path B.
4. Look at the clear section of the tubing to record the appearance, decrease, and/or disappearance of bubbles in the water line. Also record any observations when studying the water meter with Path A and with Path B respectively.

Results and Discussion

Table 1 – Computational Fluid Dynamics Simulation Results

SMART VALVE	0.75"	1.5"	2"		3"	4"	6"
Computational Fluid Dynamics (C.F.D.) Simulation Test Data							
Force on Piston Head (lb)							
Proprietary							
Spring Technical Information							
Proprietary							

The data presented in Table 1 summarizes the Computational Fluid Dynamics Simulation Test Data for each size valve in five different positions of deflection. The raw data associated with these results can be found in the Appendix of this lab in Table 5. In the second part of Table 1 the calculated technical spring information is presented. The spring data is calculated using a regression model of "$y = a0 + a1x$" with the Force on Piston Head vs. Piston Deflection data. The a_0 value is the pre-load of the spring. The a_1 value is the spring rate of the spring. This can be used for simple spiral cylindrical springs whose spring rate is defined by:

$$Spring\ Rate\ \left(\frac{lb}{in}\right) = \frac{Force\ of\ Spring\ (lb)}{Deflection\ of\ Spring\ (in)}$$

Additional steps where taken during the regression process to elimnate outliers that would contribute to excessive error in this linear model.

Table 2 – Flow Restriction Physical Testing Results

0.75 inch SMART VALVE Flow Restriction Physical Test Data			
Static Water Pressure 55 psi			
	Volume (US fluid ounce)	*Time (seconds)*	*Flow Rate (Gallons/min)*
Control			
Test 1	400	23	8.1522
Test 2	400	22.5	8.3333
Test 3	384	22.9	7.8603
		Average Flow Rate	**8.1153**
		% Difference from Control	**0.0000%**
Spring A			
Test 1	375	29.9	5.8790
Test 2	384	30.5	5.9016
Test 3	384	31.1	5.7878
		Average Flow Rate	**5.8561**
		% Difference from Control	**27.8383%**
Spring B			
Test 1	384	29.9	6.0201
Test 2	384	30	6.0000
Test 3	384	30	6.0000
		Average Flow Rate	**6.0067**
		% Difference from Control	**25.9829%**
Spring C			
Test 1	192	15	6.0000
Test 2	240	15	7.5000
Test 3	208	15	6.5000
		Average Flow Rate	**6.6667**
		% Difference from Control	**17.8503%**

The data in Table 2 presents the flow control testing results conducted on a 3/4" SMART VALVE with three different spring rates. These spring rates were calculated during a previous Computational Fluid Dynamics simulation set. Three different spring rates were calculated based on different boundary conditions. The boundary conditions used for the most successful spring, spring A, can be found in the procedure section of this lab.

Equation 2 from the appendix of this lab was used to calculate the Flow Rate and then Equation 1 was used to calculate the % savings.

Table 2 confirms that the computational fluid dynamics testing was accurate and a saving of 27.383 % was achieved. This is a flow rate savings, not a volume savings. This valve has satisfied its' first claim of flow control.

Table 3 – Backflow Protection Physical Testing Results

0.75 inch SMART VALVE Backflow Protection Physical Testing Data	
	Observations
Control	*water flows freely out of the outlet*
SMART VALVE	*no water flows out of the outlet, no leaking or dripping or wetness seen on dry cloth indicator*

In Table 3 the observations for the testing of 3/4" SMART VALVE for Backflow Protection are presented. Please refer to Fig 6 in the appendix of this lab for an image from testing. From the observations, it can be deduced that the SMART VALVE does in fact offer backflow protection. The limits of the pressure the SMART VALVE, for water, are based on the mechanics of the materials used. This test was not to find such a limit but to rather test the protection under normal operating conditions.

Table 4 – Water Meter Error Physical Testing Results

0.75 inch SMART VALVE Water Meter Error Testing Data	
	Observations (clear pipe directly before outlet)
Control	*Water clearly has bubbles in it, bubbles are moving in the direction of flow*
SMART VALVE	*no visible bubbles*

In Table 4 the observations for the testing of a 3/4" SMART VALVE for Water Meter Error from air bubbles are presented. From the observations, it can be deduced the SMART VALVE is eliminating the air bubbles introduced into the line through change in pressure. The water bubbles are a much lower density than water, thus with higher pressure the bubbles collapse. This means that the water meter, which only measures volume, will not record the volume of the air bubbles. Therefore, Water Meter Error is reduced significantly in cases where air is corrupting a water line. Please refer to Fig 6 in the appendix of this lab for an image from testing. It is also important to note that the absorption of damaging high pressure waves, due to intermittent flow, will be absorbed by the spring supported piston. The piston acts as a buffer, dampening the effects of such a wave.

Conclusion

The data gathered supports the product as advertised. All of the claims initially tested were validated through physical testing of the ¾" SMART VALVE, pictured in Figure 2. While the other valve sizes were not tested, it is safe to assume that results will be similar and scalable based on the validated Computational Fluid Dynamics data. The SMART VALVE is a multifunctional valve that will save money on your water bill by controlling the water flow rate and by reducing water meter error.

References

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Edwards, Ken. *Smart Valve Calculations*. Working paper. Athens, OH: LMNO Engineering, Research and Software, 2011. Print.

FlexPVC. "GPM/GPH Flow Based on PVC Pipe Size, Ie, How Much Water Can Flow through Sch 40 Pvc Pipe Size 1/2" 3/4" 1" 1.5" 2" 2.5" 3" 4" 6"" *GPM/GPH Flow Based on PVC Pipe Size*. FlexPVC. Web. 25 Mar. 2012. <http://flexpvc.com/WaterFlowBasedOnPipeSize.shtml>.

Guevara, Hector M., PhD *Controlling Water Flow Speed and Volume by Using a Smart Valve Control Node at Meter Egress Connection Point.* NuEnergy Technologies, 2010. Print.

"Orifice Plate." *Wikipedia*. Wikimedia Foundation, 04 Feb. 2012. Web. 06 Apr. 2012. <http://en.wikipedia.org/wiki/Orifice_plate>.

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Appendix

Part A: Formulas

Equation 1 – Percent Difference

$$\%\ Difference = \frac{|Q_{SMART\ VALVE} - Q_{CONTROL}|}{Q_{CONTROL}} \times 100$$

Equation 2 – Basic Flow Rate Equation

$$Q = \frac{\forall}{t}$$

Where:

Q = volumetric flow rate, gallon/minute or gpm
$\forall$ = volume of fluid, gallons
t = time, minutes

Equation 3 – Force of a Spring Equation

$$F = kx$$

Where:

k = spring rate, lb/in
F = force of spring, lb
x = deflection of spring, in

Part B: Figures

Figure 3 – Labeled Picture of Test Bed

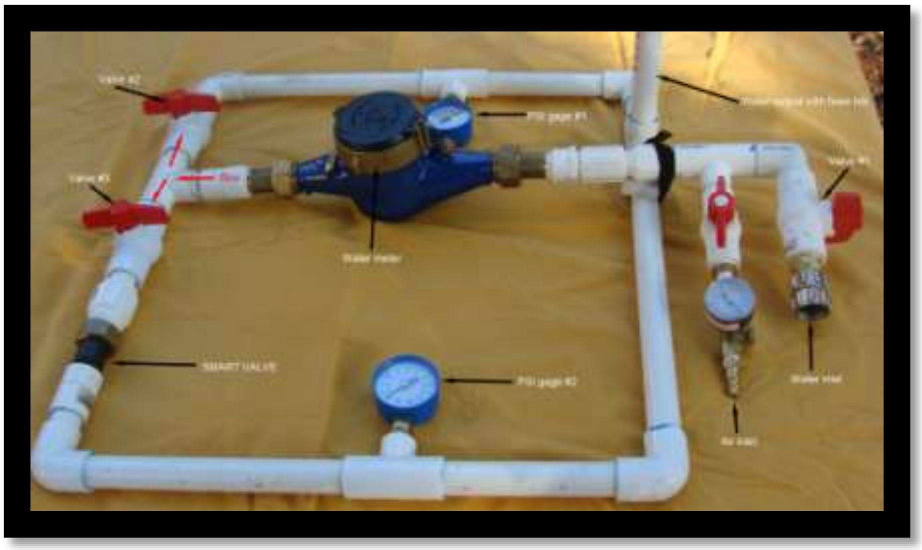
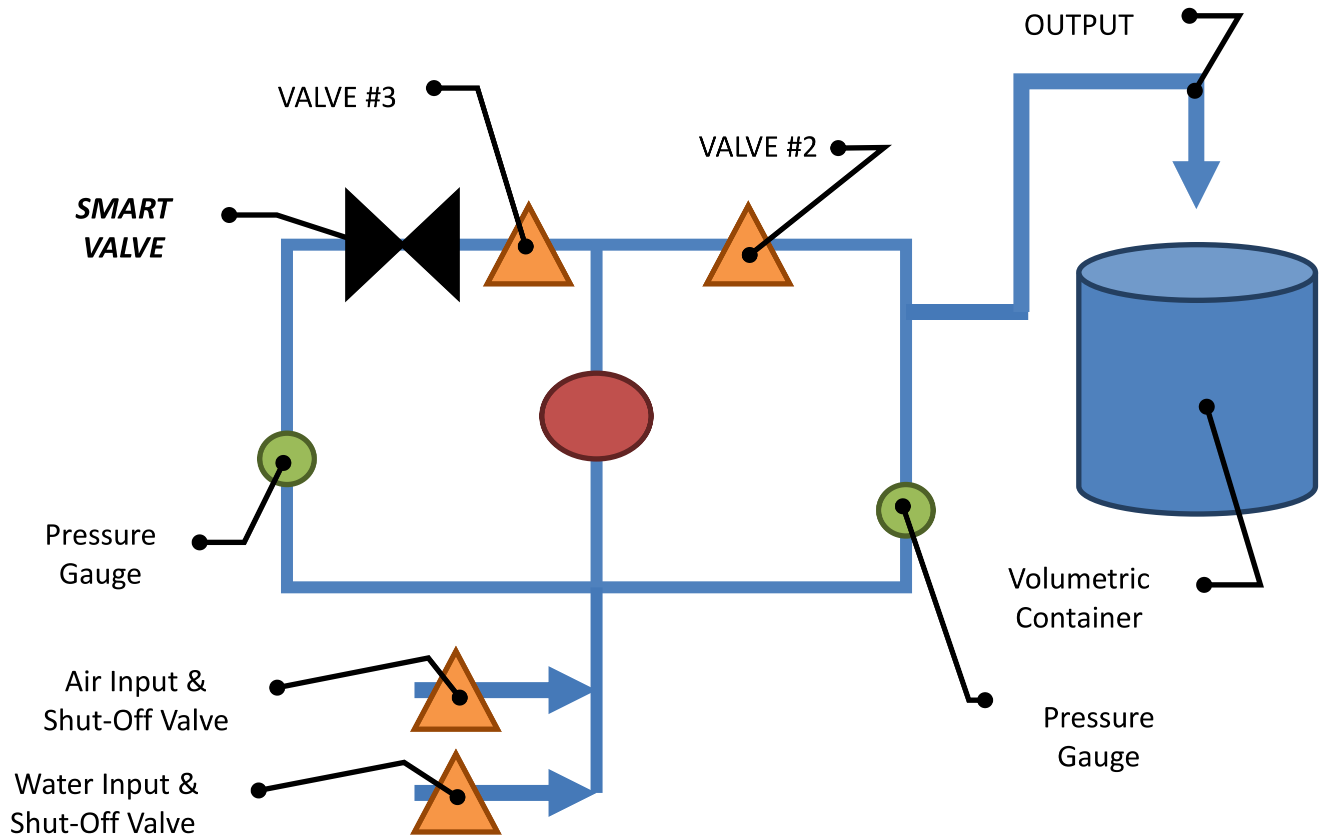


Figure 4 – Diagram of Test



Bed

Figure 5 – Backflow Apparatus

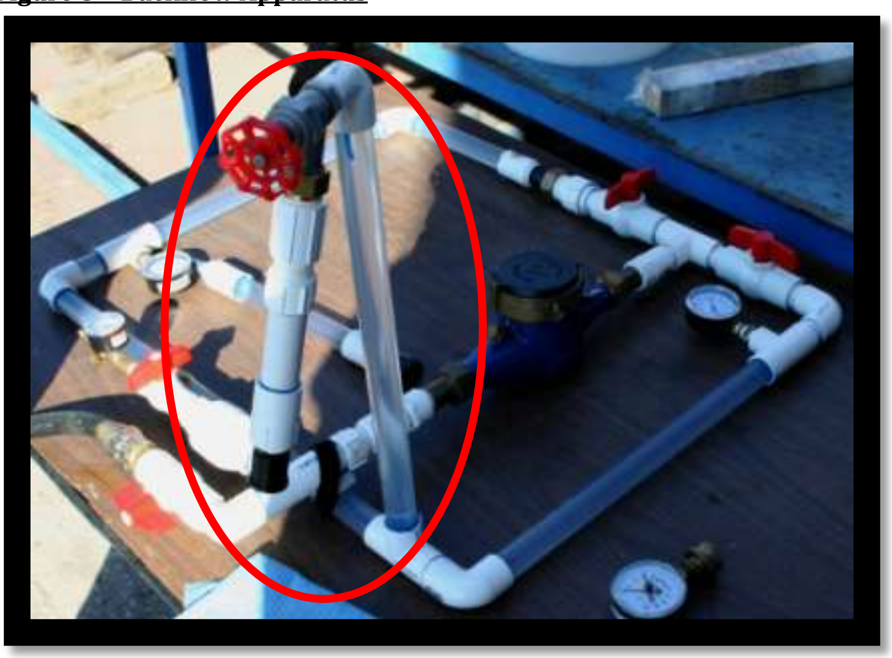


Figure 6 – Clear Pipe Showing Bubbles in the Water Line

Part C: 0.75" Physical Testing Witnesses `

The following witnessed, and attest the physical testing presented in Tables 2, 3, and 4 in this report:

- Richard Edgeworth – President and Chief Executive Officer, Automatic Flow Control, LLC.
- Ahmad Hares – Design Engineer and SMART VALVE Project Director, QTM, INC.
- Ron Politte – Senior Engineer and General Manager, QTM, INC.
- Josh Kowzan – Junior Engineer, QTM, INC.
- Christopher DeAnnuntis, Senior Research Engineer, University of South Florida

Part D: Raw Test Data

Table 5 – Computational Fluid Dynamics Simulation Data

	Position Name	Total distance to close (in)	Max-Deflection (in)	X-Position (in)	Regressed Flow Rate (in^3/s)	Force on Head (lb)
0.75 inch Smart Valve	Off	0.8070	0.1720	0.0000	0.0000	0.0000
	Position 1			0.0172	23.3036	0.8886
	Position 2			0.0860	96.1729	1.1027
	Position 3			0.1548	136.4903	4.0207
	Position 4			0.0573	69.7666	0.5887
	Position 5			0.1147	116.9277	2.1318
1.5 inch Smart Valve	Off	1.1600	0.5764	0.0000	0.0000	0.0000
	Position 1			0.0576	176.5703	20.2505
	Position 2			0.2882	515.8878	3.6432
	Position 3			0.5187	268.0633	8.4298
	Position 4			0.1921	445.8596	1.9561

	Position 5			0.3843	483.9816	-0.4640
2 inch Smart Valve	**Off**	1.1130	0.2372	0.0000	0.0000	6.3591
	Position 1			0.0237	124.9794	74.7590
	Position 2			0.1186	523.6596	4.7783
	Position 3			0.2135	760.3599	4.5425
	Position 4			0.0791	377.2279	12.1817
	Position 5			0.1581	641.9698	6.8998
3 inch Smart Valve	**Off**	1.8875	0.4023	0.0000	0.0000	13.3360
	Position 1			0.0402	282.7731	27.2770
	Position 2			0.2011	1153.5376	35.7841
	Position 3			0.3621	1607.7772	148.6075
	Position 4			0.1341	841.3384	26.6764
	Position 5			0.2682	1393.4234	105.5355
4 inch Smart Valve	**Off**	1.9875	0.4236	0.0000	0.0000	16.7470
	Position 1			0.0424	510.9477	162.1742
	Position 2			0.2118	2013.2544	20.4790
	Position 3			0.3812	2649.1863	146.3702
	Position 4			0.1412	1492.5818	43.6670
	Position 5			0.2824	2383.5146	24.6637
6 inch Smart Valve	**Off**	2.2780	0.4855	0.0000	0.0000	15.2540
	Position 1			0.0486	1135.9513	533.5509
	Position 2			0.2428	4627.6405	75.6678
	Position 3			0.4370	6435.9441	-113.6305
	Position 4			0.1618	3377.3481	31.2540
	Position 5			0.3237	5585.6784	83.8075