CONTINUOUS MONITORING OF ULTRASONIC METERS

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Introduction

There are many in our industry who would consider the advancement of the ultrasonic meter to be one of the most important improvements in gas measurement in the past twenty years. It is my opinion that the immense improvement in gas measurement is not so much the ultrasonic meter itself. Instead, I believe it is the meter's ability to detect conditions that would compromise its own accuracy and ability to communicate those conditions to the user. It is in the area of communicating those conditions, that we often under-utilize the meters capabilities.

The natural gas pipeline industry has seen tremendous changes in the past twenty years, including a smaller multi- skilled workforce. The reality of today's pipeline workforce is fewer technicians performing a wider range of tasks. Much of their measurement work is performed with less frequency, and on more complex equipment than ever before. Gaining the proficiency needed to recognize and troubleshoot ultrasonic meter problems, requires time and experience to learn. By bringing the meter's diagnostic data into our SCADA system, we can provide alarms and trending capabilities that are not dependent on the frequency at which a Technician can visit a measurement facility. Furthermore, it is not dependent on whether a Technician has the necessary expertise to recognize potential meter problems.

Another change our industry has seen are meter stations with larger but fewer meters. With the high turn down capabilities of ultrasonic meters, large volume meter stations that before would have been built with four or more orifice meters are now built with one or two larger ultrasonic meters. Fewer meters, means we are placing a higher liability on each meter.

One factor that has not changed is the expectations of a tight pipeline balance. In fact, most of us have seen our lost and unaccounted for objectives reduced to a level that would have been impossible to meet twenty years ago. Fortunately, our ultrasonic meters have less uncertainty than the meters we used in the past, and provide us with enough data to warn us when their accuracy is in question. Unfortunately, our testing practices are not much different from the way we've tested orifice meters twenty-five years ago. When testing orifice meters, we made sure the plate was clean, flat, and sharp; then the transmitters were calibrated. Similarly, with our ultrasonic meters, we look at the software display, pull a two-minute log file, calibrate the transmitters, and then assume all is well until the next test cycle. You can be quite confident that the old sayings "ignorance is bliss" and "what you don't know can't hurt you" do not apply when searching your pipeline system for lost gas.

Much like our industry's movement from chart recorders to Electronic Flow Measurement some 30 years ago, the development of Smart Measurement Diagnostic Systems is the natural progression of this technology. This is being accomplished by building on the previous developments of EFMs, PLCs and smart meters.

Benefits of Continuous Data Gathering

While today's ultrasonic meters, provide tremendous amounts of diagnostic data, if that data is only reviewed once a month or less, we may still find ourselves months behind the curve when we begin looking for measurement problems. In order to make measurement corrections, we end up spending countless hours combing massive amounts of data pulled from the meter. Historical data may not be available in many older ultrasonic meters, making it even more difficult to determine when the meter's problems began.

Think about the benefits that can be derived from polling for this data even once every five seconds. Instead of having a two-minute snap shot of the meters health each month, you will have over half a million snap shots of that data every month. By utilizing our flow computers and SCADA systems to gather and analyze this data, we can monitor our ultrasonic meters continuously, making the data readily available to Technicians, Data Analysts, and Gas Controllers.

Meter Alarm Monitoring via SCADA

Storing this data in your SCADA system can provide you with instantaneous and predictive methods of monitoring. Utilizing discrete type alarms and base line data for limits provides instantaneous alarms that can be identified by inexperienced users. These alarms provide Gas Controllers or Analysts, who may have no ultrasonic meter training the ability to identify potential meter problems, and have the confidence necessary to call the problem to the technician's attention.

Trending of this diagnostic data provides a detailed history that can be used to reveal shifts over time. This data can be utilized to uncover a variety of subtle changes in a meter that would be difficult to detect viewing maintenance logs once a month. Historical data can be used to tighten alarm limits as well. Detailed analysis of this data would require examination by someone with ultrasonic meter experience, but with the data stored in the SCADA system, it would be readily available to employees that are trained to perform such tasks.

We have found that SCADA monitoring of this data not only provides us with instant and predictive monitoring of our meters, it also provides a means of monitoring our meters at stations that do not flow on a routine basis. Additionally, it provides the ability to monitor for intermittent problems.

Ultrasonic meters at peaking power plants can be difficult to monitor, because they tend to run at unscheduled times throughout their generating season. Technicians may often find it difficult, especially during shoulder months, to catch these stations when they're flowing to perform meter tests. SCADA monitoring of ultrasonic meters not only provides warnings of possible measurement inaccuracies for these meters, it could also provide support for extending meter test frequencies on meters that flow continuously.

As we all know, intermittent problems with any equipment can be difficult to find. Prior to our polling one particular 12-inch ultrasonic meter with our flow computer, we found a bolt sleeve from an insulating gasket lying up against the flow conditioner. We caught this by chance when our Technician noticed an unusual profile factor during a meter test. Apparently, the sleeve would lie on the bottom of the pipe until the velocity increased to a point high enough to stand it up, which was the only time it created a profile disturbance. Since there was a strainer upstream of the meter, one can only assume the sleeve had been in there since the station was built. That being the case, it took nearly 5 years for someone to be there at the right time to catch it. Imagine trying to monitor your pipeline for H_2O or H_2S by performing a dragger tube test once a month to check for slugs coming through your pipeline. Collecting two-minute logs every month would give you about the same odds of discovering an intermittent problem with the meter.

Getting Started

The basic concept behind continuous monitoring of ultrasonic meters is to utilize the Modbus communications capabilities of the flow computer and meter to transfer data between the two devices. This data can then be used to execute the same or similar diagnostics performed by the meter's software or a Technician reviewing a maintenance log.
The diagnostic data in the flow computer can then be polled by a SCADA system, which makes the data available offsite. The process of polling ultrasonic meters for data has been an ongoing process for us since 2004. New meters, the availability of new data, and new calculation capabilities, such as the ability to calculate the speed of sound in the flow computer, have required us to make changes to the way data is processed and retrieved for analysis. For the most part, future changes to polling routines and calculated data can be avoided or at least reduced with proper planning.

With that in mind, you need to start by asking yourself a few questions. What data do you want to see? Do you want to poll for all the data, or do you want to poll for some of the data, and calculate some of the meter health alarms? Do you want to pull the raw data into your flow computer and perform the diagnostics there, or simply pass the data on and perform the diagnostics in your SCADA system?

There is far more data available in most ultrasonic meters than you likely want to collect. The first step is to list the meter health conditions you want to monitor. Once you have created that list, you will then need to determine the Modbus registers that contain those particular meter health alarms, or the data you will need to calculate those alarms. The Modbus register documentation is available from the manufacturer, and is listed in the Modbus references at the end of this paper.

At this point, you'll find, depending on the type of meter, whether you can simply poll for all the meter health data wanted, or if you will have to poll for some of the data, and use that data to calculate the meter health alarms. Depending on the meter manufacturer, you may find it simpler to calculate some of the alarms rather than make multiple polls to gather all the meter health data. Calculations of meter health alarms can be performed in the flow computer or a SCADA system. This would depend on the flow computer, and the SCADA system's capabilities, as well as the availability of someone to program these calculations into the system.

We opted to do a combination of polling for some of the meter health alarm, and to calculate some of them. We chose this method primarily because of the number of older ultrasonic meters we own that do not have all the meter health data we wanted assigned to Modbus registers.

Depending on the meter type, we are polling for all or some of the following data: corrected flow rate, uncorrected flow rate, average velocity, average speed of sound, as well as velocities and speed of sound for each path. We are also polling for turbulence, swirl, path performance, cross flow, AGC levels, signal to noise ratios and path status. We use the path level velocities and speed of sound data to calculate the profile factor, symmetry, and path speed of sound spread. We then perform several calculations and comparisons to provide various alarm points using the original flow calibration data as a baseline for alarm parameters.

As stated in the previous paragraph, one of the pieces of data we want from the meter is the corrected flow rate. To accomplish this requires that we provide the meter with the necessary data for it to perform the appropriate calculations. Depending on the manufacturer, pressure, temperature, and gas quality values can be given to the meter several ways. The pressure and temperature values can be sent to some meters through an analog input. As well, some meters can be up to poll an onsite GC. Pressure, temperature, gas quality and/or compressibility can all be written to the meter through the same Modbus connection used to read data from the meter. Some meters require writing the data to provide a continuous update of these values. We have meters set up both ways, but we typically write the data to the meters, because we do not have an onsite chromatograph at many of our ultrasonic stations. In this case, the gas quality being used by the flow computer for calculations is written to the meter.

To set up a meter poll in our flow computer, the Technician would select the meter type from a drop down menu, which is illustrated in figure 1. The meter type signal tells the flow computer how to configure the master port used to poll the meter. We also utilized the different meter default protocols and communication settings to minimize meter set up changes.

The port configuration set by the meter type signal dictates the appropriate floating point format, bit, byte, word orders, start register, and the number of registers to poll. Additionally, the Modbus data will be in metric units for some meters and imperial units for others. The meter type signal tells the flow computer to covert the incoming data when necessary.

The polled data is then mapped to different signals and is used for the various calculations we want to perform. This allows us to utilize the same flow computer program whether the meter station has Instromet, Daniel, or Sick Maihak meters. The fewer types of meters you have will help simplify the process.

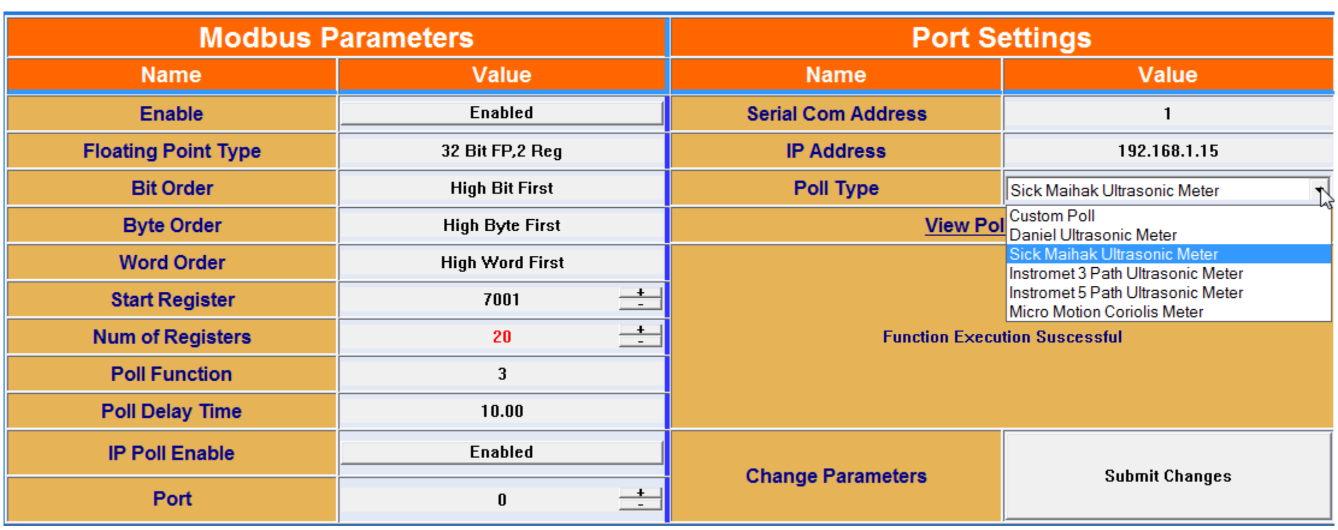

Figure 1, Meter Polling Setup Screen "Self-Diagnostic" Alarming

Originally, we used the data polled to calculate a profile factor, symmetry, speed of sound spread, and to compare the meter's speed of sound to one we calculated in the flow computer. This data is displayed in the RTU and shown in figure 7. In recent years, we explored the benefits of gathering additional data from our meters. We worked with Sick Maihak and Daniel Industries to establish some additional diagnostic logic in our flow computers for their meters. With our Daniel meters, we used the methodology described in a paper written by Dan Hackett titled "Advanced Diagnostics Firmware for Ultrasonic Meters", to detect different conditions such as, a blocked flow conditioner, meter contamination, and liquid in the meter. We performed similar calculations to provide these same alarms for our Sick Maihak meters based on information provided by John Lansing. There are some differences in the calculations each manufacturer recommends to detect the different alarm conditions. However, because both are chordal type meters, most of the logic used is identical. We used similar logic for the Instromet meters based on what data was available. The RTU display for this data is shown in figure 2.

Sick Maihak Ultrasonic Meter Polled Data			
4 + 1 Poll	Enabled		
Average SOS	1413.235		
Average Velocity	27.595		
Uncorr Flow Rate MACFH	4620.541		
Cord 1 SOS	1413.825	Cord 1 Velocity	25.707
Cord 2 SOS	1412.597	Cord 2 Velocity	28.410
Cord 3 SOS	1412.614	Cord 3 Velocity	28.277
Cord 4 SOS	1413.902	Cord 4 Velocity	24.113
Symmetry	1.045	Profile Factor	1.11319
Base Line Symmetry Factor	1.00000	Base Line Profile Factor	1.11000
Profile / Symmetry Alarm Percent	5.000	Profile / Symmetry Alarm Percent	5.000
Symmetry Factor Alarm	Normal	Profile Factor Alarm	Normal
Cal Flowrate Select	Run 1	Bidir Sta / Sta 2 Mtr Select	Run 1
Calculated SOS	1411.58	Calculated Flowrate	4532
Meter SOS	1413.23	Meter Flowrate	4621
Cal / Live SOS Pct Error	-0.117	Cal / Live Flowrate Pct Error	-0.077
SOS Alarm Percent	0.500	Path Velocity Spread	4.297
SOS Error Alarm	Normal	Path SOS Spread	1.306
SOS Spread Alarm	Normal	Write Press, Temp & Gas Quality to Meter	Enabled
		Data Write Delay Time in Sec	0.000

Figure 2, Meter Polling Basic Diagnostic Screen

For the Instromet meters, we are alarming on path performance, swirl, AGC level, and path status all from data we poll directly from the meter. We also generate alarms for profile factor, speed of sound spread, speed of sound error, frequency input error, and gas quality by performing various calculations in the flow computer.

With the Daniel meters, we are alarming on path performance, swirl, AGC level, path status, path turbulence, and cross flow, all from data we poll directly from the meter. We then generate alarms for profile factor, speed of sound spread, speed of sound error, frequency input error, volume calculation error, blocked flow conditioner, meter contamination, liquid, and gas quality by performing some calculations in the flow computer.

On the Sick Maihak meters, we are alarming on path performance, swirl, AGC level, path status, path turbulence, and signal to noise ratio, all from data we poll directly from the meter. We then generate alarms for profile factor, speed of sound spread, speed of sound error, frequency input error, volume calculation error, blocked flow conditioner, meter contamination, liquid, and gas quality. We compare the four-path meter's flow rate and speed of sound to the single path meter by performing various calculations in the flow computer.

Our objective has always been to provide warnings for our meters without creating nuisance alarms and call- outs. For that reason, we require the velocity to be at least 5 feet per second and most alarm conditions must be true for 5 minutes in order to activate an alarm.

Self-Checking Redundant Measurement

Having the meter's data in the flow computer, allows us to perform some additional diagnostics that cannot be accomplished by the meter or flow computer alone. By comparing the data from both devices, we are able to perform a number of additional measurement system examinations. All of the data necessary to perform these health checks is already available we simply need that data in one location to utilize it. By adding an additional pressure transmitter and temperature transmitter, we can take our analysis one step further. The addition of reference pressure and temperature values combined with the data from the meter and flow computer, gives us all the fundamental information necessary to build a complete self-checking redundant measurement system. The RTU display for the advanced diagnostic data is shown in figure 3.

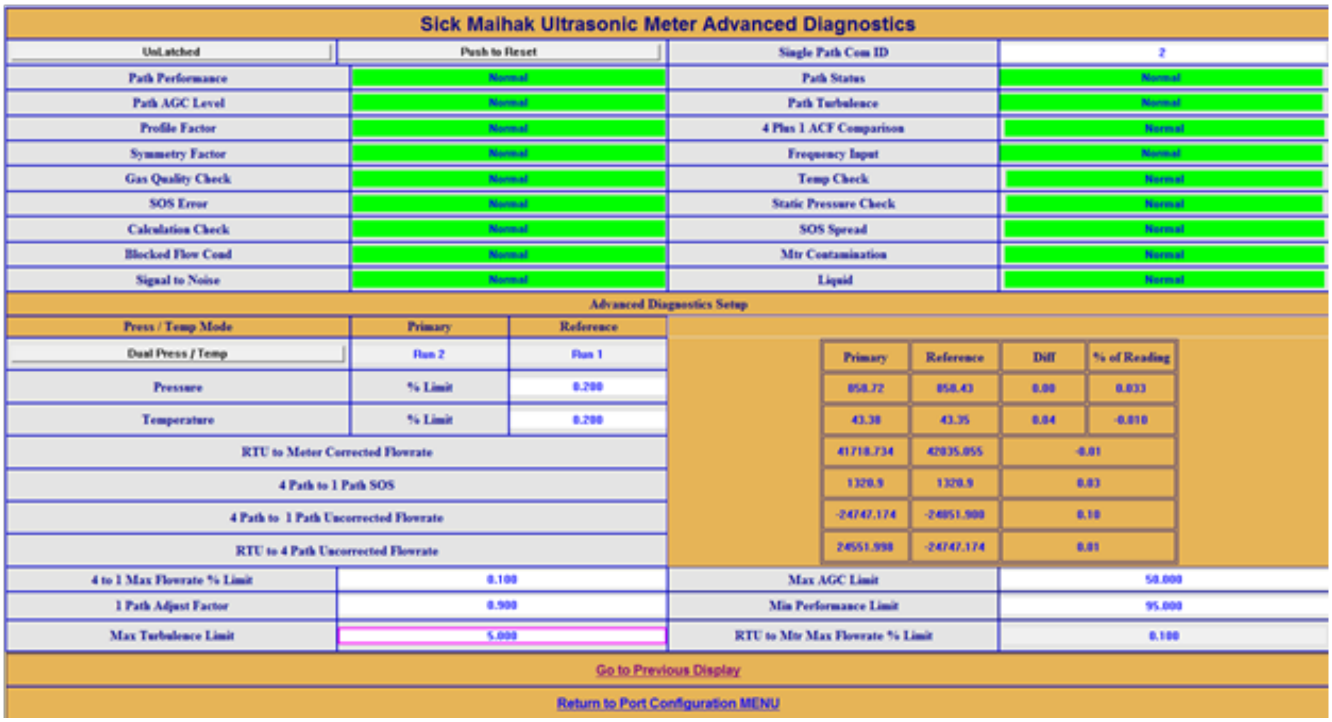

Figure 3, Meter Advanced/Self Diagnostic RTU Screen

For example, if two temperature transmitters, two pressure transmitters, a four path meter speed of sound, and a single path meter speed of sound values agree, and the measured speed of sound does not agree with the calculated speed of sound, we can make a logical assumption that the calculated speed of sound is using different gas quality than that actually flowing through the meter. This condition indicates a problem with the chromatograph or some other type of gas quality issue. In the case of the Daniel and Instromet meters, we are using the speed of sound spread to establish that the measured speed of sound is correct.

With the meter calculating a corrected flow rate, we can compare that value to the flow computers corrected flow rate. This comparison validates the flow calculation performed in the flow computer and provides backup measurement. When you combine these checks with other real time diagnostics such as insuring a good flow profile, meter performance and meter stability, we are able to significantly reduce our measurement uncertainty in the field, and provide a redundant self-checking measurement system at minimal additional cost. A system such as this could also be used to develop a "Condition Based Maintenance System". This system would be capable of informing the user when maintenance and calibrations are necessary, rather than performing these tasks on some repetitive schedule. Obviously, there would be some savings associated with the reduced maintenance and travel to meter stations using a system such as this. One should also note that the 2013 revision of API 21.1 contains some specific language regarding the use of redundancy verification for transmitters.

Other Applications

This same concept can be applied to other types of smart meters as well. Some Coriolis meters can be purchased with the ability to perform a "Smart Meter Verification". The verification is performed without measurement interruption so it can be executed without having someone onsite. The meter can be set up to perform the verification on a schedule, and the

results of that verification, as well as other meter data can be polled via Modbus from a flow computer. It is then passed on to a SCADA system for monitoring and historical trending.
We have several Coriolis meters that were purchased with the verification capabilities. We configured the meter to schedule the verification once a day, and then poll for the verification registers.

Click Here	SOS Err	Prof. Factor	Symmetry	vg Speed Of Sour	Avg Velocity	SOS Err Alarm	Prof Fac Alarm	Symmetry Alarm	SOS Spread Alm.	UMAC-1A	UMAC-1B	UMAC-C
_RUN1	0.0729	1.57872	0.14823	1408.191	0.05652	NORMAL	NORMAL	NORMAL	NORMAL			
_RUN1	-0.23203	1.125	1.02	1396.969	29.95425	NORMAL	NORMAL	NORMAL	NORMAL	0	0	0
A_RUN1	-0.09148	1.13949	0.98585	1416.589	20.59407	NORMAL	NORMAL	NORMAL	NORMAL	0	0	0
_RUN1	0.36696	-0.65843	-1.58437	1421.968	-0.02215	NORMAL	NORMAL	NORMAL	NORMAL	0	0	0
RUN1	-0.00281	-1.06938	1.	1409.093	0.00635	NORMAL	NORMAL	NORMAL	NORMAL	0	0	0
_RUN1	-0.376	1.00521	0.95897	1333.522	16.86827	NORMAL	NORMAL	NORMAL	NORMAL	0	0	0
_RUN2	0.25694	-0.12652	-2.71294	1411.901	-0.00115	NORMAL	NORMAL	NORMAL	NORMAL	0	0	0
_RUN1	0.13175	5.49984	-0.79131	1411.901	-0.00449	NORMAL	NORMAL	NORMAL	NORMAL	0	0	0
B_RUN1	0.13955	0.61757	0.04301	1400.567	0.10856	NORMAL	NORMAL	NORMAL	NORMAL			
A_RUN1	-0.00136	1.1549	0.79928	1380.188	1.67264	NORMAL	NORMAL	NORMAL	NORMAL	0	0	0
_RUN1	0.19603	-0.36245	-2.18254	1427.666	0.00128	NORMAL	NORMAL	NORMAL	NORMAL	0	0	0
_RUN1	-0.26439	1.05077	0.84318	1345.285	1.57727	NORMAL	NORMAL	NORMAL	NORMAL			
_RUN1	-0.0509	3.16973	5.52549	1376.161	0.00541	NORMAL	NORMAL	NORMAL	NORMAL	0	0	0
_RUN2	-0.0955	-0.43415	-1.63406	1423.356	0.00423	NORMAL	NORMAL	NORMAL	NORMAL	0	0	0
_RUN1	-0.46903	1.21509	-0.43698	1408.475	0.00667	NORMAL	NORMAL	NORMAL	NORMAL	0	0	0
_RUN1	5.12582	0.69821	-0.52976			NORMAL	NORMAL	NORMAL	NORMAL			
_RUN2	-0.3112	1.29247	1.	1424.885	0.01299	NORMAL	NORMAL	NORMAL	NORMAL			
_RUN1	-0.7676	1.12194	0.99021	1357.135	14.66242	ALARM	NORMAL	NORMAL	NORMAL	0	0	8
_RUN1	100.	1.	1.	0.	0.	NORMAL	NORMAL	NORMAL	NORMAL			
B_RUN1	100.	1.	1.	0.	0.	NORMAL	NORMAL	NORMAL	NORMAL			
A_RUN1	100.	1.	1.	0.	0.	NORMAL	NORMAL	NORMAL	NORMAL			

Figure 4, Ultrasonic Data displayed in SCADA

This data provides us with, Test Run Status, Test Abort Status, Test Completion Status, and Tube Stiffness Status. We also poll for an alarm register that can be decoded to individual alarm points, and registers that provide the raw tube frequency, pickoff voltages, drive gain and live zero value. Examples of the RTU coriolis meter diagnostic screen and the SCADA diagnostics screen can be seen in figures 4 and 5.

Micro Motion Meter Polled Data			
RTU Run Select	Run 1	RTU to Mtr Max Flowrate % Limit	5.000
Meter Diagnostic Code	1048576.000	Meter Flowrate LBS/Hour	857.057
Meter Density (Typically 0.0)	0.000	Calculated Flowrate	860.400
Meter Internal Temp	60.1	Cal / Live Flowrate Pct Error	-0.030
RTU Meter Temp	0.0	Freqency Alarm	Normal
	Drive Gain / Tube Freq PCT Max	10.000	
Drive Gain	4.066	Tube Frequency	122.429
Drive Gain Base	4.00000	Tube Frequency Baseline	122.00
Drive Gain Alarm	Normal	Tube Frequency Alarm	Normal
	LPV / RPV PCT Max	5.000	
Left Pickoff Voltage	0.440	Right Pickoff Voltage	0.446
LPV Base Line	0.43000	RPV Base Line	0.45000
LPV Alarm	Normal	RPV Alarm	Normal
Meter Zero Verification			
	Perform Zero Test	Start Zero Test	
Zero Test Time / Sec	120.000	Zero Test Run Status	Test In Progress
Meter Base Zero Stability	0.025	Meter Zero LBS/MIN	0.000
Zero Stability Status	Meter Zero OK	Zero Test Time Stamp	
SMART METER VERIFICATION			
	Verification Run Status	Verification Idle	
Last Verification Date Time	04/16/2014 08:47:20	Abort Code	Verification Successful
Inlet Tube Stiffness	0.151	Outlet Tube Stiffness	0.101
Inlet Test Status	Verification Passed	Outlet Test Status	Verification Passed

Figure 5, Coriolis Meter Data RTU Diagnostic Screen

Lessons Learned

As we have worked through this process over the years, we have made some changes and learned what works best for us. We found that using our SCADA system to set alarms around raw data values did not always provide the results we wanted. Analyzing the data in the SCADA system works well for some, but was somewhat problematic for us. Our issues were primarily associated with improperly set alarms requiring additional set up work for our already over worked SCADA programmers. Many ultrasonic meter health indicators provide adequate information necessary to determine the health of the meter when analyzed by someone with some ultrasonic meter expertise. A less experienced user, such as a new Technician or Gas Controller, may not be equipped with the experience necessary to perform these tasks. Performing the diagnostic logic in the flow computer enabled us to more effectively provide decipherable statuses for each meter health indicator in our SCADA system. This established a more consistent means of alarming.

Performing the diagnostics in the flow computer gave us better control over our base line and alarm settings as well. On the other hand, performing these diagnostics in the flow computer requires some programming expertise. Evaluating the method that works best for you may depend on the availability of personnel to perform these tasks.

Regardless of the method chosen to gather and diagnose the meter's health, the data will be available for Technicians, Data Analysts and Specialists to use for in-depth analysis and trending purposes. Another lesson learned, was if the data was difficult to find, view or trend in the SCADA system, then the process of additional analysis or trending of the data just didn't happen. Originally, our diagnostic data was buried in a detail display that listed every piece of data that was being polled or calculated. Consequently, when our Measurement Technicians went into our SCADA system to review the data, it took far too much time to find and view. To resolve this problem, we worked with our SCADA programmers to display the data where it was easy to access in a format that allowed users to quickly view the data, and determine if further investigation was needed. The SCADA display is shown in figure 6.

Right Click Here	Drive Gain	Left Pick Off Voltage	Right Pick Off Voltage	Tube Frequency	Freq Input Alarm	Drive Gain Alarm	Left Pick Off Alarm	Righ Pick Off Alarm	Tube Freq Alarm	Diagnostic Status	Inlet Tube Status	Inlet Stiffness	Outlet Tube Status	Outlet Tube Stiffness
RUN1	4.400748	0.4215219	0.4185174	122.5109	NORMAL	NORMAL	NORMAL	NORMAL	NORMAL	0	0	0.1597166	0	0.1826763
RUN1	10.29693	0.5429657	0.5577596	154.1195	NORMAL	NORMAL	NORMAL	NORMAL	NORMAL	0	0	0.1407385	0	0.09912252
RUN1	4.489076	0.4442223	0.4380201	122.4556	NORMAL	NORMAL	NORMAL	NORMAL	NORMAL	0	0	0.1305819	0	0.3330827
RUN1	4.103268	0.4360698	0.4441345	122.0051	NORMAL	NORMAL	NORMAL	NORMAL	NORMAL	0	0	0.1698852	0	0.10252
RUN1	4.845829	0.4189918	0.416163	121.5935	NORMAL	NORMAL	NORMAL	NORMAL	NORMAL	0	0	0	0	0
_RUN1	4.483627	0.5292963	0.52898	302.4146	NORMAL	NORMAL	NORMAL	NORMAL	NORMAL	0	0	0	0	0
RUN1	0	0	0	0	NORMAL	ALARM	ALARM	ALARM	ALARM	0	0	0	0	0
RUN1														
RUN1	4.855706	0.4039167	0.4451008	123.0799	NORMAL	NORMAL	NORMAL	NORMAL	NORMAL	0	0	0.1068354	0	-0.1940489
RUN1	0	0	0	0	NORMAL	NORMAL	ALARM	ALARM	NORMAL	0	0	0	0	0
RUN1	9.584672	0.5421575	0.550679	153.1483	NORMAL	NORMAL	NORMAL	NORMAL	NORMAL	0	0	-0.1271009	0	-0.27408
RUN2	9.696848	0.5515223	0.5354985	152.6544	NORMAL	NORMAL	NORMAL	NORMAL	NORMAL	1048576	0	0.3391981	0	0.3903031
_RUN1	3.729517	0.4452414	0.4445913	122.6641	NORMAL	NORMAL	NORMAL	NORMAL	NORMAL	1048576	0	0.638926	0	0.5976319

Figure 6, Coriolis Meter Data displayed in SCADA

When we began modifying our polling logic for the redundant self-checking diagnostics, we realized this was a large number of individual alarms to bring into the SCADA system. To resolve this problem, we grouped the self-checking alarms into three floating-point alarm signals. Each alarm signal contains six or seven normal/alarm statuses. These three alarm floating-point registers can then be decoded by converting them to binary values to identify the specific alarms. Alarm signal UMAC_1A contains alarms for profile factor, symmetry, path performance, AGC levels, path status, signal to noise ratio, and 4 plus 1 meter profile. Alarm signal UMAC-1B contains alarms for swirl, cross flow, blocked conditioner, turbulence, contamination, and liquid. Alarm Signal UMAC-Calc contains alarms for frequency input, speed of sound error, speed of sound spread, gas quality, temperature, pressure, and flow calculation.

Analyzing Historical Data

Figure 7 shows an example of the alarms indicating a partially blocked flow conditioner. Here we have a UMAC_1A alarm value of 65, indicating a 4 + 1 profile alarm and a profile factor that is outside its alarm limits. This condition is indicated again in UMAC_1B with a value of 12, indicating high turbulence and a blocked flow conditioner.

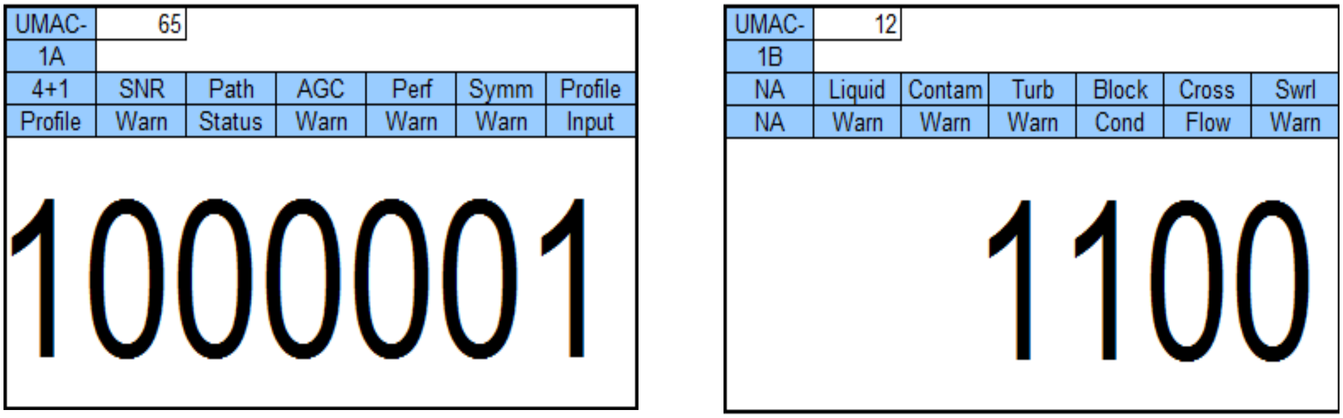

Figure 7, Blocked Flow Conditioner Alarm Example

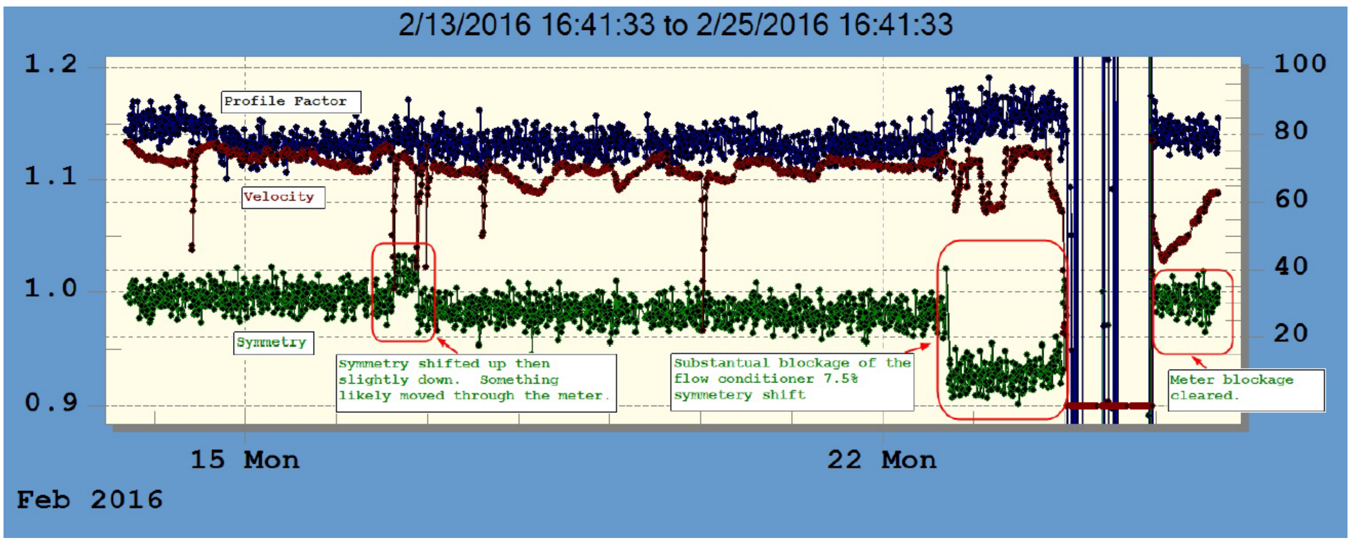

Figure 8, Blocked Flow Conditioner Data Trend

In the next example, shown in figure 9 we have an ultrasonic meter with an intermittently failing transducer. The failing transducer would at times show a lower velocity than it should to the point of going negative and sometimes it would fail. With this particular insidance when the failing path would show a negative value the average velocity was right at 20% lower than the weighted average of the other 3 paths. When the path would completely fail the path subsitution would take over and the meter would provide a proper average velocity

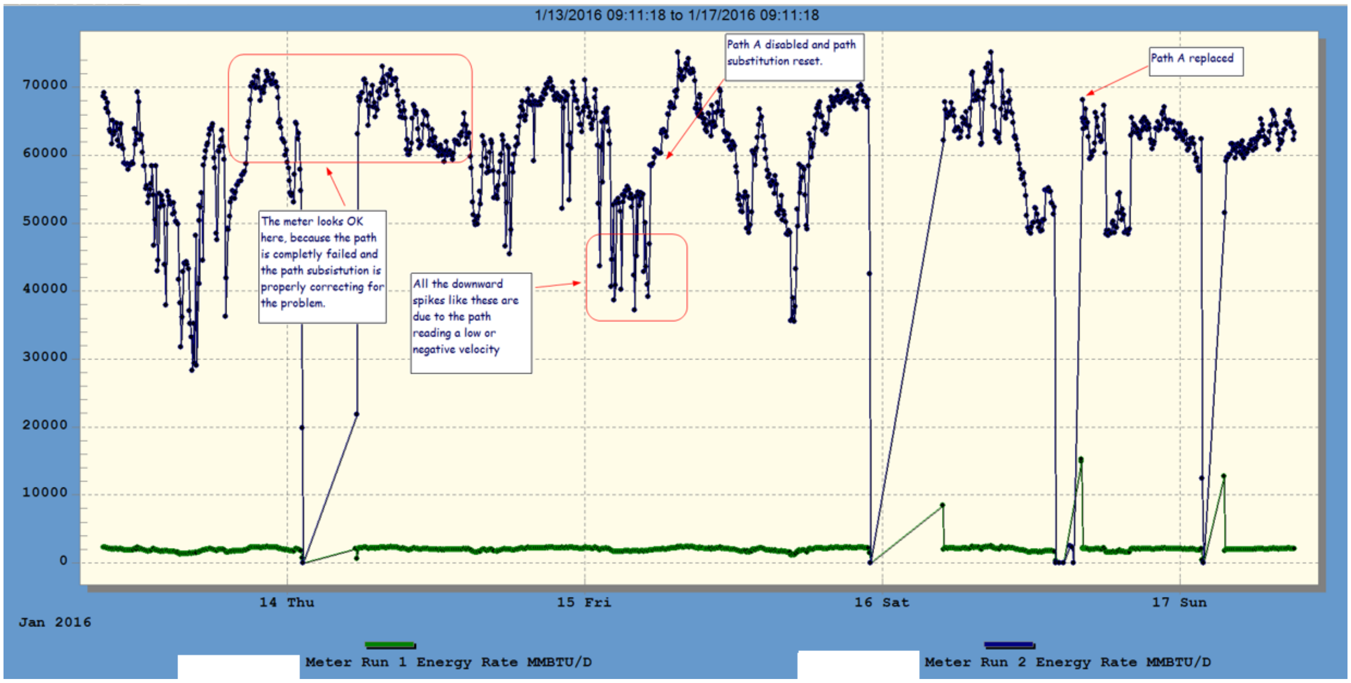

Figure 9, Intermittent Transducer Fail Data Trend

Figure 10 is a trend of the velocity and alarm history for intermittent transducer fail condition.

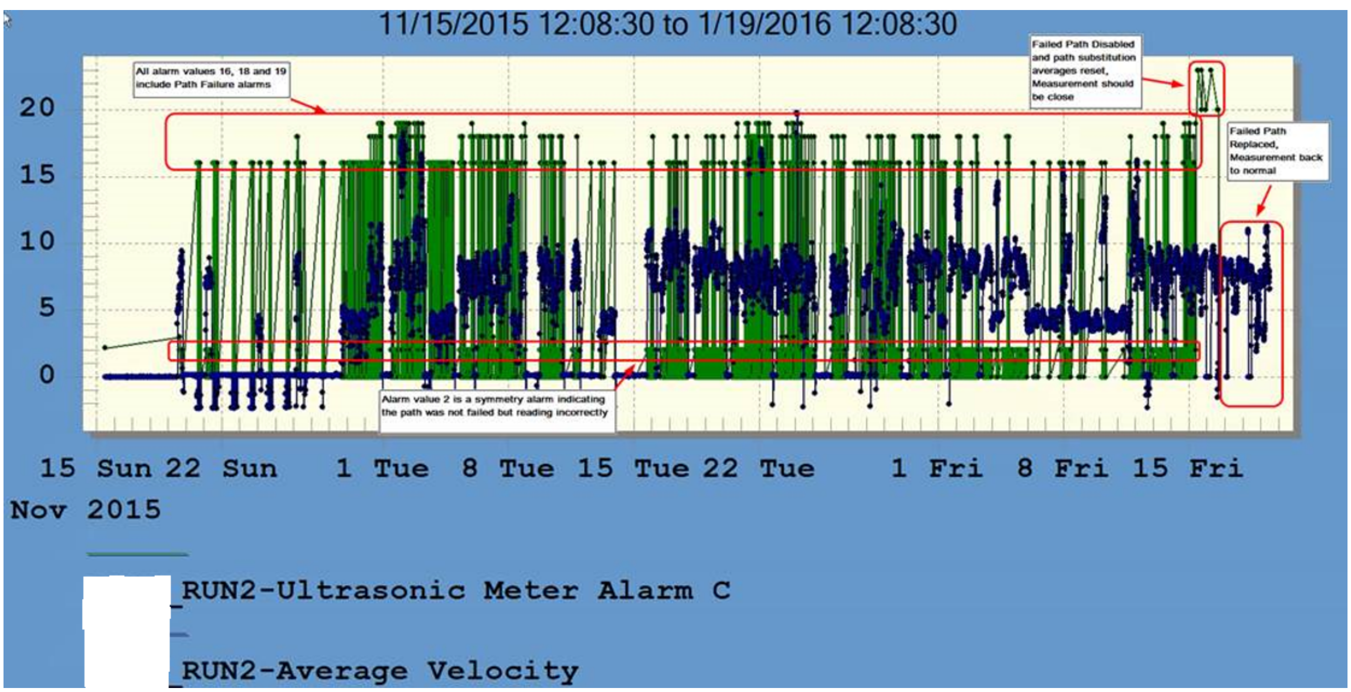

Figure 10, Intermittent Transducer Fail Alarm Trend

Figure 11 displays how a Technician or Analyst can perform quick seven-day trends of all of this data from the SCADA system, by simply right clicking on the values wanted, and adding them to a graph. Longer trends can be performed as well, by accessing the data wanted in an ADHOC report, and then building the graph in Excel. The seven-day trends are a quick and easy way for a Technician to use the SCADA system to find data on a meter he was unable to test when the meter was flowing. By trending the velocity, the Technician can locate a section of time when the meter was flowing and trend additional data such as, profile factor, symmetry, etc. during that same section of time.

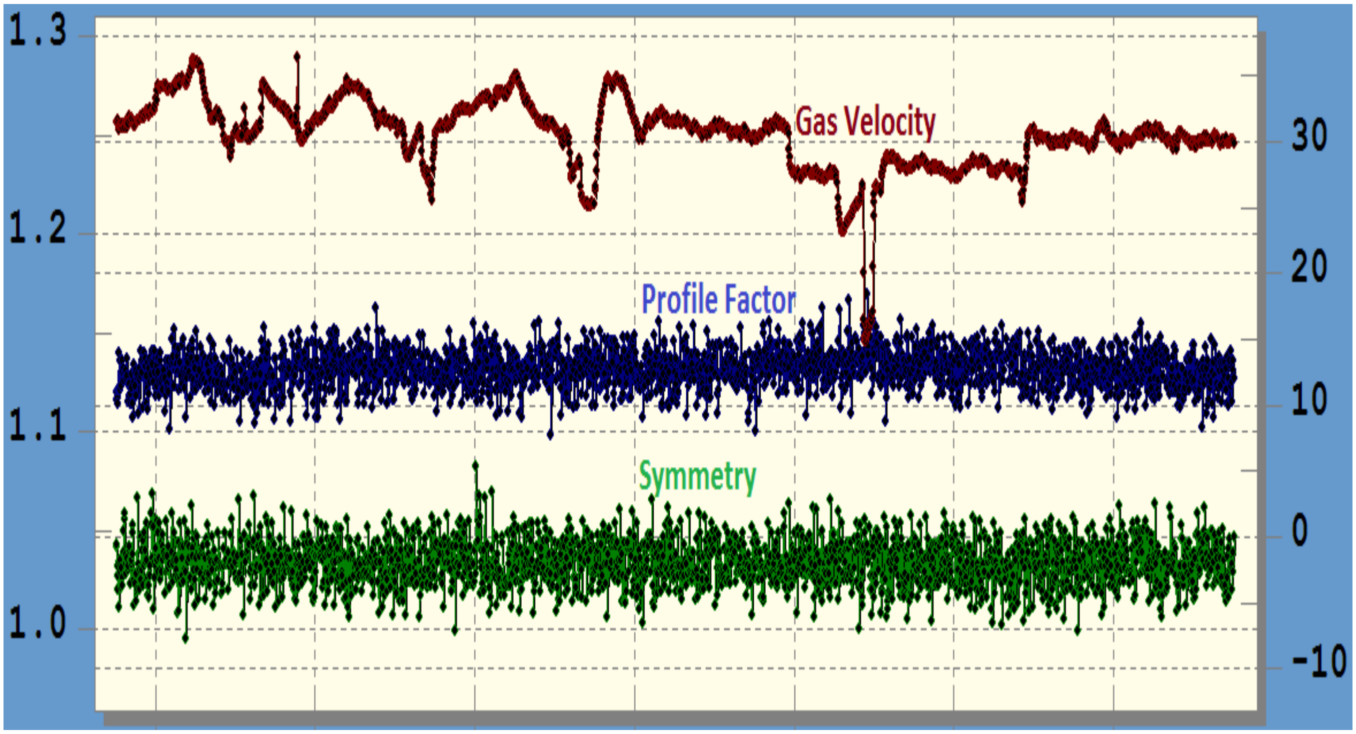

Figure 11, 7 Day Trend Example.

A combination of Normal / Alarm statuses and analog historical data provides immediate indication of alarm conditions for the entire measurement system, as well as the ability to trend data to look for subtle changes over time. Currently, this data is stored in our SCADA system, at a scan-by-scan level for 1 year, then rolled up to hourly and daily averages for 5 years. This type of data analysis requires more time and skill to utilize. It may not be used until there are imbalance issues, but it makes the data readily available when needed.

Logging Meter Alarms

Along with bringing the data into the SCADA system, we set up the flow computer to log the ultrasonic meter alarms. This provides documentation of these alarms in the measurement accounting database with a date and time stamp. Meter alarm logging also provides us with another method to catch and document potential measurement problems.

Next Generation Diagnostics

As we have progressed with our current measurement diagnostic system, we have discovered the need to do a few things differently. That need to improve on our system has brought us to the development of our Advanced Diagnostic Monitoring System or ADMS. Our ADMS system employees a flow computer that is separate from the one used on site for custody transfer. Utilizing a separate flow computer for our real time diagnostics allows us to utilize this functionality where the preferred or existing flow computer is incapable of performing the extensive polling or logic for the diagnostics. The ADMS flow computer will provide polling to the meters, the custody transfer flow computer and the gas chromatograph.

As well as performing the collecting of data the ADMS flow computer also provides instantaneous data filtering and alarming as well as data roll up to hourly minimum, maximum and averaged values. The instantaneous alarm data is packed into a number of 8-bit registers for quick polling. The rolled up data will be pulled into our ADMS database, which provides additional data filtering, analysis, trending and storage. The combination of our ADMS field device and database provides both real time and historical diagnostics and alarming of the entire measurement system at the meter station. The ADMS system will also take the responsibility for data handling, trending and storage out of our SCADA system, giving the measurement department better control over the development of the database, storage of the data and configuration of alarm settings.

The ADMS field device is setup to poll up to eight bidirectional custody, with up to eight paths. We are also able to poll up to eight check meters to compare with the custody meters and up to four coriolis meters. The current meters include Daniel, SICK, Instromet ultrasonic meters and Micro Motion Coriolis meters. We can also do some custom setups for other meters but that would involve a substantial amount of data mapping that otherwise is done automatically when the user selects the meter type. The field device programming has been completed for ultrasonic and coriolis meters. The Database, while complete for ultrasonic diagnostics, continues to be under some development for additional meter types and improved use ability. We currently have 56 ADMS field devices installed. The ADMS database allows the user to pull up all the meter's historical data, graph and trend the data as well as providing alarms when the meters parameters fall outside limits. As long-term data in the ADMS Database is analyzed, we anticipate the ability to tighten alarm bands, perform preventive maintenance and predetermine component failures. For smaller ultrasonic meter stations where we choose not to invest the dollars in the ADMS field device, the meter's maintenance logs can be loaded into the ADMS Database.

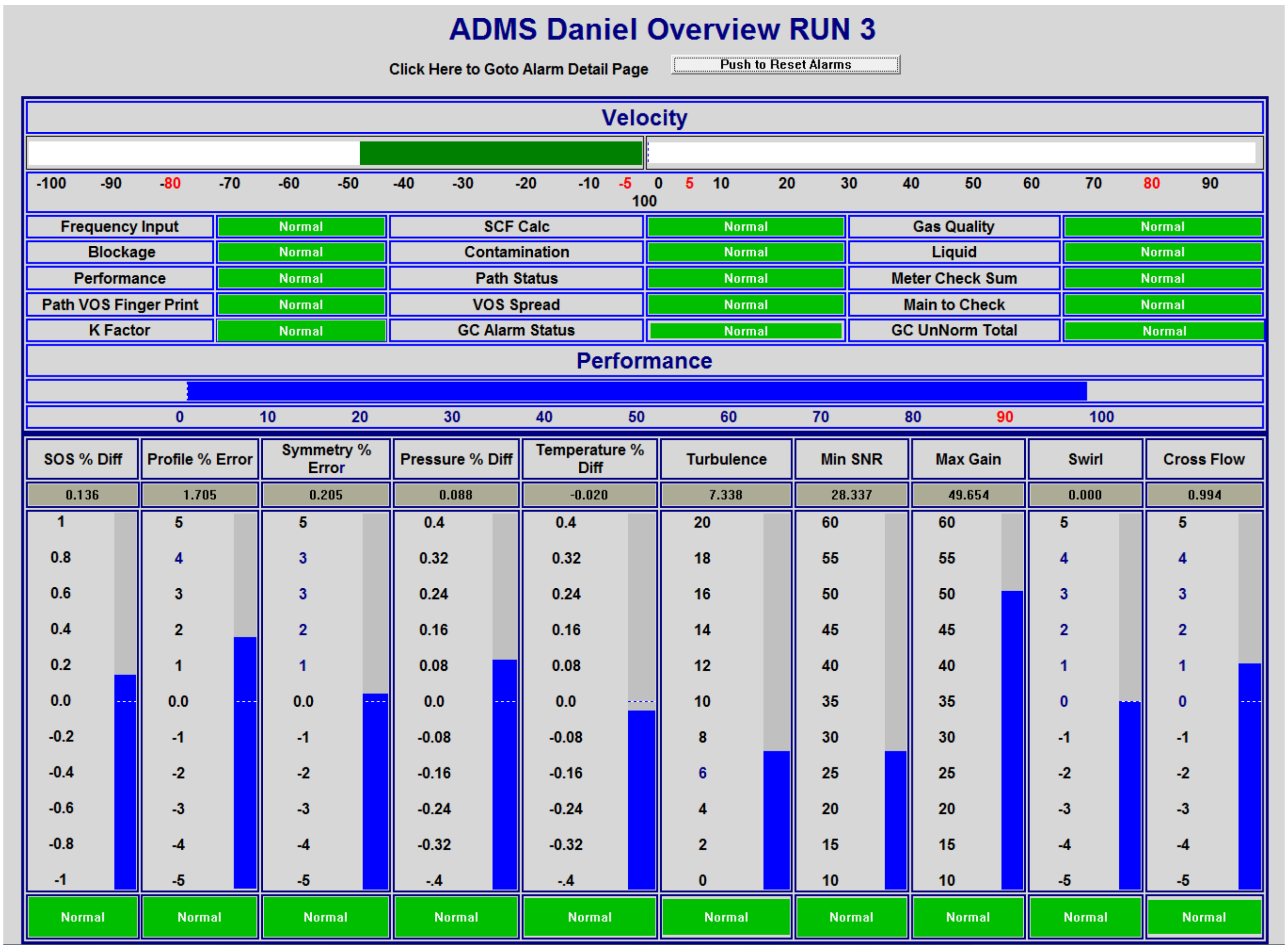

Figure 12, ADMS Field Device USM Overview.

Daniel Diagnostic Snapshot Report

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Site Name	ADMS Roswell Test	Run ID	Run 3	Gas Velocity	-49.5
Discription	**Baseline**	**Reference**	**Primary**	**Pct Differance**	**Alarm Status**
Meter Config Checksum	40385	40385	NA	NA	Normal
ACFH	0.10	-3327520.5	3351350.8	-0.7	Normal
SCF	0.10	-178568288.0	174815104.0	-0.1	Normal
Speed of Sound	0.50	1343.0	1346.0	0.22	Normal
Profile Factor	4.00	1.13	1.15	1.47	Normal
Symmetry	3.00	0.98	1.00	1.76	Normal
Pressure	0.20	690.13	690.71	0.08	Normal
Temperature	0.20	64.49	64.39	-0.020	Normal
K Factor	66.36	NA	66.36	NA	Normal
Turbulence	10.00	NA	7.66	NA	Normal
Meter Performance	90.00	NA	100.00	NA	Normal
VOS Spread	2.00	NA	0.64	NA	Normal
Gain	50.00	NA	48.92	NA	Normal
Signal to Noise Ratio	20.00	NA	29.16	NA	Normal
Swirl	3.00	NA	0.000	NA	Normal
Cross Flow	3.00	NA	0.996	NA	Normal
Main to Check ACFH	5.00	-3318323.25	-3327520.50	0.277	Normal
Other Alarms					
Meter Blockage	Normal	Contamination	Normal	Path Status	Normal
Gas Quality	Normal	Liquid	Normal	VOS Finger Print	Normal
GAS Chromatograph					
UnNormalized Total	UnNormalized Total Alarm	GC Response Factor Order	GC Alarm Status	Last Cal Date / Time	
100.03	Normal	Normal	Normal	42717	402

Figure 13, ADMS Field Device USM Snapshot Report.

Figure 14, ADMS Field Device Coriolis Overview.

Diagnostic Snapshot Report

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Site Name		Run ID	Run 2	Gas Velocity	0.0
Discription	**Baseline**	**Reference**	**Primary**	**Pct Difference**	**Alarm Status**
Meter Config Checksum	0	0	NA	NA	Normal
Frequency	0.10	0.0	0.0	0.0	Normal
Volume Calc	0.10	0.0	0.0	0.0	Normal
Density	0.50	NA	0.0	NA	Normal
Left Pickoff Voltage	0.60		0.50		Normal
Right Pickoff Voltage	0.60		0.51		Normal
Tube Frequency	200.00		194.79		Normal
Temperature	2.00	90.28	87.28	-0.546	Normal
K Factor	1000.00		1000.00		Normal
SMV Inlet Stiffness	4.00		2.06		Normal
SMV Outlet Stiffness	4.00	NA	1.78	NA	Normal
Other Alarms					
SMV Inlet	PASS	Contamination	Normal	Last SMV Test Date	42517
SMV Outlet	PASS	SMV Pass/ Fail	PASS	Last SMV Test Time	1541
Diagnostic Register	1048576				

Figure 15, ADMS Field Device Coriolis Snapshot Report.

The ADMS field devices polls up to 100 data points per meter, based on meter type, 36 data points from Micro Motion Coriolis meters, 47 data points from Daniel and ABB GCs and 9 points from the custody flow computer. This data is analyzed and compared back to baseline data from the meters flow calibration. Data from the meter, flow computer and calculations made in the ADMS field device are compared to provide additional alarming and confidence in the stations measurement system.

The ADMS Database provides data storage, reporting, trending, graphing, and alarm history of hourly data collected from the ADMS field devices as well as maintenance reports that can be downloaded into the system. The data can also be rolled up into daily, weekly or monthly values for longer trends or analysis.

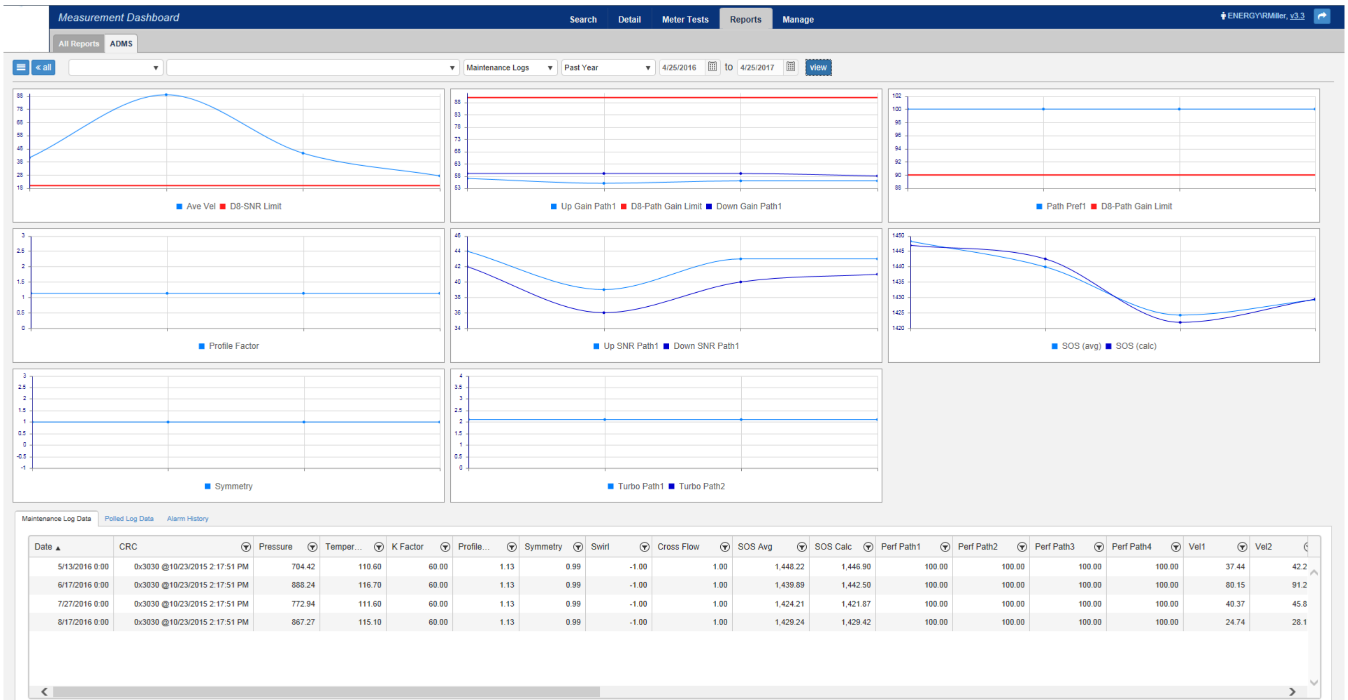

Figure 16, ADMS Database USM Overview.

Orifice Meter Diagnostics

In 2018, we began the development of orifice meter diagnostics into our ADMS system. We worked with Dr. Richard Steven and Kim Lewis to include their DP Diagnostics Prognosis algorithms into ADMS. This provides our ADMS with orifice meter diagnostics in addition to our ultrasonic meter and coriolis meter diagnostics.

The initial DP diagnostic programming process involved writing the code to determine the X1, Y1, X2, Y2, X3, Y3 and X4 values. The calculations are performed using the three different pressure differentials, DP traditional, DP Recovery and DP Permanent Pressure Loss. The calculations also required the standard meter operation information of the Coefficient of Discharge (CD), Velocity of Approach factor (Ev), Expansion factor (Y) and flowing mass gas density (rhof) which we derived from AGA Report No. 3. International Standard ISO 5167 may be utilized as well, but we chose to use AGA Report No. 3 solely because we were more familiar with that particular standard. Once we had the calculation of the X1, Y1, X2, Y2, X3, Y3 and X4 values, we were able to write the code that looks at the various X-Y patterns that determine what if any alarms are present. Because each individual X-Y pattern could potentially, be generated by more than one problem, we named our alarms, simply Alarm Condition 1 through Alarm Condition 8. We then used our interface to display the various problems that would cause that particular alarm.

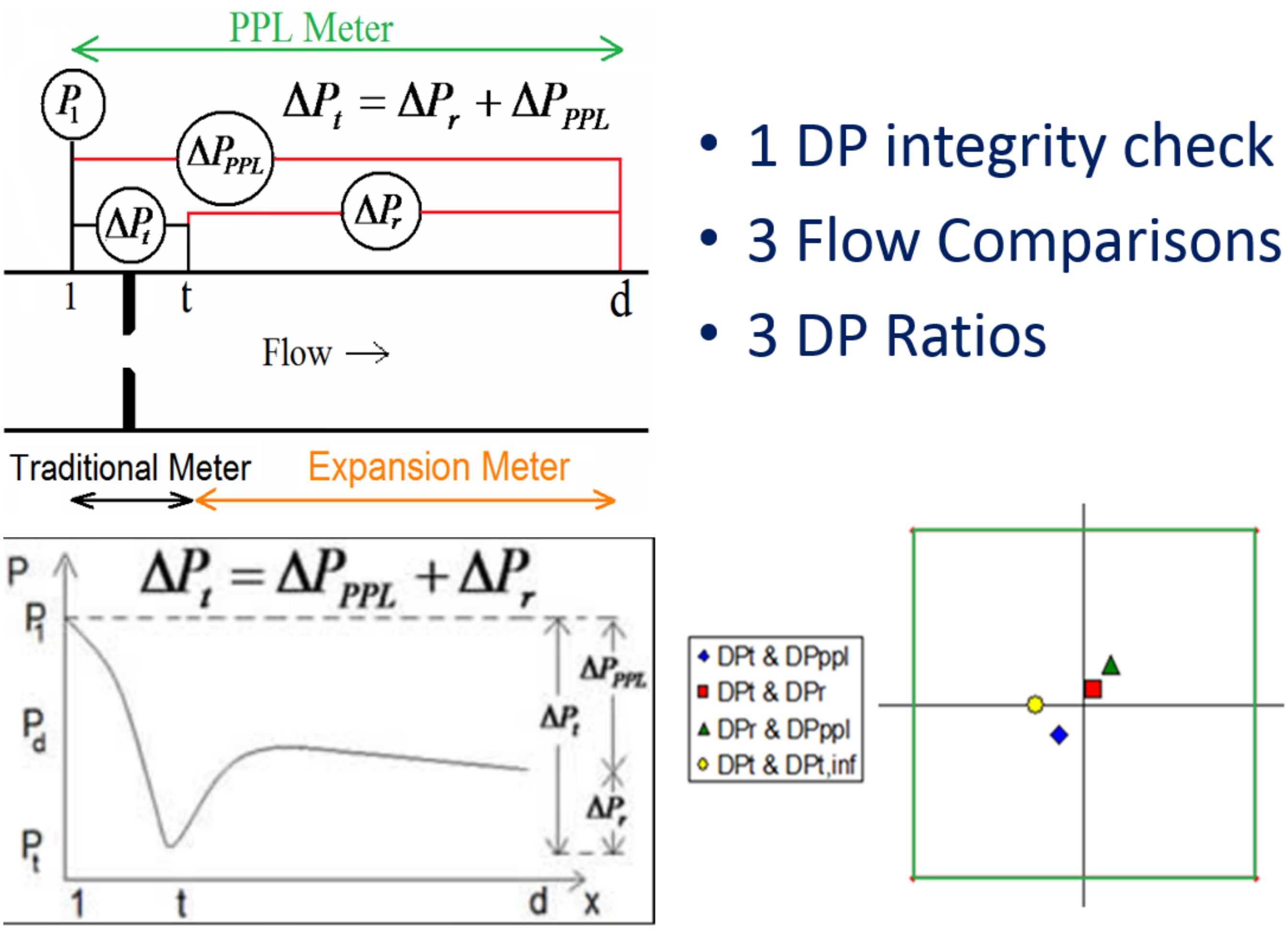

Figure 17, DP Diagnostic Prognosis Principle, image provided by DP Diagnostics

The next step was to employ some filtering to the alarms. We accomplish this in the same manner we do with our ultrasonic and coriolis alarms, by applying timers and counters to the alarm conditions. Because the ADMS flow computer checks for new alarm conditions once per second there is potential of obtaining spurious alarms. As a default, we use a 300-second timer or a 120 event count to trigger the actual alarm. Meaning an alarm condition would have to be continuously in alarm for 300 seconds or go in and out of alarm 120 times in a one-hour period to trigger an actual alarm. The 300-second timer and 120 event counter settings are both configurable in the interface.

All post-filtered alarms are latched, and then stored in the ADMS flow computer alarm log. As with the coriolis and ultrasonic meters all orifice meter alarms are cleared at the top of each hour to provide an hourly record of alarm conditions. We take Prognosis's three separate mass rate predictions calculated via each of the traditional, recovery and permanent pressure loss differential pressures. The mass rate predictions are in Kilograms per second units and we convert them to MSCFH, and place these values into hourly archives. This allows us to compare our calculations to that of the Measurement RTU to check for calculation errors. This makes available two redundant volume calculations should there be a DP transmitter failure or should the traditional DP transmitter be over-ranged. We utilize the redundant pressure and temperature transmitters used for our ultrasonic diagnostics to provide a real time verification of those values as well. DP Diagnostics's Prognosis diagnostic suite, along with secondary pressure and temperature comparisons, and gas chromatograph diagnostics provides a complete orifice meter station real time health verification. The filtered alarms along with volumes, average X and Y values and average DP values are archived and polled by our Measurement Dashboard for long-term storage, alarms as well as trending and graphing.

Configuration			Status Detail	
Discription	Default	Value	Discription	Value
X Y Alarm Band Pct	1.0	1.000	X1 Value	0.129
X Variance PCT	1.0	1.000	Y1 Value	0.290
Y Variance PCT	1.5	1.500	X2 Value	-0.673
Z Variance PCT	2.0	2.000	Y2 Value	-0.804
A Variance PCT	2.0	2.0000	X3 Value	-0.600
B Variance PCT	3.0	3.0000	Y3 Value	-0.992
C Variance PCT	3.0	3.0000	X4 Value	-0.507
D Variance PCT	1.0	1.0000		
Static Press Tap Location	NA	DnStream	Alarm 1 Live Status	Normal
Low DP Cuttoff	0.25	0.250000	Alarm 2 Live Status	Normal
DPD Alarm Filter Time Delay	300.0	300.0000	Alarm 3 Live Status	Normal
DPD Alarm Filter Max Count	120.0	300	Alarm 4 Live Status	Normal
DPD All Alarm Latch	Latched	Latched	Alarm 5 Live Status	Normal
If the downstream pipe tap distance is further than 6 pipe diameters from the orifice plate enter the distance in inches from the orifice plate to the tap.			Alarm 6 Live Status	Normal
DnStream Pipe Tap Distance in Inches Enter value if > 6D	0.0	81.0000	Alarm 7 Live Status	Normal
Use 0.012 for smooth honed pipe and 0.3 for ruff pipe.			Alarm 8 Live Status	Normal
Friction Factor	0.04	0.1000	Non-Defined Alarm Live Status	Normal

Figure 18, ADMS Orifice Meter Diagnostic Alarm Setup

The orifice meter prognosis algorithms are expecting the far downstream pressure tap to be located at six pipe diameters from the orifice plate. Where we have to install this downstream tap further than six pipe diameters, we have an additional equation to adjust for the added pressure loss, associated with the tap being further downstream. For example, in figure 17 we have the far downstream tap located at 81 inches from the orifice plate on a 10-inch meter. Since this is further than six pipe diameters, we have entered that value along with a friction factor to make the proper pressure drop adjustment.

The last development for the ADMS flow computer was to create the 'Prognosis' interface. Since the interface was already developed for our ultrasonic and coriolis meter diagnostics the process of adding in the orifice meter diagnostics interface was greatly simplified.

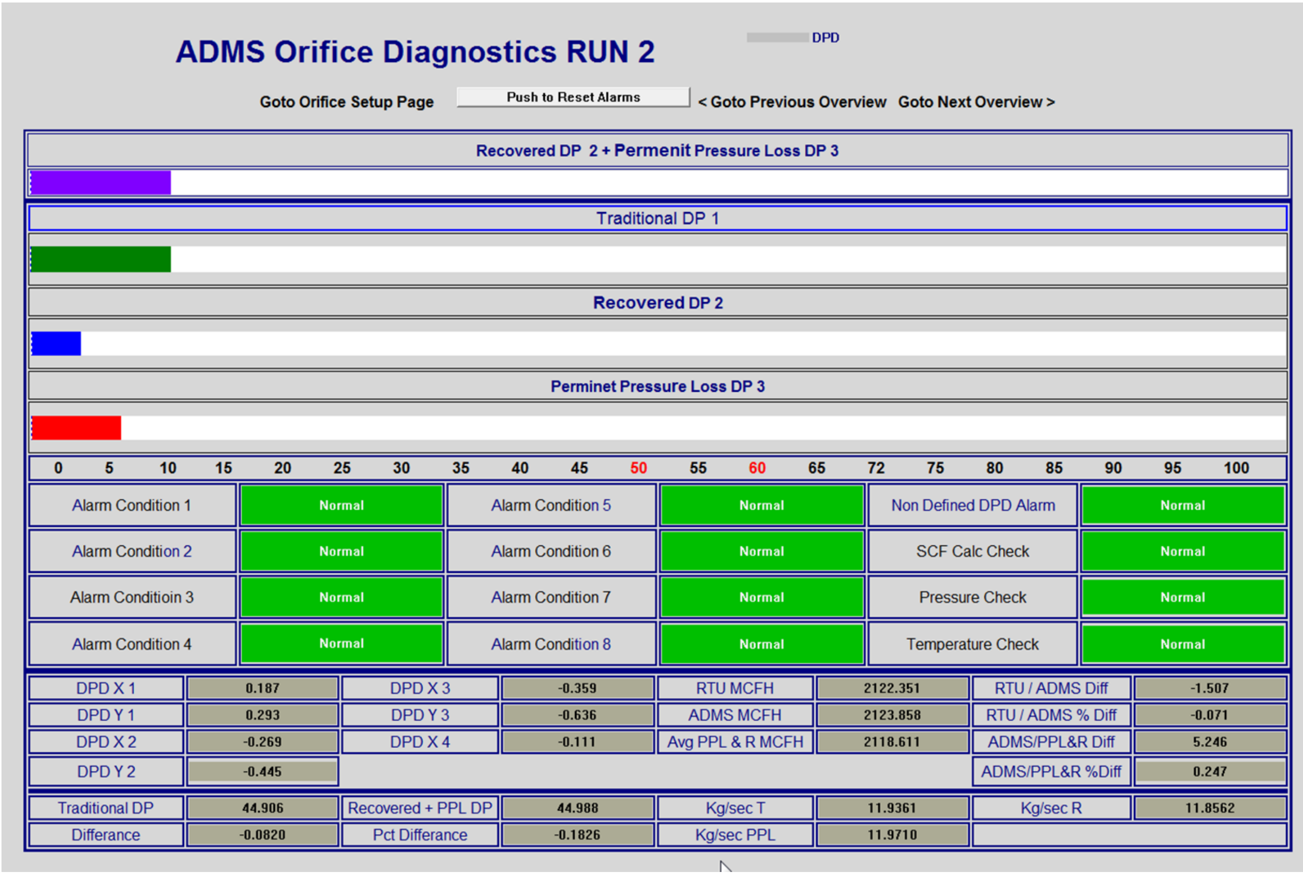

Figure 19, ADMS Orifice Meter Diagnostic Overview

The testing of the calculations and alarming was initially performed by fixing in the three different DP values, the orifice and pipe diameters, pressure and temperature values and gas quality. The results were then compared to examples DP Diagnostics provided. I later met up with Kim Lewis of DP Diagnostics where we ran tests using a demo orifice meter and compared the results to the ADMS flow computer. I eventually built a test orifice meter using PVC pipe and shop vacuum to pull air through the meter. I bent, dulled and nicked orifice plates to simulate different conditions and again verified our calculations. The values labeled Variance PCT in figure 17 are used in the X1, Y1, X2, Y2, X3, Y3, and X4 calculations and could also be referred to as sensitivity settings. I had to adjust some of these values when I performed tests on the meter I built out of PVC pipe due to the internal smoothness of the PVC pipe. As expected, the system properly identified the various problems we presented to it. This included an incorrect pipe diameter, incorrect orifice diameter; orifice plate installed backwards, bent orifice plate, dulled edge orifice plate, and nicked orifice plate. There are additional conditions DP Diagnostics provides alarming for, but these conditions were the easiest to setup and that validated our calculations and our X-Y pattern detection was correct. Our testing proved the program was capable of immediately detecting all the alarm scenarios we presented to it.

We currently have one location where we have installed orifice meter diagnostics on two, 12-inch Jr orifice meters. Several other locations have been identified for installations but we are waiting for some down time. We still need to develop the Prognosis interface into our Measurement Dashboard, which will be completed late 2019. Besides looking at particular meters to install orifice diagnostics on, we also plan to look at some of our processing plants. The thought being since our ADMS and Measurement Dashboard will be able to provide meter validation via diagnostics on orifice, coriolis and ultrasonic meters we could provide diagnostics for an entire plant. We would be able to cover the orifice measurement on the inlet to the plant, the internal coriolis meters and the ultrasonic meters of the outlet of the plant.

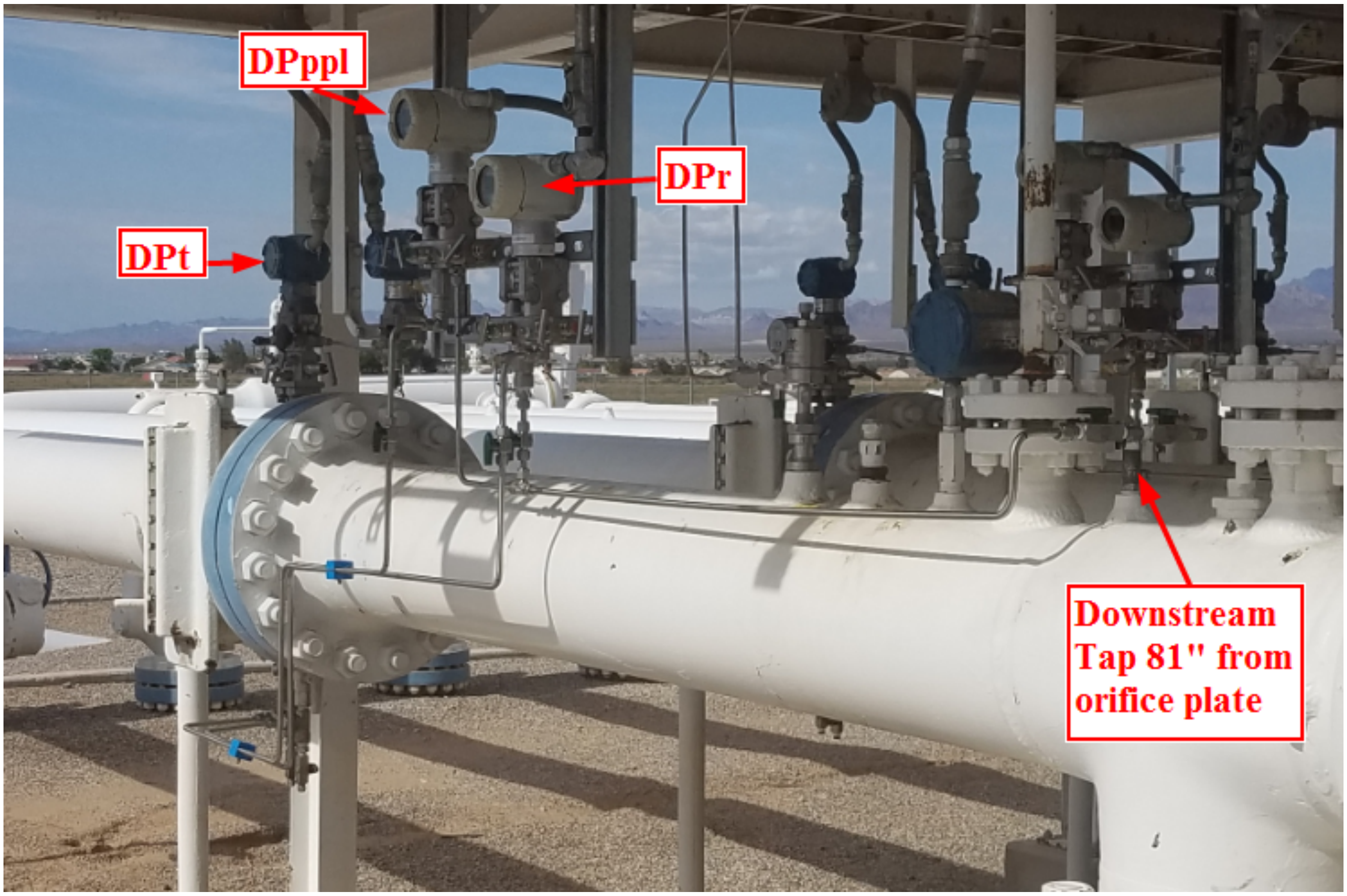

Figure 20, ADMS Orifice Meter Installation

Wet Gas Correction

In 2019, we began working again with Richard and Kim at DP Diagnostics to include their wet gas correction algorithms with the intent of developing a wet gas orifice meter. The code writing, debugging and testing of the various algorithms is currently underway and should be complete later this year. This will supply a status indicating liquid is present in the gas, the liquid loading value and a correction factor that can be applied to the "apparent" volume to provide a wet gas corrected volume.

The primary obstacle in performing wet gas correction has been the difficulty of knowing the liquid flowrate, which is one of the variables used to calculate the Lockhart Martinelli parameter. The Lockhart Martinelli parameter "XLM" is a non-dimensional expression of the relative amount of total liquid with the gas flow, or simply the liquid loading value. The liquid flowrate is used to calculate the XLM value, which in turn is used to calculate the wet gas correction. In a lab setting a known volume of liquid, is injected into the gas stream of a known volume. This of course is an impossible task in the field without separating the liquid from the gas and measuring them separately.

While limited to specific beta ratios and meter size, ISO published a method in ISO TR 1583, where the pressure loss ratio "PLR" is used to determine the XLM value. The pressure loss ratio "PLR" is a value already being calculated in the DP Diagnostics algorithms. This allows us to determine the XLM value in real time. The ability to determine the live value of XLM is the key to performing the wet gas correction in a field application. The tight beta ratio and meter size limitations of the ISO XLM equation have been expanded and enhanced using algorithms developed by DP Diagnostics, which we are in the process of writing into our ADMS field flow computer program.

Summary

We are currently performing our self-diagnostic polling on more than 100 ultrasonic meters and 15 Coriolis meters. With the addition of our ADMS system, we will be polling nearly 200 meters by year's end. We will also have maintenance logs from 200 or more meters downloaded into our ADMS database monthly. Currently the responsibility of monitoring these alarms has been assigned to the Technicians and Measurement Specialist for each area. Eventually we hope to have an employee whose primary responsibility is to monitor the entire system.

The initial research and code writing to perform the meter polling and diagnostics was admittedly time consuming. Taking the time to automate much of the set up process for the flow computer made the field set up relatively simple. As expected, it can be challenging to find the time to analyze and trend data. Having the data stored in an accessible location is the only feasible means we've found of accomplishing such a task.

We have found that our real time meter diagnostics provides a means for our Technicians and Measurement Specialists to tell at a glance if they have a potential problem with a meter. When the Technicians are unable to travel to a meter while it is flowing to perform a meter test, they can now easily look at historical data in the SCADA system to review the diagnostic data polled when the meter last flowed. Furthermore, the historical data provides easily accessible data for an in-depth analysis.

Conclusion

As when our industry progressed from chart recorders to Electronic Flow Measurement years ago, companies must continue to adapt and change as new technologies become available to remain competitive. Today's standard accepted method of testing smart meters such as ultrasonic meters is basically performed no differently than how we tested meters twenty five years ago. Like the old chart recorder, while we were comfortable with it at the time, it is quite easy to see now that the equipment and method was unacceptably inefficient and inadequate in comparison to EFM. The same can be said of our current method used for insuring accurate measurement. These changes don't come without initial costs and many hours of development. As with EFM, the return on this investment will come over time, ultimately paying for itself many times over.

Seeing what our diagnostic system has provided, I am convinced that Smart Measurement Diagnostic Systems will become the standard means of measurement validation throughout our industry in the years to come.

Diagnostic References

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"SICK FLOWSIC600 Gas Ultrasonic Redundancy Information and How to Significantly Reduce Field Measurement Uncertainty"
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John Lansing, SICK Maihak

"Gas Ultrasonic Meter Installation Effects & Diagnostic Indicators"
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"Orifice Plate Meter Diagnostics"
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Dr. Richard Steven

"Orifice Meter Multiphase Wet Gas Flow Performance"
Written by:
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