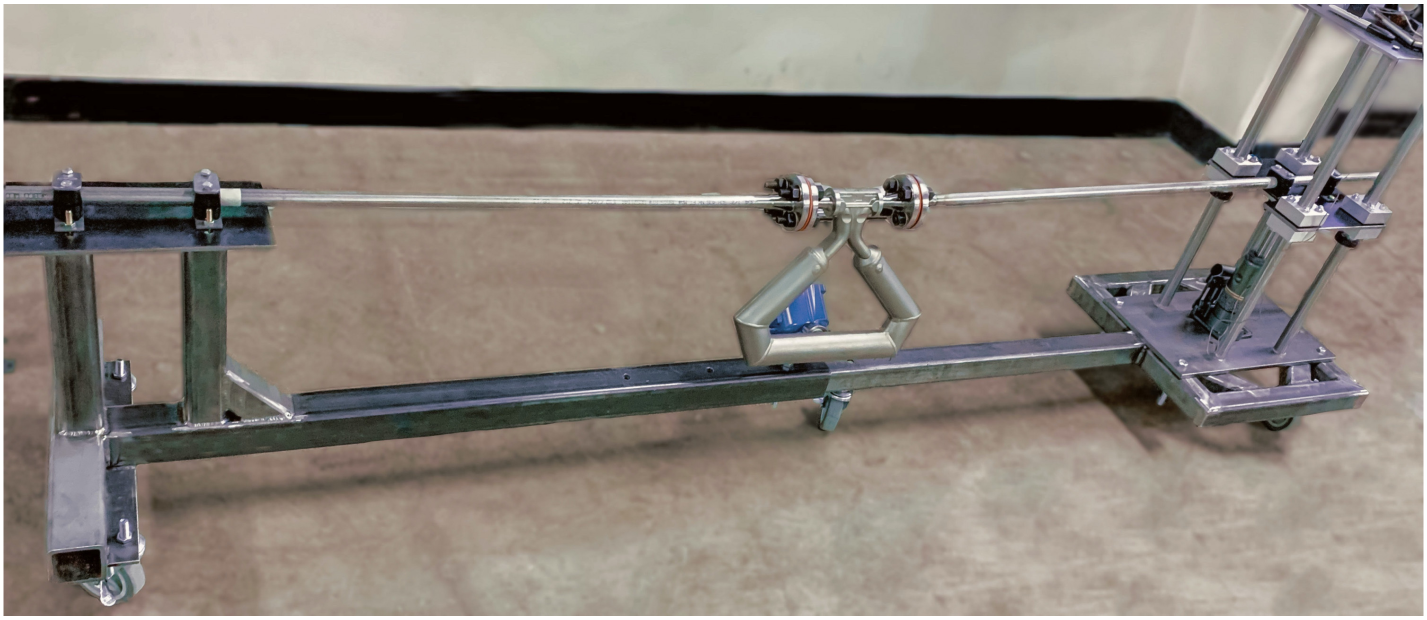

Determining the Influence of Pipeline Misalignment on Coriolis Meters

CU Team 5 April 22, 2020

Abstract

Coriolis meters are often used for the most critical or demanding applications where the highest precision of measurement is required. These applications range from oil and gas to the food and beverage industries. Coriolis meter users may have concerns that their measurement will be impacted due to the misalignment of piping systems. The purpose of this white paper is to describe the test fixture and methodology of analysis to determine the impacts of pipe misalignment on the Coriolis meter's measurements. The test fixture was designed around four major constraints: accommodation of multiple sensor bodies, ability to simulate pipe misalignment, safety, and rigidity. The data was collected from the sensor by using ProLink, a data acquisition software. An analysis of variance (ANOVA) was used to determine the statistical significance of each measurement in comparison to the aligned measurement. Further analysis of correlation was conducted to determine the direct impact of displacement on the zero mass flow readings. The results indicate that pipe misalignment of over 50% of the respective line size may result in mass flow readings outside of the acceptable zero stability range, which can affect the precision of the measurement.

Introduction

Coriolis Flow Meters are installed in the field after the rest of the piping system has already been installed. There is a possibility for misalignment of the mating pipes. The paper should provide guidelines on the amount of the allowable misalignment. Exceeding the amount of the allowable misalignment creates stresses on the meter that may impact performance. The results of these tests are described further in the Results section of the report. These results are based on tests done on two different sensor models with the same amount of misalignment.

Background

An important point to consider is the zero stability of the sensors. When fluid is introduced, the measuring tubes oscillate within the meter. If there is zero flow, the tubes vibrate in phase with one another. The zero stability is the inherent variation in the zero point of a Coriolis meter. Zero stability impacts the measurement when the fluid flows through the meter. At these low flow rate conditions, the measurements of the Coriolis meter may begin to deviate from the baseline accuracy. The meter is functionally governed by the equation:

$$\dot{m} = FCF * (\Delta T - \Delta Tzero) \qquad [1]$$

- **$\dot{m}$**: Mass flow rate [lbs/min]
- **FCF**: Flow Calibration Factor
- **ΔT** : Phase shift between inlet and outlet frequency
- **$\Delta Tzero$**: Zero offset

It can be seen from the equation that when the phase shift between the inlet and outlet (ΔT) increases, the zero offset ($\Delta Tzero$) becomes more and more negligible. This is because an increase in ΔT is directly proportional to mass flow. When there is low flow, and thus a smaller ΔT, the zero offset becomes more prevalent in the measurement. For the purposes of this case study, the sensor measurements will be taken under the zero-flow condition. At the lowest flow, the error in stability of the $\Delta Tzero$ is maximized. Analyzing how pipe misalignment affects the zero stability will be directly related to the accuracy of the meter under these conditions.

Testing and Data Analysis

Measurements and Equipment

Testing was completed by installing a meter and a typical pipe assembly in a test fixture. The Coriolis Mass Flow (CMF) and F-Series meters were tested, which corresponds to the 0.5” and 1” pipe sizes, respectively. The length of the fixture was designed to contract or extend to accommodate the different meter bodies and line sizes to minimize plastic deformation of the pipes. A vertical force was applied on one side of the fixture to simulate pipe misalignment as shown in Figure 1. Mass flow rates and live zeros were recorded in increments of 1/4" and up to a total displacement of 2". To prevent hysteresis, the sensor was brought back down to its zero point after every 1" increment and remeasured for live zero and mass flow before testing at further elevation.

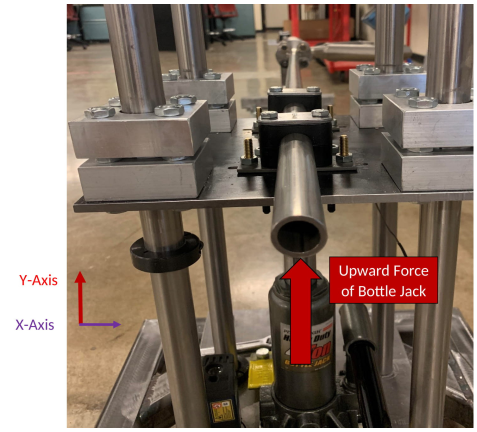

Figure 1: Bottle jack applies a vertical force on one side of the fixture, where the opposite end remains fixed.

Figure 2: CMF meter in the 90 degree orientation.

Multiple meter orientations were tested in order to simulate a variety of installation conditions as seen in the field. Testing was done with meter rotation of 0, 45, 90, 135, and 180 degrees at each displacement. A level was used to ensure that the meters were oriented at the correct angles for each cycle of testing. Figure 3 describes the relationship between the install angle and misalignment condition. Data acquisition procedures remained constant for all angles. The purpose of this is to simulate two dimensional forces on the sensor and to find any discrepancies in the meter reading as it is installed with pipe misalignment.

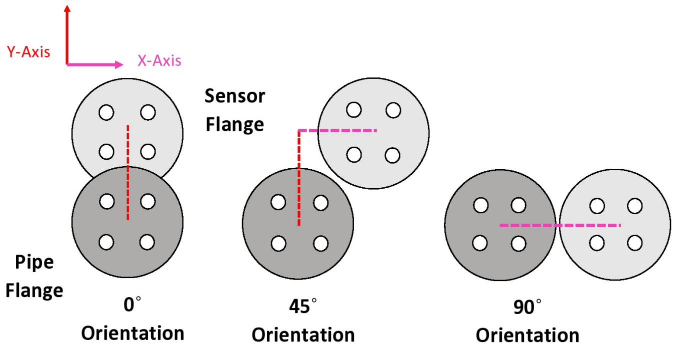

Figure 3: Pipe misalignment in respect to different angles in testing.

Because the pipes can be displaced vertically, horizontally, or a combination of both, the team developed this test methodology to simulate pipe misalignment in different directions. Figure 3 shows the direction of pipe misalignment as the angles were changed. The 0 degree orientation represents the standard way to install the sensor. As vertical displacement is induced, it simulates pipe misalignment in the vertical direction. The meter is rotated to 45 and 135 degrees to simulate pipe misalignment in both the vertical and horizontal directions. The meter is rotated to 90 degrees to simulate pipe misalignment in the horizontal direction only. The 180 degree (or inverted) meter orientation simulates pipe misalignment in the vertical direction only, similar to the 0 degree orientation. Orientation angles beyond 180 degrees were not tested due to the symmetrical body of each meter. The testing attempts to gather and analyze the data for relations in the total acceptable pipe misalignment.

Testing and Data Analysis

Data Analysis Method

For each meter, there are 30 data sets with 23 data points for each set. Three trials were carried out to obtain more accurate data. The data sets were compiled in the orders shown in Table 1. There were 3 zero points collected. The first zero point was taken at the very first stage, where no displacement (0”) was made. After the displacement was set to 1”, the displacement was then set to 0” again where the second zero point was recorded. The displacement was then set back again to 1”. After the displacement was set to 2", the displacement was set back to 0” again. This was done to confirm that there was no change for 0” readings across all the displacements. The subsequent data was then compared to respective zero points to find statistical differences using ANOVA via MATLAB. Additionally, MATLAB was used to analyze the group mean, standard deviation, range, median, normality and variance. The compiled data was then exported to Excel for further analysis. For each orientation, means of all 3 trials were averaged out. The grand means were then graphed to find correlation and possible trend for each displacement.

Displacements (inches)	Explanation
0" Comparisons	1^{st} 0 point
	2^{nd} 0 point
	3^{nd} 0 point
0.25	1^{st} 0 point
	0.25 point
0.5	1^{st} 0 point
	0.5 point
0.75	1^{st} 0 point
	0.75 point
1"	1^{st} 0 point
	1^{st} 1” point
1"	2^{nd} 0 point
	2^{nd} 1’’ point
1’’ point comparisons	1^{st} 1” point
	2^{nd} 1’’ point
1.25	2^{nd} 0 point
	1.25 point
1.5	2^{nd} 0 point
	1.5 point
1.75	2^{nd} 0 point
	1.75 point
2	2^{nd} 0 point
	2 point

Table 1. Compilations of data for each orientation.

In regard to ANOVA testing, significant statistical differences in the collected data signify that the sample means are statistically different from one another at the tested accuracy. Since much of the data showed significant statistical differences from zero, post hoc analysis was done to determine if there is any correlation between the displacement condition and the stability zero flow condition for that system.

Results

Correlation analysis concluded that horizontal displacement of pipework during installation is not recommended for any line size. For simulation that represents horizontal displacement, there are reported zero stability values beyond the desired threshold for the meters (0.009lbs/min for the 1" F-Series and 0.0026 lbs/min for the ½" CMF). As shown in Figure 4, the zero stability is maintained until displacement overreaches 0.5" or 50% of the line size for the 1" F-Series meter. Figure 5 shows that the smaller line size shows a greater effect due to horizontal displacement, with any point greater than the original zero point being outside the original threshold. The most stable readings were found when both meters were oriented in a direction that correlated with a lack of horizontal displacement (0 and 180 degrees).

In many cases, the live zero and mass flow readings were well within the reported zero stability range. This is demonstrated in Figure 6. Therefore, additional testing and analysis would be required to determine a maximum tolerated misalignment point. Additional data must be interpolated for absolute accurate conclusions. But current results show that a horizontal flange misalignment of less than 50% of the line size is best in minimizing data collection outside of the zero stability.

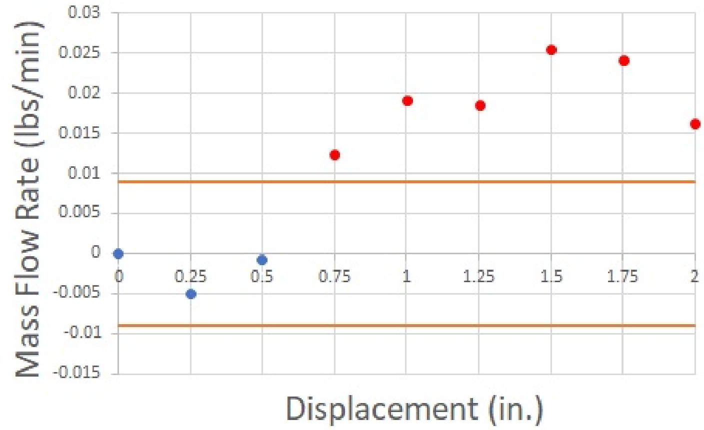

Figure 4: 1" F-Series Coriolis Meter - Correlation between displacement and the mass flow rate recorded at the no flow condition (no fluid). Data was collected at a meter orientation of 90 degrees.

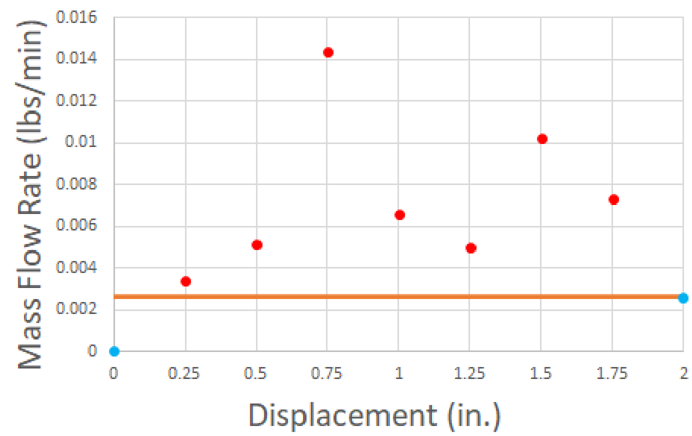

Figure 5: Correlation between displacement and the mass flow rate recorded at the no flow condition (no fluid) of the 1/2" CMF Coriolis Meter. Data was collected at a meter orientation of 90 degrees.

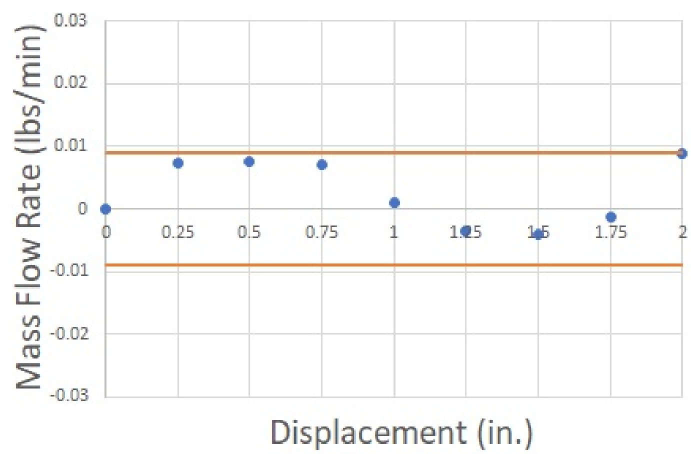

Figure 6: 1" F-Series Coriolis Meter - Correlation between displacement and the mass flow rate recorded at the no flow condition (no fluid). Data was collected at a meter orientation of 0 degrees.

Conclusion

Best Practices/Recommendations

Both meters that were tested, demonstrate robustness to a variety of installation conditions. However, the zero stability may be affected by misalignment in the pipework over 50% of the respective line size. It is not recommended to exceed the maximum flange misalignment as described in Table 2.

Line Size	Max Acceptable Flange Misalignment (for no effect on zero stability)
¼”	⅛"
½”	¼”
1”	½”
1 ½”	¾”
2”	1”
3”	1 ½”

Table 2: Maximum acceptable flange/pipe misalignment to ensure no effect on the zero stability of various Coriolis meters.

While the meters are rigid in construction, it is important to install the meters in pipework with minimal displacement to avoid any erroneous data.

Limitations

The above tests were completed using the 1” F-Series and ½” CMF meters only. Due to limited resources, resulting recommendations and conclusions have been extrapolated based on the available information. The zero stability of the meters are important to ensure the reported accuracy of readings during operation.

Team Bios

Picture from left to right: Aqil Amran, Colin Armstrong, Blake Chin, Eric Jiang, Erika Kissler, Mingxuan Li, Salah Ammar

Eric Jiang, Project Manager: Eric managed the project schedules, deliverables, and team meetings. He created agendas and led all team, client, and director meetings. Eric contributed to the design and modeling of the test fixture in SolidWorks (CAD). He also fabricated parts of the fixture in the machine shop. After fabrication, he worked alongside his team on testing the Coriolis meters with the fixture.

Erika Kissler, Logistics Manager: Erika managed communication both internally with the project team and externally with the client and director. This includes email management, recording meeting minutes, and communicating action items and deliverables. Additionally, Erika managed the data analysis section of the project. This included creating Matlab and Excel templates for analysis of the datasets, utilizing those files, and delegating tasks among the team. Erika also worked in the machine shop during the fixture fabrication.

Blake Chin, Financial Manager: Blake had the responsibility of sourcing materials from different vendors for the test fixture. He was also tasked with keeping track of the team's funds throughout the project and managing the budget. He assisted with manufacturing within the machine shop. Blake also helped during the testing phase by setting up the test fixture and performing test trials on the two different meters.

Team Bios

Mingxuan Li, Test Engineer: Ming was responsible for the testing and collecting the data, making a testing plan and analyzing the data. As test engineer, Ming designed the test plan and managed the entire testing process. Meanwhile, He helped with the manufacturing engineer to fabricate parts of the fixture in the machine shop. Additionally, he assisted with the data team for data acquisition and analysis.

Aqil Amran, Manufacturing Engineer: Aqil's main task was focused on the design of the device with an emphasis on design for manufacturability. He took lead on manufacturing all parts in the second semester. He inspected each part including preparing them for the welding processes. Additionally, he assisted Erika, Colin and Ming with data acquisition and analysis.

Colin Armstrong, Systems Engineer: Colin's task was to ensure the synergy between all subsystems within the project to facilitate a system-wide design for the test fixture. As systems engineer, he interacted with every phase of the project to maintain that subsystems interact properly with each other. He assisted in data collection and analysis of the project to generate conclusive findings for the end of term white paper.

Salah Ammar, CAD Engineer: Salah's task was to lead on the CAD work. That includes managing the team's CAD files, parts, assemblies, drawings, and revisions. Salah was responsible for managing the different designs that the team produced. That includes organizing the CAD work and providing plans on how the work on SolidWorks is going to get done. In the second half of the project, Salah was helping the team on other tasks because there was no more CAD needed.

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