The Effects of Meter Orientation Downstream of a Short Radius Elbow on Electromagnetic Flow Meters

Jared C. Justensen

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THE EFFECTS OF METER ORIENTATION DOWNSTREAM OF A SHORT RADIUS ELBOW ON ELECTROMAGNETIC FLOW METERS

by

Jared C. Justensen

A thesis submitted in partial fulfillment of the requirements for the degree of

MASTER OF SCIENCE

in

Civil and Environmental Engineering

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UTAH STATE UNIVERSITY
Logan, Utah

2016
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The Effects of Meter Orientation Downstream of a Short Radius Elbow on Electromagnetic Flow Meters

by

Jared C. Justensen, Master of Science
Utah State University, 2016

Major Professor: Steven L. Barfuss
Department: Civil & Environmental Engineering

Electromagnetic flowmeters (known as magnetic flow meters) are a widely used type of flowmeter. The accuracy of magnetic flow meters are a function of several factors, not the least of which is the flow condition inside the pipe. It has been shown that disturbances in the velocity profile affects the accuracy of a magnetic flow meter (Luntta, 1998). Accordingly, manufacturers of magnetic flow meters give installation guidelines. These guidelines help prevent the user from installing the meter in a pipe configuration that is likely to cause the meter to produce inaccurate results. Although most manufacturers provide recommendations about the amount of straight pipe that is necessary upstream of the meter, little is said about the orientation of the meter in relation to upstream disturbances.

This study examines the performance of magnetic flow meters when positioned at two different orientations: EIP (electrodes in plane with an upstream 90-degree short radius elbow) and EOP (electrodes out of plane). Four different meters were included in
the study in which a baseline straight pipe test was first performed using over fifty diameters of straight pipe upstream of each meter. The straight pipe test was used to determine the baseline accuracy of each of the meters over a velocity range that is typical for the size and function of the meters. Meters were then installed at five different locations downstream from a 90-degree short-radius elbow. At each location the meters were tested in two orientations at five different flow rates.

The intent of the research is to show that the orientation of a magnetic flow meter affects the meter’s ability to produce accurate flow readings when it is installed downstream of a flow disturbance. The results from this research showed a significant shift in measurement accuracy when the meter was in EIP and EOP orientations. All of the meters in the study produced accuracy readings at one point or another that were outside the specified accuracy from the meter manufacturer. Interestingly, the meters that had a larger manufacturer specified accuracy produced smaller shifts in accuracy when comparing the test results under EIP and EOP conditions. The results of the research are given in the section entitled “Results and Discussion” as well as in the Appendix A.
PUBLIC ABSTRACT

The Effects of Meter Orientation Downstream of a Short Radius Elbow on Electromagnetic Flow Meters

Jared C. Justensen

Electromagnetic flowmeters (known as magnetic flow meters) are a widely used type of flowmeter. The accuracy of magnetic flow meters are a function of several factors, not the least of which is the flow condition inside the pipe. It has been shown that disturbances in the velocity profile affects the accuracy of a magnetic flow meter (Luntta, 1998). Accordingly, manufacturers of magnetic flow meters give installation guidelines. These guidelines help prevent the user from installing the meter in a pipe configuration that is likely to cause the meter to produce inaccurate results. Although most manufacturers provide recommendations about the amount of straight pipe that is necessary upstream of the meter, little is said about the orientation of the meter in relation to upstream disturbances.

This study examines the performance of magnetic flow meters when positioned at two different orientations: EIP (electrodes in plane with an upstream 90-degree short radius elbow) and EOP (electrodes out of plane). Four different meters were included in the study in which a baseline straight pipe test was first performed using over fifty diameters of straight pipe upstream of each meter. The straight pipe test was used to determine the baseline accuracy of each of the meters over a velocity range that is typical for the size and function of the meters. Meters were then installed at five different
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ACKNOWLEDGMENTS

Special thanks to Steven Barfuss, Zac Sharp, Dr. Michael Johnson, and Dr. Joseph Caliendo for their guidance and support given in this project. I would also like to thank my co-workers Jordan Jarrett, Brad Clawson, and Kade Beck for the many hours spent taking data. Also, I would like to thank my wife for her support and for the many sack lunches she provided throughout the entire project.
# CONTENTS

<table>
<thead>
<tr>
<th>ABSTRACT</th>
<th>iii</th>
</tr>
</thead>
<tbody>
<tr>
<td>PUBLIC ABSTRACT</td>
<td>v</td>
</tr>
<tr>
<td>ACKNOWLEDGMENTS</td>
<td>vii</td>
</tr>
<tr>
<td>CONTENTS</td>
<td>viii</td>
</tr>
<tr>
<td>LIST OF TABLES</td>
<td>x</td>
</tr>
<tr>
<td>LIST OF FIGURES</td>
<td>xi</td>
</tr>
<tr>
<td>NOTATION</td>
<td>xiii</td>
</tr>
<tr>
<td>INTRODUCTION</td>
<td>1</td>
</tr>
<tr>
<td>Purpose</td>
<td>1</td>
</tr>
<tr>
<td>Objective</td>
<td>1</td>
</tr>
<tr>
<td>LITERATURE REVIEW</td>
<td>2</td>
</tr>
<tr>
<td>EXPERIMENTAL SETUP AND PROCEDURE</td>
<td>6</td>
</tr>
<tr>
<td>Meters</td>
<td>6</td>
</tr>
<tr>
<td>Experimental Setup</td>
<td>7</td>
</tr>
<tr>
<td>Procedure</td>
<td>16</td>
</tr>
<tr>
<td>RESULTS AND DISCUSSION</td>
<td>20</td>
</tr>
<tr>
<td>CONCLUSION</td>
<td>26</td>
</tr>
<tr>
<td>Results Summary</td>
<td>27</td>
</tr>
<tr>
<td>Need for Further Research</td>
<td>28</td>
</tr>
</tbody>
</table>
# LIST OF TABLES

<table>
<thead>
<tr>
<th>Table</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Meter Properties</td>
<td>15</td>
</tr>
<tr>
<td>2. Visual Inspection of Meters</td>
<td>16</td>
</tr>
<tr>
<td>3. Summary of Results</td>
<td>25</td>
</tr>
<tr>
<td>4. Percent Deviation for Locations 3D and 10D</td>
<td>25</td>
</tr>
<tr>
<td>Figure</td>
<td>Page</td>
</tr>
<tr>
<td>--------</td>
<td>------</td>
</tr>
<tr>
<td>1. Percent Deviation vs Distance from Flow Disturbance. (The top line shows the electrodes axis perpendicular to bend axis, and the bottom line shows the electrodes axis parallel to bend axis.)</td>
<td>2</td>
</tr>
<tr>
<td>2. Angle of Rotation, Flow Rate, and Percent Deviation</td>
<td>4</td>
</tr>
<tr>
<td>3. Straight Pipe Test Setup</td>
<td>7</td>
</tr>
<tr>
<td>4. Straight Pipe Test Setup (flow goes top to bottom)</td>
<td>9</td>
</tr>
<tr>
<td>5. Elbow Test Upstream Pipe Setup</td>
<td>10</td>
</tr>
<tr>
<td>6. Elbow Test Setup (flow goes left to right)</td>
<td>11</td>
</tr>
<tr>
<td>7. Variations in Pipe Length for Elbow Test</td>
<td>11</td>
</tr>
<tr>
<td>8. Electrodes in Plan with Elbow (EIP)</td>
<td>12</td>
</tr>
<tr>
<td>9. Electrodes out of Plan with Elbow (EOP)</td>
<td>13</td>
</tr>
<tr>
<td>10. Meter Orientation</td>
<td>13</td>
</tr>
<tr>
<td>11. Typical Manufacturer’s Schematic</td>
<td>14</td>
</tr>
<tr>
<td>12. Mfr D Meter’s Electrodes</td>
<td>16</td>
</tr>
<tr>
<td>13. Mfr A Test Plot</td>
<td>21</td>
</tr>
<tr>
<td>14. Mfr B Test Plot</td>
<td>22</td>
</tr>
<tr>
<td>15. Mfr C Test Plot</td>
<td>23</td>
</tr>
<tr>
<td>16. Mfr D Test Plot</td>
<td>24</td>
</tr>
<tr>
<td>17. Mfr A Test Data for CC, 1D, 3D, 5D, and 10D</td>
<td>32</td>
</tr>
<tr>
<td>18. Mfr B Test Data for CC, 1D, 3D, 5D, and 10D</td>
<td>33</td>
</tr>
<tr>
<td></td>
<td>Description</td>
</tr>
<tr>
<td>---</td>
<td>-------------</td>
</tr>
<tr>
<td>19</td>
<td>Mfr C Test Data for CC, 1D, 3D, 5D, and 10D</td>
</tr>
<tr>
<td>20</td>
<td>Mfr D Test Data for CC, 1D, 3D, 5D, and 10D</td>
</tr>
<tr>
<td>21</td>
<td>Mfr A Straight Pipe Test Data</td>
</tr>
<tr>
<td>22</td>
<td>Mfr B Straight Pipe Test Data</td>
</tr>
<tr>
<td>23</td>
<td>Mfr C Straight Pipe Test Data</td>
</tr>
<tr>
<td>24</td>
<td>Mfr D Straight Pipe Test Data</td>
</tr>
</tbody>
</table>
NOTATION

\[ l = \text{length of conductor (meters)} \]
\[ \nu = \text{velocity (meters per second)} \]
\[ B = \text{magnetic flux density (Tesla)} \]
\[ e = \text{Voltage} \]
\[ \text{Mfr} = \text{manufacturer} \]
\[ \text{US} = \text{upstream} \]
\[ \text{DS} = \text{downstream} \]
\[ 1D = \text{one diameter} \]
\[ 2D = \text{two diameters} \]
\[ 3D = \text{three diameters} \]
\[ 5D = \text{five diameters} \]
\[ 10D = \text{ten diameters} \]
\[ \text{CC} = \text{close coupled} \]
\[ \text{PVC} = \text{polyvinyl chloride} \]
\[ Q = \text{flow rate} \]
\[ W = \text{weight of water} \]
\[ t = \text{time} \]
\[ \gamma = \text{unit weight of water} \]
\[ mA = \text{milliamps} \]
\[ Hz = \text{hertz} \]
\[ \text{Range} = \text{range of the multimeter} \]
$\text{Max } Hz =$ Maximum hertz the multimeter can read

fps = feet per second

min = minimum

vel = velocity

DC = direct current

AC = alternating current
INTRODUCTION

Purpose

The ability to measure flow accurately is critical for the water users and for those providing the water. Magnetic flow meter manufacturers provide guidelines for appropriate meter installations so that the meter maintains accuracy standards. While typical guidelines cover many different conditions, most guidelines do not address the effect on meter accuracy caused by the orientation of the meter.

Objective

The objective of this paper is to provide data on the effects of meter orientation when the meter is installed downstream of a disturbance. The disturbance that was utilized during this study was a short-radius elbow. Four different meters were tested at four different locations downstream of the elbow. At each location downstream from the elbow, each meter was also rotated at two orientations. At each of the meter orientations, five flow rates were tested and flow measurements were made from both the test meter and a reference flow meter. Each test meter was located at lengths downstream of the elbow as recommended by the manufacturer, as well as additional pipe lengths not recommended by the manufacturers. This was done to more fully understand the effects of orientation on the meter. The results of this paper will provide information to magnetic flow meter users so they can better understand their own personal system and the effects of different meter setups.
LITERATURE REVIEW

There have been several previous studies on the effects of flow disturbances on magnetic flow meters. In Luntta’s study (1998), the distance from a disturbance and the orientation of the meter to the disturbance was evaluated. Luntta found a relationship between the errors that occurred when the meter was rotated and the distance of the meter downstream of the disturbance. The disturbance that was used during this study was a pipe bend. At various locations, the meter was rotated to two orientations, electrode axis parallel to the bend plane and electrode axis perpendicular to the bend plane. Luntta’s results are shown in Figure 1.

Figure 1. Percent Deviation vs Distance from Flow Disturbance. (The top line shows the electrodes axis perpendicular to bend axis, and the bottom line shows the electrodes axis parallel to bend axis.)

Luntta concluded that a magnetic meter should be placed more than five diameters away from the flow disturbance in order to avoid large error in results. Additional studies
have focused on how much straight pipe is needed between a flow disturbance and a flow meter.

In a study done by Kelner (2003), the distortions in velocity profiles after a single 90° long radius elbow were examined. The objective of the study was to see how the velocity profiles distortions reduced with distance downstream from the elbow. Kelner shows that after a single 90-degree, long-radius elbow the velocity profile shows distortions for up to 59 diameters away from the elbow. Further research has been done to determine how much these distortions in the velocity profile affect the meter’s output at different orientations.

In a Seametrics study (Perry, 2014), Perry studied the difference in results due to different orientation of the meters. He stated that this is related to the weight function. The weight function is explained as the relation between the shape of the velocity profile and the sensitivity of the electrodes inside the meter (Luntta, 1998). This is also seen in the experiments done by SherCliff (1955). In the Seametrics study Perry says that most magnetic flow meters do not have uniform weight functions (Perry, 2014). Essentially, this means that magnetic meters are sensitive to the location of distortions in the velocity profile. Perry was able to find a meter orientation that produced the most accurate results for the specific magnetic flow meter that was used in the research. His results are shown in Figure 2.
Figure 2. Angle of Rotation, Flow Rate, and Percent Deviation
Figure 2 shows five different plots that display contours for the shifts in output when the meter was rotated at different angles in relation to the upstream elbow. The y-axis variable is the angle about the pipe axis, and the x-axis variable is flow rate. Large magnitudes are red and low magnitudes are blue. Contour levels are labeled. However, Perry states that it is unknown if any one meter orientation will produce accurate results for all types of meters (Perry, 2014).

The research contained in this study builds upon the results of these previous studies, but focuses on how multiple magnetic flow meters from different manufacturers are effected by distance from and relative orientation to an upstream elbow.
Meters

Magnetic flow meters are capable of providing accurate and repeatable results and are among the most common flow meter types being used today. If the conditions are appropriate for their use, the accuracy of these meters can be as low as 0.25% or even better. They also are non-invasive and produce negligible head loss. They are non-invasive in that the meter does not obstruct flow because most magnetic flow meters are designed so that its inside diameter matches or is slightly smaller than the inside diameter of the pipe in which it is installed. Other advantages of magnetic flow meters are as follows: 1) they are available in most commercial pipe sizes, 2) there is minimal wear since there are no moving parts, 3) simple installation of the meter. Some disadvantages of magnetic flow meter are: 1) the process fluid needs to meet conductivity requirements, 2) high cost, 3) special care for erosive applications.

Magnetic flow meters operate based on Faraday’s Law of Induction. This law states that if a conductor of length \( l \) (meters) is moving with a velocity \( v \) (meter per second) perpendicular to a magnetic field of flux density \( B \) (Tesla), then it induces a voltage \( e \) across the ends of a conductor (Thorn 1999). This can be expressed by:

\[
e = B l v
\]

In the case of magnetic flow meters, the conductor is the water moving through the meter and the length of the conductor is the distance between the two electrodes. The magnetic field is created by magnets within the meter and the electrodes sense the induced
voltage. In this study the meters each contained two electrodes, which were located at the spring line of the meter, however some magnetic flow meters also have electrodes or sensors located at the crown and invert of the meter. When electrodes are installed at the crown and invert of the meter, they are used for grounding and sensing when the pipe is full.

When magnetic flow meters from varying manufacturers were compared, they were found to differ in a number of ways: 1) size of the inside diameter of the meter, 2) size and placements of electrodes, 3) power source; either AC or DC, 4) output signal, mA, Hz, or pulse, however, the list above does not include all the ways that magnetic flow meters differ from each other. Tables 1 and 2 show some specific differences between the four meters tested in this research.

**Experimental Setup**

The following paragraphs explain the setup for the straight pipe test and the test where the meters were downstream of the elbow. Schematics for the straight pipe test and the elbow test are seen in Figures 3 through 5.

![Figure 3. Straight Pipe Test Setup](image-url)
The pipe configuration for the straight pipe tests (as seen in Figure 3 and Figure 4) is explained in this paragraph. Starting from upstream and moving downstream, a 12-inch long-radius elbow connects to a 12-inch butterfly valve. The valve is followed by a 3’-3” carbon steel pipe (note all pipe is standard wall carbon steel unless otherwise specified). Then a flow straightener was installed inside the 3’-3” pipe. A 20’-2” long PVC 12-inch pipe was then installed, followed by a 12-inch reference magnetic flow meter. The reference magnetic flow meter was a Siemens SITRANS F M MAG 5100 W electromagnetic flow meter. With a Siemens SITRANS F M MAG 6000 sensor system. The reference meter was calibrated using the laboratory’s weight tank. For a detailed description of the reference meter calibration see the section entitled “Procedure.” A wire was used to ground the 12-inch reference meter to the upstream butterfly valve.

Following the reference meter was a 3’-4” long, 12-inch pipe, a 1’-6” long reducer from 12-inch to 10-inch, and a 16’-9” long 10-inch diameter pipe. A 10-inch diameter magnetic flow meter (test meter) was then installed followed by an 8’-5” long pipe, a short-radius elbow, and a long segment of pipe that returned the discharge water to a waste channel. A butterfly valve was installed at the end of the test line to control flow rates through the test setup.
Figure 4. Straight Pipe Test Setup (flow goes top to bottom)
The pipe configuration for the elbow tests (as seen in Figure 5 and Figure 6.) is the same as the straight test pipe configuration up to the 16’-9” pipe. From that point there is a short-radius elbow followed by 5 different pipe lengths: CC, 1D, 3D, 5D, 10D (Figure 7). The test meter location in this study is defined as the distance between the short-radius elbow and the test meter downstream of the elbow. For example, “CC” denotes the test meter is closed coupled to the short-radius elbow. The other locations are 1D, 3D, 5D, and 10D. 1D refers to one diameter (10 inches) of pipe between the short-radius elbow and the test meter, and so forth.
Figure 6. Elbow Test Setup (flow goes left to right)

Figure 7. Variations in Pipe Length for Elbow Test
At these five pipe lengths the test meter was installed in two orientations. As previously mentioned, the orientations included electrodes in plane (EIP) with the elbow (Figure 8) and electrodes out of plane (EOP) with the elbow (Figure 9). The two meter orientations were chosen because they show the maximum angle of rotation possible between two orientations. If meter orientation does affect meter performance, these two orientations show the worst case scenario of that effect. The electrodes on the four test meters used in this study were located on the springline (sides) of the meters as illustrated in Figure 10. Following the test meter there was a long pipe segment (greater than 6D) and a butterfly valve where water was then discharged into a flume.

Figure 8. Electrodes in Plan with Elbow (EIP)
Figure 9. Electrodes out of Plan with Elbow (EOP)

Figure 10. Meter Orientation
The four 10-inch magnetic flow meters used in this project were donated by their respective manufacturers. A list of the meters and their individual properties can be found in Table 1. The table shows the power source (AC or DC), the output signal, the specified accuracy of the meter, the minimum velocity, the minimum flow, recommended meter orientation from vertical, and the required length of pipe between the meter and the elbow (as defined by the manufacturer). For example, looking at meter Mfr A, if an elbow is upstream of the meter, the manufacturer specifies that there should be three diameters of pipe separating the elbow and the meter. Figure 11 shows a typical manufacturer’s schematic indicating upstream and downstream requirements. Note manufacturers state that meters should be orientation 45 degrees from vertical only to avoid sediment build up and collection of air bubbles on electrodes.
Table 1. Meter Properties

<table>
<thead>
<tr>
<th>Manufacturer</th>
<th>Power (AC/DC)</th>
<th>Measuring Frequency (Hz)</th>
<th>Signal Type</th>
<th>Accuracy</th>
<th>Min Vel (fps)</th>
<th>Min flow (gpm)</th>
<th>Meter Orientation (degrees)</th>
<th>Single Elbow</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mfr A</td>
<td>AC</td>
<td>4-20 mA</td>
<td>± 0.20 %</td>
<td>3.28</td>
<td>805</td>
<td></td>
<td></td>
<td>3</td>
</tr>
<tr>
<td>Mfr B</td>
<td>AC</td>
<td>5 4-20 mA</td>
<td>± 0.25 %</td>
<td>1.00</td>
<td>245.78</td>
<td>45</td>
<td></td>
<td>5</td>
</tr>
<tr>
<td>Mfr C</td>
<td>DC</td>
<td>5.5 Hz</td>
<td>± 1.00%</td>
<td>0.33</td>
<td>80</td>
<td>45</td>
<td></td>
<td>2</td>
</tr>
<tr>
<td>Mfr D</td>
<td>DC</td>
<td>3 Pulse</td>
<td>± 1.00%</td>
<td>0.39</td>
<td>95</td>
<td>45</td>
<td></td>
<td>2</td>
</tr>
</tbody>
</table>

It is important to note the differences in the meters so that it can be better understood as to why each meter performs differently. Each meter went through a visual inspection. The purpose of the inspection was to measure the dimensions of each meter, and to make note of anything that may differ from meter to meter.

Two things of interest during the comparative evaluation were the inside diameter of the 10-inch meters and how far the electrodes protruded out of the meter into the flow path. The inside diameter was found to be different in each meter. In most meters the inside diameter was slightly less than the inside diameter of the pipe that was connected to it. The other interesting difference between the meters was how far the electrodes protruded out of the meter into the flow path (electrode height). In some meters the electrodes were flush with the inside wall of the meter. In other meters the electrodes protruded a considerable amount out into the flow path (as seen in Figure 12). The results from the visual inspection can be seen in Table 2. Note the column "# of Electrodes" in table 2 includes electrodes that are on the springline and electrodes that are not on the springline. Electrodes on the springline are
for measuring flow and electrodes not on the springline are for grounding or full or empty pipe sensing.

![Figure 12. Mfr D Meter’s Electrodes](image)

**Table 2. Visual Inspection of Meters**

<table>
<thead>
<tr>
<th>Manufacturer</th>
<th>ID (in)</th>
<th>Upstream Pipe Insided Diameter (in)</th>
<th># of Electrodes</th>
<th>Electrode Diameter (in)</th>
<th>Electrode Height (in)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mfr A</td>
<td>10.099</td>
<td>10.02</td>
<td>3</td>
<td>0.457</td>
<td>0.058</td>
</tr>
<tr>
<td>Mfr B</td>
<td>9.746</td>
<td>10.02</td>
<td>3</td>
<td>0.3345</td>
<td>0.058</td>
</tr>
<tr>
<td>Mfr C</td>
<td>8.55</td>
<td>10.02</td>
<td>4</td>
<td>0.353</td>
<td>0</td>
</tr>
<tr>
<td>Mfr D</td>
<td>9.244</td>
<td>10.02</td>
<td>4</td>
<td>0.4865</td>
<td>0.113</td>
</tr>
</tbody>
</table>

**Procedure**

A calibration was performed on the reference meter with the laboratory weight tank by running flow rates through the reference meter and discharging the flow to the weight tank. A Fluke multimeter was used to average the meter output from the reference meter.
Depending on the meter, the output signal was frequency (hz), 4-20 mA signal, or gallon per pulse. For meters with a frequency output signal, the flow was calculated as:

\[ Q = \frac{Range}{Max \ Hz} \times Hz \]

Where \( Q \) is flow rate and \( Hz \) is the frequency reading (hertz), \( Range \) is the range of the meter, and \( Max \ Hz \) is the maximum hertz the multimeter can read. For milliamp readings, the flow was calculated as:

\[ Q = \frac{Range}{16} \times (mA - 4) \]

Where \( Q \) is flow rate, \( Range \) is the range of the meter, and \( mA \) is the milliamp reading. For gallon per pulse reading the flow was calculated as:

\[ Q = \frac{Pulse}{t} \times 60 \text{ sec/ min} \times 10 \text{gal/pulse} \]

Where \( Q \) is flow rate (gpm), \( Pulse \) is the number of pulses recorded by the NFC110 flow computer, \( t \) is time in seconds. With the weigh tank, flow was determined by recording the temperature of the water, the weight, and the time. Flow was calculated as:

\[ Q = \frac{W}{(t \times \gamma)} \]

Where \( Q \) is flow rate, \( W \) is the weight of water, \( t \) is time of test period, and \( \gamma \) is the unit weight of water. This equation was calculated using the water temperature reading taken during the test. Using the results from the calibration of the reference meter a look up table was created to correct reference meter data.
The study began by performing baseline testing. These tests are also referred to as the straight pipe test. The straight pipe test was done on all four meters, 20 diameters downstream of the 12-inch by 10-inch pipe reducer and fifty-four diameters downstream of setup connection where a long radius elbow existed and flow straightening vanes were installed. Five flows of 250 gpm, 1000 gpm, 2000 gpm, 3000 gpm, and 4000 gpm were tested. Two Fluke multimeters were used to average the flow in both the reference meter and test meter. For the meter that had a pulse output, the NFC110 computer was used to count pulses. For every flow a measurement was taken and one or two repeats were taken.

Once the baseline testing was completed and data had been collected for each meter under ideal approach flow conditions, the second phase of the study included tests with the subject meters installed at varying distances downstream of the short radius elbow. A short-radius elbow was installed after the 16’-9” pipe. The designated sections of pipe (CC, 1D, 3D, 5D, and 10D) were installed after the short-radius elbow. Next the test meter was installed in either the EIP orientation or EOP orientation. At each pipe length and meter orientation, five flows of 250 gpm, 1000 gpm, 2000 gpm, 3000 gpm, and 4000 gpm were tested. For each test set up, flow measurements were taken using Fluke multimeters or a NFC110 flow computer. This was done using one multimeter connected to the reference meter and another multimeter or NFC110 was connected to the meter being tested. The multimeters then averaged the flows of both the reference and test meters. In the case of the NFC110 flow computer, it would record the number of pulses for the test meter for the same amount of time the Fluke multimeter would take to average the flow for the reference meter.
Flow would then be recorded in a spread sheet and one or two repeats would be done for each data point.
RESULTS AND DISCUSSION

Figures 13-16 show results for test meter locations 3D and 10D. These two lengths were selected because the 3D length is a typical length requirement for installing a magnetic flow meter downstream of an elbow and 10D is a typical length at which it is commonly believed that there should be negligible effect on the magnetic flow meter because of distance. The change from EIP to EOP can immediately be seen in the Figures along with the average straight pipe percent deviation. The change from EIP to EOP is numerically shown for velocities of 4 fps and 8 fps. For the other velocities the change is only shown graphically. The average straight pipe percent deviation was calculated by taking the average of all straight pipe percent deviation data for velocities greater than the minimum velocity. It is important to note that each of the meters could perform better under baseline conditions if appropriately corrected under ideal straight pipe conditions. The minimum velocity and meter accuracy are also illustrated in the figures as indicated by the meter manufacturer. To see the results for locations CC, 1D, 3D, 5D, and 10D see Appendix A.

A summary of Figures 13 through 16 is given in Table 3. The table shows the average straight pipe percent deviation and the magnitude of the shift from EIP to EOP for 3D and 10D at 4 fps and 8 fps. For example, if looking at meter Mfr C, at three diameters downstream of the elbow and 4 fps there was a shift of 0.104% when rotated from EIP to EOP. In Table 4 the percent deviations are given for locations 3D and 10D at velocities 4 fps and 8 fps. If the percent deviation is outside the accuracy given for that meter the value is highlighted in red. Those values not highlighted in red are all within the given accuracy for
that meter. It should be noted that the red highlights in the table do not compare the meters' performance with that of others, it only shows whether or not the value is within the given accuracy of that meter as specified by the manufacturer.

![Figure 13. Mfr A Test Plot](image-url)
Figure 14. Mfr B Test Plot
Figure 15. Mfr C Test Plot
Figure 16. Mfr D Test Plot
Table 3. Summary of Results

<table>
<thead>
<tr>
<th>Manufacturer</th>
<th>Average Straight Pipe % Deviation</th>
<th>3D EIP to EOP (4 fps) % Deviation shift</th>
<th>10D EIP to EOP (4 fps) % Deviation shift</th>
<th>3D EIP to EOP (8 fps) % Deviation shift</th>
<th>10D EIP to EOP (8 fps) % Deviation shift</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mfr A</td>
<td>0.58%</td>
<td>0.17%</td>
<td>0.41%</td>
<td>0.56%</td>
<td>0.21%</td>
</tr>
<tr>
<td>Mfr B</td>
<td>-0.05%</td>
<td>0.50%</td>
<td>0.29%</td>
<td>1.18%</td>
<td>0.35%</td>
</tr>
<tr>
<td>Mfr C</td>
<td>0.70%</td>
<td>0.10%</td>
<td>0.11%</td>
<td>0.20%</td>
<td>0.01%</td>
</tr>
<tr>
<td>Mfr D</td>
<td>1.25%</td>
<td>0.24%</td>
<td>0.04%</td>
<td>1.31%</td>
<td>0.32%</td>
</tr>
</tbody>
</table>

Table 4. Percent Deviation for Locations 3D and 10D

<table>
<thead>
<tr>
<th>Manufacturer</th>
<th>3D EIP (4 fps) % Deviation</th>
<th>3D EOP (4 fps) % Deviation</th>
<th>10D EIP (4 fps) % Deviation</th>
<th>10D EOP (4 fps) % Deviation</th>
<th>3D EIP (8 fps) % Deviation</th>
<th>3D EOP (8 fps) % Deviation</th>
<th>10D EIP (8 fps) % Deviation</th>
<th>10D EOP (8 fps) % Deviation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mfr A</td>
<td>0.13%</td>
<td>0.30%</td>
<td>0.91%</td>
<td>0.50%</td>
<td>0.61%</td>
<td>0.05%</td>
<td>0.88%</td>
<td>0.67%</td>
</tr>
<tr>
<td>Mfr B</td>
<td>-0.61%</td>
<td>-0.10%</td>
<td>-0.04%</td>
<td>-0.33%</td>
<td>-0.94%</td>
<td>0.23%</td>
<td>-0.34%</td>
<td>-0.69%</td>
</tr>
<tr>
<td>Mfr C</td>
<td>-0.81%</td>
<td>-0.71%</td>
<td>0.13%</td>
<td>0.24%</td>
<td>-1.10%</td>
<td>-0.91%</td>
<td>0.28%</td>
<td>0.27%</td>
</tr>
<tr>
<td>Mfr D</td>
<td>0.25%</td>
<td>-0.01%</td>
<td>0.92%</td>
<td>0.88%</td>
<td>1.16%</td>
<td>-0.15%</td>
<td>0.70%</td>
<td>0.38%</td>
</tr>
</tbody>
</table>
CONCLUSION

Electromagnetic flowmeters are a common type of flowmeter. It is important that the installation and operation requirements for magnetic flow meters are understood. Magnetic flow meter manufacturers do give installation and operation guidelines; however, in many examples the guidelines do not address all possible situations. One such situation is when the meter is rotated at different orientations. The effects of meter orientation on the meter is the focus of this project. Four different meters where tested after a short-radius elbow at different locations and flows. Many conclusions could be made from these results and it is left to the reader to form those conclusions. The following section states some of the interesting observations made during the project.

- Meters Mfr C and Mfr D both had a manufacturer specified accuracy of 1% and many of the data shifts happen within that accuracy.
- Meter Mfr A had a manufacturer specified accuracy of 0.2% and meter Mfr B had a manufacturer specified accuracy of 0.25%. These two meters showed a large number of data shifts outside the given accuracies for both meters.
- Meters Mfr B and Mfr C have smaller electrode diameters than those of meter Mfr A and Mfr D.
- Meter Mfr C’s electrodes protrude the least into the flow than any other meter tested, and Meter Mfr C showed data shifts that were consistently small in magnitude. Note as discussed in the literature review, the electrodes are sensitive to the shape of the velocity profile (Luntta, 1998).
- Meters Mfr A and Mfr B both have mA output signal and both meters show data shifts that were consistently large in magnitude.

- Meters Mfr C and Mfr D had output signals of hertz and pulse (respectively), and both show data shifts that were consistently small in magnitude.

- Meter Mfr C had the smallest inside diameter out of all the meters and out of all the meters it shows the best repeatability.

- Meter Mfr B’s average straight pipe percent deviation is within the given accuracy. However, once the meter is placed behind an elbow almost no data points fall within the given accuracy.

Results Summary

The results from the project show the effects of meter orientation on magnetic flow meter accuracy. By examining the results for locations 3D and 10D at 4 fps and 8 fps, it is clear that there is a shift in data when the meters were rotated from EIP to EOP. For meter Mfr A, at 4 fps and 8fps, the change of orientation from EIP to EOP always resulted in a shift outside the given accuracy of the meter. It is important to note that even though meter Mfr A always had a shift outside the given accuracy, the magnitude of that shift was not always the largest when compared to other meters. For example, for location 10D and velocity 8 fps, meter Mfr A did have a shift outside the given accuracy but meters Mfr B and Mfr D had shifts of larger magnitudes. For this project meters were not compared to each other. They were compared to what each manufacturer claimed the performance of the meter should be.
The results also show that meters whose signal output is mA, show data shifts that were consistently large in magnitude. Meters with signal outputs of hertz and pulse show better repeatability and accuracy. This could be due to the fact that the mA output has a smaller range than the hertz output. It is also interesting that meter Mfr C’s electrodes protruded the least and that meter had the best repeatability. A reason why this occurs may be due to the fact that the electrodes are sensitive to the shape of the velocity profile (Luntta, 1998), and the more the electrode protrudes out into the flow the more the electrode may be able to sense the shape of the velocity profile. It should be understood that although these observations are being presented here, they by no means indicate that the author is implying that these observations are the direct cause of any inaccuracies.

Need for Further Research

Because the electrodes are sensitive to the shape of the velocity profile (Luntta, 1998), future research could focus on the relationship between electrode location and the shape of the velocity profile. This could be done using a computational fluid dynamic software to study the shape of the velocity profile at different locations downstream of a short radius elbow or any other pipe configuration. Then, with an understanding of the velocity profile shape at certain locations, data points could be taken at those locations with different electrode orientations to see how sensitive the electrodes are to the different velocity profile shapes.
REFERENCES


APPENDICES
APPENDIX A.

TEST PLOTS
Figure 17. Mfr A Test Data for CC, 1D, 3D, 5D, and 10D
Mfr B Magnetic Flow Meter Data

Figure 18. Mfr B Test Data for CC, 1D, 3D, 5D, and 10D
Mfr C Magnetic Flow Meter Data

Figure 19. Mfr C Test Data for CC, 1D, 3D, 5D, and 10D
Figure 20. Mfr D Test Data for CC, 1D, 3D, 5D, and 10D
Mfr A Magnetic Flow Meter Straight Pipe Data

Figure 21. Mfr A Straight Pipe Test Data
Mfr A Magnetic Flow Meter Straight Pipe Data

Figure 22. Mfr B Straight Pipe Test Data
Mfr C Magnetic Flow Meter Straight Pipe Data

Figure 23. Mfr C Straight Pipe Test Data
Mfr D Magnetic Flow Meter Straight Pipe Data

Figure 24. Mfr D Straight Pipe Test Data