Behaviour of Ultrasonic Measurement in Composite Pipe

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Abstract

Flow rate measurement provides important data for wastewater pump stations (WWPSs), as readings can be used for planning, quantification of overflows, and pump performance measurement. A variety of devices can be used for flow measurement at WWPSs. Water Corporation is investigating the possibility of using clamp-on ultrasonic flow meters (USMs), as they are more cost and labour effective compared to other devices. The accuracy of clamp-on USM measurements is affected by flow disturbances and the material characteristics of pipework. This study aims to further investigate the effects of material properties of common WWPS pipework on USM measurements. USM performance will be predicted by taking measurements on different pipe material that has been installed on an existing test rig simulating the actual pipework of a WWPS. Numerical models using Computational Fluid Dynamics (CFD) will assist in predicting the performance of USMs, as comparisons are made with physical testing. USM measurements recorded on polyvinyl chloride (PVC) indicated PVC does not affect the performance of the device. It is possible that pipe materials such as mild-steel (MS) and mild-steel cement-lining (MSCL) will lower the accuracy of USM measurement.

1. Introduction

Water Corporation utilises a variety of flow meters to monitor the performance of wastewater pump stations (WWPSs). Presently, magnetic flow meters (magflows) are the most widely used flow monitoring device at Water Corporation. They achieve a high level of accuracy and are directly installed in-line with pipework on the pressure main. Replacing magflows is a difficult task with only a small window available when the WWPS is offline. Installing flow meters directly in-line of the pressure main at WWPSs requires bypass which can cost approximately $35,000 to $70,000 depending on the size of the pump station. A cost-effective method of flow measurement is incorporating clamp-on (non-intrusive) ultrasonic flow meters (USMs), offering significant cost savings from easier installation and reducing risk of wastewater spillage by not disrupting the pipeline. The installation of clamp-on USMs could significantly reduce the costs associated with the need to bypass WWPS pressure mains for the maintenance of magflows.

Physical pipework and flow disturbances from pipe fittings can affect the accuracy of USM flow measurement. This presents challenges for clamp-on USMs as WWPSs have many fittings that create flow disturbances and the mild-steel cement-lined (MSCL) pipe can hinder transmission of ultrasonic waves. There are two types of flow rate measurement methods utilised by USMs, including doppler and transit-time. For this research, the USMs being investigated utilise the transit-time method of flow rate measurement. This method internally calculates the flow rate through differences in time that the sound wave takes to travel between the two transducers. It is recommended that these USMs be used when the percentage of solid particles and/or gas bubbles are less than 10 wt% (Flexim, 2016). Manufacturers of USMs recommend locating these clamp-on devices at a certain length of straight pipe, upstream and downstream from pipe fittings. A fully developed flow profile is then achieved within the testing region of the USM, which is assists in achieving a suitable level of measurement accuracy (Flexim, 2016).

Yang (2019) tested a singular USM installed using two configurations and various downstream locations from a tee joint and at different orientation angles. The two USM configurations tested were the reflective and diagonal arrangement of transducers. The orientation angle of the meters refers to the position USMs were placed around the circumference of the pipe. A reference magflow was installed 60 diameters (60D) downstream from the tee joint to quantify the accuracy of the USM measurements. The error when the USM was placed in the reflective configuration, at a downstream length of 2D from the tee joint ranged between -1 to 18%. The lowest error values of -1% were recorded when the USM was placed at orientation angles of 0, 45, and 135°. The USM produced a significantly worse error when placed in the diagonal configuration at a majority of the orientation angles. As the flow meter was placed further downstream of the tee joint, the performance of the meter improved, with error values ranging between ±10% at 20D. Flow rates recorded at 20D were consistent at all orientation angles with the USM placed in the reflective configuration. It was concluded that the location of USMs at longer downstream distances from disturbances achieved more accurate flow measurements, but acceptable accuracy could be achieved at shorter distances (Yang, 2019).

Understanding the effects of pipe material is an important aspect of USM accuracy. USMs are installed on the exterior of the pipe, bringing several factors into play. The factors affecting USM performance include size, material, wall thickness, lining/coating, and surface roughness. For strong ultrasonic transmission through a pipe, the pipe material must be sonically conducting. Acoustic penetration is achieved when the pipe and fluid does not attenuate the sound before it reaches the following transducer. From Snell's law, when sound travels through various media, part of the energy is refracted, reflected, or absorbed. Materials such as concrete dampen sound energy, and occlusions in cast iron can attenuate the sound signal (Sanderson & Yeung, 2002). The introduction of linings/coatings must be airtight, as air pockets from delamination can further attenuate ultrasonic signals (Flexim, 2016). The pipe roughness impacts the degree of sound energy that is scattered, which is related to a ratio between the wavelength of the sound energy and the relative roughness of the pipe. Pipes with a high relative roughness will produce high scattering of sound ultrasonic signal. For significantly rough pipes, the profile factor must consider pipe wall roughness, as errors can reach 4%. Thus, in the presence of rough materials, such as cement, lowering the frequency will increase the wavelength, causing reduced sound signal attenuation; assuming sound velocity is constant through any given medium (Sanderson & Yeung, 2002).

2. Process – Test Rig Modifications & Experiments

An existing test-rig has been constructed to closely model a type 40 WWPS, with a scaling factor of 1:3 and a design flow of 20 L/s and DN 150 mm (Yang, 2019). The actual flow rate and diameter of the pipework on the test rig were 2.7 L/s and DN 50 mm, respectively. Potable water is the fluid medium that is passed through the test-rig and the pipe material is polyvinyl chloride (PVC). A magflow is placed near the outlet of the test-rig and is used as a reference to verify the flow rate readings recorded by the USM. The performance of USMs is characterised by the percentage difference between the USM reading and the ideally located magflow.

Modifications are to be made to the test rig for the current project. An interchangeable section of pipe will be installed 1800 mm from the inlet of the test rig. This will allow for different pipe materials of roughly DN 100 mm to be input into the system, enabling USM measurements to be recorded on each material. The materials tested will include PVC, mild-steel (MS), and mild-steel cement-lined (MSCL), with the latter material being the most commonly installed in WWPSs. Each section of pipe material tested will be 3000 mm long, with USMs to be placed at a ratio of upstream to downstream length of 5:1 on the pipe section. Since the pipe size of the interchangeable section will be twice the original size of pipe used, the flow rate will be increased to achieve Water Corporations WWPS standard velocity of greater than 0.75 m/s. The flow rate will be changed to 10 L/s, meaning the fluid velocity through the DN 50 mm and 100 mm sections of the test-rig will be roughly 5.0 and 1.8 m/s, respectively.

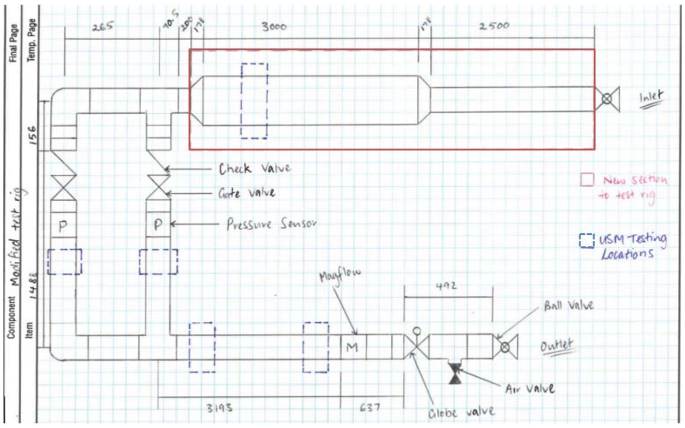

Figure 1 Schematic of test rig with modifications displayed as "New Section to test rig". USM testing locations have been specified in blue.

For the experiments, fully developed flow is desirable within the testing region of the USMs to ensure that any error in USM measurements should be mostly due to the pipe material. Thus, it is necessary that enough upstream length has been applied to achieve fully developed flow before the inlet of the interchangeable section and at the testing region of the USMs. The type of USM being tested utilises the transit-time method of flow rate measuring. A Computational Fluid Dynamic (CFD) simulation was constructed to verify that fully developed flow would occur at the test sections. Potable water and an air bleed valve will be used, making any effects from solid particles or air bubbles on the performance of USMs negligible.

The experiments will consider the performance of USMs when placed on different pipe material and the performance of two sets of USMs when placed in the same region at different orientation angles about the circumference of the pipe. All tests will utilise the reflective configuration as this offers the highest level of accuracy of the two USM configurations available. The experimental procedure is listed below:

- **Primary Testing:** USMs are installed on interchangeable pipe material following manufacturers' requirements. To isolate effects of pipe material, fully developed flow is established. Comparison of magflow and USM for verification of USM performance.
- **Secondary Test A:** Singular and dual sets of USM transducers will be placed on PVC pipe sections downstream of gate valve and tee joint, as well as interchangeable pipe section. Flow data will be collected from each configuration, averaged and compared

with magflow readings. For the dual CEED Seminar Proceedings 2020 Jason: Ultrasonic Measurement in Composite Pipe 4 set USM testing, the meters will be placed at the same downstream location on the test-rig, but situated 90° apart in orientation angle.

- **Secondary Test B:** USMs are installed over faults on MSCL pipe. Flow data is recorded and compared with data from non-faulty MSCL pipe. Faults are to be introduced at the testing region on the interchangeable pipe.

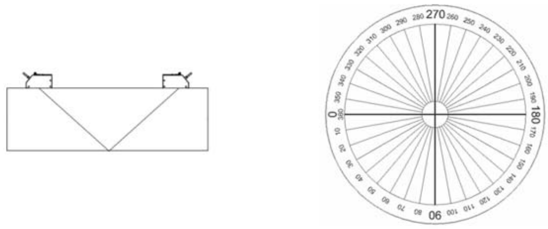

Figure 2 Representation of reflective USM transducer configuration on the left (Flexim, 2016). Reference of orientation angle looking at direction opposite to fluid flow.

3. Results and Discussion

Secondary test A has been completed, with single and dual set USM measurements recorded at multiple locations. The testing was conducted at the locations of 2D downstream from the tee joint (closest to the outlet), 7D downstream from the gate valve and 2D upstream of magflow. At 2D downstream of the tee joint testing location, there is a clear decrease in the range of error values with two USMs placed in the same testing location. The error values range from -1 to 12 % as opposed to just a single USM, which had a range of -1 to -18 % at the same location (Yang, 2019). The maximum error recorded from the dual set of USMs is roughly 6% less than the single set. Having two sets of USMs means that the flow measurement becomes less susceptible to flow profile disruptions as more sound paths are present, which is consistent with manufacturers' recommendations and literature, (Flexim, 2016) and (Baker & Thompson, 1975).

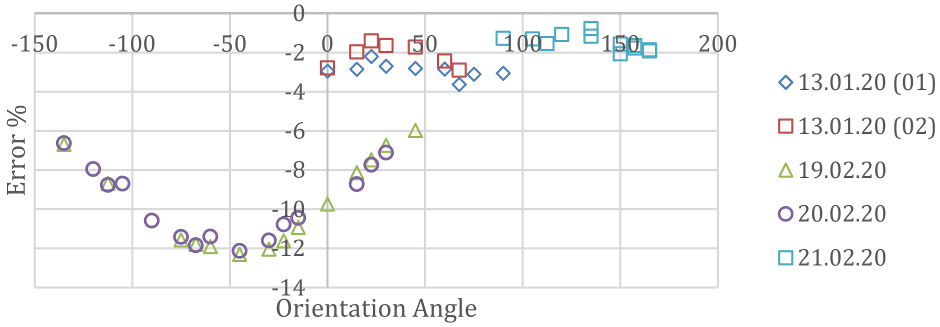

Figure 3 Error percentage values of dual USM testing at location 2D downstream of tee joint.

At 7D downstream of the gate valve, the variation in error percentage recorded was less than when compared to the 2D downstream from the tee joint case. The USMs placed at the 7D downstream from the gate valve case, the flow is given more length to re-establish, resulting in less volatility in error values measured. This is consistent with results found by Yang (2019), as measurements are less dependent on orientation angle as the distance from a flow disturbance increases. The error values taken from 7D downstream from the gate valve case with a dual set of USMs ranged from -6 to -8 %. At certain orientation angles, the error values obtained from the 2D downstream of the tee joint case are less than the 7D downstream from the gate valve case.

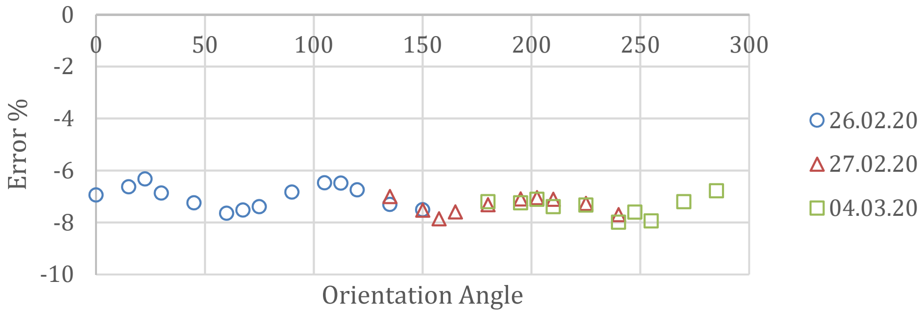

Figure 4 Error percentage values of dual USM testing at location 7D downstream of gate valve.

The error values recorded when the USMs were placed 2D upstream of the gate valve displayed similar behaviour to the results recorded from the 7D downstream of the gate valve. Again, there was less variation in error measurements obtained at all orientation angles, further solidifying the point that flow rate measurements become less dependent on orientation angle when placed further away from flow disturbances. The difference occurred in the error values obtained, as the USMs when placed 2D upstream of the magflow, the error values ranged between -4.8 to -6.0 %. The readings are slightly more accurate, but a difference is still present between measurements obtained from the USMs and the magflow, even when placed 100 mm apart.

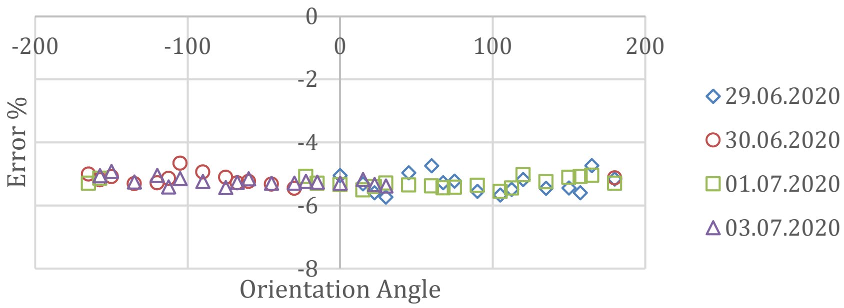

Figure 5 Error percentage values of dual USM testing at location 2D upstream of magflow.

4. Conclusions and Future Work

USM measurements are highly influenced by variation in the flow profile especially when placed close to a flow disturbance. Results depict that the accuracy of USM readings can improve when the meters are positioned further away from the flow disturbance. The results display that accuracy can be improved when the number of sound paths increases. USM measurements become less volatile when meters are positioned further away from the flow disturbance, with the dependence of orientation angle becoming negligible. The significance of the orientation angle is present when the meters are placed closer to flow disturbances for both single and dual set USM configurations.

Further interpretation of pipe material influence on USM measurement is required to offer further insight into USM behaviour when placed on composite pipe common to WWPSs such as MSCL. Construction of modifications to test rig shown above, will allow for multiple pipe materials to be fitted and tested. It is known that PVC has little effect on USM measurement when compared to disturbances in the flow profile. This is displayed when USMs are placed at distances greater than 20D, as error values are consistently low when a fully developed flow profile is established. Reduction in accuracy of USM measurement could occur with tests on MSCL, as the ultrasonic wave must travel through two different mediums, with the cement-lining known to have high surface roughness and low acoustic conductivity.

Understanding the flow profile, especially when next to the flow disturbance, can assist in deciphering the best orientation angle that USMs must take. In terms of future direction, Potential for field trials at existing WWPSs would aid in understanding the performance of USMs, especially when testing in non-ideal conditions, such as aged pipe and reduced water quality. Along with field tests, investigation of the flow field within the test rig using CFD would assist in verification of the USM performance.

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