AN ACOUSTIC VECTOR RECEIVER FOR WALL CONDITION ASSESSMENT IN A WATER-FILLED PIPE

J Watts Mechanical Engineering, University of Sheffield
K Horoshenkov Mechanical Engineering, University of Sheffield

1 ABSTRACT

Pre-emptive maintenance of buried pressurised water pipes is a challenging problem that requires accurate information on the wall thickness loss, levels of corrosion and graphitisation. Here we present a novel acoustic sensor which measures the fluid acceleration vector at a low frequency of sound to determine the presence of a wall defect. The sensor is based on a commercial triaxial wireless accelerometer adapted to work underwater. The sensitivity of the acoustic acceleration in the water-borne wave is demonstrated through a numerical simulation and in a laboratory experiment with an exhumed section of a ductile iron pipe. It is shown that the acoustic acceleration vector is significantly more sensitive to the wall loss than the traditionally measured acoustic pressure. The new sensor can be deployed on an in-pipe robotic platform to detect autonomously an early sign of pipe wall deterioration.

2 INTRODUCTION

There are approximately 220,000 miles of potable water pipes as well as a similar length of sewage pipes in the UK. 3 billion litres of potable was lost to leaks in 2019-2020, representing 20% of total treated water[1]. This is on a par with other developed countries. This lost water is a waste of resources, especially with water scarcity due to increase, as well as a waste of energy. Furthermore, OfWat has set targets to cut leakage in the UK by an average of 16% by 2025 and 50% by 2050, with fines for water distributors who do not achieve this[2]. As such asset management is becoming a priority for water management companies. The majority of these assets are buried, with buried pipes representing a challenging environment for asset management due to the difficulties involved in accessing the pipes. There are a plethora of existing technologies for inspecting pipes, with benefits and limitations of each, readers are directed to Rizzo[3] and Yu et al.[4] for a review of these.

Rising mains are a specific type of sewage pipe used to transport wastewater uphill or over long distances of flat ground where pumps are required. From an inspection point of view these pipes are more similar to potable water pipes than other sewage pipes since they are pressurized and often challenging logistically to take out of service for inspection. They are also more prone to breaks due to the period loading from intermittent pumping, their corrosive and abrasive contents and the fact that they are aging, difficult to replace and difficult to inspect. Rising mains may fail in a number of way, however the most common are scouring of the bottom surface of the pipe or chemical corrosion of the top surface, both of which cause pitting defects which develop into holes[5]. These authors have struggled to find a review of existing techniques for rising main condition assessment, with the only methods found being adaptions of CCTV technology from gravity sewage inspection or deployment of potable water methods such as Smartball and Sahara[6].

This paper presents a novel sensor for deployment on an in-pipe robotic platform, such as that in development by pipebots[7], which could be deployed in both potable water pipes and rising mains.

3 MODELLING THE PROBLEM

A vector-velocity based sensor was proposed based on modelling work in COMSOL MultiPhysics. Two models were developed, one with a pitting defect and another with a small hole in the pipe wall. A ductile iron pipe was modelled, with Young's modulus 172 GPa, Poisson ratio 0.275, density 7,150 kg/m^3, length 56 m, inner diameter 0.3 m and thickness 0.016 m. Perfectly matched layers were placed at each end to reduce internal reflections. The defects were modelled at 0 m, with a planar sound source 1 m from the defect, the mesh surrounding each defect is shown in Figure 1.

Results from these models are shown in Figure 2 and Figure 3 for the response to a 170Hz source of the pressure and radial acoustic velocity respectively. It can be seen that the acoustic vector velocity is significantly more sensitive than the acoustic pressure, with a clear change in behaviour next to the defects in addition to a distinct loss of symmetry through the length of the pipe.

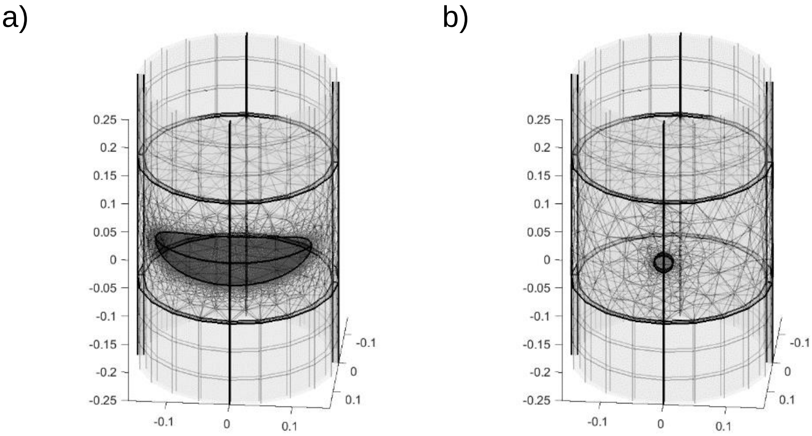

Figure 1: view of the mesh surrounding each of the defects modelled. a) a pitting defect, b) a small (10mm) hole in the pipe wall.

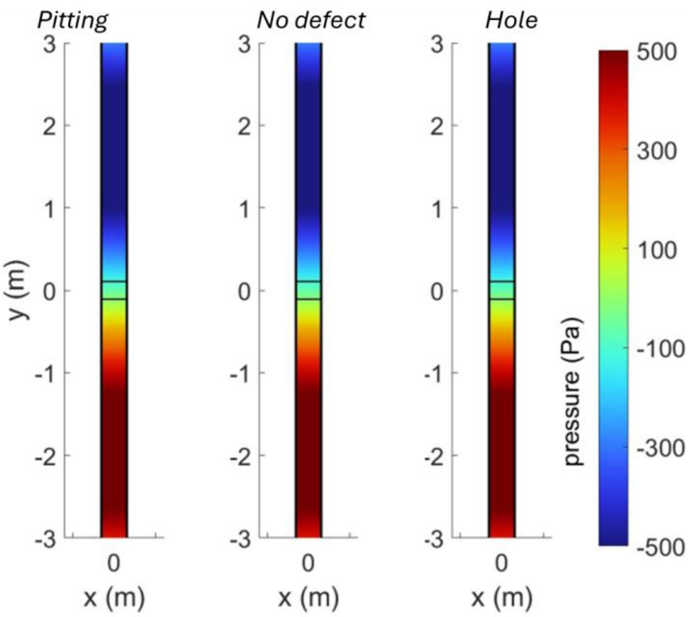

Figure 2: pressure close to defect for a plane through the centre of the pipe for models with a pitting defect, no defect and a hole defect.

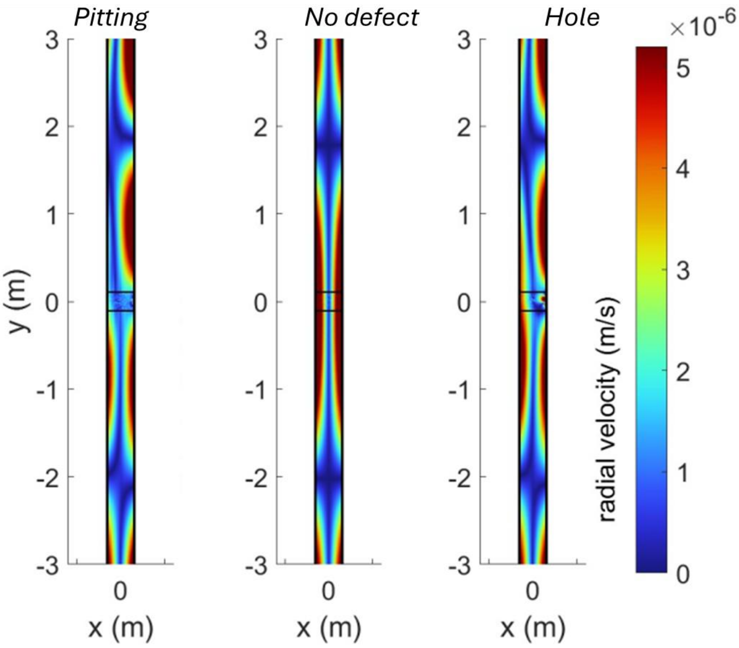

Figure 3: radial velocity close to defect for a plane through the centre of the pipe for models with a pitting defect, no defect and a hole defect.

4 EXPERIMENTAL WORK

4.1 Methodology

Based on the above results a triaxial accelerometer was acquired to measure the acoustic velocity vector. It needed to be able to detect changes in the velocity of the order 10^{-7} m/s, a G-Link-200 accelerometer was chosen with sensitivity of 10^{-9} m/s. To verify the applicability of the numerical results, measurements were taken on a 2.0 m length of 310 mm diameter ductile iron rising main provided by Thames Water. The significant deterioration of its bottom surface allowed measurements to be taken of a damaged pipe section and the relatively intact pipe wall around the remainder of the pipe was used to provide an ‘intact’ comparator. The sensor was suspended at the top of the pipe on a movable gantry, with the pipe rotated such that the wall of interest was next to the sensor. The response to a 170 Hz tone produced by a Visaton FR8 underwater speaker amplified by a Fosi Audio TDA7498E was measured at a range of sensor positions. The sensor set up is shown in Figure 4.

Figure 4: the sensor.

4.2 Results

The results of measurements of the pressure along the length of the pipe are shown in Figure 5. Results next to a defect in the pipe are shown in Figure 6 for the three axes measured: the x-direction is along the pipe, the y-direction is horizontal and the z-direction is vertical i.e. radial with respect to the pipe. The results are compared against a modified version of the model described in Section 3 where the pipe has been shortened, the tank introduced and each of the major defects present on the pipe has been included. A schematic view of this model is shown in Figure 7.

The pressure measurements show no clear separation between measurements next to the defective pipe wall and those next to an intact pipe, both for the modelled and measured results. There is a clear deviation in behaviour between the modelled and measured results for $x < 1.2$m, this is believed to be due to the speaker over-heating since measurements were taken in order from 1.8 m to 0.8 m. Consequently, the measurements of the acoustic velocity have been normalised by the pressure to remove this effect.

For the acoustic velocity (Figure 6), there is a clear separation in behaviour between the two types of pipe wall (intact vs defective), with a marked increase in the horizontal (y) and radial (z) velocities close to the defect. This separation is 2x larger than the measurement error. The axial velocity does not show such a clear separation, as expected given the strong relationship between axial velocity and pressure.

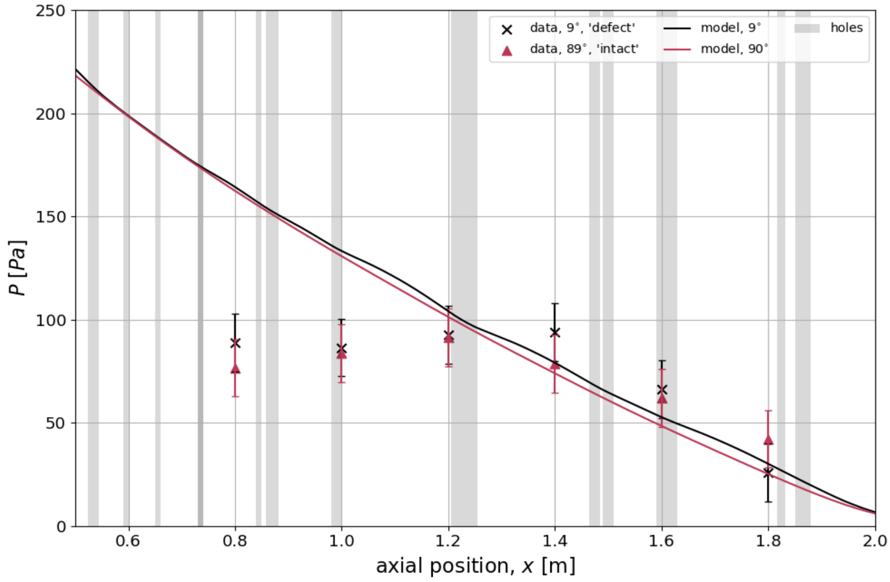

Figure 5: pressure measured along the pipe length showing the measured results including the range of the measurements as points and the corresponding model results as lines. The extent and position of defects in the pipe are shown as grey shaded regions.

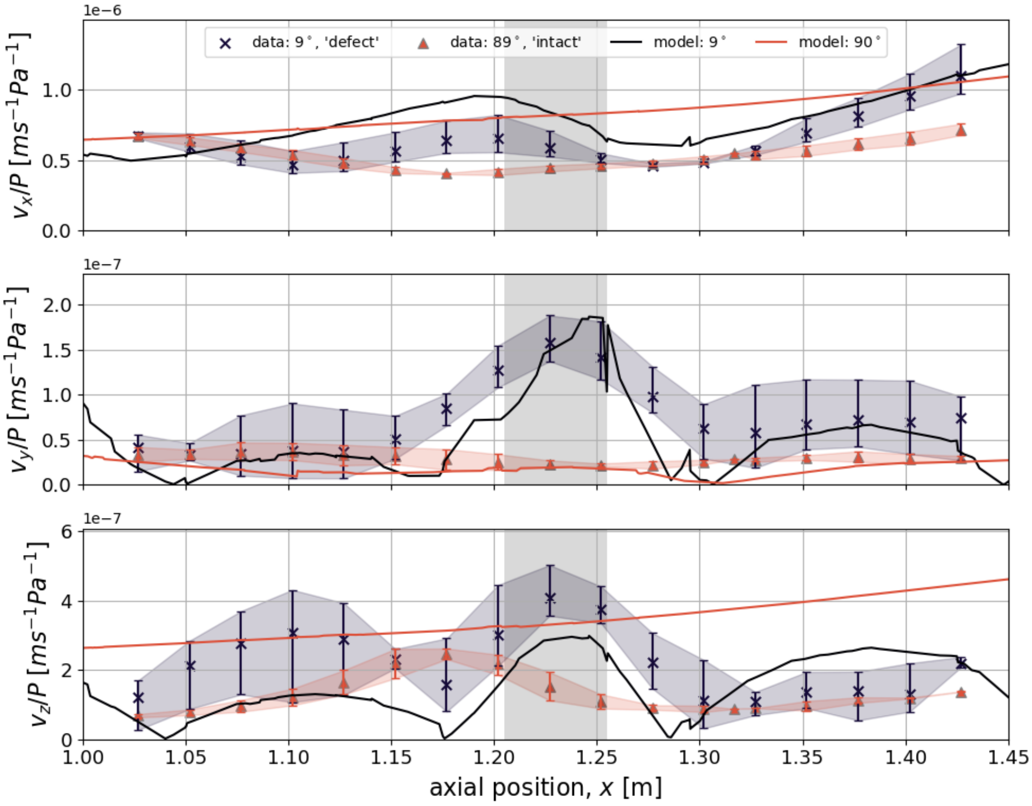

Figure 6: velocity measurements taken next to a defect at 1.21m showing the measured results including the range of measurements as points and the results of the corresponding model as lines. The extent of the defect is shown as the grey shaded region.

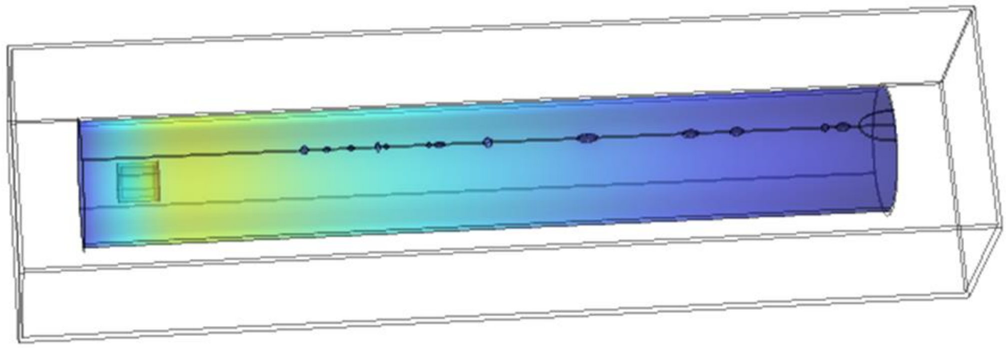

Figure 7: modified model which is more representative of the experimental set up.

5 CONCLUSION

Based on both numerical and experimental results it can be concluded that the vertical and horizontal components of the acoustic velocity vector are more sensitive to the presence of defects than the pressure and offer a new approach to defect detection. In contrast, the pressure and axial velocity are insensitive to small defects in the pipe wall. It has been shown that a commercial triaxial accelerometer can be used to measure these changes with the requisite sensitivity. In the future these sensors will be deployed on a robotic platform to allow for testing on longer pipes, paving the way for a robotic solution to condition assessment of difficult to inspect pipelines.

6 REFERENCES

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