ACOUSTIC DETECTION OF FLOW VARIATION AND LEAKAGE INWATER DISTRIBUTION PIPES

N. Hamamed[1,2], N. Yaakoubi[1], C. Mechri[1,3], R. El. Guerjouma[1], H. Hentati[2], S. Bouaziz[2], M. Haddar[2]

[1] Laboratoire d'Acoustique de l'Université du Mans, Institut d'Acoustique - Graduate School (IA-GS), Le Mans Université, CNRS UMR 6613, Le Mans, France
[2] Laboratoire de Mécanique, Modélisation et Productique (LA2MP) École Nationale d'Ingénieurs de Sfax (ENIS),Université de Sfax, Sfax, Tunisie
[3] CTTM: Centre de Transfert de Technologie du Mans, Le Mans, France

Abstract:

Water is a vital resource that is becoming increasingly scarce due to global warming, pollution and leaks in pipes, especially in urban areas. Finding non-intrusive methods to detect water flow variation and leakage is therefore essential to reduce losses in urban distribution networks that can have a significant economic impact. In this work, we have explored an acoustic method to detect the vibrations of water flows for metallic pipes. So, two piezoelectric sensors were used, the first one is made of a Lead Zirconate Titanate Ceramic (PZT) and the second one is a Polyvinylidene fluoride polymer (PVDF) to control and monitor the dynamic behavior of metallic water pipes at different flow rates.

Keywords: PVDF sensor; PZT sensor; water leakage; acoustic detection;

1. INTRODUCTION

More than one in six people in the world suffer from water stress, which means they do not have sufficient access to safe drinking water. These people represent 1.1 billion people worldwide that live in developing countries [1-2]. The threat of major water crises is thus taking hold in the countries of the South [3]. Many countries, including India, which represents nearly a quarter of theworld's population, are already exposed to the risk of extreme water stress. Water is becoming increasingly scarce. One of the ways to preserve it is to fight against leaks in public distribution networks. Studies show that many leaks in water are caused by environmental conditions and problems of aging infrastructure [4], pipe damage, and water overflow. These leakages can exceed more than 30% of the water input volume. Recently, the World Bank [5], published in 2016 that there is 45 billion cubic meters of water leakage in that year. Thus, it is essential to protect water distribution networks from losses by developingmethods to control the stability and the behavior of pipes.

M.J. Brennan et al [6] studied the noise in the water distribution network, and they showed that this noise was produced by different causes, like, the vibration of water flow and the ambient sound.

The control of the noise produced by the water flow in pipes can be obtained using different methods: Acoustic methods such as the cross-correlation of measured acoustic signals [7]. This is the most commonly used method. Its main advantages are its simplicity of calculation and implementation and its efficiency even in a noisy environment. However, it has drawbacks such as difficulty in detecting leaks in plastic pipes.

Furthermore, vibration analysis, hydrophones, and acoustic emission (AE) sensors [8-10] are also acoustic methods [10-12] produced under stress.

A E hydrophones, accelerometers, and piezoelectricsensors have gained a big interest from researchers to monitor water pipelines and detect leaks in themdue to their piezoelectric effects [13-15].

The second method to detect water leakage is thenon-acoustic method that may contain the Thermography and Tracer Gas.

Water vibration was detected using one or more sensors connected or embedded in the structure. These sensors detect elastic waves generated in thestructure and convert them to an electrical signal.

This paper focuses on the Acoustic Emission sensors to control the behavior of pipes for different flow rates. In our work, we describe an easy method to monitor pipe's behavior and detect the vibration caused by varying water flow in water pipes, comparing two piezoelectric sensors a PZT ceramic and a polymer (PVDF) one. It is a preventive step that aims to monitor and control the water distribution network from leakages.

2. DESCRIPTION OF THE WORK

The test was carried out on a public water distribution network of Le Mans University. In order to avoid water drafts and parasitic noises which can affect the measurements, these were carried out at night.
These tests aim to investigate the vibration response of water pipelines by varying water flowrates.

The water wave was excited by opening the valve to produce broadband noise. This noise was easily detected by PZT and PVDF sensors due to the strong coupling between water and pipes wall. Theexperimental device is presented in figure 1.

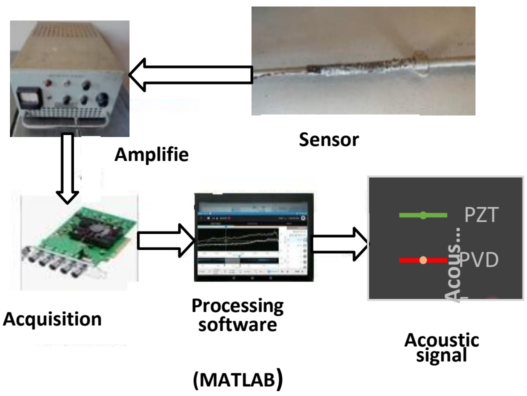
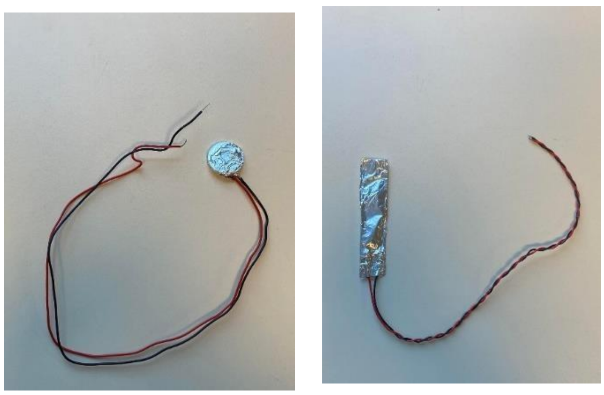


Figure 1: Experimental device

The different components of the measuring device are: PZT sensor which comes in the form of a pellet with a diameter of 20 mm and a thickness of 2 mm. PVDF sensor which comes in the form of a flexible film 0.052 x 72 x 16 mm^3. We have chosen PZT and PVDF sensors to see thecomparison between the flexible polymer and thehard ceramic sensors to detect vibration and leaks. They were shielded against electromagnetic radiation using a metal casing acting as a Faradaycage before being bonded to the inspected tubes. An electronic signal conditioning stage consistingof a low pass filter (< 4 kHz) and a preamplifier(20 dB). An acquisition system ensuring asampling at 100 kHz on a dynamic range of 16bits.
Since, the two sensors that we used, can undergo electromagnetic radiation, we created a process to protect them. It is a Faraday cage. It works by superimposing conductive and non-conductive layers and creates a shield effect to protect sensors inside it.
The steps followed to achieve protection with the faraday cage are the following:

- We wrapped the sensor in a layer of plastic.
- We completely cover the sensor with an aluminum sheet.
- For maximum protection, we covered the device with three layers of aluminum, and we added a plastic layer between each layer of aluminum: The metal allows radiation to run along the surface of the aluminum layer while the insulating plastic layer blocks radiation to reach the sensor.



(a) **(b)**

Figure 2: a): PVDF sensor, b): PZT sensor

The properties of the metallic pipes that we have usedare shown in Table 1.

Table 1: Pipe properties

Properties	**Metallic pipe (Copper)**
Pipe radius (mm)	12,7
Density (kg/m^2)	900
Pipe wall thickness (mm)	1.14
Young's Modulus (N/m^2)	1.3. 10^{11}

3. RESULTS AND DISCUSSION

The main purpose of our study is to produce a system able to detect the vibration in the water pipeline and to compare the sensitivity of detection for both ceramic and polymer sensors.
In our study, we created a system with MATLAB that uses Fast Fourier Transformation to generate corresponding frequency response for each case (no flow rate, first flow rate, and second flow rate). This study helps us to compare vibration signals by seeing how close their local maxima to the no water flow signal.
Figures 3 and 4 show the results of the recorded

acoustic intensity in (dB) as a function of the frequency for a metallic pipe at different levels of flow rates using ceramic PZT and polymer PVDF sensors respectively.

a. Use of ceramic sensor:

Results for metallic pipes using a ceramic PZT sensor are presented in figure [3].
After reading the curve, we can remark that the water flow has remarkable activity in the region between 100 Hz and 2000 Hz.
The red graph has the lowest amplitude because it presents the silence of the structure: There is no flow of water in the pipe that can generate vibrations. It is a reference curve.
The green graph is related to the first flow rate: 0,1 m^3/h, this is why we can remark that the amplitude increases.
The blue graph has the highest amplitude because it presents a lot of activities, which are caused by the vibration of the water flowing in the metallic pipe
The flow rate, in this case, is 0,5 m^3/h.

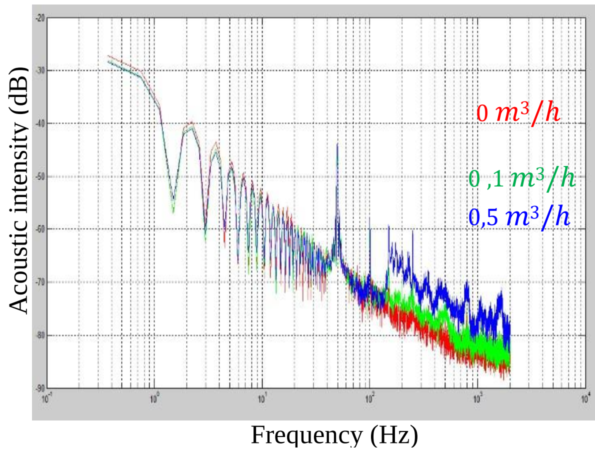


Figure 3: Acoustic intensity for the metallic pipe using PZT sensor

b. Use of polymer sensor:

Figure [4] presents, the results of frequency response for metallic pipes at the same flow rates using a flexible polymer sensor.
By examining the graphs, we can see that there is a clear difference in amplitude between the three graphs. We can easily differentiate between the silence of the structure's curve, the first flow rate water's curve, and the second one.
We remark that results using a flexible PVDF sensor over the metallic pipe are better than using aceramic sensor and this is due to the flexibility of the polymer.
Since, PVDF is a flexible polymer; it can have the same shape of the structure, in which it was connected. So that, when we glued it on the pipe's surface, it took its form.
These results show that the water flow has remarkable activity in the region between 100 Hz and 2000 Hz.
It also shows that the PVDF sensor has a greater sensitivity than the PZT one.
This sensitivity is due to the flexibility of the PVDF sensor, which can take the same form of the pipe.

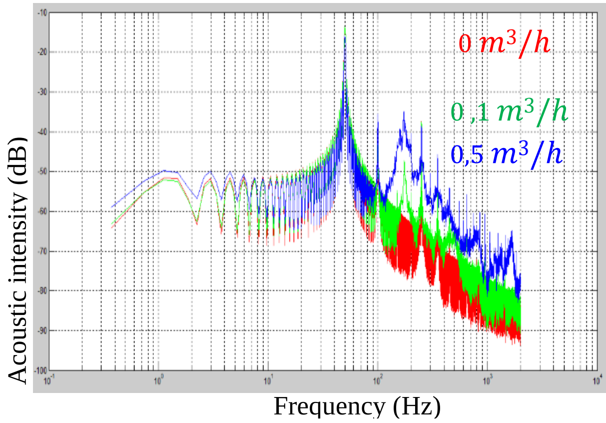


Figure 4: Acoustic intensity for the metallic pipe using PVDF sensor.

4. CONCLUSION

The results for PZT and PVDF sensors for water leakage detection in metallic pipes show good sensitivity of both types of sensors to the variation of flow in a metallic pipe. PVDF sensors show better sensitivity than PZT sensors mostly because of their flexibility. A work in progress will also allowtaking into account the distance of the source i.e. the acoustic attenuation of the guided waves in the duct. The extension of this study will also be to testthese sensors on plastic ducts, material more and more used in this type of application.

5. REFERENCES

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