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Crack and Leakage Detection on Steam Pipelines using Acoustic Technique

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Abstract: In this study, a non-destructive technique namely acoustic technique is performed to detect leakage and cracks on building pipelines. It is performed using AQUA M300D leak detector. The leakage is detected by analyzing the feedback frequency, where leakage area produced higher frequency due to the vibration resulting from a high pressure liquid that flows through the crevice. The method successfully detected steam pipelines system leakage with high level of accuracy.

Index Terms: Acoustic, crack, leakage, non-destructive technique, pipeline.

I. INTRODUCTION

Pipeline is important to carry water, gas, and fuel source to fulfil human's basic needs. Maintaining the system would cost millions of ringgit every year. Therefore, many researches were conducted to improve the monitoring system of piping including acoustic equipment, noise loggers, leak noise correlators, trace gas technique, thermography, and ground-penetrating radar [1]. Acoustic wave is chosen because it is competitively priced, inherently rugged, very sensitive, intrinsically reliable, and can be interrogated passively and wirelessly. Wireless sensors are beneficial when monitoring parameters on moving objects, such as different diameter of pipe and type of pipes. The sensors require no operating power which is highly desirable for remote monitoring of chemical vapors, moisture, and temperature. Fracture and cracks can be detected because the extension of plastic zone around crack tips produces acoustic emissions [2]. The study will cover detection of pipeline cracks and leakage on direct and indirect surface of hot pipes and effect of diameter pipe on the results. The related works in [1]-[23].

II. METHODOLOGY

A. Instrumentation

Fig. 1 shows the AQUA M300 D, a multi-purpose detector designed to allow the user to carry out electro acoustic leak detection on pipe systems carrying water, acoustic leak detection on pipes, and to perform non-destructive pinpoint leak detection on pipes which have previously been flooded with trace gas using the indicative measurement of different hydrogen concentrations.

Fig. 1: Acoustic Detector AQUA M300 D

B. Experimental Procedure

Hotpipe system is designed using Inventor Software as shown in Fig. 2. Meanwhile, Fig. 3 shows the real system set up.

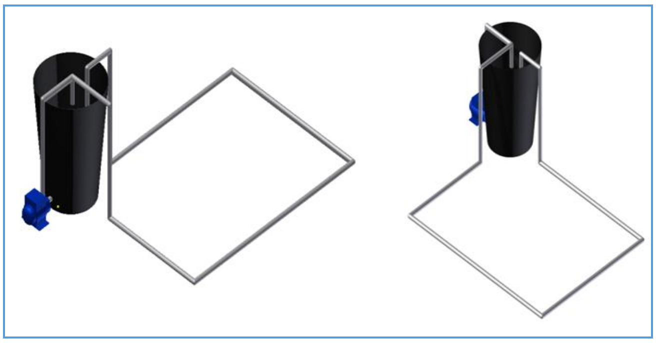

Fig. 2: 3D model of hot pipe design

Fig. 3: The actual system apparatus built

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Acoustic Detector AQUA M300 D is used to record frequency readings at the possible leakage locations of three parameters investigated which are pipe diameters, temperatures and different height.

III. RESULTS AND DISCUSSION

A. Case 1: Different Pipe Diameters

For this study, Aqua M300D is used to read frequency readings for normal pipe as shown in Fig. 4 of different diameters at a constant temperature. Three different pipe diameters were investigated with size of 25 mm, 40 mm, and 50 mm which is marked as point 1, 2, and 3 respectively. Table 1 shows readings for normal pipe. In general, smaller pipe diameter produces higher frequency reading. This is resulted from internal vibrators from a larger diameter have higher amplitude with lower frequency whereas for smaller diameter, it emits lower amplitude with higher frequency. Hot water gives energy to the water molecule to vibrate more compared to normal water temperature.

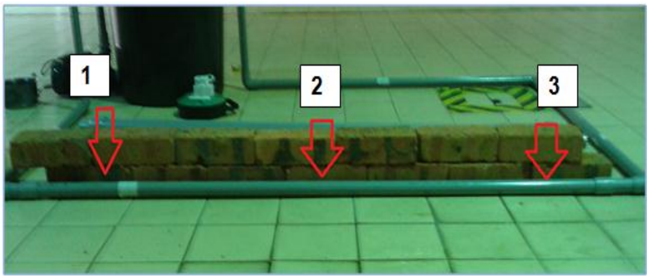

Fig. 4: Normal pipe

Table 1: Frequency readings for normal pipe

Pipe Diameter (mm)	Noise Amplitude Reading Temperature ≈ 100°C		
	Point 1	Point 2	Point 3
25	64 (150 Hz 350, 25)	64 (150 Hz 350, 25)	64 (150 Hz 350, 25)
40	52 (0 Hz 250, 13)	52 (0 Hz 250, 13)	52 (0 Hz 250, 13)
50	39 (150 Hz 350, 12)	39 (150 Hz 350, 12)	39 (150 Hz 350, 12)

Fig. 5 displays image of leaked pipe and the leakage point. Meanwhile Table 2 shows frequency readings for the pipe. Based on the results, readings at point 3 show the highest for all pipe diameters compared to the others. It shows that leakage occurred at this point. Meanwhile, readings for pipe diameter of 25 mm are higher compared to 40 mm and 50 mm. this is because smaller pipe diameter produces higher pressure thus increasing its frequency. The largest diameter, which is 50 mm gave the lowest frequency, however it was high where leakage occurred.

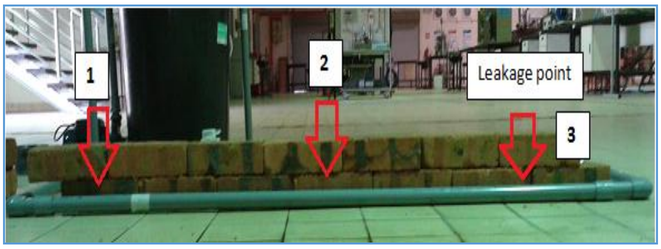

Fig. 5: Leaked pipe and the leakage point

Table 2: Frequency readings for leaked pipe

Pipe Diameter (mm)	Noise Amplitude Reading Temperature ≈ 100°C		
	Point 1	Point 2	Point 3
25	64 (150 Hz 350, 25)	80 (150 Hz 350, 28)	99 (150 Hz 325, 51)
40	53 (150 Hz 350, 37)	68 (0 Hz 250, 18)	99 (150 Hz 325, 51)
50	39 (150 Hz 350, 12)	64 (150 Hz 350, 25)	99 (150 Hz 325, 51)

B. Case 2: Different Temperatures

Frequency readings for normal and leaked pipe were taken for three different diameters which were also 25 mm, 40 mm, and 50 mm at different temperatures. For this study, the reading is taken at only one point for each diameter and temperature as displayed in Fig. 6. The temperature is detected by Picolog reader. Table 3-5 show results for effect of temperature for 25 mm, 40 mm, and 50 mm pipe diameters respectively. Based on these findings, frequency readings increased when temperature increased. This is because water molecule gained more energy and causing it to move rapidly with increasing temperature.

Fig. 6: One pinpoint reading is taken

Table 3: Temperature readings for 25 mm pipe diameter

Temperature (°C)	Reading
PLW Recorder – File Settings View Help – Awaiting data filename – Use File | New data – Channel 2 30.36 °C	35 (150 Hz 375)

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Channel 2 61.83 °C	40
Channel 2 79.89 °C	46
Channel 2 89.11 °C	53
Channel 2 99.49 °C	55

Table 4: Temperature readings for 40 mm pipe diameter

Temperature (^oC)	Reading
Channel 2 29.64 °C	40
Channel 2 60.19 °C	46
Channel 2 78.30 °C	57
Channel 2 90.60 °C	60
Channel 2 99.49 °C	64

Table 5: Temperature readings for 50 mm pipe diameter

Temperature (^oC)	Reading
Channel 2 30.49 °C	28
Channel 2 61.22 °C	31
Channel 2 80.32 °C	35
Channel 2 91.29 °C	40
Channel 2 99.49 °C	41

Summary of the results is recorded in a graph shown in Fig. 7. Same pattern of graph was achieved when all of the results from different temperatures for different pipe diameters are compared.

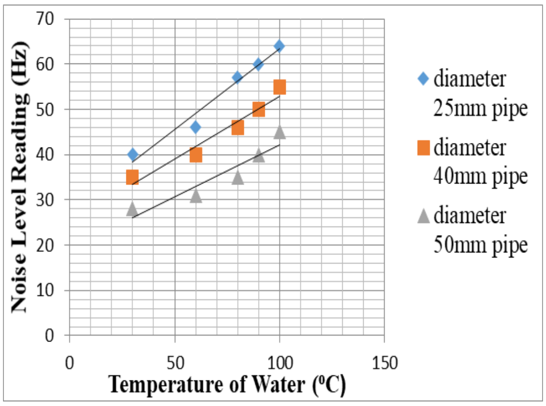

Fig. 7: Graph of noise level reading vs water temperature

C. Case 3: Different Height from Pipes

Different height is investigated to determine its noise level. Bricks are used to make a height from pipelines to the microphone point. Temperature and pipe diameters are constant. The temperature is set at 80ºC and sensitivity of microphone is 35%. Table 6 shows the total height of bricks used. Meanwhile, Table 7 displays the result from the investigation. It is found that noise level decreased when total height increased for normal pipe and leaked pipe. However, the readings for leaked pipe are higher than that of normal pipes.

Table 6: The total height of bricks

Total Bricks	Total Height (cm)
1	6.5
2	13
3	19.5
4	26
5	32.5

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Table 7: Readings for effect of height for normal and leaked pipe

No. of Bricks	Reading for Normal Pipe	Reading for Leaked Pipe
		
		
		
		
		

D. Calculations on Crack

In order to investigate whether the crack occurs in accordance of fracture calculation, one should calculate whether the operating stress could be responsible of crack or leakage. To calculate the time of the pipe start to crack, hoop stress need to be determined first. In this case, thin walled cylinder equation must be applied to determine the maximum stress on the pipe wall. The pipe sample is shown in Table 8.

Table 8: Sample pipe parameters

Parameters	Value
Pressure (ρ)	4.3 MPa
Radius (r)	50 mm
Thickness (t)	3 mm

Calculation of hoop stress:

$$\sigma_h = \frac{pr}{t}$$

$$\sigma h = \frac{(4.3)(50)}{3}$$

$$\sigma h = 71.68\ MPa$$

Calculation of meridian stress:

$$\sigma_m = \frac{pr}{2t}$$

$$\sigma m = \frac{(4.3)(50)}{2(3)}$$

$$\sigma m = 35.84\ MPa$$

From the calculations, the value of hoop stress is chosen as operating stress. It is chosen because the value of the stress is the maximum stress experienced by the pipe wall. From this operating stress, the stress state near the crack tip can be accurately. Thus, Paris's Law is applied to get the stress intensity factor, K.

$$K = Y\sigma\sqrt{\pi a}$$

where

$K = stress\ intensity\ factor$

$Y = geometric\ factor$

$\sigma = operating\ stress\ = in\ this\ \sigma taken\ from\ \sigma hoop = \sigma max$

$a = crack\ length$

Y = in this shape of crack, 1.12 is taken for the value of geometry factor

Y = 1.12 as in reference stress intensity factor handbook [3]

$$K = Y\sigma\sqrt{\pi a}$$

$$K = 1.12(71.68)\sqrt{\pi(0.001)}$$

$$K = 4.5 MPa\sqrt{m}$$

$$Kic\ for\ polyvinyl\ chloride\ pipe\ class\ is\ 2 - 4\ MPa\sqrt{mm}$$

Value of K_{ic} is referred from [4]. So,

$$K > Kic = crack\ is\ propagating$$

It is theoretically proven that the pipe in this study is undergoing pressure that leads to crack. Crack is theoretically proven propagate on pipe by applied Paris Law's equation. Therefore, it is confirming the pressure somewhat exceed of fracture toughness of the pipe materials.

IV. CONCLUSION

Detection method for leakage using hot PVC pipe was investigated using acoustic device, Aqua M300D. It was found that PVC pipe produced lower noise when analysed using the detector. Furthermore, for various type of loudness that can be detected from different between indirect and direct method ultrasonic non-destructive testing, the results obtained are as follows.

i. Sound velocity/pulse transit time: The speed of sound is directly related to both elastic modulus and density, thus changes in either elasticity or density will affect pulse transit time through a sample of a given thickness.

ii. Attenuation: Sound energy is absorbed or attenuated at different rates in different materials, governed in a complex fashion by interactive effects of density

iii. Frequency (Spectrum) content: Analysis of changes in the frequency that has passed through the test material can track the combined effects of attenuation and scattering as described above.

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