UNIVERSITI PUTRA MALAYSIA

DESIGN OF ULTRASONIC TRANSDUCER FOR LEAKAGE DETECTION ON PVC WATER PIPELINE

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By

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Nowadays most of the water pipelines for domestic and commercial areas are made from polyvinyl chloride (PVC). It has advantages such as lighter weight, higher flexibility to comply with ground quake and tremble, higher resistibility to corrosion as a result of climate and temperature changing, along with lower production and installation cost. However, it has less resistibility to endure pressures either from inside or outside the pipeline. Since these pipelines are not for valuable liquids such as petroleum, there is no particular monitoring system available for them yet. In many cases, leakage occurs for months or even years and they cannot be detected unless the leakage effect becomes significant. According to a study 10% of US water pipelines had water loss which estimated to cost around $4.3 billion per year. Almost the same percent of loss or even more is existing in European counties. Therefore having a simple and affordable monitoring system is necessary for natural resources conservation.

The conventional pipelines monitoring systems are commonly used to monitor long distance metallic petroleum pipelines and they are not reliable for monitoring the short distance PVC pipelines. This thesis discussed a non-invasive ultrasonic PVC pipelines monitoring system with modified V-topology. The proposed technique uses a pair of 40 KHz ultrasonic transducers with designed interface circuitries for emitting and receiving the signal. The designed interface circuits improved the emitted and received signal along with reduces of power consumption. The analysis carried includes signal fitness recognition and normalized cross-correlation that compared the transmitted and received signal. The developed system consumed 2.5W which can be supply from USB port. The proposed technique is for leak detection with power consumption around 2.5 watts, which can be supplied from universal serial bus or any available battery with more than 0.5 mA current injection. In wireless communication system is transmitting results of pipe monitoring in

conjunction with temperature and humidity to the center. This information is available in installed on board LCD and designed webpage through online access.

In comparison with available techniques, this ultrasonic monitoring is non-invasive to pipeline as there is no contact or involvement with it. Proposed method is designed to monitor physical condition of PVC pipelines and differentiate pipe with leakage from a healthy pipeline by use of air-coupled transducers. The system's operation has been tested on a general size PVC pipeline with 60 mm diameter for different size of orifices from 3 mm to 6 mm. As a result of experimental tests, system was able to detect orifices as small as 4.5 mm and greater accurately. System applied on pipeline with and without water and results proved that the pipe with very low pressure has very close trend to pipe without water. Occurrence of leakage in pipeline decreases the strength of received signal and increase of orifice tends to weakening it further. Operation tested for different location angles from 20 to 70 degrees and 60 degree was chosen as relatively high signal strength with recognition accuracy of 94.924% and covering area on pipeline near to 90 cm. Along with leak recognition, this research revealed that the smaller angle contributes to longer transducers distance and less accuracy. Then by increase of central frequency angles, accuracy of recognition reduced as well.

Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia sebagai memenuhi keperluan untuk ijazah Master Sains

DESIGN OF ULTRASONIC TRANSDUCER FOR LEAKAGE DETECTION ON PVC WATER PIPELINE

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Pada masa kini kebanyakan saluran paip air di kawasan-kawasan domestik dan komersial adalah diperbuat daripada polivinil klorida (PVC). Ia mempunyai banyak kelebihan seperti lebih ringan, fleksibiliti yang tinggi jika berlakunya sebarang gempa bumi dan gegaran dan mempunyai daya ketahanan yang tinggi terhadap kakisan akibat iklim dan suhu yang berubah-ubah, selain daripada mempunyai kos pengeluaran dan pemasangan yang lebih rendah. Walau bagaimanapun, ia mempunyai daya ketahanan yang rendah untuk menahan tekanan sama ada dari dalam ataupun di luar saluran paip. Oleh kerana saluran paip ini bukanlah untuk sesuatu cecair yang bernilai seperti petroleum, jadi tiadalah lagi sistem pemantauan khusus yang dihasilkan. Dalam kebanyakan kes, kebocoran paip yang berlaku tidak dapat dikesan selama beberapa bulan mahupun bertahun-tahun sehinggakan ianya mendatangkan kesan yang buruk. Menurut satu kajian, saluran paip air di Amerika Syarikat dikatakan mengalami kehilangan air sebanyak 10% yang mana dianggarkan bernilai kira-kira $ 4300000000 setahun. Negara-negara Eropah yang lain juga mengalami situasi yang sama atau mungkin lebih teruk. Oleh itu ianya amatlah penting untuk kita mempunyai sistem pemantauan saluran air yang ringkas dan berpatutan bagi memelihara dan memulihara kesejahteraan alam semulajadi.

Sistem pemantauan saluran paip konvensional biasanya digunakan untuk memantau saluran paip petroleum logam jarak jauh dan ianya tidak dapat digunakan untuk memantau saluran paip PVC jarak dekat. Tesis ini membincangkan mengenai sistem pemantauan saluran paip air PVC ultrasonik bukan invasif yang diubahsuai dengan V-topologi. Teknik yang dicadangkan adalah dengan menggunakan sepasang 40 kHz transduser ultrasonik berlitar yang direka khas untuk memancarkan dan menerima isyarat. Litar yang direka meningkatkan pemancaran dan penerimaan isyarat selain mengurangkan penggunaan kuasa. Analisis yang dijalankan termasuklah untuk

mengenalpasti kecekapan dan keberkesanan isyarat dan menormalkan korelasi silang yang membandingkan isyarat yang dihantar dan diterima. Sistem yang telah sedia ada menggunakan 2.5W yang mana boleh didapati dari port USB. Manakala teknik yang dicadangkan untuk mengesan kebocoran adalah dengan penggunaan kuasa sekitar 2.5 watt, yang boleh didapati dari USB atau mana-mana bateri terpakai sedia ada dengan kuasa lebih daripada 0.5 mA. Sama seperti di dalam aplikasi sistem komunikasi tanpa wayar, system ini juga menghantar hasil pemantauan paip berserta dengan tahap suhu dan kelembapan tertentu ke pusat. Maklumat ini boleh didapati di dalam perisian papan LCD dan akses atas talian melalui laman web yang direka.

Berbandingan dengan teknik yang sedia ada, pemantauan ultrasonik ini adalah tidak invasif untuk saluran paip kerana tidak ada hubungan atau penglibatan dengannya. Kaedah yang dicadangkan, direka dengan memantau keadaan fizikal paip PVC dan paip-paip yang berbeza, yang dalam berkeadaan baik dan elok dengan kebocoran, menggunakan sepasang transduser berhawa. Operasi sistem telah diuji pada saiz am saluran paip PVC berdiameter 60 mm pada saiz lubang yang berbeza iaitu dari 3 mm hingga 6 mm. Hasil daripada ujian experimen, sistem berkebolehan untuk mengesan lubang sekecil 4.5 mm dengan ketepatan yang sangat tinggi. Sistem ini diaplikasikan pada saluran paip dengan air dan tanpa air dan keputusan menunjukkan bahawa paip dengan tekanan yang amat rendah mempunyai kebarangkalian yang tinggi yang mana paip tidak akan mengalirkan air. Kebocoran yang berlaku kepada saluran paip mengurangkan kekuatan isyarat yang diterima dan semakin besar kebocoran tersebut maka semakin lemahlah isyarat yang diterima. Operasi juga diuji untuk sudut lokasi yang berbeza di antara 20-70 darjah dan ianya telah terbukti iaitu pada kedudukan 60 darjah, kekuatan isyarat adalah yang tertinggi dengan ketepatan dikesan pada 94,924% dan ianya meliputi kawasan sejauh 90 cm. Di samping dapat mengesan kebocoran, kajian ini juga mendedahkan bahawa semakin kecil sudut, semakin jauh jarak transduser dan semakin kurang ketepatan. Kemudian, dengan peningkatan frekuensi sudut pusat, keberkesanan ketepatan juga berkurangan.

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APPROVAL

I certify that a Thesis Examination Committee has met on (8/7/2014) to conduct the final examination of (Mohammad Kazem Chamran) on his thesis entitled "Design Of Ultrasonic Transducer For Leakage Detection On PVC Water Pipeline" in accordance with the Universities and University Colleges Act 1971 and the Constitution of the Universiti Putra Malaysia [P.U.(A) 106] 15 March 1998. The Committee recommends that the student be awarded the Master of Science.

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LIST OF ABBREVIATIONS

PVC	Polly Vinyl Chloride
AC	Alternate Current
BJT	Bipolar Junction Transistor
DC	Direct Current
F_C	Center frequency
FFT	Fast Fourier Transform
Mb/s	Mega bit per second
MC	Microcontroller
mm	millimeter
MOSFET	Metal Oxide Semi-conductor Field Effect Transistor
m	meter
ms	millisecond
NCC	Normalized Cross Correlation
LED	Light Emitted Diode
Cm	Centimeter
Hz	Hertz (unit of frequency)
IC	Integrated Circuit
PSD	Power Spectral Density
STFT	Short-Time Fourier Transform
TCP	Transmission Control Protocol
UDP	User Diagram Protocol
USB	Universal
QF	Quality fact

CHAPTER 1

INTRODUCTION

1.1 Introduction

The world population is growing very rapidly today. According to the United Nation, the earth population was less than 1 billion by 1804 and it took 123 years to reach to 2 billion, but 33 years to reach to 3 billion in 1960, only 14 years to reach to 4 billion, 13 years to reach to 5 billion in 1987 and statistics shows that it will further reach to 8 billion by the year 2028 [1], [2]. This goes to show that the increase population of human necessitates new foundation and constructions regularly to provide shelter and proper facilities for sustainable lifestyle. Since human body needs food besides oxygen and water, all these facilities and constructions are constantly in exchange of materials. New and fresh materials need to be replenished regularly and used ones need to be removed. These input and output of materials are handled by establishments provided. As for ventilation, there always has to be some facilities which bring fresh air and adjust temperature to a comfortable level. From the other side, all facilities are equipped to provide clean water for drinking, washing, fuels or other usage. At the same time, used water and wastage need to be processed out. This operation has to be done in the safest way possible without any interruption; otherwise the residents will face some serious problems. It is difficult to live a day without having any water. All these tasks are done through pipelines. Therefore pipelines in structures resemble the blood vessels in the human body.

There are many threats to the pipeline but they can mainly be categorized in four classes: operational, unintended damages, intended damages and structural [3]. Operational problems can happen as a result of equipment failure due to aging. Unintended damage is constituted by those incidents which are normally caused by workers as they perform their tasks in the vicinity of the pipeline. Intended damage can be the result of sabotage, theft or terrorist attack. Structural problems can take place as a result of corrosion, collapse, fracture, fatigue or buckling. However pipeline safety is always one of the concerns of various countries while leakage may lead to great economic loss. Leakage, if combined with environmental pollution and risk of workers (personnel) can lead to even greater problem [4]. Most of the time, leaks are invisible during the life of a large pipeline, the early time detection of leak and if possible the precise location giving time a safe shutdown and a quick dispatch of repair crew to minimize the consequence. A leak detection system that reduces the spill, duration of shutdown and casualties can usually pay for itself. Therefore, the development of a reliable leak detect system is important in the operation and further in the design of a high capacity pipeline [5]. According to a study in the United States, it is estimated that 7,000 Km of pipes are required for replacement each year which cost around $2.7 billion while water losses are estimated to be 10% which cost around $4.3 billion per year [6]. Countries such as France, England and Italy have reported that they have water losses in the range of 20-30% [7].

A leak detection system is commonly classified into two categories: internal leak detection system and external leak detection system. Internal leak detection systems are normally divided into three subgroups: volume and/or mass balance methods, wave

monitoring or pressure analysis and transient modeling in real time. External leak detection methods consist of the acquisition and sensors that are located outside the pipeline and they can be wired or wireless. The wired operation can comprise of optical, dielectric, chromatographic, sniffers, etc. wireless systems can comprise of a network which consists of nodes that are communicating with each other and which transfers the information about the condition of pipeline to the base center [8], [9], [10].

The advantage of the external monitoring systems is that they are mostly non-invasive to the pipeline as long as they do not demand change or interruption in the flow operation. In this thesis, an external monitoring method is proposed which has no invasion over pipeline. This non-invasive proposed method consists of an external transmitter and receiver which monitor the physical condition of the pipeline regardless of the liquids or materials that are flowing inside it. Neither materials inside nor sensors outside have any affect each other and as a result, they both are kept safer. The echo signal from pipeline would be sent wirelessly to the center and further analysis such as Fidelity and Normalized Cross Correlation (NCC) would be done to have a correct understanding of what is happening in the pipeline. The system consists of two methods for analyzing the received signal. One is for the stand-alone operation in which the system decides whether to turn the alarm on or otherwise. This method is based on the adjusted threshold. The other method is software monitoring whereby pure results are sent to the center and all filtering, comparing and final analyzing are done by software to reach to a conclusion whether pipes are working as normal or a change has taken place.

1.2 Background of study

There are many proposed procedures and techniques to detect leaking in pipelines and localize them between nodes in case of incident, but many of them are very time-consuming, expensive and/or require human involvement. Traditional leak detection methods are mostly dependent on periodical inspection conducted by maintenance personnel. This periodical inspection does not provide any real time monitoring and as a result, a leak may not be detected at the time of incident and cause greater economic loss and environmental pollution [11].

One of the systems that have been used is the optic sensing and consists of a single optical fiber that is sensitive in all its length distances. It is a secure method as the monitoring center is able to have a complete observation over the entire length of the pipeline [12]. This sensing operation method requires fiber optic installation attached to the whole pipe, which makes the system expensive while the system itself can face faulty error, due to aging and unwanted disconnection as a result of pipe vibration or movement. The other issue can be the change of temperature between day and night that makes the system vulnerable. However, this method is unable to indicate the corrosion and a prediction of possible leak occurrence. These disadvantages are the same for similar systems such as optical fiber thermometry [13], [14].

The other systems that are commonly used by pipeline constructors are mass balance, pressure and flow measurement. Mass balance operation is based on the rate of change between inlet and outlet, is simple and cheap but it cannot monitor the corrosion along the pipeline and is not easy to locate the leaking. Usually it needs to look at the distance

between two valves where the leaking takes place. For pressure and flow measurement, the data from past operation are needed to compare statistically the trend of the system [15]. Understanding the behavior of the system is helping to recognize the false alarm from that of real leak [11], [16], [17]. However, the false alarm may happen as a result of blocking, roughness inside the pipe, temperature change and density of the fluid.

In recent years, new methods are also deployed for pipeline monitoring such as magnetic induction which is based on applying the relay coil along the pipeline, one as a transmitter and the other one at the other side as the receiver. Relay coil induces waves along the pipe through the soil. To increase the accuracy of the system and make more reliable demands more deployment of coil which increases the price of the system but helps to improve the localization of leak. It is possible to increase the distance between relay coils which can lead to weaker magnetic field and increased false alarm. In properly adjusted distance between relay coils system can detect the leak with low percentage of error if the price of installation is ignored [11], [18].

In many of the systems mentioned above after the confirmation of leak incident, a mobile ultrasonic sensor is used to find the accurate location and start to roam. This device is carried by a person who needs to listen to the received signal by a headphone or can be identified by LED blinking. Based on the speed of LED blinks, the user can recognize if a leak is occurred. In a more advanced system, the analysis and recognition can be done by the computer through signal analysis. In short words should mention that there are many researches done to develop a system to detect leak incident more accurately and in between the concept of detection by ultrasound seems to be a suitable option but more researches in this field is required.

1.3 Problem statement

There are many pipeline monitoring systems available but mostly they are for long range pipes and they still have to meet the challenges to gain better accuracy and localization. They are used for transferring crude oil, gas, water, chemical materials, wastage, etc between refineries, factories, cities, and countries and overall for long distances. However, long-range pipe lines are regularly under the monitoring systems and they have a consistent periodical investigation as they are important for countries but even monitoring system of those pipelines are not totally save, mostly invasive and not very accurate [11], [12], [16], [18], [19], [20], [21]. On the other hand, short pipelines are left behind as they are mostly carrying water or wastage for homes and public places inside the cities. However, the current monitoring is based on water flows (including fluid velocity) [19], pressure monitoring, air tube detection [13] and valves mass balance [11], [15] which not able to localize in case of leak incidents [10] and they can face false alarms with change in the fluid velocity and pressure. Therefore a system that can only monitor the physical condition of pipeline regardless of pressure changes, temperature changes, type of fluid and velocity of flow is needed.

Another problem with the current acoustic leak finders is that they are mainly developed to detect leaks in metallic pipelines and mostly invasive. They are not effective on plastic pipes like PVC. The problem with plastic pipes is that they are absorbing some percentage of emitted signals as a result they are quieter and not reflecting the signal as efficiently as metal material [22].

It is seen that in many occurrences, personnel have to dig a long area to find out the exact location of leakage. In cases of many constructions and buildings (including condominiums, office towers and buildings, hospitals, shopping centers) there needs to be a constant applicable monitoring system for existing pipelines to monitor operation. Applied system must be non-invasive to the pipe and not interrupting operation in case of sensor or device failure.

The problems that mentioned in this section can summarize that between available ultrasonic monitoring systems:

- Existing leakage detection system cannot be used for permanently monitoring the short pipelines.
- False alarm is still a challenging problem for current systems.
- The current systems are mostly invasive to pipelines.
- Most of the systems are not designed for PVC but metallic pipelines.

1.4 Objectives of study

In this project, the aim is to design and fabricate a non-invasive system based on modified V topology which capable to monitors the short range PVC water pipeline without interrupting the operation of flow and lowest rate of false alarm. The main objectives of this research are:

1. To design the ultrasonic leak detector based on modified V-type topology.
2. To design the interfacing circuitry for optimum performance and power consumption in range of (20 to 70) degrees.
3. To implement the design and evaluate the fabricated leakage monitoring system.

To have a proper design in each step, it demands an understanding of ultrasonic behaviors. These behaviors consist of observe emitted signals from transmitter, monitor behavior of reflection and detect the echo signals in the receiver. The milestone of this part lies in the fact that the echo detector is not directly located in front of the receiver but it is getting periodical reflection from pipeline which needs to be delayed for some milliseconds and locate in accurate degree symmetrical from transmitter to avoid reverberation. This reflected signal can change depends on the size, environment, and material of the pipeline. Therefore it is a variable with much dependency and needs to be adjusted as much as possible.

1.5 Scope of the work

This thesis dwells into the communication between an emitter as signal generator and an echo detector as receiver in ultrasonic modulation frequency. The received signal indicating the condition of the pipeline and would then be sent to the microcontroller to observe the changes and compare the results with original transmitted signal. Proposed method is limited to testing for a pair of transducer only to get signal results of reflected echo from PVC pipeline with the diameter of 60 mm and to find out whether it is healthy or a leak is occurred. The system can use an acquisition card for the communication between the microcontroller to the computer. Data acquisition can be the GPIB card or DAQ card or any similar available standard depending on the demand of the project.

1.6 Contribution

In general, ultrasonic leak detection systems can be categorized into four groups:

1. The device that can be carried to a susceptible area by personnel [22] and [23]: It is not applicable permanently but the proposed method would be located for a permanent monitoring.

2. Ultrasonic sensors that are locating inside the pipeline [24]: they are not applicable for current pipelines without being replaced by new one but proposed method in this thesis is monitoring pipelines from out of pipe and applicable for current pipelines.

3. Ultrasound sensors are attached outside of the pipeline [20], [25], [26], [19]: Such detection systems are more common and still being using for long range metallic pipeline. This type of ultrasonic leak detection also hazardous to the pipeline as required drilling, or bonding sensors to pipeline to make sure there is no gap between the pipe and sensors but proposed method has no contact to pipeline and it is not invasive.

4. Ultrasound sensors are located outside the pipeline and not attached [27]: this type of monitoring is proposed for detecting gas leak in metallic pipelines only but proposed method in this thesis is usable for available PVC pipelines with water as their medium.

In proposed method in this project beside afford of generalizing a method for available current pipelines it has been tried to redesign all parts of echo detector including amplifier, band pass filter and comparator the way that have a power consumption as low as possible. The system is working in conjunction with other sensors such as temperature and humidity to reduce probability of false alarm as much as possible. The whole communication between transducers, x-bee wireless, internet shield communication and microcontroller operation is done with a single 5V power supply which can be received from a laptop universal serial bus (USB) slot [28] or a 5V battery. The system is able to have a stand-alone operation and decide without user interference. However this method is never being used for pipeline monitoring and this is the first testing of its kind.

1.7 Organization of thesis

In this thesis it is attempted to cover details of other related current projects and method of some of the close supervisory systems. Thus a different methodology is used but in some cases, the type of applied sensor and frequency may be the same. Therefore an overview of the latest proposed methods and available systems is presented in second chapter (literature review).

In chapter 3, the methodology of whole system is presented in detail, including all parts with their simulated outputs. These simulated procedures help to have an idea on how parts are designed and more predictable results can be expected.

In chapter 4, is attempted to step beyond the simulation results and operation is being observed in practice. It is very possible that researches based on simulation only lead to results different from real world outcome. Many component values such as transistors, resistors and capacitors have tolerance of accuracy which by use variety number of

them may lead to an unexpected results as well as environment character changes like temperature, humidity, noise, pollution, and etc. therefore results of real fabricated circuits are presented in this chapter and discussed.

In chapter 5, we will offer our conclusion and some future work suggestions to improve this system further, in the sense that the system be more accurate in real applications.

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