DESIGN AND DEVELOPMENT OF FLUID DENSITY DETERMINATION BASED ON PIEZOELECTRIC COUPLING SENSORS

WENDY SER ZE XIAN

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

DESIGN AND DEVELOPMENT OF FLUID DENSITY DETERMINATION BASED ON PIEZOELECTRIC COUPLING SENSORS

WENDY SER ZE XIAN

This Report is Submitted in Partial Fulfilment of Requirements for the Bachelor Degree of Electronic Engineering (Industrial Electronic) with Honours

Fakulti Kejuruteraan Electronic dan Kejuruteraan Computer
Universiti Teknikal Malaysia Melaka

June 2017

UNIVERSTI TEKNIKAL MALAYSIA MELAKA
FAKULTI KEJURUTERAAN ELEKTRONIK DAN KEJURUTERAAN KOMPUTER

BORANG PENGESAHAN STATUS LAPORAN
PROJEK SARJANA MUDA II

Tajuk Projek : Design and Development of Fluid Density Determination based on Piezoelectric Coupling Sensors

Sesi Pengajian : 1 6 / 1 7

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Disahkan oleh:

xian.
(TANDATANGAN PENULIS)

PROF. MADYA DR. KOK SWEE LEONG
Profesor Madya
Fakulti Kejuruteraan Elektronik Dan Kejuruteraan Komputer
Universiti Teknikal Malaysia Melaka (UTeM)
Hang Tuah Jaya
76100 Durian Tunggal, Melaka
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Signature :

Supervisor's Name: PM Dr Kok Swee Leong

Date : 30th May 2017

To my beloved project supervisor, family, and friends

ACKNOWLEDGEMENT

It is my pleasure to thank those who helped me and made this thesis possible. First, I would like to express my sincere gratitude to my supervisor, Assoc. Prof. Kok Swee Leong for his guidance and assistance throughout this project period and spent his time looking for the possible problems and clarifying my doubts. The thesis would not have been completed without his valuable guidance and advice.

Secondly, I would like to thank the lab technician for helping me in fabricating circuit and arranging all the facilities. Without them help, the project would not be accomplished on time and successfully.

Thirdly, I thank all my friends that gave me the encouragement to accomplish this project. Besides that, they also give me some comments and advice for this project. The comments and advice provided on the prototype made its improvement a success. Lastly, I would like to thank my parents for giving me moral support throughout my studies.

ABSTRACT

In every industry, waste-water treatment is used to remove pollutants and contaminant to reduce the impact toward the environment. Various types of sensors are used to adjust the operating system of waste-water treatment plant by measuring water flow, water pressure, water level and water quality. However, manual monitoring still involves laboratory testing for controlling water quality in the waste-water treatment process, which is not portable and involving bulky machine. Hence, a new method should be implemented to minimize the manual monitoring in waste-water treatment which can detect the density of fluid that influenced by the contaminant. For this project, the piezoelectric coupling device is being used as an actuator and a sensor to determine the changes of the density of fluid due to the contaminant. The tested sample is in the liquid state and it needs to be contained in a designated chamber for it to be measurable. The chamber is being designed in such a way that the fluid can flow in and out for the experiment. The signal that produced from the piezoelectric sensor will be amplified and filtered before it is being analyzed. It was found that the operating frequency to detect varying density is between 1 kHz to 2 kHz. In the experiment set-up, the piezoelectric coupling device is placed in parallel and the chamber is located between the piezoelectric actuator and sensor. The piezoelectric actuator converts the electrical energy to produce an acoustic wave which propagates through the liquid in the chamber. The piezoelectric sensor picks up the acoustic wave and converts the signal into electrical signal. The density of the fluid affects the speed of propagation of the acoustic wave, therefore, the resonance frequency is inverse proportional to the density. From the experimental result, tap water with density 1.016 (g/ml) has a resonance of 1460 Hz compared to higher density fluid of sugar water with the density of 1.024 (g/ml) has a resonance of 1440 Hz.

ABSTRAK

Dalam sektor perindustrian, rawatan sisa air digunakan untuk membuang bahan pencemaran dan mengurangkan kesan yang negatif pada persekitaran. Pelbagai jenis penderia digunakan untuk melaraskan sistem operasi loji rawatan sisa air dengan mengukur aliran air, tekanan air, paras air dan kualiti air. Walau bagaimanapun, pemantauan manual yang melibatkan ujian makmal yang tidak mudah dibawa dan menggunakan mesin yang besar masih terlibat dalam proses rawatan sisa air untuk mengawal kualiti air. Oleh itu, satu kaedah baru perlu dilaksanakan untuk mengurangkan pemantauan manual dalam rawatan air kumbahan dengan cara yang dapat mengesan kepadatan cecair yang dipengaruhi oleh bahan pencemaran. Dalam projek ini, piezoelektrik digunakan sebagai transducer dan penderia untuk menentukan perubahan kepadatan cecair yang dipengaruhi oleh bahan pencemaran. Sampel yang diuji adalah dalam keadaan cecair dan ia perlu dikandung dalam kebuk yang ditetapkan untuk dapat diukur. Kebuk itu direka dengan tempat masuk dan keluar untuk pengaliran cecair. Isyarat yang dihasilkan oleh penderia piezoelektrik akan dikuatkan dan ditapis sebelum ia dianalisis. Ia telah didapati bahawa frekuensi operasi untuk mengesan kepadatan yang berbeza-beza daripada 1 kHz sampai 2 kHz. Dalam ujukaji, transducer piezoelektrik diletakkan secara selari dan kebuk diletak di antara transducer dan penderia piezoelektrik. Transducer piezoelektrik menukarkan tenaga elektrik untuk menghasilkan gelombang akustik yang membiak melalui cecair di dalam kebuk itu. Penderia piezoelektrik memungut gelombang akustik dan menukarkan isyarat tersebut kepada isyarat elektrik. Kepadatan cecair memberi kesan kepada kelajuan penyebaran gelombang akustik, oleh itu, frekuensi resonans adalah songsang berkadar dengan kepadatan cecair. Daripada hasil eksperimen, air paip mempunyai resonans 1460 Hz dengan kepadatan yang 1.016 (g/ml) berbanding dengan kepadatan yang lebih tinggi, air yang mengandungi gula mempunyai resonans 1440 Hz dengan kepadatan yang 1.024 (g/ml).

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LIST OF ABBREVIATIONS

BAW	-	Bulk Acoustic Wave
SAW	-	Surface Acoustic Wave
PAW	-	Plate Acoustic Wave
SNR	-	Signal-to-Noise Ratio
DC	-	Direct Current
AC	-	Alternating Current
PCB	-	Printed Circuit Board

CHAPTER I

INTRODUCTION

1.1 Overview

This chapter is all about the introduction of this project and initiative to start this project. In the first session of this chapter, the reason for starting this project is explained. In this project, the objective is providing the solution for the mentioned problem in the session of the problem statement. Moreover, the constraints of this project are listed out as the scope of work. The structure of the thesis is explained in the session of thesis organization.

1.2 Background

Waste-water treatment is a process to remove pollutants and contaminant and make the water clear. Several types of sensors are used to adjust the operating system of waste-water treatment plant by measuring water flow, water pressure, water level and water quality. However, manual monitoring still involves conducting the laboratory testing for controlling water quality in the wastewater treatment process. In such process, the testing is carried out as much as once per hour. Thus, a system of fluid density determination for wastewater treatment is developed. Containment in a liquid will affect the density of the liquid. The density of the liquid will be detected by using a pair of piezoelectric devices. One of the piezoelectric devices will act as an actuator to excite sinusoidal wave at various frequency and the other piezoelectric will receive the signal. The received signal will be amplified and filtered by using an amplifier and active filter. The frequency response signal varies with the density of the liquid. Same as the conductivity of the liquid, the density of the liquid can be used as an indicator of water quality. Therefore, the frequency response signal can be used to analyze and perform treatment accordingly.

1.3 Problem Statement

The density of the liquid can be influenced by the contaminant. However, it needs to be contained in a designed chamber in order it can be measurable.

For piezoelectric coupling device, the produced signal contains much noises due to its high sensitivity. In addition, the amplitude of the signal which produced from piezoelectric sensor is low. The data analysis process may have influenced by the noise and low amplitude of the signal.

Moreover, the frequency of pick up signal is varying. Since the frequency is varying, the range of the frequency is difficult to identify.

1.4 Objectives

The objective of this project is to fabricate a chamber for set up experiment. The second objective is to design the charge amplifier and higher order active high-pass filter circuit to overcome the problem of the signal that received from the piezoelectric sensor has small amplitude and to filter out unwanted signal. Lastly, the received signal from piezoelectric transducer used to analyze in comparison with the density of the fluid.

1.5 Scope of Project

The project uses piezoelectric ceramic with a dimension of 42mm as actuator and sensor. The designed size of the chamber is 160mm × 160mm ×5mm (Length × Width × Height). The height of 5mm is chosen due to the constraint of manufacturing.

The samples of fluids are tap water, water mixed with sugar and artificial concentrated mango juice which is easy to pump into the chamber and their density fall in the range of between 1 g/ml to 1.1 g/ml. The state of the liquid is in the static state due to the vibration that produced by water pump will influence the accuracy of the result.

1.6 Thesis Organization

The first chapter is an introduction which dictates the overview of this project. The problem statement discusses the problem that encountered in this project. The objective is to provide the solution for the problem that encounters during this project. Lastly, the limitation and the used apparatus are explained in the scope of work.

The second chapter is literature review which summarizes the findings of piezoelectric coupling devices and the theory of acoustic wave. The result from other research also included in this session.

The next chapter named as a methodology which consists of the procedure to complete this project. To achieve the objective of this project, the procedure consists of the design of chamber, experiment set-up, circuit designation and validity tests.

Next, the result and discussion part contains all the analysis result. The analysis result is presented in table and graph form. The relationship between resonance frequency and density of transmission medium is justified in this part after the collected data is analyzed.

The last chapter is the conclusion and future work which concludes the achievement of the project and recommendation for future research which is related to this study.

CHAPTER II

LITERATURE REVIEW

2.1 Overview

This chapter is discussed about the theory that is related to this project. The background and working principle of the piezoelectric device are summarized as the first session of this chapter. The next session consists of theory of acoustic wave. For the last session, the working principle of charge amplifier and the high-pass filter is included. The knowledge and information will be applied in the next chapter for implement the project

2.2 Piezoelectricity

The history of piezoelectricity evolution is over 120 years which was discovered by brothers Curie in 1880. They were Pierre Curie (1859-1906) and Jacques Curie (1855-1941). During the study of the generation surface electrical charge by applying pressure on some material, they found out an unusual phenomenon which was a voltage of opposite polarity was generated by pressure was applied on the crystalline minerals such as quartz. The amplitude of the generated voltage was proportional to the applied load. The phenomenon was named as “piezoelectric” and the effect called as “piezo effect”. In the following year, the inverse piezo effect was proposed by Lippman which was based on the fundamental thermodynamic principles. The brothers Curie experimentally proved the presence of inverse piezo effect at the same year. However, the piezoelectric materials had not been widely used in any field before World War I[1].

Polarization of Piezoelectric

Fundamental of the piezoelectric transducer is related with orientation electric dipole. The polarization process of piezoelectric material is shown in Figure 2.1. Due to the absence of electric field, the unpoled electric dipoles are oriented randomly. When an electric field is applied longitudinally, electric dipoles are aligned themselves in a single direction that closes to the electric field. In addition, the piezoelectric material expands and contracts due to its crystalline structure[2]. Since all the electric dipoles are pointing to the same direction, a net with same polarization occurs. After the electric field is removed, the orientation of electric dipole will remain the same position and it called as remnant polarization.

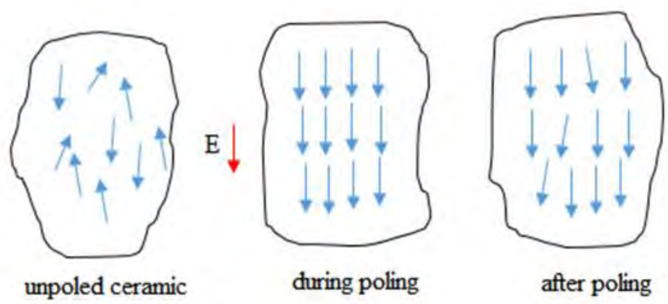

Figure 2.1: Polarization Process

Piezoelectric Relations

The piezoelectric relation is describing the relationship between mechanical stress,_mechanical stress, electric displacement and applied electric field by using constitutive equations. The total strain of transducer is assumed to equal to the mechanical strain that induced by mechanical stress and the actuation stress that caused by applied electric voltage[3]. For an unstressed medium in an electric field, the electrical condition of it is defined by electric field strength, E and the dielectric displacement, D [4].

$$D = \varepsilon E \qquad (2.1)$$

where ε = permittivity of the medium

For the same medium at zero electric field strength, the mechanical condition can be defined by applied stress T and strain S.

$$S = sT \qquad (2.2)$$

where s = compliance of the medium

Since interaction between the electrical and mechanical behavior of the medium, the interaction can be closely approximated by linear relations which shown below.

$$S = s^E T + d_{ij} E \qquad (2.3)$$

$$D = d_{ij} T + \varepsilon^T E \qquad (2.4)$$

where d = piezoelectric charge coefficient

For the piezoelectric charge coefficient, the direction of electric force represents as the first subscript while the direction of the mechanical force is identified as the second subscript where both subscripts equal to 1,2,3. For example, d_{33} represent an electric field parallel to the poling axis 3 in the same way with axial mechanical force along the 3-axis as shown in Figure 2.2[5].

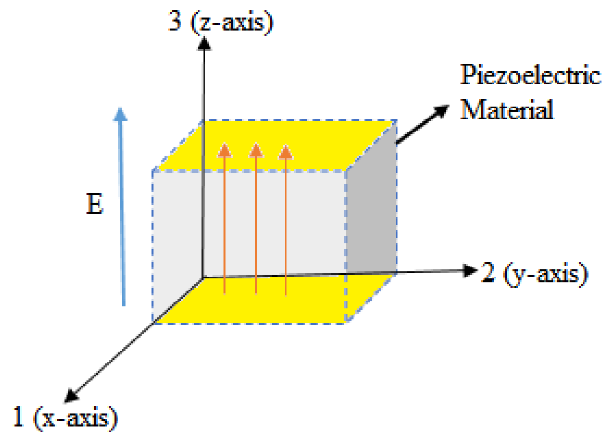

Figure 2.2: Axis Nomenclature of d_{33}

2.3 The Direct and the Indirect Piezoelectric Effect

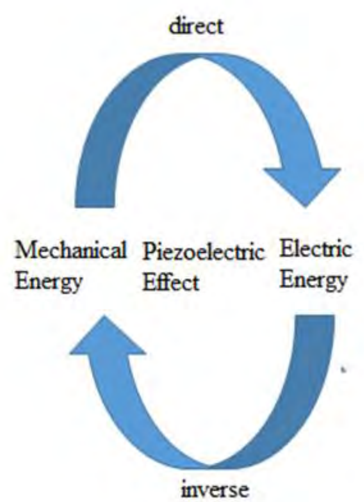

Figure 2.3: Conversion of Energy of Piezoelectric Material

The working principle of piezoelectric materials is classified as direct and indirect piezoelectric effect. The direct piezoelectric effect is a generated electric charge proportional to that stress when a mechanical stress is applied on piezoelectricity materials. The mechanical energy is produced when electrical energy applied to piezoelectricity materials such as operation principles of the piezoelectric actuator. That is called as indirect piezoelectric effect[6].

2.4 Application

Piezoelectric Actuator

When a voltage is applied to a piezoelectric transducer, a displacement is produced. Hence, the piezoelectric transducer can be used as an actuator which a device that produces motion or displacement. The different diameter and thickness PZT can produce a different distance of displacements. The relationship between the diameter of PZT and the displacement is directly proportional. However, when the thickness of PZT increases, the distance of produced displacement decreases [7].

Nowadays, piezoelectric actuators are used in many fields such as optical instruments, fine adjustment of machine tools, microelectronics, and medical field.

Piezoelectric Sensor

For making a capacitor, two metal plates are used to sandwich the crystal. When piezoelectric transducer receives a mechanical stress, the deformation of the crystal in a charge. The greater the external force applied, the more surface charge. A voltage will be generated by the charge. The generated voltage is mathematically related to the charge resulting from a force f and the capacitance the device and is given

$$v = \frac{Q_f}{c} \qquad (2.5)$$

For the phenomenon above, piezoelectric crystal acts as a sensor which converts mechanical energy to electrical charge which in turn can be turned into a voltage signal [8].

2.5 Acoustic Wave

The changes of acoustic wave are used in the measurement process when it passes through the different medium. Therefore, the working principle of the acoustic wave is important in this project.