UNIVERSITI TEKNIKAL MALAYSIA MELAKA

DEVELOPMENT OF SYSTEM IDENTIFICATION FOR PIEZOELECTRIC PATCH ACTUATOR

This report submitted in accordance with requirement of the Universiti Teknikal Malaysia Melaka (UTeM) for the Bachelor Degree of Manufacturing Engineering (Robotics and Automation) (Hons.)

by

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APPROVAL

This report is submitted to the Faculty of Manufacturing Engineering of UTeM as a partial fulfillment of the requirements for the degree of Bachelor of Manufacturing Engineering (Robotics & Automation) (Hons.). The member of the supervisory is as follow:

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ABSTRAK

Projek ini memberi tumpuan kepada pembangunan Sistem Identifikasi (SI) untuk penggerak piezo jenis tampal. Kerja-kerja penyelidikan mengenai pengenalan model-model piezoelectric penggerak yang dijumpai dalam kajian adalah sangat jarang dan terhad. Kebanyakan penyelidik melaporkan mengenai aspek hysteretic Medium tanpa pertimbangan yang lain pengaruh dinamik. Oleh itu kajian ini untuk menentukan fungsi pemindahan (TF) daripada penggerak piezoelectric yang sangat tak linear dan hysteretic diperlukan.Teknik SI dikehendaki bekerja berdasarkan ukuran terus untuk data input-output dari penggerak piezoelektrik jenis tampal. Isyarat input dan output diproses untuk mewujudkan satu model proses yang dinamik. Instrumen yang sesuai dan prosedur analisis digunakan untuk mendapatkan input dan output. Objektif projek ini adalah untuk menentukan rangkap pindah daripada sistem identifikasi yang telah dibangunkan. Selaras dengan objektif utama, beberapa sub-objektif dianggap iaitu untuk model dan mengenal pasti penggerak piezoelektrik jenis tampal menggunakan kaedah kuasa dua terkecil tak linear dan untuk mengesahkan dan menganalisis hasilnya dengan melaksanakan output plot model dan plot ralat. Hasil daripada rangkap pindah yang telah diperolehi adalah $\frac{0.078368s^2 - 8.302s + 1.501e04}{s^2 + 104.2s + 333.2}$. Keputusan telah disahkan untuk memastikan bahawa rangkap pindah yang diperolehi adalah dipadankan baik dengan output eksperimen.

ABSTRACT

This report is about the development of System Identification (SI) for piezo patch actuator. The research works on the identification of the piezoelectric actuator models found in the literature are very sparse and limited. Most researchers report on the hysteretic aspect of the actuators without due consideration to other dynamics influence. Therefore the study to determine the transfer function (TF) of highly nonlinear and hysteretic piezoelectric actuator is needed.SI technique is required to work based on direct measurement of input-output data from the patch type piezoelectric actuator. Input and output signals are processed to create a dynamic process model. A suitable instrument and analytical procedure is used to obtain input and outputs. The objective of this project is to determine the transfer function from the system identification that been develop. In line with the main objective, a number of sub-objective are considered which is to model and identify the piezo patch actuator using non linear least square method and to validate and analyze the result by implementing the model output plot and error plot. Result of the transfer function that had been obtained is $\frac{0.078368s^2 - 8.302s + 1.501e04}{s^2 + 104.2s + 333.2}$.The results were validated to ensure that the transfer function derived is fit well with the experimental output.

DEDICATION

I would like to dedicate this to my beloved parents Abd Latib Bin Wahab and Rosnah Bte Kassim who without them I would not been able to achieve anything.

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SI	System Identification
TF	Transfer Function
FRF	Frequency Response Function
Hz	Hertz
mm	Milimeter
V	volts

CHAPTER 1

INTRODUCTION

1.1 Background

Piezo can be defined as the pressure from the Greek words. In 1880 Jacques and Pierre Curie was able to prove that the electric potential can be produced by applying pressure on the quartz crystal, and named the these phenomenon as the piezoelectric effect. They also determined exposed an electrical potential piezoelectric, piezoelectric materials change shape. This they called the inverse piezoelectric effect.

Piezo effect function is used as a sensor, while the inverse piezoelectric effect is used to driving behavior. The piezoceramic plate found on the patch transducer acts is function as a capacitor. Ceramic will dielectric between the metallized surface and when a voltage is applied, the electric field will be created in the ceramic caused a uniform field perpendicular to the side of the ceramic to the direction of the electric field and it is known as the transverse piezoelectric effect determined thè magnitude of lateral contraction of the electric field strength. This is the key to easy control transducer module. When the modules are glued to the substrate, they effectively transfer over the entire surface, not only in selected places, such as conventional actuators. Instead, the patch transducer in the form of alteration to the electrical current allows them to use as sensors or energy source. Vibration in the kilohertz range can be produced or detected as piezoceramic response to the impact of changes in the electric field or deformation is very fast. Different excitation voltage is required and different contraction amounted possible, depending on the type and dimensions of ceramic. The relationship between displacement and applied voltage is not linear. A shift in the voltage curve of a typical hysteresis behavior can be produced.

1.2 Problem Statement

The research works on the identification of the piezoelectric actuator models found in the literature are very sparse and limited. Most researchers report on the hysteretic aspect of the actuators without due consideration to other dynamics influence. Therefore the study to determine the transfer function (TF) of highly non linear and hysteretic piezoelectric actuator is needed. System identification technique (SI) is required to work based on direct measurement of input-output data from the patch type piezoelectric actuator mounted on the right is designed platform equipped with appropriate instrumentation. System identification is input-output signals are processed to create a dynamic process model. The purpose of the introduction of the system can be described as finding a model with adjustable parameters, and then to adjust them so that the output matches the predicted output is measured. TF model was almost through rigorous analysis procedures. Validation and verification of the results is done to ensure that the transfer function obtained viable and practically feasible.

1.3 Objective

The main objective of this research is to determine the piezoelectric patch actuator transfer function (TF) by using system identification (SI) technique with the aid of the previously designed experimental rig. In line with the main objective, a number of sub-objective are considered as follows:

a) To model and identify the piezo patch actuator using non linear least square method.
b) To validate and analyse the result by implementing the model output plot and correlation test.

1.4 Scope of Study

The scope of this project is to develop and analyze the identification system for patch actuator transfer function. This project focuses on the developed rig for capturing piezoelectric patch actuator using MATLAB & DAQ Software to find its transfer function. The scope also includes:

1) Study the characteristic of the piezoelectric actuators, system identification (SI) and technique.
2) Apply SI technique to build mathematical model of dynamical system
3) Design and develop physical rig to perform the experimentation related to SI technique.
4) Perform comparative study of all the SI technique applied to the piezoelectric actuator.

CHAPTER 2
LITERATURE REVIEW

2.1 Introduction

This chapter describes the background related to the objectives of this study. Firstly, the piezoelectric is clearly defined on the piezoelectric theory and applications. Next, the literature search in areas related to this study are been discussed.

2.2 Piezoelectric

Piezoelectric actuators are widely used in a variety of problem especially in positioning accuracy in the various fields of engineering. Piezoelectric actuator made of ferroelectric ceramic materials, usually lead (plumbum) zirconate-titanate (PZT) as Figure 2.1. Driven by an electric dipole field, the structure of the PZT material will be polarized and deformed, and leading PZT actuator displacement. After removal of the electric field, however, there are last remaining polarizations or displacement. Driving under the cycle, therefore piezoelectric actuators will exhibit curvilinear shift between input and output voltage, the hysteresis loop well known.

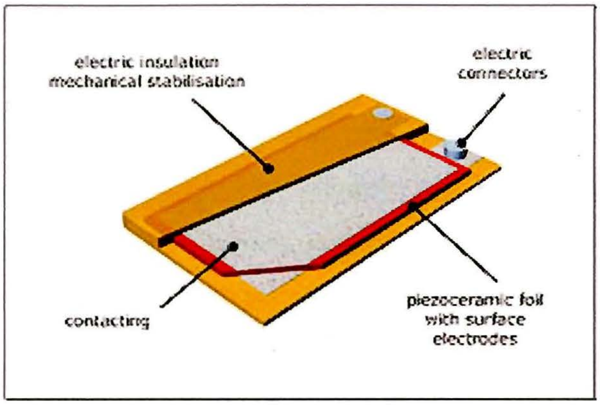

Figure 2.1 Piezoelectric designs (Source :<http://www.piezo.ws/piezo_products/Piezo-Patch-Transducer/index.php>19/11/2013)

Piezo effect function is used as a sensor, while the inverse piezoelectric effect is used to driving behavior. The piezo ceramic plate found on the patch transducer is function as a capacitor. Ceramic acts as a dielectric between the metallized surfaces. When a voltage is applied, the electric field will be created in the ceramic caused a uniform field perpendicular to the side of the ceramic to the direction of the electric field and it is known as the transverse piezoelectric effect and determined the magnitude of lateral contraction of the electric field strength.

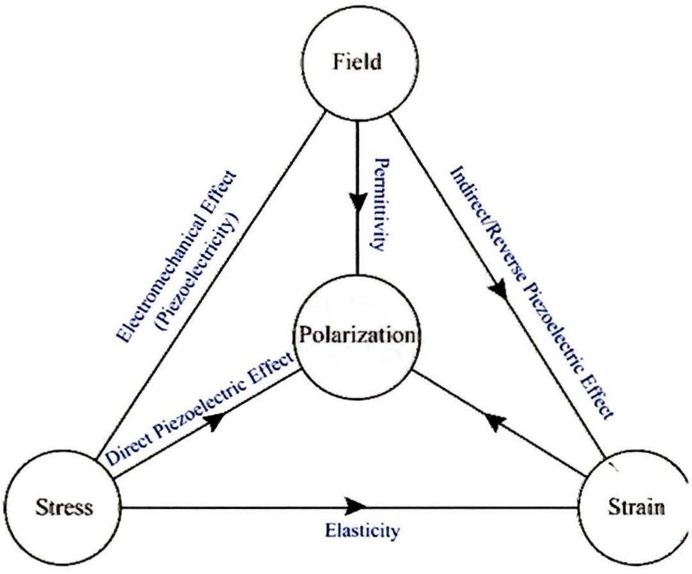

Figure 2.2 Piezoelectric concepts of polarization, (Dahiya & Valle, 2013)

According to (Dahiya & Valle, 2013), piezoelectric are the class of dielectric materials which can be polarized, in addition to an electric field, also by application of a mechanical stress Figure 2.2. This unusual property exhibited by a few dielectric materials is called piezoelectricity, or, literally, pressure electricity. Piezoelectric materials can be divided into polar (which possess a net dipole moment) and non polar piezoelectric materials (whose dipolar moments summed in different directions give a null total moment). A detailed description of the piezoelectric effect is given in following sections.

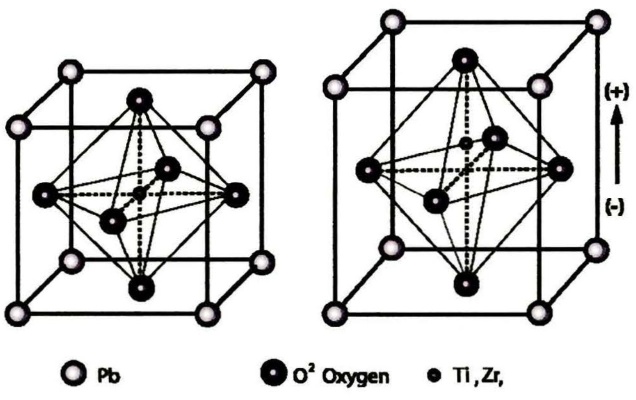

Figure 2.3 Structure of a piezoelectric ceramic, before and after polarization (Source: <http://www.piezo.ws.php>22/112013).

One of the concepts of piezoelectric materials respond to electric fields is to use externally, to adapt to this medium dynamic perturbation by changing the position of the nucleus and electrons. As a result of the dipoles are created and dipole formation process under the influence of external electric field have the strength of the electric field, E, is called polarization. Local area adjoining dipole alignment form called "domain". With the net polarization occurs as a result of the alignment. Polarization direction between neighboring domains is random as shown in Figure 2.3. "Poling process" formed after the ceramic element has no overall polarization and cause domains in a ceramic element are aligned by exposing the element to a strong DC electric field.

Dipoles will be locked after the close alignment element electric field is removed, and it will have a permanent polarization, remnant polarization and permanently elongated. It is usually in the range of micrometer size. Figure 2.4 shows the dipoles.

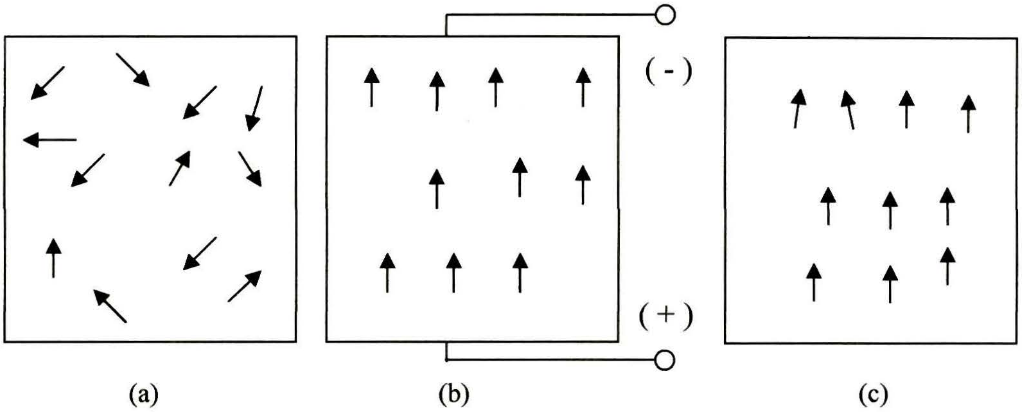

Figure 2.4 Poling process (a) Polar domains are oriented randomly ;(b) Polarization process when apply a very large DC electric field ; (c) The polarization remains even DC field is removed.(Source: <http://www.piezo.ws.php>22/11/2013)

There is a lot of research on piezoelectric and one of them is experimental studies on structural load monitoring using piezoelectric transducer based electromechanical impedance method by (Radhika, Annamdas, & Yang, 2012) .The research is based on electromechanical impedance (EMI) to develop and improve structural health monitoring (SHM) band summarizes about different types of loading effects related to EMI.

2.3 Piezoelectric Patch Actuator

The piezoelectric patch transduces is as Figure 2.5.Piezoelectric patch design as rectangular plate that can be expand and contract in preferred direction according to the effect.

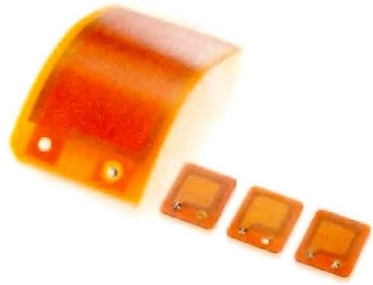

Figure 2.5 Piezoelectric patch actuator designs (Physik Instrumente,2011)

According to (Physik Instrumente,2011) hysteresis occurs in open loop piezo actuators in due to their dielectric and electromagnetic large-signal behavior. Hysteresis is based on crystalline polarization effects and molecular effects within the piezoelectric material. Hysteresis can be defined as curves of an open loop piezo actuator for various peak voltages and it related to the distance moved. Hysteresis is the result of crystalline polarization effects and molecular friction. The absolute displacement generated by an open loop Piezo depends on the applied electric field and the piezo gain which is related to the remanent polarization. Since the remanent polarization and therefore the piezo gain is affected by the electric field applied to the piezo, its deflection depends on whether it was previously operated at a higher or a lower voltage (and some other effects).

Hysteresis is typically on the order of 10 to 15 % of the commanded motion. Figure 2.6 shows the curve of the hysteresis. The amount of hysteresis increases with increasing voltage (field strength) applied to the actuator.

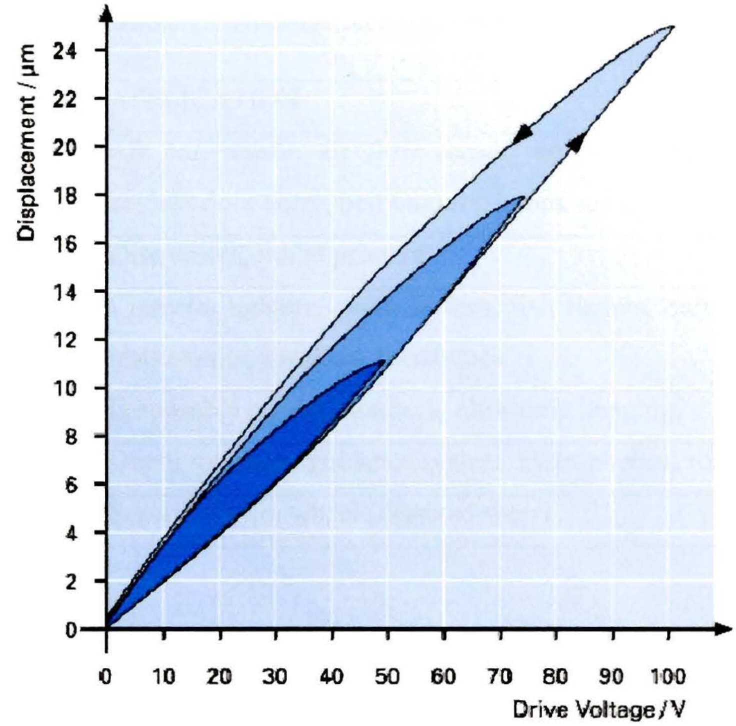

Figure 2.6 Hysteresis curve in open loop operation (Physik Instrumente,2011)

Much of the recent work and study for improving application of piezoelectric patch actuator had been done. According to Azni n Wahid *et al* (2013) parametric studies showed that changing the patch location on the structure will not affect the average power supplied. On the contrary, changing the patch size will change the power magnitude proportionally as larger patch means larger force is applied.

When force is applied to the piezoelectric transducer, it will generate voltages due to piezoelectric effect. This makes piezoelectric really suitable for sensing application. Figure 2.1 shows the application of piezoelectric patch actuator in many industry field.

Table 2.1 Application of piezoelectric patch actuator

INDUSTRY	APPLICATION
Automotive	Air bag sensor, air flow sensor, audible alarms, fuel atomizer, keyless door entry, belt buzzers, knock sensor.
Computer	Disc drives, Inkjet printers.
Consumer	Cigarette lighters, depth finders, fish finders, humidifiers, musical instruments, speakers, telephones.
Medical	Disposable patient monitors, ultrasonic imaging.
Military	Depth sounders, guidance system, hydrophones, sonar.
Transportation	Sensor of train wheel (detected wear) ,