ULTRASONIC SENSING SYSTEM FOR DETECTION OF PIPE SURFACE DEFORMATION

NOR SYAHIRAN BIN ZAHIDIN

UNIVERSITI TEKNOLOGI MALAYSIA

ULTRASONIC SENSING SYSTEM FOR DETECTION OF PIPE SURFACE DEFORMATION

NOR SYAHIRAN BIN ZAHIDIN

A thesis submitted in fulfilment of the
requirements for the award of the degree of
Master of Engineering (Electrical)

Faculty of Electrical Engineering
Universiti Teknologi Malaysia

OCTOBER 2012

To my beloved family, my father Zahidin Bin Ali, my mother Nor Aiti Binti Mat Ali, my brothers Nur Syahmi, Nur Syahir, Nur Syakir and Nur Syafiq.

ACKNOWLEDGEMENT

First of all, praise be to Allah SWT for HIS favors in guiding and helping me in to complete this thesis. No such word can show my gratefulness except Alhamdullillah with the humble position in completing the work within the limited time given. Thank to HIM over anything in this world.

Second, I would like to express my gratitude and special thanks to my supervisor, PM Dr Sallehuddin bin Ibrahim for her professional guidance, wisdom, endurance, advices, motivation and encouragement throughout the project.

I am very glad to meet the kind and helpful persons in the Wireless Data Acquisitions Laboratories who help me from the early till the end while doing this project. Treat like friend from these groups motivate me to do the work.

Finally, I really appreciate to have this responsibility to finish this project. This task has taught a lot of lesson and knowledge which would be valuable to me in the future.

ABSTRACT

The utilisation of ultrasonic is widely applied for strain measurement. However, most of the measurements are performed using strain gages. The method used in this research made use of reflected signal using air as its working medium. The purpose of this experiment is to provide an alternative to the strain gage. Ultrasonic wave from transmitter transducer is transmitted to a point, and then reflected by the surface medium which experienced strain towards the ultrasonic receiver transducer. Aluminum probe cones attached to both ultrasonic transducers collimate the transmission and reception of the signals. The strain experienced by a PVC pipe is measured by the ultrasonic transducer. The difference in distance resulted in the difference of the ultrasonic wave as well as the electrical signal. When the strain started to deform, the length of deformation increased and the electric signal became weak due to the reduction of sound intensity. The received electric signal due to this change will undergo signal conditioning consisting of pre-amplifier, amplifier, band-pass filter and rectifier before being displayed onto the oscilloscope screen. There are two types of strain measured in this experiment: tensile and compression strain. The result is consistent throughout the experiment. An experiment using a strain gage and an experiment on the deflection measurement were also carried out to determine the value of strain due to deformation. From these two experiments, the relationship between strain formation created and sound intensity rate which relies on voltage change can thus be identified.

ABSTRAK

Penggunaan ultrasonik dalam bidang pengukuran terikan semakin meluas digunakan pada masa kini. Walau bagaimanapun, kebanyakan pengukuran terikan masih menggunakan tolok terikan. Kaedah yang digunakan dalam kajian ini menggunakan konsep isyarat terpantul yang menjadikan udara sebagai medium kerja. Tujuan eksperimen ini adalah untuk mengemukakan alternatif baru bagi menggantikan penggunaan tolok terikan. Gelombang ultrasonik dari transduser pemancar akan ditala menuju ke satu titik, kemudian akan dipantulkan semula oleh permukaan yang mengalami terikan ke transduser penerima. Satu corong yang diperbuat dari alumunium dipasang pada kedua-dua transduser untuk memudahkan proses penerimaan dan pemancaran gelombang. Terikan yang dialami oleh sebuah paip PVC (Polivinil Klorida) diukur oleh transduser ultrasonic tersebut. Perbezaan jarak mengakibatkan perbezaan pada penerimaan gelombang bunyi dan isyarat elektrik. Apabila terikan tegasan berlaku, jarak terikan menjadi lebih panjang dan isyarat elektrik menjadi lemah kerana kekuatan bunyi berkurangan. Isyarat elektrik yang terhasil dari perubahan ini akan melalui proses penyesuaian isyarat pra-penguat, penguat, penapis, dan penerus sebelum disambungkan ke papan pemuka osiloskop. Dua jenis terikan yang diukur di dalam ujikaji ini: terikan tegangan dan juga terikan tekanan. Keputusan kajian menunjukkan alat ini memberi pola bacaan yang seragam dan konsisten. Eksperimen menggunakan tolok terikan dan eksperimen lenturan dilakukan juga untuk mengukur nilai terikan yang terbentuk. Melalui kedua-dua eksperimen ini, maka satu bentuk hubungan antara jarak terikan yang terhasil dan kadar kekuatan bunyi yang bersandarkan pada perubahan voltan boleh dikenalpasti.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

ASTM	-	American Standard Testing & Material
CT	-	Computed Tomography
DAS	-	Data Acquisition System
DC	-	Direct current
ECG	-	Electrocardiogram
ESPI	-	Electronic Speckle Pattern Interferometry
HMA	-	Hot Melt Adhesive
Hz	-	Hertz
IC	-	Integrated Circuit
LRS	-	Laser Range Scan
NDT	-	Non Destructive Test
POBF	-	Pulsatile Orbital Blood Flow
PVC	-	Polyvinyl Chloride
3D	-	3 Dimension

LIST OF SYMBOLS

P	-	Force
ϵ	-	Strain
ρ	-	Radian
θ	-	Angle
dx	-	Element on pipe
σ	-	Stress
E	-	Young Modulus
y	-	Distance from neutral axis
c	-	Distance from neutral axis to pipe surface
I	-	Moment of Inertia
r_i	-	Internal radian of pipe
r_o	-	Outside radian of pipe
L	-	Beam length
v	-	Deflection from beam
v	-	Wave velocity
f	-	Wave frequency
λ	-	Wavelength
Z	-	Acoustic Impedance

ρ	-	Material density
R	-	Reflection coefficient
M	-	Moment
V	-	Voltage

LIST OF APPENDICES

CHAPTER 1

INTRODUCTION

1.1. Introduction

Ultrasonic is widely used in the engineering industry because of its abilities such as excellent long term stability and low power consumption (Valentin, 1994). Since ultrasonic has many useful functions, miscellaneous investigations have been proposed to improve the present performance and explore new potential applications. Ultrasonic has always been used to justify quality control for plate typically for metal plate thickness quality, scan the mother womb to obtain fetus image and also functioning as motion sensor in automation in the industries. There are lots of other applications beside what we already know in our mind. Research and study programs are continuously ongoing to improve the ultrasonic instrumentation performance in measurement related to the fluid flow in pipe and duct (Çengel and Cimbala, 2006). Even solid bolt deformation including translation and rotational in laboratory are detected using ultrasonic (Koshti, 1997). Recently, ultrasonic is applied in the biological field, one of them is to determine the mechanical properties of cells using Scanning Acoustic Microscopy, part of ultrasonic approaches (Kundu, 1994). The agricultural sector uses the ultrasonic system to predict shelf life and maturity of food quality for avocado (Mizrach and

Flitsanov, 1995). The good aspects from these developments show that ultrasonic are suitable to be implemented in various applications.

1.2. Background of the study

Ultrasonic in Non-Destructive Testing (NDT) is well known in detecting the flaws in plate composition as part of quality inspection. The plate may be a part of water tank, pipe or others which similar. The other application of ultrasonic is as a range sensor for movement object. The improvement for this type of sensor for mobile robot is well-evaluated to run smoothly (Park *et al*, 2010). The range sensor developed by most industrial companies deal with large distance using meter unit scale. The sensor is also used for liquid level indicator, car parking safety system and others. The sensor is also applied in bottom vessel to monitor coral seabed distance and to find schools of fishes. However, this research deals with small strain formation between micrometer units with minimal cost of ultrasonic equipment application.

The axial elongation of the PVC pipe is investigated when the pipe bent due to perpendicular force. The elongation of the PVC pipe depends on the deflection from initial state and Young Modulus of the material. The results from the theoretical calculation and experiment are analyzed to observe the relationship between both of them. The air-coupled ultrasonic propagation is transmitted towards a point of the interested deformation area, and the reflected ultrasonic wave is captured with ultrasonic transducer before being displayed for analyzing process.

1.3. Statement of the problem

When ultrasonic wave from air hits a solid medium, diffraction and deflection phenomenon will occur (Bindal, 1999). There must be a deep comprehension of the

sound physical properties phenomenon of diffraction and deflection in order to determine the optimum angle of reflection. Basically, when the ultrasonic wave encounters different medium it will form shear and longitudinal waves at certain angle (Trevor and Peter, 2009) which makes the analysis more complex to handle. It is also necessary to identify other types of waves which occur simultaneously like Lamb, Love, and Rayleigh waves.

Ultrasonic behaves as part of sound physical properties operating at a higher frequency. The sound energy obeys the conservation energy equilibrium law which can be formed or transformed. When the sound energy propagates on a surface, it will scatter into three condition i.e. transmission, absorption or reflection depending on the surface's acoustic properties (Trevor and Peter, 2009). Since the wave divides into three conditions further investigation must be performed for every parameter that affects the transmission, reflection, and absorption process need to be clear. After that it will lead to selection process between either one of them.

1.4. Purpose of the study

Ultrasound for measurement process uses transducers for both transmitting and receiving process. They need medium for transmission process which may consist of gaseous, liquid, or solid phase. This study aims to minimize the cost for surface deformation measuring instrument by using ultrasonic sensors in comparison with strain gages.

There are lots of selections to find strain gage in the market and the price differs according to the type, purpose, durability and others. The price for single strain gage is quite expensive and unfortunately it is one-time disposable stuff. In contrast to strain gage, an ultrasonic transducer can be used many times and the power consumption is lower.

1.5. Objectives of the study

The objective of this project is to measure the mechanical deformation when a pipe bends due to a perpendicular load on the pipe using the ultrasonic instrumentation system. The air-coupled ultrasonic system detects deformation at the point of interest which is designed to be in tensile and compression state.

1.6. Scope of the study

A one meter PVC pipe is placed horizontally and supported only at one edge of the pipe. The weigh is hanging at the edge of the other side just one meter from the support. The experimental set up is discussed in methodology (Chapter Three) in this thesis. The pipe is bent to create the strain. As a result of the strain ultrasonic wave which is generated from the ultrasonic transmitter strikes the surface and reflects to the ultrasonic receiver. In this experiment, two aluminum probe cones are used for both transducers to collimate the ultrasonic wave. The idea to use cone for this experiment came from a research on ultra-high distance resolution (Imano *et al*, 2005), (Imano *et al*, 2006) and has also been implemented in another research to check fruit quality (Mizrach and Flitsanov, 1995).

The transducers are installed on a PVC pipe permanently. The ultrasonic transmitter transducer operates at 40 kHz using circuits while the ultrasonic receiver transducer is connected to a signal conditioning circuit containing a filter, amplifier, and rectifier circuit. The signal from the experiment is displayed on an oscilloscope. An air-coupled ultrasonic transducer has its own characteristic to investigate even though after the installation of alumunium probe cone. The scope will cover the factors that are affecting the measurement reads. Ultrasonic and acoustic impedance have close connection to each other.

1.7. Significance of the study

Ultrasonic technique in Non-Destructive Technique can be used to measure the physical surface deformation and it also can be utilized repeatedly compared to an electrical resistance strain gage which suffers from performance degradation if it is used repeatedly. The technique discussed in this research use air-couple ultrasonic transducer and it is an enhancement to the existing ultrasonic technique. This technique helps many people to measure strain deformation especially for pipe.

1.8 Organization of the thesis

Chapter one is an introduction to this thesis. It includes background of the study, statement of the problem, purpose of the study, objectives, scope of the study, research question, significance of the study, organization of the thesis and research methodology.

Chapter two is about literature review. This chapter elaborates on ultrasound, the ultrasonic sensing system, mechanical deformation of surfaces, deformation on pipe surface, physics of sound, sound pressure level, air-coupled ultrasonic transducer, the use of ultrasonic in non-destructive testing, ultrasonic probe cone, and tip opening.

Chapter three expounds the methodology of the thesis from start until the end. The process to conduct the experiment due to the bending of the pipe until the collection of data is elaborated in detail.

Chapter four expounds result and discussion on the experiment. After the experiment was carried out, the data analyzed to observe the information gathered in

tables and graphs. The information from both tables and graphs will determine the result of the thesis objective in section 1.5.

Chapter five is the last chapter which consists of conclusion and recommendation. The output from this research can be used and any weakness can be improved by other people.

1.9 Research Methodology

The flow chart showing the research methodology in Figure 1.1 starts with literature review to understand the ultrasonic and surface deformation. Every single information about these elements is vital to run the experiment. Then the process goes to fabrication stage to build electronic circuit for ultrasonic transducer and signal conditioning process, besides making the experiment work piece using PVC pipe. The first preliminary method experiment is done to get the relationship between ultrasonic and strain formation and obtain Young Modulus of PVC material. The interested spot is patched with electrical strain gage to calibrate the strain deformation.

The next step is second literature review to find out about another research technique, probe cone evaluation, and ultrasonic physic properties. After that, the second fabrication process is started by making new electronic circuit and new experiment work piece. The second experiment able to test the surface deformation under two condition states; tensile and compression. The second experiment also improves the first experiment from design aspect and range of deformation.

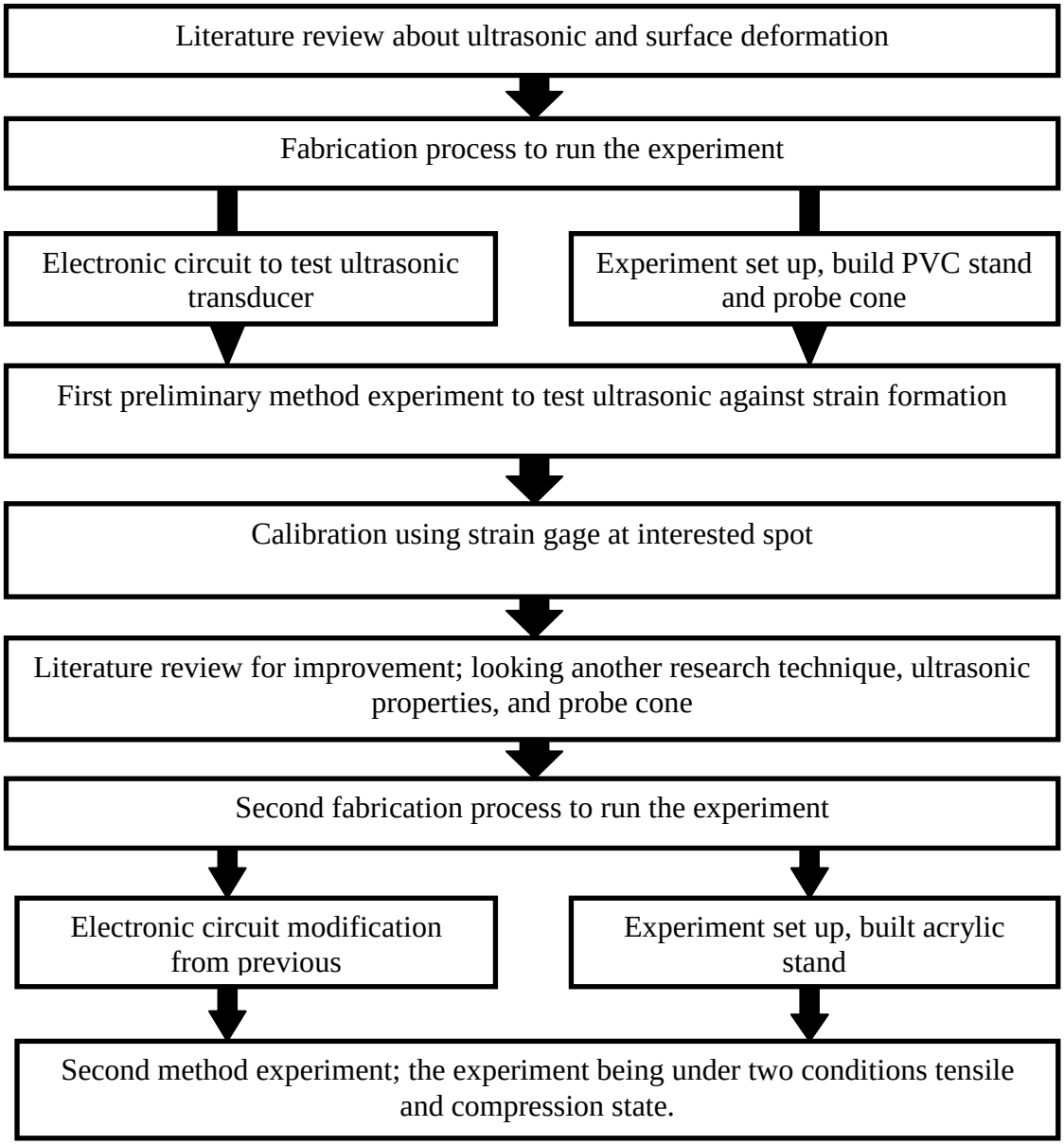

Figure 1.1 Research methodology flow chart

REFERENCES

Alqmvist, M., Hol, A., Persson, H.W., and Lindström, K. (2000). Characterization of air-couple ultrasound transducer in the frequency range 40 kHz-2 MHz using light diffraction tomography. *Elsevier,Ultrasonic 37 (2000),565-575*

Al-Iababidi, S. (2005). Clamp-on Ultrasonic Meter Economically Gauges Multiphase Flows. *Pipeline & Gas Journal, January 2005*

Bassam, S., Balqies, S., and Pierre, A. B. (2003). Measurement Of Surface Deformation Associated With Hydrofracture .*Proceedings First FIG Symposium on Deformation Measurements, Greece.*

Bindal, V.N. (1999). *Transducer For Ultrasonic Flaw Detection*. Publish by Narosa Publishing House. Printed by Rajkamal Electric Press,Delhi 110 033 India.

Blitz, J., and Simpson, G. (1996). *Ultrasonic Methods of Non-Destructive Testing*. Chapman Hall, Great Britain, University Press, Cambridge.

Bruce, N., (2010). Pipeline In-Line Inspection – Challenges to NDT. *PetroMin Pipeliner. April-June 2010, page 28-36.*

Çengel, A., and Cimbala, M. (2006). *Fluid Mechanics Fundamentals and Applications.* McGraw-Hill. Singapore.

Don, E. B. (2002). Ultrasonic Stress Measurement and Material Characterization in Pressure Vessels, Piping, and Welds. *ASME Journal of Pressure Vessel Technology, August 2002, Volume 124, page 326 – 335.*

Drury, J.C. (2005). Part 7: The Ultrasonic Beam. *Insight Volume 47 No 5 May 2005.*

Espen, S., Magne, A., Magne, V., and Per, L. (2010). Ultrasonic piezoceramic transducer for air,- finite element analysis and measurements. *33rd Scandianavian Symposium on Physical Acoustics, Geilo, Norway, 7-10 February 2010*.

Eun-Geun, K., Won-Pil, P., Dae-Gon, W., Chang-Yong, K., Yong-Heum, L., Dohyung, L., Tae-Min, S., Han-Sung, K., and Gyoun-Jung, L. (2005). Ultrasonic System for Diagnosis of Functional Gastrointestinal Disorder: Development, Verification and Clinical Trials. *International Journal of Biological and Life Science 1: 3 2005. Page 207-212*.

Gerhard, H., and Busse, H. (2003).Deformation-Measurement With Speckle-Interferometry By Ultrasound Excitation. *European Conference on Nondestructive Testing ,February 2003, Vol. 8 No.2.*

Glen, B. (2008). *Handbook for Sound Engineers, Fourth Edition*. Focal Press, Elsevier.

Graham, B., and Gordon, H. (2000). Beam profile measurements and simulations for ultrasonic transducer operating in air. *Journal Acoustic Society of America 107(4), April 2000*.

Gunther H. (2007). Potential and limitation of ultrasonic clamp load testing. *SAE International 2007 World Congress Detroit, Michigan, April 16-19, 2007.*

Halliday, D., Resnick, D., and Walker, J. (2005). *Fundamental of Physics, 7th Edition*. John Wiley & Sons. Von Hoffmann Press.

Heinrich, K. (2007). *Acoustics An Introduction*. Taylor & Francis. Great Britain, Cromwell Press, Trowbridge.

Hibbeler, R.C. (2005). *Mechanic of Material, Sixth Edition*. Pearson Education, Malaysia.

Holman, J.P. (2001). *Experimental Methods for Engineers, Seventh Edition.* McGraw-Hill, Singapore.

Huang, K.N., Huang, C.F., Li, Y.C., and Young M.S. (2003). Temperature Measurement System Based on Ultrasonic Phase-Shift Method. *Biomedical Engineering, 2003, IEEE EMBS Asian-Pasific Conference, Page 294-295.*

Imano, K., Nishira, M., and Sasaki, K. (2005). Lateral resolution beyond diffraction limit using 40 kHz air-coupled ultrasonic systems. *Electronic Letters May 2005, Volume 41 No.10.*

Imano, K., Nishira, M., and Sasaki, K. (2006). Ultra-high distance resolution using phase information of 40 kHz air-coupled ultrasonic wave. *Electronic Letters July 2006 Volume 42 No.14.*

Ji, A., Yuqing, S., Hongpeng, Z., and Yindong, Z. (2010). The Study to Pressure and Flow Measurement for Hydraulic System on Basis of Non-Inserting Technology. *2010 Chinese Control and Decision Conference ,page 696-700.*

Joseph, L.R. (1999). *Ultrasonic Waves in Solid Media*. The Press Syndicate of The University of Cambridge: Cambridge University Press.

Joseph, S.H. (1977). A CW Ultrasonic Bolt-Strain Monitor. *Experimental Mechanics Volume 17,Number 5,183-187.*

Koshti, A. (1997). Ultrasonic measurement of bending of a bolt in a shear joint. *Experimental Mechanic* (1997) Volume 38, Number 4,270-277.

Krautkrämer, J., and Krautkrämer, H. (1977). Ultrasonic Testing of Materials. Springer-Verlag Berlin Heidelberg.

Kundu, T. (2004). *Ultrasonic Nondestructive Evaluation : Engineering and Biological Material Characterization*. CRC Press, United States of America.

Logan, W.C, Prashanth, D., William C.C., Benoit, M.D., Robert, L.G, and Michael, I.M. (2011). Organ Surface Deformation Measurement and Analysis in Open Hepatic Surgery: Method and Preliminary Results From 12 Clinical Cases. *IEEE* Transactions On Biomedical Engineering, Vol. 58, No. 8, August 2011.

Mak Se-Yuen (2003). Wave Experiment Using Low-Cost 40 kHz Ultrasonic Transducers. *Physic Education 38(5), page 441 – 446.*

Malcom, J., and Povey, W. (1997). *Ultrasonic Techniques for Fluids Characterization.* Academic Press Limited: Academic Press.

Malgorzata, A. K., Henryk, T.K., Robert , D.I., Monika, D., and David, M. (2011). Ultrasonic In vivo Measurement of Ocular Surface Expansion. *IEEE Transcation On Biomedical Engineering, Volume 58, No.3, March 2011.*

Martin, F., and Bruce, D.S. (1976). Transducer Characteristic for Ultrasonic Streography. *New York Academic of Medicine Journal, Volume 52, No.10, December 1976.*

Mizrach, A., and Flitsanov, U. (1995). Ultrasonic Device For Avocado Shelflife Predicting and Maturity Detection. *Proceeding of the World Avocado Congress III,1995 300-306.*

Park, J., Je, Y., Lee, H., and Moon, W. (2010). Design of an ultrasonic sensor for measuring distance and detecting obstacles. *Elsevier Ultrasonic 50 (2010), 340-346.*

Rahman, M., Eisa, B., and Othman, S. (2004). Ultrasonic Technique for The Measurement of Pressure Below Atmospheric Pressure. *TENCON 2004. 2004 IEEE Region 10 Conference. Volume D. Pages 653-655, Volume 4.*

Richard, E.B., and David, G.S. (2005). *The physics of sound* . Pearson Prentice Hall, United States of America.

Richard, G.B., and Nisbett, J.K. (2008). *Shigley's Mechanical Engineering Design Eigth Edition In SI Units*, McGraw-Hill.

Ruzairi, A.R., Mohd Hafiz, F.R., Wei Nyap, N., and Kok San, C. (2004).On Monitoring of Liquid/Gas Flow Using Ultrasonic Tomography. *Jurnal Teknologi, 40(D) Jun. 2004:77-88.*

Sallehuddin, I., and Syahiran Zahidin, N. (2011). Preliminary Investigation on the Use of an Ultrasonic Sensing System to Detect Surface Deformation. *United Kingdom - Malaysia - Ireland Engineering Science Conference 2011 (UMIES 2011) 12-14 July, 2011.*

Szilard, J. (1982). *Ultrasonic Testing: Non-Conventional Testing Technique*. John Wiley & Sons, United State of America.

Thompson, R.B., Buck, O., Smith, J.F., and Spitzig, W.A. (1989). New Ultrasonic Methods for Measuring Deformation and Fracture Related Material States. *Metallurgical Transaction, Volume 20A, April 1989 page 611-618.*

Torbjörn Löfgvist, Kęstutis Sokas, and Jerker Delsing (2003). Speed of Sound Measurement in Humid Air Using An Ultrasonic Flow Meter. *XVII IMEKO World Congress Metrology in the 3rd Millenium, June 22-27, 2003, Dubrovnik, Croatia.*

Trevor, J.C., and Peter D' Antonio (2009). *Acoustic Absorbers and Diffusers Theory, Design and Application.* Published by Taylor & Francis. Printed in Great Britain by MPG Books Ltd, Bodmin, Cornwall.

Valentin, B., Atjun, Y., Pierre, P. (2010). Automated Surface Deformations Detection and Marking on Automotive Body Panels. *6th annual IEEE Conference on Automation Science and Engineering, Marriott Eaton Centre Hotel Toronto, Ontario, Canada, August 21-24, 2010.*

Valentin Mágori (1994). Ultrasonic Sensor in Air. *IEEE,1994 Ultrasonic Symposium.* 1051-0117/94/0000-0471.

Walaszek, H., Lieurade, H.P., Peyrac, C., Hoblos, J., and Rivenez, J. (2002). Potentialities of Ultrasonic for Evaluating Residual Stresses: Influence of

Microstructure. *ASME Journal of Pressure Vessel Technology, August 2002, Volume 124, page 349-353*.

Wehmeier, S., McIntosh, C., and Ashby, M. (2005). *Oxford Advanced Learner's Dictionary*, International Student's Edition, 7th Edition. Oxford University Press. India.

William, D.C. (2007). *Material Science and Engineering: An Introduction, Seventh Edition*. John Wiley & Sons, Asia.

Yoshihiro, W., Takshi, N., Takashi, K., Masatoshi, I. (2010). Estimation of Non-Rigid Surface Deformation using Developable Surface Model. *Pattern Recognition (ICPR), 2010 20th International Conference on 23-26 August 2010, page 197-200.*