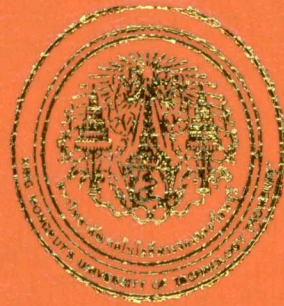


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FABRICATION OF ACOUSTIC EMISSION SENSOR AND CALIBRATION OF
ACOUSTIC EMISSION SYSTEM

MR. MAI NOIPITAK

A DISSERTATION SUBMITTED IN PARTIAL FULFILLMENT OF
THE REQUIREMENTS FOR THE DEGREE OF DOCTOR OF PHILOSOPHY
(MANUFACTURING AND SYSTEMS ENGINEERING)

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Fabrication of Acoustic Emission Sensor and Calibration of Acoustic Emission System

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A Dissertation Submitted in Partial Fulfillment
of the Requirement for
the Degree of Doctor of Philosophy (Manufacturing and Systems Engineering)
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Abstract

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Acoustic emission (AE) testing methods are becoming useful tools for integrity assessment of structures monitoring of corrosion processes, materials characterization and fluid leakage for valves and pipes. However, there are no measurement standards for estimating the absolute strength of the AE sources. The lack of standardization makes it very difficult to compare the results obtained in different laboratories or AE sensors and on different structures or materials including obtaining meaningful repeatability of measurements. The most current methods only give a qualitative rather than quantitative indication of the damage of structures and materials. The main objective of this dissertation is to study and fabricate an AE sensor and create the model formulation for the relationship between mechanical energy released from source and AE signal to transfer AE data between AE sensors and AE measurement systems. In addition, to verify the AE sensor and model formulation, the air jet implemented is demonstrated to convert AE energy from different AE sensors. Finally, the AE sensor, the air jet system calibration, the transferable of AE data and the model formulation are applied in the internal valve leakage rate measurement and the uniform corrosion monitoring, respectively. The experimental results show that the home-built AE sensor and model formulation can be applied in the internal valve leakage rate measurement and the uniform corrosion monitoring. For the internal valve leakage rate measurement, the performance to predict the leakage rate in the laboratory and in the field was tested. The error is less than 5% in almost cases. The benefit is to reduce the recalibration time when a part of measurement system is changed. For the uniform corrosion monitoring, the performance to predict the AE energy for different wave propagation paths and AE sensors in the laboratory was tested. The error of prediction of the uniform corrosion energy is also less than 5%. The benefit is outline to forecast the grade of the severity of uniform corrosion quantitatively when using various AE monitoring conditions.

Keywords: Air Jet/ Calibration/ Home-built AE Sensor/ Internal Valve Leakage Rate Measurement/ Model Formulation/ Uniform Corrosion Monitoring

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การทดสอบโดยวิธีอะคูสติกอิมิชชันได้ถูกใช้เป็นเครื่องมือในการประเมินและเฝ้าระวังการกักกรองของโครงสร้าง คุณลักษณะของวัสดุ และการรั่วของของไหลในตัวเรือนวาล์วและท่อต่างๆ แต่อย่างไรก็ตาม การทดสอบด้วยวิธีนี้ยังขาดมาตรฐานในการประมาณค่าเป็นเชิงปริมาณ เพื่อประเมินแหล่งกำเนิดคลื่นเสียงที่เกิดขึ้นจริง การขาดมาตรฐานดังกล่าวนี้ จะทำให้ยากต่อการเปรียบเทียบผลการทดสอบระหว่างห้องปฏิบัติการหรือระหว่างหัตถตรวจสอบและเมื่อ โครงสร้างหรือวัสดุเปลี่ยนไป ทำให้ผลการทดสอบไม่สามารถทวนสอบซ้ำได้ โดยที่วิธีการทดสอบในปัจจุบันจะให้ผลการทดสอบในเชิงคุณภาพมากกว่าเชิงปริมาณ ซึ่งวิทยานิพนธ์ฉบับนี้มีวัตถุประสงค์ที่จะสร้างหัตถตรวจสอบอะคูสติกอิมิชชันและสร้างแบบจำลองทางคณิตศาสตร์เพื่ออธิบายความสัมพันธ์ระหว่างพลังงานกลจากแหล่งกำเนิดกับสัญญาณอะคูสติกอิมิชชัน เพื่อให้สามารถถ่ายโอนข้อมูลการทดสอบระหว่างหัตถตรวจสอบและระหว่างเครื่องมือ รวมถึงให้ผลการทดสอบเป็นค่าเชิงปริมาณ และเพื่อเป็นการพิสูจน์หัตถตรวจสอบและแบบจำลองทางคณิตศาสตร์ที่สร้างขึ้น จึงได้ประยุกต์ใช้ในการวัดอัตรารั่วภายในตัวเรือนวาล์วและการตรวจจับการกักกรองแบบสมำเสมอร่วมกับหัตถตรวจสอบเชิงพาสซีฟ โดยใช้ลำอากาศอัดสอบเทียบหัตถตรวจสอบ ผลการวิจัยพบว่าหัตถตรวจสอบและแบบจำลองทางคณิตศาสตร์ที่สร้างขึ้นสามารถประยุกต์ใช้งานได้ โดยที่การวัดอัตรารั่วภายในตัวเรือนวาล์ว ประสิทธิภาพในการทำนายอัตรารั่วทั้งในห้องปฏิบัติการและภาคสนาม พบว่าส่วนใหญ่จะให้ค่าความคลาดเคลื่อนต่ำกว่า 5 เปอร์เซ็นต์ เมื่อเทียบกับอัตราการรั่วจริง จากผลการวิจัยนี้จะทำให้ช่วยลดเวลาในการสอบเทียบเมื่อสถานะของเครื่องมือการทดสอบเปลี่ยนไป สำหรับการตรวจจับการกักกรองแบบสมำเสมอในห้องปฏิบัติการ พบว่าประสิทธิภาพในการทำนายพลังงานการกักกรองที่แหล่งกำเนิดจะให้ค่าความ

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คลาดเคลื่อนต่ำกว่า 5 เปอร์เซ็นต์เช่นกัน ซึ่งประโยชน์ที่ได้ จะเป็นแนวทางที่ทำให้สามารถแบ่งระดับความรุนแรงของการกักกร่อนเป็นค่าเชิงปริมาณได้เมื่อสภาวะการทดสอบเปลี่ยนไป

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LIST OF SYMBOLS

A	=	Area, Constance
A_{angle}	=	Incident angle loss
A_{cable}	=	Signal loss (attenuation) by cable length (mV/m)
$A_{\alpha}(\omega)$	=	Attenuation by the wave propagation path in liquid
B	=	Decay constant, Constance
C	=	Capacitance
C_{AE}	=	The constant of system gain
C_S	=	Static capacitance of PZT material
$C_{sig.con.}$	=	Amplified signal (dB) obtained from pre-amplifiers
C_{system}	=	System constant
C_1	=	System constant to be calibrated
c	=	Rayleigh wave velocity
c_b	=	Negative compliance
c_n, c_{nb}, c_{nx}	=	Compliances
c'_o	=	Longitudinal velocity
c_s	=	Compliance of the system
c_0	=	Velocity of propagation of mechanical oscillations
$\cos \theta$	=	Similarity coefficient
D	=	Displacement, Density in grams per cubic centimeter
d	=	Piezoelectric charge constant
d_o	=	Original diameter of ceramic element
d_{15}, d_{31}, d_{33}	=	Piezoelectric charge constant of each direction
E	=	Intensity of the electric field, Voltage
E_{AE}	=	Electrical energy of AE waveform
$E_i(\omega)$	=	AE energy generated from the uniform corrosion source
$E_o(\omega)$	=	AE energy detected by an AE acquisition device
E_S	=	AE source energy
E_T	=	Sound power transmission coefficient
E_1	=	Sound power of the incidence
F	=	Force
f	=	Frequency
f_n	=	Natural frequency
$G_x(f)$	=	Respective spectral density functions of the input
$G_y(f)$	=	Respective spectral density functions of the output
g	=	Piezoelectric voltage constant
g_{15}, g_{31}, g_{33}	=	Piezoelectric voltage constant of each direction
$H(f)$	=	Frequency response function describing the dynamics of the input signal transmitted through the AE sensors
h	=	Thickness of PZT material
h_o	=	Original thickness of ceramic element

I	=	Electrical current
I_e	=	Total acoustic energy received from the uniform corrosion source
I_{e0}	=	Acoustic energy at the uniform corrosion source
K	=	Average of the uniform corrosion correction factor
KE	=	The kinetic energy
K^T	=	Relative dielectric constant
k	=	Wave number
k_p	=	Electromechanical coupling factor (thin disc)
k_{15}, k_{31}, k_{33}	=	Electromechanical coupling factor of each direction
$J(f)$	=	Reciprocity parameter
J_1	=	Bessel function of the first type
L	=	Inductance
L_c	=	AE sensor coupling loss
l	=	Original length
$M(f)$	=	Free field voltage sensitivity
m	=	Mass
N	=	Number of counts
n	=	Positive integer of $\lambda_n / 4$
P	=	Power (mechanical system and electrical system)
P_{AE}	=	Inlet pressure
PE	=	The potential energy
p	=	Pressures
p_m	=	Peak value of the acoustic pressure at the unit distance from the source
Q	=	Energy of heat
Q_{AE}	=	Leakage rate
Q_E	=	Energy measurement coefficient due to the system-source frequency bandwidth effect
q	=	Electric charge
R	=	Electrical resistance of the measuring circuit
r	=	Radial of PZT material
r_m	=	Mechanical resistance
r_n	=	Resistances
S	=	Surface of the sensor face, cross section
S_{AE}	=	Valve size
$S(f)$	=	Transmission voltage response
s	=	Stiffness
T	=	Integration time of the signal, Stress
T_{ij}	=	Six components of the stress
T_{sensor}	=	AE sensor sensitivity (mV/kPa), A_{cable}
t	=	Time
$\tan \delta$	=	Dielectric Dissipation Factor
U	=	Energy of the electric field
u	=	Electrical voltage

$u(x, y, t)$	=	Out-of-plane surface displacement
u'	=	Length squared of vectors in the three-dimensional space
u_k	=	Point in an n -dimension vector space
V	=	Output voltage of AE sensor
V_0	=	Initial signal amplitude
V_t	=	Threshold voltage of the counter
v	=	Velocity
W	=	Weight loss in milligrams
W_M	=	Effective measurement bandwidth
W_S	=	Bandwidth of the artificial AE calibration source
y	=	Displacement from the equilibrium position
Z	=	Acoustic impedance
Z_c'	=	The sum of impedance
Z_e	=	Electrical impedance
Z_M	=	Impedance of backing material.
Z_m	=	Mechanical impedance
Z_1	=	Acoustic impedance of liquid
Z_2	=	Acoustic impedance of carbon steel
Z_3	=	Acoustic impedance of the wear plate
α	=	Attenuation coefficient
δ	=	Signal duration
ε	=	Permittivity or dielectric constant
ε_0	=	Absolute dielectric constant
ε^S	=	Permittivity at constant strain
ε_{33}^S	=	Permittivity for dielectric displacement in direction 3, under constant stress
ε^T	=	Permittivity at constant stress
ε_{11}^T	=	Permittivity for dielectric displacement in direction 1, under constant stress
η_x, η_y, η_z	=	Components of displacement
$\sigma_1, \sigma_2, \sigma_3,$	=	Components of tensor
$\sigma_4, \sigma_5, \sigma_6$	=	
λ	=	Wavelength
λ_n	=	Wavelength at natural frequency
θ	=	Angular coordinate
θ_{cr1}	=	The first critical angle based on Snell's law
θ_i	=	Angle of incidence
θ_t	=	Transmission angle
ρ	=	Density
τ	=	Relaxation time
ω	=	Angular frequency
ω_n	=	Resonant frequencies

φ	=	Phase difference between the force and the velocity
ζ	=	Young's modulus for an isotropic medium
ζ_i	=	Modulus of elasticity
$\zeta_{11}^E, \zeta_{33}^E$	=	Young's Modulus of PZT material
ζ	=	Damping ratio
ψ	=	Pressure sensitivity of a receiver

LIST OF TECHNICAL VOCABULARIES AND ABBREVIATIONS

AC	=	Alternating current
AE	=	Acoustic Emission
AE_{rms}	=	Root-mean-square value of the AE
AISI	=	American Iron and Steel Institute
ASTM	=	American Society for Testing and Materials
DC	=	Direct current
E_{corr}	=	Static corrosive potential
HP 89410A	=	Hewlett-Packard, A spectrum analyzer; Model 89410A
H_2SO_4	=	Sulfuric acid
I_{corr}	=	Current density
LOCAN 320	=	AE Multi-Channel Workstation
NDT	=	Nondestructive Testing
PAC	=	Physical Acoustics Corporation
PZT	=	Piezoelectric
P_{corr}	=	Electrical energy from uniform corrosion
QC	=	Quality control
R15	=	Resonant Type of AE Sensor, Model (R15)
SCC	=	Stress Corrosion Cracking
Ti	=	Titanium
WD	=	Wide band sensor
cm	=	centimeter
dB	=	decibel
dB_{AE}	=	AE decibel
Hz	=	hertz
kg	=	kilogram
kHz	=	kilohertz
kPa	=	kilopascal
MHz	=	megahertz
m	=	meter
ml/sec	=	milliliter per second
mm	=	millimeter