Monitoring of Rail/Wheel Interaction using Acoustic Emission

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Submitted for the degree of doctor of philosophy on completion of research in the School of Engineering and Physical Sciences, Mechanical Engineering, Heriot-Watt University

June 2009

Abstract

The work presented in this thesis is related to the condition monitoring of rail-wheel interaction using Acoustic Emission (AE), the principle being that both normal and abnormal rolling give rise to AE, features of which are related to the mechanical intensity of the interaction and hence the stress range (or stress intensity factor range) to which sections of track is being exposed.

Most of the work was carried out on a model wheel running on a model circular track, which was first characterised using a simulated source before studying the wave propagation from a continuously moving (wheel) source. Using a number of sensor arrays placed on the track, primary wave propagation characteristics such as wave speeds and attenuation coefficients and also secondary wave propagation characteristics such as reflection and transmission from and through the joint. A high speed camera was used to confirm, that wheel slip does not occur at the wheel speeds and loads of interest. A simple analytical model was derived using the measured wave propagation characteristics which describes the expected AE recorded at a track-mounted sensor as the wheel approaches and recedes.

Using the analytical model, the effect of increasing wheel speed and axle load on the normal rolling signal was measured. Wheel rattling was observed, particularly at lower wheel speeds and loads, and this was eliminated in some trails by introducing a spacer. The effect of minor track defects and wheel flange rubbing on the track was also studied, where the comparison of the expected normal running signal with excursions above background allowed the locations of track defects to be identified. Finally, a set of experiments were carried out with simulated wheel defects. The signals were analysed using the principle of demodulated frequency resonance and matching to the expected pulse train spectra. .

The findings of the work, along with a limited set of field tests on actual train-track interactions allows recommendations to be made for the deployment of sensors for cumulative damage monitoring on critical areas of track.

Dedication

To my Mother, Ranjanben Ashokkumar Thakkar

Acknowledgments

A lot of hard work and ample financial support requires finishing each and every research project. Though it is individual project, a well planned team work is essential to complete it successfully within given time period. Same happened with me so that I would like to express my strong gratitude to every individual of department of Mechanical Engineering from Heriot-Watt University - School of Engineering and Physical Science as they were directly or indirectly related to my project and I want to attribute my success to them as they truly deserve it.

First of all I want to thank heartily to my supervisors, Professor R.L. Reuben and Professor J.A. Steel, who treated through out my Ph.D. as friends and provided invaluable supervision to share their knowledge, guidance, ideas that encouraged me to perform at my best for every aspect of my research.

Thanks must go to my Dad (Mr. Ashokkumar N. Thakkar), my Wife (Nikita Jitendrabhai Thakkar), my family members and friends, who motivated me to complete the research with their unlimited support and love.

My special thanks go to A.I.F. Robertson, D. Dixon, R.L. Shanks, G. Knabe, K. Mackay for giving me push ups either before or during my research by working on the same project in their final year projects.

I would like to appreciate debating nature of colleague researchers Dr. P. Nivesrangsan R. Douglas, Y. Ding, N.H. Faisal, M. Shahadeh, M.S. Nashed, W. Abdou who made my subject enjoyable by providing their valuable help. I am extremely grateful to administration staff Mrs. A. Blyth, Mrs. M. Thomson, Mrs. Josie, Mrs A Campbell, Mrs. J Suttie, Mrs. I Fox, Mrs. R. Crawford and IT staff Mr. John Pritchard, Mr. Aftab Aziz, Mr. Paul Glynn for providing their daily support. At the same time I can not forget to thank technical staff of Mechanical and Electrical Engineering, Mr. A. Buchan, Mr. R. Kinsella, Mr K. Caruthers, Mr. C. Smith, Mr. A. Huston, Mr. P. Dampster and my office mates.

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Nomenclature

a, b	Semi-axes of the contact ellipse
a_0	Crack depth (m)
A	Amplitude of the 1st pulse (V)
A_0	Amplitude at source (V)
A_1	Amplitude at distance x from the source (V)
A_w	Wave amplitude (V)
da_0/dN	Crack growth rate (m/cycle)
β_1	Angle of refraction (°)
B	Amplitude of the 2nd pulse (V)
B_1	Magnetic field (Teslas)
c	Wave velocity (m/s)
c_1	Track circumference (m)
c_2	Distance between the joint and sensor (m)
C	Amplitude of the 3rd pulse (V)
C_{HF}	High frequency wave velocity (m/s)
C_{LF}	Low frequency wave velocity (m/s)
d_1	Distance from source to first sensor (m)
D	Distance between the two sensors (m)
D_1	Source to sensor distance (m)
D_r	Rolling distance (m)
E	Young's modulus
E_0	Energy of the source (V^2s)
E_1	Young's modulus of 1st elastic body
E_2	Young's modulus of 2nd elastic body
E_g	Acoustic emission energy (V^2s)
E_x	AE energy at distance x from the source (V^2s)
E_{1x}	AE energy of sensor 1 at distance x from the source (V^2s)
E_{2x}	AE energy of sensor 2 at distance x from the source (V^2s)
E_{3x}	AE energy of sensor 3 at distance x from the source (V^2s)
E_r	Energy associated with rolling (Nm)

E_t	Energy at time, t, when the moving source is x distance from sensor (V^2s)
E_{t1}	Total AE energy recorded at the sensor over the time step (V^2s)
E_T	Energy from the fixed time window, T_w, of 0.17ms (V^2s)
f	Frequency (Hz)
F_L	Lorentz force (N)
J_e	Eddy current (Amperes)
J	Joint
k	Attenuation coefficient (m^{-1})
k_1, k_2, k_3, k_c	Pulse widths
ΔK	Stress intensity exposure ($MNm^{-3/2}$)
L	Normal load (N)
m	Constant
n	Constant
n_1	Index of refraction of incident medium
n_2	Index of refraction of refraction medium
nw	Number of wheels
N	Number of fatigue cycles
N_1	Normal load (N)
p_0	Maximum contact pressure (N)
r	Distance (m)
R_c	Radius of curvature (m)
R	Reflection coefficient
R_e	Radius of track (m)
R_{c1}	Radius of curvature of 1st elastic body (m)
R_{c2}	Radius of curvature of 2nd elastic body (m)
R^2	Correlation factor
S, S_1, S_2, S_3, S_4	Sensors positions
t	Time (s)
Δt	Arrival time difference between two sensors (s)
Δt_1	Arrival time difference between wave modes (s)
T_w	Time window (s)
T	Transmission coefficient
T_c	Cycle time or period (s)

T_m	Magnitude of creep force (N)
$v(t)$	Amplitude of the AE waveform (V)
$x,\ x_1$	Source sensor distance (m)
x_{nw}	Source sensor distances (different for each wheel)
X	Longitudinal component of creep force (N)
Y	Lateral component of creep force (N)
$z_0(x,y)$	Initial contact between two curved bodies
Z_1	Acoustic impedance of Medium 1 (kg/m^{2}s)
Z_2	Acoustic impedance of Medium 2 (kg/m^{2}s)
μ	Friction coefficient
Ω_{slip}	Slip region
Ω_{stick}	Stick region
$s(x, y)$	Relative slip velocity (m/s)
$\tau(x,y)$	Tangential stress (N/m^2)
θ	Phase of creep force (°)
θ_1	Angle of incidence (°)
ϕ_1	Phase angle between 1st and 2nd pulse
ϕ_2	Phase angle between 1st and 3rd pulse

Abbreviations

AE	Acoustic emission
ALE	Adaptive line enhancer
ASTM	American society of testing materials
BCF	Bearing characteristic frequency
DAQ	Data acquisition
DFR	Demodulated frequency resonance
EDM	Electro discharge machining
EM	Electromagnetic
ES	Electrostatic
EMATs	Electro magnetic acoustic transducers
FEA	Finite element analysis
FFT	Fast Fourier transform
GCC	Gauge corner cracking
HCT	Hertz's contact theory
HSDI	High speed diesel
MGT	Mean gross tonnage
NDE	Non destructive evaluation
NDT	Non destructive testing
NI	National instruments
NOWL	No white layer
OOR	Out of round
PRD	Portable rail detector
PSD	Power spectral density
PZT	Lead zirconate titanate
RCM	Reliability centred maintenance
RCF	Rolling contact fatigue
RMS	Root mean square
rpm	Revolution per minute
RSU	Roller search unit
SEM	Scanning electron microscope

WEL	White etching layer
WL	White layer