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Methodology for assessment of serviceability of aged transmission line conductors

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METHODOLOGY FOR ASSESSMENT OF SERVICEABILITY OF AGED TRANSMISSION LINE CONDUCTORS

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by

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I hereby declare that I have not submitted this material either in whole or in part, for a degree at this or any other institution. Whilst this thesis has been prepared with the proper care, the information, advice, opinion and recommendations contained herein are offered, I accept no responsibility for the use of the information in any particular application.

GARY BRENNAN

30 NOVEMBER, 1989

ABSTRACT

The degradation of transmission line conductors is attributed to annealing, fatigue, corrosion, creep and in the case of an ACSR construction, stress redistribution in the aluminium and steel wires. A methodology for monitoring and testing for the degradation mechanisms is presented. Simple life expectancy models presented, give confidence in the long term serviceability of conductors.

The methodology and life expectancy models developed are based on examining and testing conductor samples that are representative of various stages of each of the degradation mechanisms. The conductor samples were removed from in service transmission lines that had over twenty years service experience.

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LIST OF ABBREVIATIONS

AAAC	-	All Aluminium Alloy Conductor
AAC	-	All Aluminium Conductor
ACAR	-	Aluminium Conductor Aluminium (Alloy) Reinforced
ACSR	-	Aluminium Conductor Steel Reinforced
CBL	-	Calculated Breaking Load
CONCAT	-	Continuous Catenary
CLE	-	Coefficient of Linear Expansion
EDT	-	Every Day Tension
GZ	-	Galvanized Zinc
MWT	-	Maximum Working Tension
MOT	-	Maximum Operating Temperature
NDT	-	Non Destructive Testing
SEM	-	Scanning Electron Microscopy
STESS	-	Sag Tension by Strain Summation
UTS	-	Ultimate Tensile Strength

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LIST OF SYMBOLS

The symbols used in this thesis are, as far as possible, the symbols in common use by the electrical industry and published works. In some cases, as a result of the diverse nature of the thesis, the symbols may define more than one parameter. In this regard, to assist the reader, the symbols used, have been categorised into chapters. However in achieving a consistent approach, some duplication in the list of symbols from one chapter to the next will occur.

CHAPTER ONE

E_a - modulus of elasticity of aluminium in Pa

E_s - modulus of elasticity of steel in Pa

m - ratio of cross section area of steel to the total conductor

n - ratio of cross section area of aluminium to the total conductor

z - parameter

ε - parameter

α_a - aluminium CLE in $^{o}C^{-1}$

α_s - steel CLE in $^{o}C^{-1}$

CHAPTER TWO

A - conductor cross sectional area in m^2

A_2 - conductor creep constant

C - constant

c - conductor curve constant

D_a - aluminium thermal strain in $mm.km^{-1}$

D_s - steel thermal strain in $mm.km^{-1}$

LIST OF SYMBOLS (CONT)

E	-	conductor modulus of elasticity in Pa
H	-	vertical distance between two adjacent conductor attachment points in m
K_r	-	conductor radial thermal conductivity coefficient in $W.m^{-1}.C^{-1}$
L	-	horizontal span distance in m
l	-	conductor chord length in m
L_{eff}	-	effective level span length for a non level span
L_E	-	equivalent span in m
n_1, n_2	-	conductor creep constants
R	-	d.c. resistance of conductor in $\Omega.m^{-1}$
r_c	-	radius of conductor in m
r_s	-	radius of steel core of an ACSR conductor in m
S	-	conductor sag in m
s	-	conductor stress in Pa
T	-	conductor tension in N
T_h	-	conductor horizontal tension in N
T_{AV}	-	conductor average tension in a span in N
t	-	time in hours
t'	-	conductor tension at any point in the chord length in N
$\times$	-	conductor weight load in N
ω	-	conductor weight load in N
α	-	conductor CLE in $^{o}C^{-1}$

LIST OF SYMBOLS (CONT)

θ - conductor temperature in ^{o}C

θ_c - conductor core temperature in ^{o}C

θ_s - conductor surface temperature in ^{o}C

θ_a - aluminium temperature in ^{o}C

θ_s' - steel temperature in ^{o}C

$\mu\varepsilon$ - conductor creep in $mm.km^{-1}$

δ - conductor creep constant

γ - an angle in degrees

CHAPTER THREE

A_2 - conductor creep constant

A_a - aluminium cross sectional area in m^2

A_c - conductor cross sectional area in m^2

A_{ci} - wire area constant for the ith layer

A_n - polynominal constant, where n = 1,2,3...etc.

A_s - steel cross sectional area in m^2

B_n - polynominal constant, where n = 1,2,3...etc.

BL_s - steel wire breaking load in N

BL_{ij} - breaking load of the ith wire of material j

C_a - aluminium permanent elongation in $m.m^{-1}$ in a stress strain test

C_s - steel permanent elongation in $m.m^{-1}$ in a stress strain test

E_a - modulus of elasticity of aluminium in Pa

LIST OF SYMBOLS (CONT)

E_{af} - final modulus of elasticity of aluminium in Pa

E_{cf} - final modulus of elasticity of conductor in Pa

E_{ci} - initial modulus of elasticity of conductor in Pa

E_s - modulus of elasticity of steel in Pa

E_{sf} - final modulus of elasticity of conductor in Pa

E_{si} - initial modulus of elasticity of conductor in Pa

E_w - modulus of elasticity of wire in Pa

E_x - wire axial modulus of elasticity in Pa

D - conductor diameter in m

F - conductor axial force in N

i - layer number

j - material type

L - wire length corresponding to one lay length in m

L_c - length of the centre wire from the conductor sample in m

LR - lay ratio

Load - instantaneous load in kN during a breaking load test

m - ratio of cross section area of steel to the total conductor

M_{ci} - wire mass constant for the ith layer

M_c - mass of conductor sample in $g.m^{-1}$

M_g - mass of grease or tar in g

M_z - mass of zinc in $g.m^{-1}$

MLR - mean lay ratio

n - ratio of cross section of aluminium to the total conductor

LIST OF SYMBOLS (CONT)

N_n - conductor creep constants where n = 1,2 or 3

N_{ij} - number of wires in i layer of material j

N_i - number of wires in a conductor

R - conductor layer radius in m

R_{ci} - wire resistance constant for the ith layer

S - conductor stress in Pa

S_a - aluminium stress in Pa

S_{ao} - maximum aluminium stress in Pa at initial temperature

S_{av} - conductor average stress in Pa

S_b - conductor birdcaging stress in Pa

S_c - conductor stress in Pa

S_{co} - maximum conductor stress in Pa at initial temperature

S_{kt} - conductor critical stress in Pa

S_s - steel stress in Pa

S_{so} - maximum steel stress in Pa at initial temperature

T - temperature in ^oC

t - time in hours

W_i - mass of the ith wire in g after destranding of the conductor sample and removal of all grease or tar from the ith wire

ε - conductor strain in $m.m^{-1}$

ε_L - wire strain in $m.m^{-1}$

$\mu\varepsilon$ - conductor creep in $mm.km^{-1}$

λ - lay length in m

σ - lay angle in degrees

LIST OF SYMBOLS (CONT)

α - CLE in $^{o}C^{-1}$

α_a - aluminium CLE in $^{o}C-^{1}$

α_s - steel CLE in $^{o}C^{-1}$

α' - wire CLE in ^{o}C-1

α_c - conductor temperature in ^{o}C

α_{cmax} - conductor maximum operating temperature in ^{o}C

α_{dp} - grease/tar drop point in ^{o}C

ε_L - wire strain in $m.m^{-1}$

CHAPTER 4

A - defined distance of 89 mm or 3-1/2 inches

A_a - aluminium cross sectional area in m^2

A_c - conductor cross sectional area in m^2

$a_{(i \text{ or } j)}$ - area of the wires in the left hand lay layer (i) or the right hand lay layer (j)

a_c - homogenous conductor area in m

c - distance from the neutral plane to the outermost fibre in m

d_a - aluminium wire diameter in m

d_c - conductor diameter in m

d_s - steel wire diameter in m

d_{ij} - diameter of the wire in the ith layer of material j

d_w - wire diameter in m

E_a - modulus of elasticity of aluminium in Pa

E_j - modulus of elasticity of material j

LIST OF SYMBOLS (CONT)

E_s - modulus of elasticity of steel in Pa

EI - conductor flexural rigidity in $N.m^2$

f - conductor vibration frequency in Hz

L - conductor loop length in m

M - wire torque in N.m

m - conductor mass in g

m_{ij} - number of wires in the ith layer of material j

N_i - number of wires in a conductor

N_n - fatigue life of material at a given stress level in cycles where n = 1,2,3...etc

$N_{(i \text{ or } j)}$ - number of wires in the left hand lay layer i or the right hand lay layer j

n - ratio of cross section of aluminium to the total conductor

n_a - number of alumimiun wires

n_n - proportion of material life at a given stress level in cycles where n = 1,2,3....etc

n_s - number of steel wires

R - bending radius of conductor over suspension point in m

r - conductor layer radius in m

r_{ij} - radius of the ith layer of material j

$r_{(i \text{ or } j)}$ - radius of the left hand layer i of the right hand layer j

S - Stroudal number

T - conductor tension in N

T_4 - conductor force producing rotating torque in N

v - wind velocity in $m.s^{-1}$

Y - conductor peak to peak displacement in mm

Y′ - conductor peak displacement in mm

LIST OF SYMBOLS (CONT)

y_a	-	conductor deflection in m
σ	-	conductor stress in Pa
σ_a	-	aluminium wire stringing stress in Pa
σ_b	-	conductor bending stress in Pa
σ_d'	-	conductor stress at 89mm from the suspebsion pint in Pa
$\sigma_{(i \text{ or } j)}$	-	wire stress in the left hand lay layer i or the right lay layer j
θ	-	lay angle in degrees
$\theta_{(i \text{ or } j)}$	-	lay angle in the left hand lay layer i or the right hand lay layer j

INTRODUCTION

The transmission of power in New South Wales is achieved by over 70,000 km of steel reinforced aluminium conductors of varying size. The major part of these conductors were manufactured and erected between 1955 and 1970 making some of these conductors over 30 years old.

With time, the conductors have experienced a variety of in service conditions that may have varied from emergency operating conditions creating elevated temperatures to long exposures of low velocity winds inducing aeolian vibration. In addition, the pollution levels in the NSW transmission system range from light to very heavy.

The objective of these studies was to ascertain the level of degradation of the conductors, the continued serviceability of the conductors and develop a methodology to test conductors in the future. At the same time, a simple conductor life expectancy model was developed. The methodology presented, is based on actual conductor samples, having been exposed to pollution environments ranging from light to heavy, removed from service for testing. Testing and examinations for degradation of the removed conductor samples cover metallugical examinations, wire tests and full scale conductor tests. The degradation mechanisms discussed include corrosion, fatigue, creep and annealing. Stress distribution changes in an ACSR construction is also discussed.

To assess the level of degradation of an aged conductor, the initial parameters of the conductor need to be established. Much of the discussions are devoted to establishing these initial properties of a conductor. This provides an understanding of the fundamentals of the conductor parameters and gives a greater appreciation as to the effects and consequences of conductor property changes.

In developing the methodology to assess in service conductor creep, a review of the various methods of determining conductor sag and tension was carried out. In addition, to gain a greater understanding of the fatigue mechanism of a conductor, a conductor fatigue tester was designed and constructed. Some S-N fatigue data for a AAC construction is given.

Initially a comprehensive review and appraisal of the available literature on the subject matter is presented.