Dynamics of Open and Closed Belt Conveyor Systems Incorporating Multiple Drives

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PhD Thesis

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Dynamics of Open and Closed Belt Conveyor Systems Incorporating Multiple Drives

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Statement of Originality

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Peter Robinson

5th February, 2016

For my Family

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Abstract

The incorporation of conveyor systems throughout industry has seen an increase in demand for systems that exceed the specification of conventional conveyors. This coupled with the demand to convey bulk materials over larger distances, at higher speeds and efficiencies, requires the development of a versatile design approach.

This thesis explores the design aspects associated with modern pouch conveying systems, and how they vary, and can be adapted from theories used with conventional troughed conveyors. In particular, the indentation rolling resistance (IRR) is explored in detail, as this can account for up to 60% of the drag forces of a system. This is the drag force that arises due to an asymmetric pressure distribution as the idler roll shell indents the bottom cover of the belt. The potential idler roll arrangements for a generic pouch conveying system are analysed, and compared with experimental values.

In addition to this, the drive traction attainable from suitable drive stations is analysed. Troughed conveyors typically wrap the conveyor belt around a large drive pulley, generating large amounts of traction. Given the layout of pouch conveying systems, a different approach is required, at multiple locations. As such, pouch conveyors are typically driven through simply supported drive stations, with small areas of contact with the belt. The useable traction from these point contact drives is considered.

These theories are then united and applied to a dynamic package capable of handling multiple conveyor designs. This package utilises Finite Element Modelling (FEM) to model the viscoelastic nature of the system, based on the distributed drag forces, and inputs of the conveyor. Lastly, to qualify this theory, experimental analysis is conducted on an on-site installation, and compared with the theoretical results.

Nomenclature

a	Leading edge of the idler-belt contact region	m
a_c	Carry side idler roll spacing	m
a_r	Return side idler roll spacing	m
A	Array used to define the behaviour of the nodal elements	-
A_b	Cross sectional area of the belt	m^2
b	Trailing edge of the idler-belt contact region	m
B	Belt width	m
BC	Array used to define the boundary conditions of each state	-
c	Half-width of the idler-belt contact region	m
c_b	Speed of sound in a conveyor belt	$m/_{s}$
d_{ls}	Lip seal diameter	m
d_m	Mean diameter	m
E	Elastic Modulus	Pa
E'	Storage Modulus	Pa
E''	Loss Modulus	Pa
E_b	Elastic modulus of a conveyor belt	Pa
E_{eff}	Effective elastic modulus	Pa
F_{IRR}	Drag force due to indentation rolling resistance	N
F_N	Normal Force	N
$F_{Rimdrag}$	Drag force due to bearing resistances	N
F_{Skew}	Drag force due to belt skew	N
$F_{Special}$	Drag force due to special resistances within the system	N
F_{drag}	Total drag force	N
F_{drive}	Drive force produced by motors	N
F_{flex}	Drag force due to belt and bulk solid flexure	N
F_g	Force due to gravity	N
F_i	Belt tension corresponding to node i	N
F_{ls}	Drag force due to the lip seal	N
F_s	Shear force between the upper and suspended pouch sections	N

G	Shear modulus	Pa
h	Bottom cover thickness	m
H	Damping Coefficient	$Ns/_m$
I	Identity matrix	-
I_p	Moment of inertia of the counterweight pulley	kgm^2
K	Spring constant	$N/_m$
K_f	Foundation Modulus	Pa
K_s	Static sag ratio	-
l	Height of the pouch from the lower contact of the drive wheel to the centre of gravity of the suspended mass	m
L	Idler roll spacing	m
L^*	Additional length due to sag	m
L_e	Effective length of each finite element	m
$L_{i,j}$	Width of the labyrinth seal	m
m_{red}	Reduced mass	kg
M	Nodal mass	kg
M_1	Nodal mass of a carry side element	kg
M_{11}	Nodal mass of the upper pouch element surrounding the drive system	kg
M_{12}	Nodal mass of the suspended pouch element surrounding the drive system	kg
M_2	Nodal mass of a return side element	kg
M_c	Mass of the counterweight	kg
M_{lab}	Drag moment resulting from the labyrinth seal	Nm
M_p	Mass of the counterweight pulley	kg
n	Speed of rotation	rpm
N	Number of nodes	-
N_e	Number of Elements	-
p	Pressure	Pa
P	Normal load	N
P_e	Number of Parameters	-
q	Uniformly distributed load	$N/_m$

q_b	Belt mass per unit length	kg/m
q'	Traction generated within the slip region of contact	N
q''	Traction generated within the stick region of contact	N
Q	Tractive force	N
Q_t	Conveyor throughput	t/hr
R	Radius of the counterweight pulley	m
R_1	Primary radius of an idler roll shell	m
R_2	Cross radius of an idler roll shell	m
R_3	Radius of belt curvature	m
$S(x)$	Shear distribution	Pa
t	Thickness of the belt section	m
T	Temperature	$°C$
T_b	Tension	N
T_1	Tight side tension adjacent to the drive system	N
T_2	Slack side tension adjacent to the drive system	N
T_d	Drive Torque	Nm
v	Velocity	m/s
v_{drive}	Velocity of the drive	m/s
w	Indentation of a rigid idler roll into a belt	m
w_d	Drive wheel width in contact with the belt	m
x	Displacement	m
x_c	Displacement of the counterweight	m
x_i	Displacement of the belt corresponding to node i	m
$\hat{X}$	State vector	-
z	Indentation profile	m
Z_0	Peak indentation	m
α_R	Reflection coefficient	-
α_T	Transmission coefficient	-
γ	Shear strain	-
δ	Peak belt sag	m
ε	Strain	-

$\dot{\varepsilon}$	Strain rate	s^{-1}
ε^*	Total axial strain	-
ε_1	Apparent axial strain	-
ε_s	Strain due to belt sag	-
η	Damping Coefficient	$Ns/_{m}$
θ	Angle of wrap	rad
θ_c	Rotation of the counterweight pulley	rad
μ	Coefficient of Friction	-
μ_{eff}	Effective coefficient of friction	-
ν	Poisson's ratio	-
ρ	Density	$kg/_{m^3}$
ς	The ratio between the leading and trailing edge lengths within the contact region	-
σ	Stress	Pa
$\dot{\sigma}$	Stress rate	$Pa/_{s}$
τ	Shear force	Pa
τ_i	The wave period of the individual Maxwell elements	s
υ_d	Dynamic viscosity	$Pa\,s$
υ_k	Kinematic viscosity	$Pa\,s$
ω	Angular frequency	$rad/_{s}$
Ω	Angular velocity	$rad/_{s}$