THE TRACTIVE PERFORMANCE OF A FRICTION-BASED PROTOTYPE TRACK

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SUMMARY

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In recent years, the interest in the design, construction and utilization of rubber tracks for agriculture and earth moving machinery has increased considerably. The development of such types of tracks was initiated by the efforts to invent a more environmentally friendly vehicle-terrain system. These tracks are also the result of the continuous effort to develop more cost-effective traction systems.

A rubber-surfaced and friction-based prototype track was developed and mounted on the patented modification of a new Allis Chalmers four wheel drive tractor. The track is propelled by smooth pneumatic tyres by means of rubber-rubber friction and the tractive effort of the track is mainly generated by soil-rubber friction between the rubber surface of the track elements and terrain.

The experimental track layer tractor, based on an Allis Chalmers 8070 tractor (141 kW) was tested on concrete and on cultivated sandy loam soil at 7.8%; 13% and 21% soil water content. The contact pressure and the tangential force on an instrumented track element, as well as the total torque input to one track, was simultaneously recorded during the drawbar pull-slip tests. Soil characteristics for pressure-sinkage and friction-displacement were obtained from the field tests by using an instrumented linear shear and soil sinkage device.

By applying the approach based on the classical bevameter technique, analytical methods were implemented for modelling the traction performance of the prototype track system. Different possible pressure distribution profiles under the tracks were considered and compared to the recorded data. Two possible traction models were proposed, one constant pressure model, for minimal inward track deflection and the other a flexible track model with inward deflection and a higher contact pressure at both the front free-wheeling and rear driving tyres. For both models, the traction force was mainly generated by rubber-soil friction and adhesion with limited influence by soil shear. For individual track elements, close agreement between the measured and predicted contact pressure and traction force was observed based on the flexible track model.

The recorded and calculated values of the coefficient of traction based on the summation of the traction force for the series of track elements were comparable to the values predicted from modelling. However, the measured values of drawbar pull coefficient were considerably lower than the predicted values, largely caused by internal track friction in addition to energy dissipated by soil compaction. The tractive efficiency for soft surface was also unacceptably low, probably due to the high internal track friction and the low travel speeds applied for the tests.

The research undertaken identified and confirmed a model to be used to predict contact pressure and tangential stresses for a single track element. It was capable of predicting the tractive performance for different possible contact pressure values.

Key terms: adhesion, contact pressure, rubber track, soil-rubber friction, traction, traction modelling, tractive performance.

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TABLE OF CONTENTS

CHAPTER VIII

NOMENCLATURE

A	contact area, (m^2).
b	track contact width, (m).
b_o	width of octagonal ring transducer, (m).
b_t	tyre section width, (m).
b_w	width of wheel, (m).
C	constant to relate the entrance and the exit angles.
C_a	a constant to calculate the actual speed based on r_d and π.
C_{ct}	coefficient of traction.
C_t	a constant to calculate the theoretical speed based on r_d and π.
c	soil cohesion, (Pa).
c_a	soil-rubber adhesion, (Pa).
D	wheel diameter, (m).
d	tyre diameter, (m).
E	modulus of elasticity of octagonal ring transducer material, (Pa).
e	eccentric distance of centre of gravity in longitudinal direction, (m).
F	force, (N).
F_h	drawbar pull, (N).
F_{hi}	longitudinal force on i-th track segment, (N).
F_{hmax}	maximum drawbar pull, (N).
F_t	tractive force, (N).
F_{ti}	tractive force for i-th track segment, (N).
F_{tmax}	maximum tractive effort, (N).
F_x	force in horizontal direction, (N).
F_y	force in vertical direction, (N).
f_a	frequency recorded by ground speed sensor.
f_t	frequency recorded by theoretical speed sensor.
G	sand penetration resistance gradient, (Pa/m).
H	horizontal force, (N).
h	height, (m).
i	slip as decimal.

j	tangential displacement, (m).
K	tangential deformation modulus, (m).
K_1, K_2	empirical constants for soil shear.
K_r	ratio of the residual shear stress τ_r to the maximum shear stress τ_{max}.
K_ω	shear displacement where the maximum shear stress τ_{max} occurs, (m).
k_F	constant for measuring force F for extended octagonal ring transducer.
k_P	constant for measuring force P for extended octagonal ring transducer.
k_c	Bekker sinkage parameter related to cohesion, (kN/m^{n+1}).
k_ϕ	Bekker sinkage parameter related to internal soil friction, (kN/m^{n+2}).
k_c' and k_ϕ'	dimensionless constants related to pressure-sinkage tests.
L	track contact length, (m).
L_o	half distance between two circular centres of extended octagonal ring transducer, (m).
L_t	average travel distance, (m).
ℓ	length, (m).
ℓ_t	contact length, (m).
ℓ_i	track length represented by i-th track segment, (m).
N_{cs}	wheel numeric.
N_t	revolutions of drive wheel.
n	exponent of terrain deformation for Bekker sinkage equations
n_p	number of periods.
P	force, (N).
P_{in}	input power, (kW).
P_{out}	output power, (kW).
p	contact pressure, (Pa).
p_1	contact pressure at the front of the track, (Pa).
p_2	contact pressure at the rear of the track, (Pa).
p_c	pressure due to stiffness of the tyre carcass, (Pa).
p_i	contact pressure for i-th track segment, (Pa).
p_{ti}	tyre inflation pressure, (Pa).
$p(x)$	contact pressure on track at distance x (meter) from front, (Pa).
R	radius of deformed track between front and rear tires, (m).

R_c	motion resistance due to soil compaction, (N).
R_e	external track resistance, (N).
R_i	internal track resistance, (N).
R_r	total motion resistance, (N).
r	wheel radius, (m).
r_d	effective radius of the drum to measure ground speed, (m).
r_i	radius for i-th track segment, (m).
r_o	mean radius of octagonal ring, (m).
r_r	rolling radius of wheel, (m).
r_t	effective rolling radius of the track drive wheel, (m).
S_t	total slip of track as decimal.
T	torque, (N·m).
T_0	track pre-tension, (N).
t	time, (second).
t_o	thickness of octagonal ring transducer, (m).
V	forward velocity of tractor, (m/s).
V_a	absolute velocity, (m/s).
V_j	slip velocity, (m/s).
V_t	theoretical velocity, (m/s).
W	total vertical load, (N).
W_f	vertical load on front wheels, (N).
W_i	vertical load on i-th track segment, (N).
W_r	vertical load on rear wheels, (N).
X	projected distance in horizontal direction, (m).
x	distance, (m).
Z	vertical difference in height of contact circle between front and rear wheels, (m).
Z_r	depth of rut, (m).
z	sinkage, (m).
z_0	wheel sinkage, (m).
z_f	sinkage of track front, (m).
z_{f0}	initial sinkage of track front, (m).

z_r	sinkage of track rear, (m).
z_t	track sinkage, (m).
α	angle, (rad).
α_{1f}	entrance angle of front tire, (rad).
α_{2f}	exit angle of front tire, (rad).
α_{1r}	entrance angle of rear tire, (rad).
α_{2r}	exit angle of rear tire, (rad).
α_i	entrance angle of i-th track segment, (rad).
α_{i+1}	exit angle of i-th track segment, (rad).
β	tilt angle, (rad).
γ_s	unit weight of soil, (N/m^3).
δ	angle of rubber-soil friction, (degree).
$\varepsilon_{\phi P}$	strain caused by force P.
$\varepsilon_{\phi F}$	strain caused by force F.
η	tractive efficiency.
θ	angle, (rad).
θ_0	wheel entrance angle, (rad).
μ	traction coefficient.
μ_g	gross traction coefficient.
μ_φ	friction coefficient between contact surfaces.
π	wrap angle, (180°).
ρ	motion resistance ratio.
σ	contact pressure, (Pa).
τ	shear stress, (Pa).
τ_f	frictional stress, (Pa).
τ_{fi}	frictional stress for i-th segment of track, (Pa).
τ_{fmax}	maximum frictional stress, (Pa).
τ_{max}	maximum shear stress, (Pa).
τ_r	residual shear stress, (Pa).
ϕ	angle of soil internal shearing resistance, (degree).

ϕ_F	nodal angle for measuring force F on octagonal rings, (degree).
ϕ_P	nodal angle for measuring force P on octagonal rings, (degree).
ψ	tyre deflection, (m).
ω	angular velocity, (rad/s).
ω_d	angular speed of the drum for measuring ground speed, (rad/s).
ω_t	theoretical angular velocity, (rad/s).