THE TRACTIVE PERFORMANCE OF A
FRICITION-BASED PROTOTYPE TRACK

TINGMIN YU

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SUMMARY

THE TRACTIVE PERFORMANCE OF A FRICTION-BASED PROTOTYPE TRACK

Supervisor:  Professor H.L.M. du Plessis  
Department:  Civil and Biosystems Engineering  
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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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<tr>
<td>A</td>
<td>contact area, (m^2).</td>
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<tr>
<td>b</td>
<td>track contact width, (m).</td>
</tr>
<tr>
<td>b_o</td>
<td>width of octagonal ring transducer, (m).</td>
</tr>
<tr>
<td>b_t</td>
<td>tyre section width, (m).</td>
</tr>
<tr>
<td>b_w</td>
<td>width of wheel, (m).</td>
</tr>
<tr>
<td>C</td>
<td>constant to relate the entrance and the exit angles.</td>
</tr>
<tr>
<td>C_a</td>
<td>a constant to calculate the actual speed based on (r_d) and (\pi).</td>
</tr>
<tr>
<td>C_t</td>
<td>coefficient of traction.</td>
</tr>
<tr>
<td>C_t</td>
<td>a constant to calculate the theoretical speed based on (r_d) and (\pi).</td>
</tr>
<tr>
<td>c</td>
<td>soil cohesion, (Pa).</td>
</tr>
<tr>
<td>c_a</td>
<td>soil-rubber adhesion, (Pa).</td>
</tr>
<tr>
<td>D</td>
<td>wheel diameter, (m).</td>
</tr>
<tr>
<td>d</td>
<td>tyre diameter, (m).</td>
</tr>
<tr>
<td>E</td>
<td>modulus of elasticity of octagonal ring transducer material, (Pa).</td>
</tr>
<tr>
<td>e</td>
<td>eccentric distance of centre of gravity in longitudinal direction, (m).</td>
</tr>
<tr>
<td>F</td>
<td>force, (N).</td>
</tr>
<tr>
<td>F_h</td>
<td>drawbar pull, (N).</td>
</tr>
<tr>
<td>F_h_i</td>
<td>longitudinal force on i-th track segment, (N).</td>
</tr>
<tr>
<td>F_h_max</td>
<td>maximum drawbar pull, (N).</td>
</tr>
<tr>
<td>F_t</td>
<td>tractive force, (N).</td>
</tr>
<tr>
<td>F_t_i</td>
<td>tractive force for i-th track segment, (N).</td>
</tr>
<tr>
<td>F_t_max</td>
<td>maximum tractive effort, (N).</td>
</tr>
<tr>
<td>F_x</td>
<td>force in horizontal direction, (N).</td>
</tr>
<tr>
<td>F_y</td>
<td>force in vertical direction, (N).</td>
</tr>
<tr>
<td>f_a</td>
<td>frequency recorded by ground speed sensor.</td>
</tr>
<tr>
<td>f_t</td>
<td>frequency recorded by theoretical speed sensor.</td>
</tr>
<tr>
<td>G</td>
<td>sand penetration resistance gradient, (Pa/m).</td>
</tr>
<tr>
<td>H</td>
<td>horizontal force, (N).</td>
</tr>
<tr>
<td>h</td>
<td>height, (m).</td>
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<tr>
<td>i</td>
<td>slip as decimal.</td>
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j  tangential displacement, (m).
K  tangential deformation modulus, (m).
K₁, K₂  empirical constants for soil shear.
Kₗ  ratio of the residual shear stress τᵣ to the maximum shear stress τₘₐₓ.
Kₒ  shear displacement where the maximum shear stress τₘₐₓ occurs, (m).
kᵉ  constant for measuring force F for extended octagonal ring transducer.
kᵗ  constant for measuring force P for extended octagonal ring transducer.
kₑ  Bekker sinkage parameter related to cohesion, (kN/mⁿ⁺¹).
kᵦ  Bekker sinkage parameter related to internal soil friction, (kN/mⁿ⁺²).
kₑ’ and kᵦ’  dimensionless constants related to pressure-sinkage tests.
L  track contact length, (m).
Lₒ  half distance between two circular centres of extended octagonal ring transducer, (m).
Lₜ  average travel distance, (m).
ℓ  length, (m).
ℓᵢ  contact length, (m).
ℓᵢ  track length represented by i-th track segment, (m).
Nₑₙ  wheel numeric.
Nᵣ  revolutions of drive wheel.
n  exponent of terrain deformation for Bekker sinkage equations
nₚ  number of periods.
P  force, (N).
Pᵢₙ  input power, (kW).
Pₒᵤᵣ  output power, (kW).
p  contact pressure, (Pa).
p₁  contact pressure at the front of the track, (Pa).
p₂  contact pressure at the rear of the track, (Pa).
pₑ  pressure due to stiffness of the tyre carcass, (Pa).
pᵢ  contact pressure for i-th track segment, (Pa).
pᵢᵣ  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).

$R_t$ 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).
$\alpha$  angle, (rad).
$\alpha_{1f}$  entrance angle of front tire, (rad).
$\alpha_{2f}$  exit angle of front tire, (rad).
$\alpha_{1r}$  entrance angle of rear tire, (rad).
$\alpha_{2r}$  exit angle of rear tire, (rad).
$\alpha_i$  entrance angle of i-th track segment, (rad).
$\alpha_{i+1}$  exit angle of i-th track segment, (rad).
$\beta$  tilt angle, (rad).
$\gamma_s$  unit weight of soil, (N/m$^3$).
$\delta$  angle of rubber-soil friction, (degree).
$\varepsilon_{4P}$  strain caused by force P.
$\varepsilon_{4F}$  strain caused by force F.
$\eta$  tractive efficiency.
$\theta$  angle, (rad).
$\theta_0$  wheel entrance angle, (rad).
$\mu$  traction coefficient.
$\mu_g$  gross traction coefficient.
$\mu_{\phi}$  friction coefficient between contact surfaces.
$\pi$  wrap angle, (180°).
$\rho$  motion resistance ratio.
$\sigma$  contact pressure, (Pa).
$\tau$  shear stress, (Pa).
$\tau_f$  frictional stress, (Pa).
$\tau_{fi}$  frictional stress for i-th segment of track, (Pa).
$\tau_{f\text{max}}$  maximum frictional stress, (Pa).
$\tau_{\text{max}}$  maximum shear stress, (Pa).
$\tau_r$  residual shear stress, (Pa).
$\phi$  angle of soil internal shearing resistance, (degree).
$\phi_F$ nodal angle for measuring force $F$ on octagonal rings, (degree).

$\phi_P$ nodal angle for measuring force $P$ on octagonal rings, (degree).

$\psi$ tyre deflection, (m).

$\omega$ angular velocity, (rad/s).

$\omega_d$ angular speed of the drum for measuring ground speed, (rad/s).

$\omega_t$ theoretical angular velocity, (rad/s).