THE ANNALS OF “DUNAREA DE JOS” UNIVERSITY OF GALATI
FASCICLE XIV MECHANICAL ENGINEERING, ISSN 1224-5615
2002

RESPONSE BEHAVES OF EARTHMOVING VEHICLE WHERE THE SLIP RATIO ARE VARIATION LINEAR

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ABSTRACT

In this paper, the autor conceptualize the loader equations of motion for dynamic analysis of traction system where the slip ratio are variation linear. The wheel loader simulation model was formulated in terms of a multibody system.

1. Introduction

Wheel loaders (fig. 1) are often used to extract and load loose aggregate or cohesive materials from piles or hard banks and to dump the loaded material into on- or off-highway trucks.

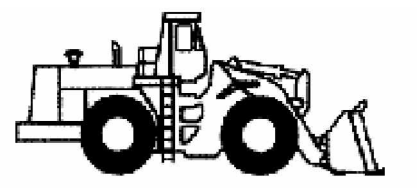

Figure 1. Wheel loader

The machine constructions model consists of vehicle dynamic model, tire model (with longitudinal tire force model) and a operating force model (fig. 2).

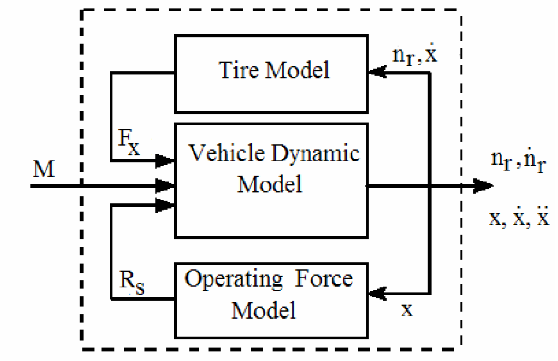

Figure 2. Model of drive load

2. Equations of motion of loader

A simplified quarter-vehicle dynamics model can be classified as rotational dynamics and translational dynamics:

$$\begin{cases} J_r \cdot \dot{n}_r + b_r \cdot n_r = M - \mathrm{sgn}(n_r) \cdot M_r - F_x \cdot r_d \\ m\ddot{x} + \frac{1}{2}\rho \cdot C \cdot A \cdot \dot{x}^2 = F_x - \mathrm{sgn}(\dot{x}) \cdot F_f \end{cases} \quad (1)$$

where

J_r - the wheel moment of inertia,
b_r - the wheel damping,
n_r - the wheel angular velocity,
M - the driving torque applied to the wheel,
M_r - rolling resistance moment,
F_x - the tire longitudinal force,
r_d - the wheel rolling radius,
m - the mass of the 1/4 vehicle,
x - the vehicle displacement,
A - the cross sectional area of the 1/4 vehicle,
C - the air drag coefficient of the vehicle,
ρ - the air density,
F_f - rolling resistance force.

The Magic Formula Tire Model [2] is capable of producing force and moment characteristics of a tire at certain slip conditions as shown in the following equation:

$$F_x = G \cdot \sin\left(F \cdot \mathrm{arctg}\left(E \cdot \lambda - H \cdot \left(E \cdot \lambda - \mathrm{arctg}(E \cdot \lambda)\right)\right)\right) \quad (2)$$

where E is the stiffness factor, F is the shape factor, G is the peak factor, and H is the curvature factor. Furthermore, when vehicle is in acceleration mode, the slip ratio λ is defined as:

$$\lambda = 1 - \frac{\dot{x}}{n_r r_d} \quad \text{for} \quad n_r r_d > \dot{x} \quad (3)$$

Figure 3 shows slip ratio versus tire longitudinal force obtained from Equation 3.

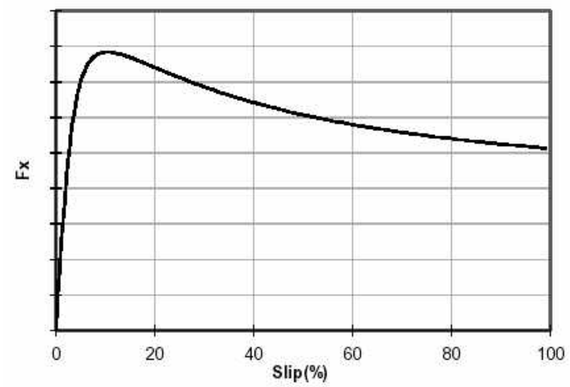

Figure 3. Variation of tractive effort with longitudinal slip of a tyre

At low slip ratio, the relationship to longitudinal force is pretty much linear up to a certain point, approximately 10%. Beyond 10%, the relationship exhibits nonlinearity as the slip ratio increases. However this characteristic is that of an on-road vehicle. Data for an earthmoving vehicle tire model in off-highway condition is not presently available and is the subject of future work.

Figure 4 shows an example of simulation results for the load dynamics of a typical 4WD wheel loader. Parameter values that are used to produce these simulation results are presented in Table 1.

Table 1: Drive load parameter values

Parameter	Values	Parameter	Values
A	4 m^2	E	0.619
B	0.171	J_r	20 kgm^2
b_r	15 Nms/rad	m	3250 kg
C	0.4	r_d	0.7 m
D	0.3	ρ	1.2 kg/m^2

This example corresponds to a normal case in an earthmoving vehicle where the slip ratio falls in the linear portion of the Magic Formula Tyre Model. At this condition, the vehicle's tyre has sufficient traction to move the vehicle. The angular and linear speed response behaves similar to a first-order system response.

3.Conclusions

The performance of an wheel loader is strongly dictated by the conditions of interaction between the machine, road and the given pile of soil. For example, the resistance faced by an loader bucket as it attempts to penetrate the soil pile may vary significantly depending upon, the properties of the excavation media (e.g. density and hardness), the soil pile geometry, and the distribution of particle sizes and shapes.

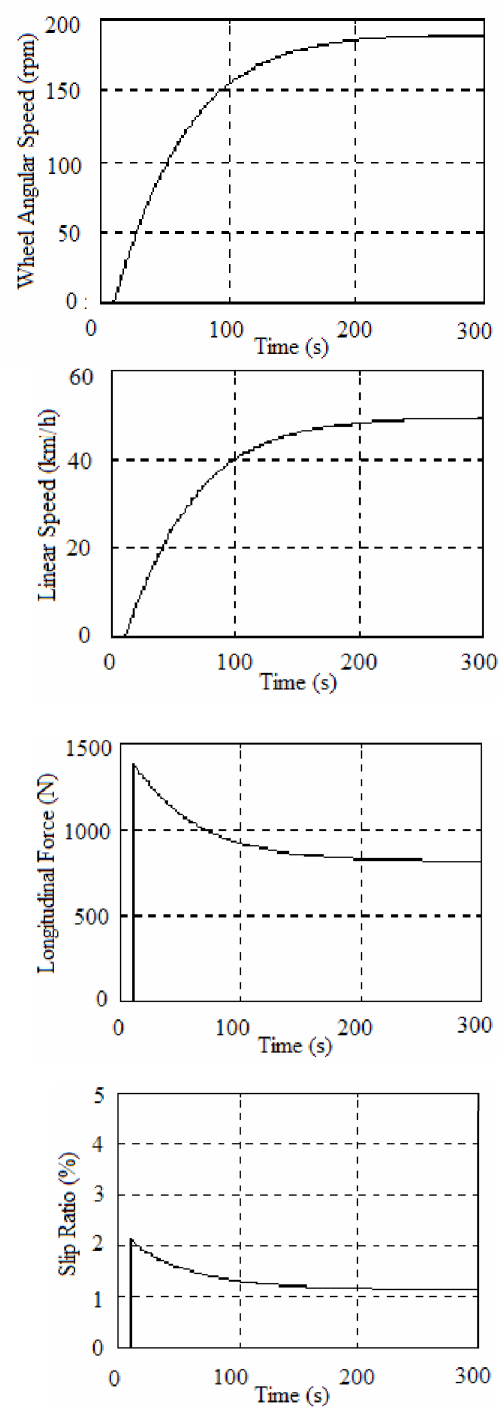

Figure 4. Drive load dynamic simulation responses

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