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Performance evaluation of a wire mesh wheel on deformable terrains

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Abstract

Because of the unique lunar environment, a suitable wheel for lunar rover decides the rover's trafficability on deformable terrains. The wire mesh wheel (hereinafter referred to as WMW) has the advantages of light weight and superior stability, been widely adopted for lunar rovers. But a comprehensive research on performance of WMW on deformable terrains has not been conduct. This paper would provide particular study on a type WMW, including quasi-static pressure-sinkage test and driving performance. A novel pressure-sinkage model for the WMW on deformable soils was presented. In order to investigate the sinkage characteristics of the WMW, tests were performed using a single-wheel testbed for the WMW with different loads and velocities. The effects of load and velocity on sinkage were analyzed, and the relationship between real and apparent sinkage was presented. The research on traction performance of WMW under different slip ratios (0.1–0.6) was also conducted, contrast tests were proceed by using a normal cylindrical wheel (hereinafter referred to as CW). The traction performance of WMW is analyzed using performance indices including wheel sinkage, drawbar pull, driving torque, and tractive efficiency. The experimental results and conclusions are useful for optimal WMW design and improvement/verification of wheel–soil interaction mechanics model.

Keywords: Wire mesh wheel; Pressure sinkage; Traction performance; Simulant regolith; Terramechanics

1. Introduction

Since 1970s, different types of wheeled vehicles were used on the lunar surface. The missions for these vehicles were completely different, and accordingly they had dissimilar wheel designs (Asnani et al., 2009). Among them, the wire mesh wheels had been widely for in lunar vehicles. Fig. 1 lists four types of wire mesh wheel, the first (Fig. 1a) was the rigid-rim wire mesh wheel of Lunokhod (the Russian made robotic rover) (Gromov et al., 2003). The second wheel (Fig. 1b) had been used in the Lunar Roving Vehicle (the American made lunar rover), which using large flexible wire mesh wheels with stiff inner frames to prevent over-deflection (Asnani et al., 2009). The last two wheels were flexible wire mesh tire, which was designed by Jilin University (Fig. 1c) Chen, 2007 and Harbin Institute of Technology (Fig. 1d), respectively (Fan et al., 2014).

Wire mesh wheel generally had a solid hub with a woven wire carcass, which made it had the advantages of low mass. The wire mesh tread also helped clear the soil on the wheel and mitigate soil buildup in front of the wheel. However, there was very little study on performance of the wire mesh wheel on deformable terrain. Vivake estimated the mobility of different wire mesh wheels by initial testing. Results showed that the wire mesh wheel developed more drawbar pull than the hoop spring wheel on the soft terrain, which provides a technical basis for developing wheel for manned lunar roving vehicle (Asnani et al., 2009). According to the Lunar Scientific Surveyor Module (LSSM) requirements (GM, 1967), the wire mesh was judged to be one of the most suitable designs. Therefore,

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Nomenclature

A	the wheel-tracking area (mm^2)
a_0, a_1, a_2	coefficients used for calculating A
b	width of wheel (m)
c	soil cohesion (N/m^2)
D	wheel diameter (m)
k	Bernstein–Goriatchkin sinkage modulus (N/m^{n+2})
$\hat{k}$	proposed sinkage modulus ($N/m^{\hat{n}+\hat{m}+2}$)
k'	proposed sinkage modulus ($N/m^{n'+2m'}$)
k_c	cohesive modulus of sinkage (N/m^{n+1})
k_φ	frictional modulus of sinkage (N/m^{n+2})
k_c'	dimensionless cohesive modulus of sinkage (–)
k_φ'	dimensionless frictional modulus of sinkage (–)
$\hat{m}$	diameter exponent (–)
m'	wheel-tracking area exponent (–)
n	sinkage exponent (–)
$\hat{n}$	proposed sinkage exponent (–)
n'	proposed sinkage exponent (–)
$p(z)$	normal wheel load (N)
r	wheel radius (m)
s	wheel slip ratio (–)
S	sensitivity coefficient to the wheel diameter-to-width ratio (–)
T	wheel driving torque (N m)
W	vertical wheel load (N)
z	wheel actual sinkage (m)
z'	wheel apparent sinkage (m)
$\sigma(z)$	stress where sinkage is z (N/m^2)
γ	soil weight density (N/m^3)
λ	proportion coefficient (–)
φ	internal angle of friction (deg)
θ	angle along wheel-soil contact arc (deg)
θ_s	static wheel-soil contact angle (deg)
v	wheel velocity (m/s)
ω	wheel rotate speed (rad/s)
TE	wheel tractive efficiency
F_{DP}	wheel drawbar pull

it is important to investigate the performance of the wire mesh wheel on deformable terrain. This provides a technical basis for wheel design and further development for lunar roving vehicle which adapts deformable terrain on the lunar surface.

Predicting wheel–soil interaction performance from the knowledge of terramechanics is of great importance to mechanical design/evaluation/optimization, dynamics simulation, soil parameter identification, and locomotion control, path following, and even to path planning of rovers (Ding et al., 2011). Therefore, In Section 2 of this paper reviews some of the most prevalent pressure–sinkage models to date. Section 3 conducts the investigation on pressure–sinkage performance of WMW, and established a new improved pressure–sinkage model. Section 4 describes the experimental setup and procedure used to evaluate the traction performance of WMW. Section 5 analyses the results of an investigation into sinkage and traction performance of WMW. Section 6 presents the summary and conclusions of this paper.

2. Terramechanics pressure–sinkage models

The pressure–sinkage models were developing for predicting wheel load–soil sinkage curves in a given soil condition for a steady-state penetration (Lyasko, 2011). They are used to derive sinkage and resistance formulae, which are in turn used to derive performance metrics such as thrust and drawbar pull.

The Bernstein–Goriatchkin model (Bekker, 1956; Ageikin, 1987) was the empirical pressure–sinkage model relationship for predicting a rigid plate load–soil sinkage curve, which also was the baseline pressure-sinkage model used in terramechanics.

$$\sigma(z) = kz^n \tag{1}$$

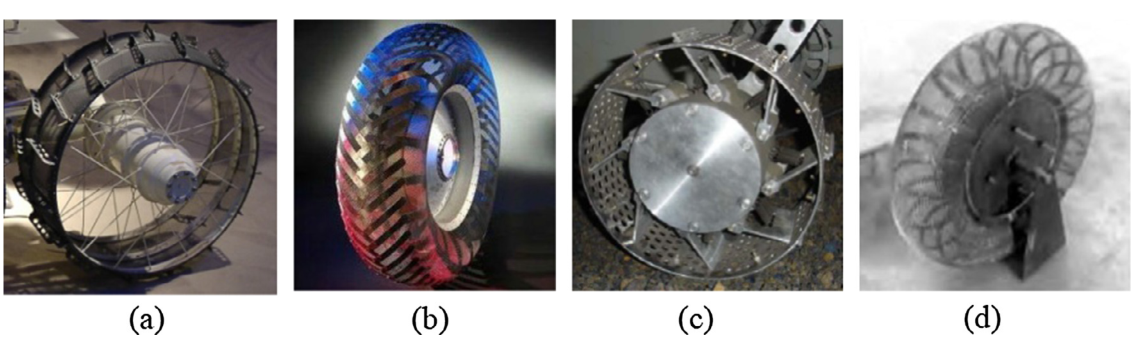

Fig. 1. Wire mesh wheels.