Available online at www.sciencedirect.com

ScienceDirect

Journal of Terramechanics xxx (2018) xxx–xxx

Journal of Terramechanics

www.elsevier.com/locate/jterra

Systematic design and development of a flexible wheel for low mass lunar rover

Gaurav Sharma *, Sidharth Tiwary, Abhishek Kumar, H.N. Suresha Kumar, K.A. Keshava Murthy

Spacecraft Mechanisms Group, ISRO Satellite Centre, Bangalore, India

Received 6 March 2017; received in revised form 8 August 2017; accepted 9 December 2017

Abstract

Low mass compact rovers provide cost effective means to explore extra-terrestrial terrains. Use of flexible wheels in such applications where the wheel size is restricted, improves traction at reduced slip and sinkage. Design of a flexible wheel for a given mission is a challenging task requiring consideration of stiffness of rim and spokes, stress induced in the wheel, chassis movement during wheel rotation and the operating mode of the wheel. Also, accurate mathematical models are required to save design and development time and reduce the number of prototypes for selection. It is observed that most of the research papers deal with performance testing of flexible wheels and information on analytical formulation is scarce. Therefore, in the present work, a methodology has been formulated to systematically design a flexible wheel for a low mass lunar rover. The prototype performance is tested and compared with analytical estimates and reasons for difference are investigated. Paper contains details of design criteria, mathematical modelling, realisation of wheel prototype, test fixture and analysis test comparison. Authors believe that this work provides a useful aid to the designer to systematically design flexible wheels for low mass lunar rovers.

Keywords: Lunar rover; Flexible wheel; Analysis; Testing

1. Introduction

Small sized rovers with low mass and high agility provide cost effective means to explore extra terrestrial terrains. For a light weight rover with volume constraints, the wheel size gets limited which makes the rover slip on the soft soil due to increased sinkage and soil resistance. Wheel flexibility can improve the tractive performance of the rover on soft soil by increasing the contact area and reducing sinkage. Wong (2001) has shown that reduced inflation pressure of pneumatic tyres results in reduced rolling resistance on sand due to reduced ground penetration. It is also asserted that the average ground pressure of the tyre should be less than the critical ground pressure so that the wheel operates like an elastic wheel (Wong, 2010). The average ground pressure is derived from experiments or finite element analysis based evaluation of contact area of wheel over soil. Same concept is used by Yalda Favaedi et al. to predict the tractive response of metallic flexible wheels (Favaedi et al., 2011). In the earliest rover missions, flexible metallic wheels made from spring steel wire mesh were used in Lunar Roving Vehicle (LRV) by NASA Asnani et al. (2009). To arrive at this design, candidate wheel designs like wire mesh wheel, hoop wheel and spiral wheel were studied. Among the future interplanetary missions, Nildeep et al. have studied eight flexible wheel and eight rigid wheel concepts and evaluated their performance

* Corresponding author at: Spacecraft Mechanisms Group, ISRO Satellite Centre, Bangalore 560017, India.
E-mail address: gsrs@isac.gov.in (G. Sharma).

https://doi.org/10.1016/j.jterra.2017.12.002
0022-4898/

using Traction Prediction Module (TPM) (Patel et al., 2010). Their analysis indicates that flexible wheels provide superior traction performance compared to the rigid wheels under identical operating conditions. In AMALIA mission, which is one of the candidates for Google lunar X Prize challenge, an innovative flexible wheel concept has been considered for a small wheel (Torre et al., 2010). A non linear finite element model of metallic wheel has been developed and analysed for resulting displacement. Same methodology has been used for preliminary assessment of a small robotic rover for Titan exploration (Genta and Genta, 2011). Kojiro Iizuka et al. have measured the performance of flexible wheel with hoops on a slope and demonstrated that flexible wheel performs better compared to rigid wheel in terms of increased slope climbing capability at reduced wheel slip (KojiroIizuka et al., 2008; KojiroIizuka and Kubota, 2009).

A flexible wheel consists of a rigid hub that houses the motor, a flexible rim usually with grousers and flexible spokes connecting the rim to the hub. For a flexible wheel to perform nominally on soft terrain, it should meet the following functional and structural requirements:-

- Wheel should be flexible enough such that the average ground pressure is less than the critical soil pressure ensuring that it rolls as a flexible wheel with flat contact patch on terrain. Otherwise, it behaves as a rigid wheel.
- Increase in wheel-terrain contact should result in a substantial increase in the traction in line with the mission requirement of slope and obstacle climbing capability and at the same time should not get dissipated entirely in flexing and unflexing of wheel.
- Radial wheel stiffness should be uniform along the wheel circumference to limit the vertical chassis movement during rover motion.
- Wheel should be stiff enough to ensure jerk free motion during steering i.e. the axial and tangential stiffness should be high.
- The stresses induced in the wheel should be within the allowable limits.

From literature survey, it is observed that most of the research papers deal with the performance testing of flexible wheels and information on analytical formulation is scarce. Moreover, systematic procedure to develop flexible wheels supported by analysis test correlation is not available. In the present work, an attempt has been made to systematically study the influence of various design parameters of a flexible wheel on its performance on soft terrain. This includes rim and spoke thickness, spoke configuration and orientation, height of grousers and number of grousers. A design criterion is evolved for the selection of flexible wheel for a given mission which is supported through finite element analysis and closed form calculations. The best performing wheel is fabricated and experimentally tested to validate the analytical estimates. The test is carried out on a compact, low cost test fixture housing lunar soil simulant JSC-1A. The set-up is configured to vary the load and resistance on wheel and allows measurement of wheel slip, drawbar pull, sinkage and drive torque. The paper is organised as follows. Section 2 describes the design criterion and mathematical modelling to evaluate the performance of flexible wheel. In Section 3, the design, development and fabrication of wheel prototype is discussed. Section 4 explains the features of the test fixture. In Section 5, test results comparison with analytical predictions is discussed.

2. Design criterion and mathematical modelling

A flexible wheel consists of a rigid hub housing the motor, flexible rim and flexible spokes connecting rim to the hub (Fig. 1). Grousers are generally added to the rim to improve the traction in the soil. This section explains the design criterion and mathematical modelling formulated to quantify the design parameters.

2.1. Design criterion

At the initial design stage, the size of the wheel can be decided based on the volumetric constraints of the rover. In the present study, wheel radius and width are taken as 90 mm and 50 mm respectively for a rover mass of 20 kg. The variables involved in the design of a flexible wheel are shown in Fig. 2.

Material selection is based on the influence of radiation, pressure and temperature extremes on the structural integrity of the material in the extra-terrestrial environment.

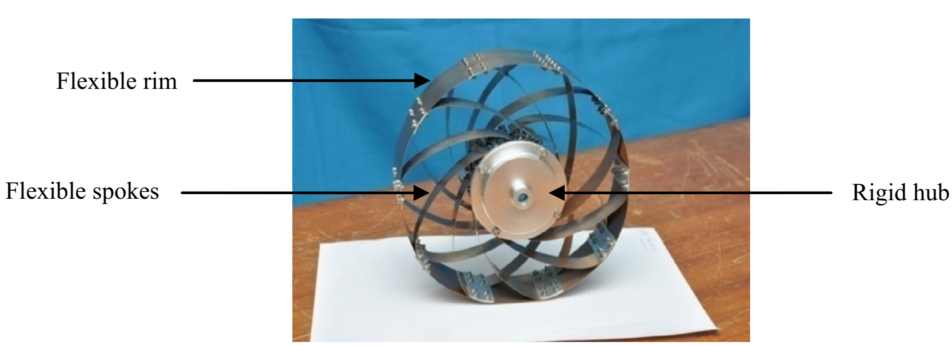

Fig. 1. Typical flexible wheel.

Please cite this article in press as: Sharma, G et al., Systematic design and development of a flexible wheel for low mass lunar rover, J Terramechanics (2018), https://doi.org/10.1016/j.jterra.2017.12.002