Indian National Society for Aerospace and Related Mechanisms

BANGALORE CHAPTER

E-NEWSLETTER

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From the Editor

Dear Member,

In the year 2012, two solar array and SAR antenna deployment mechanisms of RISAT spacecraft, two solar array and antenna deployment mechanisms of GSAT 10 spacecraft developed by the Spacecraft Mechanisms Group, ISAC were deployed in space. The editorial committee congratulates the past and present members of Spacecraft Mechanisms Group, ISAC for their commendable achievements.

This issue brings out an article titled *"Prediction of Grouser Wheel Performance on Lunar Soil"*. The wheel surface of rover must grip the soil preventing slip between wheel and the soil. This paper presents characterization of parameters like the variation of drawer pull and drive torque with slip for smooth wheel and grouser wheel on lunar soil, which governs the mobility of rover.

In July 2012, INSARM Bangalore Chapter organized a guest lecture on aerospace mechanism with the theme - *Landing gear mechanism* at ISRO Satellite Centre, Bangalore. The first lecture was given by Sri. V.N. Dinakaran, Consultant, INFOSYS, Bangalore and second lecture by Sri. Karunanidhi, Consultant, Landing gear, ARDC, The seminar was well attended and appreciated.

I am happy to inform that the INSARM member *Smt. Subhalakshmi Krisnamoorty*, Head, VSED, LEOS, ISRO Satellite Centre is the recipient of *IETE Smt. Manorama Rathore Memorial Award – 2011* for her significant achievements in the field of electronics and communication. The editorial committee congratulates for her outstanding achievement.

This news letter is intended to be a platform for the exchange of information regarding the current developments, new ideas and novel concepts in the area of mechanisms and related field through active participation of members. I request all INSARM members to contribute actively technical articles related to mechanisms to enhance the technical value of the e-new letter.
With best regards,

Dr. B.P. Nagaraj
Chief Editor

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Quote:

"Innovation comes only from readily and seamlessly sharing information rather than hoarding it."

By Tom Peters

FROM INSARM BANGALORE CHAPTER

PREDICTION OF GROUSER WHEEL PERFORMANCE ON LUNAR SOIL

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Introduction

Wheeled vehicles traversing over rough unknown terrain have many applications in the field of space exploration, defense and mining. Terramechanics is the study of the overall performance of a machine in relation to its operating environment and the terrain. The tractive performance of a vehicle over unstructured terrain is based on terrain - vehicle mechanics. Thus soil parameters play an important role in estimating vehicle drawbar pull and wheel drive torque. Prediction of wheel performance with soil for interplanetary missions is one of the important factors, which governs the mobility of rover.

The preliminary model for soil wheel interaction was developed and improved based on experimental data by [1]. The soil-wheel stresses and deformation patterns of soil beneath a rigid wheel are investigated [2]. The technique for identifying soil parameters for a wheeled vehicle traversing on unknown terrain was developed by Hutangkabodee [3]. The key soil parameters like internal friction angle, shear deformation modulus, and pressure-sinkage coefficient are required for predicting vehicle drawbar pull and wheel drive torque, which in turn can be used for traversability prediction, traction control, and performance optimization of a wheeled vehicle on unknown terrain.

Objectives

Based on Bekker's theory of Terramechanics, for rigid wheel rolling on soft terrain (Lunar surface), the present objectives are,

- To analyze the traversing characteristic behavior of wheel with soil by estimating "Drawbar pull "and "Drive Torque".
- To study the characteristic of wheel by introducing grousers (Local projections) on its surface.

Objectives are achieved by solving the Wong and Recee mathematical models through numerical technique, using MATLAB. Code generated for smooth and grouser wheels to predict the wheel performance.

Smooth wheel model

Construction of wheel-soil interaction model is basically, resolving the deformation into vertical and horizontal directions and describing them with pressure sinkage (soil related property), normal, shear stress characteristics,

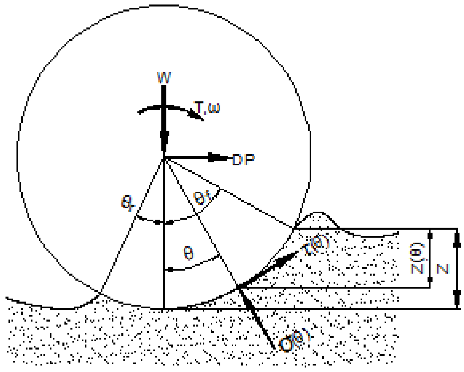

Figure 1: Diagram showing forces acting on a loaded wheel[2]

W	- Vertical Load
T	- Driving Torque
DP	- Drawbar Pull (Force)
ω	- Angular Velocity of wheel
σ (θ)	- Normal Stress at θ
τ (θ)	- Shear Stress at θ
z	- Sinkage
θ_f, θ_r,	- wheel to soil contact angle(Entry & Exit)
r	- Radius of wheel
b	- Width of wheel

From Figure 1, by resolving forces in vertical direction, it is possible to estimate sinkage (z) of wheel. DP is estimated through the equation obtained from resolving forces in horizontal direction. The equations are as follows,

$$W = rb\left(\int_{\theta r}^{\theta f} \sigma(\theta)\cos\theta\,.d\theta + \int_{\theta r}^{\theta f} \tau(\theta) sin\theta. d\theta\right) - (1)$$

$$DP = rb\left(\int_{\theta r}^{\theta f} \tau(\theta) cos\theta. d\theta - \int_{\theta r}^{\theta f} \sigma(\theta) sin\theta. d\theta\right) - (2)$$

$$T = r^2 b \int_{\theta r}^{\theta f} \tau(\theta) cos\theta. d\theta \qquad - (3)$$

According Bekker [1], the normal and shear stress developed beneath the loaded wheel is given as,

$$\sigma = \left(\frac{k_c}{b} + k_\emptyset\right) Z^n \qquad - (4)$$

$$\tau = (c + \sigma \tan\emptyset)\left(1\text{-}e^{\left(-\frac{j}{k}\right)}\right) \qquad - (5)$$

where soil properties like, k_c, $k_\emptyset$, are cohesive and frictional modulus of deformation respectively, '*n*' is exponent of sinkage. '*j*' is soil deformation, '*k*' is shear deformation modulus and '∅' is internal frictional angle.

Grouser wheel model

Many planetary rovers have wheels with grousers, which are radial paddles on the wheels that are used to improve the tractive effort of a wheel. The existing Bekker's Terramechanics models do not considers the effects of grousers. Thus a new analytical model developed by [4] and is given as,

$$\sigma = \left(\frac{k_c}{b} + k_\emptyset\right) Z^n + A\, sin\,(\omega t + \Phi) \quad - (6)$$

In which the second term accounts for periodic occurrence of grousers, where't' is time and ϕ is an optional phase shift that can be applied to the model to account for the initial orientation of the grousers. *A*, is the amplitude of the oscillation and ω_f is the frequency at which they occur.

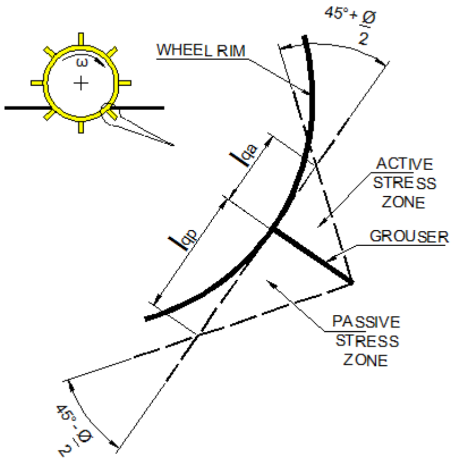

Figure 2. Active and passive stress zones on the grouser wheel [4]

According to [5] the active and passive stresses will be acting on grouser blades and their contribution is predominant in calculating the efforts it can deliver. It is stated that the amplitude of the oscillations in the pressure sinkage relationship can be related to these active and passive stresses. The passive stresses acts on the face of the grouser coming into contact with the terrains shown in Figure 2. Active stresses may be acting as the soil moves away from the grouser blade and, if present, would act on the rearward side of the grouser.

Results

Sinkage and DP equations are integrals with function of θ, thus it is difficult to solve through conventional methods, hence numerical integration (Simpson's rule) is adopted to solve these equations. Code generated in MATLAB to estimate sinkage, DP, torque and validated with literature data for wheel diameter of 49.9*in* and width of 6.0*in*.Soil properties considered are k_c=0,k_ϕ = 2, n=1.1504, c=0.12 *lb./in*^{2}Ø=31.1°. Further code is modified to account grouser effect also. Following discussion of results is specifically for the given wheel and soil parameters.

Smooth wheel:

Figure 3(a) shows the relationship between normal / shear stress vs. angle of contact of wheel with soil. It is clear from the plot that, stress band gets wider as the contact angle increases. This is because of larger area of wheel engaging with the soil. This area of contact depends on soil properties and load on the wheel. In general large load on wheel for loose soil results into wider contact angle. Therefore the relative position of the maximum stress depends on the compressibility of the soil.

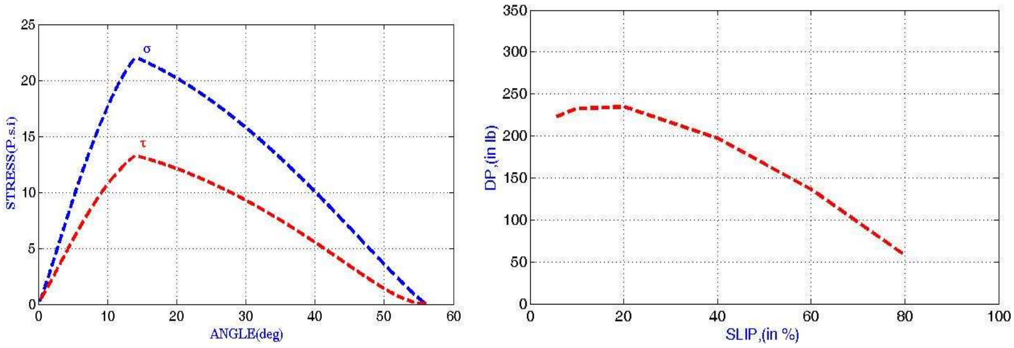

Figure 3: (a) Stress and (b) Drawbar pull output (MATLAB)for a rigid wheel

Figure 3(b) illustrates the relation between drawbar pull vs. slip. From this plot, it is clear that drawbar pull is maximum at around 20% slip and further it starts decreasing with increase in slip. The reason for this behavior is that the soil deformation in the longitudinal direction of the wheel increases with the slip ratio, results into more sinkage, which increases resistance force from soil thus net drawbar pull falls. Hence it can be concluded that, for the given wheel and soil parameters, it is recommended to run the wheel at around 20% slip.

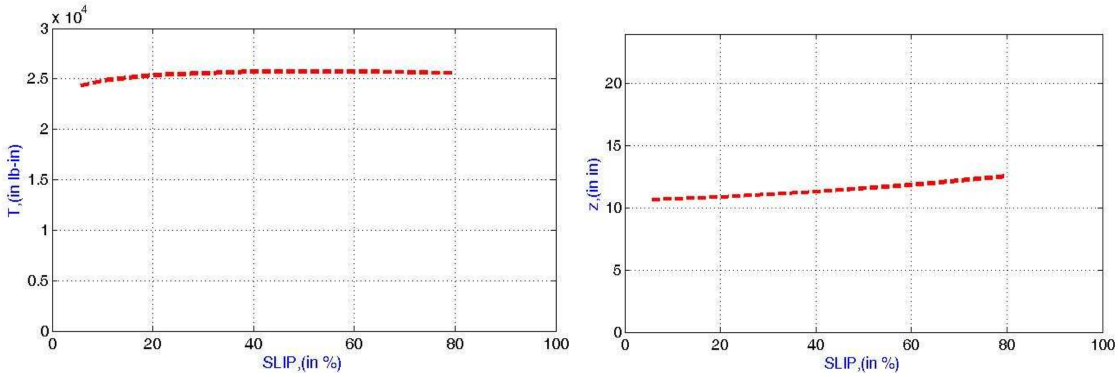

Figure 4: (a) Torque and (b) sinakge output (MATLAB) for a rigid wheel

From the torque plot in Figure 4(a), it is possible to estimate the torque required to drive the wheel for a particular slip. Figure 4(b) focuses on amount of sinkage Vs slip. This is needed to decide the safe limit to avoid locking of wheel.

Grouser wheel:

The observations made for smooth wheel described in previous section can be extended to grouser wheel. In general, it is clear from the studies, that the effective pulling force (Drawbar pull) will get increased by introducing grousers. More the number of grousers, behavior are similar to smooth wheel (with increased radius).This happens because of less space between adjacent grousers. Closely placed grousers reduce the active and passive stress zones (Figure 2). These stresses have predominant contribution towards estimation of drawbar pull. Hence it is required to optimize the number of grousers in the feasible range and it is possible from this estimation along with several trials of experimental investigations.

Conclusion

The mathematical model is solved through numerical integration technique using MATLAB. Smooth wheel performance outputs are validated with literature data. Main characteristic relations like slip vs. DP, slip Vs. torque are studied. Thus it is possible to predict the performance of rigid wheel interacting with soil. Further, the grouser model shows that the presence of grouser will enhance the drawbar pull, which results into better traversability.

Acknowledgements

The author would like to thank *Prof.P. Chandramouli* and *Dr.Sujatha Srinivasan* of Department of Mechanical Engineering, IIT, Madras, Chennai, for their guidance and expert advice. Also, sincere thanks to *Sri.C.D. Sridhara*, Group Director, *Sri. N. Viswanath*a, Group Head, *Sri.T.P.Murali*, Head, MATD and *Sri.G.Nagesh*, Head, SMAD,SMG,ISAC, Bangalore, for providing me an opportunity to work on this project.

Reference

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CONGRATULATIONS TO THE AWARD WINNER

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Bangalore

IETE Smt. Manorama Rathore Memorial Award 2011.
Awarded by Instituition for Electronics & Telecommunication Engineers for significant contributions in R&D in Electronics for Satellite Instrumentation Systems.

FORTH COMING SEMINARS

1. 8th National Seminar & Exhibition on Aerospace and Related Mechanisms
   6-8 December 2012, ARDE Pune
   email: insarm.pune@gmail.com

INVITATION FOR ACTIVE PARTICIPATION

We invite you to send technology news, technical articles, members' news and suggestions/comments on e-newsletter and the web contents to Chief Editor to improve the newsletter. The technical articles may be limited to 400 words only in MS Word format with two photographs. The direct extracts from references may be avoided. Kindly provide your e-mail & mail address to enable us to contact you.

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