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Traction Performance of Wheel and Track for Soft-Soil Traversal

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NASA's Mars Exploration Rovers achieved great success in a long-range traversal of the Martian surface and a lot of scientific discoveries based on their in-situ analyses for more than six-year period. During their robotic expedition, however, Opportunity once trapped in a sand dune and Spirit has been in a difficult situation since July 2009 with one of the wheels being stuck in loose soil. Such incidents call a special attention to intensive study on the rover's mobility in soft-soil environment.

Most of the lunar surface is covered by a thick layer of soft and dry regolith, and therefore characterized as smooth hills with shallow and steep slopes, rather than rocky field. Therefore in the design of future lunar rovers, consideration to traction performance for soft-soil traversal is more important than the performance of rock and bump negotiation. For example, JAXA is now put some effort in a crawler track based chassis design for a Japanese lunar surface robot [1]. There is an interesting discussion on whether track-based mobility or wheel-based mobility system is advantageous. The answer to this question is not easy. In general, advantages and disadvantages of tracked vehicles are summarized as follows, but more and more data are necessary before we can conclude with a specific design.

Advantages of Tracked Vehicles:
Higher slope-climbing capability
Higher bump-crossing capability*
(*This is only true when the length of the track is larger than a "wave length" of the bumps.)
Disadvantages of Tracked Vehicles:
Higher mass and energy consumption
Higher complexity of mechanism
Higher risk of track jamming or other mechanical failures

In this paper, the authors present the results of a substantial comparative study on the traction performance of wheel and track for the view point of soft-soil traversal using simplified test beds. Figure 1 shows our track-type test bed composed of a single track therefore named "mono-crawler," and a wheel-type test bed composed of four wheels in-line. Both have the same length (400mm) and the same width (40mm) in contact areas. Dry river sand named "toyoura" sand was used in the following experiments. A variety of experiments were conducted to evaluate the drawbar pull (net traction force) and slip ratio with different normal load and slope angle conditions.

Figure 2 compares the track and wheel in terms of drawbar pull. The track shows much higher magnitudes of drawbar pull over the wheel. The magnitudes of drawbar pull get larger according to the normal load on the track, however, they do not show a significant difference to the normal load on the wheel.

Figure 3 compares the track and wheel in terms of slope climbing performance. The track shows relatively higher magnitudes but not as significant as the drawbar pull. The magnitudes of slope angle get smaller according to the normal load on the wheel, however, they do not show a significant difference to the normal load on the track.

The above observation from two different aspects is very useful to characterize and estimate the traction performance of wheels and tracks. Particularly, the degradation of slope climbing performance of the wheel with increased normal load is understood by the increment of the wheel sinkage. This fact suggests that the prevention of wheel sinkage could help to keep equal performance to others.

Fig.1: (left) “Mono-Crawler”, a single track test bed
(right) an inline four-wheel test bed on the slope of dry “toyoura” sand

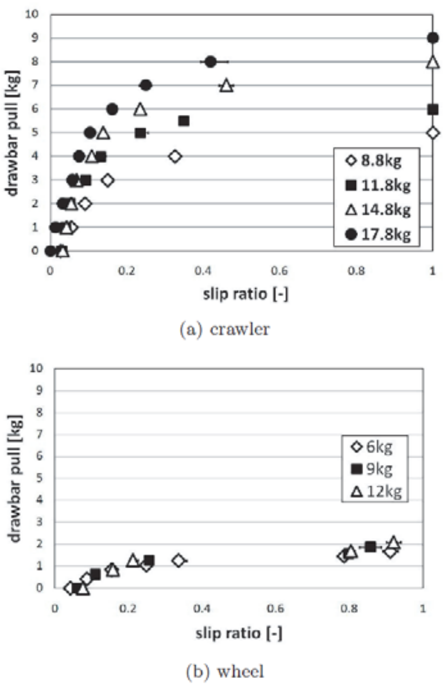

Fig.2: Comparison of drawbar pull

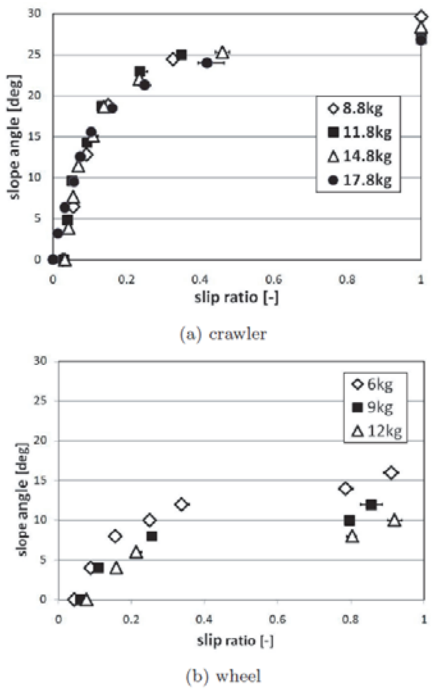

Fig. 3 Comparison of slope angle

[1] S. Wakabayashia, H. Sato and Shin-Ichiro Nishid, “Design and mobility evaluation of tracked lunar vehicle”, Journal of Terramechanics, Volume 46, Issue 3, June 2009, Pages 105-114.