APPLYING STRUCTURAL OPTIMIZATION TECHNIQUES TO DESIGNING LUNAR ROVER WHEELS

Michele Faragalli[1], Damiano Pasini[1], and Peter Radziszweski[1]

[1]Department of Mechanical Engineering, McGill University, Montreal, Québec, Canada

Recent developments in designing novel non-pneumatic, non-rubber flexible wheels have shown promise for planetary exploration vehicle locomotion systems [1, 2, 3, 4, 5]. The performance of wheels in soft soils and irregular terrain can be enhanced by achieving some flexibility, or compliance, which in turn provides greater traction, obstacle negotiation, and suspension properties to the vehicle. Therefore, the deflection of the structural elements of the wheel dictates the resulting performance. As the lunar environment precludes the use of rubber or pneumatic wheel designs, the deflection and resulting stresses in the structural elements of the wheel, typically made of steel or metal alloys, must remain in the linear elastic range of the base material and below the material endurance limit. Consequently, to determine the optimal size or shape of the internal structural elements, the stresses and strains, as well as the mobility performance metrics of the wheel, must be considered.

Although structural optimization methods are largely based on minimizing mass and compliance, there exists a large body of knowledge in the field of structural optimization for compliant structures [6, 7]. These techniques have been used to optimize the profile, cord direction, size and shape of tire carcass designs [8, 9]. However, only a select number of publications have been found which address the variation in flexible metallic wheel structural design to improve the wheel's performance in simulation [10]. Furthermore, none formulate the design problem as a structural optimization problem, which can result in a limited search of the design space and sub-optimal design solutions. In literature, most wheel design concepts appear to be developed through trial and error processes and extensive physical testing, with minimal focus on evaluating the wheel performance using analytical or numerical models.

The goal of this research is to explore the development of a systematic method for optimizing the structural design of non-rubber, non-pneumatic compliant wheel designs for lunar rovers. Analytical models, such as terramechanics relationships and quarter-car dynamics models, can determine the effective mechanical properties, mass, and size of the wheel as a function of desired performance. Desired performance of the vehicle is determined by the intended use and mission scenarios. Using numerical modelling techniques such as the Finite Element Method (FEM), in conjunction with an optimization routine, wheel design concept can be optimized to meet the effective mechanical properties found from the analytical model.

In this publication, structural optimization techniques are shown to improve compliance in a wheel design concept. The wheel concept is parameterized into a set of design variables which describe the structural elements of the wheel. The loading conditions representative of nominal vehicle operation are imposed on the wheel using FEM. The FE model is coupled to a multi-objective optimization algorithm which determines a trade-off design solution which improves the wheel performance. Finally, a discussion on future work and extending the structural optimization techniques to tailoring a wheel design concept for a given vehicle and mission scenario is made.