Terramechanics-based Analysis of Wheel Locomotion:

Proposal of Field Modeling Method and Extended Terramechanics Models

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Abstract

Terramechanics is an interdisciplinary field of study concerned with the interactions of off-road vehicles and machines with terrain . Its scope covers all types of off-road vehicles, including four-wheel drive (4WD) vehicles, construction machinery, agricultural machinery, and special vehicles. In recent years, it has also come to include lunar and planetary exploration equipment and disaster-response robots. However, a practical terramechanics-based analysis requires the development of a versatile method for modeling a wide variety of terrain surfaces, independently of the sophistication of the terramechanics model itself . The present work first discusses the usefulness and limitations of such methods . This is done by analyzing the multibody dynamics of mining dump trucks based on an existing terramechanics model and by examining the shape of rover-wheel grousers. Next, based on existing studies, a new method is proposed for creating a road-surface model. An extended terramechanics model is also presented that considers terrain surface deformations.

The eight chapters of this paper are outlined as follows.

Chapter 1 introduces the background of the present study and reviews relevant research, focusing on the terramechanics model and numerical analysis related to wheel locomotion. The purpose and contribution of this paper are also formulated.

Chapter 2 describes the terramechanics interaction model used in conventional wheel locomotion analysis. In particular, two typical terramechanics models, the Bekker-Wong-Reece (BWR) model and Resistive Force Theory (RFT), are introduced, and their application to wheel locomotion is outlined.

Chapter 3 describes the results of applying the terramechanics model to a multibody-dynamics analysis of mining dump trucks. A BWR model is used to describe the interaction between the tire and the ground, and the analysis results of the climbing performance on soft ground are shown. Furthermore, the effectiveness of the traction control system (a control method for avoiding becoming immobilized), is demonstrated based on a systematic numerical analysis.

Chapter 4 presents the results of a locomotion analysis of wheels with grousers, based on RFT. The appeal of RFT in recent years stems from its ability to analyze the interaction between an object with a complicated shape or movement and the ground at low cost . However, given the scant literature on applications of RFT to wheel locomotion, this chapter analyzes this phenomenon using both the discrete element method and RFT. By comparing the results obtained by both methods, the applicability and limitations of RFT are clarified.

Chapter 5 proposes a grouser shape designed to improve wheel runnability by combining model experiments, discrete element method analysis, and terramechanics analysis using RFT. Specifically, a grouser with a trapezoidal cross section is shown to exert a "packing effect" that is effective in avoiding immobilization.

Chapter 6 proposes a multi-stage analysis method that exploits ground-surface information obtained from other numerical analysis and measurement techniques. The data are applied to the terrain surface model of the terramechanics analysis. First, the outline of the multi-stage analysis method is explained. Then, the analysis method for generating wind ripple patterns is described, as a concrete example of the ground surface formation analysis.

Chapter 7 proposes an extended terramechanics model that considers the deformations and changes in the terrain-surface properties associated with machine-ground interactions. In addition, the effectiveness of the model is demonstrated by comparing the model experiment results for plate drag and for wheel locomotion.

Chapter 8 closes with a concluding summary and an outlook of future prospects.