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Development of a dynamic simulation model of a towed seeding implement

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Abstract

As the size of western Canadian farms increase and the productivity demands on seeding equipment rise, improvement in the depth consistency performance of seeding implements at higher seeding speeds is a future focus of equipment designers. The objective of this work was to develop a dynamic simulation tool for predicting the motion of a hoe-opener style seeding implement with independent row units. The model was developed using simple low-order models available in the literature to compute the forces generated at soil-tire and soil-tool interfaces. By maintaining low computational cost, early-stage parameter sensitivity and design trade-off studies can assess the risk of a given design change. The amplitude of the power spectral density (PSD) of simulated row unit motion was typically lower with sharper peaks than measured results up to 3.3 m/s; these differences were due to both input amplitude differences, and the sensitivity of the model itself. Frequency agreement of major measured and simulated PSD peaks was acceptable considering the model simplifications. Row unit motion was dominated by two phenomena – a strong periodic input in the terrain surface, and feedback between the hoe-opener and packer wheel of the row unit.

Keywords: Vehicle dynamics; Soil-tire interaction; Soil-tool interaction; Vibration; Seeding depth

1. Introduction

Modern farming operations are continually looking for ways to reduce operational costs, and increase productivity. Naturally, equipment manufacturers are also looking to increase equipment throughput. This is particularly evident in seeding technology changes over the past several decades. Seeding equipment as wide as 25 m is commonly available in Canada today; equipment developed two decades ago was typically no wider than 15 m. However, factors such as the mechanical strength of the frame, public roadway size restrictions, field layout, and available tractor power present challenges to future width increases. Therefore, productivity gains from increased seeding speed are increasingly important. However, with increased ground speed, current seeding technology typically exhibits excessive dynamic motion which is detrimental to consistent seeding depth, hence the trend of past productivity gains through wider equipment.

Taking lessons from the automotive industry, the ability to simulate the dynamic performance of a given vehicle design and to quickly compare many potential design configurations has led to drastically shorter development schedules and lower development costs. Simple models with reduced degrees of freedom (DOFs) and ideal representations of mechanical elements have become useful tools in understanding parameter sensitivity and reducing design change risk.

This work aimed to combine basic first-principle and semi-empirical models of the various elements of a seeding

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implement (tires, tillage tools, etc.) for use in the dynamic simulation of a hoe-opener type seeding drill, a seeding implement common throughout western Canada. The purpose of the model was to calculate the kinematic and kinetic response of a towed seeding implement as it passes over field terrain while the tillage tools are engaged.

The structure of the paper is as follows: Section 2 reviews background information on the effects of poor seed depth consistency, past off-road dynamic modelling efforts, applications of the Bekker soil-tire interaction model in dynamic modelling, soil-tool interaction models appropriate for low-cost computation, and the specifics of the machine being modelled. Section 3 covers data collection activities involved in this research, and the shortcomings of interpreting operational data without understanding system sensitivities. Section 4 explains the sub-models used to represent soil-tire and soil-tool interaction. Section 5 explains the model calculation structure and highlights some specific challenges in robust numerical modelling. Section 6 compares simulation results to test data with a discussion of the limitations of the model, and Section 7 presents conclusions.

2. Background

Agronomic considerations regarding seeding equipment performance, and previous work on off-road vehicle dynamics, soil-tire interaction, and soil-tool interaction are discussed, followed by a description of the seeding apparatus used in this research.

2.1. Literature review

Seed depth is a critical agronomic factor in successful plant emergence, development and overall yield. The effect of depth on yield has been observed in chickpeas (Gan et al., 2003) and canola (Harker et al., 2012), and seeding too deep can increase root rot in cereal grains (Government of Alberta Agriculture and Rural Development, 2002). Seeding depth can affect emergence, seedling stress, and weed competition (Canola Council of Canada, 2013). By extension, inconsistent depth within a field can cause plant development variation, so consistent seed depth is an important performance characteristic of modern seeding equipment.

While simply driving faster may increase apparent productivity, depth consistency can degrade beyond ground speeds of approximately 2 m/s with the independent row unit design offered by contemporary manufacturers. Measurements of canola emergence after seeding at multiple speeds up to 4.25 m/s with several different brands of field-scale equipment indicated a general trend of reduced emergence success with increased ground speed at multiple test sites (Canola Council of Canada, 2014). While many factors affect plant emergence, this supports the industry's working hypothesis that higher speeds can result in decreased depth consistency.

A mature body of off-road vehicle dynamics literature can be found regarding equipment operator exposure to machinery vibration. To understand the radial stiffness and damping characteristics of an agricultural tractor tire, Lines and Murphy (1991a,b) experimentally measured these parameters on a variety of tractor tires in static and rolling conditions. Generally, both the stiffness and damping of a tire decreased once rolling began. Lines and Peachey (1992) further highlighted the importance of using rolling tire characteristics when performing dynamic simulations. Crolla et al. (1990) used a spring and viscous damper acting in parallel to model the vertical response of tractor tires, and proposed a spring and damper in series to represent the lateral and longitudinal response of the tires. Pazooki et al. (2011) developed a dynamic model of a forestry skidder to explore the performance effects of adding rear axle suspension using simple representations of the mechanical elements of the machine with reasonable agreement to measured vibration data.

The types of investigations noted above indicate that simulation and parameter optimization using relatively simple tools of low computational complexity can play a role in improving the rigid-body vibration performance of tractors and other power-unit equipment. However, the literature is comparatively sparse regarding modelling efforts focused on improving the dynamic characteristics of towed implements. Cowell (1969) and Dwyer et al. (1974) both presented work on automated depth control of a tractor-mounted plow, but neither presented dynamic equations of the apparatuses. Shaw et al. (1972) developed a basic 1-DOF model of a planter row unit using an analog computer. A multi-point-follower tire model was included. The number of point followers had a significant affect on the motion of the row unit; however, the number of point-followers was selected arbitrarily. It was suggested that soil deflection be represented by an equivalent parallel spring-damper assembly; parameters such as effective soil mass, and mass of tire contact length were also required for this approach, but methods for estimating values of these lumped parameters were not included.

Smith et al. (1982) presented a 2-D model of a corn planter row unit developed in the commercially available Dynamic Response of Articulated Machinery (DRAM) programming environment (Chace, 1978), and other 3-D mechanisms in the Automated Dynamic Analysis of Mechanical Systems (ADAMS) environment (MSC Software, 2016). These programs enable the analysis of 2-D and 3-D mechanisms while saving the user from manually developing and solving the equations of motion for the machine of interest. However, Smith et al. (1982) highlighted the need for user-written FORTRAN subroutines during the model development of several example mechanisms. Specific to the corn planter model, details regarding the representation of soil-tire and soil-tool contact forces were incomplete, although the application of these programs to the analysis of off-road machinery appeared promising.