Modeling and optimization of a no-till direct seeding machine

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Abstract: In direct seeding systems, soil strength variability and crop residues increase the difficulty of seeding operation. Especially when trying to achieve uniform seeding depth that will result in reliable seed germination and plant emergence. An advanced improvement has been accomplished using direct seeding systems. However, some problems still exist in soil-machine interaction due to various reasons, such as high machine speeds, furrow-opener design, soil undulations, soil compaction, etc. These problems, in terms of seeding depth, occur mainly due to extreme machine dynamics and hard soil conditions. In order to assess seeding machines working quality it is necessary to identify the effect of compacted-soil undulations, soil reaction forces and high operating speed on machine dynamics. In the present paper, the vertical forces of a coulter aggregate and the surface profile were acquired to describe machine dynamics. Furthermore, the displacements of the coulter arm were also recorded to assess seeding depth variation.

Keywords: Field surface profile, soil reaction forces, vertical motion behavior of aggregate.

Introduction

The main goal of seeding is to put the seed at a certain distance and depth in the seedbed for maximum germination rate [KÖ04]. In direct seeding, it is more difficult to achieve a precise seeding depth due to extreme conditions such as compacted soil, undulations, stubble residues, higher operation speeds, etc. Therefore, significant improvements in germination and emergence in direct seeding could be achieved by controlling seeding depth, regulating compacted surface undulation impacts, and optimizing the machine dynamics. The machine dynamics, in terms of vertical motion behavior of the machine relative to soil surface, specify the seeding depth, since the dynamic response of the system is highly affected by draft and vertical forces, and operation speed [Mo88]. In addition, soil profile variations and soil resistance that is affected by soil physical properties, can be described by soil reaction forces on the furrow opener, which in turn, influence the mean seeding depth across the seeder width [Fo13]. Even when the seeding depth is manually fixed, it is difficult to keep a precise depth during field operation, as the demand for operational efficiency is maximized with higher driving speeds [PO15]. The recommended driving speed for seeding machines from many manufacturer is 8-10 km/h, but the relatively higher traveling speed shows that the mechanical system, in terms of coulter aggregate, is not able to behave as proposed and follow the fine contour

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of the field. As a result, the seeding depth varies along the driving line [SO15].

A project was set up with the aim to optimize a no-till seeder, in terms of vertical motion stability, for better seeding depth and weight reduction under realistic high capacity performances. The principles were based on measuring machine dynamics and soil condition parameters, i.e. accelerations, displacements, forces, and surface profiles. One of the main objectives was to perform experimental tests on the machine with various traveling speeds and under rough soil condition. To perform simulations, the soil reaction forces and surface profile were measured on a single aggregate of the seeder. The current status of the seeder, based on vertical motion behavior of its single aggregate, was assessed. The present paper focuses on the instrumentation and measurement methodology for gaining the desired input parameters for later simulation modelling. Some preliminary results regarding the measured surface profiles and the developed vertical forces are also presented.

Materials and Methods

In Fig.1 the concept of the project is presented. The first stage includes experiments on the seeder under different traveling speeds in order to obtain forces, vertical accelerations and displacements on both seeder main frame and single aggregate. A combination of surface data with soil profile impact forces and coulter vertical forces can be used as an input to simulate the aggregate vertical motion behavior with the aim to output the same accelerations and displacements as the measured ones.

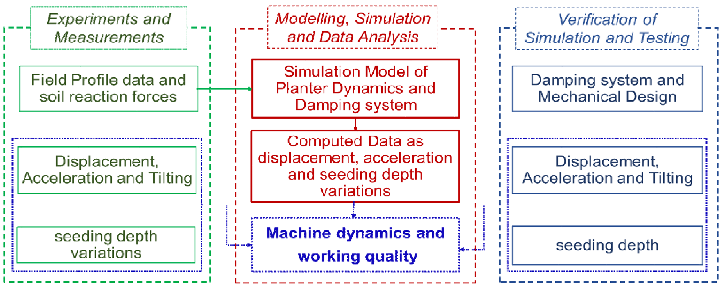

Fig.1: Project concept with the interactions between field experiments and simulations.

An Amazone direct seeder and a 176kW tractor (John Deere 6210R) were used for the field experiment. To measure the vertical and surface profile impact forces, a number of linear 350 Ohm DY41-1.5 - Strain Gauges with two Parallel Measuring Grids (HBM GmbH, Darmstadt, Germany) were attached at three points on one coulter aggregate of the seeder (Fig. 2). In addition, two VN 100 inertial measurement units (IMUs) (VectorNav, Dallas, USA) were utilized; one on the aggregate and another one on the main frame of the seeder. An AgGPS 542 RTK-GNSS (Trimble, Sunnyvale, USA) attached on the main frame provided georeference of the acquired data. The CatmanEasy AP software and QuantumX-MX840B (HBM GmbH, Darmstadt, Germany) data acquisition system, utilizing three channel in a full bridge configuration for every channel, were used for data storing and recording with a 300 Hz sample rate.

To measure the field surface profiles [PG14], a sensor system was developed that carried all the needed sensors (Fig.2). This construction utilized a metal frame which was mounted on the main frame of the seeder. A DT50 laser range finder (SICK AG, Waldkirch, Germany) was used to measure the coulter wheel displacement from a plate that was fixed to the coulter. An SCS930 total station (Trimble, Sunnyvale, USA) provided the in-field absolute position of the seeder by tracking a prism placed on the developed sensor-frame.

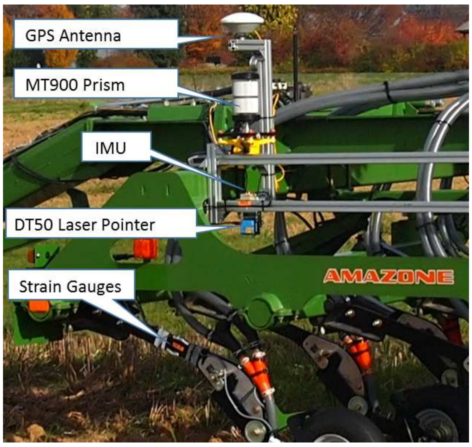

Fig.2: The developed sensor-frame for measuring machine dynamics.

In the field experiments, vertical and surface profile impact forces, displacement and accelerations were acquired with different traveling speeds under stubble field condition. The 62 Hz sampling rate of the laser pointer allowed to measure the surface elevation every 44 mm and 67 mm with a speed of 10 km/h and 15 km/h, respectively. Furthermore, the 300 Hz sample rate of the strain gauges data allowed to calculate the vertical forces and the surface impact every 9 mm and 13 mm for 10km/h and 15 km/h, respectively. Data acquisition from all sensors was conducted with a time-stamp for data synchronization during post-processing.

Results and Discussion

In Fig.3 the surface profiles in driven distance and the corresponding vertical forces on the tine of the coulter aggregate with speeds of 10 km/h and 15 km/h, are presented. It can be easily noticed that the vertical forces are following the same pattern of the surface profile. Further analysis should include the consideration of the vertical forces and the traveling speed.

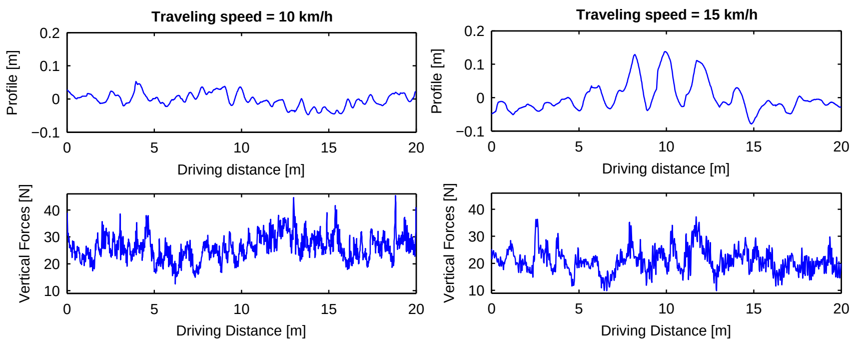

Fig. 3: Surface profiles and the corresponding vertical forces having a speed of (left) 10 km/h and (right) 15 km/h.

Conclusion

For assessing the current status of the seeder, a sensor-frame was developed to measure field surface profiles utilizing a laser pointer and a total station. Three full-bridge strain gauges were attached on a coulter aggregate to measure the corresponding vertical forces. Accelerations on the aggregate and the main frame of the seeder were acquired. Preliminary data analysis revealed the connection between the surface profiles and the vertical forces on the coulter aggregate. For optimization purposes, further analysis, in terms of the vertical motion frequency range of the aggregate related to surface profile and soil reaction forces, will be carried out. Measured seeding depth will be assessed in terms of the corresponding surface profile and vertical motion of the aggregate.

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