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Development and performance assessment of a DC electric variable-rate controller for use on grain drills

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ABSTRACT

Site-specific crop management is a technology that modulates the application rate of field inputs such as seeds, fertilizers, and herbicides based on the needs of each management zone within a field. There are two methods available for changing the seeding rate in fluted-feed-roll type seed drills: (1) changing the active feed-roll length and/or, (2) changing the seed meter drive shaft speed. A possible method to develop a variable-rate seeder is to add a controller to a conventional grain drill which can change the speed of the seed meter drive shaft on-the-go. This was explored in the present study with the following main objectives: (a) to design a DC electric variable-rate controller to change a grain drill from a uniform to a variable-rate seeder, and (b) to determine the response time of the system. A motor control circuit was designed which used the output signals of two encoders as feedback. The system was consisted of: (1) a DC motor with a fixed-ratio gearbox, (2) encoders for sensing the rotational speeds of the grain drill drive wheel and the motor, (3) a GPS receiver, (4) a pulse-with-modulation (PWM) DC motor controller, and (5) a laptop. Dynamic tests were conducted at application rates of 87.5 (low) and 262.5 (high) kg ha^{-1}. Sigmoid equations were best fitted to the transition data from low-to-high and high-to-low seeding rates. Our findings showed that the response times of low-to-high and high-to-low transition rates were 7.4 and 5.2 s, respectively.

1. Introduction

Site-specific crop management aims at balancing agricultural inputs such as seeds, fertilizers, and herbicides to match the requirements of specific soil fertility levels and/or landscape positions. Moisture content and fertility are the most important field variables whose variations affect optimum seeding rate in the field. Given that fertility and/or moisture may be variable within a field the optimal seeding rate may also be variable. Clearly, maximizing yield calls for optimal seeding rates in the various field areas (Taylor et al., 2006). In site-specific crop management, the geographical information system (GIS) is used to prepare a seeding rate map for the field, which is uploaded into a computer prior to the planting. The controller of the agricultural machines changes the application rates of the planter at each management zone within a field using the predefined prescription map and positioning information generated by a differential global positioning system (DGPS) receiver.

One possibility for obtaining variable application rates is to add a controller to the conventional agricultural machines that are normally used for applying inputs uniformly (Robert et al., 1992). It is, therefore, important to note that a retrofit kit would be desirable for updating existing grain drills to variable-rate status in cases where viable seeding unit already exists but the variable-rate option is required. The process of changing the application rate while the seeder is traveling across the field depends on the dynamic response of the controller, and therefore can be, accompanied by some misapplication (Bahri, 1995). The severity of this misapplication depends upon the characteristics of the metering controller in switching from one rate to another. A decisive factor in this regard is the control system's response time that should be reduced to a minimum by selecting appropriate control system components.

Depending on the type of metering mechanism used in a grain drill, two methods are commonly available to change the seeding rate: (a) changing the active feed-roll length, and/or (b) changing the seed meter drive shaft speed. Bahri (1995) developed a simple operated open-loop control system to vary the seeding rate on-the-go by changing the feed-roll length, and thus modifying a conventional grain drill to a variable-rate seeder. The control system consisted of a battery, on-off control switches mounted inside the tractor cab, and an electrical linear actuator attached to the meter adjustment lever. It was reported that the response time of the control system averaged 5.6 *s* for a 20 kg ha^{-1} rate increase. The presence of seeds in the feed rolls prevented the free movement of the metering mechanism inside the metering cup for a decrease in application rate input command. This finding

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suggested that changing active feed-roll length is not a feasible method for varying the seeding rate on-the-go.

There are two control systems available for changing the seed meter drive shaft speed; namely position and speed control systems. Maleki et al. (2008) used a pneumatic seeder with an infinitely variable gearbox equipped with an electrical linear actuator to develop a variable-rate fertilizer in which the linear actuator was used to adjust the gearbox ratio. An interface program was developed using LabVIEW (Laboratory Virtual Instrumentation Engineering Workbench) programming to initiate the electrical actuator. The actuator adjusted the flow-rate in interval steps of 5 kg ha^{-1}. Similarly, Tola et al. (2008) developed a variable-rate granular fertilizer by the use of an air seeder with a fluted-feed roller and an infinitely variable gearbox. The speed of fluted-feed roller was adjusted by positioning the gearbox lever. The setting lever was adjusted using a DC motor and a linear gauge. To measure fertilizer output, an incremental encoder was used in an experimental hopper to detect the incremental rate of the fertilizer depth inside the hopper. The control system response to step changes in the target fertilizer rate at a predetermined intervals was within the range of 0.95–1.9 s.

Bahri (1995) also developed another open-loop control system using a rheostat to control the speed of an electric motor driving the seed meter drive shaft. The response times varied from 3 to 9 s depending upon the rate change magnitude. It was reported that the control system performed well for rate increases and decreases. The open-loop control system eliminates the need for feedback signal and the feedback-based command signal correction. Inaccuracy is due to the inability of the system to dynamically adjust for changes in load as a result of actuator aging or other operating conditions. In contrast, the feedback signals in a closed-loop control system are compared with command signals to calculate application rate errors. The error, in turn, is used to adjust the command signal. The mechanical controller, thus, moves closer to the target rate and the error approaches zero (Anderson and Humburg, 1997). Kim et al. (2008) built a prototype granular applicator which consisted of a controller, a boom with a pneumatic conveying system and a DGPS receiver. The controller received the DGPS signal, calculated the current working speed, read from a previously developed prescription map, and controlled the metering motor speed using the pulse-with-modulation method. In this research a matrix pan was used to determine the transition seeding rate parameters. The response time ranged from 1.5 to 3 s. In another research, Yu et al. (2006) built a prototype variable-rate applicator for granular fertilizer. It was fabricated with a F/G servo system and discharger. Control performance and discharged characteristic of the control system were evaluated by a test rig. In both of the above experiments, researchers built a prototype granular applicator with a closed-loop control system.

Changing a conventional fluted-feed-roll type seed drill to a variable-rate seeder requires adding some variable-rate controllers. Alternative designs of the controllers could be used to obtain the variable-rate seeding. If the grain drill, for instance, had an infinite gear ratio, it would be possible to change the seeding rate on-the-go by controlling the position of the gear shift lever. A variable-speed belt drive could also be used to change the seed meter drive shaft speed. This mechanism may consist of two pulleys with variable pitch diameters, thus providing a variable ratio between the two pulleys. As the belt length is fixed, decreasing the diameter of one pulley results in a corresponding increase in the diameter of the other. Moving two half-pulleys could give an extensive range of ratios (Huffmeyer, 2003). Multiple sprockets could be also mounted between the metering mechanism and the drive wheel of the grain drill to obtain different seeding rates. All the sprockets mounted on the seed meter drive shaft are normally idle. One of the sprockets on the shaft, however, may be locked at each time step by a magnetic clutch depending on the seeding rate demanded (Drummond, 2002). Other type of controller would be one that transfers the rotational speed of the grain drill drive wheel to the sun gear of a planetary gearbox and to connect the seed meter drive shaft to the carrier. In order to change the rotational speed of the metering mechanism, the rotational speed of the ring gear could be varied with the addition of an electric motor. In order to damp out load variations, the seed meter drive shaft speed could be used as a feedback in a closed-loop control system (Landphair, 2005).

Using DC motor is an alternative approach that has some advantages and deserves to be explored. Therefore, the objective of the present study was to: design a DC electric variable-rate controller for an existing grain drill which will enable the seeding rate of wheat to be varied on-the-go benefiting farmers in developing countries who do not have access to the technology available in developed countries and obtain its response times when seeding rate changes from high-to-low or vice versa.

2. Material and methods

2.1. Seed specifications

In this study, wheat seed (*Triticum aestivum* L.) with purity and germination percentages of 99% and 98% were used. The bulk density and 1000-seed weight were 800 kg m^{-3} and 43.5 g, respectively. The moisture content was measured at 7.8% wet basis.

2.2. Grain drill specification

In this experiment, a Hassia grain drill (model no. DU100) with 19 planting rows was used whose metering mechanism was of the external straight fluted-feed-roll type. The metering mechanisms were located on a seed meter drive shaft. The drill row spacing was 16 cm. The power for the seed meter drive shaft was provided by drive wheels via sprockets and chain to the gearbox. The gearbox with the cam and a follower mechanism using a one-directional ball-bearing made it possible to adjust the metering mechanism for different seeding rates at a constant ground speed.

2.3. Design specification

In this study, a DC motor with a fixed-ratio gearbox was used to rotate the seed meter drive shaft directly. Changing the rotational speed of the motor was accomplished by a DC motor speed control drive. Due to the independence of the seed meter drive shaft speed from the forward speed of the grain drill, a feedback from the grain drill drive wheel speed was obtained. In order to have a closed-loop control system and to compensate for load changes, an encoder was used to sense the rotational speed of the grain drill seed meter drive shaft (Fig. 1).

Upon the selection of the controller design, the different components of the system were specified. For this purpose, a torque meter was used to measure the torque of the seed meter drive shaft, which read 10 N m. The maximum wheat seeding rate and tractor speed were assumed to be 350 kg ha^{-1} and 10 km h^{-1}, respectively. A maximum rotational speed of 50 rpm was thus obtained for the seed meter drive shaft. The power required for the rotation of the shaft was determined to be 52.3 W. A DC motor was selected to change the seed meter drive shaft speed. DC motors commonly have high rotational speeds, for which reduction gearboxes are required to obtain appropriate rotational speeds. For the present study, a worm type gearbox with a reduction ratio of 1:40 was selected. Given the low efficiency of the worm gearbox, a 250 W, 24-V electrical scooter motor with a maximum current of 13.5 A was chosen. The motor was a permanent magnet DC type with 4 poles. The maximum motor torques at rotational speeds of