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ELECTRIC SERVO DRIVE FOR FEEDING DEVICE IN CONVENTIONAL SEED-DRILL

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ABSTRACT: **C**ombine drillers rely on mechanical power for turning feeding devices. The shafts are connected to a ground drive wheel with chain drives and gearboxes. The rotating speed of the shaft is relative to the forward speed of the seed drill. Earlier attempts to control fertilizer and seed rate using fluted-roller seed meters and electric linear actuators were considered too slow. With electric servo drive attached to feeding device shaft the required variable rate application properties can be achieved. In this paper the design of electric servo drive(s) for conventional driller is presented. The paper discusses requirements for electric drive, electric supply and other electro-mechanical components. The control design for servo system is presented through system identification and rule based PID control tuning.
KEYWORDS: seed drills, feeding device, electric motors, servo systems, control systems

INTRODUCTION: Conventional combine drillers rely on mechanical power for turning feeding devices where fluted-roller seed meters are used commonly: one feeding device unit per one coulter and all feeding device units are rotated with a one common shaft. The shafts are connected to a ground drive wheel with chain drives and gearboxes. This construction usually requires several chain drives and gears which all need lubrication. According to HEEGE (1993) and SCARLETT (2001) slip of the drill mechanism driving wheel(s) causes variations in seed delivery rate. The rotating speed of the shaft is relative to the forward speed of the seed drill. This gives a constant application rate that does not depend on the forward speed. Variable rate application (VRA) can be achieved by using a variable gear ratio or some by other actuator that changed the effectiveness of the feed units. For example, the feeding rate can be adjusted by changing the effective length of the feed rollers inside the feed chambers. SCARLETT (2001) reviews the potential opportunities for the application of integrated control techniques to cultivation and crop establishment implements like driving the seed metering mechanism independently, via variable-speed electric motor in drillers.

Electric motors are standard equipment in industrial applications and quite inexpensive. Modern tractors are equipped with powerful chargers (≥ 1kW) and some of that power can be used to operate actuators in the implement. Unfortunately, tractors still use 12V system, which means that the large currents are needed for high-power actuators. A higher voltage would allow smaller currents, lighter cables and more powerful actuators. The ISO 11783 standard for agricultural machines (a.k.a. ISOBUS) provides standardized mobile communication between a tractor and implements. Standardized communication is needed to ensure compatibility and interoperability of devices from different manufacturers. However, implementing a standard compliant control system is not an easy task. The ISO 11783 standard requires that a compatible tractor must be able to provide 30A of current to the implement. The implement connector is rated at 60A, so even larger current are possible although not required from tractor by the standard. This limits the maximum total power of electric actuators in implements to about 720W.

The feed units in seed drills require calibration. It is usually done by adjusting the feeding rate, then rotating the feeding device with a manual crank to simulate working some predetermined area and finally weighing the result. This procedure is repeated until the required amount is obtained. With electric drives the calibration can be done under software control. The electronic control unit (ECU) can turn feeding device a certain amount of revolutions.
Earlier attempts to control fertilizer and seed rate using fluted-roller seed meters and electric linear actuators were considered too slow. Feeding device consists of fluted roll with a horizontal axis of rotation (shaft). With fluted roll, a sleeve is mounted on the shaft. When the shaft of feeding device was moved for the VRA control remarkable backlash was observed. (OKSANEN et al. 2005)

METHODOLOGY: The platform for which the prototype was realized is Junkkari Maestro 3000 is an adaptable, module-structured combination fertilizer and seed drill suitable for traditional and minimum modified sowing and direct seeding. In a toothed wedge roller coulter (weighing 6-140kg) places the fertilizer and seed in the same coulter (24 coulters are used). There are two separate tanks and feeding devices for the seeds and fertilizer. Fluted-roll seed meters were used in fertilizer feeding device and studded seed roller meters were used seed feeding device. In production version the power to rotate feeding device shaft is taken from driving wheel.
In the preliminary tests it was found that the resisting moment of the feeding device shaft is about 5Nm. According to the manufacturer the resisting moment may increase up to 12Nm due to wear and tear. The manufacturer also states that the maximum permitted rotation speed for feeding device shaft is 3 revolutions per second, or 180 RPM. At higher speeds there is risk that the granules have not enough time to enter feeding device unit. For the design of the electric drive the maximum rotation speed was set to 135 RPM. At 5Nm and 135 RPM the required mechanical power is 71W. As the required moment will increase over time, the required mechanical power to turn the shaft is >150W. The gear has a significant power loss, so the mechanical power from motor has to be even more. The electric supply wires from tractor were replaced with 10mm^2 in order to minimize voltage drop.
The motor/gear selected was Bonfiglioli BC220 DC-motor (12V/21A, 2000rpm, 190W mechanical power) and it was equipped with gear VF44A-14 (i=14, η=0.82). For measuring the rotating speed of motor, an incremental optical encoder (360 pulses / revolution) was installed to its rotor. Electromen EM-115 DC-Motor Control Unit (25A, 4-quadrant) was selected for motor control. The construction is shown in Figure 1.
For rapid control prototyping purposes, the system was first controlled with LabJack U3 USB/IO-device and Simulink. The time step of 50ms was used in the control system. The communication delay between LabJack and PC was measured to be not longer than 10ms. After tuning the PID controller was realized to ISO 11783 compliant control system prototype, which was developed using RTI's Constellation software development system (ÖHMAN & VISALA, 2006). The control software runs on PC using the Linux operating system. Both the Linux operating system and the control software are installed in an USB memory stick.

FIGURE 1. Junkkari Maestro combined fertilizer and seed drill

RESULTS AND DISCUSSION: For process identification, a pulse response was recorded with empty tank and with regular grains and fertilizers; example of data is presented in Figure 2. The input for the process is DC-motor power in range [0,1] and the output is the speed as RPM (revolutions per minute). From the data the process structure was identified to be first-order + delay + lag, see Equation 1.

$$P(s) = \frac{K}{T_F s + 1} e^{-Ls}. \quad (1)$$

The process parameters were identified from pulse responses, for both feeding devices separately. The results are presented in Table 1.

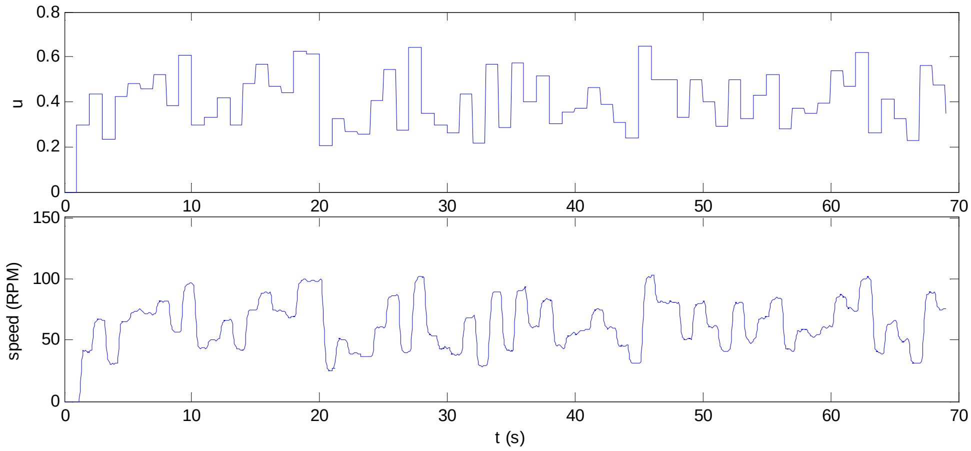

FIGURE 2. Pulse response test with empty seeder

TABLE 1. Identification results for feeding devices

Scenario	Gain (K)	Delay (L)	Lag (T_F)	Fit (%)
Front/Empty	184	0.19	0.11	89.2
Front/Fertilizer	167	0.20	0.11	82.3
Rear/Empty	178	0.19	0.10	85.8
Rear/Wheat	150	0.26	0.07	60.5

It can be seen from the identification results that delay and lag are equivalent with empty tanks and with fertilizer/wheat. The gain of the process decreases about 10% in the case of fertilizer and 15% in the case of wheat. The change in gain is so small, that constant gain controller can be used, and it should be tuned for the normal operation. It should be stable with an empty and also the performance should remain good even if the gain decreases more after wear and tear.

For tuning recently published AMIGO (approximate M-constrained integral gain optimization) tuning rules were used (ÅSTRÖM et al 2004). In those tuning rules the interest has been both in robustness and performance, through robust loop shaping. The tuning rules are (ÅSTRÖM et al 2004):

$$\begin{cases} K = \frac{1}{K_p}\left(0.2 + 0.45\frac{T_F}{L}\right) \\ T_i = \frac{0.4L + 0.8T_F}{L + 0.1T_F} L \\ T_d = \frac{0.5LT_F}{0.3L + T_F} \end{cases} \quad (2)$$

The controller structure is:

$$u(t) = K\left(\left[y_r(t) - y_m(t)\right] + \frac{1}{T_i}\int_0^t e(\tau)\,d\tau + T_d\left(-\frac{dy_m(t)}{dt}\right)\right). \tag{3}$$

In Figure 3 is presented the control response of rear seeder with wheat. The oscillation can be seen in control response; the reason behind the oscillation is the mechanical construction of the feeding device shaft. The bearings at the other end are not precisely installed. The conventional chain drive has so much torque that such inaccuracies in bearings do not matter. For electric shaft drive the installation angle and position of the bearings should be more accurate. However, the simple controller can decrease the oscillation a little bit especially in low speeds.

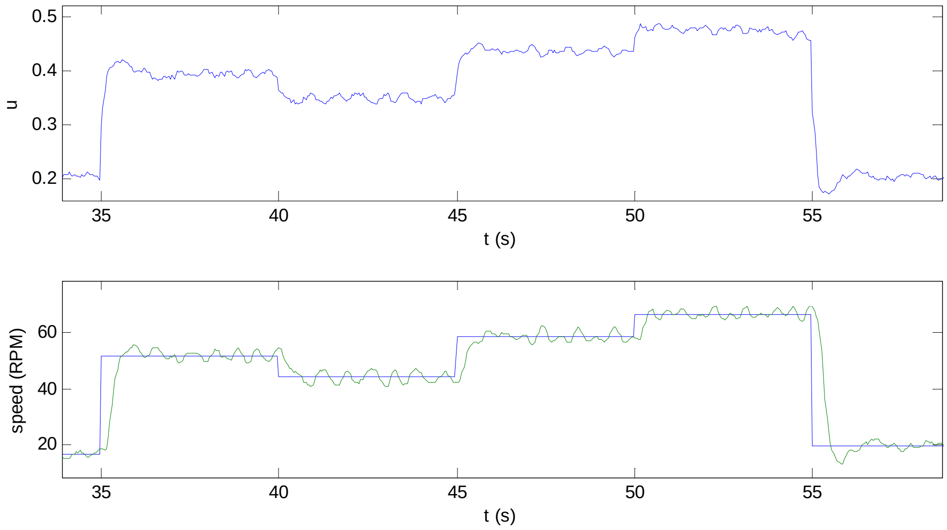

FIGURE 3. Control response of rear seeder with wheat

CONCLUSION: With an electric feeding device drive it is possible to get higher bandwidth control for variable rate applications with conventional seed drills. Carefully designed electric drive system for feeding device can provide responsive and backlash free rate control compared to the realistic accelerations of tractor-seeder. However, the shaft should be mounted with smaller tolerances, the coupling of motor/gear to the shaft and bearings of the shaft. The required electrical power is very close to maximum power the current tractors can provide to the implements. Using higher voltage than the 12V would allow smaller currents, lighter cables and more powerful actuators.

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