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CENTER-PIVOT AUTOMATIZATION FOR AGROCHEMICAL USE

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Abstract: This paper presents an agrochemical application system that could be incorporated to existing irrigating center-pivots. The system consists in a hydraulic circuit with emitters dose controlled with variable valve timing. The electronic control system has been designed to be modular and distributed along the pivot with a main algorithm based on determining every emitter absolute speed to obtain their adequate timing control. *Copyright © 2002 IFAC*

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1. INTRODUCTION

Center-pivot irrigation machines are among the most popular systems for irrigating general field crops and are widely used on the sprinkler-irrigated land. They have made it easy to efficiently irrigate (King *et al*., 1999) many areas where surface or conventional sprinkler irrigation methods are not adaptable.

The center-pivot (fig. 1) rotates around a fixed pivot point. The laterals are supported above the crop by a series of towers usually supported on two rubber-tired wheels powered by low speed electric or hydraulic motors. Typical span length is between 30 to 50 m with a total lateral length between 60 to 800 m.

Most center-pivot irrigation systems currently being used are designed to apply a constant rate of water over the entire irrigated area. Due to the turn displacement of center-pivots, the precipitation must be adjusted through the lateral, increasing as we distance from the fixed pivot point. This can be accomplished using several sprinkler-spacing configurations (Allen *et al*., 2000), varying sprinkler spacing, sprinkler flow or both. Center-pivots have a good uniformity for irrigation, with a Christiansen uniformity coefficient between 70 to 88 %.

Fig. 1. Center pivot with hanged agrochemical application system prototype.

Center-pivots are also being used nowadays for chemigation; the application of agrochemicals mixed with the water during the irrigation. Although chemigation has become quite used, it has some important disadvantages. The more relevant are the high application volumes because you irrigate when you chemigate. The big droplet size gives worst agrochemical crop coverage because sprinklers are designed for reducing drift and increase the irrigated area, but not for agrochemical spraying.

In this paper, we will introduce a precision agrochemical application system that could be added to almost any kind of running center-pivot. The system is based in a variable rate technology depending in the emitter's radial absolute position and speed, to maintain a uniform application dose along the covered area. The system is truly independent and can apply the agrochemical with no irrigation, just using the center-pivot as the transport of the hanged agrochemical application system. In this paper, the control methodology and the electronic implementation are described; the hydraulic design will be introduced elsewhere.

2. PROBLEM DEFINITION

The circular shape of the center-pivot covered area with different linear speeds along the lateral during the displacement increases the difficulty of the hydraulic design to obtain a constant rate of water over the entire irrigated area. There are many hydraulic possibilities to obtain reasonable solutions to this irrigation problem. However, from the agrochemical point of view, the problem becomes more complex because the sprinkler dose at a nominal pressure combined with the center-pivot linear speed produces an application rate suitable for irrigation but normally higher for agrochemical application (fig. 2). This problem persists even if specific agrochemical emitters are used. This means that a variable rate control technology must be used in order to obtain the desired agrochemical dose with an emitter's total activation time proportional to their absolute linear speed.

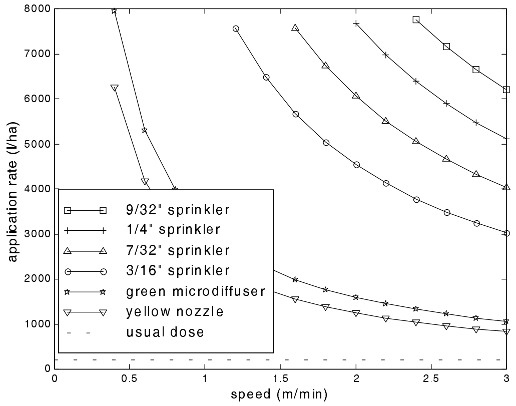

Fig. 2. Application rate depending on the absolute speed for different emitters (lower dashed line: desired usual dose).

Variable rate operation is based on the calculation of the adequate spray activation time, t_{ON}, and the time between consecutive activation, t_{AC}. t_{ON} depends on the emitter sprayed area, the emitter nominal flow and the desired application dose, while t_{AC} depends on the emitter diffusion shape (fig. 3) and their absolute displacement speed.

The ratio between t_{ON} and t_{AC} fixes the effective dose. One way to adapt these ratios is fixing one value and modifying the other in order to guarantee the application dose according to the absolute emitter speed. This individual speed can be obtained analytically sensing the adjacent tower speed. However, the pivot movement is quite complex. Each tower is motorized and can run at a constant displacement speed but mechanical angular sensors are used to modulate the motor activation (like a PWM speed control) to obtain the adequate rotating mean speed maintaining the pivot's spans alignment.

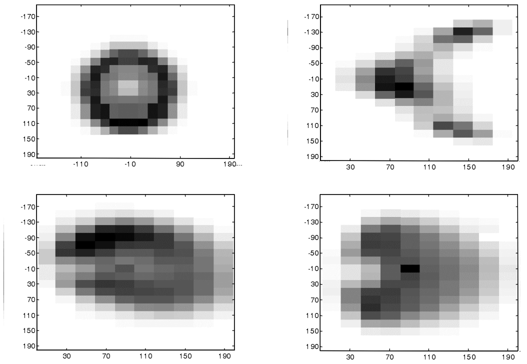

Fig. 3. Several emitter diffusion shapes available commercially.

3. PROPOSED SYSTEM

The proposed solution for agrochemical dispensation using the existing pivot structure can be summarised in the following points: fully configurable modular solution, tower speed measurement and variable rate emitter's electrovalve control.

Available center-pivot structures can have from one to more than ten towers. Therefore, the electronic control system has been designed to be distributed along the pivot in a modular manner (fig. 4). Each span between towers will have a module to control the inner agrochemical emitters. Another central module fixes the dose and sends to all the control modules.

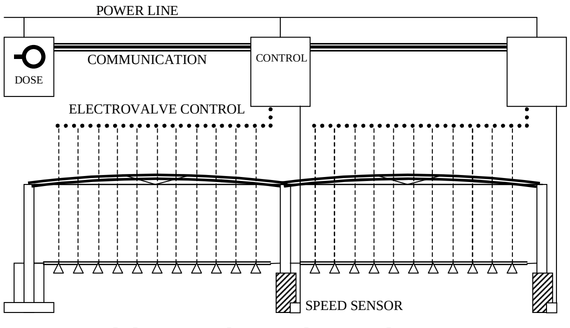

Fig. 4. Modular agrochemical control system.

Each emitter has an electrovalve associated for variable rate individual control. To obtain the desired dose t_{ON} is fixed while t_{AC} depends on the absolute emitter rotational speed. This speed is obtained analytically from the speed of the span's towers but requires several structural information as the span length and the absolute emitter position, all of them established by initial configuration. There are two possibilities to obtain the tower speed. With an additional wheel with an electronic encoder for maximum precision, or detecting the motorized tower activation and assuming that the tower will run at a fixed speed established by initial configuration.

The electronic control system has two parts: a modular control unit and a central dose unit. The modular control unit is located in the towers, controlling the span in direction to the center of the pivot. The unit consists on a microcontroller with a communications interface, a sensors interface and a power output driver to open or close the electrovalves (fig. 5). In the initial configuration stage, each unit stores local and global information needed for the analytically real-time computation of t_{AC}, while t_{ON} depends on the central unit dose. All the mathematical operations are done using floating point variables for maximum precision, with the operations simulated by software. In normal operation, each modular control unit inform his tower displacement speed to his adjacent control unit.

The number of electrovalves, N, in each span has been carefully analysed because a connection cable must be included between the control unit and each electrovalve. The total cable length can be evaluated depending on the *span_length* between towers and N:

$$total\_cable\_length = span\_length \cdot \tfrac{1}{2} \cdot N \tag{1}$$

Taking in consideration the usual span lengths, a number of eleven electrovalves has been selected.

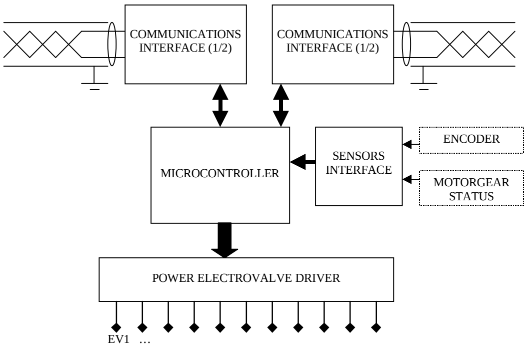

Fig. 5. Control unit schema.

The central dose unit (fig. 6) is used to select the desired dose and send it to all the modular control units. The dose can be adjusted by an embedded dial or by a small remote wireless infrared digital display. Several input detectors permit to stop the agrochemical application in case of wind or other unfavorable spraying conditions detected by means of convenient sensors. The unit is also a bridge between a RS232 serial port and the internal communication bus. For statistical purposes, each control unit stores several functional parameters that could be obtained remotely. Through this unit, a PC can be used to control remotely the agrochemical application system and to monitorize its operation in real-time.

The optimal emitter separation is used to obtain the time between successive activation, t_{AC}, depending on their speed while the activation time, t_{ON}, is fixed depending on the desired dose.

$$t_{AC} = \frac{emitter\_separation}{emitter\_speed} \tag{2}$$

$$t_{ON} = dose \cdot \frac{emitter\_area}{emitter\_flow} \tag{3}$$

Where the *emitter_flow* is expressed in litres/second, the *emitter_area* is expressed in square meters and depends on the cone shape and *dose* is the desired litres/m^2 to be applied. All this expressions are correct while maintaining the pressure constant in all the application area. However, this condition is not true in long hydraulic circuits as the used in this system. A pressure loose must be expected and the entire hydraulic circuit has to be designed to reduce this error source.

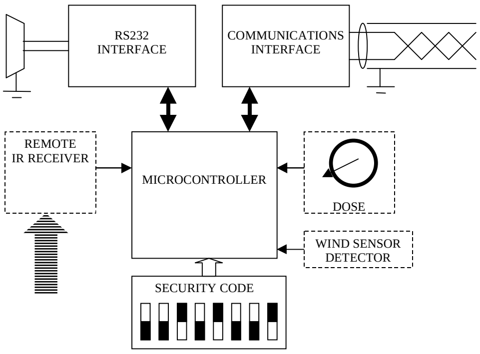

Fig. 6. Dose unit schema.

4. TEST

The proposed system has been implemented and tested in a medium size center-pivot with four spans of fifty meters and a twenty meters overhang (fig. 1). The pivot has been equipped with an agrochemical application pipe supplied by means of a pump that injects the agrochemical products at the convenient pressure. Mechanical supports have been added to the pivot's chassis in order to hang the agrochemical polyethylene pipe at an appropriate height of approximately 50 cm above crop. Micro diffusers have been selected as emitters, connected to electrovalves for the pulsed spray of the agrochemical products. A modular control board has been installed in each tower for the variable rate control of each span's electrovalve. The control board has been isolated inside a case in order to protect it from the outdoor conditions. Each case has been subjected in the outer tower of the span.

4.1 Test procedure I

As mentioned, the span's towers speed is needed to individually control each electrovalve. This speed can be obtained using an encoder or sensing the tower activation. Using an encoder is obviously the

most accurate solution but also the most expensive; for this reason there is the possibility to detect the motorised tower activation and assuming a fixed speed. This second option can be considered because the tower's speed is very low (usually between 1 and 3 m/min) and has a small variance if the slope doesn't strongly change in the radial direction. This option is cheaper but is supposed to be less accurate.
This test has been designed to evaluate the accuracy of this low cost speed detection alternative. The expected tower speeds has been introduced in the system by initial configuration and each control system only detects motor activation assuming no acceleration or deceleration delay.

Figure 7 shows the results obtained measuring the relative error in the distance between consecutive activation in 12 of the 44 available pivot emitters. This distance depends on t_{AC} time and must be always the same to guarantee de adequate spacing between the spraying spots for an optimal overlapping. Results show a very small relative error in this distance with a total mean error of +1.4%. This total positive mean error also indicates that the real tower speeds is lower that the initially assigned by configuration (due to the acceleration delay), and suggests that this results can be improved reducing 1.4% the declared tower speeds, but this conclusion needs further intensive tests in different pivots.

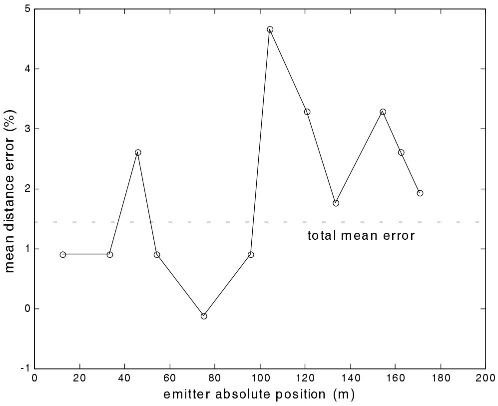

Fig. 7. Non-cumulative mean distance error in consecutive emitter's activation distance.

4.2 Test procedure II

The following test has been designed to evaluate a low cost hydraulic circuit. The quantity of agrochemical applied in each emitter activation must be the same in all the pivot emitters because t_{ON} is also the same. Therefore, this test will give information about the influence of pressure looses in the hydraulic circuit.

Figure 8 shows the mean relative volumetric error in the emitted agrochemical application in successive activation. The results correspond to the quantity measured in 12 of the 44 available emitters. Pressure dependence can be observed because there is a reduction in the volume measured when increasing the relative emitters position from the center of the pivot. The obtained 10% of volumetric error are worse than expected and are motivated by the pressure loose in the low cost hydraulic circuit used and the density of the agrochemical products. With the improvement of the hydraulic system design, especially in the most critical parts to reduce the pressure loose, the accuracy of the complete system can be increased. However in certain applications, this 10% of application variation can be good enough considering the lower cost of the hydraulic circuit.

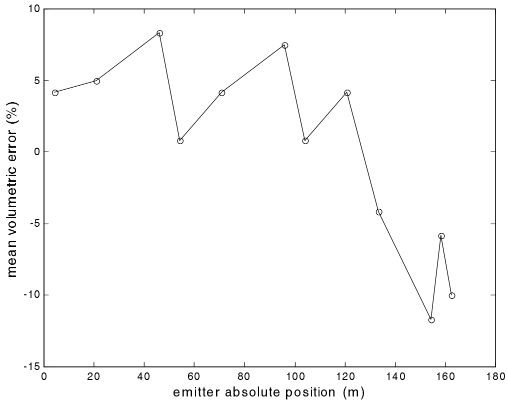

Fig. 8. Mean error for the agrochemical emitted volumetric application.

5. CONCLUSIONS AND FUTURE WORK

In this work, a new agrochemical application system has been presented. The system consists in two basic electronic modules and a hydraulic circuit with electrovalves and emitters. Each emitter activation is controlled individually with a variable valve timing control that depends on their absolute rotational speed. The system has been designed to be incorporated to existing irrigating center-pivots but can also be incorporated to lateral pivots and now is in an intensive test stage. Results confirm that a low cost alternative for the tower speed determination can be used with good accuracy. In addition, a dose error of 10% can be expected when using a low cost hydraulic circuit in cost critical applications.

In the near future, a networked system design is planned to reduce the total cable length and installation costs. The use of accelerometers to sense tower movement and avoid slips is also planned.

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