Introduction

Liquid application systems are used for a variety of pesticide and liquid fertilizer applications. Self-propelled sprayers commonly use flow-based liquid control systems to implement application rates. Sprayers are also fitted with automated guidance and automatic section control (ASC) for individual boom and nozzle control.

Flow-based control systems regulate product flow rate in the plumbing system to account for changes in ground speed (acceleration and deceleration) and spray swath width (ASC actuation) during field operation. These systems use fixed-orifice nozzles as selected based on product label specification including recommendations on application rate, travel speed, and droplet-size classification. However, typical field application speeds vary from 6 to 20 mph, depending on factors such as field shape, obstacles, and operator driving style. ASC actuation can vary spray swath width from minimum to maximum.

Such varying field conditions would require the product control system to increase and decrease the flow rate in the plumbing system and thereby nozzle pressure to maintain the target product rate (Sharda et al., 2011). Consequently, nozzle pressure can vary with an increase or decrease in nozzle pressure, potentially changing the droplet size distribution and affecting the spray fan angle.

Both droplet size distribution and spray fan angle consistency are critical to achieve desired overlap from adjacent nozzles and maintain uniform coverage.

Technology Basics

A Pulse Width Modulation (PWM) system uses solenoids mounted at each individual nozzle to the existing nozzle body drip check to provide automatic proportional flow compensation based on the speed of the sprayer (Figure 1).

The solenoid is an electromagnet that opens and closes the nozzle flow by way of a plunger and a spring. The default position of the solenoid valve is closed, held shut by the spring, so it retains the original purpose of the drip check.

PWM is based on two key components: duty cycle and frequency. The duty cycle represents the amount of time the signal is in a high or ON state, as a percentage of total time to complete one cycle (Figure 2). In each cycle, a digital signal determines the duration of the nozzle in an On-state (high with 12 volt direct current input) and Off-state (low with 0 volt...
The frequency, indicated in Hz, is represented by the number of such cycles completed per second. All commercially available PWM systems from manufacturers such as Capstan, Raven, and Teejet operate at a 10 Hz frequency, which means they have 10 cycles per second or a 100-millisecond (ms) cycle to operate solenoids mounted on each nozzle. For example, a PWM system at a 40% duty cycle means that during each 100 ms cycle, the nozzle solenoid will be in the On-state for 40 ms and the Off-state for 60 ms; whereas, an 80% duty cycle means the nozzle will be in the On-state for 80 ms (Figure 2). Therefore, an 80% duty cycle would release twice the amount of product during 100 ms compared to a 40% duty cycle.

**Operation**

Mangus et al. (2016) showed that systems maintain constant desired nozzle application pressure (Figure 3) irrespective of the number of nozzles in the On or Off states during different duty cycles. Liquid application at target pressure maintains uniform nozzle-to-nozzle overlap and droplet size. PWM technology typically uses coverage information from as-applied maps to turn individual nozzles On and Off (no-spray). Since each nozzle is controlled by a solenoid, individual nozzle section control capability is built into this technology. Previous studies have shown that individual nozzle capability significantly increases application resolution and thus improves application accuracy for a variety of products and applications (Luck et al., 2010).

PWM technology can be implemented for liquid products such as pesticides and nutrients on sprayers, and nutrient applications such as a nitrogen application to side dress and starter fertilizer on planters. Another important advantage of the PWM system is the ability for the system to almost instantly turn Off and On. This is possible due to the actuation response time of the solenoid valve at each nozzle, which holds the product at the application pressure when in the Off-state. As a result, when the solenoid valve is energized, the nozzle applies product at the desired pressure while quickly closing, eliminating product drain.

Figure 2. Nozzle on-state time variation during 40% (left) and 80% (right) duty cycle with a 10Hz (100ms cycle) PWM system.
When disengaged, the odd and even nozzles (Figures 4 and 5) on the boom are programmed to turn on and off consecutively.

For example, when even-numbered nozzles are in the on state, the odd-numbered nozzles are in the off state and vice versa. PWM technology can be implemented easily without any need for structural changes and uses all the existing plumbing.

Another feature offered by PWM and individual nozzle control technology is turn compensation. The PWM control software adjusts product flow to individual nozzles while spraying on contour paths, thereby regulating flow that is based on the angular speed of each individual nozzle during application. For instance, if the sprayer is turning left (Figure 6), the system...
7. Individual nozzle diagnosis capability.
8. Droplet size monitoring capability while spraying.

**Commercial Systems**

Several large agricultural manufactures are providing PWM liquid application systems; three key manufacturers are Capstan Ag Systems, Raven Industries, and Teejet Technologies. All these systems use the sprayer’s existing flow control and feedback components to decrease and increase product flow rate within the plumbing system. The change in flow rate is required to maintain target application pressure and also provide sufficient product in the plumbing system to complement the changing duty cycle. The end users should consult the equipment manufacturers and carefully program the PWM hydraulic flow control valves mounted on the pumps for product flow control response (Figure 8). More information on programing...
these valves is available in the 2015 publication *Understanding Controller Setup for Accurate Liquid Application*, MF3273, (by Ajay Sharda and others) available in the K-State Research and Extension bookstore. The sprayer display controller provides a user interface to load prescription maps, visually monitor spray coverage, receive a signal from the flow meter and send it to the PWM system, implement required control commands to the flow control valve, and record as-applied data. The Capstan Ag Systems product uses a Gateway hub for feedback and control. The Gateway hub captures information on speed, application rate, system On or Off status, global positioning (GPS), flow rate, pressure, sends out control commands to the flow control valve, and sends the output duty cycle to the valve control modules. The Raven Hawkeye and Teejet technologies Dynajet systems function almost in a similar fashion; however, there are slight changes in the way the whole feedback and control commands are originated and routed in the PWM system.

### Components Needed and Functionality

**Solenoid valve**
- Turn nozzles On and Off based on PWM duty cycle with capability to provide nozzle-valve diagnostics

**Valve control module (VCM):**
- Send target duty cycle to each nozzle on the sprayer boom

**Gateway hub or ECU:**
- Implement feedback and control functions, including sending target PWM requirements to each VCM

**User interface controller:**
- Program and monitor PWM system during application

**Remote control:**
- Control option for nozzle diagnostics

![Figure 8. PWM product flow control valve setting page in the Raven Viper Pro rate controller.](image)
**Final Comments**

End users can expect reduced spray overlap and more uniform spray rate across the entire field when using PWM technology. The benefits of this technology, just like automatic section control, will increase as field irregularity increases. The users should carefully follow manufacturer’s recommendations to properly select boom height, nozzle orifice size, and travel speeds when implementing PWM technology. Appropriate selection and implementation of the aforementioned parameters are critical to achieve proper lateral nozzle overlap and nozzle flow rates as the system pulses at 10 Hz. Additionally, since nozzles in a PWM system continuously turn On and Off, unlike flow based systems, users should carefully follow the manufacturer’s recommendation on range of duty cycles (typically 50% to 100%) for proper overlap and uniform coverage (Figure 9).

**More detailed information on commercially available products**

- http://www.capstanag.com/products/pinpoint

**References**


