K·STATE Research and Extension | Biological and Agricultural Engineering

Pulse Width Modulated (PWM) Technology for Liquid Application

Ajay Sharda, Terry Griffin, Lucas Haag, Devin Mangus, John Fulton, John Slocombe

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).

Figure 1. Solenoid operated mounted to apply product based on pulse width modulation (above) and exploded view of the solenoid valve system assembly (below).

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

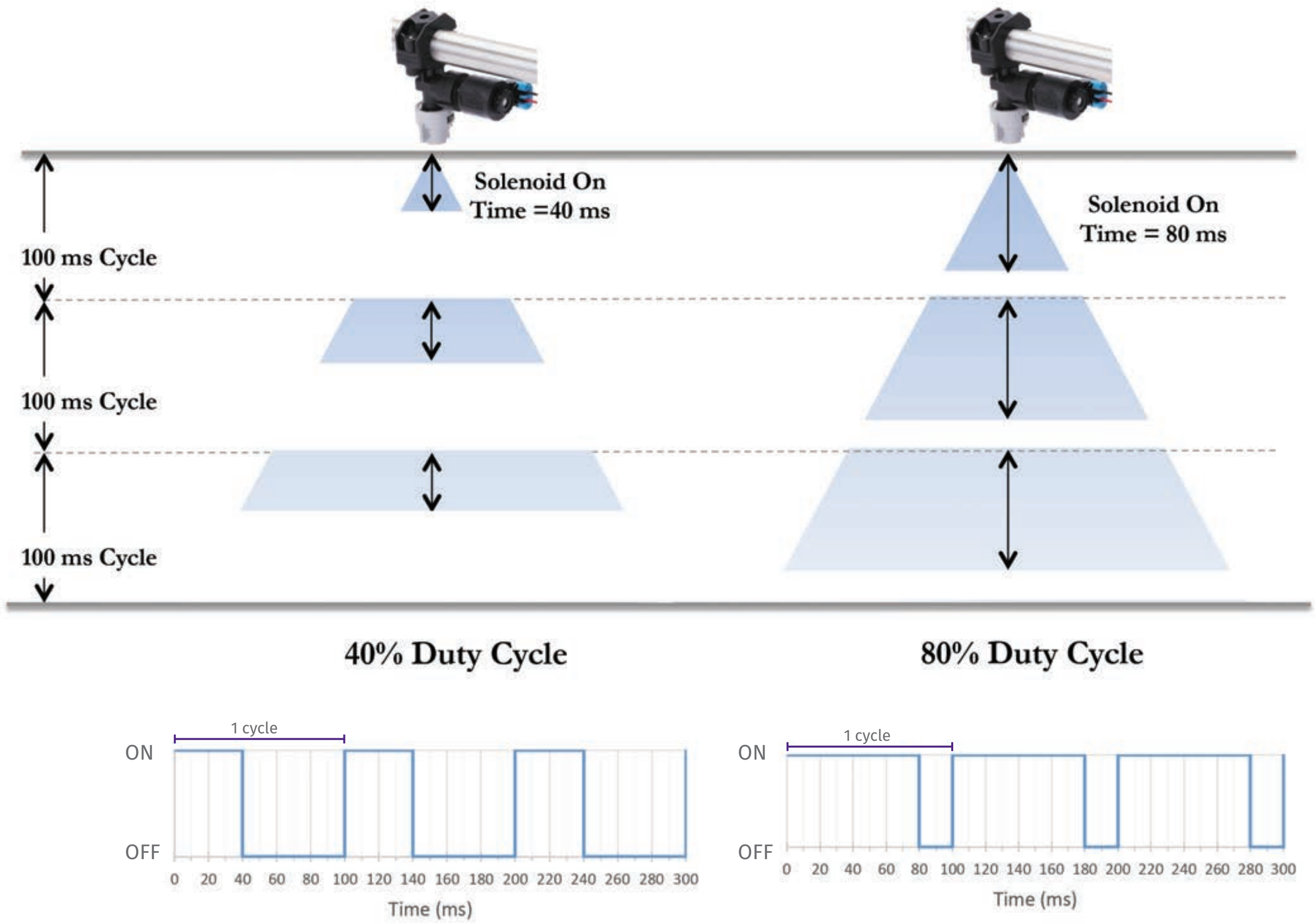


Figure 2. Nozzle on-state time variation during 40% (left) and 80% (right) duty cycle with a 10Hz (100ms cycle) PWM system.

direct current input). 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 in to 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

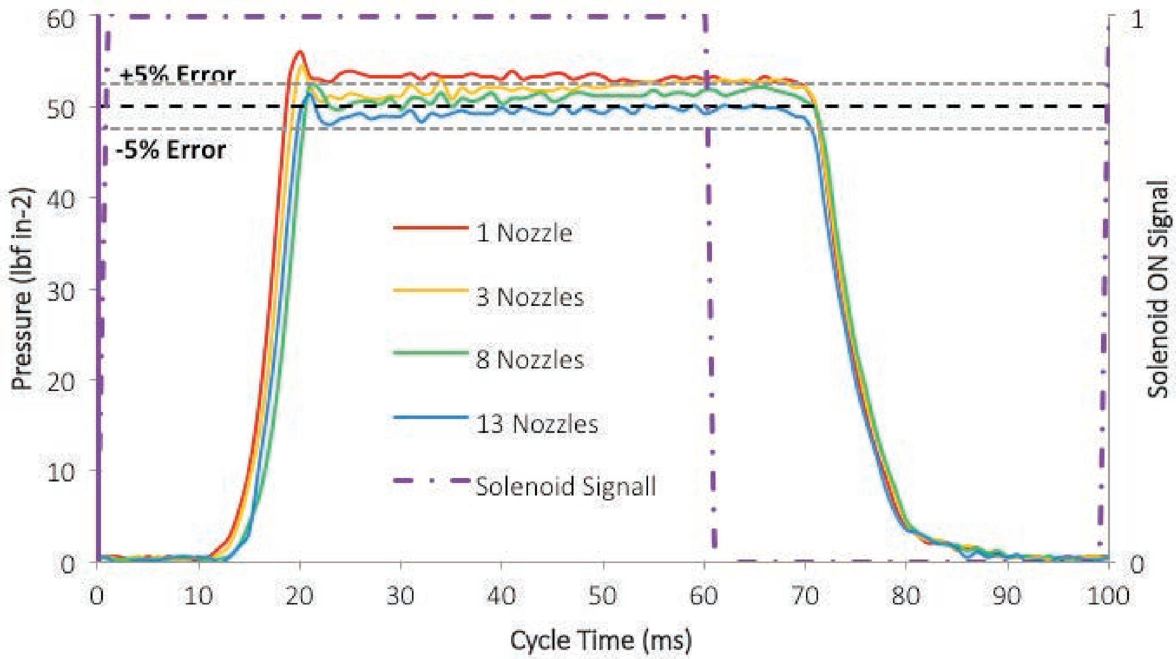


Figure 3. Operating nozzle pressure always within ±5% of target pressure of 50 psi and 60% duty cycle irrespective of number of active nozzles in on-state when using PWM technology.

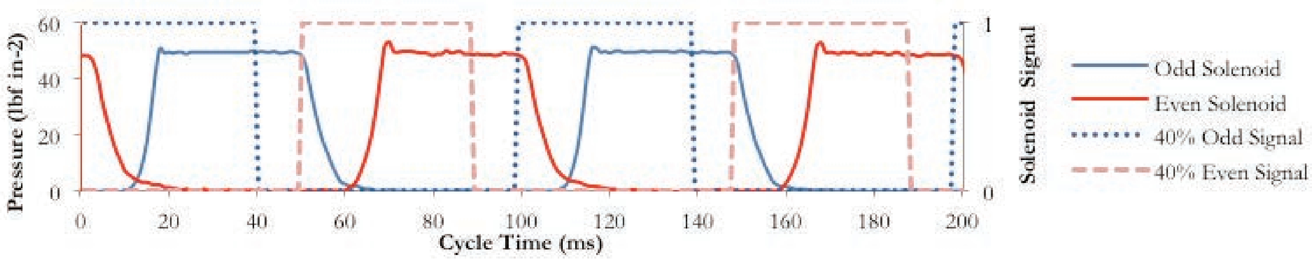


Figure 4. Odd and even nozzle solenoid actuation during application at 50psi pressure and 40% duty cycle.

Figure 5. Odd nozzle spraying and even nozzles off during application.

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

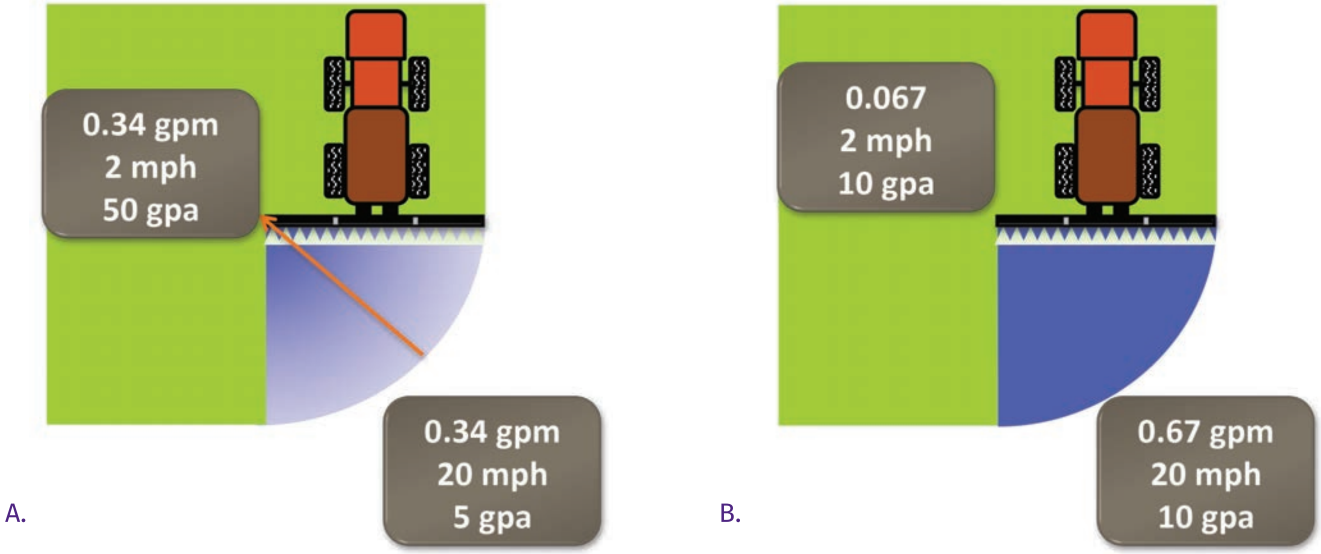


Figure 6. The turn compensation feature for a PWM spray system modulates individual nozzles in order to maintain the target rate across the boom regardless of velocity between the inside and outside boom during curvilinear travel such as turning at field headlands or maneuvering around other obstacles. Off-rate application occurs without turn compensation technology (A.) whereas uniform rate across the boom is maintain with the technology (B.)

will compensate product flow rate at each nozzle by increasing the duty cycle for nozzles on the right side (faster speed for greater flow rate) and decreasing the duty cycle for nozzles on the left to decrease flow rate. This feature results in even coverage, which otherwise could result in over- and under- application rate errors (Figure 6a).

Advantages

The PWM technology provide users several technological advances and various functionality including:

1. Variable rate capability by varying the duty cycle.
2. Individual nozzle shut-off control with negligible drain time.
3. Turn compensation on contours by reducing duty cycle for nozzles inside of turning radius and increasing the duty cycle on the outside nozzles.
4. Greater application resolution.
5. Potential to apply product by complying with label specifications.
6. Consistent spray pattern and droplet size.
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

Figure 7. Commercial sprayer with PMW technology

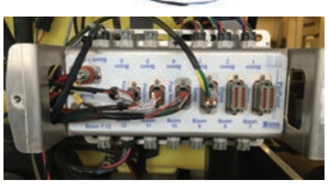
components to decrease and increase product flow rate within the plumbing system. The change in flow rate is required to maintain target application pressure and also provide sufficient product in the plumbing system to complement the changing duty cycle. The end users should consult the equipment manufacturers 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 commends are originated and routed in the PWM system.

Figure 8. PWM product flow control valve setting page in the Raven Viper Pro rate controller.

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

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).

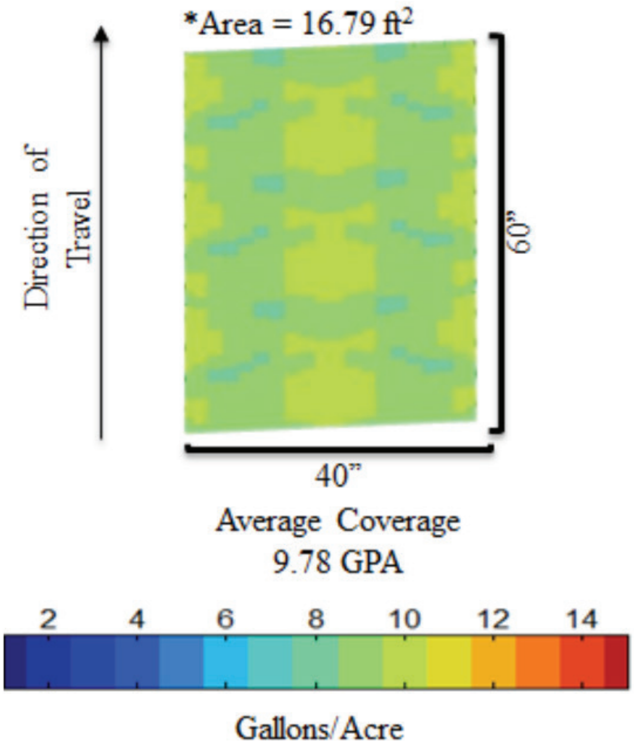


Figure 9. Simulated application coverage of three complete pulses at a duty pace of 80%, 50psi target pressure and 10 GPA target application rate (Mangus et al., 2015).

More detailed information on commercially available products

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

http://ravenprecision.com/products/application-controls/hawkeye-nozzle-control-system/

http://www.teejet.com/spray_application/dynajet-flex-nozzles.shtml

References

Luck, J. D., R. S. Zandonadi, B. D. Luck, and S. A. Shearer. 2010. Reducing pesticide over-application with map-based automatic boom section control on agricultural sprayers. Trans. ASABE 53(3): 685-690.

Mangus, D., A. Engelhardt, A. Sharda, D. Flippo, and R. Strasser and J. D. Luck. 2015. Analyzing Dynamic Spray Fan Pattern (SFP) Coverage with High Speed Imaging to Simulate Ground Coverage of a Pulse Width Modulated Sprayer. Annual International Meeting of American Society of Agricultural and Biological Engineering, New Orleans, Louisiana, July 26 – 29, 2015. (doi: 10.13031/aim.20152189633)

Sharda, A., J.P. Fulton, T.P. McDonald, and C.J. Brodbeck. 2011. Real-time nozzle flow uniformity when using automatic section control on agricultural sprayers. Computers and Electronics in Agriculture. 79(2011): 169-179.

Sharda, A., John Slocombe, Terry Griffin and Lucas Haag. 2015. Understanding Controller Setup for Accurate Liquid Application. K-State Research and Extension. MF3273. Available at http://www.bookstore.ksre.ksu.edu/pubs/MF3273.pdf.

Notes

Authors:

Ajay Sharda, Precision Ag and Machine Systems Engineer, Biological and Agricultural Engineering, Kansas State University

Terry Griffin, Cropping Systems Economist, Agricultural Economics, Kansas State University

Lucas Haag, Northwest Area Agronomist, Agronomy, Kansas State University

Devin Mangus, graduate student, Biological and Agricultural Engineering, Kansas State University

John Fulton, Associate Professor, Food Biological and Agricultural Engineering, Ohio State University

John Slocombe, Professor, Biological and Agricultural Engineering, Kansas State University

Publications from Kansas State University are available at:
www.ksre.ksu.edu

Kansas State University Agricultural Experiment Station and Cooperative Extension Service

K-State Research and Extension is an equal opportunity provider and employer. Issued in furtherance of Cooperative Extension Work, Acts of May 8 and June 30, 1914, as amended. Kansas State University, County Extension Councils, Extension Districts, and United States Department of Agriculture Cooperating, John D. Floros, Director.

MF3314 October 2016