Application Technology Series

Understanding Controller Setup for Accurate Liquid Application

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Introduction

Precision application technologies are increasingly being adopted by U.S. producers and service providers to enhance seed, fertilizer, chemical and water use efficiency and increase field efficiency. Current precision technologies for agricultural sprayers include auto-guidance, rate controllers, automatic section control (ASC), and variable-rate controllers — all of which improve the application accuracy of crop protection products and nutrients. A critical component of sprayers is the application rate controller, which maintains the target application rate during changes of ground speed and swath width. Target application rate during speed and spray swath width changes are maintained by changing product flow rate (gallons per minute), typically using a flow control valve. These types of systems are referred to as flow-based systems because application rates are maintained by controlling the flow within the system. The majority of self-propelled sprayers use flow-based control technology to account for variations in ground speed and spray swath width. However, automatic rate controllers must be configured correctly because improper usage can result in under- and over-application of products, product waste, and reduced pest control.

The spray system typically uses a hydraulic driven centrifugal pump to pressurize and pump liquid product. The flow control valves are used to increase and decrease the product flow rate (gallons per minute) to match the target application rate (gallons per acre) for the current swath width and ground speed. Flow regulation is typically achieved either through a flow control valve in the spray solution line between the pump and the boom (Figure 1) or a hydraulic flow control valve that controls the pump speed (Figure 2).

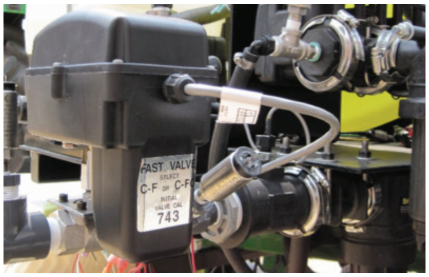


Figure 1. Fast ball flow control valve.

Controlling the hydraulic flow to the solution pump is the most common system on current production self-propelled sprayers. The regulating valves used in the solution line are butterfly and ball valves, while hydraulic flow control valves are typically pulse width modulated (PWM) valves.

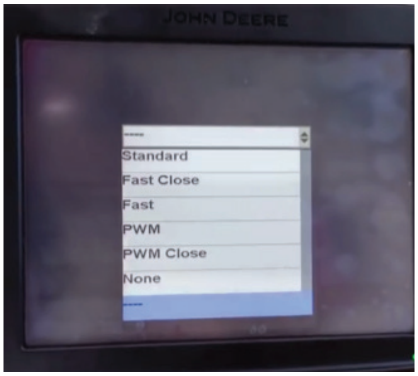
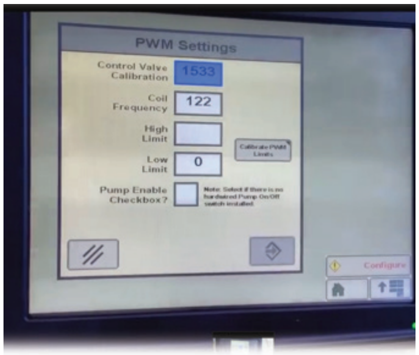


Figure 2. Flow control valve options available within John Deere GS 3 rate controller.



PWM Settings

Control Valve Calibration: 1533
Coil Frequency: 122
High Limit:
Low Limit: 0
Pump Enable Checkbox? ☐ Note: Select if there is no hardwired Pump On/Off switch installed.

Figure 3. PWM regulating valve setup screen in John Deere GS3 rate controller.

Regardless of system type, the key role of the flow regulating valve is to increase or decrease the amount of product flow in the plumbing system. This setup is true for most of the major sprayers including John Deere, Case IH, AGCO, Hagie, and others. Sprayer manufacturers use third-party flow control valves from Raven, Sauer Danfoss, and others. There are various versions of flow control valves (Table 1, on page 2) that could be used with a wide range of rate controllers (Figure 2). The response characteristics of a control valve are typically programmed within the rate controller using a valve calibration number, or VCN. The VCN establishes the flow regulating valve response characteristics during required system flow transitions.

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Table 1. Types of control valves used in the self-propelled sprayers

Standard Control Valve	Used in conjunction with an on/off valve. The on/off valve completely shuts off product flow, and the standard control valve stays at current position. When the on/off valve is opened again, the standard control valve takes over from last open position, assuming the target flow rate has changed very little.
Fast Close Control Valves	Used in single-valve systems. Since it has quicker response time, a fast close valve does not need an on/off valve. It serves as the rate control valve and will also completely close when no product flow is needed. On re-actuation, this valve quickly opens to achieve the target application rate.
Fast Control Valves	Used in conjunction with an on/off valve. The on/off valve completely shuts off product flow and the fast control valve stays at current position. When the on/off valve is opened again, the standard control valve takes over from last open position, assuming the target flow rate has changed very little.
PWM Control Valves	Used in conjunction with an on/off valve. The on/off valve shuts off flow and the PWM Valve remains at its current position. When the on/off valve is opened again, the PWM valve takes over from last open position, assuming the target flow rate has changed very little.
PWM Close Control Valves	Used in single-valve systems. Due to its quick response time the PWM valve serves both as the rate control valve and to shut off valve to fully stop flow. To re-start product flow, the PWM valve quickly opens to achieve the target application rate.

The configuration of most rate controllers requires the user to select the valve type and program the flow control valve. A typical screen for valve setup (Figure 3) requires the user to input the valve calibration or control valve calibration number: high limit and low limit. The coil frequency is typically standard and is 122 for Raven, John Deere, and other systems. The high limit sets the maximum, and the low limit sets the minimum desired RPM or hydraulic output of the Pulse-Width Modulated (PWM) control valve.

Manufacturers usually recommend one VCN, typically expressed as a four-digit number. For example, Raven Industries recommends a VCN of (0)743 for their fast ball valve (Figure 1). Each digit in a VCN represents a unique control aspect of the valve. For example, for the Raven fast ball valve, the first digit (0) is inactive; the second digit controls the response speed of the valve motor and can be selected from 0 (fast) to 9 (slow). The third number sets the brake point at which the control valve motor starts braking to prevent overshooting the target flow, and can be set from 0 (5%) or 1 (10%) through 9 (90%). The fourth digit or "dead band" defines the allowable difference between the target and actual measured flow at which no further rate control is performed and can range from 1 (1%) to 9 (9%). In general, the four digits represent the same control characteristics as discussed for the Raven fast ball example; however, the number selection and number range may vary.

Table 2. Different flow control valves used in self-propelled sprayers and recommended VCN.

Valve Type	Model	Valve Calibration Number (XXYZ)
Standard Valve Type	RAVEN 165	2513
	RAVEN 894	2513
	RAVEN 125	2513
	TEEJET 344B	1003
	HARDI	7051
Fast Valve Type	RAVEN 177	0753
Fast-Close Valve Type	RAVEN 177	0753
PWM Valve Type	Raven 381	0043
	Sauer Danfoss Hagie MFG T540	1533
	Command Controls Corporation FV1501	1411
PWM-Close Valve Type	Sauer Danfoss Hagie MFG T540	1533
	Command Controls Corporation FV1501	1411

Sprayer users usually use the number recommended by the manufacturer or one suggested by dealership personnel based on experience. However, there is no functionality built into the rate controller to self-calibrate and recommend the optimal valve calibration to the end user. Therefore it is important for users with sprayers using third-party flow control valves to contact equipment and valve manufacturers for VCN details and options for their operation. Newer self-pro-

Table 3. Description of simulated field scenarios of sprayer maneuvers on point rows, headlands and across a grassed waterway.

Simulated scenario (SS)	Description	Angle of incidence
SS1	Field condition – Sprayer starts in the spray boundary and maintains a constant speed of 10 mph (v2) with ASC actuation turning boom-sections Off in No-Spray areas when moving across point row	20°
SS2	Field Condition – Sprayer starts in the spray boundary and maintains a constant speed of 10 mph (v2) with ASC actuation turning boom-sections Off in No-Spray areas when moving across point row	70°
SS3	Driving Style – Sprayer starts from Headland to enter spray boundary at 4 mph and at slow acceleration of 1.3 ft/s2 (a1) attains constant speed of 10 mph and then slowly decelerates at -1.3 ft/s2 (d1) to 4 mph with ASC turning boom-sections Off at headlands	0°
SS4	Driving Style – Sprayer starts from Headland to enter spray boundary at 4 mph and at slow acceleration of 2.2 ft/s2 (a2) attains constant speed of 10 mph and then slowly decelerates at -2.2 ft/s2 (d2) to 4 mph with ASC turning boom-sections Off at headlands	0°
SS5	Combination of field condition and driving style – Sprayer starts from spray boundary at 10 mph (v2), slowly decelerates at -1.3 ft/s2 (d1) to a constant speed of 4 mph (v1) when approaching grassed waterway. The ASC actuation while crossing a grassed waterway. The sprayers once back in spray boundary fast accelerates at 2.2 ft/s2 (a2) to attain constant speed of 10 mph	45°

pelled sprayers have integrated systems. These integrated systems require the user to input the high limit and low limit of pump flow, and the rate controller selects one VCN from embedded algorithms. The advantage of these kind of systems is that it automatically selects one number, but the disadvantage is that the rate controller in these systems do not show the VCN it selected on the screen for the user.

Some other available valve types and recommended VCNs are presented in Table 2. The application accuracy depends on the programmed VCN which defines response behavior in achieving and maintaining correct system flow rate. Inappropriate flow rates could result in over- and under-application also referred as application errors. Therefore, the appropriate selection of a VCN is not only critical to quickly achieve flow stability, but also to reduce response time and minimize application errors of the agricultural sprayer.

Experimental Study on Behavior of VCN

The ability of an operator to define only one VCN could limit a rate controller's ability to minimize response and application errors for all field and operating conditions that demand a varying degree of response time. Experiments were conducted to quantify application errors using real-time nozzle flow rate with different regulating valve calibration characteristics during five simulated field conditions (see Table 3 and Figure 4). The flow regulating valve was a Raven fast valve. The selected VCNs comprised three different valve speeds (3, 5, and 7) and three brake points (1, 2, and 4) while keeping the dead band constant at 3 for all the tests. Therefore, nine VCNs (313, 323, 343, 513, 523, 543, 713, 723, and 743) were used along with the five simulated field scenarios (Table 3) for a total of 45 treatments. Simulated field scenarios were designed to

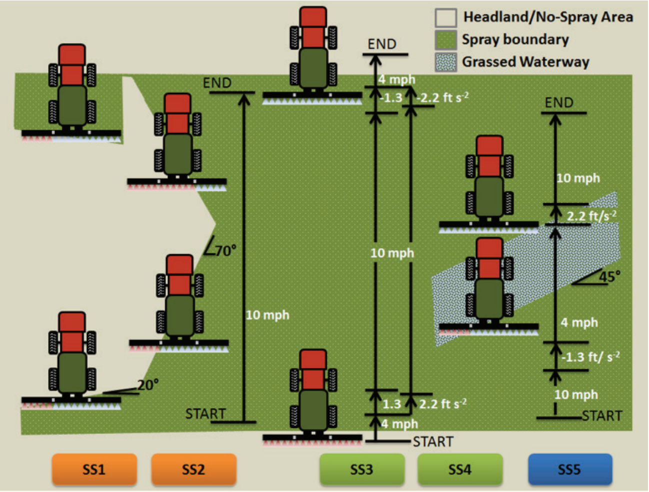

Figure 4. Illustration of the simulated sprayer operation on point rows, at headland areas where turns occur, and across grassed waterway (dotted blue area) scenarios. SS indicates a simulated scenario while the nozzles in red and blue represent a boom-section in the Off and On state, respectively.

evaluate the impact on possible operating conditions requiring ASC actuation and sprayer acceleration and deceleration. The spray simulation scenarios involved one of three categories 1) field operating condition at headland and point rows and traversing a grassed waterway (SS1 and SS2); 2) operator driving style (varying magnitude of acceleration and deceleration) (SS3 and SS4) and; 3) combination of field operating condition and driving style (SS5).

Accumulative application errors were computed using mean over- and under-application. The over- and under-application equaled the percent difference between actual nozzle flow and target system flow (Equation 1). The positive percentage differences of greater than 3% between the actual and target nozzle flow rate was termed as over-application and negative values represented under-application. The program cumulated the time, over-application values, and under-application values to calculate the average over- and under-application. Finally accumulated application error was calculated by integrating application error over 50 ms time interval to highlight the effect of VCN selection for each scenario. For all illustrations/figures, flow data from only one nozzle within a boom-section was selected.

Results

Results indicated that the recommended VCN (i.e. 743) did not provide quicker flow stabilization and resulted in greater accumulated application errors (Table 4). An example flow rate response during SS3 (Figure 5) showed that 313 VCN responded much quicker to manage nozzle flow during acceleration and also during the straight run as compared to 743 VCN. The comparison of point row results indicated that nozzle flow stabilization time will be greater for point rows with greater angle of incidence. During SS3 and SS4, VCN selection exhibited greater impact on application error during acceleration; therefore operators selecting an appropriate VCN will realize lower application errors at headlands and portions of straight runs (Figure 5). Operators accelerating and decelerating slowly (SS3) would result in greater application errors, and operators who accelerate and decelerate faster (SS4) will reduce application errors. Additionally, operators maintaining a stable ground speed, when possible, reduce over- and under-application errors.

The results for SS1 through SS4 revealed that irrespective of ASC being utilized with rate controllers, each instance of machine acceleration and deceleration the operator would inadvertently keep over- and under-applying chemical with 0743 VCN because of the delayed response. Therefore, it is critical to select a

Table 4. Accumulated application error observed for SS1 through SS5 using different VCNs. Underlined observations indicate the VCN exhibiting the minimum accumulated error for respective simulation scenarios.

VCN	SS1	SS2	SS3	SS4	SS5
313	44	69	543	524	1008
323	40	81	641	616	511
343	36	130	939	886	891
513	38	80	774	781	704
523	40	103	797	826	654
543	39	100	1152	946	1194
713	44	101	1176	992	1629
723	41	126	964	958	1711
743	42	107	1284	1072	1895

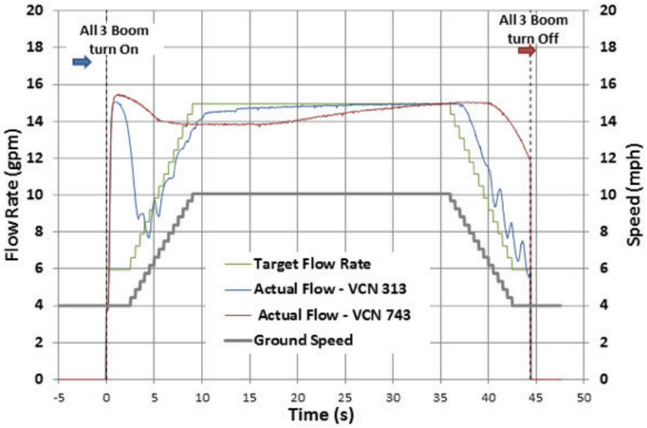

Figure 5. Resulting nozzle flow rate stabilization between the 313 and 743 VCNs for SS3 in which the operated accelerated (reentry from previously sprayed headland) and decelerated (entering previously sprayed headland) slowly. The shaded areas in purple shows the reduced over-application around headland by selecting 313 VCN.

Equation 1.

$$\text{Application error} = \frac{\text{Actual total nozzle flow} - \text{Target system flow}}{\text{Target system flow}} \times 100$$

Positive (+) value of application error indicate over-application.

Negative (-) value of application error indicated under-application.

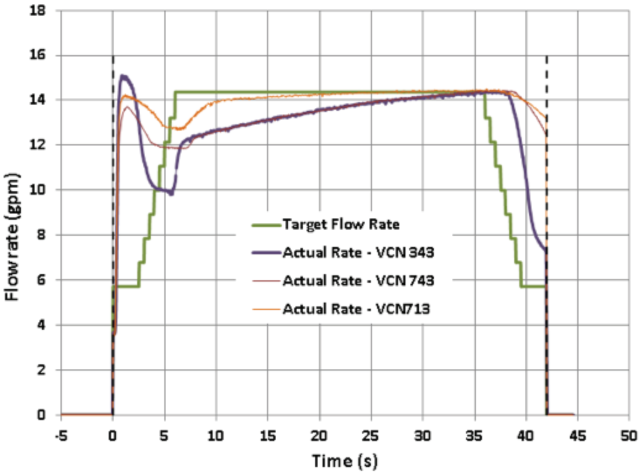

Figure 6. Actual nozzle flow overshoot target flow increased with 3 as valve digit number (faster motor speed) in comparison to 7 for SS4 where sprayer accelerated (after exiting headland and entering spray zone). Enhanced control response when changing only brake digit (4 to 1) for VCN 743 and 713.

correct VCN that can accurately conduct variable rate applications. Producers with more irregularly shaped fields need to be more cautious in selecting the VCN for greater application accuracy.

The results provided insight to producers, service providers, and third-party technicians on the proper selection of the VCN. Results in Table 4 shows that accumulated application errors decreased with smaller brake digit point and combination of low valve speed (greater valve speed) and brake point (lower brake point) digits (Figure 6). The accumulated application errors reduced as the regulating valve motor turned at a faster speed up until actual nozzle flow was within 10% (brake point digit 1) of target rate as regards to 40% with brake point digit 4, before braking. This reduced accumulated application errors for 343 VCN by half (Table 4) compared to 743. The accumulated application errors were reduced by a fourth by selecting 313 VCN for SS5. When selecting their VCN, end users should first select a lower brake point (third digit) and then number for increased valve speed (second digits) for quicker response and to reduce application errors.

Overall, selecting 313 VCN decreased over-application of chemical when accelerating and decelerating on headlands (Figure 5 and Table 4) and under-application even when the sprayer attained uniform speed on straight runs. Operators not properly selecting the VCN inadvertently over-apply and under-apply chemical each time entering from the headland to spray the boundary, which can potentially increase chemical resistance in weeds, non-uniform weed control, and a potential to damage environmentally sensitive structures. Therefore, producers should work closely with service providers and equipment manufacturers to discuss their application needs and carefully select the proper VCN to harvest the full potential of precision technologies for uniform product application and pest control.

Resources

Sharda, A., J.D. Luck, J.P. Fulton, T.P. McDonald and S.A. Shearer. (2012). Field application uniformity and accuracy of two rate control systems with automatic section capabilities on agricultural sprayers. Precision Agriculture. 14(3): 307-322.

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