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THE DEVELOPMENT OF A STANDARD TEST METHOD FOR MEASURING THE EVENNESS OF FLOW OFF METER ROLLERS

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ABSTRACT Currently, air carts come equipped with a product metering device that consists of a fluted/studded roller or rotary valve of various sizes, depending on seed size and profiles. The rollers are required for metering seed into the distribution system for precise placement into the ground by a tillage tool. The flow of material pulsates as each flute of the roller gradually lets the next batch of seed empty into the distribution system. This discontinuity of flow off the meter roller will lead to uneven seed placement in the ground that is sub-optimal for plant growth. Flow is affected by certain factors such as the seed properties and physical parameters of the roller. Currently, there is no standard for testing the discontinuity in the output of rotary valve metering systems. To evaluate the problem of uneven flow, an experimental procedure and apparatus were developed to look directly at the flow coming off the roller on a discrete mass-per-degree basis and on a continuous roller rotation basis. As measured by the coefficient of variation, a discontinuity of flow has been observed in canola, wheat, and field pea of up to 18, 32.4, and 35.7%, respectively, of the theoretical even continuous flow using the discrete method, and up to 22.9, 19.8, and 18.6%, respectively, in the continuous method of meter roller testing. These procedures were effective for visualizing and quantifying the discontinuity of product flow in the metering devices.

Keywords: meter roller, rotary valve, discontinuity, discrete, continuous, product flow, flute.

INTRODUCTION

In pneumatic conveying, granular materials such as seeds and granular fertilizer are commonly metered by augers or fluted cylinders (meter rollers). As the meter roller is rotated, the product is introduced into a conveying air stream. In typical air-seeding equipment, this air stream carries the product through the distribution system of hoses to secondary distribution manifolds that lead to the seed boots where the seed is placed in the soil directly behind the ground openers of the tillage equipment (Ernst and Gregor, 1999). The more evenly distributed the flow as seen by the secondary distribution system, the more evenly it will be distributed across the ground openers. Current conventional air seeders have trouble rationing the product evenly into the secondary manifolds across the width of the seeding equipment. Therefore, if a metering system can be devised to provide continuous evenly distributed flow into the secondary system, a more consistent and efficient placement of seed in the ground will be seen (Mayerle, 2006).

Buckmaster et al. (2006) state that seed metering is split into two categories, seed metering by volume and by individual seeds. The oldest method of metering seeds is by a variable orifice mechanism. It is also the least accurate of all methods because the metering rate is not directly linked to the travel speed of the seeder, but rather by regulated adjustments of orifice size by the operator. Buckmaster et al. (2006) also included the fluted wheel and the internal double-run assembly as volumetric metering mechanisms, both of which are placed at the bottom of the seed hopper and gravity fed. A typical meter roller can be seen in Figure 1. Each mechanism has an adjustable feed gate to match seed sizes and regulate flow rate along with rotational speed. Both of these mechanisms allow for the seed rate to be more accurately controlled than the variable orifice because it is directly connected to the travel speed. Therefore accurate rates can be calculated for any variety of seeds through calibration of the mechanism. However, in actual field operation the average seeding rate may be accurate, but the placement precision of each seed along the row is decreased because it is deposited into the distribution stream in stages as each flute goes by (Buckmaster et al., 2006).

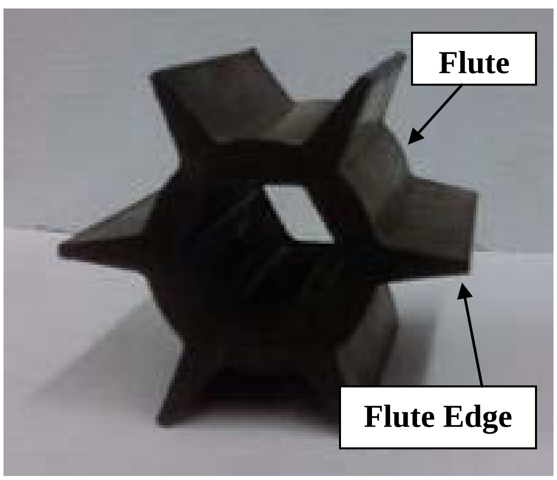

Figure 1. Segment of a Typical Meter Roller with 6 Flutes

The number of flutes affects the volume released per revolution of the roller along with the number of times product is released in one revolution. A larger number of flutes contribute to a larger portion of the metering area being occupied by flute edge. The number grooves on a roller greatly influences the dispersion of seeds. Increasing the number of flutes increases the number of times product is released. Rollers with fewer flutes require an increase in roller speed so as to keep the time between droppings to a minimum. Increasing the number of flutes also effectively decreases the release angle of the roller (Kim, 1998).

Flute volume determines the amount of seed to be released per revolution of the roller. The volume is affected by flute width, flute depth, and the distance between flutes. In general for fine seeds such as alfalfa or canola, as roller speed and flute width increase, the flow rate will increase but the flow rate uniformity will decrease (Guler, 2005). Volume released determines what speed the roller must be rotated at to achieve a given volume with respect to time and distance traveled.

The type of product being metered also affects how it will be released from the roller. Static and kinetic friction, both between the apparatus and the granular particle interaction during their relative motion, affects how product will be released from the metering roller (Strochine, 2000). The shape of the product also greatly affects how the product will be released. Product with a spherical profile releases with less resistance compared to a kernel with an oval or irregular shape. Strochine (2000) discussed how materials of high moisture content or irregular shape may not be free flowing because of binding as they flow passed each other. The shape also affects the void ratio in filled flutes. Fuller flutes also optimize the amount of product to be released at an appropriate speed.

Karayel et al. (2006) discussed the importance of seed spacing uniformity as a criterion for evaluating the performance of seed drills. They looked at methods for evaluating the longitudinal distribution of seeds from a fluted meter roller and compared a sticky belt test and a high-speed camera system method. A sticky belt test involves metering product on to a sticky belt passing underneath the roller at the same speed as the roller. The metered product sticks to the belt so the seed distribution can be evaluated. It was found that the high-speed camera system could be used to accurately evaluate the seed distribution much faster than the sticky belt method. The high-speed camera could allow for many more repetitions, a much larger sample size, and reduce product consumption because of the non-contact measurement (Karayel, 2006). Implementing a high-speed camera also provided other advantages that included the ability to incorporate a much larger sample size and the possibility of measuring the velocity of falling seeds (Karayel, 2006).

Evaluating a meter roller on the basis of how much product released, in terms of mass, at any given point on the roller was hypothesized to be a necessary to more fully assess the performance of a roller and to understand the interaction of factors contributing to that performance. It would allow a close analysis of how the rollers characteristics affect the continuity of product flow being released at any point.

The purpose of this study was to develop a method for testing the performance of meter rollers based on the continuity of flow off the metering wheel during operation. This was be achieved by implementing an experimental procedure and apparatus testing the performance of the meter rollers based on two methods. The two methods are referred to as the discrete test method and the continuous test method.

METHODS AND MATERIALS The study evaluates the performance of three products on three different fluted meter rollers. The three products used were canola (*Brassica napus* L.), wheat (*Triticum aestivum*), and field pea (*Pisum sativum* L.) with an average seed mass of 4.8, 41.0, and 223mg respectively. The three rollers used were an extra fine, fine, and coarse meter roller. The rollers were characterized by flute width, depth, volume, and the number of flutes. The extra fine roller had the smallest flute volume, therefore was best suited for metering canola, whereas the fine roller was best suited for metering wheat and the coarse roller for field pea. The extra fine, fine and coarse rollers had 15, 10, and 10 flutes respectively.

Discrete Test Method The discrete method requires the user to rotate the meter roller in small-angle rotational increments until the roller has rotated at least one full rotation. After each rotational increment the product released must be collected and weighed. This method was intended to reveal how the flow rate varies as the roller rotates.

If the flow off the roller is continuous, the same amount of product should be released over every degree of rotation. For example, if the roller is rotated one degree, 360 times to achieve one full revolution, then for every one degree of rotation, the same mass of product should be released from the roller. Therefore the theoretical continuous flow would appear as a horizontal line if graphed on a mass-per-degree basis. It was hypothesized that data collected on a mass-per-degree-of-rotation basis would show a pulsating waveform if plotted over a full rotation of the roller. This waveform would peak as product is released, and reach a minimum when the flute has already emptied.

The standard deviation of mass-per-degree of roller rotation and the coefficient of variation of each test were calculated and presented as a measure of the discontinuity of product flow. A standard deviation and coefficient of variation of zero would indicate perfectly continuous product flow.

Continuous Test Method The continuous test method requires the user to rotate the roller on a continuous basis at roller velocities that correspond to typical seeding rates in the field. A camera is positioned in front of the metering assembly to capture images of the product as it is dropped from the meter roller over at 25 frames-per-second (fps). From each of the images, the percentage of the total image area covered by the product, *A*, is determined. This area covered by the product can be calculated by thresholding the image so that the product shows up as black and the background as white. To improve the thresholding, the falling seeds were back-lit by a lamp shining through a diffusing plastic sheet.

The area of product in the end of each frame was converted into percent area per degree of roller rotation based on the frame rate and roller speed. The equation for the number of roller degrees per frame, C_D was:

$$C_D = \frac{V_R \times k}{f} \tag{1}$$

Where V_R = rotational velocity of the roller in RPM,

k = 60 (min × °) / (s × rev), and

f = 25 fps.

The area per degree, A_d, is the quotient of A and C_D. If the flow off the roller is continuous, the percent of area occupied by the product in each image should be the same in every frame over a complete revolution of the meter roller.

The continuous method was tested under conditions that closely resembled actual meter roller speeds from field operation from a 9-run metering system with a ground speed of 8.8 km/hr. The canola test was conducted at a roller speed of 6.83 RPM which is equivalent to a seeding rate of 6.7 kg/ha on a 9-run system with an extra fine roller. The extra fine roller has 15 flutes with a flute depth of 3.2 mm. The wheat test was conducted at a roller speed of 30.36 RPM which is equivalent to a seeding rate of 100.9 kg/ha on a 9-run system with a fine meter roller. The fine meter roller has 10 flutes with a flute depth of 6.4 mm. The field pea test was conducted at a roller speed of 30.45 RPM which is equivalent to a seeding rate of 151.3kg/ha on a 9-run system with a coarse meter roller. The coarse meter roller has 10 flutes with a flute depth of 12.7 mm.

Validation of Methods The first aspect of the discrete test method to be validated was that data from each replicate were consistent and repeatable. Each test with canola, wheat, and field pea consisted of three replicates of each collected from 90, 4° increments of the roller over one full revolution. The within-product replicates were compared using an analysis of variance (ANOVA) at the 95% confidence level to determine if the amount of material metered in each replicate was statistically the same. If this were the case, it would allow the mean output of each step could be averaged across replicates for a particular product.

The second component of the discrete test method to be validated was that the mass of product collected from rotating the roller at 4 degree increments for a full 360 degrees was actually equal to the product mass collected from rotating the roller 360 degrees without interruption. Therefore, a number of replicates were conducted from a test that consisted of rotating the roller three continuous revolutions, collecting the total mass, and dividing by three to give the total mass of product released over 360 degrees of rotation. The result of the three revolution tests was termed the benchmark or standardized mean, representative of actual field operation. With a known standardized mean and sample mean from the discrete tests, a two sample t test was chosen to evaluate the statistical difference between the two sample means. They were evaluated at a 99% level of confidence.

The continuous test method was validated using an analysis of variance (ANOVA) to verify that each test was consistently producing repeatable results. The standard deviation of the percent area that the product covers and the coefficient of variation of each test were calculated and presented as a measure of the discontinuity of product flow.

Apparatus The experimental apparatus consisted of the metering assembly and seed tank, a drive unit to turn the meter roller, a sensor for measuring the actual position of the meter roller, a container to catch the product dispensed by the roller, a precision balance (±0.5 mg) to measure the mass of the product leaving the apparatus, and a machine-vision camera (not shown) . Figure 2 shows the implemented test stand.

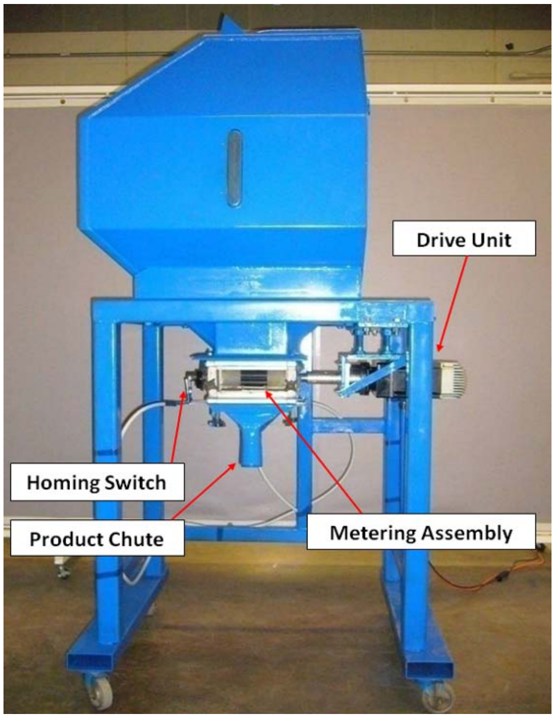

Figure 2. Experimental Test Stand

The metering assembly is suitable for a single primary run segment for a typical agricultural air cart. The single run can easily be scaled up to actual air cart configurations of up to 9 runs.

A computer-controlled stepper motor with a low-backlash reducing gear head was used to drive the roller shaft. This facilitated precision in both incremental motion and velocity control of the roller. A homing switch was mounted at the end of the roller shaft to ensure the same start position of each replicate of each test.

For this study a monochrome machine-vision camera was used to capture the amount of product discharged by the roller in terms area coverage as the roller is rotated continuously. The percent of area occupied by the product in a specific image can be calculated over time as the roller is rotated at typical seeding rates for corresponding products. Images were captured at 25fps and 800 × 600 pixel resolution.

RESULTS AND DISCUSSION The results from the ANOVA statistically prove the consistency and repeatability of the data between the replicates of each test. In all cases, the data from repeated runs were found to be statistically the same at the 95% confidence level. F values from the tests are shown in Table 1, with values of F needing to be less than 3.0 for statistical sameness at the 95% confidence level.

Table 1. ANOVA Results From Discrete and Continuous Test Methods.

Test Method	Product	$F_{0.05}$
Discrete	Canola	0.0635
	Wheat	0.0019
	Field pea	0.0030
Continuous	Canola	1.057
	Wheat	0.651
	Field pea	0.463

While all cases were well within the 95% threshold, tests with canola resulted in a greater F value than the corresponding tests with wheat or field pea. This is hypothesised to be a function of smaller flute volume and smaller seed mass and projected area. As a result, sample sizes at each step would be smaller. The continuous test F values were observed to be higher than those of the discrete test method. Seed overlap and thresholding error presumably introduced greater uncertainty than was introduced by the weigh scale.

The last step of validating the results was the two sample *t* test for equal means between two separate samples of two different variances. The two means being compared were the total mass from the 3 revolution tests and the discrete tests. Therefore, the average mass of product per revolution of the three replicates from each test must be compared against the average mass per revolution produced from the 3 revolution. In all cases the means were found to be statistically the same at the 99% level.

Continuity of Flow To evaluate the continuity of the flow from the rollers, the mass-per-degree data from the discrete test (Figure 3) and the area-per-degree data from the continuous test (Figure 4) were plotted against the angle of roller rotation in degrees. Because there was not a clear starting reference point for the continuous test, data were shifted with respect to angle to best match the discrete data.

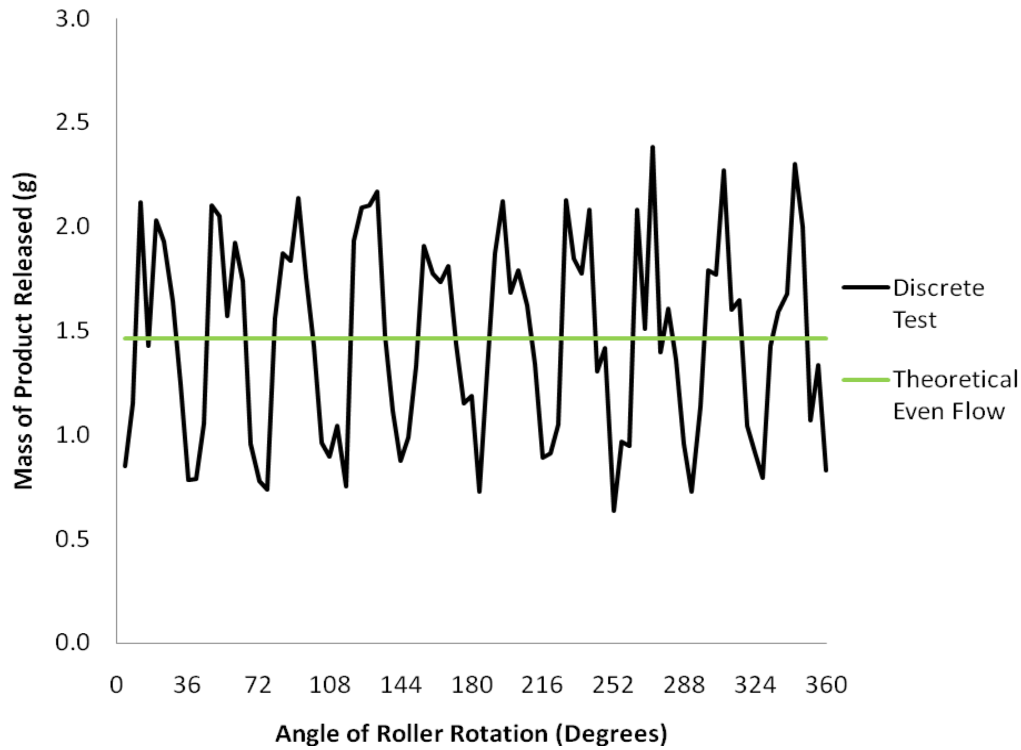

Figure 3. Discrete Method Graphical Representation of Product Flow Discontinuity from Wheat Tests.

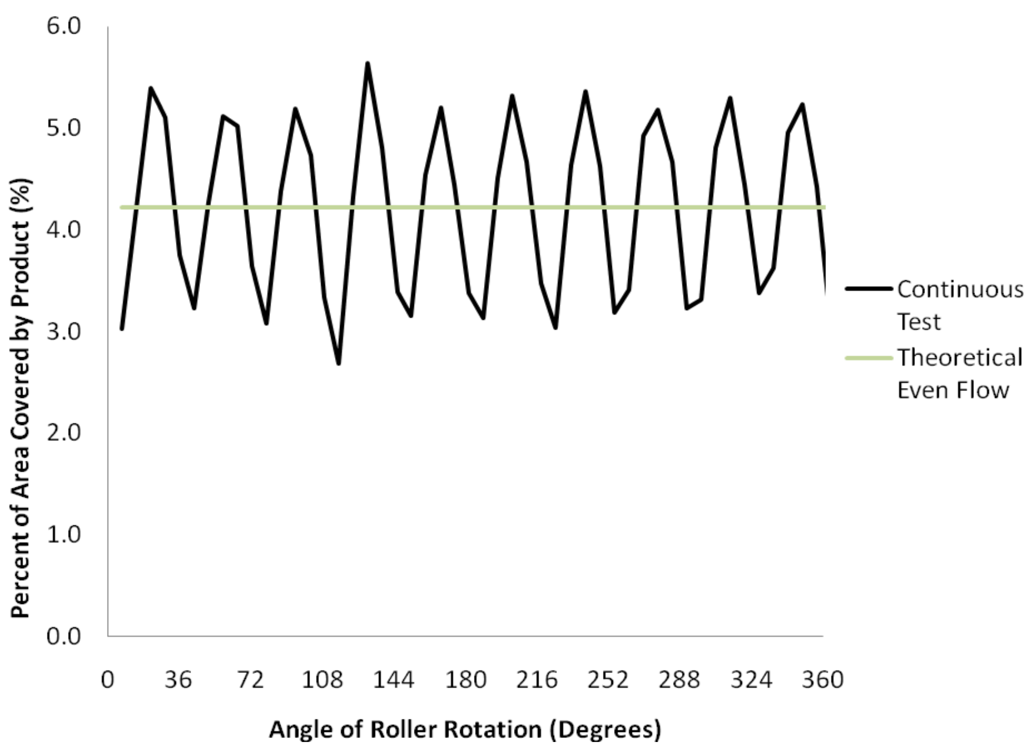

Figure 4. Continuous Method Graphical Representation of Product Flow Discontinuity from Wheat Tests.

The similar output reaction of rotating the meter roller both continually and with a stepping motion can be observed by comparing Figure 3 and 4, demonstrating that the stepping motion does not exaggerate the product flow discontinuity. In both figures, ten distinct maximums and minimums are observed, corresponding to the 10 flutes of the fine meter roller used for the wheat test. The hypothesized and emperically observed flow rate pulsations are evident in these data.

The standard deviation and coefficient of variation were calculated for each test as a way to numerically capture the discontinuity of flow present in the meter rollers for the different products. The result of each test's standard deviation and coefficient of variation are shown in Table 2.

Table 2. Summary of the Standard Deviation and Coefficient of Variation of each Test.

Test Method	Product	St. Dev.	Coeff. of Var. (%)
Discrete	Canola	0.128	18
	Wheat	0.474	32.4
	Peas	0.670	35.7
Continuous	Canola	0.028	22.9
	Wheat	0.840	19.8
	Peas	0.643	18.6

The corresponding values between the two test methods will not necessarily match up because they are two different types of measurement. They should, however, be a general measure of the observed discontinuity of product flow coming off the meter roller. The slightly larger discontinuity of flow for the canola in the continuous method shows that the flow does not even out with the extra fine roller, and because of the much lower roller speed has a greater discontinuity.

The trend difference between the discrete and continuous method with respect to the coefficient of variation results above could be attributed to several factors. The large difference between canola and the other products in the discrete method could be due to the much smaller mass of the canola kernel, resulting in a lower variation between each kernel as it is released. The larger variation of canola compared to wheat and peas from the continuous method could be caused by some thresholding issues. The much smaller size of the canola makes it more difficult to precisely capture every seed. Therefore, more fine tuning and adjustments may need to be made to the machine-vision settings and back light.

CONCLUSION Both of the methods evaluated in this paper have been demonstrated to be statistically repeatable, and appear to be statistically sound and acceptable techniques to quantify the performance of meter rollers based on the discontinuity of product flow rates which they deliver. The results also allowed the continuity of flow to be measured on a mass-per-degree basis as well as the percent of area covered by the product per degree of roller rotation. Standard deviation and coefficient of variation of the results collected verified that a discontinuity in flow out of the metering assembly exists.

The evaluation of meter roller performance would best be achieved by applying the continuous and discrete method in conjunction with each other. The continuous method allows the user to observe the flow off the roller over continual rotations as if it were in field operation, while the discrete method lets the user know where in the rotation amounts of product are being released.

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