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Review of vane design influence on centrifugal fertilizer spreading outlet properties

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ABSTRACT Particle motion on disc and early ballistic flight are reviewed. Resistance and propelling forces are discussed to acquire fundamental information on their interaction with vane design and outlet properties. The influence of the metering device, hopper, and later ballistic flight of the granular fertilizer are not addressed. Unlike lengthwise profiles, transversal design effects on the overall kinetic energy loss are not well known and may have an influence on ballistic throwing quantities and spatial fertilizer distribution evenness on the soil, by imposing extra resistant components on the particles.

Symbols:

g	gravitational acceleration, m s-^{2}
F	mass inertia vector force, N
F_c	centrifugal vector force, N
F_{cor}	Coriolis vector force, N
F_g	gravitational vector force, N
Fn	normal vector force, N
r	distance between particle and disc centre, m
t	time, s
β	pitch angle of the vanes, degrees
μ_v	friction coefficient for particle-vane interaction
μ_d	friction coefficient for particle-disc interaction
ω	angular velocity of the disc, rad s-^{1}

1. INTRODUCTION

Vanes are a vital part of a spinner spreader system. They transfer most of the momentum from the power source to the particles. From the drop point to the exit, they interact with both longitudinal and transversal profiles, being subject to several physical phenomena while moving through the system forces. These changes reflect final main they are the as on the outlet variables of the system, as velocities outlet angle and productof any centrifugal distribution processeses, that is, the location of the grains on the ground construct the distribution profile. Both the angle and velocity of a particle will dictate where they will land on the soil and thus, helping to may. The fertilizer distributed by rotational shaped, for being, they are the fertilizer is, bound to experience contact forces, described by dry granular mechanics while flowing (Duran, 2000). Grain interactions are almost negligible unless mass flow is large enough for collisions on a larger scale to begin to occur. Higher control over the resulting pattern can lower economic and environmental impacts, after effects of inaccurate spinner part design.

Particle motion on disc

Spreading of fertilizer with spinner mechanisms is largely considered a two-step sequential process, particle acceleration on the disc and ballistic flight (Villette et al., 2013). Changing the way the grains interact with the disc will essentially modify the ballistic outlet properties. Although particle motion through the air is well known, grain dynamics on disc were not reliably modelled until the research by Patterson and Reece (1962). An one of the earliest description of the motion with spherical particles focusing on near-centrethe near-center centrefeed without bouncing against the vane, and pure-sliding friction, using D'Alembert principle, results in the motion equation, Eqn (1).

$$\frac{d^2r}{dt^2} + 2\omega\frac{dr}{dt}\mu_v - \omega^2 r = -\mu_d g \qquad (1)$$

where r is the distance between particle and disc centre, ω is the angular velocity of the disc, μv is the friction coefficient for particle-vane interaction, μd is the friction coefficient for particle-disc interaction and g is the gravitation acceleration.

Eqn (1) is an equilibrium of components acting on a particle, excluding multiple interactions, in which the first variable ($d^2rdt\text{-}^2$) is the mass inertia, second ($2\omega drdt\text{-}^1\mu v$), is the Coriolis, the third (ω^2r) is the centrifugal and the fourth (μdg) is the gravitational force. Inns and Reece (1962) covered the off-centreoff-centre feedmodelling incorporating the bounce due to the position of the first contact, requiring impact forces for correct equilibrium. Mennel and Reece (1963) investigated the vertical distribution of four transversal vane designs, from flat to sigma section. The results showed that the complex shaped sigma section outperformed by more than 50% compared to other designs in an experiment that measured the amount of particles moving through a 6-degree slot opening. Cunningham (1963) developed analytical models for various lengthwise vane designs and disc shapes. Forward curved vanes exhibited faster acceleration and the results agreed with the experimental data by Cunningham and Chao (1967), who also developed the description of composed blades. Hofstee (1995) reviewed early information on vane lengthwise design, simulating spread patterns with various friction coefficients and comparing the results with experimental data acquired by a Doppler velocity meter.The blade shape and pitch angle was found to be a function of the coefficient of fricti Olieslagers, Ramon, and De Baerdemaeker (1996) further refined the analytical model to predict spread patterns of single and double discs. Their findings deviated from experimental distributions, and these differences were attributed to the lack of multiple interactions. The model was adapted and showed good results.

With the introduction of the discrete element methodand the increase of computational power available at lower costs, a renewal of interest on the subject led to an increasing number of investigations. The capabilities of the method allowed the access to data that enabled further research on the dynamic behaviour of the particle. Van Liedekerke et al. (2008) described the Discrete Element Method approach to spinner spreader granular distribution modelling.

Van Liedekerke, Tijskens, Dintwa, Anthonis, and Ramon (2006) developed one of the earliest discrete element models in granular disc dynamics for single particles. Simulations were compared to analytical and experimental data, showing good general agreementwith some minor differences. Friction forces were overestimated indicating that rolling motion was more prevalent than otherwise thought, causing the particle to eject earlier and climb the vane on its way out, contrary to theoretical predictions. Van Liedekerke et al. (2009) investigated the application of the Discrete Element Method model as an alternative to spreading halls. The authors compared two experiments to verify the cylindrical and static spread pattern of the two disc types against simulations. At low rotational velocities (less than 500 rpm), the agreement with experimental data was good, but deviations at higher velocities were significant.The introduction of rolling friction coefficient as a function of velocity did not address the issue leaving only unknown external factors as a possible answer. Coetzee and Lombard (2011) designed a deflector plate forconcentrate the flow in two rows, applying fertilizer directly on the needed region, mainly for its use on orchards while developing a single spinning disc computational model. The influences of particles and disc properties on the spread pattern were investigated. Again, the method was not capable of reliably predicting the experimental results at high rotational velocities, yet it provided valuable trend forecasting on both deflector and pattern experimental evaluation.

Forces acting on the particle

An analysis of a single grain in motion on a plane disc with straight vanes, shown in Fig. 1, will give a general form of the Eqn (1) that may be rewritten as Eqn (2), adapted from Olieslagers et al. 1996, that, sums the force balance relative to the mass inertia, F,centrifugal, F_c, and friction, F_f, in a pitch-mounted vane ($\beta \neq 0$) on a plane disc.

$$F=F_c-F_f \qquad (2)$$

A more careful approach can account for multiple particle interaction with two modes of grain energy loss combined, sliding and rolling into the resistance components. The decomposition of forces that the vane exert as vectors, in a coordinate system centred in the particle, as shown in Fig. 1, will yield the parallel and perpendicular components. Vectors of the last definition will afore mentioned cause friction forces that contribute negatively to the movement (Hofstee, 1995), contrary to the first positive components that propel the particle of the disc. The forces the vane exerts may be classified as propelling forces, which aid particle exit, and resistance forces, which hinder the momentum acquired.

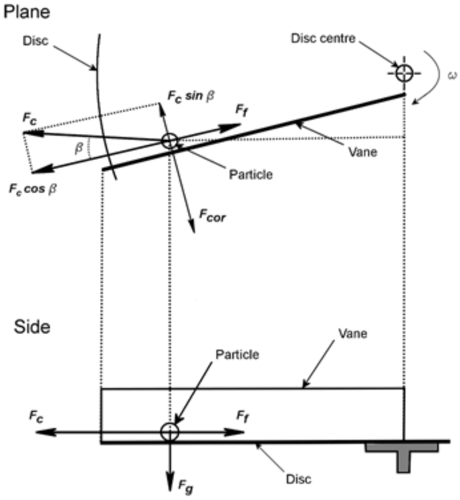

Figure 1 – Forces acting on the particle with a plane disc and vane configuration (falta permissão). Adapted from "Calculation of Fertilizer Distribution Patterns from a Spinning Disc Spreader by means of a Simulation Model", by R. Olieslagers, H. Ramon, and J. De Baerdemaeker, 1996, *Journal of Agricultural Engineering Research, 63,* p. 142. Copyright 1996 by the Silsoe Research Institute. Adapted with permission.

Propelling forces

Propelling forces are a function of the lengthwise design and rotational velocity of the vane. The blade acts as the thrust agent, driven by the shaft power. Although the design will modify the force components, the only propelling force is centrifugal (Dintwa, Van Liedekerke, Olieslagers, Tijskens, Ramon, 2004) excluding other particles interactions that are generally unpredictable as their role are case-dependant.

As a complex system, its interactions with multiple factors affecting the result, propelling forces do not act alone. Its appearance always brings a forth resistance and geometric effect, but at least three important variables are more affected by propelling components than by resistive ones,. The first, duration of stay of the grain on the disc is related to rotational velocity that shorten the time and transfer more kinetic energy to the particleN's (Hofstee, 1995).its ,may derive fromas seenin may bind theeither Discharge angle and velocity are the second and third entangled variables that are strongly reliant on the propelling forces as the result of all processes that the system subjected the grains.

Resistance forces

Resistive efforts are the most influential forces on the particle motion. packing of grainsP lose the momentum provided by disc movement in two distinct phenomena, friction and collisions.

Friction forces are extremely important and influential on ejection properties (Hofstee, Huisman, 1990), precisely because their action takes place on the vanes. The contact mode between the vane and the particles establishes the process and the amount of energy loss. The main issue with friction on this condition is that its value fluctuates between pure sliding and pure rolling (Aphale et al., 2003) and it is dependable on the particular particle size (Grift, Kweon, Hofstee, Piron, Villette, 2006). These facts indicate that the loss does not settle on a single mode as the particle oscillates and climbs the vane (Kweon, Grift, Miclet, 2007; Van Liedekerke et al., 2006), present stronger tit would hinting at a possible dependency of the friction to the transversal vane design. Geometry may play a significant role in modifying the force vectors by inducing new contacts between particles in motion and the vane.

Unlike particle-wall friction, particle-particle interactions are stochastic, having less impact in comparison to the former (Coetzee, Lombard, 2011; Van Liedekerke et al., 2009). It may be assumed that because of the large amount of grains involved in the motion, collisions would play a bigger role on the ejection parameters, However, as particles move from the hopper discharge through a short distance, and of the disc where theyorganizes as a few-grains-thick layer. In this situation, acceleration forces and consequential dynamic friction are higher than the few particle-particle interactions. As the grains arrive at the tip of the vane, the resultant net forces will influence the outlet properties that will affecting the landing point and spatial particle distribution.

Disc outlet properties

Outlet variables, velocity and angle of exit, are a direct result of the interactions between the grains and vane,intrinsically being closely related to friction forces and spatial fertilizer distribution. Both properties are relatively easy to measure and infer changes about resistance phenomena on the disc (Grift et al. 2006), as well as predictions of particle landing positions on the field (Olieslagers et al. 1996; Van Liedekerke et al. 2006). They can be considered mutually dependent, both sides of a single larger variable, allowing the approximate calculation of the velocity when the angle is known (Villette, Piron, Cointault, Chopinet, 2008). Two main exit anglesi may be identified in relation to the disc geometry employed. Horizontal outlet angles are always present, as they are deeply connected to operation parameters and vane design. Ballistic angles are linked to the use of conical-shaped discs, which allowed the particles to gain upward momentum and reach larger working widths. Although this is vital to extended machine reach, horizontal angles and their relation to earlier system parameters are not so clearly described. Generally, they are modelled using friction coefficients (Aphale et al., 2003; Van Liedekerke et al., 2006) that are unknown or difficult to measure. However, as the angle is related to resistance forces, its value may provide relevant information about friction for multiple vane designs (Villette et al., 2010). The exit velocity will provide particle momentum and working width for distinct fertilizer-machine combination, nonetheless its relation to resistance forces and geometric characteristics are much less explicit.

Particle-specific properties such as, affect outlet variables as much as their behaviour on the vane. Larger grains do exit the system earlier with greater velocity than smaller particles (Reumers, Tijskens, Ramon, 2003) resulting from resistance forces affect them less. Multiple particle packing on the other hand, if compared to single grains, lose more kinetic energy (Van Liedekerke et al. 2008), reaching the end of the vane with less velocity.

Vane design influence on resistance forces

As the vanes have a significant importance on the process of granular distribution on spinner spreaders work, their design also influences the forces acting on the particles. Propelling forces are transmitted from the vanes to the grains, while also generating resistance forces through the contact, alongthe. Alterations in disc assemblies have known effects on the spatial distribution profile, are well described (Coetzee, Lombard, 2011; Olieslagers et al., 1996) and will not be covered in this review. Variations on the two vanes main design profiles however, may have profound consequences on outlet properties that are not clearly characterized.

Lengthwise profile

Several traditional shapes have their own model, from simple to composite shapes and assembly angles, wherein their effects on movement forces are satisfactorily outlined. Hofstee (1995) compiled data on four common profiles: circular, straight, parabolic and logarithmic, relating shapes with multipliers in the motion equation, Eqn (1). Every multiplier is introduced because of geometrical differences that affect the main movement forces. They occurred on both resistance and centrifugal forces that resulted in shifts on duration of stay and discharge velocity of particles.

Transversal profile

Villette et al. (2010) briefly discussed them as comparing C and V designs. The difference between profiles caused shifts in friction reaction, Fig. 2, restricting particle motion via geometric changes.Considering their, thus it reflected in the mechanical model, by incorporating modifications in the expression of the velocity on the motion equation, Eqn (1), based on the geometric profile in use. By imposing larger losses for the grains, it eliminated a large portion of the deviation observed, improving the stability of the resulting pattern.

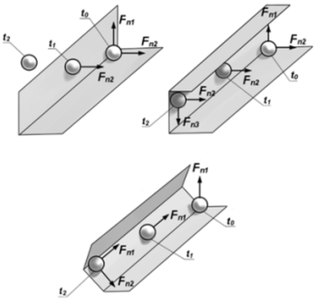

Figure 2 – View of a particle carried through an L-profile (*upper left*), C-profile (*upper right*), and V-profile (*down centre*) vane, showing normal forces F_{n1}, F_{n2}, and F_{n3} that cause friction forces evolving from t_0 to t_2.

This was reinforced by a later investigation (Villette et al. 2013) using a high speed photographic system to analyse outlet fertilizer distribution by a plane disc and C shaped vanes. The material discharged presented a highly erratic behaviour by the lower losses, low friction forces, inducing the particles to climb the vane at higher rotational velocities.

2. Conclusions

This paper reviewed the effects of vane design on spinner disc granular spreader outlet properties. Particle motion was and modelling were characterized, detailing the two main forces acting on the grains. Exit variables were described, as well as their connections to resistance forces and final spatial distribution.

The influence of vane design was analysed by its effect on both mechanical model and experimental data. Lengthwise variations of the design act by changing the way that both main forces react, geometrically, altering the path made by the particle on the disc, and transversal shapes operate by by restraining or enabling freedom of movements-, and as a function of the geometric construction affecting only resistance forces.

By potentially imposinging new resistance components, modifying net momentum loss, friction may organize granular flow and control outlet variables. This effect indicates that the geometric transversal vane design may have a strong influence on the ground fertilizer distribution.

References

1. Aphale, A., Bolander, N., Park, L., Shaw, J., Svec, J., Wassgren, C. (2003). Granular Fertiliser Particle Dynamics on and off a Spinner Spreader. Biosystems Engineering, 85, 319-329.
2. Coetzee, C. J., Lombard, S. G. (2011). Discrete element method modelling of a centrifugal fertiliser spreader. Biosystems Engineering, 109, 308-325.
3. Cunningham, F. M. (1963). Performance characteristics of bulk spreaders for granular fertilizer distributors. Transactions of ASAE, 6, 108-114.
4. Cunningham, F. M., Chao, E. Y. S. (1967). Design relationships for centrifugal fertilizer distributors. Transactions of ASAE, 10, 91-95.
5. Dintwa, E., Van Liedekerke, P., Olieslagers, R., Tijskens, E., Ramon, H. (2004). Model for Simulation of Particle Flow on a Centrifugal Fertiliser Spreader. Biosystems Engineering, 87, 407-415.
6. Duran, J. (2000). Sands, Powders, and Grains: An Introduction to the Physics of Granular Materials. (1st ed.) New York: Springer-Verlag, (Chapter 2).
7. Grift, T. E., Kweon, G., Hofstee, J. W., Piron, E., Villette, S. (2006). Dynamic Friction Coefficient Measurement of Granular Fertiliser Particles. Biosystems Engineering, 95, 507-515.
8. Hofstee, J. W., Huismann, W. (1990). Handling ahd Spreading of Fertilizers Part 1: Physical Properties of Fertilizer in Relation to Particle Motion. Journal of Agricultural Engineering Research, 47, 213-234.
9. Hofstee, J. W (1995). Handling and Spreading of Fertilizers: Part 5, The Spinning Disc Type Fertilizer Spreader. Journal of Agricultural Engineering Research, 62, 143-162.
10. Inns, F. M., Reece, A. R. (1962). The theory of the centrifugal distributor, II: motion on the disc, off-centre feed. Journal of Agricultural Engineering Research, 7, 345-353.
11. Kweon, G., Grift, T. E., Miclet, D. (2007). A spinning-tube device for dynamic friction coefficient measurement of granular fertiliser particles. Biosystems Engineering, 97, 145-152.
12. Mennel, R. M., Reece, A. R. (1963). The theory of the centrifugal distributor, III: particle trajectories. Journal of Agricultural Engineering Research, 8, 78-84.
13. Olieslagers, R., Ramon, H., De Baerdemaeker, J. (1996). Calculation of Fertilizer Distribution Patterns from a Spinning Disc Spreader by means of a Simulation Model. Journal of Agricultural Engineering Research, 63, 137-152.
14. Patterson, D. E., Reece, A. R. (1962). The theory of the centrifugal distributor, I: motion on the disc, near centre feed. Journal of Agricultural Engineering Research, 7, 232-240.
15. Reumers, J., Tijskens, E., Ramon, H. (2003). Experimental Characterisation of the Tangential and Cylindrical Fertiliser Distribution Pattern from a Spinning Disc: A Parameter Study. Biosystems Engineering, 86, 327-337.
16. Van Liedekerke, P., Tijskens, E., Dintwa, W., Anthonis, J., Ramon, H. (2006). A discrete element model for simulation of spinning disc fertilizer spreader I. Single particle simulations. Powder Technology, 170, 71-85.
17. Van Liedekerke, P., Piron, E., Vangeyte, J., Villette, S., Ramon, H., Tijskens, E. (2008). Recent results of experimentation and DEM modelling of centrifugal fertilizer spreading. Granular Matter, 10, 247-255.
18. Van Liedekerke, P., Tijskens, E., Dintwa, W., Rioual, F., Vangeyte, J., Ramon, H. (2009). DEM simulations of the particle flow on a centrifugal fertilizer spreader. Powder Technology, 190, 348-360.
19. Villette, S., Piron, E., Cointault, F., Chopinet, B. (2008). Centrifugal spreading of fertilizer: deducing three-dimensional velocities from horizontal outlet angles using computer vision. Biosystems Engineering, 99, 496-507.
20. Villette, S., Piron, E., Martin, R., Miclet, D., Boilletot, M., Gée, C. (2010). Measurement of an equivalent friction coefficient to characterise the behaviour of fertilisers in the context of centrifugal spreading. Precision Agriculture, 11, 664-683.
21. Villette, S., Piron, E., Martin, R., Miclet, D., Jones, G., Paoli, J. N., Gée, C. (2013). Estimation of two-dimensional fertiliser mass flow distributions by recording granule impacts. Biosystems Engineering, 115, 463-473.