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RESEARCH NOTE

Development of a Fertilizer Particle Accelerator

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Testing of fertilizer spreaders is traditionally carried out by using the collecting tray method, requiring a large hall to eliminate the influence of wind and rain. The Dutch government has announced mandatory periodic testing of fertilizer equipment which could require a significant number of these costly halls. Therefore, an alternative method has been developed which is based on scanning the spreading zone and measuring the velocity vector and diameter of individual fertilizer particles, emanating from the spreader. A model then predicts the landing spot of each particle and accumulation of these spots gives the desired spread pattern.

To test the proper functioning of the sensors that are used to measure the velocity and diameter of the particles, it was found necessary to develop a test device which is capable of discharging fertilizer particles with a realistic velocity and a fixed direction. The desired maximum launch velocity of the device is 70 m/s, the most extreme value that particles reach in practice. The principle of the accelerator that was developed is similar to that of a disc type spreader which has been fitted with an encapsulating housing. The machine was tested in combination with an optical device for the measurement of velocity and diameter, at ejection velocities up to 52 m/s. At higher velocities, virtually all fertilizer particles fragmented owing to the severe forces on particles when being accelerated. © 1997 Silsoe Research Institute

1. Introduction

An alternative method for testing fertilizer spreaders has been developed, which is based on the measurement of velocity, direction and size of individual fertilizer particles. For this purpose, Hofstee[1] discussed the use of an ultrasonic method, which is based on measuring the Doppler frequency of a reflected ultrasonic beam. Grift and Hofstee[2] describe the use of an optical principle based on particles blocking infrared light beams. To test the performance of both principles, a device was developed to launch fertilizer particles with a controlled velocity and fixed direction. The general requirements for the fertilizer particle accelerator were that the launch velocity should be independent of particle mass, size and shape, it should operate continuously (no ‘‘reloading’’), have an adjustable velocity, and a fixed launch direction. Furthermore, the device should not interfere with either of the proposed velocity measurement methods.

For the development of the launcher, different methods were evaluated in relation to the specified requirements and the most promising method has been realized and tested. This paper gives a brief description of the methods investigated and the device developed.

2. Acceleration methods

Acceleration methods can, in general, be divided in non-contact and contact methods. Non-contact methods, based on electric or magnetic fields, cannot be used since fertilizer particles do not interact with them. Two contact methods have been analysed. The first method, using an expanding gas such as compressed air, cannot be used because the discharge of particles would produce a large air flow which would interfere with the ultrasonic measurements. Purely mechanical contact methods remain and three of these have been investigated as described below.

The catapult principle can be embodied in a bar with a small orifice, in which a particle is placed. This bar is accelerated by a spring and decelerated by a shock absorber. Directly after the bar hits the shock absorber, the particle is ejected and initially follows a

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straight path. However, to realize a particle velocity of 70 m/s within a 90 deg movement of the bar requires special materials and construction for the bar, spring and shock absorber, and the principle is not readily embodied in a continuously acting device. The principle of an oscillating pipe, as used in a spout type fertilizer spreader could be employed, but analysis shows that for mechanical reasons it is very difficult to achieve launch velocities higher than 35 m/s. The oscillating movement of the spout causes very high acceleration forces on the spout so this would require very rigid construction. A rotating disc with one or more blades is a straightforward, widely applied method for acceleration of fertilizer particles. The discharge position, velocity and direction of particles depend on interaction of the fertilizer particles with disc and blade material and the starting point of motion. The disc principle appeared to offer the best solution and was selected for development.

3. Description of the particle accelerator

The device is shown schematically in *Fig. 1* which shows a plan view and an elevation in cross section. The device consists of a horizontally oriented, stainless steel disc with a diameter of 0·48 m, which spins within a housing. The radial clearance between housing and disc is 0·25 mm.

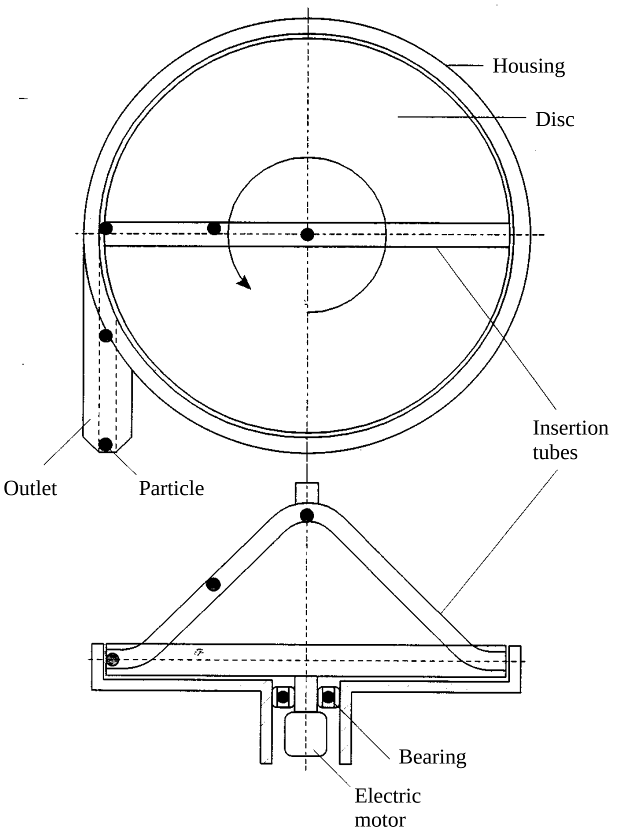

Fig. 1. Principle of particle accelerator

The accelerator functions as follows. A particle is dropped into the insertion tube which splits into two radial tubes at the saddle point. The particle then enters one of the radial insertion tubes where it is subjected to a centripetal force which accelerates it radially. After a short time it hits the wall and the radial velocity becomes zero. At that point the particle has a tangential velocity equal to that of the circumference of the disc. The particle then slides along the wall and at a certain point is ejected through the outlet shown in the plan view. The launch velocity of the particle is equal to the tangential circumferential velocity of the disc. In practice, it will be slightly lower owing to mechanical and aerodynamic friction. Since the maximum velocity of the particle is virtually equal to the tangential velocity of the disc at its circumference, this means that at the required velocity of 70 m/s the disc must spin at 292 rad/s, or 2788 rev/min. The rotational velocity of the accelerator disc is set by applying an appropriate voltage to a frequency controller. This controller has no velocity feedback however, so the pre-set rotational velocity is not guaranteed. The electric motor is provided with a pulse generator which produces 360 pulses per revolution, from which the actual rotational velocity can be derived. For safety reasons the accelerator is shielded with a polycarbonate housing.

A problem that occurs when particles hit the wall is breakage. As will be shown later, the maximum radial velocity that a particle can achieve theoretically is the tangential velocity at the circumference of the disc. Therefore the radial insertion tubes are mounted on the disc at an angle with respect to the disc surface as can be seen in the elevation view of *Fig. 1.* This arrangement enables a frictional force to act on the particle when it slides along the inside of the tube and this frictional force limits the radial acceleration.

The motion of a particle, moving outwards in one of the two radial insertion tubes at an angle α with the disc axis is determined by the forces acting as shown in *Fig. 2.* It must be remembered that the particle is inside a tube which can exert forces on it in all radial directions of the tube. This influences the frictional forces that can act between the particle and the tube. The particle of mass (m) is accelerated down the plane by the components parallel to the plane of the centripetal force (F_c) and the gravitational force (F_g). These components are $F_c \sin \alpha$ and $F_g \cos \alpha$ where α is the angle of the tube with respect to the disc axis. The forces resisting motion down the plane are the fric-

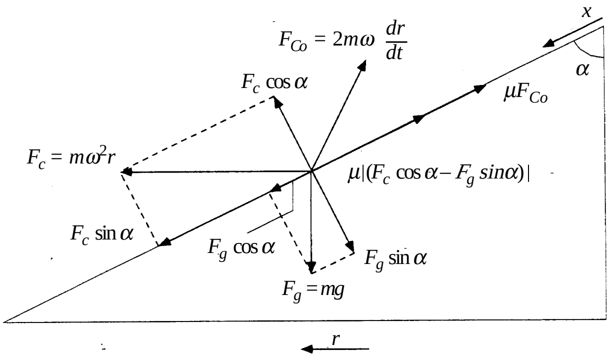

Fig. 2. Force equilibrium on particle in insertion tube

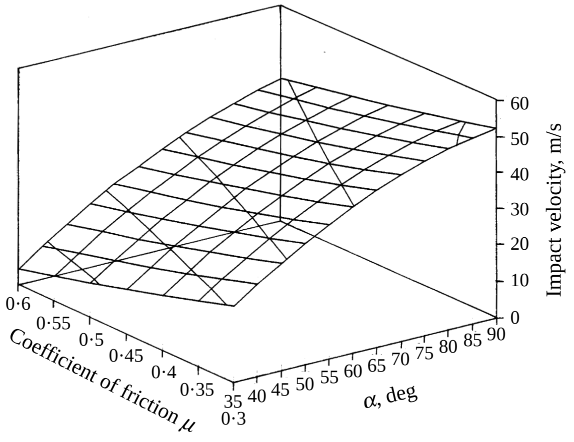

Fig. 3. Impact velocity of particle against wall

tional forces owing to the resultant of the components of gravitational force (F_g) and centripetal force (F_c) perpendicular to the plane and the Coriolis force (F_{Co}) which acts on the side of the insertion tube, resulting in a force perpendicular to the plane of the figure. These forces are given by: $\mu\,|(F_c \cos\alpha - F_g \sin\alpha)|$ and μF_{Co} respectively, where μ is the coefficient of friction. Note that a modulus sign must be included in the first term because the resultant always opposes motion. When $F_c \cos\alpha$ is greater than $F_g \sin\alpha$, the particle is in contact with the top of the tube. When $F_g \sin\alpha$ is greater than $F_c \cos\alpha$, contact is with the bottom of the tube. The acceleration force acting on the particle (or inertia force of the particle) down the tube is $m\ddot{x}$ and force equilibrium parallel to the plane gives

$$m\ddot{x} = F_c \sin\alpha + F_g \cos\alpha - \mu\,|(F_c \cos\alpha - F_g \sin\alpha)| - \mu F_{Co} \qquad (1)$$

Now $F_c = m\omega^2 r$, $F_g = mg$ and $F_{Co} = 2\omega\dot{r}$ where ω is the velocity of the disc and x is the distance travelled along the tube at radius r such that $r = x \sin\alpha$ and $\dot{r} = \dot{x} \sin\alpha$. If the above relations are substituted in Eqn (1), the following equation of motion results.

$$\ddot{x} + 2\mu\omega\dot{x}\sin\alpha - \omega^2 x \sin^2\alpha + \mu\,|(\omega^2 x \sin\alpha\cos\alpha - g\sin\alpha)| - g\cos\alpha = 0 \qquad (2)$$

When $\alpha = 90$ deg (insertion tubes parallel to the disc) and $\mu = 0$ (no frictional forces) Eqn 2 becomes $\ddot{x} - \omega^2 x = 0$. This may be rewritten as $\mathrm{d}v/\mathrm{d}x \cdot \mathrm{d}x/\mathrm{d}t = \omega^2 x$. Hence $v\,\mathrm{d}v = \omega^2 x\,\mathrm{d}x$ and following integration $v = \omega x$. Thus at all times, the radial velocity equals the tangential velocity.

The radial velocity at the circumference as a function of the angle α and the coefficient of friction μ was computed by numerically solving Eqn 2. The results are shown in *Fig. 3*. A maximum circumferential velocity of 70 m/s was calculated for $\alpha = 90$ deg and $\mu = 0$ (not shown in *Fig. 3*). For an angle $\alpha = 40$ deg, the impact velocity is in the range 15 to 35 m/s and has the particular value 30 m/s for $\mu = 0{\cdot}4$. A smaller angle for α would increase the chance of particles decelerating to zero velocity in the insertion tubes, so the value of 40 deg was used in the design.

The reduction in radial velocity that can be achieved through friction is insufficient to prevent particle breakage. Previous research has shown that at an impact velocity of 15 m/s, 50% of calcium ammonium nitrate (CAN) particles broke. To further reduce the chance of particles breaking on impact with the wall, the particles are caught in an air bed which is shown in *Fig. 4*. In the wall of the housing which encloses the disc, a large number of holes of 0·6 mm diameter were drilled. These holes were fed with air from a channel in which compressed air was present at 4 bar. Because the clearance between disc and housing is very small (0·25 mm), the air flows into the insertion tubes when they pass and the particle is decelerated before it impacts the wall. The circumference is divided into six sections through which the air flow can be controlled individually.

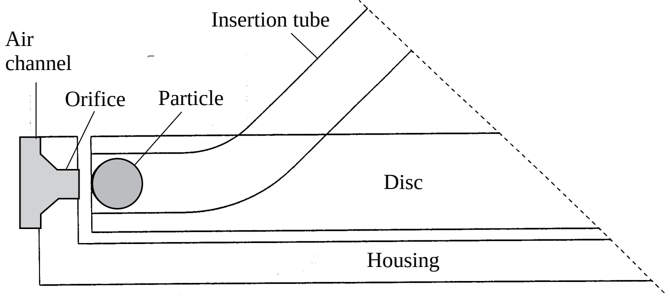

Fig. 4. Principle of air bed capture

4. Results

The particle accelerator was tested with 4 mm plastic spheres to test its ejection performance. The accelerator was set at launch velocities of 30, 40 and 50% of 70 m/s (21, 28 and 35 m/s). The actual launch velocity (tangential velocity at the circumference of the disc) was computed using the pulse generator. The ejection velocities of the plastic spheres were measasured with an optical sensor described by Grift and Hofstee.[2] The principle of this detection device is shown in *Fig. 5.* It has a light source which produces a parallel beam, comparable with the projection unit of a slide projector. The beam is widened by using a lens system, because it uses individual infrared receivers of which the dimensions are large with respect to the smallest particle to be detected. Two arrays of light sensitive receivers are used that produce a "high" signal as long as **all** receivers are lit by the light source. This behaviour is obtained by connecting each receiver array in a logical OR function. By using two arrays, two light sensitive layers are created as shown in *Fig. 5.* When the particle is ejected from the outlet of the accelerator, it blocks the beams which causes the signal of the receiver arrays to become "low" for the period that they are blocked. From the known physical distance between the receiver arrays and the time difference between the two blocking events, the particle velocity can be computed. The diameter of the particle may be calculated from the total time that a particle blocks a single receiver array.

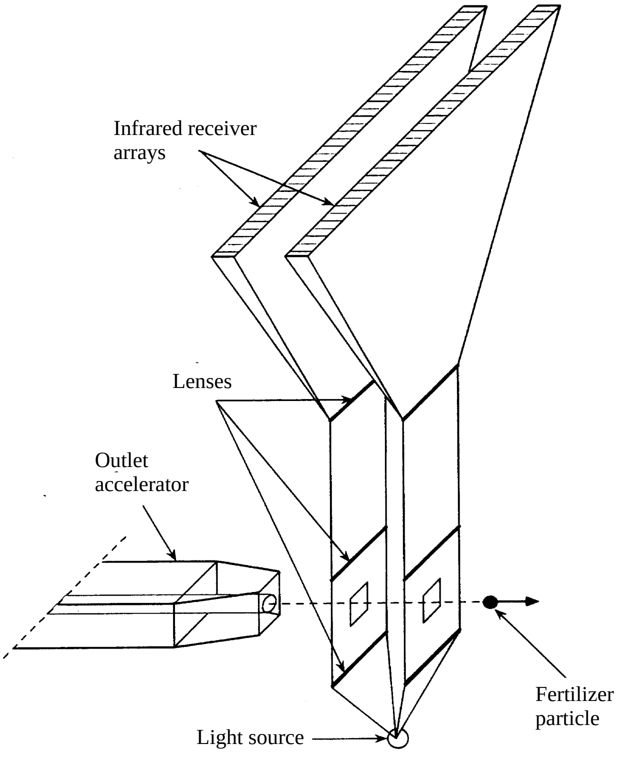

Fig. 5. Measurement of particle velocity with an optical detector

Table 1

Fraction of broken fertilizer particles in particle accelerator at given tangential ejection velocities

Velocity m/s	*Broken %*
22·6	5
29·7	15
34·3	25
44·2	40
51·9	90

For the setting of 30% (21 m/s launch velocity), the circumferential velocity set was 22·5 m/s. The tangential ejection velocities showed a mean of 21·65 m/s with a standard deviation of 2·56 m/s. Furthermore, for the 40% setting (28 m/s launch velocity) the circumferential velocity set was 29·65 m/s. The mean of the tangential ejection velocities was found to be 28·35 m/s with a standard deviation of 2·9 m/s. Finally, for a setting of 50% (35 m/s launch velocity) the circumferential velocity set was 36·85 m/s, with a mean tangential ejection velocity of 34·2 m/s and a standard deviation of 1·52 m/s. These results show that the ejection velocity of the particle is always lower than the set tangential circumferential velocity of the disc. This is owing to mechanical and aerodynamic resistance in the outlet of the accelerator.

When the device was tested with calcium ammonium nitrate (CAN) fertilizer particles, a relatively large number of particles broke owing to the inherent brittleness of the material as shown in Table 1. At 52 m/s, 90% of the particles broke, so further increase of the test velocity would not be useful.

5. Conclusions

A particle accelerator has been developed which is capable of launching particles with a tangential velocity of up to 52 m/s. The ejection velocity of the particle is always lower than the tangential circumferential velocity of the disc. The variation in measured ejection velocities was around 5–10% of the mean ejection velocity. Tests with calcium ammonium nitrate (CAN) fertilizer particles showed that at a velocity of 52 m/s. 90% of the particles broke, despite attempts to limit the radial velocity at impact with the wall of the accelerator. Plastic particles withstood the launching process up to this velocity with negligible damage to them.

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