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Calculation of the motion of particles ejected from the spreading disc of a special road machine when changing the disc height

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Abstract: This article analyzes the effect of changing the height of the spreading disc of a special road machine on the motion trajectory and rebound height of technological material particles. Based on theoretical calculations and practical experimental results, the relationships among the particle ejection angle, restitution coefficient, and disc rotational speed were determined. The experiments were conducted at a disc speed of 450 rpm, at various heights (h = 0.4–0.6 m), and on different surface types (rubber, metal, asphalt). The results showed that the particle rebound height is directly proportional to the disc height and ejection angle, and that moisture and weather conditions significantly affect the restitution coefficient. The research findings have practical importance for determining the optimal geometric and kinematic parameters of the spreading system and ensuring uniform distribution of technological materials over the road surface.

Keywords: spreading disc, technological material, particle trajectory, restitution coefficient, rebound height, disc height, spreading speed, road machine, sand-salt mixture, experimental research

1. Introduction

During the winter season, the risk of road surface icing and the need to ensure traffic safety are addressed by spreading a sand–salt mixture on the roads. This mixture serves to melt the ice layer on the road surface and increase the surface's friction coefficient. The efficiency and cost-effectiveness of the spreading process, as well as the minimization of its environmental impact, depend on the uniform and targeted distribution of the mixture over the road surface. To ensure effective spreading, the particles must reach the road surface at an optimal velocity and angle. [1-8]

The main component of the spreading mechanism is a disc mounted on a special road machine that rotates at high speed. The sand–salt mixture particles falling onto the center of the disc are ejected through radial fins as a result of the disc's rotation. Practice shows that adjusting the height of the spreading disc can significantly influence the dispersion range and uniformity of particle distribution. Changes in the disc height affect the particle's ejection velocity and trajectory, which in turn directly determine how the material is distributed over the road surface. [8-12]

When the disc height is changed, not only does the initial ejection height of the particles vary, but their interaction with the disc fins also changes. As the height increases, the particle's flight time to the road surface becomes longer, causing the trajectory to bend under the influence of wind and gravity. Conversely, a lower disc height may result in reduced particle velocity, preventing the particles from reaching the desired spreading distance. The specific properties of the sand–salt mixture — such as differences in particle density and shape, as well as moisture content — further complicate this process [13-17].

2. Research methodology

Sand Spreaders (Sand Spreading Disc). The icing of road surfaces sharply reduces the adhesion between vehicle tires and the pavement, resulting in a loss of vehicle stability and traffic safety. On a dry asphalt–concrete surface, the adhesion coefficient of vehicle tires is 0.6–0.7, while under icy conditions it decreases to 0.06–0.08. To combat this problem, road surfaces are sometimes treated with sodium chloride ($NaCl$) or calcium chloride ($CaCl_2$). However, these substances are rarely used because they contribute to the corrosion of vehicle bodies and frames. The most common and cost-effective method of preventing slipperiness is spreading sand on icy road surfaces. Sand spreaders are used for this purpose to distribute sand evenly across the road surface.[18-21]

The Working Mechanism of the Spreader

The working equipment of the spreading device is mounted on the rear part of the vehicle and consists of a horizontal metal disc that rotates around a vertical axis. Radial fins are welded to the upper working surface of the disc.

A sand hopper, installed on the vehicle chassis, has sloped side walls and an opening at the bottom connected to a trough. The trough, supported by a bracket, performs a reciprocating motion under the influence of an eccentric mechanism, which feeds sand from the hopper onto the disc.

The shaft of the eccentric mechanism is driven from the disc shaft through a belt transmission. The disc itself is rotated by power taken from the vehicle's power take-off (PTO) through a cone-type gearbox.

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Depending on the type of machine, the disc diameter ranges from 0.60 to 0.70 m, and the rotational speed varies between 300 and 600 rpm.

The sand is delivered to the disc at a point slightly offset from its center and, under the influence of centrifugal force, moves outward along the radial fins toward the edge of the disc, simultaneously overcoming frictional resistance on the disc surface.

The variation in the spreading speed of the technological material is achieved by changing the operating speed of the sand spreader.

The velocity V_A of a technological material particle ejected from the disc is calculated as follows:

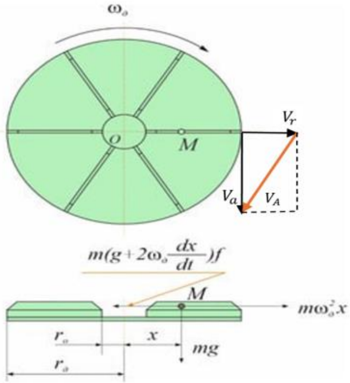

Fig. 1. Spreading disc and the diagram of forces acting during its rotation

$$V_A = \sqrt{V_r^2 + V_a^2} = \sqrt{r^2(n-f)^2\omega^2 + r^2\omega^2} = r\omega\sqrt{(n-f)^2+1}\ , m/sek$$

V_{A1} – The rebound velocity of a technological material particle (sand–salt mixture) after colliding with an obstacle., *m/sek* .

α_A - The impact angle of a technological material particle (sand–salt mixture)., *grad*

$\alpha_A = 90^0 - \gamma$; – The collision angle of a technological material particle (sand–salt mixture)., *grad.*

β_A – The rebound angle of a technological material particle (sand–salt mixture) after colliding with an obstacle, *grad.*

γ – The installation angle of the metal and rubber barrier, *grad.*

β_B – The rebound (departure) angle of a technological material particle (sand–salt mixture) after impacting the road surface., *grad.*

α_B – The impact angle of a technological material particle (sand–salt mixture) upon collision with the road surface, *grad.*

k – Coefficient of restitution

H_0 =h = 0.5 - The rebound (lifting) height of a particle after impacting the road surface, *m*.

f = 0,5; – Coefficient of friction

n = 1,2; – Conversion coefficient

N= $\omega_д$ – Disc rotational speed, rpm *revolutions/minute*,

r =0,3 – Disc radius, *m*.

g = 9.81 - Acceleration due to gravity [m/s^2]

At the lower part of the hopper, a scraper (paddle) conveyor moves the material along with its blades and transfers it to the spreading disc. From the spreading disc, located at a height h relative to the roadway of the improved spreading unit of the special road machine, the technological material particles are ejected at a velocity V_a. These particles strike a deflecting barrier (made of rubber or metal), which changes their direction of motion, after which they continue to move with a velocity $V_{a1} = V_\beta$ and hit the road surface at point B, changing their direction again and rebounding upward with a velocity U_β, reaching a rebound height of H.

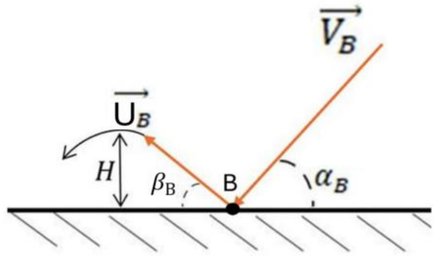

Fig. 2. Diagram of the particle's rebound motion after impact at point B, showing the change in direction and rebound (bounce) height

Calculation of the rebound height (H) of the particle after striking the roadway surface (asphalt).

$$V_B \cos\alpha_B = U_B \cos\beta_B \qquad (1)$$

$$k_{asf} = \frac{U_B \sin\beta_B}{V_B \sin\alpha_B}\ ;\ Coefficients\ of\ restitution$$

$$U_B = kV_B \cdot \frac{\sin\beta_B}{\sin\alpha_B}\ ;$$

$$U_B^2 \sin^2\beta_B = 2Hg\ ;$$

$$H = \frac{U_B^2 \sin^2\beta_B}{2g}\ .$$

To evaluate the reliability of the mathematical model developed on the basis of theoretical and experimental test results, the following variable parameters were selected.

The coefficients of restitution and variable values for rubber, metal, and asphalt were determined based on the results obtained from experimental tests.

k_rez = h/H = 6/1000= 0,006-0.008, - Coefficients of restitution of rubber

k_met = h/H = 25/1000 = 0,025-0.03-0.5, - Coefficients of restitution of metal

k_(asf)=45/1000 = 0.45, - Coefficient of restitution of asphalt

The coefficients of restitution for rubber k_{rez}, metal k_{met}, and asphalt concrete k_{asf} , as well as the spreading disc height above the ground (roadway surface), are given as follows: 450 rpm, k_{rez}=0.01, k_{met}=0.05, k_{asf} =0.45, h=0.4 m. The dependence of the particle rebound (bounce) height H on the rotational speed N and the ejection angle γ is shown in Figure 3**.**

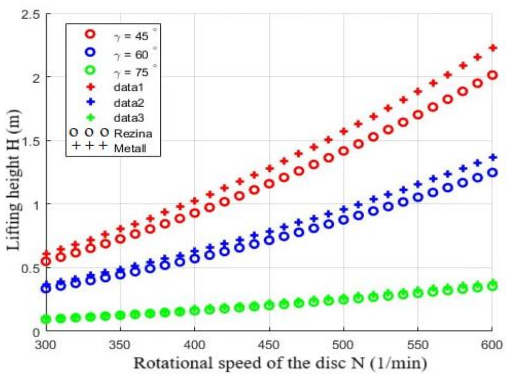

Fig. 3. Graph of the particle rebound (bounce) height

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The coefficients of restitution for rubber k_{rez}, metal k_{met}, and asphalt concrete k_{asf}, as well as the height of the spreading disc above the ground (roadway surface) h, are given as follows: disc rotational speed N=450 rpm, k_{rez}=0.01, k_{met}=0.05, k_{asf}=0.45, h=0.5 m. The dependence of the particle rebound (bounce) height HHH on the disc rotational speed N and the ejection angle γ is shown in Figure

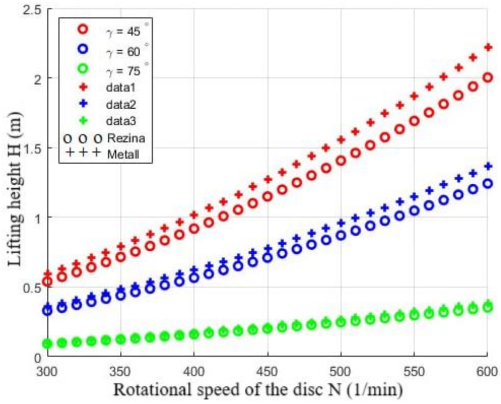

Fig. 4. Graph of the particle rebound (bounce) height

The coefficients of restitution for rubber k_{rez}, metal k_{met}, and asphalt concrete k_{asf}, as well as the height of the spreading disc above the ground (roadway surface), are given as follows: 450 rpm, k_{rez}=0.01, k_{met}=0.05, k_{asf}=0.45, h=0.6 m. The dependence of the particle rebound (bounce) height H on the disc rotational speed N and the ejection angle γ is shown in Figure 5.

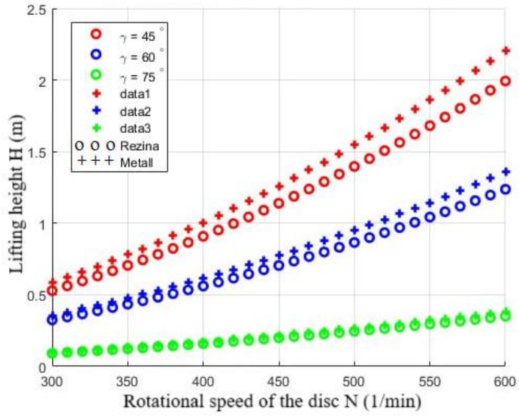

Fig. 5. Graph of the particle rebound (bounce) height

The coefficients of restitution for rubber k_{rez}, metal k_{met}, and asphalt concrete k_{asf}, as well as the height of the spreading disc above the ground (roadway surface), are given as follows: disc rotational speed N=450 rpm k_{rez}=0.01, k_{met}=0.05, k_{asf}=0.45, h=0.6 m. The dependence of the particle rebound (bounce) height H on the disc rotational speed N and the ejection angle γ is shown in Figure 6.

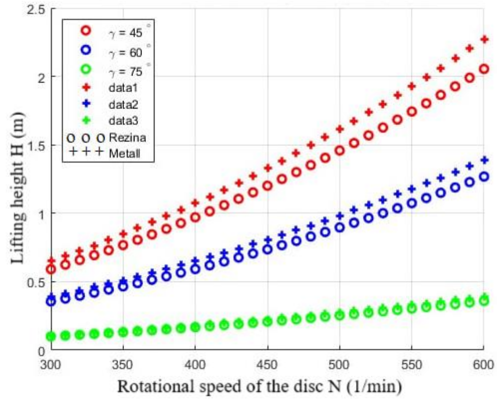

Fig. 6. Graph of the particle rebound (bounce) height

When the disk speed is 450 rpm, and the coefficients are k_{rez}=0.01, k_{met}=0.05, and k_{asf}=0.45, while the height h is variable — that is, h = 0.04, 0.05, 0.06 m — it was determined that the particle rebound (bounce) height increases gradually by approximately 0.002 m**.** When h = 1 m, the particle rebound height reaches 0.01 m (10 mm)**.**

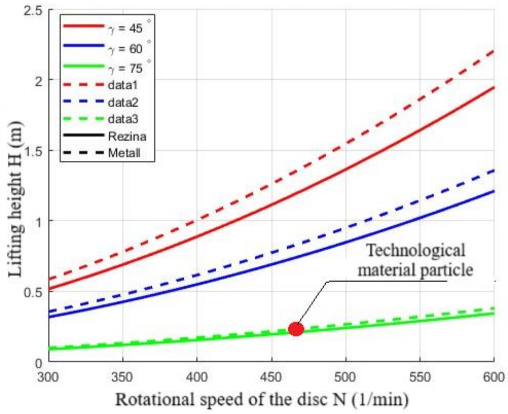

Fig. 7. Graph of the particle rebound (bounce) height during the experimental process

The practical experimental study was conducted under real weather conditions — specifically, cloudy weather following rainfall. The technological material (a salt-sand mixture with particle diameters ranging from 0.5 mm to 5 mm) was wet, and the road surface was moist and covered with a thin layer of water. The results of the theoretical and practical experimental studies showed that the technological material particles ejected from the spreading disk, after colliding with the rubber barrier and then the road surface (asphalt), reached a rebound (bounce) height H = 0.22 m.

3. Conclusion

The results of the theoretical and experimental studies showed that in the spreading system, the rebound (bouncing) height H of the technological material particles directly depends on several technical and physical factors — such as the coefficients of restitution, the height of the spreading disk, the particle ejection angle, and the weather conditions.

The experiment was carried out at a disk rotational speed of 450 rpm, with the following parameters: k_{rez} = 0.01, k_{met} = 0.05, and k_{asf} = 0.45. The disk height above the road surface (h) was gradually changed to 0.4 m, 0.5 m, and 0.6 m. As a result, the dependence of the particle rebound height H on N (disk rotational speed) and **γ** (particle ejection angle) was determined.

Key findings:

- As the disk height increased, the particle rebound height increased linearly.
- When h increased from 0.04 → 0.05 → 0.06 m, the rebound height H increased by 0.002 m at each step.
- At h = 1.0 m, the maximum particle rebound height reached H = 0.01 m (10 mm).
- As the particle ejection angle γ increased, the rebound height also increased, confirming the dependence of kinetic energy on the elastic restitution coefficients.

The experiments were conducted under real operating weather conditions — cloudy weather, wet and slippery road surfaces after rainfall, using a salt-sand mixture with particle diameters ranging from 0.5 mm to 5 mm. Under wet conditions, the particle contact characteristics changed, reducing their restitution ability, which affected the rebound height.

In the final test, the measured rebound height was H = 0.22 m.

In conclusion:

- The rebound height of particles is strongly influenced by the coefficients of restitution, disk height, and ejection angle.
- Increasing the disk height leads to higher rebound heights, allowing better modeling and optimization of the spreading process.
- Wet conditions reduce the particles' elastic rebound ability, thereby lowering the technological process efficiency.

By accurately accounting for the coefficients of restitution, road surface conditions, and disk height, it is possible to ensure uniform material distribution and improve process efficiency.

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