https://doi.org/10.1051/bioconf/20237101039

A way to increase the efficiency of straw spreaders

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Abstract. The use of high-quality bedding is important for the health of farm animals. Straw is an excellent material for bedding, but before use it must be crushed to particles no larger than 100 mm, which will achieve optimal moisture and gas absorption capacity, as well as simplify the mechanization of application and cleaning. Centrifugal spreaders, belt conveyors and blow spreaders are used to apply litter. The paper considers some types of litter spreaders used in farms in the north-West. It is revealed that, along with the obvious advantages, the considered machines have disadvantages. The main one is the uneven distribution of the litter when it is applied. This, in turn, leads to the need for manual labor when leveling the straw layer after its introduction in a mechanized way. A new design of the spreader-blower is proposed aimed at ensuring the uniformity of the litter layer during application. The calculation of optimization of some parameters of the new installation is described. In addition to the calculated value of the straw particle velocity, the angle of inclination of the front wall of the discharge duct is also determined.

1 Introduction

Providing animals on livestock farms with high-quality litter is no less important than observing the parameters of the microclimate. The litter should absorb gases and moisture and provide a soft and warm resting place for animals. Straw is an excellent bedding material. It has good moisture capacity (370-400%), gas absorption (up to 0.6% ammonia per 1 kg of dry weight of straw) and a specific heat transfer coefficient of 0.06.

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Before using as bedding, straw must be grinded to pieces no larger than 100 mm in size, which will achieve optimal moisture and gas absorption capacity, as well as simplify the mechanization of application and harvesting [1].

To apply bedding in animal rooms, centrifugal spreaders, belt conveyors and blow spreaders are used. They must have a number of technical characteristics and properties that ensure savings in energy resources and working time. These properties include:

- Spreading of bedding perpendicular to the direction of movement of the machine on two sides.
- Dimensions, allowing to pass through the stern aisle.
- The bunker allowing to distribute a bedding for one pass.
- Mechanism for grinding bedding material to the required size.
- Equable distribution of bedding material over the area of the room.
- Compatibility with tractors of traction class up to 1.4 inclusive.

2 Materials and methods

When keeping dairy cattle, keeping cows in clean, comfortable conditions is a priority. This is achieved, among other things, by optimizing the time for preparing and applying the litter. Consider some types of chopper-spreaders used in farms in the northwest. Specific brands are given here as examples of machines with a similar principle of operation.

3 Results and Discussion

Chopper-spreader Tomahawk 404 [2].

The device breaks the straw stalks, separating them from each other, and produces a homogeneous crushed mass. Due to the absence of blades, there is no danger of damage due to small stones encountered, the machine does not require much maintenance.

The main components of the Tomahawk 404 chopper-spreader are: chute, rotor and drum (Figure 1). A hydraulic motor through drive belts rotates the drum. The discharge volume is controlled by changing the drum angle and rotation speed. The cutting rotor is rotated by direct drive with PTO. As the bale rotates with the drum, material is removed from the end of the bale. The rotor discharges material on one of two sides depending on the characteristics of the chute. The troughs can be switched off independently of each other.

Fig. 1. General view of the Tomahawk 404 chopper-spreader.

The grinding system of the Tomahawk 404 chopper-spreader consists of four central knives that turn the bale; blades for fine chopping or hammers for grinding (hammers are required for nets smaller than 15 mm or for working in stony conditions). The length of the crushed material at the outlet is 10-150 mm. Spreading radius up to 10m (depending on chopping length and PTO speed). The capacity reaches up to 2.5 t/h (depending on the size of the mesh and the type of straw).

Table 1. Main technical characteristics.

Parameter	Parameter values
Maximum round bale diameter	1.2 m
Max rectangular bale size	N/A
Drum diameter	1.57 m
Drum length (standard)	1.55 m
Drum length (optional)	1.85 m
The weight	904 kg
PTO power consumption	80 HP

Advantages: finely chop the straw and scatter it on the stalls on both sides, moving along the aisle; maneuverable in tight spaces, low power consumption.

Disadvantages: relatively large mass and metal consumption; high unevenness of bedding material introduction leads to the need to level the layer with the help of manual labor;

APV disc spreaders [3].

The appearance of the APV spreader is shown in Figure 2.

Fig. 2. General view of the ZS 200 M4 disc spreader.

The body of the hopper is made of plastic, which makes the spreader light in weight. Due to the operation of the agitator, bulk material flows freely from the hopper to the dosing gate. The application rate is set by stepless adjustment of the metering slide. The spreading material falls on the spreading disc and is evenly distributed over the working width. The spreading disc speed as well as the working width are set on an ergonomic control unit accessible from the driver's seat. Technical characteristics of the spreader are presented in Table 2.

To give the litter material the necessary impulse during application, centrifugal type spreaders are used. They create an impulse attached to a portion of the bedding material, which will depend only on the speed of rotation and the radius of the spreader's working body. The equality distribution of the bedding in such devices can be controlled by the shape and angle of the blades on the disk of the spreader.

Table 2. Specifications of the ZS200M4 disc spreader.

No.	Parameter	Value
1	Capture width, m	1…31
2	Dimensions, mm	850x1050x700
3	Bunker: - material volume, l.	plastic 200
4	Own weight, kg	50
5	Operating voltage, V	12
6	Maximum current, A	40

Advantages: quick and easy installation; simple and clear control; does not require preparation for operation, the standard delivery includes a complete set: wiring, control module, mounting hardware, etc.; uniform application over the desired working width.

Disadvantages: the design of the spreaders requires the application of seeds and/or insecticides to the soil, so a plastic hopper for spreading material requires from 50 to 200 liters, depending on the modification. The relatively small volume of the bunker and the spreading apparatus, the design of which does not provide the required performance, do not allow the use of this and similar machines in the process of spreading the litter without preliminary preparation of the latter [4].

Spreader B-MAX [5].

The device is designed for spreading bedding material, for rear and front hanging, with a high-speed high-performance conveyor. Spreading of all types of materials, such as chopped straw, a mixture of straw and lime or sawdust, is possible thanks to auger metering rollers with broken teeth. The general view of the spreader is shown in Figure 3.

Fig. 3. General view of the bedding spreader B-MAX.

Table 3. Specifications and dimensions of bedding spreader (B-MAX).

No.	**Parameter**	**Model**					
		1000	**1200**	**1500**	**1700**	**600**	**dusty**
1	Aggregated by tractor, kN	30				10	
2	Required tractor power, HP	1400		2000		1485	1450
3	Height, mm	1800					
	Power consumption, kW	30	30	35	35	30	30
4	Weight, kg	360	405	485	530	185	320

Advantages: solid construction; the possibility of self-filling; universal machine for spreading all types of materials, such as chopped straw, a mixture of straw and lime or sawdust;

Disadvantages: spread of bedding material in both directions is implemented only on the B-MAX 1500 and 1700 models; the hydraulic motor does not allow the effective use of this spreader on tractors MTZ 80/82 and lower power; high unevenness of bedding material introduction leads to the need to level the layer with the help of manual labor; there is no bedding material grinding device [6].

Based on the features of the above designs, we have developed a chopper-spreader scheme that solves the problem of uneven distribution of bedding material during application (Figure 4). A hammer grinder to straw sizes of 80 will carry out straw crushing…100 mm. Further, the crushed material enters the air duct, from where it is blown out by a tangential fan.

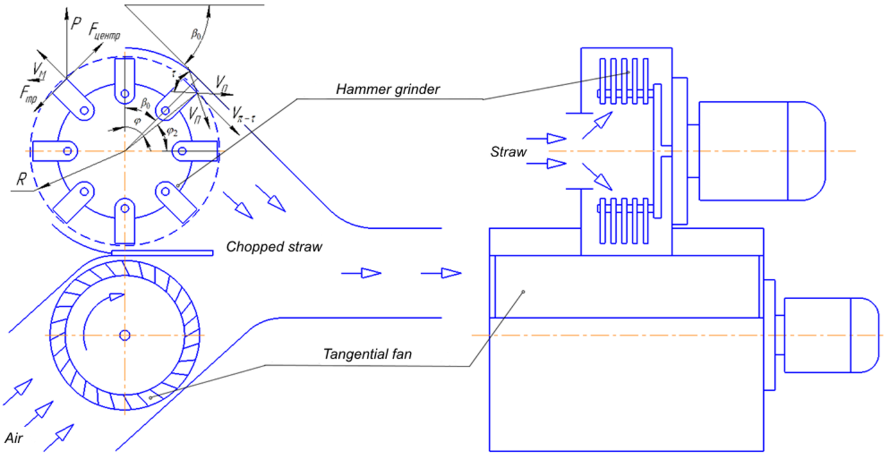

Fig. 4. Scheme of a new design chopper-spreader.

The use of this type of fans is due to the fact that the air moves in a plane perpendicular to the axis of rotation of the impeller, which is a drum with solid end disks and forward-curved blades. A wide diffuser (500…1000 mm) promotes good mixing of the supplied air with chopped straw.

To justify the choice of technological parameters of the equipment, to calculate the power to drive the working bodies, it is necessary to know the values of the friction coefficients of straw on various surfaces [7]. The values of these coefficients can be determined from the formulas:

$$k_c = \frac{F_c}{P_н}, \; k_д = \frac{F_д}{P_н} \tag{1}$$

Where k_c и $k_д$ – static and dynamic friction coefficients, respectively; F_c и $F_д$ – tractive force required to break off a sample of material at the initial moment of its movement (F_c) and during steady state ($F_д$) movement, N; $P_н$ – force of normal pressure on the material, N.

When the material comes off the hammer, the movement of the particle is accompanied by friction against the walls of the socket, while the absolute velocity of the particle at the moment of leaving the working body is determined by the following expression:

$$\bar{v} = \overline{v_n} + \overline{v_o} \tag{2}$$

Where $\overline{v_n}$ – vector of the portable velocity of the particle. Equal to the circumferential speed of the rotor, m/s; $\overline{v_o}$ – particle relative velocity vector, m/s.

When moving along the deflector, the material overcomes the force of friction against the walls of the latter, as a result of which the initial speed of the particles with which they leave the working body decreases.

In the unloading deflector, the air is mobile (the rotor works as a fan) and therefore the transfer speed of the material is determined from the condition:

$$v_n = \omega \cdot R \cdot \sqrt{\frac{2 \cdot \eta \cdot k}{E+1}} \tag{3}$$

Where ω – working rotor speed, s^{-1}; R – rotor radius, m; η – fan efficiency; k and E – coefficients taking into account, respectively, the shape of the working bodies and losses in the pipeline.

The relative velocity of a particle is determined from the condition:

$$v_o = \frac{P \cdot t}{m} \tag{4}$$

Where $j = \frac{P}{m}$ – average particle acceleration at the moment of motion, m/s^2; P – the sum of the forces acting on the particle, N; m – particle mass, kg; t – particle exit time, s.

From the condition that the initial velocity of a particle in relative motion is zero, the particle goes under the hammer after shifting its center of gravity by a value $\frac{L}{2}$ and in uniformly accelerated motion, we can write:

$$\frac{L}{2} = j \cdot \frac{t^2}{2}\text{. Where } t = \sqrt{\frac{L}{j}} \tag{5}$$

A particle in motion is affected by:

- Centrifugal force $F_{ц} = m \cdot R \cdot \omega^2 \cdot \sin\tau$.
- Friction force $F_{тр} = tg\gamma \cdot m \cdot R \cdot \omega^2 \cdot \cos\tau$.

The particle weight and the Coriolis force can be neglected due to their small values.

Then $P = F_{\text{ц}} + F_{\text{тр}} = m \cdot R \cdot \omega^2 \cdot \sin\tau + tg\gamma \cdot m \cdot R \cdot \omega^2 \cdot \cos\tau$.

To determine the relative velocity of a particle, we obtain a differential equation:

$$\frac{dv_o}{dt} = \frac{\left(m \cdot R \cdot \omega^2 \cdot \sin\tau + tg\gamma \cdot m \cdot R \cdot \omega^2 \cdot \cos\tau\right) \cdot t}{m} \tag{6}$$

$$\frac{dv_o}{dt} = \frac{m \cdot R \cdot \omega^2 \cdot \left(\sin\tau + tg\gamma \cdot \cos\tau\right) \cdot t}{m} \tag{7}$$

$$\frac{dv_o}{dt} = R \cdot \omega^2 \cdot \left(\sin\tau + \frac{\sin\gamma \cdot \cos\tau}{\cos\gamma}\right) \cdot t \tag{8}$$

$$\frac{dv_o}{dt} = R \cdot \omega^2 \cdot \left(\frac{\sin\tau \cdot \cos\gamma + \sin\gamma \cdot \cos\tau}{\cos\gamma}\right) \cdot t \tag{9}$$

$$\frac{dv_o}{dt} = R \cdot \omega^2 \cdot \left(\frac{\sin(\tau - \gamma)}{\cos\gamma}\right) \cdot t \tag{10}$$

$$v_o = \int R \cdot \omega^2 \cdot \left(\frac{\sin(\tau - \gamma)}{\cos\gamma}\right) \cdot t dt \tag{11}$$

$$v_o = R \cdot \omega^2 \cdot \left(\frac{\sin(\tau - \gamma)}{\cos\gamma}\right) \cdot \frac{t^2}{2} = L \cdot R \cdot \omega^2 \cdot \frac{\sin(\tau - \gamma)}{\cos\gamma} \tag{12}$$

The absolute velocity of a particle can be found from the condition:

$$v^2 = v_n^2 + v_o^2 - 2 \cdot v_n^2 \cdot v_o^2 \cdot \cos(\pi - \tau) \tag{13}$$

$$v = \sqrt{v_n^2 + v_o^2 - 2 \cdot v_n^2 \cdot v_o^2 \cdot \cos(\pi - \tau)} \tag{14}$$

Where do we get:

$$v = R \cdot \omega \cdot \sqrt{\sqrt{\frac{2 \cdot \eta \cdot k}{E + 1}} + L \cdot \frac{\sin(\tau - \gamma)}{R \cdot \cos\gamma} + 2\sqrt{\frac{L \cdot \sin(\tau - \gamma)}{R \cos\gamma}} \cdot \cos\tau} \tag{15}$$

In addition to the calculated value of the speed on this path, you can find the angle of inclination of the front wall of the unloading duct from the condition:

$$\beta_0 = \varphi - \varphi_2 \tag{16}$$

By the sine theorem, we get:

$$\frac{v_o}{\sin\varphi_2} = \frac{v}{\sin(\pi-\tau)} = \frac{v}{\sin\tau}, \text{ where} \sin\varphi_2 = \frac{v_o \sin\tau}{v} \tag{17}$$

Substituting the values v and v_o we get:

$$\varphi_2 = \arcsin\left(\frac{\sqrt{L\cdot\frac{\sin(\tau-\gamma)}{R\cdot\cos\gamma}}\cdot\sin\tau}{\sqrt{\sqrt{\frac{2\cdot\eta\cdot k}{E+1}}+\frac{L\cdot\sin(\tau-\gamma)}{R\cdot\cos\gamma}+2\cdot\cos\tau\cdot\sqrt{\frac{L\cdot\sin(\tau-\gamma)}{R\cdot\cos\gamma}}}}\right) \tag{18}$$

Then:

$$\varphi = \omega\cdot t = \sqrt{\frac{L\cdot\cos\gamma}{R\cdot\sin(\tau-\gamma)}} \tag{19}$$

4 Conclusion

It has been established that spreaders used in small farms do not provide sufficient uniformity in the distribution of litter, and it becomes necessary to level manually.

A new design of the bedding spreader-blower is proposed. It is based on a hammer grinder and a tangential fan. The use of a hammer chopper is due to the simplicity of design, insensitivity to straw clogging with small stones and the ability to grind straw to the required length of 80 ... 100 mm. The choice of a tangential fan is based on the need to distribute the bedding material across the width of the air channel, which will ensure its uniform application during blowing.

An analytical method is proposed for determining the rate of particle descent from the hammer and the dependence of the angle of inclination of the air duct deflector on the radius of the impeller of the chopper and the length of the straw is determined.

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