The Distribution of Stalked Particles During the Operation of the Levelling Device

Vladimir Teterin, Mikhail Kostenko, Olga Teterina, Dmitry Blagov, and Sergey Mitrofanov

Abstract When cattle breeding and keeping, the main factor is to provide animals with the necessary amount of balanced feed. One of the main factors affecting the profitability of livestock production is the quality of roughage. When harvesting hay into bales, balers with a constant volume bale chamber are most often used. In the process of picking up a hay swath, uneven distribution of the swath along the width of the bale chamber is observed. In order to improve the uniformity of distribution of the hay swath across the width of the roll baler, the levelling device in the improved baler is made in the form of two discs with inclined fingers rotating in opposite directions. The study of the trajectories of movement of the stalked particles showed that the displacement of the stalked particles is more intense towards the periphery of the disc. Therefore, the fingers are located on the disc in two rows with a predominant location along the periphery. The analysis of the obtained trajectories makes it possible to establish the basic parameters of the levelling device: the distance between the fingers is 0.15–0.2 m, the degree of compaction when levelling is 20–25%, the angular velocity is 23–30 rad/s, the diameter of the levelling disc is 0.74 m.

Keywords Roll baler · Bale chamber · Compressed hay · Levelling device

1 Introduction

When cattle breeding and keeping, the main factor providing high milk productivity, excellent reproductive ability and prevention of various nutritional diseases is to provide animals with high quality feed, which supply the body with the necessary nutrients. This factor largely depends on the animal husbandry system [1–3].

The common methods of cattle keeping in the Russian Federation include year-round stall and stall-pasture systems. The presented livestock management systems are used in farms with a high concentration of livestock and provided with fodder

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lands. As a result, providing livestock with high quality feed becomes a paramount task, which requires advanced technologies and technical means for the preparation of rough, juicy and concentrated forage. Rough feeds such as hay, haylage, straw provide the animal not only with nutrients, but are also able to stimulate rumen motility, as a result of which cows have increased salivation and an increase in the number of chewing movements, thereby achieving a better mechanical processing of merycisin, which subsequently has positive impact on health and milk production [4–6]. Therefore, the use of new technologies and technical means for harvesting first-class hay, haylage, etc. is an urgent task today.

The generally accepted technology for harvesting stalk forage is using roll balers. This technology allows to reduce the loss of nutrients, improve preservation, reduce labor costs and transportation costs.

When harvesting hay in rolls, balers are used with a bale chamber of variable and constant volume. The process of forming a roll in them consists in continuously winding the plant mass onto the core up to a predetermined diameter [7, 8].

When harvesting hay with the use of balers with a constant volume bale chamber, the shape of the swath is an important factor. This factor can significantly affect the storage processes of the hay, since it leads to the formation of zones with insufficient density of hay in the process of roll formation, that contributes to the penetration of moisture, the development of microbiological processes [9–11].

2 Materials and Methods

During the research, the process of movement of stalk particles in the process of picking up a swath of hay and supplying it into the bale chamber of a baler with a levelling device installed on it was theoretically considered.

In addition, studies were carried out to determine the profile of hay rolls obtained on natural forage lands as a result of the operation of a GVK-6 rake in an aggregate with an MTZ-80 tractor. For this purpose, a profiler (Fig. 1) with a length of 1.6 m with measuring rods was used. In the course of the research, the profiler was installed

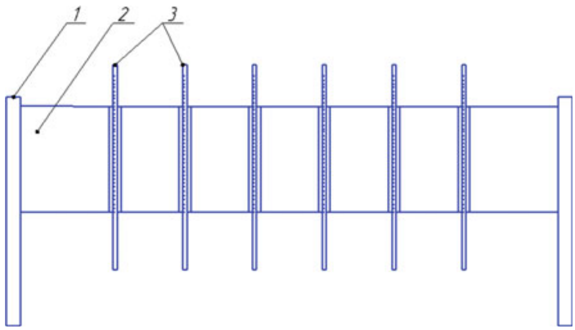

Fig. 1 Diagram of the profiler for determining the swath shape. 1—Frame; 2—ground; 3—measuring rods

across the hay roll every 0.5 m on registration plots, which were located diagonally across the field, while at least 5–7 registration plots were selected, the length of which was 25 m. The data obtained were averaged and tabulated, then their statistical analysis was carried out.

3 Results

The uneven distribution of stalk particles across the width of the pick-up is primarily due to the shape of the hay swath that enters the bale chamber. To determine its shape, a series of experiments was carried out, as a result of which a statistical model of the distribution of stem particles in the cross section of the roll was obtained (Fig. 2).

In order to improve the uniformity of the distribution of the swath of hay across the working width of the pick-up in the developed roll baler, the levelling device is made in the form of two discs with inclined fingers rotating in opposite directions (Fig. 3) [12]. The swath of hay raised by the pick-up enters the gap between the pick-up fingers and the inclined fingers of the rotating discs, while the discs above the pick-up are pushed forward to improve the distribution of the swath, forming a descending gap.

Let us write down the differential equations of particle motion

$$\begin{cases} m\frac{d^2x}{dt^2} = F_n + F_d\cos(\omega t) \\ m\frac{d^2y}{dt^2} = -F_d\sin(\omega t) \end{cases} \tag{1}$$

where Fn is the impact force of the pick-up on the hay roll, N;

Fd is the impact force of leveling disks on the hay roll, N;

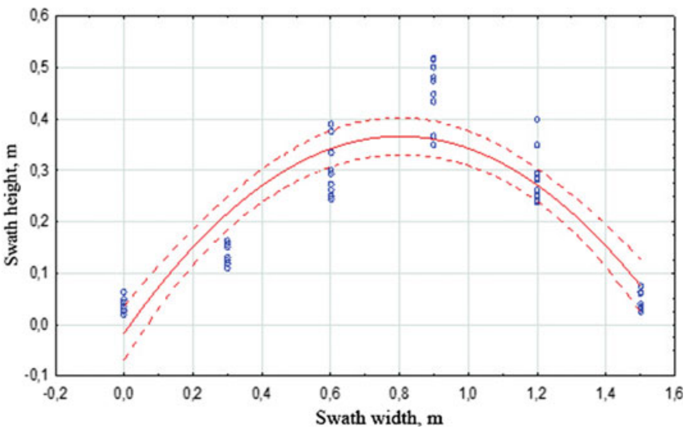

Fig. 2 The results of studies of the uniformity of a hay roll in cross-section

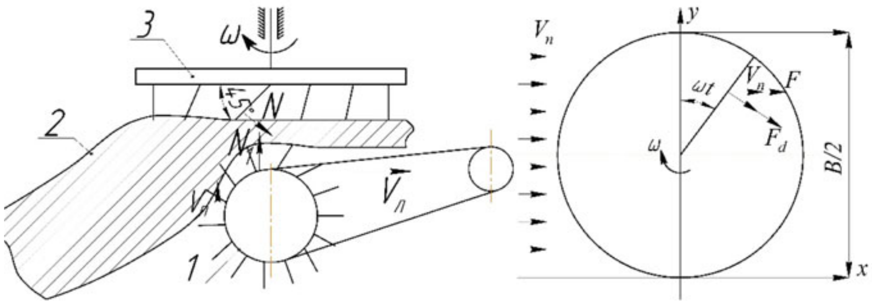

Fig. 3 The scheme for determining the law of particle motion when levelling a roll. 1—Pick-up; 2—hay roll; 3—levelling discs

ω is rpm of disks, s^{-1}.

Since the swath is unevenly distributed over the pick-up width of the baler, the degree of compaction and, accordingly, the forces will vary across the pick-up width.

As a result of studying the transverse profile of the hay swath before pressing, the regression equation is obtained:

$$H(b) = -0.016 + 0.9498b_{\text{B}} - 0.5926b_{\text{B}}^2 \tag{2}$$

Statistical analysis of the model shows that the correlation coefficient is R = 0.89, the determination coefficient showing the adequacy of the model is 0.79, which exceeds the limit value of 0.75, which indicates the performance of the model.

Considering that the swath is evenly distributed during the operation of the levelling discs, the average height of the swath across the working width is determined.

To do this, the cross-sectional area of the swath is determined

$$S = \int_0^b H(b)\mathrm{d}b = \int_0^b \left(-0.016 + 0.9498b - 0.5926b^2\right)\mathrm{d}b \tag{3}$$

After performing integral calculations, one gets:

$$h_{aver} = \frac{S}{b} = \frac{-0.016b + 0.9498\frac{b}{2^2\frac{b^3}{3}}}{b} \tag{4}$$

Compaction of the swath before pressing is

$$\Delta h = h_{aver} - h_0 = -0.016 + 0.9498b - 0.5926b^2 - 0.1 \tag{5}$$

where h0 is the clearance between levelling disc fingers and the pick-up (h0 = 0.1 m), m;

haver is the average height of the swath, m.

Therefore, the elastic force of the hay swath will be determined according to the following expression:

$$F_{elast} = c\Delta h = c\left(-0.116 + 0.4749b - 0.1975b^2\right) \tag{6}$$

where b is the roll baler width, m.

Since the velocity of the hay swath is constant, the interaction of the disc with hay can be investigated statically. Therefore, the impact force of the levelling discs on the hay swath will be performed according to the following expression:

$$F_{\Pi} = N_2 \cdot f_{if} = f_{if}\left(\frac{F_{elast}}{n_f} + P_{sw}\right) \tag{7}$$

where N2 is the normal pressure per unit of swath volume from the pick-up side (from below), N;

fif is the hay roll internal friction coefficient;

nf is the number of fingers, pcs;

Psw is the weight per unit of swath volume, N.

Based on the assessment of the impact of the levelling device on the hay swath and mathematical transformations of the expression (2), the law of motion of stem particles in the zone of operation of levelling discs with fingers was obtained

$$\begin{cases} x = x_0 + V_{0x} \cdot t + \frac{1}{m_s} \cdot f_{if} \cdot \left[\left(\frac{F_{elast}}{n_f} + P_{sw}\right) \cdot \frac{t^2}{2} - \frac{F_{elast}}{n_f \cdot \omega^2} \cdot \cos(\omega t) + \frac{F_{elast}}{n_n f \cdot \omega^2}\right] \\ y = y_0 + V_{0y} \cdot t + \frac{1}{m\,s} \cdot f_{if} \cdot \frac{F_{elast}}{n_f \cdot \omega} \cdot \left(\frac{1}{\omega}\sin(\omega t) - t\right) \end{cases} \tag{8}$$

where x0, y0 are coordinates of the initial position of stalked particles, m;

V0x, V0y is initial velocity of stalked particles before levelling, m/s.

Based on the obtained expression, the trajectories of movement of stem particles were studied using MathCad program. The following parameters were set as the initial ones: the degree of compaction (decrease in the height of the swath when levelling), the coefficient of friction, the angular speed of the levelling discs, the number of fingers, the speed of the hay swath. As a result of the research, a graph of the trajectories of movement of stem particles during the operation of the levelling discs is made (Fig. 4).

It is also found that the displacement of stalk particles is significantly influenced by the number of fingers in the levelling discs and the distance between them, the angular velocity of the levelling discs and the amount of compaction of the hay swath.

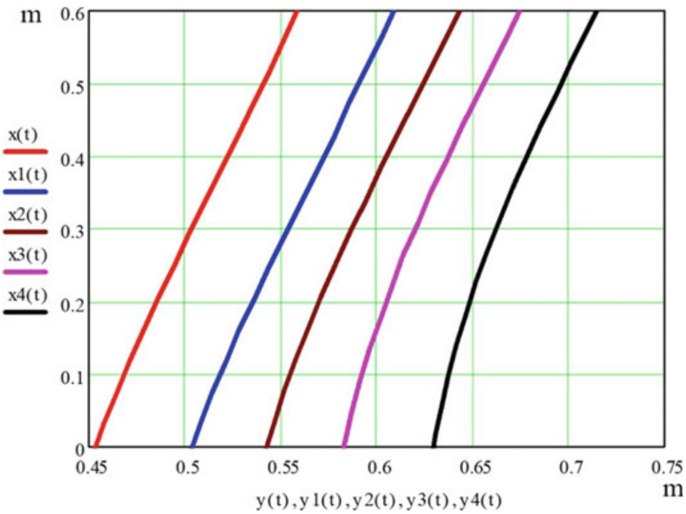

Fig. 4 Trajectories of movement of stem particles

4 Discussion

Analysis of the graph (Fig. 2) shows that the swath is extremely uneven in width, has the greatest height in the middle part, and on the sides of the swath the hay is located at an angle of natural slope (internal friction). Taking into account the complex structure of the hay swath and the multidirectional stalks, it can be concluded that the standard operations of the baler including picking, transportation and pre-pressing do not sufficiently contribute to the uniform distribution of hay across the width of the baler. When baling, the problem is aggravated, as the middle of the roll is approximately in the middle of the bale, as a result of which the middle part of the bale has a higher density, and the edges of the bale have a lower density, which leads to moisture penetration and hay spoilage.

The graph clearly shows that the displacement of stalk particles located closer to the center of the levelling disc is slightly lower, therefore the fingers are located on the disc in two rows with a predominant location along the periphery. The analysis of the obtained trajectories makes it possible to establish the basic parameters of the levelling device: the distance between the fingers is 0.15–0.2 m, the degree of compaction when levelling is 20–25%, the angular velocity is 23–30 rad/s, the diameter of the levelling disc is 0.74 m.

5 Conclusion

The conducted experimental studies have shown that the swath of hay entering the roll baler has uneven structure and shape, and therefore in the process of roll formation zones with lower density will appear, which leads to moisture penetration and hay spoilage.

Since the uneven supply of the hay swath into the bale chamber cannot be completely eliminated by stress relaxation during the formation and subsequent storage of the roll, it is relevant to use an additional operation to align the roll before pressing.

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