Analysis of Haylage Round Bale Wrapper Operating Mechanism

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Abstract: The construction of round bale wrapper for haylage wrapping into polymeric film is examined and recommendations suggested for increase of its efficiency. Dynamic analysis of the mechanism of round bale rotation round vertical axis is made. Dependences are derived for determination of the necessary round bale wrapper driving power. Theoretical prerequisites are presented for justification of the round bale wrapper characteristics which could be used by the designers in the development of its construction.
[Zhortuylov O., Kalym K., Kassymbayev B., Karaivanov D. **Analysis of Haylage Round Bale Wrapper Operating Mechanism.** *Life Sci J* 2013;10(12s):349-352] (ISSN:1097-8135). http://www.lifesciencesite.com. 61

Keywords: Dynamics, hay, wrapper, power calculation.

1. Introduction

Recently, with the purpose to preserve haylage natural properties its conservation in polymeric film wrapped round bales is applied [1, 2]. This decreases the loss of dry substance during haulage storage; the necessary area of warehousing and in general decreases the cost price of stock-raising production [3]. This method is new in Kazakhstan and is tested in KH «Imanbaev» in Eskildinisk region of Almaty province. The test results showed that the application of baler with forage chopper improves the round bale density to 30 % and reduces the amount/number of layers of bale wrapping film to 2-3 layers which decreases the consumption of polymeric film for a ton of forage 1,5-2,0 times. In the same time the losses during distribution of haylage to the animals also decrease.

Bearing in mind that the cost of a complex of machines from foreign companies for round bale wrapping in polymeric film is quite high, the “Kazakhstan Research Institute for Agriculture Mechanization and Electrification” develops the machines required for this operation. Mounted mover KP-3,1, Round bale handler, Round baler PR-400 and Round baler with chopping device PRI-400 are already developed. In order to do without use of expensive foreign analogues, it is envisaged to develop and manufacture round bale wrapper for haylage wrapping into polymeric film by means of two rotational motions [4]. After analysis of the available machines for round bale wrapping in polymeric film, the team selected as initial construction the Round bale wrapper OR-1 produced by BobruiskAgroMash [5]. With the purpose of optimizing its parameters it is necessary to carry out dynamic analysis of its operating mechanisms that is the aim of the present paper.

Wrapper construction

The Round bale wrapper consists of (Fig. 1) hanger 1, frame 2, rotating platform 3, polymeric film tensioner 4, driving drums 5, hydraulically driven counter of turns and bales, idle rollers. The frame is attached by hinge joint to the hanger and fixed by holder. On the frame there are fastened the rotating platform axle and the hydraulic engine which by means of chain gear ensures the rotation of the rotating platform and drums. The rotating platform is centered on the frame axle and rests on the frame running/support path by four rollers. On the platform there are attached the two driving drums, the two idle rollers and the knife for polymeric film cutting. In the platform frame on rolling bearings there is fixed the shaft which transmits the rotation from the platform to the drums by bevel gear and chain transmissions.

The film tensioner is designed for holding-down the reel of the synthetic pressure sensitive film of length 750 mm and 500 mm ensuring film elastic extension on account of the difference in the peripheral speed of the grooved rollers and film unwinding when it is laid on the round bale.

The counter of turns and round bales is designed for counting the amount of the preset turns of film laid on the bale and estimation of the quantity of wrapped bales.

The technological process of round bale wrapping into polymeric film is performed in the following way. Establish the wrapper by means of tractor on a flat place without sharp subjects and turn the rotating platform so that the driving drums are perpendicular to the tractor axis. Put the round bale by means of loader with clamps on the rotating platform between the idle rolls. Place the polymeric film reel in the film tensioner and load it. Place the film tensioner in the hanger bracket so that the centers of the bale and film are at the same level. Fix the film end for bale twine binding or netting. Prepare the counter of turns and bales for operation, i.e. set the required number of turns.

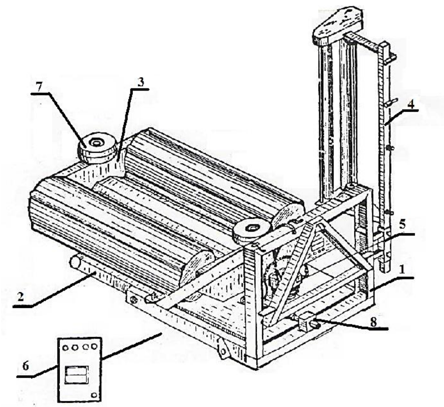

Fig. 1. Round bale wrapper OR-1 [5]

Smoothly feed pressure in the wrapper hydrosystem and carry out bale wrapping. On sound signal and light emitting diode (LED) indication, move the tractor hydraulic distributor lever of the hydraulic drive control in position securing the unlocking of the hanger and frame. Feed pressure into the wrapper hydrosystem and turn the rotating platform clockwise not less than one revolution to bale axis position perpendicular to the tractor. Cut the film off the bale, by the tractor suspension bracket lift the hanger and remove (drop) the bale from the rotating platform. When the hanger descents the frame and hanger automatically lock. Move 1,5 or 2,0 m forward and load the next bale and start the process of round bale wrapping in polymeric film.

For wrapping round bales of diameter 1450 mm regulate the counter of turns and bales and set the wrapper operation mode: for polymeric film width of 750 mm bale wrapping in two layers – nine turns; four layers – 12 turns; six layers – 27 turns; for polymeric film width of 500 mm: two layers – 11 turns; four layers 22 turns, six layers – 33 turns.

After carrying out the experiments it was found that when using bale wrapper OR-1 for wrapping milled masses in polymeric film in round bales the amount of layers of bale film wrapping is reduced to 2-3 layers which reduces film consumption for wrapping of 1 ton of forage in bales 1,5 – 2,0 times.

Shortcoming of the bale wrapper is that the round bale loading on the wrapper OR-1 is carried out by loader used for bale storage. Moreover, during wrapping the bales in regular shape there are air pockets and unreliable bale wrapper operation which requires improvement and justification of the parameters.

Mechanical-mathematical model

Figure 2 shows the wrapper mechanical-mathematical model. The wrapper platform together with the round bale rotates round the vertical axis Oz, while the bale rotates round the longitudinal axis Ox.

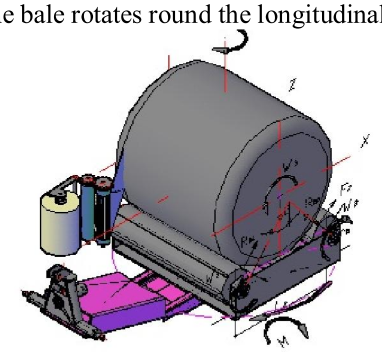

Fig. 2. Wrapper – mechanical-mathematical model

For determination of the operation body basic parameter, the angular velocity of wrapper platform rotation, we shall examine the processes of film unwinding from the reel and its movement along the guide rollers and winding over the bale.

The platform with the haylage round bale rotates on account of the applied torque on the drive that overcomes the resistance to rotation and the film elastic elongation during winding.

The differential equation of platform and bale rotation round the vertical axis Oz has the form of [6]

$$J_z \cdot \ddot{\varphi} = \sum_{k=1}^{n} T_z\left(F_k\right), \quad (1)$$

where

J_z inertia moment of the platform with the bale about axis Oz; kg·m^2.

$\sum_{k=1}^{n} T_{zk}\left(F_k\right)$ main torque of the external forces about rotation axis Oz; N·m.

The following external forces and torques are applied to the platform:

G - force of bale weight;

R_{b1} and R_{b2} - components of bale reactions to drums;

F_1 и F_2 - friction forces of drums sliding against the bale;

T_1 - torque rotation axis Oz of the platform;

F_t - force of film tension during bale wrapping.

As the torques of the support reactions and the force of bale weight about rotation axis Oz are equal to zero so the sum of torques of all external forces is equal to the torque about rotational axis Oz and the torque of force of film tension during winding. Opening both members of equation (1) we get

$$\left(J_{pz}+J_{rz}\right)\ddot{\varphi}=F_t\cdot r_w\left(\varphi\right)-T_1, \quad (2)$$

where

J_{pz} - moment of inertia of platform about axis Oz [7], kg·m^2 ;

$J_{rz}=m_r\dfrac{3r_r^2+4l_r^2}{12}$ - moment of inertia of round bale set on the platform [7], kg·m^2 ;

m_r - round bale mass, kg;

r_r - round bale radius, m.

l_r - round bale length , m.

F_t tension force of the film being wound around the bale, N;

$r_w\left(\varphi\right)$ - variable radius of the film being wound around the bale, m.

The film tension after passing through the rollers (Fig. 3) is defined by the formula [8]

$$F_t=\left(F_{t0}+F_{tB}\right)e^{(\alpha_1+\alpha_2)\mu\frac{r_{01}}{\rho}}, \quad (3)$$

where

F_{t0} - film tension force to the rollers, N;

α_1, α_2 – angles of film coverage by the guide surface (angles of wrap), rad;

μ - coefficient of film friction along the guide surface of rollers;

r_{01} - radius of roller shafts, m;

ρ - radius of roller guide surfaces, m;

F_{tB} - force of film tension produced by the break device of the tensioner, N.

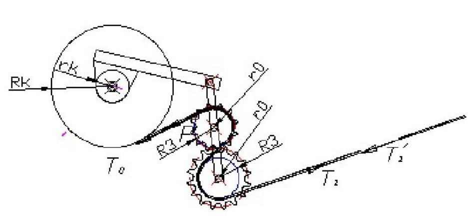

Fig. 3. Film tensioner

On the basis of the principle of action and counteraction parity the same force F_t acts on the round bale.

After replacing (3) in (2) we get

$$\left(J_{pz}+J_{rz}\right)\ddot{\varphi}=\left[\left(F_{t0}+F_{tB}\right)e^{(\alpha_1+\alpha_2)\mu\frac{r_{01}}{\rho}}\right]r_w\left(\varphi\right)-T_1$$

, (4)

From there we obtain differential equation of platform rotation with the bale about axis Oz

$$\ddot{\varphi}=\frac{\left[\left(F_{t0}+F_{tB}\right)e^{(\alpha_1+\alpha_2)\mu\frac{r_{01}}{\rho}}\right]r_w\left(\varphi\right)-T_1}{J_{pz}+J_{rz}}. \quad (5)$$

Integrating (5) we find

$$\dot{\varphi}=\frac{\left[\left(F_{t0}+F_{tB}\right)e^{(\alpha_1+\alpha_2)\mu\frac{r_{01}}{\rho}}\right]r_w\left(\varphi\right)-T_1}{J_{pz}+J_{rz}}t+C. \quad (6)$$

For $t=0$, $\varphi=0$ therefore, $C=0$.

So the angular velocity of platform rotation with the round bale equals to

$$\dot{\varphi}=\frac{\left[\left(F_{t0}+F_{tB}\right)e^{(\alpha_1+\alpha_2)\mu\frac{r_{01}}{\rho}}\right]r_w\left(\varphi\right)-T_1}{J_{pz}+J_{rz}}t\ . \quad (7)$$

For platform uniform rotation ($\ddot{\varphi}=0$) by formula (7) it is possible to determine the torque T_1 about the vertical axis Oz as function of the platform turning angle.

Determination of the wrapper necessary driving power

For determination of the torque required for bale rotation during wrapping into polymeric film we determine the load on the drum (Fig. 4) projecting the forces on axis Oz

$$G=R_{b1}\cdot\cos\alpha+R_{b2}\cdot\cos\alpha\ . \quad (8)$$

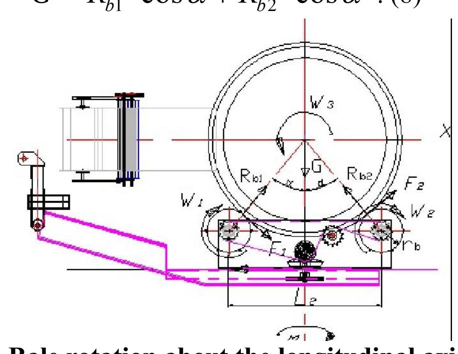

Fig. 4. Bale rotation about the longitudinal axis Ox

As the drums are installed symmetrically to the longitudinal axis there is equality of the support reactions $R_{b1}=R_{b2}=R_b$ and the friction forces $F_1=F_2=F$ and (8) takes the form

$$G=2R_b\cdot\cos\alpha\ , \quad (9)$$

from where

$$R_b = \frac{G}{2\cos\alpha} \quad (10)$$

and the torque T_2, required for bale rotation during wrapping

$$T_2 = 2F \cdot r_2 = \frac{G \cdot f \cdot r_2}{\cos\alpha}, \quad (11)$$

where

r_2 - radius of platform drums;

f - coefficient of rolling friction between the bale and drums.

The power necessary for the wrapper driving during bale wrapping in polymeric film is determined by the formula

$$P = P_1 + P_2, \quad (12)$$

where

P_1 - power necessary for platform rotation with the bale during wrapping in polymeric film about axis Oz;

P_2 - power necessary for bale rotation about its longitudinal axis Ox;

These powers are determined by the formulae

$$P_1 = T_1 \cdot \omega_1, \quad (13)$$

where

T_1 - torque of the platform with the bale about the vertical axis Oz;

ω_1 - angular velocity of bale rotation about axis Oz;

and

$$P_2 = T_2 \cdot \omega_2, \quad (14)$$

where

T_2 - torque of the platform with the bale about the longitudinal axis Ox determined according to (11);

ω_2 - angular velocity of bale rotation about axis Ox;

Substituting in formula (13) the value of T_1 determined by formula (7) it is possible to obtain the value of power variation from the angle of platform turn.

Conclusion.

The shortcoming of the technology of haylage preparation in round bales and wrapper is the high consumption of polymeric film of greater value - 0,6-1,0 kg per 1 ton of forage. The cause is that the rough thick plant stems damage the film. Therefore the round bales have to be wrapped in 6-8 layers.

It is necessary to find way to decrease the polymeric film losses during wrapping of bales.

It is ascertained that one of the methods for polymeric film consumption reduction is the use of baler with chopper that provides round bale density increase to 30 % at decrease of amount of layers of bale wrapping film to 2-3 layers which reduces film consumption per 1 ton of forage 1,5-2,0 times. Simultaneously, the losses during haylage distribution to the animals are less.

On the basis of the dynamic analysis dependences are deduced for determination of bale angular velocity about the vertical axis. From them it is possible to obtain the torque dependence and the required power as function of platform turning angle.

The theoretical prerequisites for parameters reasoning could be used by the constructors in the design and improvement of the round bale wrapper construction which will allow acceleration of the transition of haylage use to industrial basis.

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23/11/2013