Determination of the Bonding Force Between the Rettery and Flax Swaths in Their Picking Up by Pick-Up Device Fingers

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Abstract. The quality of flax products depends on the way of flax straw retting. Currently, the best and most widely used method of flax straw retting is way of dew retting. Flax stems are laid in a thin layer on the flax field where they were grown or on a clover or grass field. During the retting process, plants tend to grow through the flax swaths depending on the air temperature (starting from 18°C) and humidity (50-60%). Therefore, the flax straw picking up process should be done with certain efforts, however, without damaging the stems. (*Research purpose*) To determine the bonding forces of the flax straw with the rettery (a flax field or a grass field). (*Materials and methods*) The authors have designed an instrument to measure and register the considered forces as well as a general mechanism of the flax straw picking up process, which operates in conjunction with the IP 264 (BS) measurement information system, and also developed a research methodology. This system is integrated with to a laptop with the pre-installed «Testing» software. The system is adopted to use the MS Excel software to transfer data in MS Excel format for further plotting. (*Results and discussion*) It has been shown that the bonding forces of flax stems, their changing pattern, and the maximum value during the picking up process depend on the degree of penetration by grass plants into flax swaths and the grass plant density per square meter. (*Conclusions*) In process of picking up the grass-penetrated swaths, they show weak strength characteristics for transportation and an increased tendency to break the continuity of their picking up. The values of the ratio of the translational speed of a pick-up device and the rotary speed of a picking device fingertip can be greater than the value of the relative elongation at the point of pulling the swath away from the ground. The coefficient of strength to pick up the swaths from a clover rettery is higher than that of flax and grass retteries.

Keywords: retted flax straw, flax field, flax stems, bonding force, coefficient of strength.

Flax harvesting includes a number of successive operations: stalking of stems, detaching seed boxes, laying stems down for retting, their picking up, and the transportation of packs. A special place among the operations listed above belongs to the picking up of stems and pressing them into large packs, which largely determines the quality of products [1]. The production of long fiber on flax factories largely depends on the quality of a retted flax straw and its condition after its picking up. In other words, it depends on the right selection of the method of its obtaining.

The most widespread method is dew retting. At present, it is considered the best one [2]. The stems of flax are laid in a thin layer in a rettery on a field from under clover or flax (where it was previously grown). During the retting process, the swath is penetrated by growing grass at a temperature of 18°C and an air humidity of 50-60%. Therefore, for picking it up, it is necessary to exert a certain effort not to damage the stems.

Choosing a rotary speed of the tips of the -up fingers, as well as the interaction mechanism of the pick-up device's moving fingers with the picked up swath can be considered only on the basis of sufficient data on the stiffness of the retted flax stems and their connection with the rettery.

To ensure the cleanliness of the swath picking up from the rettery and the obtaining of long fiber without losses, it is necessary that the swath enter the pick-up device without tearing and piling up, and this depends on the setting of rotary speed of the picking device fingertips, and the value of the interaction force between the fingers and the stems [1-4].

PURPOSE OF RESEARCH – is to determine the value of the binding forces between retted flax stems and the rettery and the cohesion coefficient of the stems.

MATERIALS AND METHODS. To record and measure the analyzed forces, as well as to identify separate phases of the picking up process, a device was developed that functions in conjunction with the IP 264 (BS) measurement

information system (Fig. 1). The system is designed for research purposes, as well as power, operational and technological evaluations of machines and traction testing of tractors. It receives discrete and analog signals from primary converters of any type. The instrument and the schematic diagram of the measurements are shown in Figure 2.

The figure shows power link *1* and devices located in the mobile IP 264 (BS) measuring system. This system was connected to a mobile computer, with the embedded «Testing» software that can transfer data in MS Excel format for further plotting purposes.

Fig. 1. General view of the testing system IP-264 connected to the laptop and the module of coordination MC-1
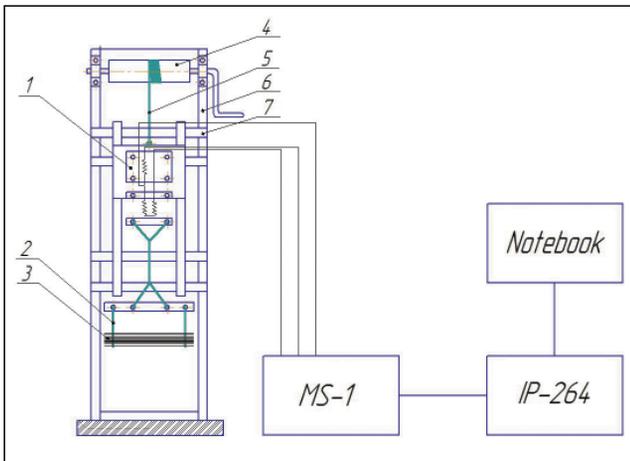

Fig. 2. The device and the basic scheme for the measuring of bonding forces of the flax stems swaths with the field

The power link is an elastic rubber plate of rectangular cross-section 30×40 mm with two wire sensors attached to it.

The connection between the power link, the PI 264 (BS) measuring system and the laptop is carried out using a wired connection. A portable 12 V power supply was used for tests.

Results and discussion. Experiments were carried out in the Bezhetsk district of the Tver region. The device was installed along the laid swath. The ends of flexible cables *2* passed under swath *3* so that the connection between the retted flax stems and the rettery could not be not broken. When drum *4* was rotating, cable *5* was wound on it, moving upwards along rails

6 of slide *7*. The slide entrained a rubber plate with sensors attached to it (a power link), which was connected to the picked up retted flax stems through the wire and rail.

Due to the binding forces between the retted flax stems and the rettery, the rubber plate was deformed, and the working sensors attached to its surfaces deformed as well.

When the sensors were deformed, their resistance changed, and, consequently, the bridge left the balance state: the current entered the matching module MS-1, from it to the IP 264 (BS) system, and then the signal entered the laptop, which registered the efforts of the stems' connection with the rettery.

Each of the experiments had a tenfold retake on different swaths and with a different number of simultaneously picked up stems.

Previously, the power link was calibrated by deforming it in conditions similar to the operating ones. Figure 3 shows the load characteristic of the power link.
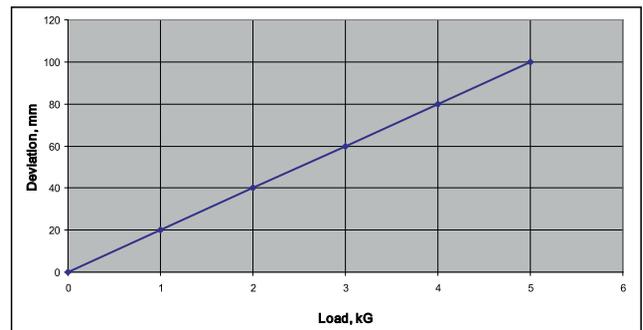

Fig. 3. Load characteristic of the power link

Oscillograms recorded the nature of changes in the binding forces of the flax stems during their ascent, and the value of the maximum bond strength for a certain number of stems.

If we compare the nature of changes in the curves on the oscillograms of different experiments (with a different number of stems), it will be easy to see that, regardless of the number of stems, the curves on the oscillograms are similar in shape and differ only in the magnitude of the ordinates. We can distinguish three characteristic areas on each oscillogram (Fig. 4).
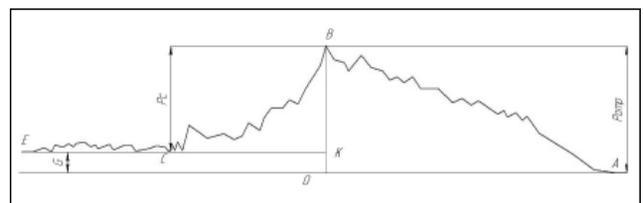

Fig. 4. Characteristics of the phases of a flax swath's detachment: A –beginning; B – maximum banding force; C – the ending of detachment

Section *AB* – the section corresponds to the maximum

tearing resistance of the stems. Point A – the beginning of the phase of separation of flax stems from the rettery (breaking of the bonds of the captured stems with the grass cover of the rettery and the stems of neighboring swaths). Point B is the maximum binding force of flax stems with the rettery that corresponds to the moment of tearing the stems away from the rettery for most of them along the swath width.

The second section BC – there is further and final tearing away of the stems along the entire swath width with a characteristic drop in the binding force. The point C corresponds to the end of the phase of tearing the flax stems from the rettery.

Section CE is parallel to the axis of abscissas and corresponds to the mass of picked up flax stems from the rettery. Point E is the end of the detachment of the flax stems from the rettery.

As noted above, point B corresponds to the maximum value of the binding force between the flax stems and the rettery, and its value on the oscillograph – to the ordinate BO. We denote it as $P_{\text{отр}}$. The ordinate KO on the oscillogram corresponds to the mass of the picked up stems G. So the difference between $P_{\text{отр}}$ and the mass of the stems is regarded as the binding force between the stems and the rettery, that is $P_{\text{сц}}$, which corresponds to the ordinate BK on the oscillogram. Mathematically, this relationship can be expressed by the formula:

$$P_{\text{сц}} = P_{\text{отр}} - G, \tag{1}$$

or

$$P_{\text{отр}} = P_{\text{сц}} + G. \tag{2}$$

The binding force $P_{\text{сц}}$ between the stems and the rettery can be expressed as:

$$P_{\text{сц}} = l_{\text{ср}}\, c f_{\text{сц}}, \tag{3}$$

where $l_{\text{ср}}$ – the average length of stems, m;

c – the length of the stem gripping area, m;

$f_{\text{сц}}$ – the coefficient of adhesion or tearaway resistance of stems, kG/m^2 [5, 6].

The product $l_{\text{ср}}c$ is the area occupied by the picked up stems, m^2. If the average number of stems "n" is known, $pcs./run.\ m$, it is easy to establish the relationship between the number of stems, m/pcs, located on the interval c and n [7]:

$$m = cn, \tag{4}$$

or

$$c = m/n. \tag{5}$$

Formula (3) can be represented as:

$$P_{\text{сц}} = l_{cp}\,\frac{m}{n}\,f_{\text{сц}}, \tag{6}$$

If we insert the value of the binding force $P_{\text{сц}}$ in formula (2), we obtain:

Number stems, pieces	Bonding force $P_{\text{отр}}$, kg		
	Flax field with the plants of biomass in 105 g/m²	Flax field with the plants of biomass in 137 g/m²	Flax field with the plants of biomass in 150 g/m²
50-100	1,4	1,7	1,9
100-150	1,6	2,1	2,1
150-200	1,9	2,3	2,4
200-250	2,1	2,8	2,9
250-300	2,3	3,0	3,0
300-350	2,6	3,2	3,3
350-400	2,8	3,4	3,6
400-450	3,0	3,6	3,7

$$P_{omp} = l_{cp}\,\frac{m}{n}\,f_{\text{сц}} + G, \tag{7}$$

The weight of the picked up stems from the interval C can be expressed by the formula:

$$G = q_{\text{ср}}\,m, \tag{8}$$

where $q_{\text{ср}}$ – the average weight of a single stem.

Thus, equation (7) can be represented as follows (8):

$$P_{omp} = l_{cp}\,\frac{m}{n}\,f_{\text{сц}} + q_{cp}m, \tag{9}$$

As experimental studies have shown, for different rettery types, this force varies significantly with the same number of stems and depends on the grass height, its density and type, as well as some other factors.

The average value of the detachment force, depending on the number of stems, as well as the limits of its vibration, depending on the type of rettery with the same number of stems m, are given in the table.
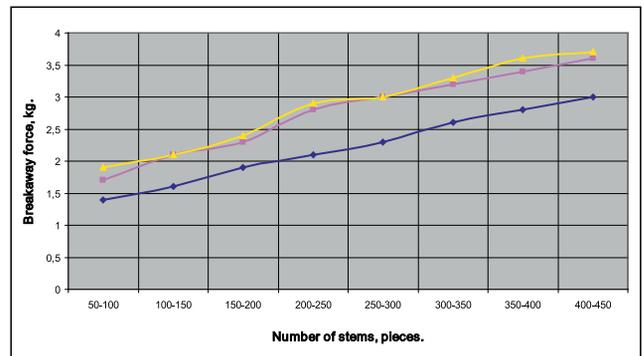

Fig. 5. Dependence of the bonding force P on the number of lifted stems: yellow line – flax field with the plants of biomass in 150 g/m²; pink line – Flax field with the plants of biomass in 137 g/m²; blue line – Flax field with the plants of biomass in 105 g/m²

The dependence of the detachment force $P_{\text{отр}}$ on the number of stems is shown in Figure 5. The experimentally determined values of $P_{\text{отр}}$ for different types of rettery, with reference to formula (9), make it possible to calculate the limits of changes in the tearaway resistance coefficient of the flax stems, for swaths laid:
- in a flax rettery = 0.0015 – 0.0020 kg/cm^2;
- in a grass rettery = 0.001 – 0.0018 kg/cm^2;
- in a clover rettery = 0.0025 – 0.0046 kg/cm^2.

CONCLUSION

Improving the quality of raw flax resources, which determines the competitiveness of the industry, requires studying the features of flax harvesting under various conditions of retted flax maturing and applying technical means that most effectively perform technological steps [8]. The experiments carried out to study the peculiarities of detaching flax swaths prepared on different backgrounds have established that:
- the larger the grass height and density is, or the more the grass has penetrated the swath, the higher the tearaway resistance coefficient is, and therefore the greater the effort it takes to tear away the stems from the ground is;
- the coefficient of tearaway resistance of a swath laid on a clover rettery is greater than that for flax and grass retteries;
- when an interpenetrated swath is picked up, the values of the ratio of the translational speed of a pick-up device and the rotary speed of a picking device fingertip can be greater than the value of the relative elongation at the point of pulling the swath away from the ground.

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Conflict of interest. The authors declare no conflict of interest.