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Development of Optimal Parameters for Determining the Diameter of Wool Fibres Using the Instrument PAM-1

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ABSTRACT: In this article, we consider the geometric properties of local wool, determined by the standard length method on a comb analyzer and thickness using a micrometer, and also on an acoustic PAM-1 instrument. The results of the experiments using the standard procedure showed that the weighted average length and thickness index is higher for the wool fibers of the sheared breed of sheep. The results of the experiments on the acoustic device showed that the coarser and irregular fibers, the less the density of the fibers in the chamber, and consequently the more intense passage of the sound pulse. The result obtained on the PAM-1 device is an affirmation of the fact that fibers of the sheared breed of sheep are coarser and irregular, that is, with two methods for evaluating wool fibers, similar results were obtained.The influence of mass, humidity and diameter of the samples on the transmission of the sound signal with the use of the PAM-1 device.

KEY WORDS: fibers, wool, length, diameter, unevenness, acoustic device, comb analyzer, moisture.

I. INTRODUCTION

For wool is characterized by a large heterogeneity in physical and mechanical properties, which complicates its processing. The world has departed from the subjective assessment of the characteristics of raw wool and entered the era of objective measurements and specifications, and the trade in raw wool quickly goes on to the sale according to a general description, which requires accurate, rapid and cost-effective measurement of the entire raw material. Wool characteristics important in price determination, and end use. The development and availability of new technologies and equipment allowed to objectively measuring many characteristics of woolen fibers than it was in the past [1,2].
At present, the problem of creating devices for evaluating the quality characteristics of wool fibres express has become relevant in ways based on non-destructive methods of quality control and diagnostics

II. METHODOLOGY

It is of great practical interest to determine the characteristics of cotton fiber by acoustic method. JSC "Pahtasanoat ilmy Markazi" has developed an acoustic device PAM-1 for measuring the micronaire index of cotton fibre. Figure 1 shows a block diagram of this instrument. Apply the device operation as follows [3].

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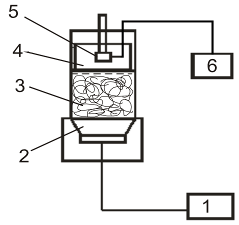

Fig. 1. Flowchart of the PAM-1 device

Sound vibrations excited by means of generator 1 and radiator 2 are directed to the working chamber of the device, where the test sample 3 is placed. The sound waves passed through the fiber sample are converted into an electrical signal by means of a microphone 5 mounted inside the plunger 4. The magnitude of the signal is proportional to the amplitude of the sound vibration pressure. The magnitude of the output signal is measured by the measurement and detection unit 6.

Comparative analysis of methods for determining the geometric characteristics of woolen fibers. The results of tests carried out to determine the geometric characteristics (fineness, length) of wool fibers of different breeds by the standard method are given in the table 1 [7,8].

Table 1. Indicators of fineness, length of woolen fibers

№	Name of the characteristic	Samples of woolen fibers		
		Hissar	Karakul	Crossbreed
1.	Weighted average length, mm	48	53,6	66,1
2.	Modal length, mm	59,8	58,4	65
3.	Staple length, mm	64,8	65,1	81
4.	Standard deviation in length, mm	3,52	3,50	3,2
5.	Coefficient of variation in length,%	7,9	6,5	4,8
6.	Average diameter, micron	29	33	44
7.	Coefficient of variation thickness,%	37,9	51,5	40,9

The results of determining the average diameter of the wool are shown in Figure 2.

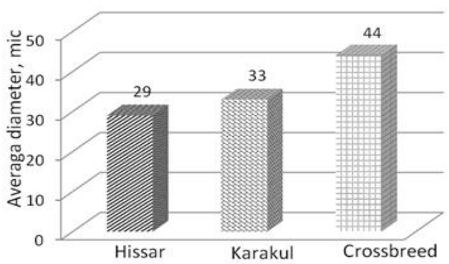

Fig.2. Average diameter of wool fibers of different breeds

The analysis of the results showed that the coarsest of the three samples of wool fiber is wool of a Cross-breed with an average diameter 34% larger than that of the Hissar breed and 25% larger than that of the Karakul breed of sheep. Indirect characteristics of tones and roughness of wool fibers of selected breeds were also determined on the PAM-1 unified acoustic device. Acoustic device PAM-1, designed to determine the grade of raw cotton and cotton fiber by the express method. The principle of the device is based on the ability to transmit sound pulses through textile fibers, depending on their structure [9]. The method is an indirect method of estimating the fineness and roughness of the fibers. To evaluate the wool fibers on the PAM-1 device, an experimental study was carried out using an express method. The results of the determination of the propagation of signals of sound pulses through wool fibers on a PAM-1 device with a mass of samples of 10 grams and a humidity of 17%. The results of the passage of sound pulses are shown in Figure3.

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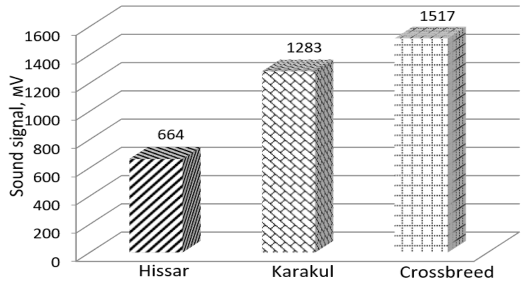

Fig. 3 Passing sound pulses through wool fibers on the PAM-1 device indication

III. RESULTS AND DISCUSSION

Analysis of the results shows that the largest value of the sound pulse transmission is the coarse cross-hair coat, which has the highest fiber thickness and uniformity in length, which facilitates a uniform laying of the fibers in the measuring chamber and the passage of the highest value of the sound pulse. The smallest value of the passage of the sound signal is in the sample of Hissar wool. It is accordingly 48% and 56% less than Karakul and Crossbreed wool, which can probably be explained by the higher density of fiber laying in the chamber of the device. This can be explained by the fact that Hissar's wool has the smallest diameter, greater uniformity in tin and the presence of short fibers, gives a strong seal and prevents the penetration of sound.

In general, it can be noted that the readings of the PAM-1 device correlate well with the results of the geometric properties of the fibers determined by the standard method and can be used to indirectly assess the fineness of the wool, provided that the gradation of the fineness of the wool is determined depending on the magnitude of the sound pulse.

To determine the influence of different moisture values and geometric characteristics of wool fiber on the passage of a sound signal on the PAM-1 device, an experiment was performed that realizes all possible non-recurring combinations of the levels of the investigated factors, called a full-factor experiment [6].

To solve the problem of optimizing the tuning parameters of the improved drafting system, a 3^2 full factorial design - 9 experiments, i.e. a complete search of all possible combinations, all levels of factors, as in textile research the usual search is the most effective method of searching for an optimum.

Three factors are affected: the mass of wool fiber (X_1) at levels: 8, 9, 10 grams, wool fiber moisture (X_2) at levels: 7%; 12%; 17%, wool fiber diameter (X_3): 22 micron, 33 micron, 44 micron.

As a result of the calculation, we obtain a regression multivariate model

$$Y_R = b_0 + b_1x_1 + b_2x_2 + b_3x_3 + b_{12}x_1x_2 + b_{13}x_1x_3 + b_{23}x_2x_3 + b_{123}x_1x_2x_3;$$

$$Y_R=1253{,}2917-199{,}9583x_1+27{,}2083x_2+336{,}9583x_3+9{,}9583x_1x_2+88{,}375x_1x_3+9{,}875x_2x_3-$$
$$-8{,}7083x_1x_2x_3, \quad (1)$$

Let's check the significance of the regression coefficients. For this, use the Student's test, whose calculated value t_R {bi} is compared with the tabulated t_T. If $t_R > t_T$, then the hypothesis about the significance of regression coefficients is not rejected. Thus, the attainment of maximum values of the sound pulse of wool fiber samples is possible when the values of the factors approach the upper level of the chosen variation interval.

To check the possibility of measuring the diameter of the wool fiber, we analyze the process of the passage of sound vibrations through a sample of wool enclosed in the measuring chamber of the device. When plane sound waves pass through a fiber sample, energy losses occur due to friction against the fiber surface, which leads to a change in the amplitude of sound vibrations and a phase shift of sound waves. The amplitude of a plane sound wave along the OX axis, which coincides with the direction of wave propagation, varies according to the formula:

$$\mathbf{P} = \mathbf{P_0} \mathbf{e}^{-\mathbf{j}l}, \quad (2)$$

where P_0 – is the pressure of sound vibrations before the breakdown of the fiber;

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l - is the thickness of the fiber sample layer;

j - is the propagation constant, determined by the formula:

$$\mathbf{j} = \boldsymbol{\alpha} + \boldsymbol{\beta} i \tag{3}$$

where **α** - sound attenuation coefficient;

β - wave number.

After determining the optimal parameters of the wool fiber for measurement on the PAM-1 device, the principle of measuring the attenuation of sound fibers is considered.

Therefore, the relationship of the output signal in the low-frequency region of sound vibrations shows the dependence of the attenuation of acoustic vibrations on fiber parameters

$$\alpha = \frac{1-\varepsilon}{\varepsilon} k\, S_O \sqrt{f} \tag{4}$$

where **ε** - porosity of the fiber sample equal to the ratio of the pore volume in the sample to the total sample volume;

f – frequency of sound vibrations; Hz

S_0 – specific fiber surface equal to the ratio of the lateral surface area of the fibers in the sample to their volume, 1 / m

k – constant coefficient.

In this work, we study the dependence of the fineness of a wool fiber on the attenuation of sound vibrations.

For this purpose, we derive the functional relationship of the damping coefficient of sound vibrations α with the diameter of the wool fiber.

Woolen fiber has a cylindrical shape. Therefore, the specific surface of the wool fiber is determined from the following relationship;

The specific surface of the wool fiber is determined by the expression

$$S_O = \frac{S_B}{V_B} \tag{5}$$

where, S_B - the area of the side surface of the wool fiber

V_B - fiber volume is determined by the following expressions

$$S_B = \pi \cdot d \cdot l\,, \tag{6}$$

$$V_B = \frac{\pi \cdot d^2}{4} \cdot l \tag{7}$$

where d – diameter of fiber; mm:

l – fiber length, mm.

By substituting the expressions (6) and (7) in (5) after simple transformations, we obtain the following expression for the specific surface area of wool

$$S_O = \frac{4}{d} \tag{8}$$

By substituting the expression (8) in (4) we obtain the following ratio for attenuation factor

$$\alpha = \frac{4(1-\varepsilon)}{\varepsilon \cdot d} k \sqrt{f} \tag{9}$$

having designated

$$B = \frac{4k(1-\varepsilon)}{\varepsilon} \sqrt{f} \tag{10}$$

let's receive

$$\alpha = \frac{B}{d}, \tag{11}$$

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By replacing in formula (2) the sound vibration pressure on the device output signal proportional to it, we have the following expression

$$U=U_0\, e^{-al}\ , \qquad (12)$$

By substituting in formula (12) the expression (11) for the attenuation factor and prologarithm the resulting expression

$$\mathbf{Ln\,U} = LnU_0 - \frac{B \cdot l}{d} \qquad (13)$$

Given the assumptions taken in the inference of formula (10), it can be assumed that there must be a linear regression between the logarithm of the output of the instrument and the diameter of the wool fiber.

$$\mathbf{LnU} = A_0 - \frac{A_1}{d} \qquad (14)$$

here $A_o = LnUo$, $A_1 = Bl$.

In order to study the dependence of the output signal of the PAM-1 device on the wool diameter, experimental studies were carried out on 14 samples of wool fibres of different diameter and origin. The tests were carried out according to the following procedure: 2 samples weighing 10 grams were taken from each sample, which were previously dissolved manually and flattened. Samples were placed in the measuring chamber of the instrument and the value of the output signal was determined, then the sample was re-measured without being taken out. A second sample of the first sample was then tested in a similar pore. The average value of four-fold measurements was taken as the measurement result. The remaining wool fiber samples were measured in a similar order. Then, diameters were determined using a microscope with an ocular nozzle according to the standard method according to the interstate standard GOST 17514-93. The test results are shown in Table 2.

Table 2. Results of experimental studies on the influence of the diameter of six on the readings of the instrument PAM-1

№	Name of wool fibre rocks	PAM-1 instrument readings, mV					Average diameter as per GOST 17514-93, micron
		I-1 option	I-2 option	II-1option	II-2 Option	Average value	
1	Goat rough	1703	1700	1698	1698	1699,75	43,7
2	Goat thin	1146	1146	1155	1155	1150,5	29,6
3	Goat hair 3selection	1155	1155	1155	1155	1155	30
4	Goat hair 4selection	1554	1554	1473	1473	1513,4	38,9
5	Goat hair 5 selection	1771	1769	1739	1737	1754	45
6	Camel's wool 1 selection	926	926	943	943	934,5	24
7	Camel's wool 2 selection	979	979	948	948	963,5	25
8	Camel's wool 3 selection	1620	1620	1620	1620	1620	42
9	Camel's wool 4 selection	1028	1028	972	972	1000	25,7
10	Sheep wool light 1 selection	1385	1385	1366	1366	1375,5	35,3
11	Sheep wool light 2 selection	1253	1253	1229	1226	1240	31,8
12	Sheep wool light 3 selection	1407	1407	1419	1419	1413	36,3
13	Sheep wool black 1 selection	1221	1221	1246	1246	1233,5	31,7
14	Sheep wool black 2 selection	1136	1133	1143	1140	1138	29,2

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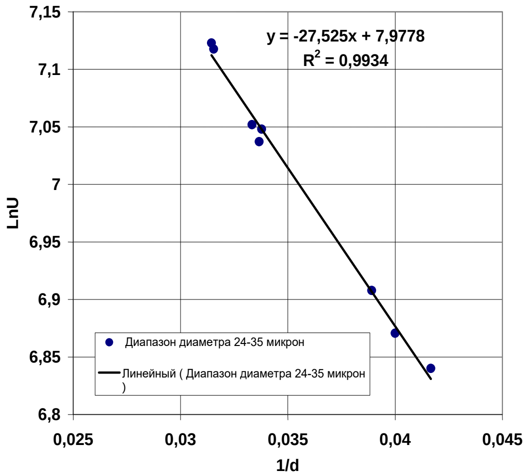
IV. CONCLUSION

Using the experimental data by the method of regression analysis, we constructed the regression calibration dependences of the output signal of the PAM-1 device on the diameter of the wool fibers, which are presented graphically and by regression equations below. Figure 4 shows a graph of the calibration dependence for the range of wool diameters of 24-35 microns.



$$\ln U = 7.9778 - 27.525 / d,\ R^2 = 0.9934, \quad (15)$$

Figure 5 shows a graph of the dependence of the output signal of the acoustic instrument PAM-1 on the wool tone in the 35-45 micron diameter range.

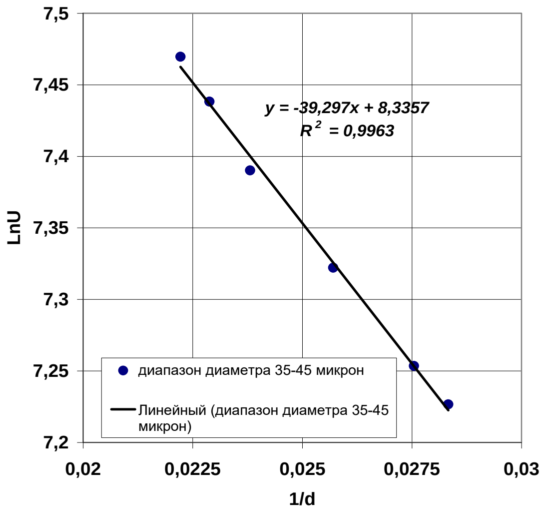


Fig.5 Graph of dependence of output signal of ПАМ-1 acoustic priory on wool tone in 35-45 micron diameter range.

The regression equation for this range is as follows:

$$\ln U = 8.3357 - 39.297 / d,\ R^2 = 0.9963, \quad (16)$$

From the results of the studies it follows that between the output signal and the diameter of the wool fibre on a logarithmic scale there is a linear regression dependence with an approximation factor of more than 0.99, which is

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consistent with theoretical conclusions. This shows the promise of using an acoustic instrument to measure the diameter of wool.

Based on the results of the experiment planning, the following conclusions can be drawn:

- the sound impulse of the samples increases with increasing diameter, mass and humidity in the selected ranges of variation;
- comparison of regression coefficients with the corresponding factors shows that the greatest influence in the conducted experiments is the diameter of the woolen fiber.

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