Methodology for designing the pressure characteristics of the cutting-separating unit of the flax harvester

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Abstract. The paper considers the features of the innovative design and gas dynamics of the flow in the flow path of the cutting-separating turbine unit of the flax combine. On the basis of the combine tests, the possibility of using a turbine unit to ensure a stable movement of the working mixture in the pneumatic transport system of the combine was considered. To provide the necessary pressure characteristics, a method for designing a flow path is proposed on the basis of the hypothesis of the analogy of the action on the flow of a set of cutting sets with a centrifugal compressor blade. Stodola for turbomachines and calculation of ideal gas flow on the axisymmetric surface of the interscapular channel

1. Introduction
For several years, through the joint efforts of the Vyazemsky Machine-Building Plant, the All-Russian Research Institute for Mechanization of Bast Crops and the Smolensk State Agricultural Academy, an innovative design of a flax-harvester for the primary processing of flax-straw in the field was developed [1-3]. The prototypes of the flax harvester were manufactured and passed field tests, which confirmed the efficiency of the structure and determined the directions for improving the laid down technological solutions.

The main element of the proposed design is the cutting-separating unit, which separates the flax fibers, crushes the fire and ensures the movement of the bone fiber mixture along the pneumatic transport system of the combine. The general view of the unit is shown in figure 1.

Linseed straw enters through the suction pipe in the cutting - separating impeller, where the fibers are mechanically separated from the wood of the stems and the wood itself is chopped into separate pieces and the bone fiber mixture is mixed with air. The impeller moves the bone fiber fluffed mass further along the collection chamber and the pressure air duct of the pneumatic conveying system.

Figure 2 schematically shows a general view of the impeller of the cutting-separating unit, which consists of the main disk of the impeller 2, on which a set of cutting sets 1 is installed along the radius. A cone-shaped fairing 4 is installed in the center of the main disk 4. The impeller is driven through shaft 3 (figure 2).

Cutting - the separating device for separating fibers and fires is a power part of the pneumatic transport system, consisting of a suction pipeline with an inlet into the device itself and an outlet injection pipeline of rectangular cross section, through which the fiber mixture is transferred for further processing. The design of the pneumatic transport system provides for the possibility of a relatively simple transfer from the stationary mode of use to the transport position due to the
disassembly of the vertical and horizontal section of the injection part, which makes it possible to fold the indicated elements protruding beyond the dimensions of the vehicle.

![General view of the cutting-separating turbine unit.](image1)

**Figure 1.** General view of the cutting-separating turbine unit.

![Impeller of the cutting and separating unit.](image2)

**Figure 2.** Impeller of the cutting and separating unit.

The calculation of the pneumatic transport system is carried out in order to determine the geometric dimensions of pipelines, as well as to determine the pressure characteristics of devices that ensure reliable transport of the bone fiber mixture.

2. Materials and methods
To assess the energy characteristics of the pneumatic conveying system, it is necessary to determine the optimal ratio of the air velocity in different sections of the flow path, pressure losses on vertical and horizontal straight and curved sections and local hydraulic resistance, i.e. determine the pressure characteristic of the pneumatic conveying network. This will allow you to calculate or select the pressure characteristic of the blower and calculate the operating point of the installation.

Cargo-air three-dimensional flow is a three-component medium: a mixture of solid particles of fire, flax fibers and air.
Let us note some features of the flow that allow us to determine the calculation algorithm. When calculating gas-dynamic characteristics, the compressibility of air can be neglected due to the relatively low speeds of motion (Mach criterion $M < 0.3$). Thus, all relations for the flow of an incompressible medium can be applied. There are no phase transitions between the components in the mixture. The pneumatic transport system is considered adiabatic.

The theoretical calculation of the movement of a three-component (flax fibers, pieces of fire and air) mixture is an independent problem in terms of difficulty. But relying on the rich experimental and theoretical experience of research of pneumatic transport in the woodworking industry and other industries [4-5], it is relatively easy to build an algorithm for calculating the pressure characteristics of the network for the transport of fiber air mixture in a flax harvester.

During the experimental tests of the mobile flax-processor for the primary processing of flax, it was noted that the cutting-separating unit, in addition to the main technological function - separating flax fiber and chopping fires, also has pressure properties. This determined one of the directions of this research - the study of the possibility of using the cutting-separating unit as a pumping unit. Obviously, for a mobile block-modular plant for flax processing, such an opportunity would certainly be attractive, because this greatly simplifies the technological scheme and reduces the overall dimensions of the entire installation.

3. Results
The hypothesis put forward above about the analogy of the set of cutting sets with a solid blade of a radial compressor makes it possible to evaluate the injection properties of the cutting-separating unit, using a sufficiently developed theory of turbomachines and calculating a two-dimensional flow on the axial-radial flow surface in the inter-blade channels of the flow path [6-7].

Within the framework of this work, we believe that the pressure characteristic of the pneumatic transport network is available, which allows for a given flow rate $Q$ to find the required pressure value $h_T$ that provides reliable (without the formation of stagnant zones) movement of the fiber mixture. Thus, the solution is reduced to calculating the pressure characteristic of the cutting-separating unit and determining its operating point.

According to the theory of turbomachines, the specific flow energy transferred $h_T$ from the impeller to the flow of the transported medium is determined by the Euler equation:

$$h_T = C_{U2}U_2 - C_{U1}U_1$$

(1)

Where $C_{U2}$ and $C_{U1}$ are the projections of the absolute speed on the circumferential direction at the outlet and inlet to the impeller, respectively;

$U_2$ and $U_1$ - peripheral speeds at the outlet and inlet to the impeller, respectively.

In the designed cutting-separating unit, the installation of an inlet guide vane is not assumed, thus, the absolute movement at the inlet to the impeller has a radial direction, i.e. $C_{U1} = 0$. In this case, the head will be determined by the following ratio:

$$h_T = C_{U2}U_2$$

(2)

Based on this ratio, in an enlarged form, the sequence of designing the cutting-separating unit for the given pressure and flow parameters can be represented as follows:

- The consumption of the fiber mixture in the flowing part of the cutting and separating unit is determined by the projected capacity of the combine. Obviously, it is also necessary to set the dimensions and select the drive. The main dimension that determines the dimensions of the structure is the diameter of the main disc of the impeller $d_2 = 2r_2$;
- The diameter and number of revolutions of the drive determine the peripheral speed at the outlet of the impeller $U_2 = \omega r_2 = 2\pi n r_2$;
• The pressure calculates \( h_T \), determined when calculating the pneumatic transport system, and the value of the peripheral speed \( U_2 \) from the Euler equation (2), the value of the pressure component of the absolute speed at the outlet of the impeller \( C_{U2} \).

• The consumption component of the absolute speed at the exit from the impeller is determined based on the specified performance of the combine:

\[
Q = C_{r2} 2\pi r_2 b_2 \tau_2
\]  

(3)

Where: \( b_2 \) - blade height and \( \tau_2 \) - coefficient of flow restriction by the blades at the outlet of the impeller.

• The found values of velocities \( (U_2, C_{r2}, C_{u2}) \) make it possible to construct a parallelogram of velocities on the radius \( r_2 \) and, accordingly, to calculate the pressure characteristic of the supercharger.

• Determination of the blade angle at the outlet of the impeller \( \beta_{l2} \) requires calculation of the flow in the interscapular channel. In the general case, for this it is necessary to jointly solve the equations of motion, energy, continuity and state for a viscous, unsteady compressible flow of a three-component medium. Such a solution in a strict formulation is currently impossible to implement. Therefore, various assumptions are used, ranging from the one-dimensional jet theory to the three-dimensional formulation of the problem.

In the case of an infinite number of blades, the flow exit angle \( \beta_2 \) is equal to the blade angle \( \beta_{l2} \). In real machines, a relatively small number of blades are installed, therefore, the flow exit angle is always less than the blade installation angle, which significantly reduces the head developed by the impeller. Therefore, it is necessary to find a relationship between the angle of flow and the angle of the blade. The study of this issue has been and is still receiving close attention of numerous researchers of turbomachines.

When using certain assumptions A. Stodola, K. Pfleiderer, B. Eck, K. Strahovich [6-7] obtained a number of calculated relations. The most physically justified formula of A. Stodol, which is used in the calculation algorithm:

\[
\psi_T = 1 - \frac{\pi}{z} \sin \beta_{l2} - \varphi_2 \cot \beta_{l2}
\]  

(4)

Where \( \psi_T \) is the pressure coefficient, defined as the ratio of the pressure component of the absolute speed to the peripheral speed at the outlet of the impeller;

\( \varphi_2 \) - the coefficient of consumption, defined as the ratio of the consumption component of the absolute speed to the peripheral speed at the outlet of the impeller.

• The angle of installation of the cutting attachments at the inlet (angle of the blade) into the cutting-grinding device \( \beta_{l1} \) is determined by the design of the suction section. In the absence of a guide vane \( \beta_{l1} \) it is 900.

• The values of the angles of installation of the blade at the inlet \( \beta_{l2} \) and outlet and the structural dimensions of the impeller determined in this way make it possible to calculate the center line of the blade, which provides a given head of the impeller.

4. Discussion

The considered algorithm is the first approximation to the real processes occurring in the impeller of the cutting-separating unit. To take into account the influence of secondary flows in the gaps between the cutting sets and, accordingly, the influence of these flows on the angle of flow out of the impeller, it is necessary to calculate the relative motion of the mixture in the interscapular channels. The method for calculating the plane flow of an ideal gas on an axisymmetric current surface is given in [4-5].

The complex nature of gas movement in the flow path of the cutting-separating unit, a combination of diffuser and confusor flows, rotating and stationary elements in the flow path, energy supply to the
gas by a set of impeller cutting sets, shock waves and flow separations create significant difficulties in modeling the ongoing gas-dynamic processes and calculation of flow parameters.

The creation of an adequate and physically grounded mathematical model for calculating the flow assumes a step-by-step way of solving this problem - the sequential formulation of a one-dimensional, two-dimensional and spatial model. This, in turn, leads to the need to conduct, analyze and generalize a large number of options for computational and experimental studies. As well as the use of appropriate mathematical approaches to solving the resulting systems of equations, which allow achieving good accuracy, speed and reliability of convergence required for practically used computer programs.

The calculation of the gas dynamics of the flow will make it possible to develop algorithms for optimizing the flow path of the cutting and separating unit of the flax harvester to determine the geometry with the maximum efficiency for the required pressure and flow rates, taking into account possible overall restrictions to ensure the mobility of the flax harvester.

The analogy of gas-dynamic processes in the flow path of the cutting-separating unit of a flax combine and the flow path of turbo machines allows us to hope that the use of commercial CFD packages will provide the necessary apparatus for practical application in subsonic flows in radial turbo machines. The presence of secondary flows in the gaps between the cutting garurs forming the impeller blade leads to the need to develop our own CFD code SINF / Flag-S.

Large problems with the reliability of the results of CFD calculations include in the rotating elements of the cutting-separating unit, in which energy is supplied to the gas, therefore CFD calculations include only a part of the research package using several primary calculations, one-dimensional, two-dimensional and quasi-three-dimensional calculations. You also need the ability to access the settlement codes of the CFD program in order to correct it during identification. This allows you to create your own CFD code SINF / Flag-S.

The complex problem to be solved caused the need to create complex digital design methods, including preliminary design methods, one-dimensional and software design methods implemented in engineering techniques, CFD calculations, a program for the design of the unit and visualization of blade grids of the elements of the cutting-separating device, programs for creating a model for creating a 3D models of the designed turbine unit and meshing for CFD calculations.

The spatial nature and the presence of multiply connected secondary flows determine the need to use large computing power (the amount of RAM, the number and clock frequency of processor cores, etc.), which cannot be obtained on computers. To achieve these goals, it is necessary to use the computing power of supercomputer programs, which have at their disposal all the necessary computing power, computer programs, special equipment, and experience with computing systems for CFD calculations [8–19].

5. Conclusion
Based on a number of assumptions about the physics of gas-dynamic processes occurring in the flow path of the cutting-separating unit, and using the theory of turbo machines, an engineering algorithm for the optimal design of an innovative design of a pneumatic transport system for a flax combine is proposed. A distinctive feature of the proposed design is the combination of various functions in one device: separation of flax fibers, cutting a fire and ensuring the movement of the fiber-fire mixture along the pneumatic transport system of the combine.

Acknowledgments
В данном разделе можно указать название гранта или источника финансирования (необязательный раздел).

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