THE ROLE OF THE PHYSICAL PROPERTIES OF SEEDS IN THE DESIGN OF HULLERS

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A b s t r a c t The paper presents a method for the design of hullers and describes the significance of the morphological features of seeds in the development of a concept of the way of seed hulling, as well as the role of the physical properties of seeds in the design of the working elements of hulling machines. It has been found that in rational design of hulling machines their parameters should be chosen on the basis of simulation studies performed by means of mathematical models. A mathematical model should combine into relationships the design and operational parameters of the huller designed, as well as the physical properties of the seeds to be hulled.

K e y w o r d s: seeds, physical properties, huller, design, methodology

INTRODUCTION

The seeds of many plant species used in food processing are subjected to hulling the objective of which is the preparation of the plant material for processing for food or fodder. Seeds vary in their morphological and physical features, and therefore the design of hulling machines and their principles of operation are also varied [3,7,9].

For the husking of a large number of seeds, e.g., lupines, rape, pumpkin, peanuts, etc., there are either no hulling machines at all, or the existing ones require modernisation, or modification of the design of their working elements in order to improve the capacity and the effectiveness of the hulling process. Agricultural and food processing machines are often designed and built without sufficient prior knowledge of the physical properties of the plant materials to be processed by the machines [1,2,6,8,10]. Hulling machines are no exception here - they are frequently designed on the basis of intuitive criteria or of ones resulting from engineering traditions. Before rational work can be undertaken on the design of hulling machines, it is first necessary to study the process of hulling, taking into consideration both the morphological and the physical features of the seeds to be hulled [6].

The objective of the study presented herein was to show the importance of the knowledge of the physical properties of seeds in the process of rational design of hulling machines.

MAIN PARAMETERS

The seeds subjected to the hulling process must be suitably prepared first so that their physical properties meet the requirements of the process. For example, seed moisture content should be at such a level that their rheological status is close to that of brittle or

elastic-brittle materials. The physical properties of the material may affect the process. Therefore, knowledge of the values of the physical properties of seeds before and during the process is necessary in the rational design of hulling machines.

As follows from the abbreviated algorithm for the design of the huller (Fig. 1), the critical phase, affecting all the further stages of the design process, is the development of a concept and the selection of the optimum concept which will ensure efficiency of the hulling process. If the concept under development is erroneous, no efficiency of the hulling process can be expected, even if the solution are food in itself. The type of criteria adopted and the method of their to value will determine the choice of the design solution which in turn will determine the effect of the operation of the huller designed.

At the initial phase of huller design an analysis is performed which provides the basis for the development of the design criteria. The

basic guidelines for the development of the design criteria for a new huller are presented in Fig. 2. It is very important to make sure that the design criteria provide information on the requirements concerning the effective output of the huller, its efficiency, and the energy consumption of the hulling process. It should be pointed out that these parameters are affected by the moisture content of the seeds to be hulled, and by the moisture-related physical properties of the seeds.

At the stage of concept development it is necessary to pay attention to the morphological features of the seeds to be hulled, as the working elements of the machine will come into direct contact with the seeds. It is, therefore, necessary to find out whether the seed cover is actually connected with the seed leaf or the endosperm or only encapsulates them. Analysis of this particular morphological feature of the seeds to be hulled will provide the basis for the decision concerning the method of removing the seed cover. The decision consists
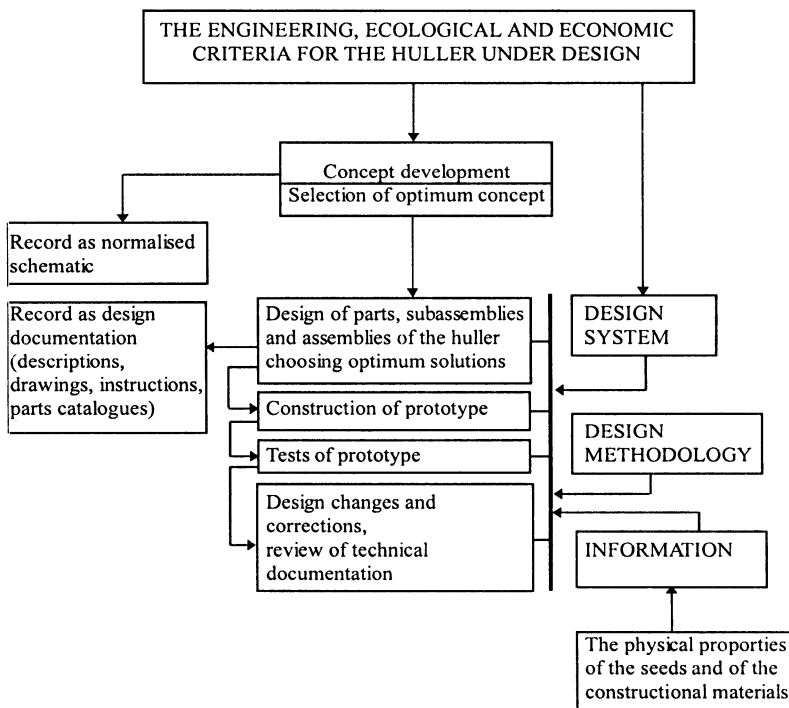

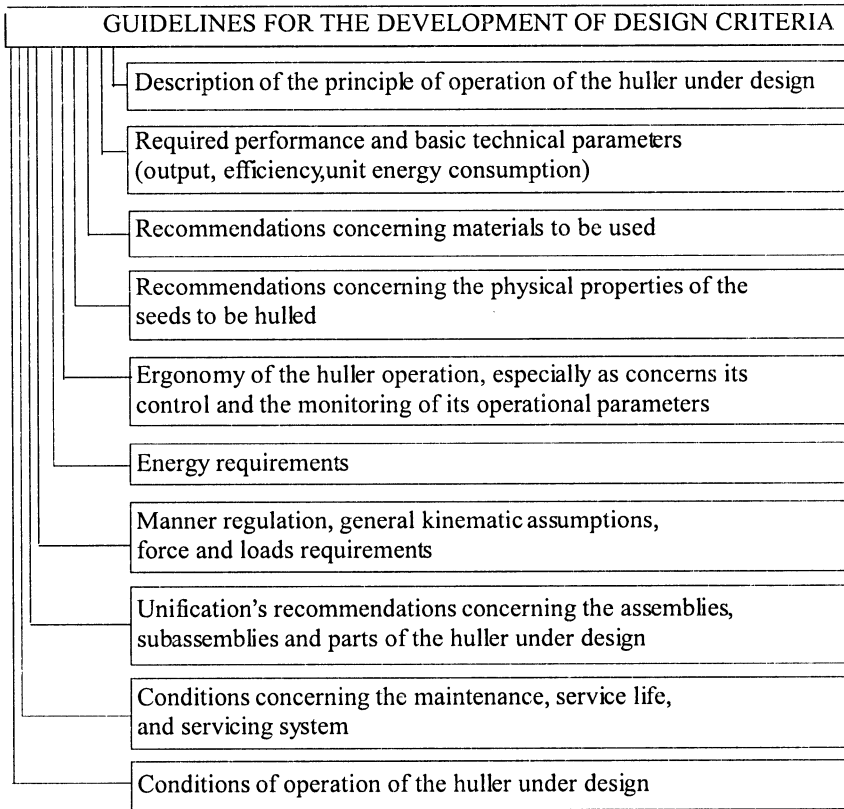Fig. 1. Abbreviated algorithm for the design of the huller.

GUIDELINES FOR THE DEVELOPMENT OF DESIGN CRITERIA
Description of the principle of operation of the huller under design
Required performance and basic technical parameters (output, efficiency,unit energy consumption)
Recommendations concerning materials to be used
Recommendations concerning the physical properties of the seeds to be hulled
Ergonomy of the huller operation, especially as concerns its control and the monitoring of its operational parameters
Energy requirements
Manner regulation, general kinematic assumptions, force and loads requirements
Unification's recommendations concerning the assemblies, subassemblies and parts of the huller under design
Conditions concerning the maintenance, service life, and servicing system
Conditions of operation of the huller under design

Fig. 2. Principal guidelines for the development of the design criteria for a huller.

in choosing between breaking the seed cover off the seed, abrading it away in layers, and the removal of its fragments from crumbled seeds. The principle of operation can be reflected as a succession of working elements (Table 1, Fig. 3). In the development of the concept of a huller the following methods can be useful: iterative, analysis of known design solutions, morphological box, dialogue, brainstorm.
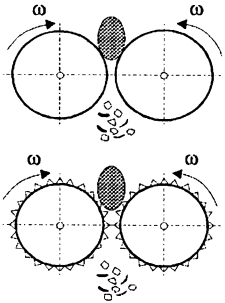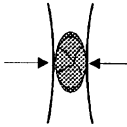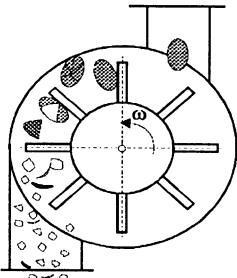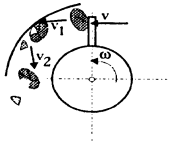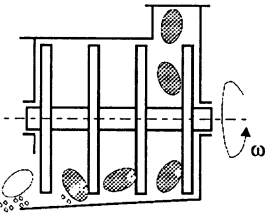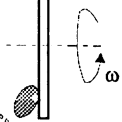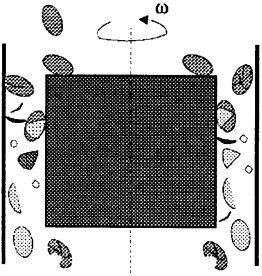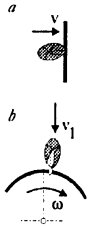
To be effective, the hulling process need at that stage simulation studies should be conducted, based on a mathematical model describing the hulling process. A well designed and verified mathematical model includes convenient physical properties of the seeds to be hulled.

Physical properties of the seeds can be exponed of as histograms, mean values with regression equations, etc. At the current state of knowledge, the numerical values of the value of a given physical property are determined experimentally. It should be kept in mind that every measurement is burdened with an error which is the difference between the measured and the true values. Neither the error nor the true value are known to the researcher, therefore, in the analysis of results, limit or maximum error levels have to be included. The determination of the values of physical properties through experimental methods as well as mathematical description of their manifestation have to describe their status only in a simplified and approximate manner. The problem is closely related to the accuracy of mathematical modelling of the process. A block diagram of the mathematical model is presented in Fig. 4.

The mathematical model is a theoretical description of the behaviour of a physical model. It permits to connect the input values to the output values by means of mathematical equations (due to shortage of space, as presented in Fig. 4 in a discrete form). As a result of introduction into the model of idealised

T a b l e 1. Development example of a concept for the design of a hulling machine taking with consideration to the physical properties of the seeds

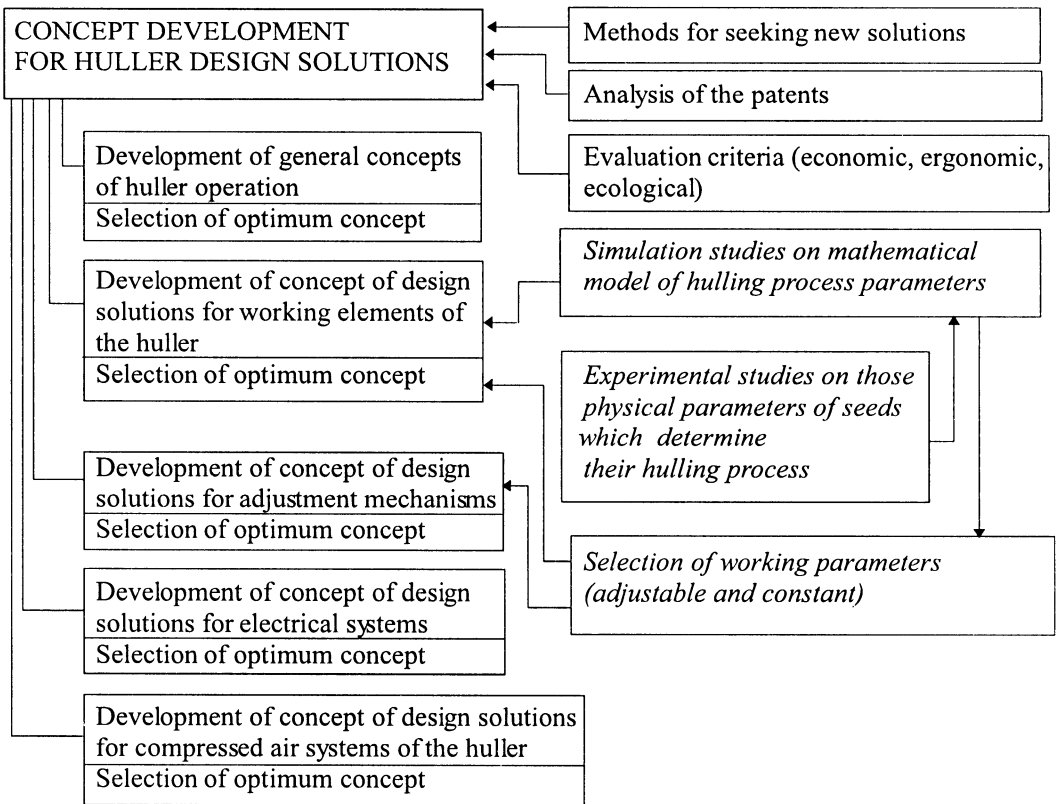| Function of working element of huller	Motion type of the working element of the machine designed	Significant physical properties of the seeds process according to	Effect of the working element
Reduction of brittle seed into small parts		Compressive strength, mass (weight), shape	Parts of seed leaf, irregular in shape
			Parts of the hull
			Dust
			(GRITS)
Reduction of brittle seed into small parts		Impact energy, mass (weight) coefficient of restitution, modulus of elasticity	Parts of seed leaf, irregular in shape
			Parts of the hull
			Dust
			(MIDDLINGS)
Removal of surface layer of the seed		Abrasive resistance, mass (weight), shape, friction coefficient	Seed leaves
			Parts of the hull
			Dust
Removal of surface layer of the seed			Seed leaves
			Parts of the hull
			Dust
		a) Impact energy, mass (weight), shape, coefficient of restitution *b)* Force required to break off a piece of the hull	

Fig. 3. Algorithm of the development of concept of design solutions for hullers.

process conditions on the one hand and values of physical properties of hulled seeds burdened with measurement error on the other, the mathematical model approximates the process of hulling with relation to the true process. The geometrical features of the seeds can be used as an example here such as length, width and thickness, since existnig methods do not permit a complete difinition of seed size. In reality the shape of seeds, and thus also their dimensions, are unique. The researcher has to use far-reaching simplifications in describing the values of those properties.

The true process of seed hulling needs the use of a unique value for a given physical properties. It is very difficult to find two identical seeds even in a batch of seeds of the same species and variety. In spite of the limitations, the design engineer employing the rational approach to the design of a hulling machine should select the working parameters of the

huller designed on the basis of the mathematical model. Such an approach limits the need to build many expensive prototypes, and thus limits the effect of the trial-and-error method on the designing process.

Simulation studies using a mathematical model which takes into account the physical properties of the seeds allow us the determination of the relations between the seeds and the working elements of the huller. The properties determining the process of hulling are the following: the basic dimensions of the seeds, the orthogonal projections of their surfaces, the proper weight, the seed bulk porosity, the internal friction coefficient, the coefficient of kinetic energy restitution, the required force causing the breaking off of the seed cover, abrasive resistance of the seeds. Moreover, the knowledge of the seed compressive strength, impact energy, hardness of the seed cover and seed leaves, will contribute to optimisation of

Xw, Xs, XJ
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Type of working element,
Geometrical parameters of
working element,
Kinematic parameter of
working element,
Width of working slot,
Species and variety of seeds,
Seed moisture content,
Substitute diameter of seeds,
Orthogonal projection of
seed surface,
Specific weight of seeds,
Bulk porosity of seeds,
Coefficient of kinematic
energy restitution of seeds,
Coefficient of seed-working
element external friction,
Seed impact energy,
Force causing breaking off
of hull fragments,
Abrasive resistance of anatomical
parts of seeds,
Rate of lifting of anatomical
parts of seeds,
Height of seed drop above the
inlet to the working space

WORKING SPACE
OF THE HULLER
_____

Mathematical models
describing the output,
efficiency and unit
energy consumption in
seed hulling process
_____

$f_w(X_w) + e$
$f_s(X_s) + e$
$f_J(X_J) + e$

Wt, St, Jt
_____

Output, efficiency,
unit consumption of
energy in seed hulling
process

e

Factors interfering with seed hulling
process (vibration of grinder and casing,
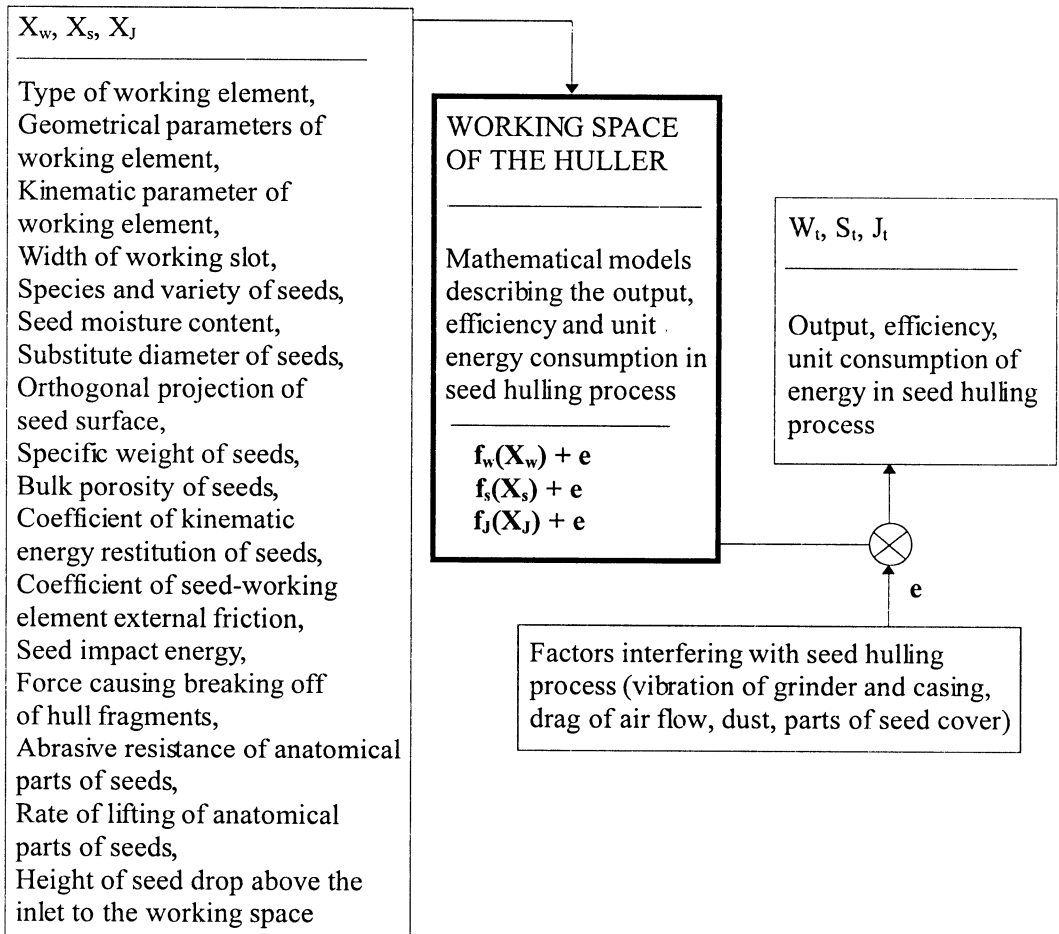drag of air flow, dust, parts of seed cover)

Fig. 4. Schematic presentation of the mathematical model of a seed hulling machine.

the moisture content of the seeds. Their knowledge permits the determination of the optimum kinematic parameters of seeds in the working space of the huller. The speed at which seeds get in contact with the working elements of the huller is the basic parameter for the determination of the output, efficiency and unit consumption of energy. The value of the convection velocity the parts of the hulls and cotyledons is the basis for the determination of the parameters of air flow in the separator assembly of the huller.

Using the method described above, the design of a huller for broad bean seeds has been developed at the Olsztyn centre (Fig. 5). In the huller, the process is realised through multiple impacts of seeds against the working elements, which results in the cracking of the hulls, followed by breaking off of its fragments and removal from the cotyledons of the remainder of the hulls. Such a way of hulling was possible because the hull was not adhering to the cotyledons. The layer of palisade cells of the hull pay an important role. In that layer the cells are strongly elongated, fibre-like, and adhere closely to one another. When external compressive loads are applied to the hull, cracks will appear along the fibres. The choice of such a design solution according to the structure of the hull, will limit to a minimum the abrasion of the hull and the cotyledons in the process of hulling [6]. The huller consists of a tubular, cylindrical part, to which the upper cover with the seed tank is attached [4]. The
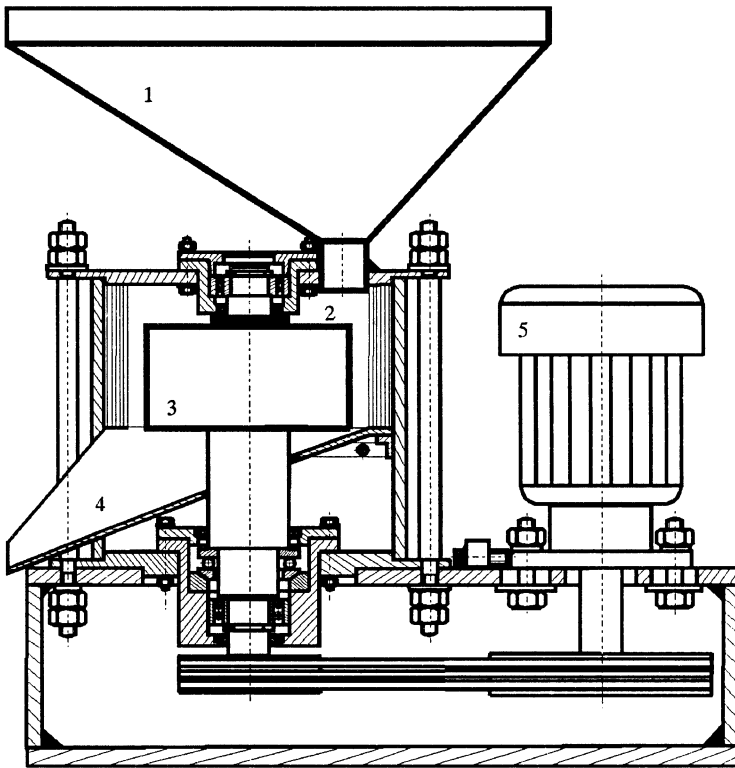
Fig. 5. Section of a broad bean huller designed by the author [4]: 1 - seed tank, 2 - tubular inserts, 3 - grinders, 4 - chute, 5 - electric motor.

lower part of the housing is supported on the cover in the base. The upper cover and the base house bearings support a shaft with a cylindrical grinder block, beneath which the chute is located. Electric motor fastens the base provides drive for the shaft. Tubular inserts between the housing and the grinder block provide adjustment of the working slot width. Broad bean seeds from the seed tank fall onto the upper surface of the rotating grinder, then move within the working space of the huller in to which the process of hulling is realised. The resultnig mixture of cotyledons and hulls fragments flows down outside the machine. A separator, which uses aerodynamic features of the component parts of the mixture, realises the process of separating the hulls and dust from the cotyledons.

Another huller design (Fig. 6) realises the process of hulling on the basis of the same principle. The working assembly of the huller is different here [5]. The conical working ele-ment and the conical casing permit easier working slot width adjustment than in the former design. The conical head need not necessarily be the grinder. Its working surface can be used to install cutting edges, the size of which depends on the position of the centre of gravity of the seeds hulled. The separator assembly permits the separation of the hull from the cotyledons. In the process of separation the decisive role is that of the aerodynamic features of cotyledons and their fragments, and those of the hull and its fragments.

Figure 7 presents a schematic of a huller for small seeds, especially for rape seeds. The main working element here is the disc. On the working surface of the disc cutting edges are radially mounted; the height of the cutting edges has been selected taking into consideration the diameter of rape seeds [11]. Studies on the design of this particular huller are still under way at the Olsztyn and Płock research centres.
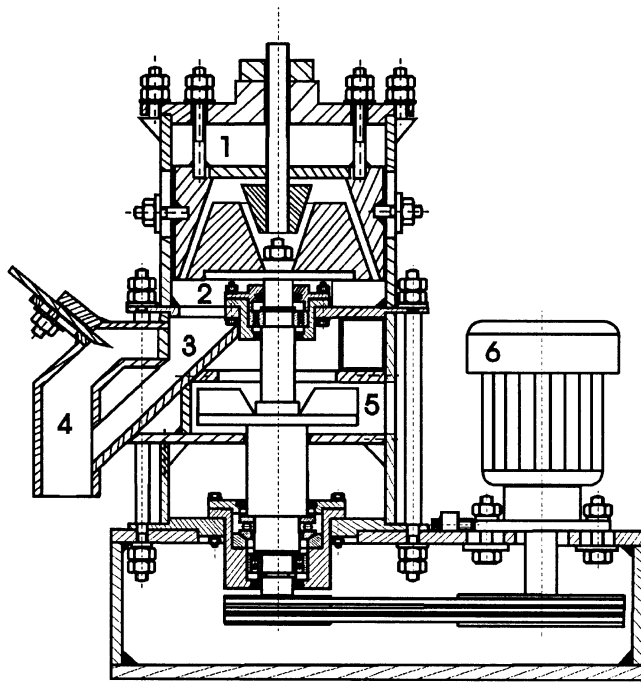
Fig. 6. Section of a huller designed by the author [5]: 1 - conical casing, 2 - conical head, 3 - chute, 4 - seed inlet duct, 5 - fan rotor, 6 - electric motor.
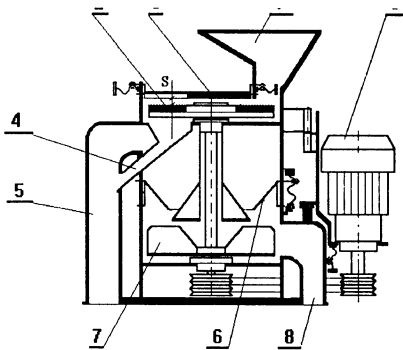

Fig. 7. Schematic of a huller for rape seeds [11]: 1-charging chute, 2-disc with cutting edges, 3-upper cover, 4-chute, 5-vertical suction duct, 6-shutter, 7-fan, 8-outlet duct, 9-electric motor.

physical phenomena occurring in the course of the hulling process.

The values of the physical properties of seeds must be considered in connection with the design and kinematic parameters of the huller.

Connectnig the values of physical properties with the other parameters of the process can be ensured by a properly developed mathematical model which provides a basis for simulation studies.

The morphological and physical status of the seeds determines the geometrical and the working parameters of the assemblies of the hullers designed.

CONCLUSIONS

In the design of hulling machines, it is important to properly utilise and relate to one another the physical properties of both the construction materials and the seeds to be hulled, and to create accurate descriptions of

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