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RHEOLOGICAL PROPERTIES OF CEREALS AND THEIR THEORETICAL INTERPRETATION

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Mohsenin defines rheology as a science describing the influence of time on the behaviour of bodies subjected to stresses. Such a definition seems to be sufficient in the cases that are subject to the present considerations.

Although investigations of the rheological properties of plant materials, and cereals in particular, have been carried out for several years. I think it necessary to stop for a while for a discussion of the reasons of all the interest taken in this problem. It is not so obvious as in the case of fruit or potatoes where the main object is to find such working speeds of mechanisms used for harvesting and storage and to establish such conditions of storing so as to lower to minimum the losses resulting from the damages of material.

In the case of cereals the problem of grain damages has a different character, particularly at greater ripeness, and from the point of technology of processing the influence of the conditions of harvesting does not seem to have any greater importance. It is a little different in the case of straw damages, particularly if the straw is to be bricketed. However it seems to be beyond doubt that the main reason for investigating the rheological properties of cereals is the tendency to optimize the construction of machines, and first of all to reduce the weight of machines moving upon the surface of fields, that is combined harvesters, straw presses and green fodder cutters. The necessity of reducing the weight is caused by many factors, among others by the rapidly rising price of such machines. Still, one of the most important reasons is the destructive influence on soil of the exceedingly loaded wheels of the machines, which causes losses in crop yields for many years.

What should be strongly stressed is the heuristic character of the hitherto applied methods of construction of the mentioned machines, which resembles attempts at building an airplane without the knowledge of the principles of aerodynamics. Hence it is possible to pose the thesis that a rational optimization of machines whose task is the processing of cereals will not be possible without a precise determination of the mechanical characteristic of the material that is to be processed by them. One can still often hear opinions that these are problems invented by researchers, but of slight significance for practicing constructors of machines and for devisers of technological processes.

To what extent this view is false can be proved by a statement of a representative of one of greatest in the world concerns producing agricultural machines — John Deere, Jay B. Agness stated during a conference devoted the application of investigations of the mechanical properties of materials of agricultural origin, which took place a year ago:

"At the designing and evaluation of our machines we often need information about the mechanical properties", and then "only too often the need is not apparent till a critical situation arises and a construction cannot wait any longer for a detailed analysis".

This is the most decided opinion that I managed to read on the subject, and it comes from the mouth of a representative of a technologically developed industry. And, although not so sharp in their formulation, similar statements can be found in Russian and Czech publications.

The notion "rheological properties of cereal plants" to be found in the title of my paper is in fact so imprecise that it recquires a wide commentary. Once again I will quote a fragment of the statement of the above mentioned J. B. Agness: "Properties of green fodder are rather well determined for a single stalk but this is never of any use to the constructor, since green fodder is always processed in mass". In the case of cereals the situation is not so extreme, but even more complex, since the properties of a single stalk are equally important as the mean values for mass.

Taking the needs of the constructor as the starting point we should stress strongly the problem of the necessity of non-deterministic treatment of information about the rheological properties. Contrary to the so-called classical branches of machine construction, where loadings can be treated as determined, in the construction of agricultural machines we deal with material whose properties can be described solely by the parameters of the statistical distribution. Attempts at constructing "just in case" with the consideration of the most unfavourable loadings unavoidably lead to constructions of monstrous dimentions and working parameters that cannot be accepted in practice. A modern way of machine designing, taking into consideration the optimization of the working parameters, durability, wear and reliability, must be based on stochastic methods, which should be complemented by investigations of parameters characterizing materials being the object of processing.

The interest that the Polish scientists and constructors take in investigating the rheological properties of agricultural raw materials is obvious. On the one hand Poland is one of the greatest in Europe producers of agricultural raw materials. The particularly favourable conditions of agricultural production in Poland — large area of agricultural lands and their favourable situation encourage the expectation that the contribution of Poland in the agricultural production of the world will continue to grow. Thus it is necessary to increase efforts to breed new varieties of cereals that would be an easy object for mechanized technologies. And because of this we should precisely define the properties that decide about this aspect of the varieties, and determine the values of the appropriate properties that are to be obtained.

Poland is also a producer of combined harvesters for harvesting cereals and green fodder, that becomes more and more important in the world market; a producer who must take constant care that its products are up to date. Hence again the interest in the results of our investigations.

It remains to answer one more question — is it necessary to conduct own investigations, is it not enough to keep in touch with the current level of knowledge obtained by the great research teams in other countries, mainly in the USA and the USSR. And the answer seems to be rather obvious. It is necessary to conduct own investigations since the variability resulting from the physiographical differences and from the different conditions of cultivation is so great, that exact information can be obtained only on the basis of own investigations carried out parallelly to the process of breeding and to the determination of the technological detailes of the cultivation of a given variety.

There are also many important arguments for the development of theoretical and methodological investigations. In spite of the advanced level of these investigations in other countries, it is stall a long way to a final solution of the problem. The object is so complex, and the so far proposed models so simplified, that the scope of the theoretical considerations seems limitless. Similarly the far from perfect measurement methods encourage the creative activity of teams that do not have a very sophisticated equipement at their disposal, as can be exaplified by the workings of the Lublin team.

Let us get back to the definition of the "rheological properties of cereals". It is impossible to define what is understood by the term "cereal" as an investigation object for rheology.

Rheology principally operates with certain mechanical models of the investigated media. Thus it is necessary to make such divisions that will allow for the creation of models describing the investigated body with a pre-assumed exactness. A few words should be said about the notion of time and its role in the formation of the models of agricultural raw materials, since here we are dealing with a metamorphic material, the physical properties of which change in time, and in time changes the model simulating its behaviour. This is a quite unusual situation in the case of materials used in industry, where a rheological model is considered to be a constant attribute of a given material. It is easy to show that such reasoning is completely useless in the case of modelling the plant materials. Investigations of Bogusław Szot and Janusz Haman on the resistance of the grain-to-ear bond in cereals proved that not only are the rheological constants subject to change, and in different stages of maturity their relations are like 1:10, but the parameters of the statistical distribution of the values change completely. Thus we are dealing with an extremely difficult case of variability in time of a rheological model, and the equations describing the model have a stochastic character. At the same time it should be stressed that the physical image of the deformation process in biological materials is completely unknown. Although in investigations of the mechanical properties of plants some characteristic points describing the deformations of the initial cell structure of the material are determined, like the biological flow limit when cells begin to burst, or the biological resistance limit, at the point of piercing the outer wall (skin) of plant. These however, are certain phenomenologically determined images of a phenomenon in the macroscopic scale, that does not at all explain the mechanism of deformation of such a basic element as a plant cell.

Volumetric deformation of a cell body of clear porosity — such as for instance a cereal grain, is generally connected with a change in the porosity, caused by the filtration of the gases contained in vapours of gases and liquids. Thus it is not possible to apply in this case the more exactly determined ideally plastic model of granulated materials fulfilling the Coulomb-Mohr condition, while the application of the model of a plastic body amplification is confronted with considerable difficulties of formal and experimental nature.

Similar difficulties are met while considering the rheological phenomena in a mass of materials, like for example in a mass of cereal grain, in a mass of whole or cut straw, in a mixed mass of cut straw and grain, as can be found in a working combined harvester. Strains operating in these cases are relatively small and do not cause permanent plastic deformations of the material. The plastic deformations of mass are the result of particle dislocation, and the dissipation of energy is caused by the friction of particles and by the process of filtration of the air contained in the mass.

If we assume that the processes of plastic deformations lead to either strengthening or weakening of material, we should consistently assume that the material has not one plasticity limit, but a sequence of them, described by a certain function of determined or stochastic parameters. This can be expressed by the following relation

$$f(\sigma_{ij}, R) = 0, \tag{1}$$

in which σ_{ij} is the strain tensor and R is the amplification parameter. Usually it is assumed that the amplification parameter is the density of the material ϱ, and then the relation becomes

$$f(\sigma_{ij}, \varrho) = 0, \tag{2}$$

but in reality the process of the filtration of gases and liquist connected with the overcoming of capillary forces leads to

$$R = R(\varepsilon_{ij}), \tag{3}$$

where ε_{ij} is the tensor of the deformation ratio.

Even the recently published papers do not assume such a complication of the rheological model, bringing the problem down to the generalized model of Maxwell, that is they leave out the problem of the bilogical flow. They are usually limited to the determination of the value of the Poisson's coefficient, of deformation and strain as a function of time, and thus to the determination of the changes in time of the relaxation and flow functions. De Baerdemaeker and Segerlind solved this problem numerically for static loadings and dynamic loadings, studying the relaxation functions at a uniaxial compressing of a sample of free side walls, and of the side walls closed, which made horizontal deformation impossible, and approximating them by power strings.

Without questioning the great value of such interpretation for some materials, like fruits and potatoes, particularly in the case of high strains, it seems that both for single grains and stalks of cereals, and for a mass of these materials we should try to find solutions of the type of the Maxwell-St. Venant's model, sometimes, and more precisely called the model of Maxwell-Prandtl and the related models, that is the Schwedoff's and Hohenemser-Prager's models, that is models of at least 4 parameters.

Despite the great formal difficulties with the application of these models, the most recent works of Lakowluk and his co-workers indicate some possibilities of extending the description of the phenomena of flowing and relaxation of linear-visco-elastic bodies to nonlinear bodies. What still remains a problem is the extention of the problem to include a model that would also take into consideration plasticity, as a coefficient of dry friction, and the overcoming of the really great experimental difficulties connected with the measurement of deformations in the conditions of very frequent changes of strains.

The above and similar considerations directed our investigations to the following problems:

1. Theoretical investigations of elementary models.
2. Investigations of the basic physical properties of cereals.
3. Investigations of the influence of ripeness and of the changes of the exterial conditions on the basic parameters characterizing the mechanical properties of cereals.
4. Considering that all deformations are connected with dissipation of energy and have the character of thermodynamicaly irreversible processes, investigations of the thermophysical properties were begun, which however is the subject of another report.

It should be clearly stressed that the investigations were started without any comprehensive plan determining their logical sequence. This followed from the many spontaneous and simultaneous initiatives caused by the needs of practice, by the possibilities of the apparati, and by the personal interests of the researchers. In this situation it seems to the point to present not only the state of the investigations, but also of those plans in relation to which there is the certainty that their realization will be undertaken in the nearest future.

THEORETICAL INVESTIGATIONS OF ELEMENTARY MODELS

MODELS OF SINGLE ELEMENTS

The most advanced are the works concerned with the model of a single stalk of straw. Miczyński considered the problem of a rod deformed by bending loads, on the basis of non-linear statics of thin roods. Such an assumption turned out to be advantageous, considering that the existing solutions comprise cases when transitions are values of the same order as the length of the rod. Such deformations are typical of the bending of stalks under the influence of wind, with the consideration of their own weight and their loading with the weight of an ear. The author accepted the assumption of the constant value of the Young's modulus for each perpendicular intersection. The author presents a general differential equation of balance at the bending in one plane without twisting. This equation does not have an analytic solution. Numerical solution can be obtained by dividing the rod into a finite number of sections with the loading and mass concentrated at one end, in which case it is possible to solve the square differential equation describing the curve of tension, while the necessary parameters are tabulated. On the basis of this method calculations of a model in the form of a straight uniaxial pipe of constant diameter were carried out at different conditions of wind pressure. This method is also applicable for calculations considering a variable shape of the interesection of stalk, which will constitute the next stage of investigations. 7 different geometrical models were accepted according to the data obtained from field measurements of the Grana winter wheat.

Another investigations task in this range will be the departure from the assumption of the invariability of the Young's modulus in the whole intersection and on the whole length of the stalk, and the accepting of the assumption that the wall of the stalk consists of alternating fibers, parallel to the axis, of different moduluses of the lengthwise and perpendicular elasticity. The complexity of the task, however, makes it necessary to begin with experimental investigations leading to the determination of the limits of the parameters within which the calculations are to be carried out.

In the theoretical investigations of the elementary models of cereal grain works have not been started yet. We intend to start with considerations of a very simplified elementary model of a plant cell. There seem to be three kinds of such a model:

a) elastic hull filled with elastic noncompressible medium,

b) elastic hull fillded with elastic compressible medium,

c) elasto-platic hull filled with elastic compressible medium.

Considerations must go in two directions. One of them is the behaviour of such a model in the conditions of static loading, the other, being a logical development of the first one, would consider dynamic loading and would also consider the vibrations of such a system. This difficult problem must be solved as a preliminary task of further investigations of a set of such elementary models. We have slightly more results in the range of theoretical investigations of models of the medium that is a mass consisting of single grains or stalks of straw.

Grochowicz and Haman proved that a mass composed of dry grain of cereals can be treated as a medium characterized by plastic flowing in which there is no clear amplification. In relation to this it is possible to apply the typical triaxial compression apparatus in investigating the interial friction and cohesion. In the case of a greater moisture of grain there occurs the phenomenon of plastic flowing of the medium, and thus the postulate is met that the deformation speeds are determined by the potential law, where the potential is a certain scalar function of the state of tention

$$\dot{\varepsilon}_{ij} = \lambda \frac{\delta g}{\delta \sigma_{ij}'}$$

where

$\varrho(\sigma_{ij}) = 0$ — is the potential,

λ — is a coefficient which does not have the character of a material constant.

If then the Coulomb-Mohr's plasticity condition is fulfilled then

$$\dot{\varepsilon}_{ij} = \lambda \frac{\delta f}{\delta \sigma_{ij}}$$

where

$f(\sigma_{ij}) = 0$ is the condition of plasticity

$$f[(\sigma_{I}+\sigma_{III}), (\sigma_{I}-\sigma_{III})].$$

In such a case then investigations on the triaxial compression apparatus allow for the determination of the parameters of the flowing of the medium. Appropriate experimental investigations have already been started.

Malicki has worked out a similar problem for a straw medium at the assumption that it is an isotropic medium. The assumption is true in the case of cut straw of thoroughly broken, like for instance in the working slot of the drum of a cereal combined harvester. The author starts from the Huber Schleicher plasticity condition and extends the considerations to the visco-plastic model. In such a case the intensities of tension can be expressed as follows

$$\tau_i = \bar{\tau}_i + \mu\, \xi; \qquad \bar{\tau}_i = c + \sigma + g\,\psi$$

where

c — cohesion,

σ — average normal tension,

ψ — internal friction coefficient on the octaedric plane,

ξ_i — intensity of speeds of the cutting tensions,

μ — coefficient of the visco-plastic flowing.

These parameters can be determined by the standard experiment of triaxial compression, provided that a constant vertical loading in the sample is preserved. Then the state of tension and deformation is as follows

$$\sigma = p + \frac{N}{3S}; \qquad \tau_i = \sqrt{3}\,\frac{N}{3S}; \quad \varepsilon_i = \sqrt{3}\,\ln\frac{h_0 - \Delta h}{h_0}$$

where

p — hydrostatic pressure,
S — area of the intersection of the sample,
N — vertical load,
h_o — initial height,
Δh — increase of height.

Investigations on the triaxial apparatus consist in this case in determining the intensity of the cutting deformations as a function of time for constant tension σ. A diagram so prepared allows for the determination of the relationship between τ_i and ξ_i, that is the coefficient of plastic viscosity. In this way, then, it is possible to determine the functions of relaxation and the functions of creep, and also the coefficient of volumetric viscosity. In a similar way the author consideres the case of the flowing of mass between two parallel moving plates and between two uniaxial cylindrical surfaces that allow for the determination of the values of c, σ, ψ and μ. Changing the density of the medium, its comminution, moisture etc enables the determination of their influence on the basic parameters of the functions of creeping, relaxation, and also on the coefficient of volumetric viscosity and on the speed of volumetric deformations.

Starting from the assumption of isotropicity of straw medium the same author undertook to solve the problem of extending and bending a "straw rod" in which the material is bound by the interial forces of friction and cohesion caused by the entanglement of fibers. The author consideres the extention and bending of such a rod in the conditions of the occurrence of hydrostatic pressure assuming that the properties of the medium correspond to the generalized Maxwell's model, or to the Maxwell-St. Venant's model. The author particularly consideres the time in which the plasticity limit of a material is reached, and points to the methods of investigating all the material constants of the two considered models, as following the accepted assumptions.

It is worthwhile to notice that the non-linear elastic and viscous properties were accepted here, which constitutes a considerable progress in relation to the so far used Maxwell's model. This has a capital significance for the explanation of the mechanism of deformations occurring where there are layers of a compacted straw medium, like for instance in the working slots of the drums of combined harvesters or in the straw and hay presses.

Malicki in his considerations treats the material constants of the straw medium as determined. Another point of view is presented by Marciniak in his considerations entitled "Probabilistical aspects of rheological models". Marciniak consideres the possibility of generalizing any rheological model into a case of functions of random variables. The author points out that the rheological properties of this kind of materials depend largely on the system enforcing the reaction of the material. Hence also the concept of creating a rheological model, correct from the point of the greatest probability of its closeness to actual conditions. The author does not concern himself with any concrete material, he only proposes courses of action when the parameters characterizing a rheological model have a certain statistical distribution. In the instances of results normal and even distributions, as well as a distribution with a constant parameter were included. As a result of these solutions we get a certain distribution of solutions.

The author paid a special attention to analyzing the process of friction, as significant for all biological media considerd in a mass scale. They are characterized by a loose structure of considerable energy dissipation, caused by interial friction during deformation. The author points out that the interial friction must be a nonlinear function of speed, and proposes the introduction of a function that is a measureless statistical characterization of friction. Then the author consideres the shock processes occurring between the enforcing elements and the deformed mass at different distributions of material constants and the enforcing conditions leading not only to deformations, but also to secondary phenomena, like the sedimentation of the substrata of the mass resulting from the differentiation of the coefficients of friction.

At the close of his considerations the author mentions the aspects determining the methodology of measuring the material constants and their statistical distributions.

As can be seen from the presented review theoretical investigations of elementary models of cereal mass are much more developed than investigations of single plants or grains. The most disquieting is the lack of interest in the interrelationships between those two ocurrents of investigations.

INVESTIGATIONS OF THE BASIC PROPERTIES OF CEREALS

Z. Staszczak and others presented a report "Investigations of rheological properties of wheat". The authors point out to the great discrepancies in the recent results of investigations of the material constant of wheat grains; discrepancies that are not justified by the variety differences. They probably result from differences in the methods of measurement. The usually applied methods of uniaxial compressing lead to considerable errors because of the heterogeneity of material and the irregular shape of samples. The authors point out that for a sufficient characterization of only the elastic properties of a grain it is necessary to investigate at least 5 material constants, that is:

1. Young's modulus,
2. Poisson's coefficient,
3. Formal elasticity coefficient,
4. Volumetric elasticity coefficient,
5. Lengthening at destruction.

Actually wheat grain is a visco-elasto-plastic material, which requires the determination of all the material constants allowing for the description of rheological model with the statistical parameters of distribution of these constants. Grain is not a homogenous material but is a complex structure of totally different properties for the particular elements of the structure.

In search of appropriate measurement methods finally the method of uniaxial compression of the grain along the longest axis was chosen. At a sufficiently short deformed part it is then possible to treat the intersection as constant, and the breaking tensions as unchangeable in the whole intersection.

The measurements were carried out on the resistance measuring apparatus "Instron" and on a microcreeper of own design. A technology of fixing the grain into the holders by glueing was mastered, which allowed to avoid the errors resulting from deformations of the holders. The construction of the apparatus allows for measuring lengthenings with the exactness of 0.5 μm and for the measurement of the Poisson's coefficient.

Also measurements of the transverse elasticity modulus was done by twisting a grain in a specially designed apparatus with a microscopic reading of the angle of twisting.

Results of the investigations allowed to accept, for wheat grain of moisture level of about 10%, the Bingham's model, with a limited time of creeping, dependent on the tension value.

Grain turned out to be a rather brittle material, whose lengthening at breaking does not exceed 6%.

The resistance to breaking is almost independent from variety and is about 4.8 N mm^{-2}. Similarly no variety differences were found for the longitudinal elasticity modulus, which is 800—1000 N mm^{-2}.

Since the applied method was more exact than the hitherto used methods of compressing it was possible to determine which of them gives better results. This is a method of loading a grain with a cylindrical pin of small diameter; the tensions being calculated according to Bussinesq's formula.

It was found that the Poisson's coefficient is about 0.25 independent from the variety. So the usually accepted coefficient of 0.4 is much too high.

Investigations of the transverse elasticity modulus indicate that it is approximately equivalent to the longitudinal elasticity coefficient, which points to the anizotropicity of the material which has an outer cover of considerable inflexibility. This is confirmed in experiments with breaking, where there are clear offsets in the diagram of deformations, caused by the breaking of the successive layers of the grain. The heterogeneity of plant material suggested the application of elasto-optical techniques for the modelling of the distribution of tensions in a stalk of straw. Koper and Gowin made a model of a transverse intersection of stalk of elasto-optical material of the Young's modulus of 250 $kNcm^{-2}$. The model had an outer diameter of 170 mm and had a wall with numerous orifices imitating the cells. For comparative purposes models with unperforated wall and models with walls perforated with orifices of different diameters were made. From the analysis made by the method of compensation of liminal tensions it was found that their course was more even and their values lower by 20%.

G. Skubisz presented investigations of the longitudinal elasticity modulus for winter wheat, determined in both field and laboratory conditions.

The field investigations consisted in measuring the arrow of bending of stalks with a certain force obtained with the help of a dynamometer. The experiments were carried out in the conditions of free and limited root lodging.

In laboratory conditions 6 cm long sections of stalk were being bent with their ends supported. In each case geometrical measurements of the stalk were made.

Young's modulus was determined assuming the applicability of the theory of Timoszenko for the buckling of rods at great bendings. It the second case the theory of bent rods was applied. The author found an increase of the Young's modulus with the increasing maturity of stalk, and the greatest values were obtained for the milk maturity for the Aurora variety and for the wax maturity for the remaining varieties. A great distribution of the obtained values allows to think that the inter-variety differences are negligible. Results of the laboratory measurements seem to show that the elasticity modulus varies with the decrease of the radius of the curve of bending, and the lowest values of the modulus occur in the lowest part of the stalk.

The great changeability of the material constants of stalk and the necessity of making rapid and frequent measurements of them in field conditions made Gawda start investigations of the possibility of applying ultrasonic methods to measuring the Young's modulus of stalk. The anisotropicity of stalk causes the value of the modulus to depend on the direction of tensions is relation to the directions of fibres. The ultrasonic method allows to measure the modulus in any direction. Waves of the intensity of $10^{-2} \div 10^{-5}$ cm^{-2} were used with the help of specially designed heads of working frequency of 204 to 500 kHz. When the length of wave is sufficiently high in relation to the thickness of the layer the material constants of which are under investigation the value of the modulus can be calculated from the formula $E = \varrho c^2$, where ϱ — the density of the medium and c = the speed of the longitudal wave diffusion. The speed of wave diffusion was investigated in whole internods and in sections 6 cm long for both fresh and dried material.

A clear dependence of the wave diffusion speed on the place of measurement was established. Under the ear the speed was from 1400 m/s to 2400 m/s in the second and third internod. After drying the speed of wave increases approximately two times.

The value of the Young's modulus in the period of earing is very variable on the whole length of the stalk and forms the range from 1200 N mm^{-2} to 10 000 N mm^{-2}; in the stage of full maturity the value of the modulus becomes more even and varies within the range from about 2000 N mm^{-2} right under the ear to 5000 N mm^{-2} in the second internod. The values are much more exact and are characterized by much smaller distribution than those obtained in direct determinations of the arrow of bending, but concern only the anatomical elements of the highest Young's modulus. It seems that this is the only known method allowing for very rapid field determinations of the material constants in field conditions. Probably it is possible to build head for the measurement of transverse wave diffusion, which would allow also for the determination of the Poisson's constant.

The above quoted investigations of Staszczak, Skubisz and Gawda clearly indicate the considerable influence of the development stage of cereals on the values of their material constants, and thus on the rheological models proper for these stages and also indicate the importance of the place of measurement. Similar results were presented in the paper by Szot, Korejtko and Grundas. It is concerned with a problem closely connected with practice, namely with investigating the resistance and energy of static shearing of cereal stalks. Determination of these values is necessary for the evaluation of forces operating in the cutting systems of harvesting machines. In this case the process of shearing was not analysed; only the values of force and energy were determined from direct measurement. The shearing was carried out on 8 varieties of winter wheat and 3 varieties of rye on the resistance measuring apparatus "Instron" with an automatic integrating device. The system imitated an actual cutting system. The shearing speed was 0.3 mm/s. The cutting was done at every 2 cm on the bottom section of the stalk, 30 cm in length. A large number of results allowed to make a detailed statistical analysis and to determine the significant differences. For all wheats a clear minimum of the shearing force and energy was found on the level of 16—18 cm from the nodium, while all the varieties of rye showed an almost linear decrease of the shearing force and energy together with height. The differences in wheats were up to 20%, which indicates the high energetic advantages resulting from appropriate choice of cutting level. The undertaken attempt at approximating the results with the method of the smallest squares allowed to establish that the function of the value of both the force and energy in relation to the length of stalk can be presented in the form of a poylnominal of the order not higher than 4, and in the case of many varieties it is enough to consider the first 2 or 3 elements of the polynominal. Also the functions of distribution of their slimness, as well as excess, were determined, since, as is shown by the results of investigations of Haman and Szot, often the parameters of distribution, and particularly the statistical moments of higher orders, are of primary signifficance in the evaluation of the usability of a variety.

Similar practical investigations of the shearing resistance of hay with the application of disc and ordinary knives were carried out by Kwiecień. They led to the formulation of some statements that, although with no physical justification, are of considerable practical significance. The most important seems to be the decrease of shearing resistance with the speed of shearing and the extremum of this relation occurs for thin layers. For each diameter of knife there is a layer of optimum thickness, influenced also by the speed of feeding the mass and its density. The lack of attempts at explaining the process makes impossible its modelling, and thus the optimization of the constructions of designed machines.

The presented review does not contain the whole of the Polish contribution into the field of investigations of the rheology of cereals. Particularly the older investigations of phenomena occurring on the grain-ear connection were left out from the present recapitulation. This is because the investigations, carried out in Kraków and Lublin, were published earlier.

It seems that independent from carrying on, and even intensifying the applicational investigations necessary for practice, it is absolutely vital to expand investigations of rheological models, their methamorphosis connected with the devolopment of plant and the process of deformation, and also investigations of methods of measurement allowing for sufficiently exact determination of the values of the material constants. It seems that the development of applicational investigations without an appropriate theoretical interpretation will be made impossible by increasing costs and the only way with prospects for the future is the symulational modelling of processes.

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