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# DETERMINATION OF CRYSTALLINE FIBRES OF PLANTS FROM ULTRASONIC MEASUREMENTS[1])

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The distributions of the velocity of the propagation of rod waves (1 MHz) along a plant stalk "in situ" and along segments cut from the stalk have been determined experimentally. It has been established that the velocity measured for moist stalks changes approximately between 800 and 3200 $ms^{-1}$ and depends strongly on the volume fraction of the crystallites and that the same velocity in the limit of the vanishing moisture changes between 2300 and 5800 $ms^{-1}$, respectively. The comparison of the results of the usefulness of ultrasonic measurements has been carried out for comparative estimations of the volume fraction of crystallites in the fibres of plant stalk.

## ОПРЕДЕЛЕНИЕ КРИСТАЛЛИЧЕСКИХ ВОЛОКОН РАСТЕНИЙ НА ОСНОВЕ УЛЬТРАЗВУКОВЫХ ИЗМЕРЕНИЙ

В работе экспериментально определены распределения скорости распространения волн частотой 1 МГц вдоль стебля растения прямо на месте его роста, а также вдоль отрезков стеблей. Установлено, что скорость, измеренная для сырых стеблей, изменяется в пределах между 800 $мс^{-1}$ и 3200 $мс^{-1}$ и в значительной мере зависит от относительного объема кристаллита. Та же самая скорость в пределе нулевой влажности изменяется соответственно между 2300 $мс^{-1}$ и 5800 $мс^{-1}$. Сравнение результатов эффективности ультразвуковых измерений выполнено на основе сравнительных оценок относительных объемов кристаллитов в волокнах стеблей растений.

## I. INTRODUCTION

The present work is a continuation of previous investigations concerning the utilization of ultrasonic methods for studying the properties of cereal plants [1, 2, 3].

From the analysis of works concerning the application of physical methods to testing the fractions of crystallites [4, 5, 6, 7, 8] it follows that the method employing X-ray, infrared radiation, colorimetry and measurements of density has

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certain drawbacks. In particular one cannot observe by the use of these methods the changes in the volume fraction of crystallites in plant fibres during vegetation. Since these methods require the cutting of the stalk, they cannot measure metamorphic changes in the properties of a living organism.

However, it should be stressed that these methods of testing plant fibres are very useful in industry, where measurements are carried out on samples in the form of bandless fibres separated from a plant stalk without taking into account the biological ripeness, height and vegetation conditions of the plant and the position of the sample fibres in the stalk. However, all the factors just mentioned determine the volume fraction of crystallites and their orientation in a plant stalk.

On the other hand, the volume fraction of crystallites and their orientation in the fibres of the plant stalk determine the ability of the stalk to maintain its vertical position. For this reason all these factors determining the amount and orientation of crystallites in a plant stalk cannot be neglected in investigations for purposes of agriculture.

In the present work the ultrasonic impulse method was used for examining the volume fraction and orientation [1, 2, 3] of crystallites in cereal stalks. The results of the estimation of the crystallite orientation from ultrasonic measurements were presented in a common work with Lewadowski [3] at the International Congress on Ultrasonics in Biology and Medicine last year and are now in print in the quarterly "Achieves of Acoustics".

Attempts at applying ultrasonic impulse methods to examining the volume fractions of crystallites have been initiated recently.

In my present report I would like to present some concepts of using ultrasonic impulse methods for examining the volume fraction of crystallites in the fibres of the plant stalk.

## II. MEASUREMENT METHODS

To estimate the volume fraction of crystallites in plant fibres the following devices were used: ultrasonic material tester, diffractometer, set-up for moisture measurement.

The ultrasonic investigation was reduced to the measurement of the travelling time of acoustic waves. The travelling time was measured by means of an ultrasonic apparatus. The generation head and the reception head are affixed to the investigated medium in two places on the stalk surface of a known separation. The travelling time of a wave along the stalks of the cereal was measured by two procedures.

The first permits the determination of wave velocity in a segment of the stalk during growth. The heads were affixed at a minimum distance of 60 mm from the surface of the stalk to produce and detect rod waves. The travelling time of a rod



wave was measured by a unipan Material Tester type 543. This device is accurate to 0.02 μs and the regularity of its indications can be checked every time by means of a control standard.

The second procedure (destructive) examines under laboratory conditions the sections of a known lengths of a stalk already investigated by the first procedure. An ultrasonic apparatus equipped with an oscilloscope indicator enabled time measurements of an exactness of 0.01 μs. Two heads with a 1 MHz frequency were positioned perpendicularly to the sample axis, one opposite to the other. The rod wave was produced by the first head and detected by the second [1, 2].

The results of both experiments were identical, thus showing the feasibility of performing the first nondestructive type of investigations on a growing plant. The accuracy of measurements was quite hight. The relative error of measurements calculated by the total differential method did not exceed 4 percent.

Immediately after measuring the travelling time by the first procedure the stalk was divided into sections by cutting. During the second procedure the measurements were performed on sections of the stalk immediately after cutting. In this way one can say that measurements performed just previously concern in both cases the plant material in natural moisture.

The results of successive mass measurements enabled to determine the values of moisture and to observe the changes in moisture with time. The results of the successive measurements of travelling time enabled us to determine the values of the rod wave velocity and changes in the velocity with moisture. Both measurements were repeated during the drying process of the sample under laboratory conditions. The measurements ended when the changes in the sample mass with time and simultaneously in the travelling time could be observed longer. processing in this way several hundred plants were examined.

In the next step the samples were divided into several groups each group being characterized by the same value of rod wave velocity. The samples belonging to each group were milled separately by a ball mill and next pills were made of this material for each group. The volume fraction of crystallites of the material of each pill was estimated by using the X-ray difraction method proposed by L. Segal et al. [7].

## III. RESULTS

From the analysis of the results of many measurements of wave propagation velocity in the stalks of a known moisture it follows that the effect of the water volume fraction on the variation in the velocity depends on the properties of the material examined in the limit of the vanishing moisture. Since the accessibility of the plant material for water closely depends on the crystallite volume fraction of the sample material the crystallite can be estimated from measurements of the velocity of rod wave propagation in the moist material with the vanishing moisture.

A comparison of the results of the ultrasonic measurements with the results of the X-ray diffraction measurements shows that the relative crystallite volume fraction, $B_{cr}$, can be estimated from the formula

$$B_{cr} = a \int_0^1 v(m)\, dm \tag{1}$$

where $a$ is a constant coefficient, $v$ is the velocity of the rod wave propagation and $m$ denotes the relative moisture defined by the formula

$$m = B_2 / \left[ \left( B_2 - \frac{\varrho}{\varrho_2} \right) B_1 \right]. \tag{2}$$

$B_1$ *and* $B_2$ denote the volume fraction of the plant material and water in a sample, respectively, $\varrho_1$ and $\varrho_2$ denote the density of the plant material and water, respectively.

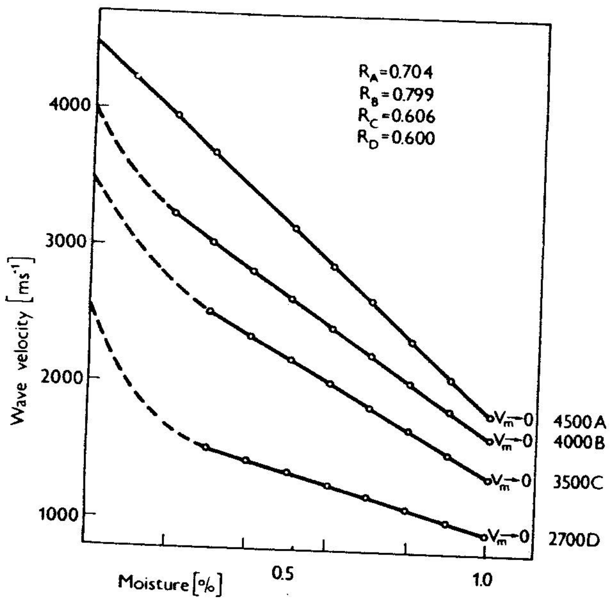


Fig. 1. Moisture dependence of the velocity of rod wave propagation in stalk material. The presented lines can be described by the following equations: A. $v = 4519.4650 - 2708.2801$ m, B. $v' = 3638.6472 - 2001.9314$ m, C. $v = 3045.8840 - 1686.6115$ m, D. $v = 1794.8571 - 852.4930$ m, respectively. R denotes the correlation coefficients corresponding to the respective lines.



Thus the presented method allows us to compare the volume fractions of crystallites in different segments of the same stalk. Using the method helped to establish that the volume fraction of crystallites reaches the maximum value in the middle part. It has been experimentally determined that the maximum value of the volume fraction of crystallites of every plant depended on the height of its stalk and increases with it.

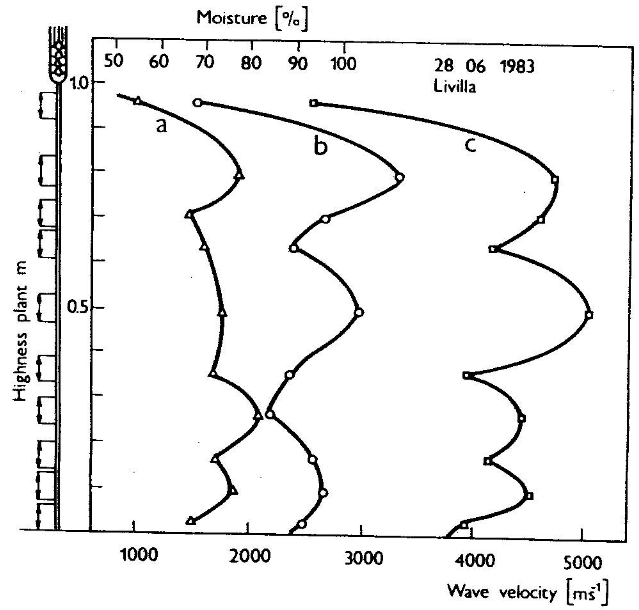


Fig. 2. Distribution along the stalk of a — moisture, b, c — velocity of rod waves in moist and dry stalk material, respectively.

It has also been determined that the volume fraction of crystallites in every internode segment of the plant stalk reaches the maximum value of the full ripness.

From the result presented in Fig. 1 it follows that the mechanical (acoustic and elastic) properties of samples of the same moisture differ from each other if the volume fraction of crystallites varies from sample to sample. From the results it follows that the moisture of the stalk material cannot be regarded as a criterion of the mechanical properties of the stalk, especially not as a criterion of the resistance to lodging.

In Fig. 2 there is presented an example of the distribution of moisture along the stalk immediately after cutting and within the limit of the vanishing moisture. From this figure one can see that the mechanical properties (velocity of rod waves) change essentially along the stalk while the variations in moisture are rather small.

These results confirm that the moisture of the stalk material is not an important factor for determining the mechanical properties of the living plant.

## IV. CONCLUSIONS

The analysis of the results obtained from the measurements of velocity of the wave propagation in plant stalk material shows that the ultrasonic method may be useful for a comparative investigation of the volume fraction of crystallites of the stalk fibres. These analyses also show that the effect of moisture of the stalk on the mechanical properties of stalk material is rather small as compared with that of the volume fraction of crystallites. From this it follows that the measurements of the volume fraction of crystallites in cereal stalks should be regarded as a reliable basis for estimating the resistance of cereals to lodging.

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