Biodistortiometry as a new method for determining the properties of agricultural products

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Abstract. The development of new methods for the study of agricultural products is an actual task. A large number of studies on the electrical properties of biological objects are performed today for scientific and industrial purposes. Distortions of electric signals are considered conventionally as harmful. The authors performed test-bench analysis of harmonic distortion, produced by different agricultural products. Apple, banana, tomato, tangerine were tested. The digital source of sinusoidal signals and a computed spectrum analyzer were main components of the test-bench circuit. Results of measurements of harmonics, from first to tenth, were presented in a graphic form. Each kind of agricultural products created harmonic distortion with an authentic set and a level of harmonics. So, the authors have shown the ability of analyzing harmonic distortions to determine properties of agricultural products.

1. Introduction

In connection with scientific and industrial purposes, a large number of studies of biological objects, including agricultural products, are carried out. New research methods are being developed – optical, ultrasonic, electrical [1]. A certain place in the list of methods of detection, measurement and diagnostics in the study of agricultural products is occupied by the evaluation of the electrical properties and manifestations of agricultural products [2]. From the point of view of the evaluated features, the following directions can be mentioned.

The first part of bioelectric techniques is based on the study of electrical potentials formed by biological objects. At present, a large amount of data on the electrical signals of plants has been accumulated. A new scientific direction is being formed – plant neurophysiology. For example, an experimental study of the biopotentials of fruit trees as a response to their supply with light and water has been published [3]. However, there is still no industrial technology based on the principle of biopotential registration. This fact contrasts sharply with the presence of a long list of generally accepted methods for recording biopotentials in related fields – in human and veterinary medicine. For example: electrocardiography, electroencephalography, electrogastroenterography, etc. [4, 5, 6].
The second part of bioelectric methods is based on the study of the features of the flow of current through biological objects. Since the agricultural products exhibit the properties of both conductors and insulators, the methods of this group are also heterogeneous. Some are based on measuring the permittivity constant and its derivatives. Others are based on the measurement of Ohmic and complex resistance, and electrical conductivity [2, 7]. However, in both cases, an electrical circuit is equipped with a source, cables, electrodes or antennas and a measuring device.

In the case of conductivity measuring, electric voltage is applied to the product sample through electrodes: direct, alternating, pulse. An alternating, sinusoidal or another form of current is more often used as a probing current. The method is widely used in scientific research, but industrial applications are yet to come [2, 7, 8]. In the related fields of human and veterinary medicine, a range of generally accepted techniques are presented: electrorheography (ERG) [9], stimulation electroneuromyography [10], bioimpedance measurement [11] and others.

When measuring the dielectric constant, the agricultural product is placed in an alternating electromagnetic field. Suitable antenna designs are used to create the field. The signal frequency when examining fruits and vegetables is in the range of 10 MHz-20 GHz. Research is carried out non-destructively. Based on the measured dielectric values, it is possible to calculate the content of sugar, water, and a number of other components in the sample [12, 13, 14].

Bioimpedansometry is a well-known method of bioimpedance analysis – a contact method for measuring the electrical conductivity of biological objects. Bioimpedance analysis measures both the active and reactive electric resistances. A probe alternating current of either one frequency or of several different frequencies is used. A number of studies and the experience of using the equipment presented evidence of objective and stable patterns linking the measured values of the impedance with the parameters of the biological objects, including agricultural products, composition [15, 16].

With the help of electrodes, the agricultural product is connected to an electrical circuit, an alternating voltage is applied, and a probing current is formed. The impedance is calculated from the magnitude of the current and the phase shift. The capacitive and inductive components of the impedance are caused by the biochemical composition of both cellular and non-cellular media of a biological object, such as fruit, vegetables, meat [16]. This method is widely used in the analysis of the human body. The mass of water, fat, and muscle tissue of the body can be calculated from the values of the impedance [11].

The authors can mention several special techniques, for example, a method of single-frequency bioimpedance measurement [14]. The measurements are carried out at a single fixed frequency. For each biological tissue, the frequency at which the impedance of the tissue changes most significantly is determined in advance. Therefore, the reactive component of the muscle tissue impedance is close to the maximum at a frequency equal to 50 kHz – in this case, the characteristic frequency is 50 kHz.

Advanced techniques for bioimpedance measurement are multi-frequency impedance measurement and impedance tomography. In any case, an electric current of a certain frequency is passed through biological tissues along a given trajectory using an electrode system. The frequencies are selected depending on the tasks of the study, in the range from 1 kHz to 1.3 MHz. The measured value is the impedance of the object at the selected frequency. Based on the value of the impedance and the current path, they conclude about the properties of tissues, cells, and other biological objects and environments. [15, 17]. But bioelectric techniques are rarely used for industrial analyzing of agricultural products.

When analyzing the effectiveness of these research methods, experts note that an inherent part of the received electrical signal is deviation, pathological signals, interference, distortion. The causes and mechanisms of the appearance of interference and distortion lie in the plane of electromagnetic pollution of the environment and the imperfection of electrical circuits. One of the types of distortion is a harmonic distortion caused by the nonlinear and semiconductor electrical properties of electrical circuits [11, 16].

Harmonic distortions that occur in the recorded signal are considered harmful and their causes are seen exclusively in the defects of the electrical circuit [11, 16].
2. Problem statement

Harmonic distortions have a number of quantitative characteristics, including the harmonic number and the level of this harmonic. Both of these characteristics are relative to the characteristics of the reference (probing) signal. The harmonic numbers and their level, which make up the spectrum and the amount of distortion, can be measured today with high accuracy – 150 decibels (≈0.000003%) and higher. Another characteristic is the frequency of the reference signal, which is set by the operator. Special devices are used for measurement – nonlinear distortion meters, spectrum analyzers, etc. Universal devices can also be used. Both analog and digital generators of various designs can be used to generate the probing signal [18, 19].

As mentioned above, each non-linear element of an electrical circuit has the ability to make changes to the signal shape. As a result, harmonic distortions are formed. The characteristics of these distortions depend on the non-linear electric properties of a given element and can be predicted fairly accurately if these properties are known. And, on the contrary, based on the analysis of the characteristics of distortions, it is possible to conclude about the non-linear electric properties of the source of these distortions within the circuit or device and identify it. This approach has long been successfully implemented in the design and production of audio equipment [18, 19]. According to the authors’ opinion, this approach can be extrapolated to the study of agricultural products. Thus, we have got closer to the formulation of the problem.

The scientific problem is to study the ability of a technique based on measuring the nonlinear distortions of an electrical signal passing through agricultural products to determine the properties of these agricultural products. In other words, it is necessary to confirm or deny the hypothesis that the signal distortions that occur when the signal passes through the agricultural products are properties of this product and can be used to obtain information about this product. The purpose of this study is to prove the fact that different agricultural products introduce different distortions into the probing electric signal and have a different portrait of harmonic distortions.

The authors consider it appropriate to use the term "Biodistortiometry" (BDM) to refer to the measurement technique of the characteristics of harmonic distortions introduced by agricultural products.

To achieve this goal, the following tasks must be resolved.

1. To design and manufacture a test bench containing a generator, cables, electrodes, and a harmonic distortion analyzer, allowing one to work with agricultural products.
2. To conduct a study of samples of agricultural products and record the results of measuring harmonic distortion.
3. To compare the results of measuring the harmonic distortions of samples of agricultural products.
4. To draw a conclusion about the ability of biodistortiometry to determine the properties of agricultural products.

3. Materials and methods

3.1. Research materials

The research was carried out in the structural division created jointly by OmSMU (Rector – MD, PhD, Professor M.A. Livzan), OmGAU (Rector – MD, PhD, Professor O.V. Shumakova) and WSMC FMBA (Director – MD, PhD, V.Yu. Shutov) "Educational and Scientific Center of Endoscopic Surgery" (Director – VD, PhD, Associate Professor V.P. Dorofeeva).

To solve the first task, we assembled a test bench. Highly qualified specialists in the field of radio electronics took part in the selection of components and equipment for the stand, as well as in its assembly: metrologist D.Yu. Kropachev - representative of JSC "NPP Etalon" and V.O. Ryabchevsy - graduate student of OmSTU. As a hardware part, authors used a personal computer with an installed expansion board containing both high-quality digital-to-analog and analog-to-digital converters. The authors also used individually manufactured cables and electrodes. The sinusoidal probing signal was
generated by a software generator via a digital-to-analog converter of the expansion board. To measure nonlinear distortions, a software spectrum analyzer in the mode of harmonic distortions’ meter was used. It received a digital signal from the analog-to-digital converter of the expansion board. The results of the analysis could also be presented in the graphical form. The authors used an apple, a banana, a tomato, and a tangerine as their researched agricultural products. Technical details of the software and hardware are beyond the frameworks of this article and are a subject to separate publication.

To resolve the second task, we conducted bench tests. We carried out the bench tests in the following manner. During each test the agricultural products under study were connected to the electrical circuit of the test bench by two electrodes in the same way. The electrodes were immersed in the substance of the agricultural products. The first electrode was used to provide a reference signal. The second electrode was used to receive the information signal. The generator and analyzer were switched on. The achieving of the operating modes by the generator and analyzer was verified. As a starting point, the harmonic components of the signal itself and the circuit were studied with the first and second shorted electrodes. Then the electrodes were opened, and the harmonic distortion of the circuit containing the agricultural products was measured. The measurement results were recorded in files and stored on the hard disk of a personal computer [20]. The authors named the graphical form of file data as “distortiometric portrait”.

As part of the solution of the third task, authors used to analyze results. The initial analysis was performed visually from a graphical representation of the harmonic distortion measurement. The points of interest on the chart were outlined. The updated numerical values of the harmonic distortion characteristics were extracted from the recorded file in the corresponding window of the software analyzer interface.

The solution of the 4th task followed from the solution of the 3rd.

3.2 Methodology and methods of research

The authors used the methodology of bench tests. As a method of obtaining primary information, the method of biodistortiometry was used. Direct comparison was used as a comparison method. No statistical processing of the results was used, as it is beyond the framework of the study. No comparison with other methods was used, because the goal was to establish the very fact of the ability of BDM to determine the properties of agricultural products. No correlation among the distortiometric portrait and organoleptic, laboratory and other features of samples was studied. This is a task for the subsequent scientific work.

4. Results and discussion

4.1 Results

As a result of solving the first task, it is stated that the above-described configuration of the test bench for BDM is workable, reproducible and able to achieve the solution of subsequent tasks.

The results of solving the second task are as follows. A sinusoidal signal with a frequency of 1 kHz was used as a probing signal.

The results of the distortiometry for each studied agricultural products are shown in the graphic form below (figures 1-4). In all figures, the abscissa axis is the frequency. The frequency of probing signal of 1 kHz forms the first harmonic. It appears as the tallest peak in all figures. The frequency of the 2nd harmonic is 2 kHz, the 3rd - 3 kHz, etc. On the ordinate axis, the relative level indicated in decibels (dB) from the level of the output generator signal.

Levels of the 2nd, 3rd and all consequence harmonics were designated relatively as a level of the first harmonic. This was done because in fact the first harmonic is an undistorted, but attenuated probing signal. All other harmonics were attenuated in an identical proportion with first harmonic due linear electrical properties of studied agricultural products.
Figure 1. The results of distortiometry of the apple. The 2nd harmonic level is 115 dB. There are no peaks of the 3rd-8th harmonics. In the area of the 9-10th harmonics there is a "hill" to -115 dB.

Figure 2. The results of distortiometry of the banana. The 2nd harmonics level: 80 dB; 3rd: -102 dB; 4th: -98 dB; 5th: -118 dB; 6th: -112 dB. In the area of the 7-10th harmonics there is a "wave".

Figure 3. The results of distortiometry of the tomato. The 2nd harmonics level: -112 dB; 3rd: -102 dB; 4th: -121 dB; 5th: -112 dB. In the area of the 7-10th harmonics there is a "plateau".
Figure 4. The results of distortiometry of the tomato. The level of the 2nd harmonics: -90 dB; 3rd: -109 dB; distinct peaks of the 4-8th harmonics are absent; in the area of the 9-10th harmonics there is a "plateau".

The results of solving the third problem are as follows. When compared, an obvious difference was obtained between the spectra of each medium, including the harmonic’s number and the ratios between levels of harmonics.

As a result of solving the fourth problem, the hypothesis that the signal distortions that occur when a signal passes through the agricultural product are properties of this object and can be used to obtain information about this product is true. The goal has been achieved. The ability of distortiometry to determine the properties of agricultural products is proved [20].

4.2 Discussion

In terms of the characteristics of the method, it is necessary to specify the following. The first is accuracy. The technical base we used allows us to work with signal levels up to -150 dB (≈0.00000003 of the original one). Second, it is the flexibility of the system settings. The frequency of the signal, its shape, level, etc. are determined by the settings of the generator and the digital-to-analog converter and may be different.

The results of BDM can be presented in different forms, other than graphic ones. We used immersion electrodes, but it is possible to use surface ones. The development of detailed subtleties and specific industrial-oriented applications is a further challenge. Third, it is a small time-cost for carrying out the measurement. They are measured in seconds, which distinguishes BDM from laboratory methods. Otherwise, real-time monitoring is simply to set. Fourth, the BDM is true digital and can easily be integrated into IT circuits. Fifth, the method is characterized by a low cost of materials, as well as the ability to conduct non-destructive analysis.

In our opinion, BDM can find its place as a supplement to laboratory and other existing technologies for the study of agricultural products. BDM can be used to study any agricultural products, both animal husbandry and crop production, as well as fisheries.

5. Conclusion

This study opens up broad prospects for further development. We see the development of the topic in several directions. The scientific part may consist in the creation and accumulation of databases of distortiometric portraits of specific samples of agricultural products. The second aspect of the scientific component is the search and justification of the biochemical and biophysical mechanisms of the cellular and molecular levels that generate distortions of the probing signal [16, 17]. This will serve as a more complete theoretical justification of the BDM. Another area of development of the topic, focused on the practical use of the methodology, is the creation of methods and devices for studying specific properties.
of agricultural product samples. It is also an urgent task to identify the biodistortiometric characteristics of those properties of products being key to assessing their quality.

Finally, it should be noted an important, in authors’ opinion, scientific fact. The production of harmonic distortions by samples of agricultural products indicates that in addition to the properties of a conductor and a dielectric, agricultural products have the properties of a semiconductor. Undoubtedly, this layer of information requires further development.

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