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Theoretical Analysis of Electromagnetic Field Electric Tension Distribution in the Seeds of Cereals.

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ABSTRACT

In this paper, based on the developed model of seeds, theoretical research are performed concerning the distribution of the electric intensity within low-energy (information) electromagnetic field of millimeter range wave lengths (frequency, power flow density, exposure, amplitude modulation), which may affect the biophysical processes in seeds. The seeds were modeled by spheroids filled with a homogeneous isotropic medium with relative dielectric $\varepsilon = \varepsilon' - i\varepsilon''$ and magnetic $\mu = 1$ permeability. The boundary surface of a spheroid is formed by the rotation around the axis z of the circular arc with the radius R. An electromagnetic wave with the amplitude modulation of an electric field was considered as the excitation of an electromagnetic radiation. The task was to determine an electromagnetic field appeared within a dielectric spheroid by its interaction with a modulated electromagnetic wave. In order to simplify the analysis, let's assume that the electric field tension excited in a dielectric spheroid has a dominant component E_{Z+} (other components E_{X+} and E_{Y+} are negligible as compared with E_0). The equation for the determination of the components E_{Z+} contained two types of integrals, the integral by the volume of the spheroid and the integral by its boundary surface. The changes resulted in the equations for an electric field determination in a spheroid numerically. However, for practical applications, an important characteristic of the electromagnetic radiation interaction with biological objects is an electric field magnitude, averaged by the volume of an object. The solution to this problem was reduced to the solution of two similar objectives for the wave numbers k+ and k-. These solutions were obtained using the Born approximation with a relative error of less than 5%. These expressions allowed to determine the biotropic parameters of an electromagnetic field (frequency, flow density, exposure, amplitude modulation), which may have an impact on the biophysical processes in seeds. The use of an electromagnetic field with established biotropic parameters for the pre-treatment of seeds, allows to increase the yield and quality of seeds within a new harvest.

Keywords: seeds; the frequency of the electromagnetic field; modulation parameters; the power of the electromagnetic field; seed pre-treatment.

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INTRODUCTION

Economic analysis shows that at the present time the post-Soviet countries have an average crop yield decrease by 20 ... 25%, also due to the high cost and the lack of fertilizers and plant protection from pests [1].

Therefore, an urgent task is the development of a new cost-effective and ecologically sound technologies aimed at the production improvement and the quality of grain seeds. One solution to this problem is the use of information electromagnetic field (EMF) of ultra high frequency (UHF) band [2]. The main advantage of an electromagnetic technology for preplant treatment of seeds is by low-energy electromagnetic radiation is explained by the possibility to improve their growth and development due to the mobilization of seed internal reserves without chemicals or genetic engineering techniques [3].

During recent years in order to intensify the crop production in agricultural practice the electric physical methods of influence on the cereal plants and seeds and vegetable crops were introduced actively in order to increase yields and improve the quality of the obtained products [4,5].

RESEARCH METHODOLOGY

The task is to determine the electromagnetic field produced within a dielectric spheroid by its interaction with a modulated electromagnetic wave. This problem was studied in D. G. Armour, Z. Kuryak, R. Srinandan, D., D. Burton works [6,7,8,9].

The electrophysical preplant treatment methods include: the impact of a constant electric field, a constant magnetic field, infrared rays, the electric field of high voltage AC, strong electrostatic field, the electric field of the corona discharge3. A common drawback of all existing technologies with the use of preplant seed treatment by elctrophysical methods is the low reproducibility of processing results, and a low yield increase by 10 ... 12% [10].

This can be explained by the imperfection of the existing technical means and the methods of research, the lack of rapid diagnostic methods, as well as the lack of sufficiently deep theoretical and experimental studies of various physical factor influence mechanism on seed material [11].

The most effective, energy-saving and cost-effective way is the seed treatment by information of UMF [4].

On the basis of it, one may assume that the application of electromagnetic techniques may improve the productivity and the quality of cereal crop seeds. However, it should be noted that an effective use of low-energy UMF is impossible without the development of physical and mathematical models that take into account the parameters of UMF exposure and dielectric characteristics of agricultural facilities in plant production [3].

RESULTS AND DISCUSSION

In order to determine the parameters biotropic UMF a model should be developed which allows to determine the range of these parameters variation (frequency, power, exposure, modulation) for the pre-plant processing of cereal seeds.

Let's consider an electro-magnetic wave with the electric field tension, changing by law as an exciting electromagnetic radiation:

$$\vec{E}^i = \vec{E}_0(1 + m\sin\Omega t)\sin(\omega t + k(\vec{n}, \vec{R})), \qquad (1)$$

where $k = \dfrac{\omega}{c}$ is the wave number; c - the speed of light in vacuum;

$\vec{n}$ – a single vector which determines the direction of wave distribution;
ω – circular frequency;
Ω – modulation frequency;
m – modulation depth ratio, which characterizes the rate of amplitude change;

$\vec{E}_0$ – constant vector, $\vec{R} = x\vec{e}_x + y\vec{e}_y + z\vec{e}_z$, $\vec{e}_x, \vec{e}_y, \vec{e}_z$ the vectors of the Cartesian coordinate system. It is assumed that $\Omega / \omega << 1$. In this case, we may talk about the amplitude modulation of a harmonic wave with the frequency ω.

Seeds will be simulated by spheroids filled with a homogeneous isotropic medium with relative permittivity $\varepsilon = \varepsilon' - i\varepsilon''$ and magnetic permeability $\mu = 1$.

Fig. 1 shows a spheroid, the boundary surface of which is formed by rotation around the axis z of a circular arc with the radius R. The geometrical parameters of this arc are the following: $2h_1$ - the length of the line segment connecting the ends of an arc; $2h_2$ – he maximum distance between the points of a boundary surface in a plane of the perpendicular axis z. Let's introduce a cylindrical coordinate system R, φ, Z with the axis z and the Cartesian coordinate system x, y, z as shown on fig. 1.

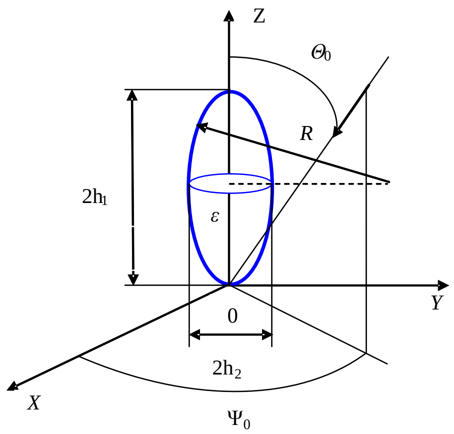

Figure 1: Electrodynamic model of seeds

Then the boundary surface of the spheroid may be described by the following parametric equations:

$$X = \overline{R}(v)\cos\varphi, Y = \overline{R}(v)\sin\varphi, Z = \overline{Z}(v). \qquad (2)$$

Here v is the length of a circular arc, measured from the point of 0 (the top of the spheroid), φ is the polar angle in a cylindrical coordinate system, and the functions $\overline{R}(v)$ and $\overline{Z}(v)$ have the following form:

$$\overline{R}(v) = R\,sin\frac{v}{R}, \quad \overline{Z}(v) = R\left(1 - cos\frac{v}{R}\right). \qquad (3)$$

The parameter v is changed within the interval $(0, L)$, where $L = \arccos\left(1 - \frac{h_2}{R}\right)$, and the angle φ differes within the interval $(0, 2\pi)$.

Let θ_0 and φ_0 are the angles determining the direction of an exciting electron-magnetic wave distribution (see Fig. 2.1). The angle θ_0 is calculated from the axis Z within the plane, going through this axis and the vector $\vec{n}$, and φ_0 is the angle between this plane and the axis X. Then, an electric field tension of an exciting wave may be represented as follows:

$$\vec{E}_+^i = \frac{m}{2}\vec{E}_0 e^{ik(sin\,\theta_0\,cos\,\varphi_0 X + sin\,\theta_0\,sin\,\varphi_0 Y - cos\,\theta_0 Z)}. \qquad (4)$$

Regarding the polarization of an exciting wave, without the loss of generality, we will assume that the vector $\vec{E}_0$ is parallel to the axis Z, i.e. $\vec{E}_0 = E_0 \vec{e}_z$, and the directing angles θ_0 and φ_0 are equal $\theta_0 = \frac{\pi}{2}$, $\varphi_0 = \frac{\pi}{2}$. Therefore, we obtain from (4) that the exciting wave has the following form:

$$\vec{E}_+^i = \frac{mE_0}{2} e^{iky} \vec{e}_z , \qquad (5)$$

Where the wave number $k = \omega / c$, $\vec{e}_z$ is a single vector along the axis Z.

Taking into account the things mentiond above it is natural to assume that an electric-field tension excited in a dielectric spheroid will also have a dominant component E_{Z+} (other components E_{X+} and E_{Y+} are negligible in comparison with E_0).

Let's introduce the designation $E_+ = E_{Z+}$ and put down an integral equation for E_+. This equation contains two types of integrals: an integral by a spheroid volume and an integral by its boundary surface.

Let's consider a surface integral. First, let's calculate of the integrand $(\vec{n}_q, \vec{E}_+) grad_q G(p,q)$. The equation for the vector $\vec{n}_q$ of the normal to the boundary surface of a spheroid taking into account the parametric equations (2), is as follows [12]:

$$\vec{n}_q = -\dot{Z}\vec{e}_R + \dot{\mathrm{R}}\vec{\mathrm{e}}_Z , \qquad (6)$$

where the point denotes differentiation, and $\vec{e}_R$ and $\vec{e}_Z$ – the unit vectors of the cylindrical coordinate system at the point q.

Let's introduce (6) into scalar product $(\vec{n}_q, \vec{E}_+)$, then we will obtain the following:

$$(\vec{n}_q, \vec{E}_+) = \dot{R} E_+ , \qquad (7)$$

Where according to (3) $\dot{R} = \cos \frac{\nu}{R}$.

Now let's consider $grad_q G(p,q)$. The function $G(p,q)$ may be represented as a Fourier series according to the azimuthal coordinate φ of the cylindrical coordinate system. Omitting the intermediate conversion and using the results of [13], we have:

$$G(p,q) = \sum_{n=-\infty}^{+\infty} S_n e^{in(\varphi_1 - \varphi_2)} . \qquad (8)$$

Here $p = (\Gamma_1, \varphi_1, \mathrm{Z}_1)$ and $q = (\Gamma_2, \varphi_2, \mathrm{Z}_2)$, and the coefficients S_n are presented in the form of the following integrals

$$S_n = \frac{1}{2\pi}\int_0^{2\pi}\frac{e^{ik_+\Gamma}}{\Gamma}e^{-in\varphi}d\varphi,$$
$$r = \sqrt{(\Gamma_1-\Gamma_2)^2+(Z_1-Z_2)^2+4\Gamma_1\Gamma_2\sin^2\varphi/2} \qquad (9)$$
$$n = 0, \pm 1, \pm 2, \ldots .$$

Using the formula [13] to calculate the gradient of the function in a cylindrical coordinate system, we obtain for Z component $grad_q G(p,q)$ the following expression:

$$\frac{\partial G(p,q)}{\partial Z_2} = \sum_{n=-\infty}^{+\infty}\frac{\partial S_n}{\partial Z_2}e^{in(\varphi_1-\varphi_2)}. \qquad (10)$$

It is considered in (10), that the gradient is calculated according to the variable $q = (\Gamma_2, \varphi_2, Z_2)$. We have the following from (9):

$$\frac{\partial S_n}{\partial z_2} = \frac{(Z_1-Z_2)}{2\pi}\int_0^{2\pi}\frac{e^{ik_+r}(ik_+\Gamma-1)}{r^3}e^{-in\varphi}d\varphi. \qquad (11)$$

Now let's represent the function $E_+(q)$ – the electric field tension in a spheroid within a Fourier series according to the azimuthal coordinate φ. We have the following:

$$E_+(q) = \sum_{n=-\infty}^{+\infty}E_n^+(\Gamma_2, Z_2)e^{-in\varphi_2}. \qquad (12)$$

Let's substitute (7) and (10) in the surface integral. Using the parametric equations (2) for the boundary surface of a spheroid, we transform this integral in the double integral by the variables V and φ_2, then we will get the following:

$$\int_S (\vec{n}_q\vec{E}_+)\frac{\partial G(p,q)}{\partial Z_2}dS = \frac{R}{2}\int_0^{2\pi}d\varphi_2\int_0^L \sin\frac{2V}{R}\sum_{n=-\infty}^{+\infty}\vec{E}_+(\bar{R}(v), \bar{z}(v))e^{in\varphi_2}\times$$
$$\times\sum_{n=-\infty}^{+\infty}\frac{\partial S_n}{\partial Z_2}e^{in(\varphi_1-\varphi_2)}dV, \qquad (13)$$

where $L = \arccos\left(1-\frac{h_2}{R}\right)$.

If you now use the property of orthogonal functions $e^{in\varphi_2}$ on the interval $(0, 2\pi)$, then we have ultimately the following from (13):

$$\int_S (\vec{n}_q\vec{E}_+)\frac{\partial G(p,q)}{\partial Z_2}dS = \pi R\sum_{n=-\infty}^{+\infty}e^{in\varphi_1}\int_0^L \sin\frac{2V}{R}E_n^+(\bar{R}(v), \bar{z}(v))\frac{\partial S_n}{\partial Z_2}dV. \qquad (14)$$

Now let's consider the integral according to the volume of spheroid. Let's reduce this volumetric integral to the two-dimensional integral according to the variables Γ_2, Z_2. Using the orthogonality property of the function $e^{in\varphi_2}$ and the function $G(p,q)$ and $E_+(q)$ decomposition in в ряды Fourier series (see (8) and (12)), after a series of transformations we obtain the following:

$$\int_V E_+(q)\partial G(p,q)dV = 2\pi \sum_{n=-\infty}^{+\infty} e^{in\varphi_1} \int_0^{2h_1} dZ_2 \int_0^{a(Z_2)} E_n^+(\Gamma_2, Z_2) S_n \Gamma_2 d\Gamma_2, \quad (15)$$

where $a(Z_2) = \sqrt{Z_2(2R - Z_2)}$.

Considering the equation (14) and (15), and applying the Uniquness theorem of function expansion in Fourier series, we obtain the following:

$$E_n^+(\Gamma_1, Z_1) = E_{+n}^i(\Gamma_1) + \frac{(\varepsilon - 1)k_+^2}{2} \int_0^{2h_1} dZ_2 \int_0^{a(Z_2)} E_n^+(\Gamma_2, Z_2) S_n \Gamma_2 d\Gamma_2 +$$
$$+ \frac{(\varepsilon - 1)R}{4} \int_0^L E_n^+(\overline{R}(v), \overline{z}(v)) \sin \frac{2v}{R} \frac{\partial S_n}{\partial Z_2} dV \quad (16)$$
$$n = 0, \pm 1, \pm 2, \ldots .$$

Here

$$E_{+n}^i = \frac{mE_0}{4\pi} \int_0^{2\pi} e^{-in\varphi + ik\Gamma_1 \sin\varphi} d\varphi = \frac{mE_0}{2} I_n(k\Gamma_1) \quad (17)$$
$$n = 0, \pm 1, \pm 2, \ldots .$$

The expansion coefficients in the Fourier series, the tension (unreasonable proposal) of the exciting wave electric field, and $I_n(\cdots)$ is the Bessel function of n-th order.

The functions S_n and $\frac{\partial S_n}{\partial Z_2}$ from (16) are calculated according to the formulae (9) and (11), and the functions $\overline{R}(v)$ and $\overline{z}(v)$ are calculated according to the formula (3).

Using the equation (16) we may calculate the electric field tension inside a dielectric spheroid (an electrodynamic model of sunflower seeds).

In general, the construction of equation solution (16) is possible only by numerical methods, using a computer. However, an important characteristic of the interaction process concerning electromagnetic radiation with biological objects is the magnitude of an electric field, averaged by the volume of object for practical applications.

It follows from (12) that the magnitude of an electric field, averaged by the volume of a spheroid, is determined only by the coefficient with the index n = 0, within the expansion in Fourier series of the function $E_+(q)$. Therefore, an averaged electric field intensity E_{cp}^+ is equal to:

$$E_{cp}^+ = \frac{2\pi}{|V|} \int_0^{2h_1} dZ_2 \int_0^{a(Z_2)} E_0^+(\Gamma_2, a(Z_2)) \Gamma_2 d\Gamma_2, \quad (18)$$

where $|V|$ is the volume of a spheroid and the function $E_0^+(\Gamma_2, Z_2)$ satisfies the equation (16), in which we assume that the index *n* = 0.

The spheroid volume may be calculated by the following formula:

$$|V| = 2\pi \int_0^{2h_1} dZ_2 \int_0^{a(Z_2)} \Gamma_2 d\Gamma_2 = \pi \int_0^{2h_1} Z_2 (2R - Z_2) dZ_2 = \frac{4\pi h_1^3}{3}\left(3\frac{R}{h_1} - 2\right). \quad (19)$$

As we mentioned above, the development of solutions concerning the original problem of modulated electromagnetic wave interaction with a dielectric spheroid is reduced to the solution of two similar problems for wave numbers $k_+ = \frac{\omega_+}{c} = \frac{\omega + \Omega}{c}$, $k_- = \frac{\omega - \Omega}{c}$ and $k = \frac{\omega}{c}$.

Therefore, the tension averaged over by the volume of the spheroid of the electric field E_{cp} has the following form:

$$E_{cp} = E_{cp}^0 + E_{cp}^+ + E_{cp}^- = \frac{2\pi}{|V|} \int_0^{2h_1} dZ_2 \int_0^{a(z_2)} \left(E_0^0 + E_0^+ + E_0^-\right) \Gamma_2 d\Gamma_2 \, . \quad (20)$$

Here $E_0^{\pm}$ are the solutions of the integral equation (16), for the wave numbers $k_{\pm}$ and $n = 0$, and E_0^0 is the solution of the same integral equation for the wave number k and $n = 0$.

Thus, the original problem was reduced to the development of the integral equation (20) solution for two values of the wave number k_+ and k_-. As numerical estimates demonstrated, these solutions may be obtained using the Born approximation [14]. At that the relative error makes less than 5% for real geometrical parameters of a sunflower seed and a relative-dielectric permeability $\varepsilon = \varepsilon' - i\varepsilon''$, $2 \le \varepsilon' \le 4$, $2 \cdot 10^{-3} \le \varepsilon'' / \varepsilon' \le 2 \cdot 10^{-3}$ within the frequency range 25 GHz $\le \frac{\omega}{2\pi} \le$ 40 GHz and the modulation frequency $\frac{\Omega}{\omega} \le 10^{-9}$. On the basis of Born’s approximation we have the following formulae:

$$\begin{aligned} E_0^{\pm} &= \frac{mE_0}{2} I_0(k\Gamma_1) + \frac{m(\varepsilon - 1)k_{\pm}^2}{4} E_0 \int_0^{2h_1} dZ_2 \int_0^{a(Z_2)} I_0(k\Gamma_2) S_0 \Gamma_2 d\Gamma_2 + \\ &+ \frac{m(\varepsilon - 1)RE_0}{8} \int_0^L I_0\left(k\bar{R}(\nu)\right) \sin\frac{2\nu}{R} \frac{\partial S_0}{\partial Z_2} d\nu, \\ E_0^0 &= -\frac{iE_0}{2} I_0(k\Gamma_1) - \frac{i(\varepsilon - 1)k^2 E_0}{4} \int_0^{2h_1} dZ_2 \int_0^{a(Z_2)} I_0(k\Gamma_2) S_0 \Gamma_2 d\Gamma_2 - \\ &- \frac{i(\varepsilon - 1)RE_0}{8} \int_0^L I_0\left(k\bar{R}(\nu)\right) \sin\frac{2\nu}{R} \frac{\partial S_0}{\partial Z_2} d\nu. \end{aligned} \quad (21)$$

Thus, using the formulas (20) and (21) one may calculate the tension of an electric field, resulting from the interaction of a modulated electromagnetic wave with a dielectric spheroid being an electrodynamic model of most cereal seeds.

CONCLUSION

The abovementioned analysis showed that the impact of low-energy UMF for the development of crops is conditioned by a number number of features which include:

- low-energy UMF do not make a significant energy impact on the fabric of biological objects - no heat, no radiation changes, so its effect may be determined only by the mobilization of forces and the release of the object large energy reserves;

- the interaction of information UMF with biological objects should be considered in the development of information field theory of the noosphere. Within the micropower level of information UMF interaction with biological objects is an information type of interaction with the capacity of about 10^{-12} watts. UMF is only an energy carrier of information within the noosphere, so you need to consider the carrying element of these fields during the treatment of animals.
- in order to study the biophysical action of low-energy UMF the technical analogues of biological objects are necessary, knowing the nature of which it is possible to model the structure of biological systems with the volume processing of information signals.
- the desired changes in the properties of biological objects may be obtained only at the optimum combination of biotropic UMF parameters (frequency, power flow density, exposure, modulation, etc.).
- low-energy electromagnetic waves may cause conformational rearrangements of cellular structures, influence the permeability of biological membranes and serve as an information signal to the regulatory systems of the whole biological object.
- the plants, formed from seeds irradiated with stimulating electromagnetic radiation doses, the change of morphological and biochemical parameters take place. The associated intensification of metabolic processes during the early stages of ontogenesis contributes to the accumulation of a phytomass, to the increase of photosynthesis productivity, the change of water regime and the ratio of aboveground and underground organ weight. As a result, the seeds of plants accumulate more protein, its qualitative structure changes, the yield of crops is increased.

The main conclusions of our study are as follows:

- In order to determine the parameters of low-energy biotropic UMF (frequency, power, exposure, modulation), causing an increase in crop yield and the seed quality of grain cultures, theoretical studies are necessary taking into account the developed model.
- To analyze the distribution of UMF electric intensity in the seeds of cereal crops, one should use the model of a spheroid filled with homogeneous isotropic dielectric medium with relative dielectric $\varepsilon = \varepsilon' - i\varepsilon''$ and magnetic $\mu = 1$ permeability.
- In order to determine the intensity of the electric field in the middle of a dielectric spheroid one should use the uniqueness theorem for the expansion of the Fourier series.
- The expressions of an average value for the electric field tension in the volume of a spheroid obtained using the Born's approximation, are essential for the analysis of UMF electric tension distribution and for the determination of biotropic parameters for the irradiation of seeds.

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