Effect of Different frequency Electromagnetic Wave on Electric Properties of Tea Caterpillar Larvae with Comsol Multiphysics Software Simulation

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Abstract
An electromagnetic model of tea caterpillar larvae irradiated with electromagnetic wave is established, and the effects of different frequency electromagnetic wave on electric properties of tea caterpillar larvae are explored. Based on 3D electromagnetic model of tea caterpillar larvae established with Comsol Multiphysics software, electric properties of tea caterpillar larvae exposed in static magnetic field in different frequency electromagnetic wave are calculated with the software, where experiment group is set in environment with static magnetic field strength of 0.15T, internal relative dielectric constant and electric conductivity of tea caterpillar larvae irradiated with electromagnetic wave in different frequencies of 0 kHz, 100 kHz, 1 MHz and 10 MHz are calculated. There are significant differences between experiment and control groups. Established electromagnetic model of tea caterpillar larvae can be used for calculating internal relative dielectric constant and electric conductivity of tea caterpillar larvae irradiated with electromagnetic wave and providing parameters to researches on related insect electromagnetic biological effect and physical methods of controlling tea caterpillar disaster.

Key words: Tea Caterpillar Larvae, Model, Electromagnetic Field, Electric Property.

Efecto de la onda electromagnética de diferente frecuencia en las propiedades eléctricas del té

Resumen
Se establece un modelo electromagnético de las larvas de la oruga del té irradiadas con ondas electromagnéticas, y se exploran los efectos de las ondas electromagnéticas de diferente frecuencia en las propiedades eléctricas de las larvas de la oruga del té. Basado en el modelo electromagnético 3D de las larvas de la oruga del té establecido con el software Comsol Multiphysics, las propiedades eléctricas de las larvas de la oruga del té expuestas en el campo magnético estático en diferentes ondas electromagnéticas de frecuencia se calculan con el software, donde el grupo experimental se establece en un entorno con una intensidad de campo magnético estático de 0.15T, constante dieléctrica relativa relativa y conductividad eléctrica de las larvas de la oruga del té irradiadas con ondas electromagnéticas en diferentes frecuencias de 0 kHz, 100 kHz, 1 MHz y 10 MHz. Existen diferencias significativas entre los grupos de experimentación y control. El modelo electromagnético establecido de las larvas de la oruga del té se puede utilizar para calcular la constante dieléctrica relativa relativa y la conductividad eléctrica de las larvas de la oruga del té irradiadas con ondas electromagnéticas y proporcionar parámetros a las investigaciones sobre el efecto biológico electromagnético de los insectos y los métodos físicos para controlar el desastre de la oruga del té.

Palabras clave: té, oruga, larvas, modelo, campo electromagnético, propiedad eléctrica.
1. Introduction

At present, some researchers have revealed possible biophysical mechanism of biological effects produced by interaction between static magnetic fields and living organisms. Experimentally, Okada studied the effects of magnetic fields on protein crystal growth in structural biology. He believed that growth quality of protein crystals can be improved by applying magnetic fields in microgravity environment. Hashish and others studied the changes in their internal organizational structure after mice bodies were treated with static magnetic field and extreme-low frequency electromagnetic field exposure. They pointed out that the combination of two magnetic fields can cause activity of lactate dehydrogenase in liver to increase greatly [1]. Ueno and others studied biological effects produced by static magnetic fields from different aspects, including the effects of static magnetic fields on nervous system [2]. Some scholars believed that too strong or too weak magnetic fields are bad for insects. Also some scholars studied negative effects of magnetic fields produced by high-voltage line on insects from chromosome variation, behavior changes and other aspects. For example, American cockroaches can avoid being in electromagnetic fields. If magnetic fields reach certain degree, they will change their behavior [3]. For mechanism of biological effects produced by extreme-low frequency electromagnetic fields, researchers experimentally put forward theory of electromagnetic energy resonance effect, and further gave biophysical explanation [4]. Biologically, electromagnetic energy is a kind of trigger signals of biological effects [5]. At present, World Health Organization and China have carried out some cooperation projects to explore biological effects of extreme-low frequency electromagnetic waves and related medical protection strategies [6]. Although there are no obvious electric fields under the action of low frequency and weak magnetic fields, electric fields of certain intensity exist at some positions in living organisms, such as cell transmembrane electric fields [7].

Comsol Multiphysics [8], an advanced numerical simulation software called “the first true arbitrary multiple physical fields direct coupling analysis software” by modern scientists, is applicable to simulation of various physical processes in simulation science and engineering area. The software on its high efficiency calculating performance and excellent multi-field direct coupling analysis capability realizes highly accurate numerical simulation of arbitrary multiple physical fields and is widely used in global advanced numerical simulation field. Comsol Multiphysics software integrates preprocessor, solver and postprocessor and can accomplish geometry modeling, mesh dissection, equation and boundary parameter setting, solving and post-processing in the same graphical operating interface. With rich tools in C software, users can build their own geometric models in graphical interface, such as geometric structure built by means of sphere, ellipsoid, cube, stage, point and line in 3D. Additionally, superordinate operation of geometric objects can be performed by means of mirror, copy, move, zoom and others, also cutting, bonding and other operations between geometric structures can be performed with Boolean operation. Comsol Multiphysics software with CAD core of P format can perfectly be led into geometric structures produced by most professional CAD software. In Comsol Multiphysics software, every geometric object exists in a geometric frame, such as 1D, 2D or 3D, named after G successively. Each frame remains independent, where geometric objects, solving domain and boundary conditions are completely enclosed. Any geometric frame cannot directly visit variables or dependent variables in other geometric frame. Accessible intermediate variables in different frames must be defined with coupling variables, integral coupling variables, stretching coupling variables, projection coupling variables and so on.

Life body always exists in certain physical environment, where important factors are geomagnetic field, cosmic magnetic field and artificial magnetic field [9]. Especially, with development of global industries and biomedical progress in recent years, harms of these environment magnetic fields on human are gradually concerned. On the other hand, physical treatments to certain diseases with external magnetic field show versatility of magnetic fields. It becomes more and more concerned topic how to use positive functions of magnetic fields and avoid harm of magnetic fields. Generally, based on characteristics of biological effects produced by electromagnetic fields, electromagnetic fields can be divided according to frequency spectrum into following intervals: low frequency, radio frequency, and microwave, infrared, visible light, ultraviolet ray, X-ray, γ-ray and other ionization zones. As a special material form, electromagnetic fields are mainly described by field distribution, frequency, wave length, wave shape, power density and other characteristics. So, generation of electromagnetic field biological effects is closely related to the characteristics of electromagnetic fields themselves. The objects of action by electromagnetic fields with different frequency, field intensity and amplitude are different. Next, biological effects generated by electromagnetic fields to living organisms in different time length are also different [10].
Figure 1. Chain effect of EM exposure on living organisms

Figure 2. 3D structure of tea caterpillar larvae in static magnetic field

Figure 3. The change of average length of the male and female euproctispseudoconspersa with frequency

Figure 4. The change of hatchability of euproctispseudoconspersa with frequency
Tea caterpillar is one of main injurious insects on tea trees in China. Magnetic field may produce certain effects on growth, development and survival ability of the insect [11-14]. However, there are fewer researches on biological effects of magnetic fields nowadays. In this paper, a 3D model of tea caterpillar larvae is established by means of Comsol Multiphysics software. Then based on the acquired electromagnetic model, electric properties of tea caterpillar larvae exposed in static magnetic field in different frequency electromagnetic wave are calculated with the software. Analysis for the results of electric properties of tea caterpillar larvae after accepting the action of different frequencies in static magnetic fields can help show absorption of living organisms to electromagnetic wave and transformation mechanism of electromagnetic wave in living organisms, also explore the manage mechanism of electromagnetic wave on biological system so as to estimate the effects of different frequency magnetic fields on insects’ activities. Preliminary researches on the mechanism of growth and development of tea caterpillar larvae under the effects of electromagnetic fields and protection strategy can provide related guidance for scientific control of the pest.

2. Model Establishment

Establishing 3D model of tea caterpillar larvae: In cor relational research of biological electromagnetism and dosiology, lossy mediums with regular shapes are usually used to simulate living organisms with irregular shapes and nonuniform electric properties. For example, sphere or ellipsoid among lossy mediums can simulate living organisms, sphere for simulating head, and cylinders of different sizes for other parts. In this experiment, based on an atomic structure of tea caterpillar larvae, insect body, hair and silk of a tea caterpillar larva are simulated by using Comsol Multiphysics software. Thus established 3D model of tea caterpillar larva is very realistic in shape, matching actual size and basic structure of tea caterpillar larvae.

First, geometrical structure of 3D model of tea caterpillar larva is established. In the process, rectangle, circle, line, Bezier curve, mirror, difference set, chamfering and other drawing tools are used. Specific steps are as follows:

(1) Press on Shift, click rectangle / square button on drawing toolbar, set parameters of the rectangle, and then click OK.

(2) Click zoom on main toolbar to window size.

(3) Open menu, option > shaft/lattice, set dialog box, enter setting value: Click lattice tab, then clean up automatic check box, set y compartment, click OK.

(4) Click cubic Bezier curve button on drawing toolbar to draw Bezier curve.

(5) Click line button on drawing toolbar to draw line.

(6) Click the right mouse button to complete a closed geometric object. Now upper half of geometric structure is completed. Next, lower half of geometric structure can be obtained by mirror.

(7) Click mirror button on drawing toolbar, retain points on default line, modify normal vector to (0, 1), click OK.

(8) Press on Shift, click ellipse/circle on drawing toolbar, set parameters of the circle to draw a circle.

(9) Click zoom to window size. Click create compound object button on drawing toolbar, in open dialog box, clean up preserve internal boundary check box, enter R1+CO1+CO2-C1 in set formula edit, click application. Click preserve internal boundary check box, enter R2+CO3 in set formula edit, and click OK.

(10) Finally, chamfer the square on the left of two sides, click fillet/chamfer button on drawing toolbar, set parameters, and click OK. Through above steps, a geometric structure diagram of 3D model of tea caterpillar larvae is obtained.

In this experiment, after 3D profile line diagram of tea caterpillar larvae is drawn by Comsol Multiphysics Company’s Computer Aided Design software, AC/DC modules in Comsol Multiphysics software is used. Steps of analog computation of simulation are as follows:

(1) Geometry modeling: Model of tea caterpillar is established by CAD drawing software in Comsol Multiphysics software.

(2) Material assignment: parameter assignment to each area of geometric model of tea caterpillar is entered by manual input. Material parameters involved in this paper are as follows:

Air: $\sigma = 0.00001 \text{S/m}$, $\mu = 4\pi \times 10^{-7} \text{H/m}$, $\varepsilon = 8.854 \times 10^{-12} \text{F/m}$;

(3) Boundary conditions setting: Tangential component of electric field intensity and normal component of magnetic induction intensity on interfaces of different materials are continuous, and the external boundary is set with magnetic insulation, that is, the field at infinity is zero.

(4) Source adding: Magnetic dipole source is selected for emission source in 3D model.

(5) Mesh dissection: Mesh dissection is performed for model of tea caterpillar. Principle of mesh dissection: “dense dissection for concerned area, thin dissection for less concerned area, reasonably linking mesh at interfaces of different areas.”

(6) Solving: For predictive research type in this paper, “frequency domain” is selected. For
frequency distribution, several different values of 0 kHz, 100 kHz, 1 MHz and 10 MHz are set. Solver is FGMERS in iterative solver.

7 Post-processing: The results of calculation can be made diagrams according with demands. Before making diagrams, source data of graphs, lines and points to be drawn are first defined. After data set are built, corresponding diagrams can be drawn, including estimation for point value, data export for the results of calculation can also be made.

In this experiment, 3D profile line diagrams of tea caterpillar larvae are drawn by means of Comsol Multiphysics Company’s Computer Aided Design software in Comsol Multiphysics software. Then solid models of tea caterpillar larvae are created by stretching profile line, including organizational structure with different electromagnetic parameters drawn in different layers which are in different colors. Finally, space distribution of organizational structure of tea caterpillar larvae to be computed is obtained. Model size is 20 mm×3 mm×4 mm, and space resolution is up to 0.2 mm×0.2 mm×0.2 mm.

3. Processing Method of Experimental Data

Generally, magnetic field intensity is divided into three levels: small dose below 0.05T, median dose between 0.05-0.15T and large dose above 0.15T. In order to guarantee a single variable, the effects of different frequency electromagnetic waves in field intensity of median dose below 0.15T on electric properties of tea caterpillar larvae are researched in this experiment. So, in the range of 10 KHz to 10MHz, capacitance and resistance of both tea caterpillar larvae exposed in 0.15T static magnetic field and tea caterpillar larvae in control group are computed by means of solving function of Comsol Multiphysics software. Then dielectric and electric properties of the larvae are computed by software testing. The 0.15T static magnetic field is simulated by parameters set with Comsol Multiphysics software. For calculation results of data of experiment and control groups, differences in electric properties between experiment and control groups of tea caterpillar larvae are respectively analyzed by means of Student’s T test method in Comsol Multiphysics software. Possible reasons of produced various phenomena are further discussed.

In actual data processing, main frequency points to be tested are as follows: 2 of 1M and 10MHz. The effects of different frequency electromagnetic wave on electric properties of tea caterpillar larvae exposed in static magnetic field are further analyzed by the difference results of electric properties of tea caterpillar larvae exposed in static magnetic field.

4. Results and Analysis

Applied electromagnetic field can cause changes of electromagnetic properties of biological tissues. These changes can be designated by the changes of conductivity, magnetic susceptibility, dielectric constant, capacitance and other electromagnetism characteristic parameters, computed by solving function of Comsol Multiphysics software. Relative dielectric constant $\varepsilon_r$ in static electric field can be measured by the following method: first, when there is air between two polar plates, capacitance $C_0$ of capacitor is tested. Next, capacitance after dielectric medium is added between the polar plates with the same spacing is tested. Relative dielectric constant $\varepsilon_r$ can be calculated with the following formula

$$\varepsilon_r = \frac{C}{C_0}$$

The calculated results are shown in Table 1:

<table>
<thead>
<tr>
<th>Frequency (Hz)</th>
<th>0 k</th>
<th>10 k</th>
<th>100 k</th>
<th>1 M</th>
<th>10 M</th>
</tr>
</thead>
<tbody>
<tr>
<td>Relative dielectric constant($\varepsilon_r$)</td>
<td>296±54</td>
<td>313±33</td>
<td>47±4.3</td>
<td>10±0.72</td>
<td>2.45±0.69</td>
</tr>
<tr>
<td>Conductivity $\sigma$ (S/m)</td>
<td>0.161±0.007</td>
<td>0.165±0.016</td>
<td>0.181±0.016</td>
<td>0.23±0.018</td>
<td>0.293±0.018*</td>
</tr>
</tbody>
</table>
Effect of different frequencies on electric properties of tea caterpillar larvae exposed in static magnetic field is shown in Table 1. In the table, sign “*” denotes there are significant differences in the results of t test, that is p<0.05. So, in the above measured frequency range, the effects of static magnetic field exposition on relative dielectric constant of tea caterpillar larvae are characterized by less effects in low frequency, but relative dielectric constant in higher frequency range of tea caterpillar larvae under static magnetic field exposition is much lower than the control group (p<0.05). Additionally, the effects of static magnetic field exposition on conductivity of tea caterpillar larvae are similar to relative dielectric constant. Obvious differences in relative dielectric constant happen at two frequency points of 1MHz and 10MHz, and obvious differences in conductivity is only at 10MHz. The results show, in low frequency range, relative dielectric constant of tea caterpillar larvae rapidly decreases as frequency increases, and conductivity increases as frequency increases.

5. Results and Discussion

Biological electromagnetism aims to study the interaction between the effects of electromagnetic field produced by biological life activities and applied electromagnetic field on living organism. Then the nature of electromagnetic phenomena in life activities and intrinsic mechanism of effects of electromagnetic field on living organism are revealed. Understanding the relationship and regular patterns between biological activities and electromagnetic phenomena will play a promoting role with milestone significance in diagnosis and treatment of various diseases and environmental protection [14]. In brief, biological electromagnetism is a new subject to study mechanism, characteristics and results of the interaction between electromagnetic fields and living organisms. Biological electromagnetism study is helpful for people to understand biological effects of electromagnetic fields, find right ways to avoid harms of electromagnetic fields, and provide service for improvement of human living environments and life health.

Occurrence mechanism of biological effects of electromagnetic fields is closely related to the characteristics of the electromagnetic fields themselves and changes of the electromagnetic properties of the biological tissues under the action of electromagnetic field. When biological tissues are in applied electromagnetic field at different frequencies, their electromagnetic characteristics will change, especially there will be obvious differences in dielectric constant and conductivity of biological tissues in different frequency electromagnetic fields [15]. Finding change law of electromagnetic characteristic parameters of biological tissues in different frequency electromagnetic field is the key to study the occurrence mechanism of biological effects in electromagnetic fields and to prevent problems. The electrical properties of biological tissues can be used in the theoretical calculation of biological effects of electromagnetic fields. The organisms themselves have specific electromagnetic properties. So there must be specific interaction between the static magnetic field in surrounding environment and living organisms. In order to explore effects of magnetic field on living organisms, some possible effects of different frequency magnetic field on living organisms are further investigated by studying the changes in the electrical properties of tea caterpillar larvae under the action of different frequencies after static magnetic field exposure. Structural properties of cell, the most basic structure unit composing living organisms, determine the electrical properties of living organisms. Because of different type and concentration of ions at both sides of the cell membrane, membrane impedance will fall with frequency increasing. When applied magnetic field frequency is high, electrical properties of the cell membrane are similar to that of the cell liquid. At this time, charging effect of cell membrane will rapidly decrease with frequency increasing. Dielectric properties reflect electrolyte dielectric properties of between cells and inside cells. The most fundamental mechanism of interaction between static magnetic fields and living organisms is that static magnetic field can make charged bodies moving in living organisms change the direction, and then affect the micro life movement of living organisms. If charged bodies in living organisms move at a high rate, relatively high induced electromotive force will be produced. So some studies have shown that the static magnetic fields with relatively high intensity can significantly inhibit cell division. Especially for charged ions needing transmembrane transport, because of its large charge, charged ions in static magnetic fields during transmembrane transport are affected heavily, which may be one of the main reasons for cellular level biological effects produced in static magnetic fields.

Magnetic field can not only affect the physiological activities of insects, but also have certain effects on behavioral ecology. Electromagnetic fields have a wide spectral range, and which wave bands affect life of insects is a problem worth studying [16]. Compared with other environmental factors (such as temperature and humidity), magnetic fields are relatively weak, and their biological effects are not easily found. As research objects, insects with short growth cycle and fast breeding are ideal experimental material. This new research field should carry out multi-level
researches on the effects of magnetic fields on insects from the micro to the macro. C software with its powerful computing performances and multi field coupling analysis ability realizes highly accurate numerical simulation in physics, and helps to study mechanism of effects of electromagnetic fields on biological system and evaluate the effect of magnetic fields with different frequencies on insects. Preliminary study for mechanism of electromagnetic fields on growth development of tea caterpillar larvae and protection strategy will provide some guidance for the scientific control and management of the pests.

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References


