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OPTIMIZATION OF RESOURCE ALLOCATION, EXPOSURE TIME AND ROTARY SPEED OF INCUBATIVE EGGS

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***Abstract**. Recently, the laser technology of influencing biological objects in biology, medicine, and veterinary medicine has become widespread in order to activate certain biochemical and physiological processes in the organism. Any influence of electromagnetic radiation (in particular optical emission) requires the exact adherence to the recommended illumination dose to obtain a positive effect on the biological object. The article presents the results of a theoretical study concerning provision of uniform illumination of the egg's surface, taking into account the location of the laser radiation source and rotating time of the egg.*

Keywords: laser emission, radiation dose, incubating egg

OPTYMALIZACJA ALOKACJI ZASOBÓW, CZASU EKSPOZYCJI I PRĘDKOŚCI OBROTOWEJ JAJ INKUBACYJNYCH

***Streszczenie**. Ostatnio technologia laserowego oddziaływania na obiekty biologiczne w biologii, medycynie i weterynarii stała się powszechna w celu aktywacji pewnych procesów biochemicznych i fizjologicznych w organizmie. Każdy wpływ promieniowania elektromagnetycznego (w szczególności emisji optycznej) wymaga dokładnego przestrzegania zalecanej dawki oświetlenia w celu uzyskania pozytywnego wpływu na obiekt biologiczny. W artykule przedstawiono wyniki badań teoretycznych dotyczących zapewnienia równomiernego oświetlenia powierzchni jaja, biorąc pod uwagę lokalizację źródła promieniowania laserowego i czas obrotu jaja.*

Słowa kluczowe: emisja lasera, dawka promieniowania, inkubowane jajo

Introduction

In the process of laser illumination of the shell surface of the incubating egg it is necessary to provide a uniform dose of radiation all over surface under the stipulation that egg rotates around its large axle. A graphs have been drawn under the stipulation that the value of the angular velocity of egg rotation is at the level $\omega = 0.5s^{-1}$ for which the dose value $E_D(z,\theta)$ is obtained. The present and average radiation dose, depending on the position of two lasers against to the egg's surface have ascertained by the way of ccalculations. As a result of theoretical studies, the graphs were obtained: of the changes of average radiation dose, depending on the angle of sight of the laser beam on the egg's surface; excess of the radiation dose above the average values at nodal points; change of the laser radiation dose on the egg's surface with optimal placement of lasers. As a result, it is shown that the position of the lasers against the egg substantially affects the uniformity of the illumination of the egg's surface. The optimum conditions for placing lasers against the egg's surface is the minimum excess of the radiation dose over its average value. The calculations have showed that with high probability ($P = 0.9973$) an increase in the dose of irradiation of the egg's surface, in comparison with the average does, not exceed 5.46%, and the corresponding decrease is 5.92%.

1. Setting the task

The current level of industrial poultry farming requires the use of modern technologies aimed at intensifying the production process, which are base on the results of recent scientific achievements in biophysics and medicine, in particular studies connected with the usage of laser emission [3, 28].

The pointed laser technologies are capable of providing the highest level of productive indicators of poultry at all stages of poultry production, including at the stage of incubation [1, 4, 22]. In addition, the regulating effect of the laser emission of the red wavelength range on the activity of some enzymatic systems [16], the metabolism of proteins, nucleic acids, and lipids [25] has been ascertained. Stimulation of proliferative activity of cells under the influence of laser emission [9, 18], marked hemostimulating [24] and immunomodulating action [7] of laser emission have been shown [17, 24].

A number of studies are devoted to the ascertainment of a probable mechanism of laser emission on biological objects of different levels of organization from cells to a holistic organism [23, 27]. Moreover, all researchers point out that the effectiveness of laser emission, with the wavelength and emission power, significantly depends on the dose of emission $D = J \cdot t$ and the general effect may have both activating and inhibiting effects on biological structures [8, 28].

Therefore, in the application of laser technologies in biology, medicine and agriculture, it is important to observe the required radiation dose [10, 11, 16].

2. Purpose study

Investigation of the conditions of placing the source of laser radiation in relation to the biological object on the example of irradiation of the shell surface of the incubation egg to provide the required radiation dose.

3. Reseach results

Consider the case where the left and right sources are located, respectively, at the points Q' and P' (Fig. 1a). Then the rays from both sources will come to the point D of the cross-section of the ellipsoid at an angle $\gamma = 90°$, leaving the middle part of it to remain non-irradiation. Ideally, in this case, the edges of the ellipsoid will be irradiated (Fig. 1b).

With the given dimensions $c = 0.0293\ m$, $b = 0.0227\ m$ of the half-axles, the angles $\theta = 165°$, $\Theta = 9°$, correspond to the described situations. Obviously, an increase of the angle θ above 165º and a decrease of the angle Θ below $9°$ will only worsen the exposure. If the emission source are at points Q'' and P'' ($\theta = 89°$, $\Theta = 69°$), then a similar situation will arise on the edges O and M of the ellipsoid, which will not be illumined, and the greatest part of the illumination will be obtained by the middle part of the ellipsoid (Fig. 1g). To reduce the angle θ (increase Θ) is impractical for the same reason. Therefore, a qualitative (uniform) illumination should be expected in the range of angles: $89° < \theta < 165°$, $9° < \Theta < 69°$.

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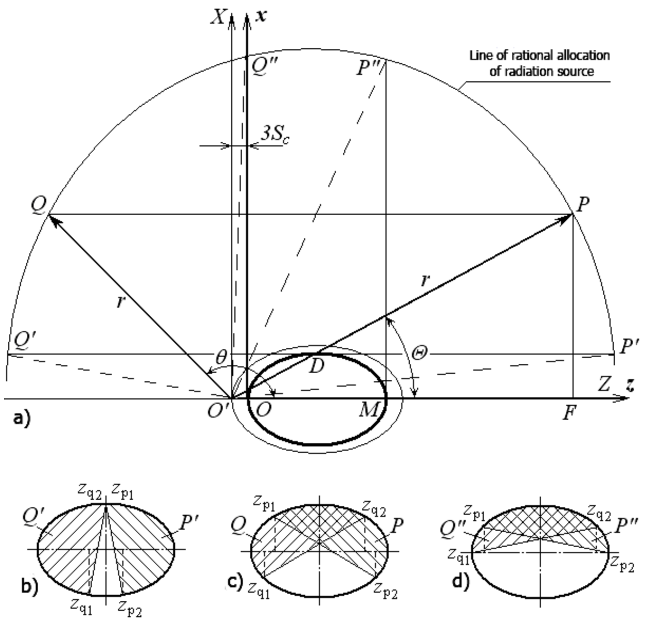

Fig. 1. Estimated pattern of irradiation of the ellipsoid by two sources

As we see, with $\theta = 89°$ the central part of the ellipsoid is the most illuminated, and with the approach to its ends the radiation dose decreases to zero. This corresponds to the scheme in Fig. 1a. If $\theta = 165°$ we have the opposite effect: the radiation dose decreases to zero in the central part of the ellipsoid and the maximum at its ends (Fig. 1b).

And in this case, there is the largest dose rate (from 0 to 50 Ws/m^2). This is explained by the fact that in this position of the sources the ellipsoid are deployed to them with a narrow part and it is closer to the sources than in the case of smaller corners θ. Fig. 1 also shows that the average value of the dose, with change of the sources position, varies slightly, but the deviation of the dose from the average significantly depends on the angle θ [5, 6].

In Fig. 2., on the basis of formula (1), (2) evaluation, the more exacerbated graphs of the current dose of radiation (together with the average value) are at five points of sources placement from the given range of angles. The positions (a), (e) of the figure correspond to the extreme points of the range [2, 13, 26].

The dose of irradiation for the length of the ellipsoid by two symmetrically located sources is equal to

$$E_D(z,\theta) = \frac{2J_i}{\omega}\left[EQ(z,\theta) + EP(z,\theta)\right] \qquad (1)$$

Determine the average value of the radiation dose of the ellipsoid surface:

$$E_D(\theta) = \frac{1}{c}\int_0^c E_D(z,\theta)\,dz = \frac{2J_i}{\omega c}\int_0^c \left[EQ(z,\theta) + EP(z,\theta)\right]dz \qquad (2)$$

As it was shown above (Fig. 2), the irradiation dose excess over the average values substantially depends on the angle θ, which determines the allocation of both sources relative to the exposure object. Below we will show that the configuration of the radiation line of the ellipsoid along the axis Oz with suboptimum angular values θ is rather complicated. The program of automatic search of the largest and smallest values irradiation dose in the presence of several (up to seven) local extremes is greatly complicated, and its application is difficult due to a sharp increase in search time. In these conditions, it seems advisable to use the function "Trace" - the system tracing "Mathcad", which allows with sufficient accuracy (up to three characters after a comma) to get the desired quantity according to the function graph [15, 21].

Let's note one more important feature. Graphs of the dose of irradiation in Fig. 1 were being constructed when the value of the circular frequency of the ellipsoid rotation equal to $\omega = 0.5\ s^{-1}$. The optimal value of this frequency is unknown to us yet. But to determine the dose of irradiation, we use formula (3), in which the circular frequency - ω and the radiation source of the source – J_i are included as a constant multiplier – $2\ J_i/\omega$ with a variable part $-[EQ(z,\theta)+EP(z,\theta)]$ [12, 14, 28].

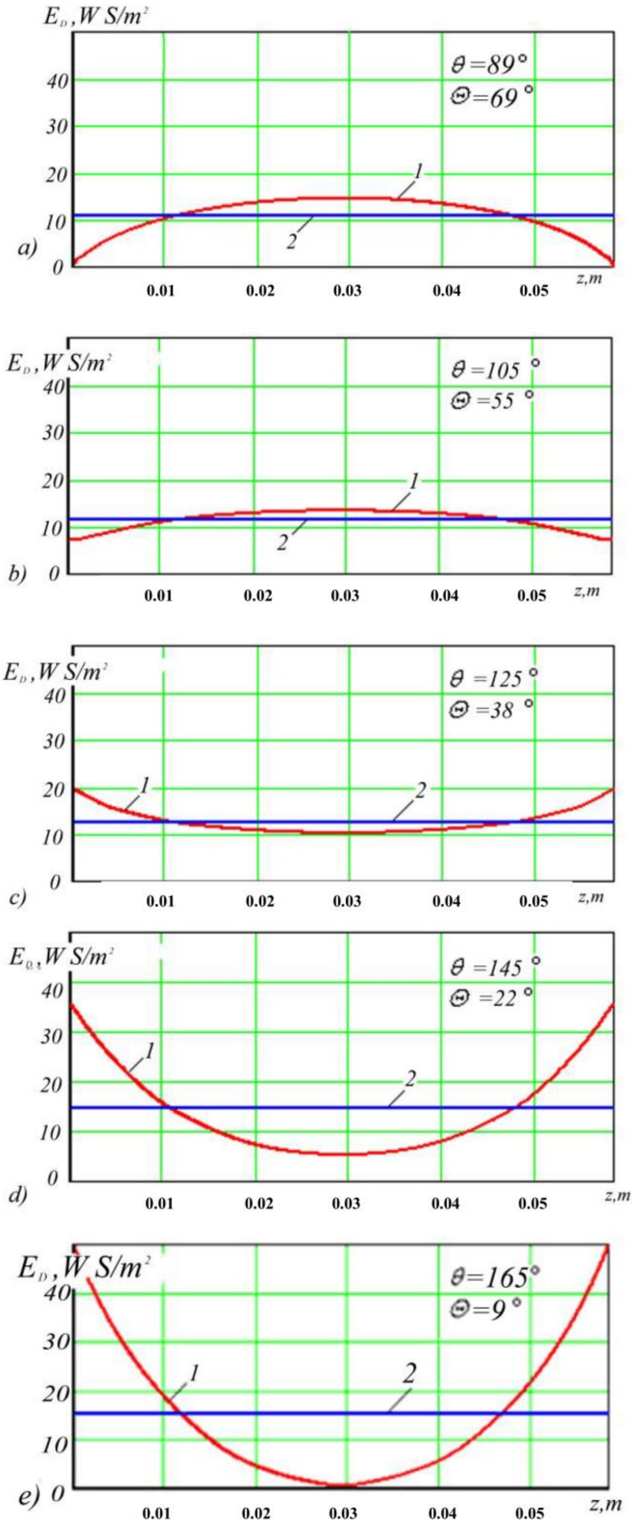

Fig. 2. Current (1) and average (2) doses of radiation depending on the position of sources when $c = 0.0229\ m$; $S_c = 0.0014\ m$; $\varepsilon = 0.634$; $\psi = 22°$; $J_i = 0.05\ BT$; $\omega = 0.5\ s^{-1}$

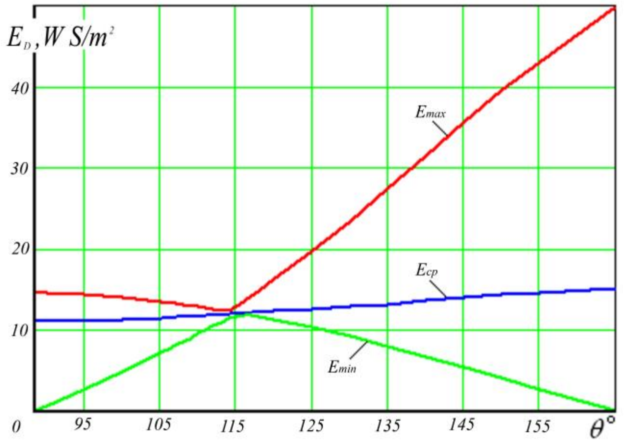

Fig. 3. The average dose rate of radiation and its correlation against the location of the radiation source

Thus, the radiation dose for the length of the ellipsoid by two symmetrically located sources is:

$$E_D(z,\theta)=\frac{2J_i}{\omega}\left[EQ(z,\theta)+EP(z,\theta)\right] \quad (3)$$

Therefore, neither frequency – ω nor power – J_i effect the optimum position. We further, for preserving the physical meaning of the measured value of the dose (radiation dose), will save the multiplier 2 J_i.ω in formula (3) with the indicated above the previous value of the frequency ω. And after determining the optimal allocation of sources of irradiation, this value we are going to specify [13, 17, 19].

On the basis of the obtained equality it is possible to determine the average value of the radiation dose of the ellipsoid surface:

$$E_D(\theta)=\frac{1}{c}\int_0^c E_D(z,\theta)\,dz=\frac{2J_i}{\omega c}\int_0^c\left[EQ(z,\theta)+EP(z,\theta)\right]dz \quad (4)$$

The average (4) and current (3) axis dose values *Oz, z ϵ [0;2c]* were determined to reveal the optimal angle value θ. By the method of tracing the current dose its maximum and minimum values were founded. The table of these variables is calculated with a corner angle θ in 5º, and in the area of the expected optimum – with step in *1º* (appendix X2). Output data for the calculation are the same as in Fig. 1. Based on the results of calculations, the graphs are drowned (Fig. 3), which allow to reveal (by the same method of tracing) a narrow range of angle θ *(113º...114º*). There is a minimum excess of the dose of irradiation above the mean value. The graphs also show that the maximum of the minimum dose and the minimum of the maximum are near, and thus, with a minimum excess of the radiation dose above the mean value, the lower deviation will also be small. In the specified range, the dose exceeded $\Delta E = 100(E_{max}-E_{cp})/E_{cp}$ by step *0.1º*. The results of the calculation are represented by two vectors [14, 27]:

$$Teta := (113.5\ \ 113.6\ \ 113.7\ \ 113.8\ \ 113.9\ \ 114.0\ \ 114.1\ \ 114.2)^T$$

$$DelE := (3.680\ \ 3.506\ \ 3.330\ \ 3.140\ \ 2.979\ \ 3.044\ \ 3.265\ \ 3.729)^T$$

where "T" denotes transposition operation. For the given values, a smooth curve is constructed by the method of cubic interpolation, which in the environment of "Mathcad" is follows:

$$\Delta E(\theta) := \mathrm{interp}\left(\mathrm{cspline}\left(Teta, DelE\right), Teta, DelE, \theta\right)$$

The graph of the obtained dependence is presented in Fig. 4.

The optimal angle value θ is obtained using the built-in "Mathcad" function - "Minimize":

$$\theta := 113 \qquad \theta_{opt} := \mathrm{Minimize}(\Delta E, \theta) \qquad \theta_{opt} = 113.92 \quad (5)$$

The same value can be obtained by tracing the graph in the picture below. The value 113.92° corresponds to 1.988 rad.

The second source corresponds to the optimal angle:

$$\Theta_{opt}=\Theta\left(\theta_{opt}\right)=\Theta(1.988)=46.7^\circ=0.815rad \quad (6)$$

But, since the radiation sources are symmetric, the necessary optimal parameters can be obtained from a single source.

Height of laser stand holder:

$$H = X\left(\theta_{opt}\right)=X(1.988)=0.134m \quad (7)$$

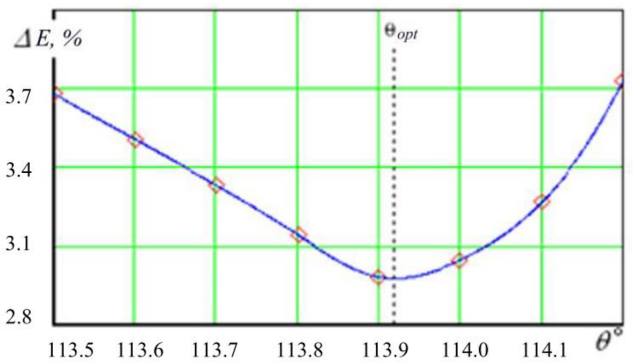

Fig. 4. Excess dose above average together with nodal points

Distance from the rack to the center of the ellipsoid:

$$L = c - Z\left(\theta_{opt}\right)=c-Z(1.988)=0.093m \quad (8)$$

The circle frequency of the ellipsoid can be founded from formula (4) to determine the average dose of irradiation. Substituting there instead of the angle θ its optimal value θ_{opt}, and instead of the average dose value $E_D(\theta)$ – normative $[E_D^N]$, we obtain:

$$\omega=\frac{2J_i}{c[E_D^N]}\int_0^c\left[EQ(z,\theta_{opt})+EP\left(z,\theta_{opt}\right)\right]dz=0.46s^{-1} \quad (9)$$

The time of irradiation and the frequency of rotation of the ellipsoid can be found by the way of using the known dependencies:

$$T=\frac{2\pi}{\omega}=13.6s\,,\ n_{ob}=\frac{60}{T}=4.4rpm \quad (10)$$

Frequency n_{ob} can be multiply increased without losing the effect of irradiation (eg.: $n_{ob} = 8.8$ revolutions per minute, $n_{ob} = 13.2$ revolutions per minute etc.), under the condition if the time T is saved [18, 19].

Now, when the magnitude becomes known, it is necessary to clarify the value of the deviations of the irradiation dose of the ellipsoid from the mean value, which is equal to the normative – $[E_D^N]$. For clarity, we are going to present a schedule for changing the dose along the length of the ellipsoid, which corresponds to the optimal allocation of radiation sources ($\theta = 1.988$; $\Theta = 0.815$).

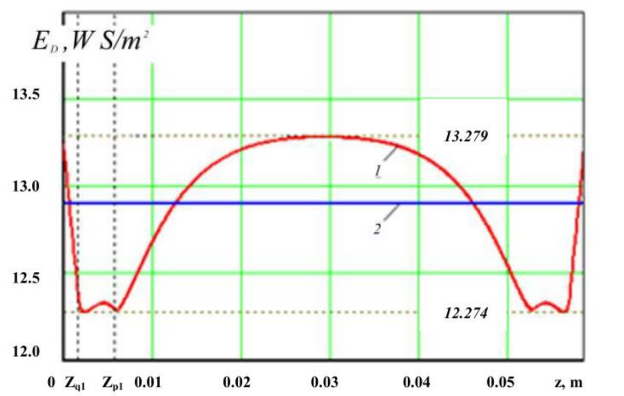

Fig. 5. The irradiation dose change along the length of the ellipsoid under the condition of optimal placement of sources

In the interval $z \epsilon [0;z_{q1}]$, the endpoint of the ellipsoid at first receives an irradiation dose above the mean, and then, to the end of the segment, it drops to almost the minimum value due to the distance from the source *Q* (increase of coordinate *z*). At the site $z \ \epsilon[z_{q1};\ z_{p1}]$, with increasing coordinate *z*, the angle of incidence of rays γ on the surface of the ellipsoid decreases, resulting in a dose increasing. But, at the same time, the irradiated surface continues to move away from the source, and the coverage angle $\phi(z)$ of the irradiation spot decreases. As a result, it reduces the radiation dose to the end of the segment. In the absence of the second source *P*, the dose reduction would continue to zero at a point $z = z_{q2}$, any longer of which the rays of the first source *Q* do not reach the surface of the ellipsoid. However, starting from the point $z = z_{p1}$ the influence of source *P* appears. As a result of radiation imposition of both sources, the radiation dose increases to the maximum value in the middle part of the ellipsoid. The second half of the graph $z = [c,2c]$ is symmetrical to the first and has the same explanation of the "behavior" of the curve [12, 27, 28].

According to the schedule, the upper and lower deviations of the radiation dose from the average value, which, respectively, are equal to: $\Delta E = 2.94\%$; and $\Delta E_H = 4.85\%$ are determined simply. These figures occur for an ellipsoid with medium-sized *c*, *b* of half-axes. As has been mentioned more than once, the indicated sizes in the process of radiation range: $c \pm 3S_c$; $b \pm 3Sc\sqrt{1-\varepsilon^2}$. For ellipsoids with the maximum and minimum dimensions of the half-axis, the deviation from the average dose $[E_D^N]$ may not coincide with the same values which were obtained for the average size. Therefore, for the specified limits, additional calculations have been made. From the three pairs of the founded values, including the above, the maximum values of the required indicators are selected [12, 20]:

$$\Delta E = 5.46\%;\ \Delta E_H = 5.92\% \qquad (11)$$

Thus, on the basis of the rule of "three sigmas", it can be argued that with an optimal allocation of sources with a probability of 0.9973, the increase of the irradiation dose of the ellipsoid will not exceed 5.46% compared to the average value, and the reduction does not exceed 5.92%.

All calculations related to the irradiation of the ellipsoid by two sources, conducted in the environment of "Mathcad" on the developed program, which is presented in Annex X3 [28].

4. Conclusions and future work

Ellipsoid irradiation is considered with two identical sources which are installed symmetrically on the line of rational placement. Expressions for determining the current and average doses of the ellipsoid irradiation by each source were obtained. The resulting dose of irradiation was the imposition of radiation doses received from each source.

The dependence of maximum, average and minimum doses of irradiation in the case of synchronous motion of sources along the rational placement is constructed. They showed a significant dependence of the irradiation uniformity on the position of the sources on the specified line. The optimal approach was such sources positioning in which excess radiation dose above the mean value was minimally possible. Calculations conducted in the interval of the ellipsoid size "three sigma" from the average showed that with the probability of 0.9973 increase in the dose of the ellipsoid compared with the average does will not exceed 5.46%, and decrease – will not exceed 5.92%.

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