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Determination of the parameters of an ellipsoidal electrode tip for treating agricultural animals using UHF – therapy methods

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Abstract. The use of non-medicamentous means of treating farm animals presupposes the presence of not only an ultra-high frequency electromagnetic radiation generator but also a rectal emitter, which is directly inserted into the animal's rectum. The effectiveness of the treatment carried out using UHF therapy methods largely depends on the shape of the emitter tip. When choosing the external shape of the emitter tip in the form of half of an ellipsoid of revolution, it becomes necessary to optimize the parameters of this ellipsoid. The goal of optimization is to minimize the resistance force of the living tissue of the animal when a cylindrical emitter with a tip is inserted into the rectum.

1 Introduction

Nowadays, increasing milk production is one of the main tasks facing the agricultural industry. This industry, like all others, requires the use of modern technologies. The diseases of animals can be attributed to one of the significant factors that restrain the volume of milk production when an animal consumes various resources to maintain its vital activity but does not bring any return. This causes significant economic damage to every enterprise in the agro-industrial complex and the industry.

Endometritis, mastitis, and a host of other diseases reduce the productivity of animals. Treatment of animals is carried out mainly by medical methods. But this method has several disadvantages. These include a prohibition for a long time on the use of milk from an animal undergoing treatment [1]. After treatment for a long time, milk may contain substances harmful to humans, such as antibiotics [2].

During treatment, the animal's body becomes accustomed to drugs, and the side effects. The listed disadvantages and the cost of medicines search for other methods of treatment intensify.

Physiotherapy treatment can be considered an alternative to medication. The body of a sick animal reacts to the action of external factors, which entails an increase in its protective properties. The range of physiotherapeutic effects is very wide. But they are all based on a limited number of factors: heating or cooling, mechanical compression or, on the contrary, stretching, electromagnetic fields of different frequencies. All treatment methods differ in both their advantages and disadvantages. The impact on the animal leads to an increase in metabolism, expansion, or vice versa, to a narrowing of blood vessels. As a result, the blood supply to the diseased tissue increases, which leads to an increase in the healing tendencies. It is generally accepted that physiotherapy methods have different effects, which depend on several factors, such as how the application of cooling is used: snow, wet compress, ice, cold water. Cooling leads to vasoconstriction, which helps to reduce edema. Heat is used when inflammation is reduced. This happens 3-5 days after the onset of the disease. The animal receives heat by means of compresses, using paraffin, heating pads. Heating leads to the activation of recovery processes in diseased tissues, but the depth of its penetration is insignificant. Therefore, it is more expedient to carry out heating from the inside of the animal using a rectal emitter.

For a long time, there has been treatment with light, electromagnetic waves and ultrasound. These methods are applied independently and together with medications. When absorbed by animal tissues, light quanta are converted into thermal energy and have a therapeutic effect, which depends on the frequency and power of radiation with frequencies:

- Infrared - from 2 mm to 740 nm;
- Visible - from 400 to 740 nm;
- Ultraviolet - from 180 to 400 nm.

A decrease in the wavelength of electromagnetic radiation leads to a decrease in the depth of exposure to biological tissue. For example, infrared radiation penetrates 2-3 centimeters, visible radiation up to 1 cm, ultraviolet radiation 0.5-1 mm. The degree of tissue heating is determined by the time of exposure and distance to the place of irradiation. UV rays are the most energetic. As a result, biologically active substances are generated, such as histamine, biogenic amides, acetylcholine, etc., which activate positive reactions of the immune system and enhance metabolic processes of

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substances in tissues. Variable frequency currents in the range from several hertz to several gigahertz are widely used in physiotherapy. The use of high-frequency electromagnetic fields (HF) in physiotherapy is considered the most effective because of the penetration into the deep layers of tissues, which is exactly what is required in the treatment of internal inflammation.

The main advantage of the use of physiotherapy in the treatment of farm animals is the absence of antibiotics in products and the possibility of preventing possible diseases. The disadvantages of physiotherapy include the low effectiveness of treatment in the acute period of the disease, when the animal's body is in a weakened state. The best result of treating an animal weakened by the disease is observed in a combination of a medical approach and subsequently accelerating the recovery time with the help of physiotherapy. Disease prevention reduces the percentage and severity of diseases and allows limiting only to physiotherapy.

Among the advantages of using ultra-high frequency (UHF) electromagnetic field, one can note a decrease in the period of commissioning a cured animal, a decrease in the cost of treatment due to the unnecessary use of expensive drugs, and a decrease in labor costs during treatment. The animal's body does not get used to the UHF field.

2 Formulation of the problem

Electrodes, depending on animal diseases, can have a different appearance. Consider an electrode designed to be inserted into the rectum of an animal. It consists of a cylindrical part, completed by a streamlined surface. Inside the cylindrical part is the actual electrode made of metal. The outer cylindrical shell of the UHF radiator has the shape and dimensions indicated in Figure 1. The end of the radiator, as seen in Figure 1, is described by the surface of rotation.

It is necessary to determine and calculate the parameters of the irradiator tip that minimized the resistance force of living tissue when it is introduced into the rectum. We will consider it a shell with a thickness of δ and a known diameter.

Let the surface of the UHF energy transmitter tip be obtained as a result of the rotation of the line $z = f(\rho)$ around the applicate Z axis (Figure 2). Let us introduce the designation $\Pi(R_0,R_1)$ – the part of the surface of revolution lying between the planes bounded by the radii of the rectum and the cylindrical part of the emitter $z = R_0$ and $z = R_1$ (Figure 1).

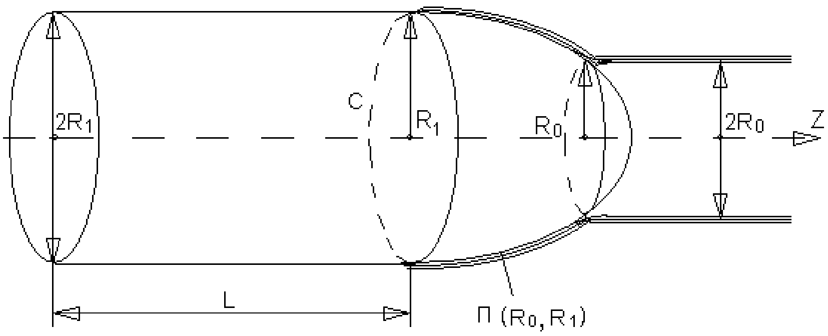

Fig. 1. Rectal emitter

Then the resistance force of rectal tissues is determined by the following surface integral of the projection of force $\overline{F} = \overline{P} + \overline{T}$ ($\overline{P}$ is the force of action, and $\overline{T}$ is friction) on the axis of the application Z:

$$F_{res} = \iint_{\Pi(R_0,R_1)} F_z dS .$$

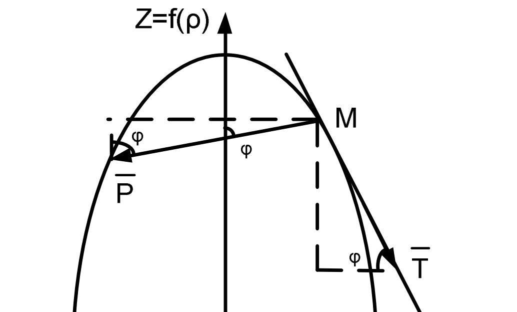

Fig. 2. Resistance forces of rectal tissues to the emitter of UHF energy

The force F_z is found from the theory of shells [3]:

$$\frac{d}{d\varphi}(N_m \cdot \rho \cdot \sin\varphi) + F_z \cdot \rho \cdot \rho_m = 0,$$

where N_m is the force along the meridian, ρ_m is the radius of curvature along the meridian, ρ is the radius of a circle parallel to the x0y plane:

$$F_z = -\frac{1}{\rho \cdot \rho_m}\frac{d}{d\varphi}(N_m \cdot \rho \cdot \sin\varphi)$$

Since $f'(\rho) = tg\beta,\ \varphi + \beta = 180^0$ (Figure 2), whence it follows,

$tg\varphi = -f'(\rho)$, then

$\cos\varphi = \frac{1}{\sqrt{1+[f'(\rho)]}^2}$ and $\sin\varphi = \frac{-f'(p)}{\sqrt{1+[f'(p)]}^2}$.

Since

$$\varphi = -arctg[f'(\rho)],$$

it is expedient to replace the derivative with respect to the value through the derivative with respect to the value of ρ:

$$\frac{d}{d\varphi}=\left(\frac{d\varphi}{d\rho}\right)^{-1}\frac{d}{d\rho}=-\frac{1+\left[f'(\rho)\right]^2}{f''(\rho)}\cdot\frac{d}{d\rho},$$

due to the fact that

$$\rho_m=\frac{\{1+[f'(\rho)]^2\}^{\frac{3}{2}}}{-f''(\rho)},$$

we get

$$F_z=\frac{1}{\rho\cdot\sqrt{1+[f'(\rho)]^2}}\frac{d}{d\rho}\left[\rho\cdot\frac{f'(\rho)}{\sqrt{1+[f'(\rho)]^2}}N_m\right].$$

Then $F_{res.}$of rectal tissues takes the form:

$$F_{res}=\iint_{\Pi(R_0,R_1)}F_z\cdot dS$$
$$=\int_0^{2\pi}d\varphi\int_{R_0}^{R_1}F_Z\cdot\sqrt{1+[f'(\rho)]^2}\,\rho d\rho=$$
$$=2\pi\left[\rho\cdot\frac{f'(\rho)}{\sqrt{1+[f'(\rho)]^2}}\cdot N_m(\rho)\right]\int_{p=R_0}^{p=R_1}=2\pi\cdot R_0\cdot\frac{-f'(R_0)}{\sqrt{1+[f'(R_0)]^2}}\cdot N_m(R_0),$$

since$N_m(R_1)$.

We define the variable $N_m(\rho)$ using the Laplace equation for the theory of shells as [3,9]:

$$k_t\cdot N_t+k_m\cdot N_m+P=0,$$

where P is the force of external pressure on the emitter.

We find the meridian and circumferential curvatures by the expressions:

$$k_m=\frac{-f''(\rho)}{\{1+[f'(p)]^2\}^{\frac{3}{2}}}\ (1)$$

and

$$k_t=\frac{-f''(\rho)}{\rho\sqrt{1+[f'(\rho)]^2}}.\ (2)$$

Let us find the force of external pressure P proceeding from the second equation of the shells

$$F_z=\frac{1}{\rho\cdot\sqrt{1+[f'(\rho)]^2}}\cdot\frac{d}{d\rho}\left[\rho\cdot\frac{f'(\rho)N_m}{\sqrt{1+[f'(\rho)]^2}}\right].$$

Due to the fact that

$$F_z=P_z+T_z=P(\cos\varphi+k\sin\varphi)$$

with coefficient of friction k (Fig. 2)

$$P=\frac{1}{\rho\cdot[1-k_0f'(\rho)]}\frac{d}{d\rho}\left[\rho\cdot\frac{f'(\rho)}{\sqrt{1+[f'(\rho)]^2}}N_m(\rho)\right].$$

Considering the expressions for the curvatures (1), (2) and the relationship of forces and stresses for thin shells with a thickness of δ :

$$N_t=\delta\cdot\sigma_t,\ N_m=\delta\cdot\sigma_m,$$

we derive the equation in derivatives:

$$\frac{d}{d\rho}\left[\rho\cdot\frac{f'(\rho)}{\sqrt{1+[f'(\rho)]^2}}\cdot\sigma_m\right]$$
$$=\left[\frac{f'(\rho)}{\sqrt{1+[f'(\rho)]^2}}\sigma_t+\frac{\rho\cdot f''(\rho)}{\left(\sqrt{1+[f'(\rho)]^2}\right)^3}\sigma_m\right][1-k\cdot f'(\rho)].\ (3)$$

Using Hooke's law, we combine the stress along the meridian σ_m and the stress along the entire circumference σ_t [4,7]:

$$\varepsilon_t=\frac{1}{E}\left(\sigma_t-\nu\cdot\sigma_m-\nu\cdot\sigma_\zeta\right),$$
$$\varepsilon_m=\frac{1}{E}\left(-\nu\cdot\sigma_t+\sigma_m-\nu\cdot\sigma_\zeta\right),\ (4)$$
$$\varepsilon_\zeta=\frac{1}{E}\left(-\nu\cdot\sigma_t-\nu\cdot\sigma_m+\sigma_\zeta\right),$$

where ε_t, $\varepsilon_m$and ε_ζ – shape changes; $E\left[\frac{n}{m^2}\right]$ (n/m^2) – modulus of elasticity from reference materials; ν– Poisson's ratio [5].

Since σ_ζ is an insignificant value, compared to σ_m and σ_t the equation forε_t from expressions (4) will be represented as [6,8]:

$$\varepsilon_t=\frac{1}{E}\left(\sigma_t-\nu\cdot\sigma_m\right),$$

and

$$\sigma_t=E\cdot\varepsilon_t+\nu\cdot\sigma_m.$$

The value of ε_t is determined based on Figure 3 and the formula:

$$\varepsilon_t=\frac{\Delta l}{l_0}=\frac{\rho-R_0}{R_0}.$$

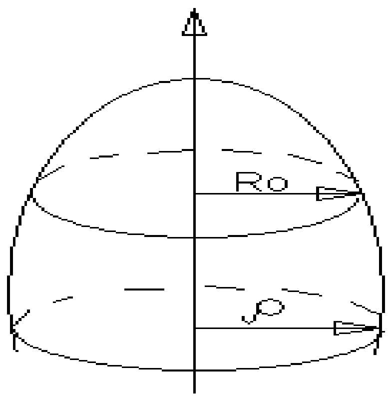

Fig.3. Emitter tip

The expression for$\sigma_t$takes the form:

$$\sigma_t=E\cdot\frac{\rho-R_0}{R_0}+\nu\cdot\sigma_m.$$

Differential equation (3) is transformed to the form:

$$\frac{d}{d\rho}\left[\rho\cdot\frac{f'}{\sqrt{1+[f'(\rho)]^2}}\sigma_m\right]=$$
$$=\rho\cdot\frac{f'(\rho)}{\sqrt{1+[f'(\rho)]^2}}\cdot\sigma_m$$
$$\cdot\left\{\frac{v}{\rho}+\frac{f''(\rho)}{f'(\rho)[1+[f'(\rho)]^2]}\right\}+E\cdot$$
$$\cdot\frac{\rho-R_0}{R_0}\cdot\frac{f'(\rho)[1-kf'(\rho)]}{\sqrt{1+[f'(\rho)]^2}}\cdot$$

We have a linear inhomogeneous differential equation of the 1st order with variable coefficients with respect to

$$Y(\rho)=\rho\cdot\frac{f'(\rho)}{\sqrt{1+[f'(\rho)]}^2}\cdot\sigma_m(\rho).$$

$Y(\rho)$ depends on unknown σ_m and surface function $f(\rho)$ is the equation of the end surface of the radiator. The force of the action of the emitter on the rectal tissues F_{res} with the help of $Y(\rho)$has the form [9,10]:

$$F_{res}=-2\pi\cdot\delta\cdot Y(R_0).$$

Let us assume that the emitter tip is described by the equation of the upper half of the ellipsoid:

$$\frac{x^2+y^2}{b^2}+\frac{z^2}{a^2}=1,\ z\geq 0,$$

i. e. $z=f(\rho)=\frac{a}{b}\sqrt{b^2-\rho^2}$, $b=R_1$, (Figure 4):

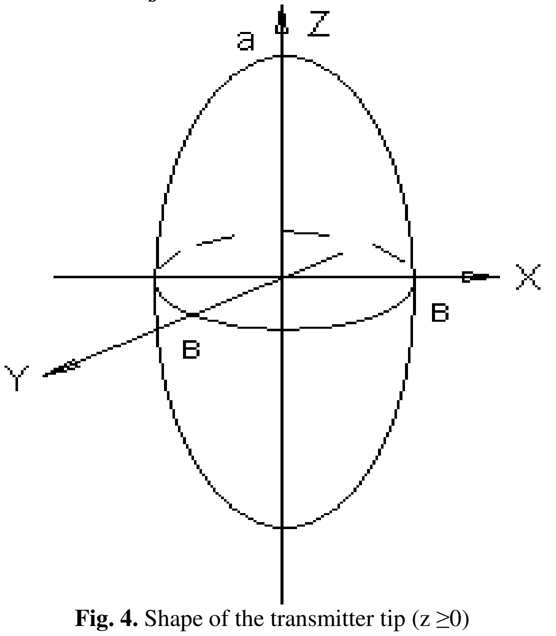

Fig. 4. Shape of the transmitter tip (z ≥0)

Let us concretize the differential equation (3). After solving it, we get the required resistance force:

$$F_{res}=F(a)=\frac{2\pi\cdot\delta\cdot E\cdot b^v}{R_0^{v+2}}\cdot a\cdot\sqrt{b^4+(a^2-b^2)R_0^2}\cdot$$
$$\cdot exp\left\{k\left[arctg\left(\frac{b}{a}\frac{\sqrt{b^2-R_0^2}}{R_0}\right)\right.\right.$$
$$\left.\left.-\frac{va}{b}arc\sin\left(\frac{R_0}{b}\right)\right]\right\}$$
$$\cdot\int_{arc\sin\left(\frac{R_0}{b}\right)}^{\frac{\pi}{2}}\frac{b\sin u-R_0}{R_0}$$
$$\cdot\frac{(\sin u)^{v+2}(b\cos u+ka\sin u)}{a^2sin^2u+b^2cos^2u}$$
$$\cdot exp\left\{k\left[\frac{va}{b}u-arc\,\mathrm{tg}\left(\frac{b}{a}ctgu\right)\right]\right\}du$$

3 Conclusion

Having investigated this expression from *a* to a minimum and taking the remaining values as constants, we will have the optimal value of the parameter *a* of the ellipsoid, which minimizes the resistance force of the soft tissue membrane of the rectal intestine of the animal. In the future, the task can be concretized by introducing such a parameter as a predetermined length of insertion of the electrode into the rectal intestine of the animal.

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