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GEOMETRICAL PARAMETERS FOR COMPUTATION OF CYLINDER INDUCTORS OF UNCIRCULAR TO CUT

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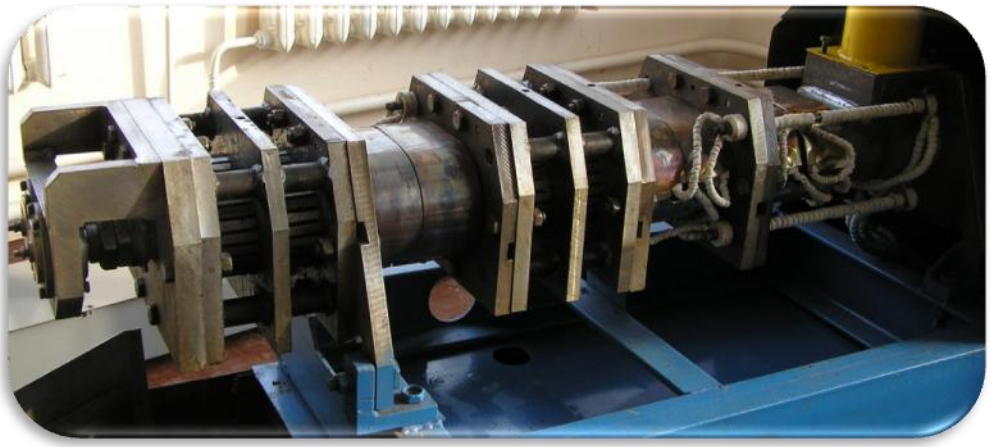
The methods of ecvivalentouvannya cylinder obectiv, that have an uncircular form are considered, by circular cylinders. Coregouyochi coefficients which allow to decrease the error of computations of power parameters of inductors for heating of metallic elements of uncircular to the cut are definite.

Inductor, equivalent diameter, induction heating, experiment, active resistance of inductor.

The induction heating is the effective mean of providing of temperature conditions of technological equipment. Often the use of exactly inductor as thermal energy sources in place of traditional nihromovih nagrivachiv or TENiv allows substantially to promote energoefectivnist of thermal treatment, reliability of nagrivalnogo equipment, and also to simplify the methods of support of the set temperature in the object of heating through bezinertsiynist induction heating. In presses for processing of oily material 75 % common quantity of energy is expended on support of necessary temperature of corps and raw material. Rezistivni nagrivachi from a nihromovogo wire uses for heating of technological equipment. The unevenness of the temperature field and short space of service of nagrivachiv such type induces to the search of alternative thermal energy sources which can be used in oily-fatty industry. The ecological and small time of output on the set temperature conditions on comparison with rezistivnimi nagrivachami induces to introduction of induction methods of heating in processing of oily materials. Nagrivachi on the corps of ecstroudera (rice. 1) are disposed in three areas. Power of each of them makes 3 cVt, and an inductor is set in the state place of nagrivachiv on a corps. The corps of ecstroudera, where heating is executed, has an oval form, length of area 0,32 m, perimeter of corpousa 0,444 m.



Rice. 1. Original appearance of corps ecstroudera EC 75/1200:
1 - corps of ecstroudera; 2 - areas of heating of corpousa; 3 - entrance mouth of press.

Computation of power descriptions of induction nagrivacha is executed for his oval form. For application of simple methods of computation notion of equivalent diameter of good which is heated is entered. In literature there is absent synonymous information in relation to determination of equivalent diameter. So, in [4] the equivalent diameter of load with the rectangular cut is determined as:

$$D_{ек} = \frac{2(a+b)+4\Delta_к}{\pi}, \quad (1)$$

whear: a, b – sides of rectangle, m; $\Delta_к$ – depth of penetration of current on frequency of source of feed, m, $\Delta_к = \sqrt{\frac{2}{\mu\sigma\omega}}$; μ – permeance of steel; σ – specific conductivity of steel, См/м; ω – angular speed, red/s.

In a formula (1) undertakes to attention that vortical currents on high-frequency of feed (f >1000 Hertzs) lock oneself on the surface of good. In work [3] an author determines an equivalent diameter on condition of equality of areas of transversal cuts of equivalent cylinder load and characteristic size of square. So, for a square with a side and an equivalent diameter will be it is calculated as:

$$D_{ек} = \frac{2a}{\sqrt{\pi}}. \quad (2)$$

For square to the cut 100x100 mm and frequencies 50 Hertzs the comparison of results of computations after expressions (1) and (2) equivalent diameter, gives disagreement on 1,5 %. From one side, the size of equivalent diameter after expression (1) relies on the mode of operations of induction nagrivacha, which the value of permeance is determined by, that in the turn determines the depth of active layer. From other side expression (2) such the dependence scorns.

The purpose of researches is determination of equivalent diameter of uncircular cylinder taking into account the modes of operations of induction nagrivacha. Materials and method of researches. The put task we will decide, using the numeral experiment which we will execute with the use of software product COMSOL Multipfisics. Results of researches. COMSOL Multiphysics - this software environment which provides all stages of design: determination of geometrical parameters, description of physical descriptions that visualization. The marked allows to design processes which can be given as a system of the differential evening at partial derivative. In our case for the design we will use the module AC/DC Module in a section Quasi-Static, Magnetic in subsection In-Plane Induction Current, Magnetic Field taking into account the harmonic analysis - Time-harmonic analysis.

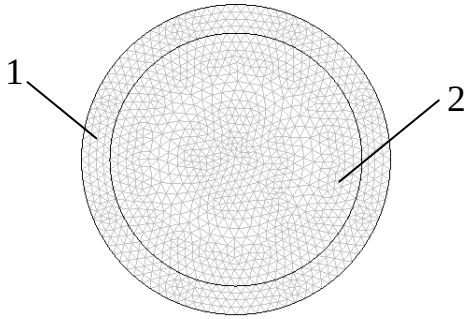
On rice. 2 the cut of corpousa ecstroudera is resulted with an eventual-element net in the object of design. Distributing of the electromagnetic field is determined as a result of decision of the such differential evening[5]:

$$j\omega d\mu_0\mu_r H_z + \nabla\times d\left(\sigma + j\omega\varepsilon_0\varepsilon_r\right)^{-1}\left(\nabla\times H_z - \bar{J}^e\right) - \bar{v}\times\mu_0\mu_r H_z = 0, \qquad (3)$$

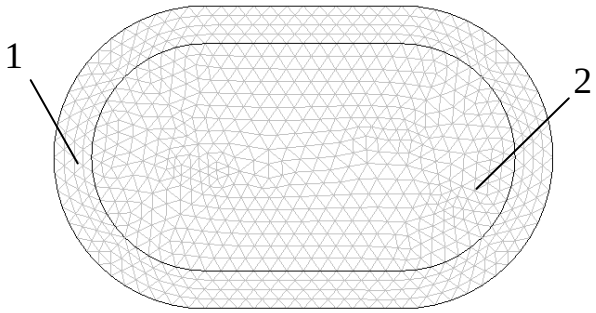
whear: j – density of current, A/m^2; d – thickness of corps, м; μ – permeance of vacuum; μ_r – permeance of material of corps; H_z – tension of the magnetic field, A/m; ∇ – operator Nabla; ε_0 – dielectric permeability of vacuum; ε_r – relative dielectric permeability of material of corps; $\bar{J}^e$ – density of current, A/m^2; $\bar{v}$ – speed, m/s.

Evening (3) can be untied on condition of setting of values of power of the magnetic field on granitsi of external region of geometry of detail. For

determination of equivalent parameters of uncircular cylinder inductor we will make a comparison of two geometriy uncircular and circular cuts (rice. 3). By the terms of equivalence we adopt equality of power of the mognitnogo field on the surface of models and achievement of identical power losses after both geometriyami. The electro-physical parameters of environment here - are identical.



Rice 2. Geometry of corpousa ecstroudera with an eventual-element net: 1 - steel corps; 2 - air



Rice 3. Geometry with an eventual-element net equivalent to the corps of ecstroudera:
1 - steel corps; 2 - air

It is suggested to calculate an equivalent diameter after the perimeter of uncircular model taking into account clarifications at the change of values of tension of the magnetic field and frequency of feed. Consequently, we will determine an equivalent diameter so:

$$D_{ек} = \frac{1}{k}\frac{П}{\pi}, \qquad (5)$$

whear: $П$ – perimeter of detail, м; k – coregouyochiy coefficient.

For determination of correcting coefficient of k we will conduct the dvofactorniy experiment. We will explore co-operation of tension of the electromagnetic field and frequency of source of feed. The value of coefficient of k, at which quantity of the energy selected in the volume of equivalent and real details will be identical, will be the resulting size of experiment.

We will define the scopes of varying of factors of influencing H and f on the basis of literary data and results of analytical computation. So H is varied in scopes

from 10000 to 100000 A/m, we change f from 50 to 8000 Hertzs. For the detailed study of areas of surface of review of k at the change of value of tension of the magnetic field and frequency of current the polynomial of the second order, got as a result of conducting of number povnofactornogo experiment of the second order, can be used [1]. The plans of 2th order allow to get mathematical description of process as a complete quadratic model which contains, except for the basic effects of bi, all parni co-operations of bij and quadratic effects of bii. On the basis of present data analysis we choose such even and intervals of varying of factors (tabl. 1).

1. Intervals of varying of factors of influencing

Factors		Levels				
		-1	0	+1	+α	-α
Tension of the magnetic field, *H*	x_1	23175	55000	86825	100000	10000
Frequency, *f*	x_2	1213.8	4025	6836.2	8000	50

Value of star shoulder ±α for the plans of the second order makes 2,828 [1]. Size of power losses which arise up in the corps of ecstroudera and equivalent construction, we measure by means intrinsic function of the program Comsol Multipfisics 3.5a, Subdomain Integration. On the basis of the accepted parameters we make the matrix of planning of experiment (tabl. 2).

2. Matrix of planning of dvofactornogo experiment

Number of experience	Factors in conditional units	Factors in a natural scale

in a matrix	*x1*	*x2*	*H,A /m*	*f, Hz*
1	-1	-1	23175	1213,8
2	-1	+1	23175	6836,2
3	+1	-1	86825	1213,8
4	+1	+1	86825	6836,2
5	0	0	55000	4025,0
6	-a	0	10000	4025,0
7	+a	0	100000	4025,0
8	0	-a	55000	50,0
9	0	+a	86825	8000,0

As a result of experiment the regressive evening of dependence of correcting coefficient of k is collected from tension of the electromagnetic field and frequency of source of feed.

$$k(H, f) = 0{,}955 + 4{,}468 \cdot 10^{-7} H - 8{,}1 \cdot 10^{-6} f - \\ - 2{,}63 \cdot 10^{-11} Hf - 1{,}23 \cdot 10^{-12} H^2 + 6{,}56 \cdot 10^{-10} f^2. \quad (6)$$

Using evening (6) we will define computations and experimentally the got values of correcting coefficient for determination of error of experiment (tabl. 3).

3. Experimental and computation correcting coefficient

№ досліду	1	2	3	4	5	6	7	8	9
$k_{експ}$	0,9556	0,9346	0,9837	0,9434	0,9453	0,9342	0,9593	1	0,9413
$k_{розрах}$	0,9551	0,9358	0,9727	0,9438	0,9479	0,9364	0,9544	0,9754	0,9430

We will define the absolute error of measuring:

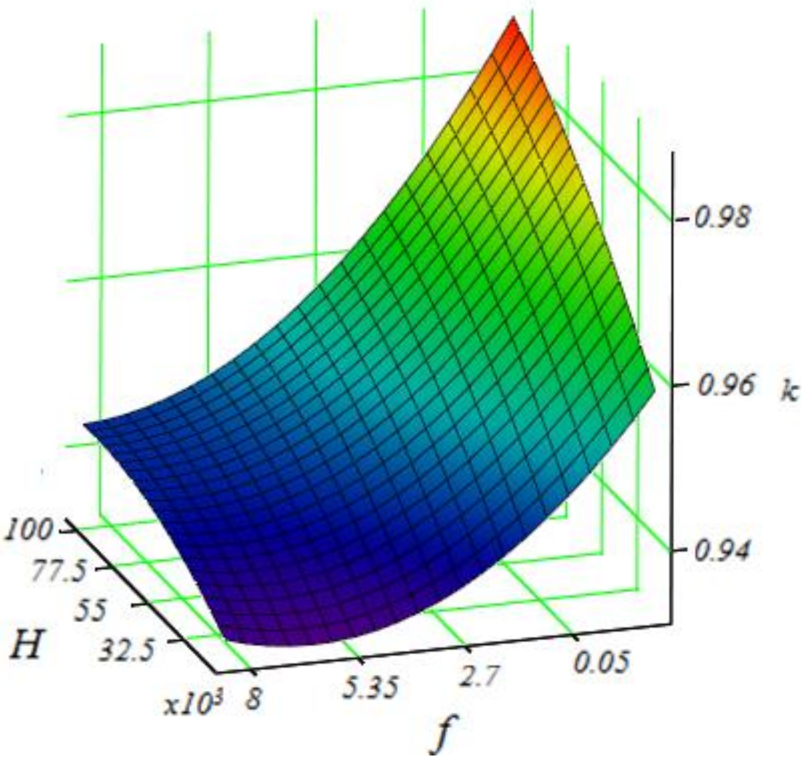
$$\epsilon = \sqrt{\frac{\sum_i (k_{експ_i} - k_{розрах_i})^2}{n-1}}, \quad (7)$$

whear: n – quantity of experiments.

Relative error:

$$\delta = \frac{\epsilon}{\frac{\sum k_{експ}}{n}}. \tag{8}$$

As a result of computations we get: absolute errors *e=0.00978*; relative error *δ=1,024* %. On rice 4. the graphic image of surface of review of correcting coefficient is resulted within the limits of intervals of varying *H* and *f*. In our case for corpousa ecstroudera by the perimeter of P=0.444 m, tension of the magnetic field *H=24710* A/m, by frequency of source of feed of *f=50* Hertzs a correcting coefficient will make *k=0,982*. The calculated equivalent diameter taking into account k will be $D_{ec}= 0,144м$.



Rice 4. Surface of review of k at the change of value of tension of the magnetic field and frequency of current.

Except for determination of equivalent diameter of load of inductor, which has a form, that differs from round, it should be noted importance of determination of equivalent diameter of inductor. As an equivalent diameter of inductor determines Computation of active resistance of inductor is a separate problem, as a

feed of inductor relies on frequency, construction of puttee (odnosharova, bagatosharova), and in work are not considered. Education to the gap between an inductor and load is linked with the use of teploizolyatsiynih materials, that are used for the rise of efficiency of heating and reduction of losses of warmth in an environment. Exactly the thickness of teploizolyatsiynogo material determines distance between an inductor and detail, and consequently and area unoccupied by the load. For computation of equivalent diameter of uncircular inductor we accept that areas unoccupied by the load in an inductor for a corpousa press and equivalent to him circular geometry must be even. We will execute computation of equivalent diameter of inductor, using the classic formula of determination of ecvivalentouvannya after a perimeter and we will compare the got result to expression which the area of teploizolyatsiynogo material is used in:

$$D'_{ін} = \sqrt{\frac{4S}{\pi} + D_{ек}{}^2}, \qquad (7)$$

vear: S – area of teploizolyatsiynogo material, м^2.

We change the thickness of teploizolyatsiynogo material of h in a range from 5 to 20 to mm, the results of computations are resulted in tabl. 3.

3. Results of computation of equivalent to the diameter inductor

h, мм	*П, м*	*S, м*	$D_{ін}$, *м*	$D_{ін}'$	*S', м*	*Δ, %*
5	0,476	0,00229	0,151	0,154	0,00228	1,56
10	0,507	0,00475	0,161	0,164	0,00475	1,40
15	0,538	0,00736	0,171	0,173	0,00736	1,21
20	0,570	0,01014	0,181	0,183	0,01014	1,12

Denotation: $П$ - perimeter of teploizolyatsiynogo material, m; D_{in} - equivalent circular diameter of inductor, m; S - area of equivalent thermal isolation, m^2; Δ-error of computation of determination of diameter of inductor, using a classic formula and formula which the area of teploizolyatsiynogo material is taken into account in.

Determination of equivalent diameter of inductor with the use of area of teploizolyatsiynogo material diminishes the error of computation of geometrical parameters of inductor on 1,5 % on comparison with a classic formula.

Conclusions

Of details of uncircular to the cut expediently to calculate geometrical parameters after a perimeter taking into account thegot correcting coefficient.

The diameter of equivalent inductor settles accounts from the condition of equality of areas unoccupied by the load in an uncircular and equivalent circular inductor. In engineering computations for reduction of error expediently to use a correcting coefficient for determination of equivalent diameter of corpousa uncircular detail, and diameter of inductor - with the use of area of thermal isolation.

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Considers the methods to simplify calculation of cylindrical objects that are not circular shape, a circular cylinder. Definitely adjustment factors to reduce the error calculations of energy parameters inductors for heating metal elements are not circular section.

Inductor, Equivalent diameter of the inductors, induction heating, experiment, inductor resistance.