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CALCULATION MAGNETIC FLUX OF THE PERMANENT MAGNETS IN THE SHAPE OF A CYLINDER IN THE PRESENCE OF FERROMAGNETS

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Has been solved the problem of calculating the homogeneously magnetized permanent magnet, which is disposed between two ferromagnetic bodies of cylindrical shape.

Magnetic flux, permanent magnets, boundary value problem, a ferromagnet

In material was carved infinitely long cylindrical plane of with radius R_3 (stator). On its axis has two infinitely long coaxial cylinders with radii R_1 and R_2, at that $R_1 < R_2 < R_3$.

We introduce a cylindrical coordinate system centered at the point O, which is located on the axis of the cylinders. Space, which given by the conditions $r < R_1$ filled with ferromagnetic ($\mu = \infty$), which given by the conditions $R_1 < r < R_2$ filled with permanent magnet with a given magnetization vector $\vec{J}$ (reference system is chosen in such a way that the vector $\vec{J}$ was perpendicular to the plane of), which given by the conditions $R_2 < r < R_3$ — material with insight μ_0, which given by the conditions $r > R_3$ — filled with ferromagnetic ($\mu = \infty$). We denote selected areas respectively I, II, III, IV.

The purpose of research — formulation and solution boundary value problem of calculating the magnetic field uniformly magnetized permanent magnet cylindrical shape in ferromagnetic cavity.

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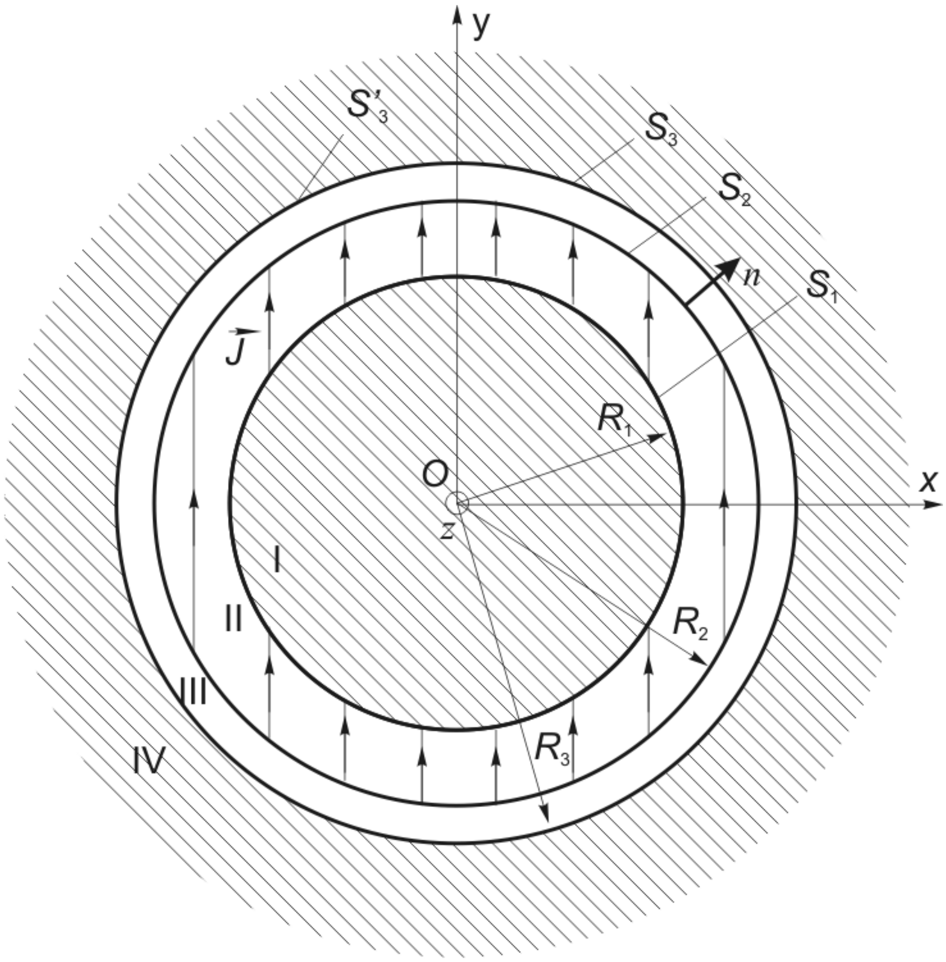
Materials and methods of research. The task consists in finding flow Φ of magnetic induction $\vec{B}$ through the surface of $S_3^{`}$, which is given by the system of equations (in cylindrical coordinate system):

$$\begin{cases} r = R_3 \\ 0 \le \alpha \le \pi \\ 0 \le z \le 1. \end{cases} \quad (1)$$

Flux of vector $\vec{B}$ through $S_3^{`}$ is defined as follows [3]:

$$\Phi = \int_{S_3^{`}} \vec{B} d\vec{s} \,. \quad (2)$$



1. The cross section of the magnetic system

From which we see the need for knowledge of the field $\vec{B}$ of $S_3^{`}$, or, what is the same in III. Without knowing its distribution in region II find it definitely is not given possible by the theorem unique solvability of Maxwell's equations [2]. Thus, the problem reduces to finding the field $\vec{B}$ in the ring $R_1 < r < R_3$.

To calculate the magnetic induction use Maxwell's equations:

$$rot\vec{H} = 0, \quad (3)$$

$$div\vec{B} = 0, \quad (4)$$

$$\vec{B} = \mu_0 \vec{H} + \mu_0 \vec{J}. \quad (5)$$

From the first equation of the system implies that the vector field $\vec{H}$ can introduce the scalar magnetic potential φ according to the rule:

$$\vec{H} = -grad\varphi. \quad (6)$$

When substitution of (6) in the system of equations (3) - (5), the first of its equations is satisfied automatically, and the second equation we obtain the Laplace equation:

$$\Delta\varphi = 0. \quad (7)$$

Write it for each of regions II and III:

$$\Delta\varphi_1 = 0, \quad (8)$$

$$\Delta\varphi_2 = 0, \quad (9)$$

where, φ_1 — potential in region II, φ_1 — potential in region III.

We write the boundary conditions for the scalar potential φ:

$$\varphi_1 = \varphi_2 \text{ of } S_2, \quad (10)$$

where S_2 - the boundary between two media II and III.

From the condition of continuity of the normal component of the vector $\vec{B}$ on the boundary between two media, we have:

$$B_{2n} = B_{3n} \text{ of } S_2, \quad (11)$$

where B_{2n}, B_{3n} — normal component at the border S_2 tends to it, respectively from the second and third regions.

Given the constraint equation (5), as well as the fact that in the region III $J = 0$, we obtain:

$$\mu_0 H_{2n} + \mu_0 \vec{J} \cdot \vec{n} = \mu_0 H_{3n} \text{ of } S_2, \quad (12)$$

where $\vec{n}$ — external to the surface S_2 normal.

From (6), (12) follows the second boundary condition for the scalar magnetic potential:

$$\frac{\partial \varphi_2}{\partial n} - \frac{\partial \varphi_1}{\partial n} = -\vec{J} \cdot \vec{n}. \qquad (13)$$

Let S_1 - boundary between the media I and II, S_3 - between the media III and IV . In regions I and IV consider $\mu=\infty$, i.e. the magnetic field H_1, H_2 therein is zero:

$$H_1 = H_4 = 0. \qquad (14)$$

From the condition of continuity of the tangential component of the vector at the interface with different permeability, we have:

$$H_{1\tau} = H_{2\tau} \text{ of } S_1, \qquad (15)$$

$$H_{3\tau} = H_{4\tau} \text{ of } S_3. \qquad (16)$$

But by (14) and (6) we obtain:

$$\varphi_1 = C_1 \text{ of } S_1, \qquad (17)$$

$$\varphi_2 = C_2 \text{ of } S_3, \qquad (18)$$

where C_1 and C_2 some constants.

Consider the plane *zOx*. It will equipotential because the vector field lines penetrate it at right angles. In this way:

$$\varphi_1 = \varphi_2 = C \text{ of } zOx, \qquad (19)$$

where C — a constant that we can take to be zero, ie .:

$$\varphi_1 = \varphi_2 = 0 \text{ of } zOx. \qquad (20)$$

Since the plane *zOx* intersects the surface S_1 and S_3, then from (17), (18) and (20):

$$\varphi_1 = 0 \text{ of } S_1, \qquad (21)$$

$$\varphi_2 = 0 \text{ of } S_3. \qquad (22)$$

Equations (8) and (9) together with the boundary conditions (10), (13), (21) and (22) allow us to unambiguously find scalar potentials φ_1, φ_2.

And so we have the following boundary value problem:

$$\Delta\varphi_1 = 0 \text{ in region II}, \qquad (23)$$

$$\Delta\varphi_2 = 0 \text{ in region III}, \qquad (24)$$

$$\varphi_1 = \varphi_2 \text{ of } S_2, \qquad (25)$$

$$\frac{\partial \varphi_2}{\partial n} - \frac{\partial \varphi_1}{\partial n} = -\vec{J} \cdot \vec{n} \text{ of } S_2, \qquad (26)$$

$$\varphi_1 = 0 \text{ of } S_1, \tag{27}$$

$$\varphi_2 = 0 \text{ of } S_3. \tag{28}$$

We solve the equation (23) by the method of separation of variables [4]. In a cylindrical coordinate system, equation (23) has the form:

$$\frac{1}{r}\frac{\partial}{\partial r}\left(r\frac{\partial \varphi_1}{\partial r}\right) + \frac{1}{r^2}\frac{\partial^2 \varphi_1}{\partial \alpha^2} + \frac{\partial^2 \varphi_1}{\partial z^2} = 0. \tag{29}$$

Note that the potential φ_1 does not depend in the present case of *z*, since its distribution is the same in any plane parallel to the plane $z = 0$. So the last term in the left-hand side of equation (29) vanishes. Equation (29) takes the form:

$$\frac{1}{r}\frac{\partial}{\partial r}\left(r\frac{\partial \varphi_1}{\partial r}\right) + \frac{1}{r^2}\frac{\partial^2 \varphi_1}{\partial \alpha^2} = 0. \tag{30}$$

The solution of equation (30) will be sought in the form

$$\varphi_1 = A(\alpha)R(r), \tag{31}$$

where $A(\alpha)$ — depends only on, $R(r)$ — only on r.

Introducing the intended form of the solution (31) into the original equation (30), we obtain after differentiation:

$$\frac{1}{r}A(\alpha)\frac{\partial}{\partial r}\left(r\frac{\partial R(r)}{\partial r}\right) + \frac{1}{r^2}R(r)\frac{\partial^2 A(\alpha)}{\partial \alpha^2} = 0. \tag{32}$$

Multiplying both sides of equation (32) to $\frac{r^2}{A(\alpha)R(r)}$, we obtain:

$$\frac{r}{R(r)}\frac{\partial}{\partial r}\left(r\frac{\partial R(r)}{\partial r}\right) + \frac{1}{A(\alpha)}\frac{\partial^2 A(\alpha)}{\partial \alpha^2} = 0. \tag{33}$$

From which we obtain:

$$\frac{r}{R(r)}\frac{\partial}{\partial r}\left(r\frac{\partial R(r)}{\partial r}\right) = -\frac{1}{A(\alpha)}\frac{\partial^2 A(\alpha)}{\partial \alpha^2}. \tag{34}$$

Left in the equation (34) should function which depends only on *r*, right – on only α. Equation (34) is possible only if they are both equal to a constant.

In this way:

$$\frac{r}{R(r)}\frac{\partial}{\partial r}\left(r\frac{\partial R(r)}{\partial r}\right) = k, \tag{35}$$

$$-\frac{1}{A(\alpha)}\frac{\partial^2 A(\alpha)}{\partial^2\alpha}=k\,, \tag{36}$$

where k - so far unknown constant.

Since $\varphi_1(r,\alpha+2\pi)=\varphi_1(r,\alpha)$, then $A(r,\alpha+2\pi)=A(r,\alpha)$. In this way:

$$A''(\alpha)+kA(\alpha)=0\,, \tag{36}$$

we find $\sqrt{k}=n$, where n — whole number, and

$$A_n(\alpha)=a_n\cos(n\alpha)+b_n\sin(n\alpha)\,. \tag{37}$$

Further, from (35), assuming that $R(r)=r^{\lambda}$, we obtain:

$\lambda^2=n^2$, i.e. $\lambda=\pm n$, $n>0$, and, so

$$R_n(r)=ar^{n}+br^{-n}\,. \tag{38}$$

When $n=0$ ($k=0$) from (35) we find:

$$R_0(r)=C_0\ln r+C\,. \tag{39}$$

The solution of equation (8) in the area $R_1<r<R_3$ under the given boundary conditions are looking for in the form of a series:

$$\varphi_1(r,\alpha)=a_0\ln r+b_0+\sum_{n=1}^{\infty}\left[r^{n}\left(a_n^{+}\sin(n\alpha)+b_n^{+}\cos(n\alpha)\right)+r^{-n}\left(a_n^{-}\sin(n\alpha)+b_n^{-}\cos(n\alpha)\right)\right].$$

(40)

Obviously, the solution of equation (9) in the form:

$$\varphi_2(r,\alpha)=c_0\ln r+d_0+\sum_{n=1}^{\infty}\left[r^{n}\left(c_n^{+}\sin(n\alpha)+d_n^{+}\cos(n\alpha)\right)+r^{-n}\left(c_n^{-}\sin(n\alpha)+d_n^{-}\cos(n\alpha)\right)\right]. \tag{41}$$

The coefficients a_0, b_0, a_n^{+}, b_n^{+}, a_n^{-}, b_n^{-}, c_0, d_0, c_n^{+}, d_n^{+}, c_n^{-}, d_n^{-}, $n=1,2,3,...$ determined from the boundary conditions (10), (13), (21), (22).

From the boundary conditions (10) we obtain:

$$a_0\ln R_2+b_0+\sum_{n=1}^{\infty}\left[R_2^{n}\left(a_n^{+}\sin(n\alpha)+b_n^{+}\cos(n\alpha)\right)+R_2^{-n}\left(a_n^{-}\sin(n\alpha)+b_n^{-}\cos(n\alpha)\right)\right]=$$

$$=c_0\ln R_2+d_0+\sum_{n=1}^{\infty}\left[R_2^{n}\left(c_n^{+}\sin(n\alpha)+d_n^{+}\cos(n\alpha)\right)+R_2^{-n}\left(c_n^{-}\sin(n\alpha)+d_n^{-}\cos(n\alpha)\right)\right].$$

From which it follows:

$$a_0 \ln R_2 + b_0 = c_0 \ln R_2 + d_0\,, \tag{42}$$

$$R_2^{n}\left(a_n^{+} - c_n^{+}\right) + R_2^{-n}\left(a_n^{-} - c_n^{-}\right) = 0\,,\; n = 1,2,3,\ldots, \tag{43}$$

$$R_2^{n}\left(b_n^{+} - d_n^{+}\right) + R_2^{-n}\left(b_n^{-} - d_n^{-}\right) = 0\,,\; n = 1,2,3,\ldots. \tag{44}$$

From equation (26) we find:

$$\frac{c_0 - a_0}{R_2} + \sum_{n=1}^{\infty}\Big[nR_2^{n-1}\left(\left(c_n^{+} - a_n^{+}\right)\sin n\alpha + \left(d_n^{+} - b_n^{+}\right)\cos n\alpha\right) +$$

$$+ nR_2^{-n-1}\left(\left(c_n^{-} - a_n^{-}\right)\sin n\alpha + \left(d_n^{-} - b_n^{-}\right)\cos n\alpha\right)\Big] = -J \sin\alpha\,. \tag{45}$$

From the last equation:

$$c_0 = a_0\,, \tag{46}$$

$$nR_2^{n-1}\left(c_n^{+} - a_n^{+}\right) - nR_2^{-n-1}\left(c_n^{-} - a_n^{-}\right) = 0\,,\; n = 2,3,4\ldots, \tag{47}$$

$$R_2^{0}\left(c_1^{+} - a_1^{+}\right) - R_2^{-2}\left(c_1^{-} - a_1^{-}\right) = -J\,, \tag{48}$$

$$nR_2^{n-1}\left(d_n^{+} - b_n^{+}\right) - nR_2^{-n-1}\left(d_n^{-} - b_n^{-}\right) = 0\,,\; n = 1,2,3,\ldots \tag{49}$$

Condition (27), (28) can be written, respectively:

$$a_0 \ln R_1 + b_0 + \sum_{n=1}^{\infty} R_1^{n}\left(a_n^{+}\sin n\alpha + b_n^{+}\cos n\alpha\right) + R_1^{-n}\left(a_n^{-}\sin n\alpha + b_n^{-}\cos n\alpha\right) = 0\,,$$

$$c_0 \ln R_3 + d_0 + \sum_{n=1}^{\infty} R_3^{n}\left(c_n^{+}\sin n\alpha + d_n^{+}\cos n\alpha\right) + R_3^{-n}\left(c_n^{-}\sin n\alpha + d_n^{-}\cos n\alpha\right) = 0\,.$$

From which it follows:

$$a_0 \ln R_1 + b_0 = 0\,, \tag{50}$$

$$R_1^{n} a_n^{+} + R_1^{-n} a_n^{-} = 0\,,\; n = 1,2,3\ldots, \tag{51}$$

$$R_1^{n} b_n^{+} + R_1^{-n} b_n^{-} = 0\,,\; n = 1,2,3\ldots, \tag{52}$$

$$c_0 \ln R_3 + d_0 = 0\,, \tag{53}$$

$$R_3^{n} c_n^{+} + R_3^{-n} c_n^{-} = 0\,,\; n = 1,2,3\ldots, \tag{54}$$

$$R_3^{n} d_n^{+} + R_3^{-n} d_n^{-} = 0\,,\; n = 1,2,3\ldots. \tag{55}$$

Solve the system of equations (42) - (55) for n = 0. We have:

$$a_0 \ln R_2 + b_0 = c_0 \ln R_2 + d_0 \,, \tag{56}$$

$$c_0 = a_0 \,, \tag{57}$$

$$a_0 \ln R_1 + b_0 = 0 \,, \tag{58}$$

$$c_0 \ln R_3 + d_0 = 0 \,. \tag{59}$$

Obviously, this system has the correct zero solution, i.e.:

$$a_0 = b_0 = c_0 = d_0 = 0 \,.$$

If n = 1, then we have a system of equations:

$$R_1 a_1^+ + R_1^{-1} a_1^- = 0 \,, \tag{60}$$

$$R_3 c_1^+ + R_3^{-1} c_1^- = 0 \,, \tag{61}$$

$$R_2 \; a_1^+ - c_1^+ \; + R_2^{-1} \; a_1^- - c_1^- \; = 0 \,, \tag{62}$$

$$R_2^0 \; c_1^+ - a_1^+ \; - R_2^{-2} \; c_1^- - a_1^- \; = -J \,, \tag{63}$$

$$R_1 b_1^+ + R_1^{-1} b_1^- = 0 \,, \tag{64}$$

$$R_3 d_1^+ + R_3^{-1} d_1^- = 0 \,, \tag{65}$$

$$R_2 \; b_1^+ - d_1^+ \; + R_2^{-1} \; b_1^- - d_1^- \; = 0 \,, \tag{66}$$

$$d_1^+ - b_1^+ \; - R_2^{-2} \; d_1^- - b_1^- \; = 0 \,. \tag{67}$$

Add up (66) and (67):

$$2 \; b_1^+ - d_1^+ \; = 0 \,, \text{ т.е. } b_1^+ = d_1^+ \,. \tag{68}$$

Substituting (68) into (66) we obtain:

$$b_1^- = d_1^- \,. \tag{69}$$

Rewrite (64), (65) with (68) and (69):

$$R_1 b_1^+ + R_1^{-1} b_1^- = 0 \,, \tag{70}$$

$$R_3 b_1^+ + R_3^{-1} b_1^- = 0 \,. \tag{71}$$

The system of linear algebraic equations (70), (71) is homogeneous. Its determinant is nonzero. Consequently, it has a trivial (zero) solution. So

$$b_1^+ = b_1^- = d_1^+ = d_1^- = 0\,. \tag{72}$$

olve the system of equations (60) - (63). Subtract from the equation (62), equation (63):

$$a_1^+ - c_1^+ = J/2\,. \tag{73}$$

Add up equation (62) and (63), we obtain:

$$a_1^- - c_1^- = -\,JR_2^2 \Big/ 2. \tag{74}$$

Using (73) and (74) equation (60), (61) can be written:

$$R_1 a_1^+ + R_1 a_1^- = 0\,, \tag{75}$$

$$R_3\left(a_1^+ - \frac{J}{2}\right) + \frac{1}{R_3}\left(a_1^- + \frac{JR_2^2}{2}\right) = 0\,. \tag{76}$$

Expressing equation (75) $a_1^+ = -a_1^- \big/ R_1^2$ and substituting into equation (76) we obtain:

$$R_3\left(-\frac{1}{R_1^2}a_1^- - \frac{J}{2}\right) + \frac{1}{R_3}\left(a_1^- + \frac{JR_2^2}{2}\right) = 0\,. \tag{77}$$

Next,

$$a_1^-\left(\frac{1}{R_3} - \frac{R_3}{R_1^2}\right) = -\frac{R_2^2}{2R_3}J + \frac{R_3}{2}J\,. \tag{78}$$

From which it follows:

$$a_1^- = -\frac{R_2^2 - R_3^2}{2\; R_1^2 - R_3^2} R_1^2 J\,. \tag{79}$$

Substituting (79) into (75) we find:

$$a_1^+ = \frac{R_2^2 - R_3^2}{2\; R_1^2 - R_3^2} J\,. \tag{80}$$

From the relations (73), (80) we find:

$$c_1^+ = -\frac{R_2^2 - R_1^2}{2\; R_3^2 - R_1^2} J\,. \tag{81}$$

From the relations (74), (89) we find:

$$c_1^- = \frac{R_2^2 - R_1^2}{2\left(R_3^2 - R_1^2\right)} R_3^2 J. \qquad (82)$$

Thus, the system (60) - (67) is solved. If n = 2,3,4 ... is to find the coefficients in (40) and (41) we have a set of systems of equations

$$R_1^n a_n^+ + R_1^{-n} a_n^- = 0, \qquad (83)$$

$$R_3^n c_n^+ + R_3^{-n} c_n^- = 0, \qquad (84)$$

$$R_2^n \left(a_n^+ - c_n^+\right) + R_2^{-n} \left(a_n^- - c_n^-\right) = 0, \qquad (85)$$

$$nR_2^{n-1} \left(c_n^+ - a_n^+\right) - nR_2^{-n-1} \left(c_n^- - a_n^-\right) = 0, \qquad (86)$$

$$R_1^n b_n^+ + R_1^{-n} b_n^- = 0, \qquad (87)$$

$$R_3^n d_n^+ + R_3^{-n} d_n^- = 0, \qquad (88)$$

$$R_2^n \left(b_n^+ - d_n^+\right) + R_2^{-n} \left(b_n^+ - d_n^+\right) = 0, \qquad (89)$$

$$nR_2^{n-1} \left(d_n^+ - b_n^+\right) - nR_2^{-n-1} \left(d_n^- - b_n^-\right) = 0. \qquad (90)$$

Each of the systems (83) - (86) and (87) - (90) can be solved similarly to (64) - (67), so that:

$$a_n^+ = a_n^- = b_n^+ = b_n^- = c_n^+ = c_n^- = d_n^+ = d_n^- = 0, \; n = 2,3,4\ldots \qquad (91)$$

Substituting the coefficients in (40) and (41) we obtain the expression for the potential in regions II and III :

$$\varphi_1 = \frac{R_3^2 - R_2^2}{R_3^2 - R_1^2} \frac{J}{2} \left(r - \frac{R_1^2}{r} \right) \sin\alpha, \qquad (92)$$

$$\varphi_1 = -\frac{R_2^2 - R_1^2}{R_3^2 - R_1^2} \frac{J}{2} \left(r - \frac{R_3^2}{r} \right) \sin\alpha. \qquad (93)$$

Field $\vec{H}$ in the desired region III is determined from the expression $\vec{H} = -grad\varphi$. In the chosen coordinate system:

$$-grad\varphi = -\frac{\partial\varphi}{\partial r}\vec{e}_r - \frac{\partial\varphi}{r\partial\alpha}\vec{e}_\alpha.$$

In this way,

$$\vec{H}_{III} = \frac{R_2^2 - R_1^2}{R_3^2 - R_1^2} \frac{J}{2} \left[\vec{e}_r \left(1 + \frac{R_3^2}{r^2} \right) \sin\alpha + \vec{e}_\alpha \left(1 - \frac{R_3^2}{r^2} \right) \cos\alpha \right].$$

The magnetic flux through the surface $S_3^{'}$, which is defined by the system of equations (1):

$$\Phi = \mu_0 \int_{S_3^{'}} \vec{H} d\vec{s} .$$

Given that the surface element $d\vec{s} = \vec{e}_r R_3 d\alpha dz$, find:

$$\Phi = \mu_0 \int_{S_3^{'}} \vec{H}\vec{e}_r R_3 d\alpha dz = -\mu_0 \frac{R_2^2 - R_1^2}{R_3^2 - R_1^2} \frac{J}{2} 2R_3 \int_0^\pi \sin\alpha d\alpha \int_0^l dz .$$

Whence we find,

$$\Phi = 2J\mu_0 R_3 \frac{R_2^2 - R_1^2}{R_3^2 - R_1^2} . \qquad (94)$$

From (94) it follows that the maximum magnetic flux at fixed radii R_2, R_3 is:

$$\Phi_{max} = 2J\mu_0 \frac{R_2^2}{R_3} . \qquad (95)$$

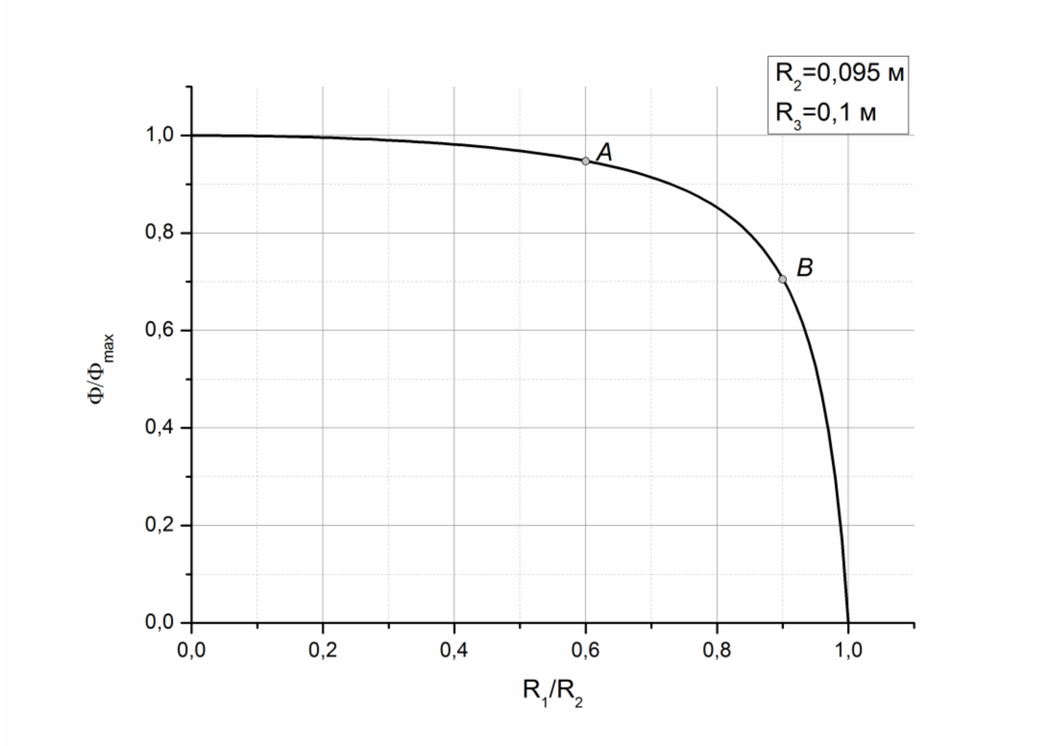
If we introduce the relative values of the equations:

$$R_{10} = \frac{R_1}{R_2},\ R_{30} = \frac{R_3}{R_2},\ \Phi_0 = \frac{\Phi}{\Phi_{max}}, \qquad (96)$$

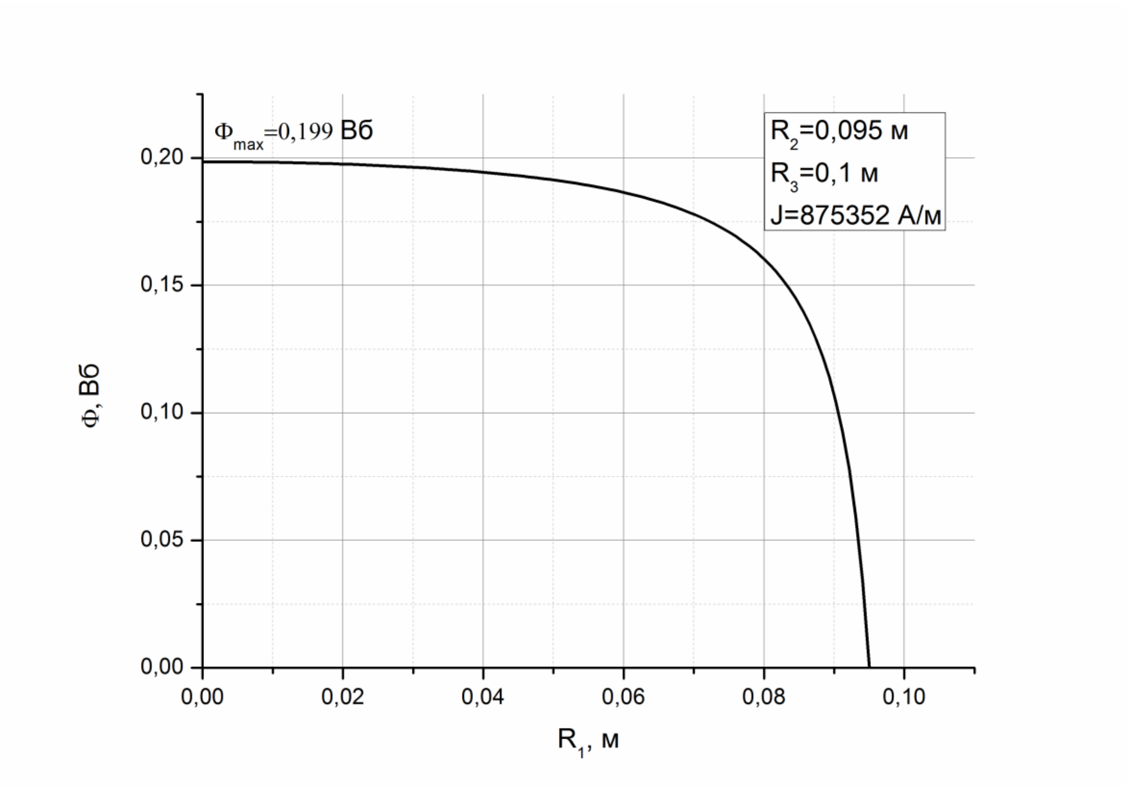
then the formula (94) can be rewritten as

$$\Phi_0 = \frac{1 - R_{10}^2}{R_{30}^2 - R_{10}^2} R_{30}^2 . \qquad (97)$$

An inner cylinder of the rotor may be made of steel for saving permanent magnet. Radius R_1 must be such that the magnetic flux was to close to the maximum. This can be achieved by selecting an operating point on the segment AB (in the specific case it is necessary to take into account the cost of the magnet and steel). On it, the magnetic flux will vary from a maximum of not more than 30%, while the R_1/R_2 lies in the range of 0.6 - 0.9 , i.e. $R_1 = 0,6R_2 ... 0,9R_2$.



2. A plot of the relative radius R_1 of the magnetic flux in arbitrary units



3. A plot of the magnetic flux

Findings

Was solved boundary value problem of calculating the magnetic field of the permanent magnet cylindrical shape in the plane ferromagnetic. We obtain an expression for the magnetic flux generated by the magnet system, which has allowed to establish the limits of variation of the inner radius of the ferromagnetic inserts, which are placed on the surface of the permanent magnets of the conditions specified deviation of the magnetic flux from its maximum value.

References

1. Bessonov, L.A. *(1964), Teoreticheskie osnovy elektrotekhniki* [Theoretical Foundations of Electrical Engineering], Moskva, Russia.
2. Stadnik, I.P. (2012), *Elektrodinamika* [Electrodynamics. Lecture with questions and problems], Tekhnika, Kyiv, Ukraine.
3. Tamm, I.E. (1991), Osnovy teorii elektrichestva [Fundamentals of the theory of electricity], Moskva, Russia.
4. Tichonov, A.N. and Samarskiy, A.A. (1999), Uravneniya matematitheskoy fiziki [Equations of Mathematical Physics: Proc. allowance], Moskva, Russia.