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ПЕТРА ВЕЛИКОГО

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THE INVESTIGATION OF THE SHIELDING EFFECT IN A MAGNETOSTATIC FIELD

(Исследование экранирования в постоянном магнитном поле)

Учебное пособие

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Предисловие.

Настоящее пособие составлено на основе практикума «Теоретические основы электротехники. Теория электромагнитного поля», являющегосячетвертым изданием широко известного руководства к лабораторным работам, содержание и структура которого постоянно обновлялись в соответствии с совершенствованием методики преподавания дисциплины, техники измерений, компьютерной обработки экспериментальных данных. Данное же руководство обобщает опыт проведения лабораторных занятий по дисциплине«Теория электромагнитного поля» для студентов Института энергетики и транспортных систем на английском языке.

В данное пособие вошло описание одной из лабораторных работ, выполняемых в лаборатории ТЭМП университета: «Исследование экранирования в постоянном магнитном поле». Содержание работы включает в себя описание лабораторной установки, программу работы, методические указания по обработке экспериментальных данных и выполнению аналитических и численных расчетов, а также вопросы для самопроверки. В приложении приводится форма протокола, в которой записываются экспериментальные данные, а также подробный словарь терминов по теме лабораторной работы.

Лаборатория ТЭМП относится к последней части курса «Теоретические основы электротехники», т.е. рассчитана на работу студентов, имеющих высокий уровень подготовки по данному предмету и достаточный уровень знаний иностранного языка.

Настоящее пособие ставит своей целью помощь студентам в подготовке к выполнению лабораторной работы, усложненной необходимостью общаться с преподавателем, оформлять отчет по лабораторной работе на английском языке.

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LABORATORY WORK №5

THE INVESTIGATION OF THE SHIELDING EFFECT IN A MAGNETOSTATIC FIELD

Introduction

The aim of the work is studying the shielding effect in a uniform magnetostatic field. The task of the work includes exploring composite shields of various forms, thickness and materials they made of. It is necessary to carry out not only theoretical, but also experimental research of the shielding effect of the screens. The theoretical research includes analytical and numerical calculation methods.

Setup Specification.

The laboratory installation is shown in fig.1. The main part of it is the electromagnet (EM), which has two poles and the air gap between the poles. The external magnetic field is produced in the air gap of electromagnet. The width of air gap is equal 12 cm. The winding of electromagnet consists of 8 sections with 175 turns in each section. The sections' terminals are taken out to the insulating pad. That allows to connect them in series or in parallel using special plane connectors. We can supply the installation with direct or alternating current (*DC* or *AC)*. The series connection is used when the electromagnet is supplied from *DC* source and the magnetostatic field is generated. The unit of laboratory installation named "Shielding in a magnetostatic field" is used in this case. The magnitude of a direct current *I* in the winding is corrected by the transformer ATP2. The ammeter measures the current in the windings of an electromagnet. The analyzed shield is placed in the air gap of electromagnet. In order to measure the magnetic flux density Hall sensor *PB* is used. Hall sensor is connected with magnetometer MTM-3 by the cable. Hall sensor inside the shied together with milliteslameter is the main measuring device. As ferromagnetic material may have a remanent magnetization, the demagnetization of ferromagnetic shields should be done. The laboratory installation includes the special device which performs a demagnetization of ferromagnetic shields before taking magnetic flux density measurements.

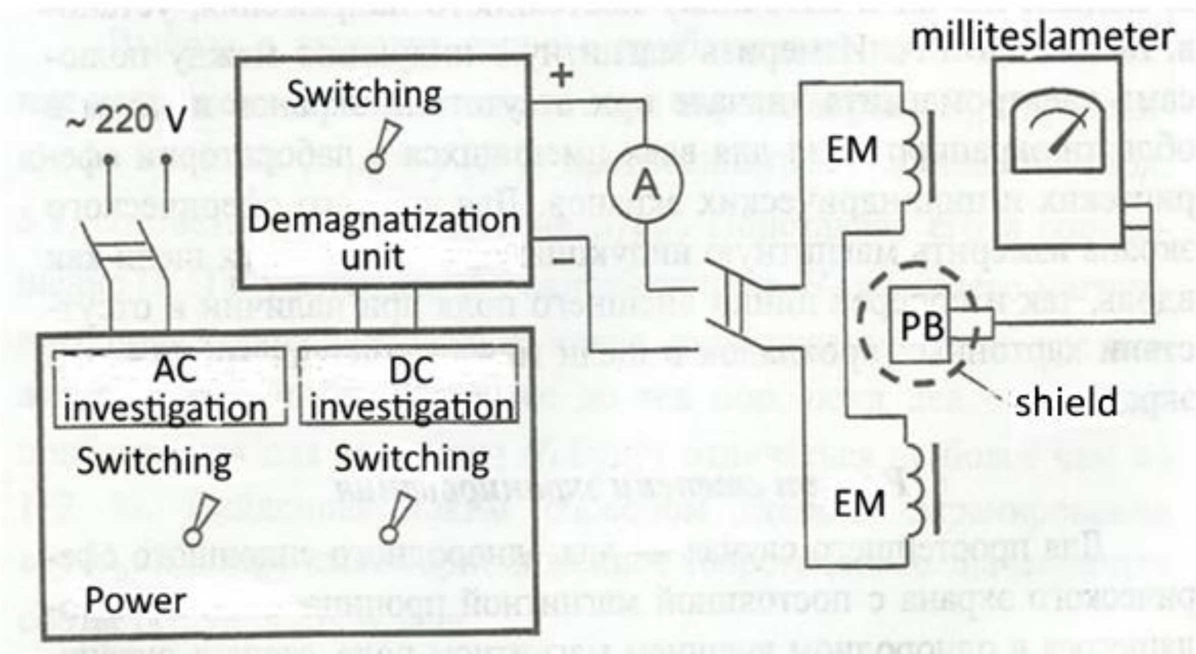

Fig.1. Laboratory installation

The set of examined shields consists of spherical and cylindrical ones. There are steel, copper, aluminium and brass shields in the laboratory installation. The inner radius of a spherical shield is $R_1 = 27$mm. The inner radius of a cylindrical shield is $R_1 = 23$mm. The wall thickness of spherical shields is 1.5 or 3 or 5mm. The wall thickness of cylindrical ones is 3 or 5mm.Thus outer radii R_2 are different for shields. The shields are composite: each of them has two identical parts. A spherical shield consists of two hemispheres, a cylindrical one consists of two cups. There is a hole in the junction of two parts of the shield. When Hall sensor is placed inside the shield, the cable connected with sensor is taken out through this hole. When measuring the magnetic flux density the shield with the sensor inside is put on the special support which is placed in the magnetic field (in the air gap of electromagnet).

Work Program.

The quality of shielding is estimated by such a parameter as the degree of shielding (shielding factor). The degree of shielding is the ratio of external magnetic field strength $H_0$to the strength of magnetic field inside the shield H_i: $a = H_0 / H_i$. The task of the work includes the experimental determination and calculation the degree of shielding for various shields.

1. Connect sections of electromagnet winding in series with the aid of special plane connectors; turn the knife-switch in the position "*DC*"; set the operation current at the range from 0.8A to 1A.

2. Measure magnetic flux density of external field B_0 i.e. the field between the poles of electromagnet in the absence of the shield. Follow the instruction on operation when applying the milliteslameter.

3. Perform magnetic flux density measuring with offered shields. As for spherical shields they should be examined at various orientation of the junction of two parts of the shield. It means that the gap may be orientated differently relative to the direction of magnetic lines, that is along the field and across the field. You should examine how the orientation of the gap influences the shielding quality. The cylindrical shields are tested only when the junction is across the field (or horizontal).The demagnetization of ferromagnetic shields should be performed in accordance with the instruction.

Analytical Calculation of Shielding Degree.

Shielding degree $a=H_0/H_i$ for uniform spherical shield with constant permeability of the material in uniform magnetic field is:

$$H_i = H_0 \frac{1}{1+\frac{2}{9}\left(1-\frac{R_1^3}{R_2^3}\right)\left(\frac{\mu_0}{\mu}+\frac{\mu}{\mu_0}-2\right)}, \qquad (1)$$

where H_0 is the magnetic field strength in the air gap of electromagnet without shield (external magnetic field strength), H_i is the magnetic field strength inside the shield, R_1 , $R_2$are inner and outer radii of the shield, μ=const is the permeability of the shield, $\mu_0 = 4\pi 10^{-7}$H/m,

$$H_0 = \frac{Iw}{h_0}, \quad (2)$$

where Iw is the magnetomotive force of the electromagnet, h_o=12cm is the distance between poles of the electromagnet.This formula is accurate if the magnetic permeability of the shield is the same at all points of the shield. But the magnetic permeability of the ferromagnetic shield depends on the strength of the magnetic field, which is different at different points inside the shield. In this case for using (1) we should find the average value of the ferromagnetic shield permeability .

The average value of the shield permeability can be found by the iterative method. Firstly we choose some value of magnetic field intensity inside the screen as a first approximation. Further, from the table 1 we can find the relative magnetic permeability $\mu_r=\mu/\mu_0$of the shield.

Table 1

H, A/m	B, T	μ/μ_0
50	0,030	477
100	0,095	756
150	0,206	1087
200	0,325	1293
250	0,445	1416
300	0,535	1419
350	0,600	1364
400	0,650	1293
450	0,685	1211
500	0,720	1146
550	0,745	1078
600	0,770	1021
650	0,800	979
700	0,820	932
750	0,840	891
800	0,860	855
850	0,880	824
900	0,900	796
950	0,915	766
1000	0,930	740
1050	0,945	716
1100	0,960	694

Then we substitute this value of μ_r in (1) and find the new value of the magnetic field strength inside the shield H_i. We continue this iterative finding H_i until two subsequent approximations of magnetic field strength H_i inside the shield will not differ by 1-2%. Then we can find the approximate theoretical value of the degree of shielding $a=H_0/H_i$, where H_i is the result of the iterative procedure (H_0 is known from (2)).

Another way of defining magnetic permeability of the ferromagnetic shield is the graphic method. Let us denote the expression (μ_r+1/μ_r) in (1) as $b$and rewrite (1) in the form:

$$b=4.5(H_0/H_i-1)/(1-(R_1/R_2)^3)+2 \quad (3)$$

Let us introduce two functions:

$$F_1= \mu_r+1/\mu_r,$$

$$F_2 =4.5(H_0/H_i-1)/(1-(R_1/R_2)^3)+2$$

And plot these functions F_1 *vs* H_i , F_2 *vs* H_i on the same graph. The intersection of these curves gives us the values of the magnetic field strength H_i, magnetic permeability μ_r (from table 1) and then shielding degree.

Numerical Calculation of Shielding Degree.

The magnetic field inside and outside the shield can be calculated using the program *Qfield*. The computational model of the shield and the boundary conditions in the calculation area are shown in Fig.2.Since the investigated shields are bodies of rotating, it is sufficient to perform numerical calculation of the field only in the plane of their cross section $r0z$ passing through the rotation axis z. The calculation area is limited by lines $z=z_0=10R_2$and$r = r_0 =10R_2$. The following conditions are taken on the boundary of the calculation area: magnetic vector potential A=0 on the rotation axis z, $\partial A/\partial z=0$ on the axis r and on the line $z = z_0 =10R_2$. And the magnetic vector potential takes the constant value $A=A_0$ on the line $r = r_0 =10R_2$: $r_0 A_0= B_0 r_0^2/2$, where B_0 is magnetic flux density of external field .

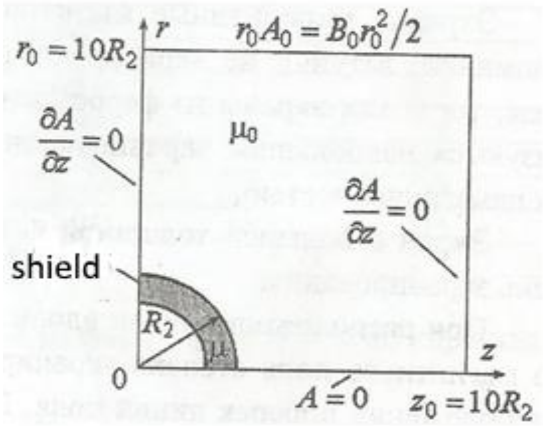

Fig.2. The computational model of the shield

Numerical calculations of the field and degree of shielding should be performed for all screens studied in the laboratory, with the exception of the shields with a gap in the junction of two parts of the shield oriented across the field lines.

Questions for Self-Examination

1. How does the wall thickness influence the degree of shielding?
2. Does the orientation of the slot influence the degree of shielding?
3. The slot is located along the field lines. How does its width influence the degree of shielding?
4. How should the plane of Hall sensor inside the shield be placed: along or across the lines of magnetic induction of the external field?

Supplement1.

The Protocol of the Laboratory Work

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The Department of Theoretical Electroengineering and Electromechanics

The Laboratory of Electromagnetic Field Theory

«INVESTIGATION OF THE SHIELDING EFFECT IN MAGNETOSTATIC FIELD»

____.____.201_

Fulfilled by students of gr. ___________, team №_______

________________________ ________________________ ________________________

(surname) (surname) (surname)

Checked by ______________________

I - the current in the electromagnet winding, *I* = ……A

Magnetic induction of the external field B_0 = ……..T, *B* - those inside the shield

Δ – the wall thickness, mm,

a – the degree of shielding (shielding factor)

Spherical shields

Shield material	Δ,mm	The gap is along the field		The gap is across the field	
		B,T	*a*	*B*,T	*a*

Cylindrical shields

Shield material	Δ,mm	*B*,T	*a*

Supplement2.

Glossary of Terms.

экран –shield, screen
экранирующее действие экрана –the shielding effect of the shield (screen)
степень экранирования - degree of shielding
размагничивание -demagnetization
конструкция экрана- shield design
тело вращения- body of rotation,
ось вращения- axis of rotation
сфера - sphere
полусфера- hemisphere
сферический (экран)- spherical
цилиндрический - cylindrical
замкнутый- closed,
незамкнутый- open
радиус - radius
внешний -outer
внутренний- inner
стенка экрана –screen shell
толщина стенки – wall thickness
торцы- ends
подставка -support
прокладка -spacer
изолирующая картонная - the cardboard insulating
щель - gap

стык– joint,
отверстие в месте стыка- the hole in the junction
материал экрана- shield (screen) material
ферромагнитный материал -ferromagnetic material
немагнитный -nonmagnetic
магнитная проницаемость - magnetic permeability
стальной -steel
алюминиевый - aluminum
бронзовый - bronze
медный - copper
латунный - brass
среднее значение магнитной проницаемости - the average value of the magnetic permeability,
основная кривая намагничивания - normal magnetization curve, *B-H* curve
нелинейная характеристика -nonlinear characteristic
лабораторная установка -laboratory installation
источник питания – power source ,
блок силовой –the power
блок установки -laboratory installation unit
блок «Исследование на постоянном токе»-«Shielding in magnetostatic field» unit
блок размагничивания- demagnetization unit
постоянный ток – direct current
электромагнит- electromagnet
конструкция электромагнита - electromagnet design
воздушный зазор- air gap
полюс электромагнита- electromagnet pole
изолирующая колодка- insulating pad
перемычка- connector
обмотка- winding
секция обмотки- winding section
зажимы секций–section terminals
виток - turn
последовательное и параллельное соединение – series and parallel connection
датчик Холла – Hall probe, Hall sensor
реперная метка –reference mark
миллитесламер - milliteslameter
амперметр - ammeter
кабель -cable
магнитное поле- magnetic field
внешнее магнитное поле - external magnetic field
однородное магнитное поле –uniform magnetic field
линии поля- field lines,

магнитная индукция - magnetic flux density
касательная и нормальная составляющие – tangential and normal components
амплитуда -amplitude
напряженность магнитного поля - magnetic field strength
векторный магнитный потенциал - magnetic vector potential
вдоль поля -along the field ,
поперек поля - across the field ,
магнитный поток -magnetic flux
магнитодвижущая сила (МДС)-ampere-turns**,** magnetomotive force
численный расчет - numerical calculation, numerical computation
плоскость сечения –plane of cross section
граничные условия -boundary conditions

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