Computer Applications in Electrical Engineering
Vol. 13 *2015*

Use of LabVIEW software for electromagnetic calculation of induction motors

Damian Burzyński, Leszek Kasprzyk
Poznań University of Technology
60-965 Poznań, ul. Piotrowo 3a, e-mail: {Damian.Burzynski, Leszek.Kasprzyk}@put.poznan.pl

The possibilities of use of LabVIEW software for electromagnetic calculations of induction motors were presented in the article. It also includes the most important dependencies describing electromagnetic parameters for the motors in question together with the used calculation algorithm. The application used for electromagnetic calculations of wound-rotor induction motors with drop-shaped groves was developed and described in detail. On the basis of the presented algorithm implemented in LabVIEW environment of graphic programming, the parameters of magnetic circuit for three-phase motor with rated power of 2.2 kW were determined.

KEYWORDS: LabVIEW, electromagnetic calculations, induction machines

1. Introduction

Along with technical progress, methods of designing of all the equipment developed by people are being improved. Until mid of the last century, the design issues were solved using analytical approach, without the use of IT techniques [1]. Simplified calculation methods were applied then. The objective of the designers of this time was to create the sequential calculation mode which would perform a series of calculations according to strictly specified sequence. Calculation forms together with charts of formulas and diagrams were used in designing as an aid. The parameters of the designed systems were determined manually, which was a very time-consuming process.

As a result of technological development which took place in 20th century, most of the equipment designed by people requires a drive unit which would – to a considerable degree – be powered with electrical energy – electric motors. In most cases these are machines supplied from a three-phase electrical power network (three-phase induction motors). Along with industrial progress and due to economic and ecological reasons, the motors were expected to be more and more efficient and durable. This was connected with the need to modernize the used designing methods which should enable consideration of growing number of parameters and, consequently, determination of the analysed values with greater accuracy [1].

Due to that, currently the electrical machines are designed solely with the use of computers. As a result, the calculations are made using analytical and numerical methods. This not only shortens the time needed for calculations but also considerably contributes to improvement of the accuracy of calculations and consequently to improvement of quality and durability of constructed equipment. As a result of development of these fields, designing of electrical machines today is considered as a comprehensive issue which concerns the following aspects:

- calculations of parameters of machines;
- use of computer software for synthesis, analysis and predicting of behaviour of the designed machines;
- calculation of desired values, with simultaneous meeting of applicable standards, with the option of their subsequent optimization [1, 6].

Contemporary computer technologies also enable creating virtual designing environments. Their main advantage is the possibility of preliminary verification of the properties of the designed machines, still before they are manufactured. Comprehensive designing of electrical machines in virtual environments is connected with the need to consider many complex design aspects at the same time.

From among the designing elements of electric machine, the most important elements include electromagnetic calculations. The objective of them is to determine quality parameters which decide on electromagnetic properties of an electric machine. As a result of calculations made on the basis of structural data of the designed machine, you obtain such parameters of the magnetic circuit as, for example: main stream and magnetizing current, inductions and magnetic voltages, magnetic field strengths of individual parts of the core. These parameters enable to conduct calculations during subsequent stages of designing the machine, e.g. during mechanical analysis.

There are many software systems for virtual designing, however one of the most popular ones includes LabVIEW. Due to that this study presents the application used to calculate electromagnetic parameters of induction motors in LabVIEW graphic software environment.

2. LabVIEW graphic programming software

LabVIEW software is the environment of an integrated graphic programming. It is used to create the applications, above all for control and measurement systems in which data acquisition is used [2]. It also makes it possible to create engineering interfaces connected with control, testing and visualisation of measurement results. The applications created in LabVIEW environment operate using graphic programming language.

The application written in LabVIEW consists of user interface (main panel) and block diagram which is created with the use of components and functions implemented in the programme. The user interface comprises controls for entering input data as well as controls (indicators) for displaying calculation results. The controls for entering input data are most frequently the fields used for entering numbers, but they can also have the form of slides, switches, buttons or drop down menu. Results of calculations or measurements may be displayed as numbers in the fields or in the form of diagrams, charts and by indications on virtual metering instruments (keeping the properties of actual metering instruments). The block diagram includes the code of the programme in the form of a number of ready mathematical, measurement, programming and other functions which define dependencies between the entered parameters.

The user interface and block diagram are strictly integrated with each other because the variables entered in the main panel are connected on the block diagram using functions, loops or various types of structures. The important advantage of applications created in LabVIEW environment useful during development of design and optimisation programmes is the possibility of starting them in the mode of cyclical loops.

3. Determination of electromagnetic parameters of induction motors

The magnetic circuit of induction motor is treated as non-branch circuit which is not dimensionally homogeneous [3]. It consists of two parts which differ from each other in magnetic properties: gaps with permeability μ_δ and core defined by magnetizing characteristics. For the circuit considered in such a way the calculations of replacement values of magnetic voltages for the air-gap, yokes, stator and rotor teeth are conducted. The sum of the values of magnetic voltages of these elements θ is equivalent with total flow and described with the following formula [3, 7]:

$$\theta = U_{ds} + U_{dr} + U_{ys} + U_{yr} + U_\delta \tag{1}$$

where: U_δ – magnetic voltage of the gap; U_{ds} / U_{dr} – magnetic voltages of stator/rotor teeth; U_{ys} / U_{yr} – magnetic voltages of stator/rotor yokes.

The value of total flow is used to determine magnetizing current which decides on the value of power coefficient of the induction motor. The magnetizing current is calculated using the following formula [3, 7]:

$$I_m = \frac{0{,}37\theta p}{N_s k_{ws}} \tag{2}$$

where: p - number of pole pairs; N_s - number of serial coils in the stator band; k_{ws} - stator winding factor.

The magnetizing current generates the flow of the main stream in the induction motor. This stream vibrates with the synchronic speed (depending on the frequency of the supply voltage) and magnetically couples the winding of the stator and rotor. Assuming sinusoidal flows of currents, the stream in the stator yoke is described using the following dependency [3, 7]:

$$\phi_{ys} = \frac{U_{iys}}{4k_B f_s N_s k_{ws}} \tag{3}$$

where: U_{iys} - stator yoke voltage; k_B - coefficient of field curve shape; f_s - supply voltage frequency.

Next, parameters obtained as a result of electromagnetic calculations are magnetic induction in stator yoke and magnetic induction of the gap and teeth. Magnetic induction in the stator yoke depends on the value of the magnetic stream in line with the following formula [3, 6]:

$$B_y = \frac{\phi_{ys}}{2h_{ys} l_s k_{Fe}} \tag{4}$$

where: ϕ_{ys} - magnetic stream in stator yoke; h_{ys} - effective height of stator yoke; l_s - length of the stator's core; k_{Fe} - package filling coefficient.

The value of magnetic induction of the yoke is converted into the value of substitute magnetic field strength in line with a given magnetizing characteristics of the sheet used for the core. Finally, the value of magnetic voltage of the yoke is calculated for the stator and rotor using the following formula [3, 7]:

$$U_y = l_y H_y \tag{5}$$

where: l_y - length of the route in the yoke; H_y - substitute magnetic field strength.

Magnetic voltage of the gap depends on the value of induction in the gap and on Carter coefficient and is described using the following dependency [3]:

$$U_\delta = 796 k_c B_\delta (\delta + \Delta\delta) \tag{6}$$

where: B_δ - magnetic induction of the gap; k_c - Carter coefficient; δ - width of the air-gap; $\Delta\delta$ - value considering the increased magnetic voltage during calculations of magnetizing current.

Magnetic voltage of teeth of the stator and rotor is calculated on the basis of their size and magnetic field strengths of their individual parts. For stator and rotor grooves with drop sections the magnetic voltage of the teeth is determined using the following formula [3, 7]:

$$U_d = \frac{1}{6}(H_{d1} + 4H_{d2} + H_{d3})h_d \tag{7}$$

where: H_{d1-3} - magnetic field strength of individual parts of the tooth; h_d - height of the tooth.

The electromagnetic parameters mentioned hereinabove are determined on the basis of many auxiliary parameters and dependencies described in detail in the studies [3, 4, 5, 7]. Due to considerable volume of the calculation algorithm as well as big number of formulas, it was not attached to this study.

4. Example of the application written in LabVIEW and used for electromagnetic calculations of induction motors

Due to the need to consider big number of variables and criteria during designing of induction motor, an engineering application in LabVIEW environment was developed, which performs the calculation algorithm using cyclical loops. The application makes it possible to adjust the input parameters at any designing stage, as well as facilitates observation of their impact on determined parameters. The application's functionality is based on dividing it into two basic parts:

- part used to enter set parameters (structural data of the induction motor),
- part covering the tabs with the results of next designing stages.

The set parameters may be entered from the winding chart of the motor or according to the applicable standards and regulations. The parameters essential to obtain complete results of calculations include:

- electrical parameters: efficiency, rated power, frequency of the stator's voltage, power coefficient, slip, number of pole pairs;
- structural parameters for the stator and rotor: internal and external diameter, core length, diameter of band winding wire, coil span, number of grooves, number of conductors in the grooves, number of parallel branches, number of parallel conductors in the coils, thickness of the gap between the stator and rotor.

Results of calculations are grouped in 6 tabs which include:

- basic and auxiliary parameters used for further calculations, including: Carter coefficient, winding factor, reactance of the main stream as well as selection of the type of windings and electrotechnical sheet;
- calculations of stator and rotor grooves, in particular groove conductivity coefficients, calculation sizes as well as areas with and without the flow;
- calculations of masses and losses in the stator core, for example: tooth and yoke masses, values of power losses on individual elements;
- parameters of the substitute diagram, such as resistances and reactances of the stator and rotor, parameters of the elements of reduced diagrams as well as substitute impedance of the whole motor;
- calculations of moments and characteristics in the state of load, above all of the rated moment, break-down torque, curve with the characteristics of the load for the agreed slip;

– calculations of electromagnetic parameters, described in detail in chapter 3.

The application is used to determine electromagnetic parameters of the induction motor with ring rotor with the consideration of the following assumptions:

– windings of the stator and rotor of band type have the wheel section;
– stator is powered from the network with symmetric, sinusoidally variable voltage;
– stator and rotor grooves have the shape of a drop;
– losses connected with current displacement were disregarded;
– lack of bevels of the stator's grooves;
– calculation results are reliable for motors with small or average powers, with induction values in the stator's or rotor's teeth within the range from 0.8 T to 1.8 T,
– thickness of the gap is the same along the whole perimeter and length of the motor.

The fragment of the main panel of the application is presented in Fig. 1. Electromagnetic calculations are conducted according to the algorithm presented in Fig. 2.

Calculations of the most important electromagnetic parameters of the induction motor with the following structural parameters were conducted with the use of developed application:

– rated power: 2.2 kW,
– efficiency: 80%,
– slip: 9.1%,
– power factor: 0.8,
– number of pole pairs: 4,
– external diameter of the stator/rotor: 181/134 mm,
– stator/rotor core length: 142/141 mm,
– internal diameter of the stator/rotor: 135/65 mm,
– gap thickness: 3.5 mm,
– number of the stator/rotor grooves: 48/38,
– stator/rotor coil span: 6/4,
– number of parallel conductors in the stator/rotor coils: 2/1,
– number of parallel branches of the stator/rotor: 1/2,
– number of conductors in the stator's/rotor's grooves: 82/16,
– characteristic sizes of the rotor's groove $b_{1r} / b_{2r} / b_{3r} / h_{1r} / h_{3r}$: 2.5/6.1/2.4/0.5/14.3,
– characteristic sizes of the stator's groove $b_{1s} / b_{2s} / b_{3s} / h_{1s} / h_{3s}$: 2.8/5.4/7/0.5/9.1,
– rotor's groove bevel: 9.9 mm.

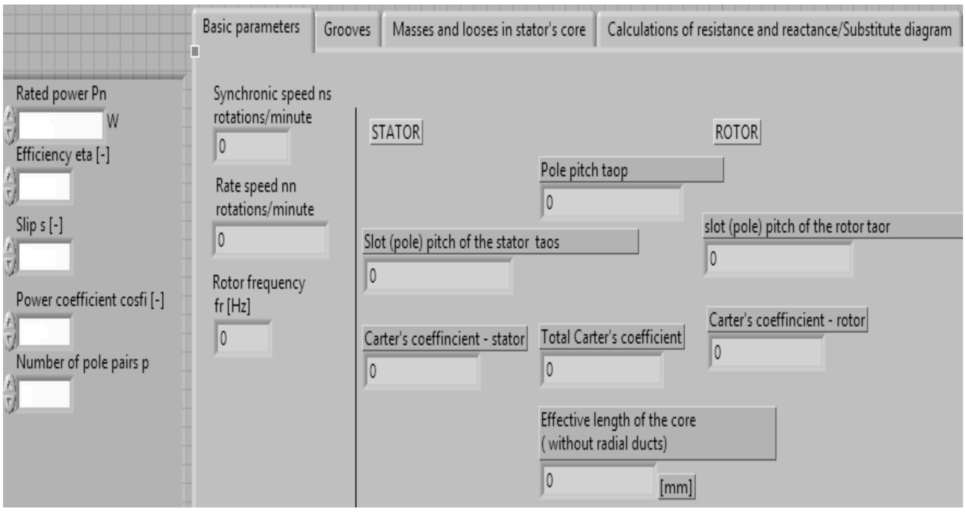

Fig. 1. Fragment of the application's main panel

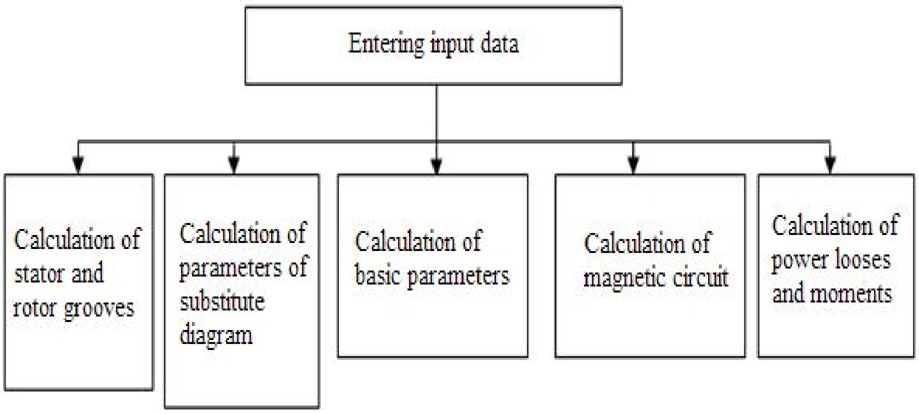

Fig. 2. Calculation algorithm of electromagnetic parameters

Calculations of the stator's and rotor's grooves parameters

The application is used to determine values of electromagnetic parameters with grooves of drop section. The values of auxiliary parameters used for further calculations are the result of calculations of groove parameters. They influence the value of power losses as well as the values of magnetic voltages of the teeth in the stator and rotor. It is necessary to declare the size of the grooves in order to obtain them. View of the fragment of calculation tab of the grooves was presented in Fig. 3.

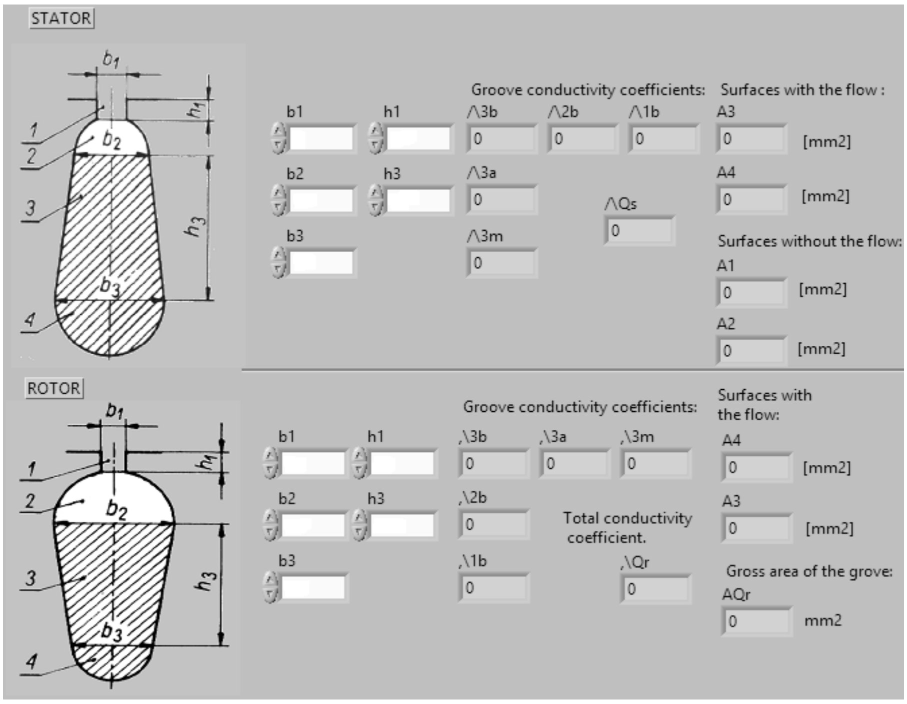

Fig. 3. View of the fragment of calculation tab of grooves in the main panel

The calculation algorithm of the stator groove was developed on the basis of dependencies presented in the studies [3, 4]. Its fragment was presented in Fig. 4. Calculations of auxiliary parameters of the grooves were conducted with the use of the created application. These parameters are used, above all, for final calculations of electromagnetic parameters and for determination of masses of the stator's and rotor's teeth. The calculation results were specified below.

Stator's parameters:

- total groove conductivity coefficient: 1.36;
- areas with magnetic flux flow: A_3 = 56.4 mm^2, = 19.3 mm^2;
- areas without magnetic flux flow: = 1.4 mm^2, A_2 = 11.5 mm^2,
- grove depth: 15.8 mm;
- gross area of the groove: 88.5 mm^2.

Rotor's parameters:

- total groove conductivity coefficient: 1.43;
- areas with magnetic flux flow: A_3 = 60.8 mm^2, = 2.3 mm^2;
- areas without magnetic flux flow: = 1.3 mm^2, A_2 = 14.6 mm^2,
- grove depth: 19.1 mm,
- gross area of the groove: 78.9 mm^2.

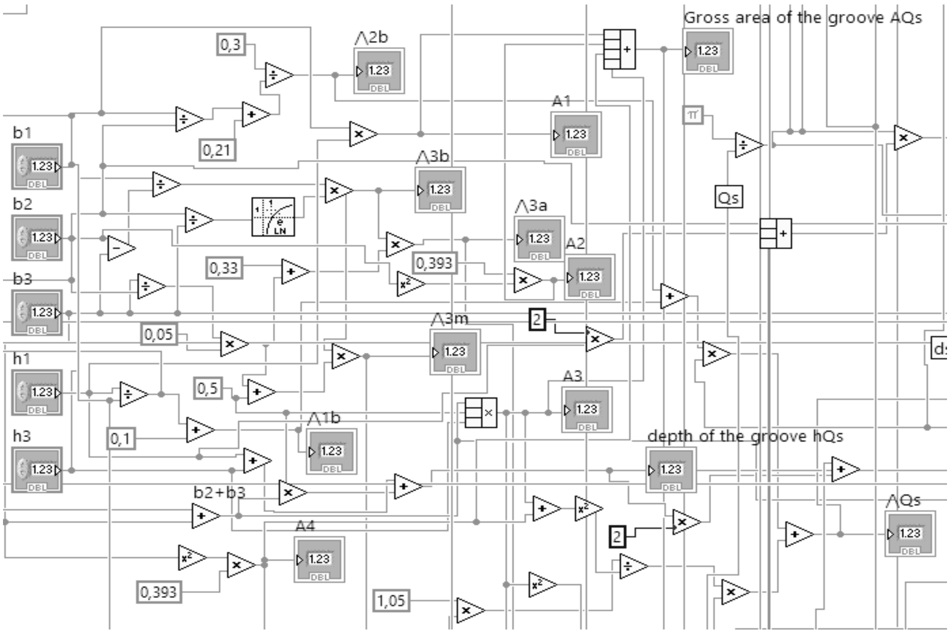

Fig. 4. Fragment of the calculation algorithm of the stator's groove

Calculations of the magnetic circuit

Results of calculations of electromagnetic parameters are obtained after entering the values of the stator's phase voltage to the programme (Fig. 5). The values of core tooth and yoke voltages as well as induced internal voltage will be determined. Then the induction value in the gap will be calculated as well as induction values in individual sections of the teeth for the stator and rotor. The induction values in teeth sections will be converted to the corresponding values of magnetic field strengths in line with the formula of the approximated characteristics of the electrotechnical sheet used for the core. The result of these calculations is the value of magnetic voltages of teeth as well as magnetic voltage of the gap.

The values of these parameters for the considered induction motor amount to:

- induced internal voltage: 200.3 V,
- core tooth voltage: 204.2 V,
- yoke voltage: 208.1 V,
- induction in the gap: 0.57 T,
- magnetic voltages of the stator's/rotor's teeth: 19.7/11.8 A,
- magnetic voltage of the gap: 272.5 A.

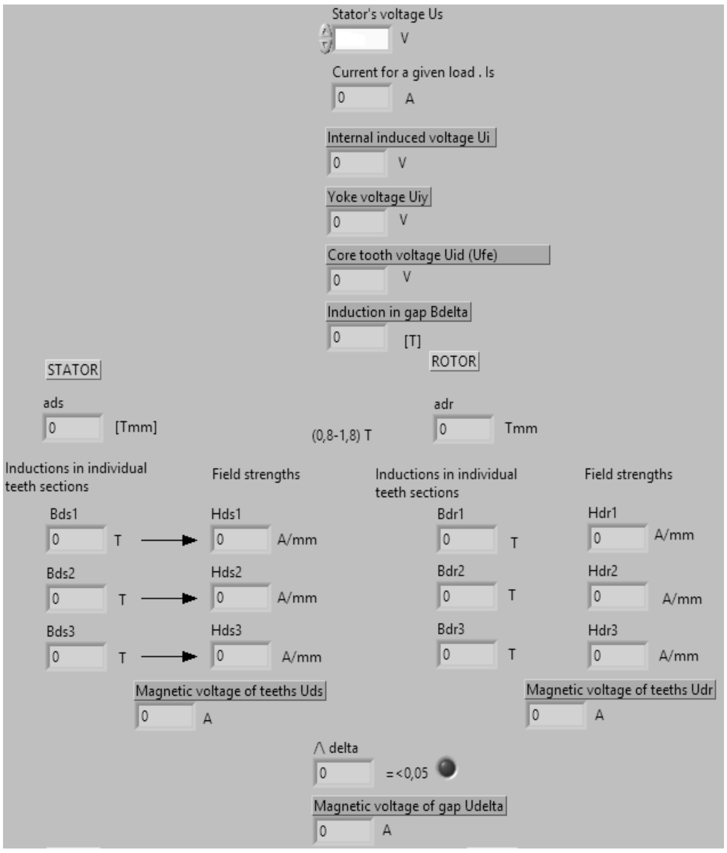

Fig. 5. Fragment of the calculation tab of the magnetic circuit

The last stage of determination of parameters of magnetic circuit are calculations of magnetic fluxes and magnetic field strengths of rotor and stator yokes. These parameter define distribution of magnetic flows in the induction motor. The view of the panel's part for calculations of electromagnetic parameters was presented in Fig. 6.

Calculation results of the most important electromagnetic parameters:

- magnetic flux in the stator's/rotor's yoke: 0.0029/0.0028 Wb,
- magnetic voltages of the stator's/rotor's yokes: 2.5/1.7 A,
- flow to the core: 51.3 A,
- flow in the gap: 246 A,
- total flow: 543.3 A,
- magnetizing current: 2.5 A.

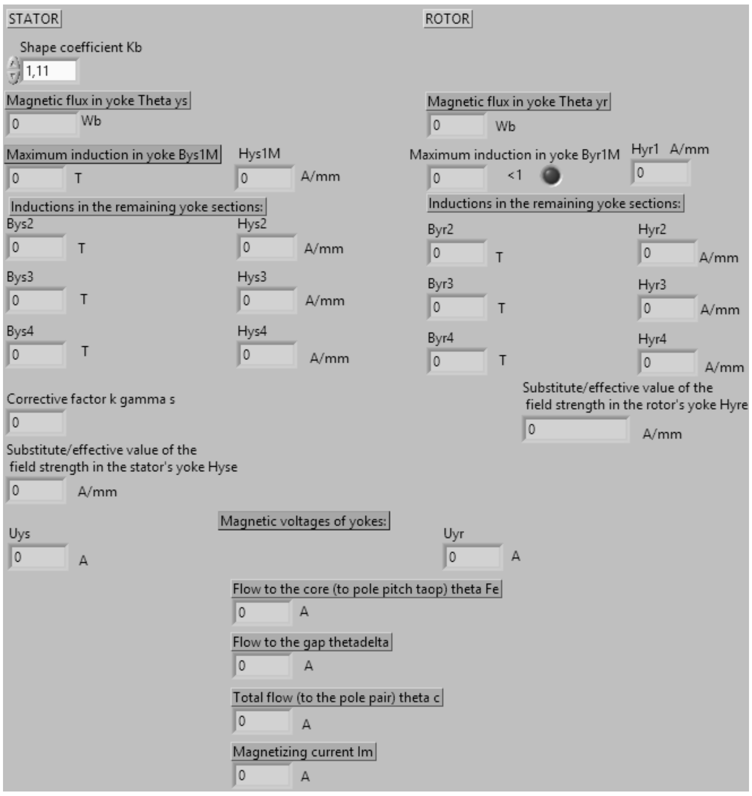

Fig. 6. Fragment of the calculation panel of the magnetic circuit

5. Summary

The objective of the study was to present the possibilities to use the integrated LabVIEW graphic software for electromagnetic calculations of induction motors. This is an important and current topic connected with more frequent need to conduct engineering calculations on personal computers. As presented in the study, various types of equipment use computer application for the purposes of designing today. These are usually dedicated applications which enable to conduct detailed analyses of the selected system types. However, the integrated systems intended for graphic software which are appearing lately give the possibility to prepare – in a relatively simple and intuitive way – own applications used for engineering calculations, even by persons without big programming experience.

Due to that, the article presents the example of using the environment of LabVIEW graphic programming for electromagnetic calculations of the induction motor.

The procedure of determining the parameters of the designed motor is a complicated issue due to the need of considering many factors and phenomena occurring during its operation. The created application allows to considerably shorten the time needed for their analysis and facilitates the decision-making processes during designing. The use of graphic structure allows to adjust calculation parameters with regard to ensuring the best operating properties of the designed machine. The calculation algorithm is executed in the mode of iterative loops, which is a beneficial solution, especially in designing processes conducted in stages. In further part of the studies, the authors plan to modify the application to enable conducting calculations of electromagnetic parameters of electric motors of various types.

Reference

[1] Dąbrowski M., Zarys projektowania maszyn elektrycznych. Prace Instytutu Elektrotechniki, Zeszyt 217, 2003.

[2] National Instruments, LabVIEW 8.5 User Manual April 2003 Edition.

[3] Głowacki A., Obliczenia elektromagnetyczne silników indukcyjnych trójfazowych. Wydawnictwa Naukowo-Techniczne, Warszawa 1993.

[4] Dąbrowski M., Projektowanie maszyn elektrycznych prądu przemiennego. Wydawnictwa Naukowo-Techniczne, Warszawa 1994.

[5] Śliwiński T., Metody obliczania silników indukcyjnych. Wydawnictwo naukowe PWN, Warszawa 2008.

[6] Śliwiński T., Optymalizacyjne obliczenia projektowe silników indukcyjnych. Prace Instytutu Elektrotechniki 1980. Vol. 114, pp. 5 - 26.

[7] Kozłowski H., Turowski E., Silniki indukcyjne. Projektowanie. Konstruowanie. Wytwarzanie. Wydawnictwa Naukowo–Techniczne. Warszawa 1961.

(Received: 5. 10. 2015, revised: 11. 12. 2015)