DESIGN OF AN ELECTRIC DRIVE MODEL WITH SUPPORT FOR CA SYSTEMS

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This article shows an example of designing an induction motor model. Calculation of electrical parameters of induction motor in Ansys Electronic Suite - Maxwell RMxprt. The finite-element analysis of the CAD model was performed both in two-dimensional space using Ansys Electronic Suite software of Maxwell RMxprt subprogram and in three-dimensional space using Ansys Mechanical software. The natural frequency of the motor rotor is between 922 Hz and 1014.6 Hz, so these frequencies must be skipped when controlling a motor of this configuration. The obtained values of electric current, torque, and operating speed can be adjusted by changing the internal components of the winding, stator, and rotor design. All the studies can be modified and used to study induction motors with other parameters. In particular, the created project in Ansys software can be used to design an induction motor with its characteristics, optimal for the required tasks.

KEYWORDS

Design, CA systems, electric drive

1 INTRODUCTION

An induction motor (IM), like any other motor, can be described by its electrical parameters. Power, supply voltage, current consumption, and connection type are the main parameters that describe an induction motor. Many parameters described in the motor datasheet are nominal, without taking into account any inaccuracies or assumptions.

The deployment and use of computer-aided (CA) systems [Jakubowski 2014] have become a common engineering and research practice in almost all areas of social life for several years. Various computer-aided design/computer-aided manufacturing (CAD/CAM), computer-aided assembly (CAA) [Peterka 2008, Vaclav 2007], reverse engineering (RE) systems [Buransky 2013], and various software applications designed for special purposes in different fields [Polakovic 2008, Nemeth 2018, Borkin 2019] have been used.

Calculation of an IM AIR 63V2 using the program RMxprt, included in the package ANSYS Electronic Suite as a part of Maxwell RMxprt [Funk 2017, Tlach 2019, Cubonova 2019] is described. The calculation is based on the classical analytical theory of electrical machines, as well as the method of the equivalent magnetic circuit. Such effects as the nonlinearity of electrical steel, the non-sinusoidal magnetic flux in the gap, and current displacement in massive conductors are taken into account [Stolarski 2018, Saga 2011]. Also, the advantage of this program is the ability to change parameters throughout the calculation, which allows to compare different characteristics under different input data to obtain the most optimal values [Chen 2019, Dyadyura 2021].

No single aspect of electric-machinery analysis and design has received so much attention in the literature as that of how computers can be used in the process. Nevertheless, most of this material is concerned with specific problems and applications, and until now a general view of the whole area, as seen from the perspective of historical experience, has not been available. The book opens with a look at the nature of a programmable engineering problem and discusses the selection and mechanics of digital computer equipment. Both equipment and procedures are judged in terms of economic considerations as well as from a strict engineering point of view. The author then describes the experiences of Reliance Electric's Engineering Computer Center and puts forth some general conceptual approaches regarding the nature of the design problem and outlines the analysis and synthesis approaches to design. Notes on programming explain such techniques as branching, decision and structure tables, flowcharting, and iterative (or cut-and-try) procedures. Some specific electromechanical applications are taken up next. These include the design of single-phase and polyphase induction motors, the calculation and design of laminations for both stators and rotors, the design of direct-current machines, and the problems of mechanical design (weight and inertia calculations, rotor design, rating and efficiency calculations, and the design of worm gears). The later chapters introduce the working up of test data and the elements of curve fitting, QUIKSPEK (a computerized sales-order-specification system), and a final "Potpourri" of topics, including transient phenomena, synchronous machine design, distributed parameter problems, and electronic power supplies [Blatnicky, 2020, Vishnu 2008].

The objective of this study was to explore the differences in the use of a professional FEM-Software and a FEM-Simulation-Tool that is integrated into 3D-Design software. The study was commissioned by Seppo Toivanen of Saimaa University of Applied Sciences. To determine the differences a vibration analysis of an output shaft of an electric motor with an attached planetary gear was carried out. Three different cases were simulated in each software. For every simulation case, a control calculation was carried out to verify the results of the simulation. The same check calculations were also performed by the authors [Saga 2019]

The information for this thesis was collected from books, internet sources, journals, and the Help Guides of each software. The results of this study show that both softwares can deliver adequate results, but the professional FEM-Software offers more possibilities to reproduce the reality within the software. Therefore, it is recommended to use professional FEM Software for special and complex cases. Simulation of those cases requires highly skilled engineers, who know exactly what they do. In return, the simulation tool is excellent for beginners in FEM to learn the basics and for quick analysis in between the designing work. For further investigations, it is recommended to spread the study over several analysis types and to analyze several structures with different boundary conditions [Grunwald 2018].

The first part of this volume provides the user with assistance in the selection and design of important machine and frame components. It also provides help with machine design, calculation, and optimization of these components in terms of their static, dynamic, and thermos-elastic behavior. This includes machine installation, hydraulic systems, transmissions, as well as industrial design, and guidelines for machine design. The second part of this volume deals with the metrological investigation and assessment of the entire machine tool or its components concerning the properties discussed in the first part of this volume. Following an overview of the basic principles of measurement and measuring devices, the

procedure for measuring them is described. Acceptance of the machine using test workpieces and the machine and the machining process is discussed [Brecher 2022, Kuric 2018].
The development of a five-phase motor and analysis the results of the model and full-scale experiments is considered in [Kuric 2022]. It is shown that the use of five-phase motors for automatic devices gives high efficiency.
To ensure the high reliability of engines, their diagnostics is required [Cacko 2014, Bozek 2021, Kuric 2021, Stepanov 2021, Trefilov 2021, Kuric 2020, Nikitin 2022]. The application of artificial intelligence methods for engine diagnostics is discussed in papers [Peterka 2020, Nikitin 2020 a-d].

2 MATERIALS AND METHODS

Calculation of electrical parameters of an induction motor in Ansys Electronic Suite - Maxwell RMxprt [Lakshmi 2021]. For larger-scale calculations, the configuration created in RMxprt can be converted to the Maxwell model. Maxwell is based on the Finite Element Method (FEM) and accurately calculates static, harmonic electromagnetic, and electrical fields and transients in field problems [Kassa 2021].

The FEM is an integer method for solving partial differential equations and integral equations arising in solving problems of applied physics. The method is widely used for solving problems in the mechanics of deformable solids, heat transfer, hydrodynamics, and electrodynamics [Gope 2021] and visual inspection of the resulting design is essential, as the authors prove in their work [Kuric 2019]. The essence of the method follows from its name. The domain in which the solution of differential equations is sought is divided into a finite number of subdomains (elements). In each of the elements, the type of approximating function is chosen arbitrarily. In the simplest case, this is a polynomial of the first degree. Outside its element, the approximating function is zero. Function values on element boundaries (in nodes) are the solution to the problem and are unknown in advance. The coefficients of approximating functions are usually found from the condition of equality of values of neighboring functions on the boundaries between elements (in nodes). Then these coefficients are expressed through the values of functions in the nodes of elements. A system of linear algebraic equations is composed. The number of equations is equal to the number of unknown values in the nodes, on which the solution of the original system is sought, is directly proportional to the number of elements, and is limited only by the capabilities of the computer. Since each of the elements is related to a limited number of neighbouring elements, the system of linear algebraic equations has a sparse form, which greatly simplifies its solution. If we speak in matrix terms, the so-called stiffness matrices (or Dirichlet matrix) and masses are collected. Next, boundary conditions are imposed on these matrices (e.g., under Neumann conditions, nothing changes in the matrices, while under Dirichlet conditions, the rows and columns corresponding to the boundary nodes are crossed out of the matrices, since the values of the corresponding solution components are known due to boundary conditions). Then the system of linear equations is assembled and solved by one of the known methods.

The application of the method in electrodynamics is based on Maxwell's equations:

Gauss's law:

$$\oint D \cdot ds = Q \tag{1}$$

Gauss's law for the magnetic field:

$$\oint B \cdot ds = 0 \tag{2}$$

Faraday's law of induction:

$$\oint E \cdot dl = -\frac{d}{dl}\int B \cdot ds \tag{3}$$

Bio-Savara-Laplace Law:

$$\oint H \cdot dl = I + \frac{d}{dl}\int D \cdot ds \tag{4}$$

Equations of State:

$$B = \mu \cdot \mu_0 \cdot H \tag{5}$$

$$D = \varepsilon \cdot \varepsilon_0 \cdot E \tag{6}$$

$$j = \sigma E + j_{\text{стр.}} \tag{7}$$

The calculation begins with the creation of a new project, in which has to be specified what type of electrical machine is to be calculated (Figure 1). In the project manager appear 4 categories in the created project: Machine – the setting of model parameters, Analysis – the setting of model calculation, Optimetrics – the setting of model optimization parameters, and Results – the output of analysis results. The initial data of the IM AIR 63V2 are entered into the project. Using the previously created 3D model in SolidWorks software we fill in the graphs with the dimensions of stator and rotor slots. In this calculation, unlike the 3D model, simplification of the stator winding is unacceptable.

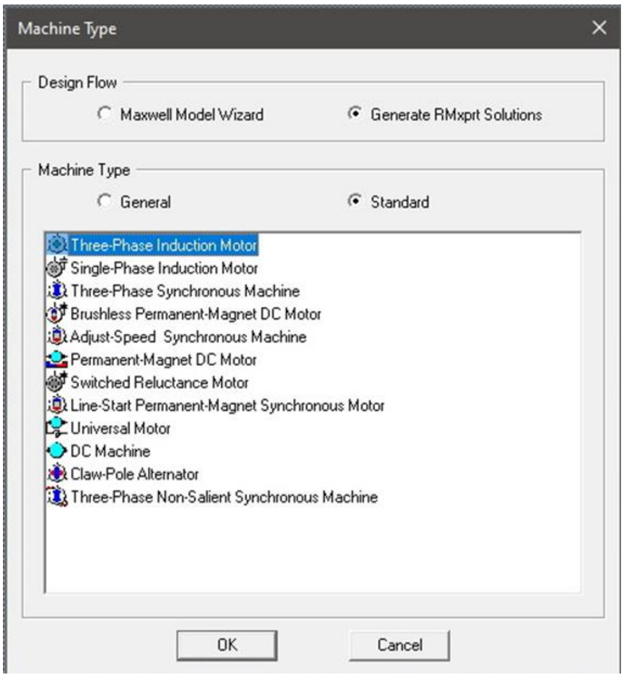


Figure 1. Selecting the type of IM

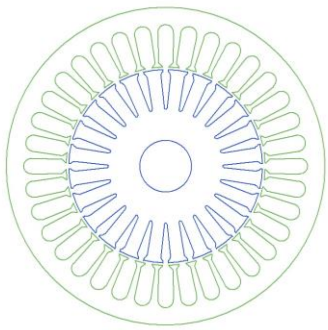


Figure 2. IM stator and rotor in the RMxprt program

After filling in the parameters, the screen displays a conditional image of the object being worked in Figure 2, and Figure 3.

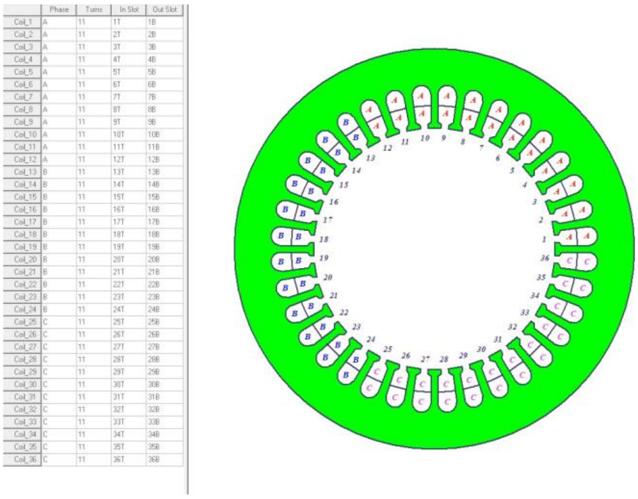
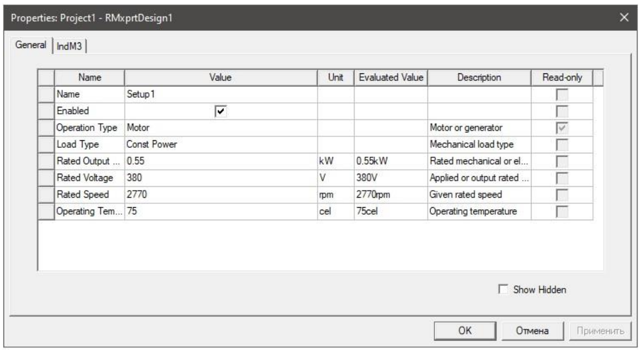


Figure 3. End connections in the stator winding

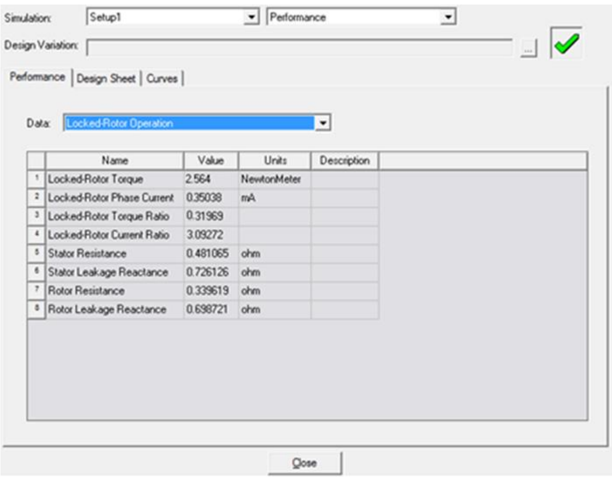
As a result of filling out the RMxprt forms, the project is ready to perform the calculation. A new solution profile is created and solution parameters are entered, which include various load types such as constant speed, power, torque, as well as fan load, etc.



Name	Value	Unit	Evaluated Value	Description	Read-only
Name	Setup1				
Enabled	✓				
Operation Type	Motor			Motor or generator	✓
Load Type	Const Power			Mechanical load type	
Rated Output ...	0.55	kW	0.55kW	Rated mechanical or el...	
Rated Voltage	380	V	380V	Applied or output rated ...	
Rated Speed	2770	rpm	2770rpm	Given rated speed	
Operating Tem...	75	cel	75cel	Operating temperature	

Figure 4. Solution Profile window

Next, a check is performed and the project is calculated. The calculation results are presented in two views: in the form of data tables and as a set of characteristics.



	Name	Value	Units	Description
1	Locked-Rotor Torque	2.564	NewtonMeter	
2	Locked-Rotor Phase Current	0.35038	mA	
3	Locked-Rotor Torque Ratio	0.31969		
4	Locked-Rotor Current Ratio	3.09272		
5	Stator Resistance	0.481065	ohm	
6	Stator Leakage Reactance	0.726126	ohm	
7	Rotor Resistance	0.339619	ohm	
8	Rotor Leakage Reactance	0.698721	ohm	

Figure 5. Project calculation results in the window in tabular form

The creation of Maxwell project is made in automatic mode. As a result, a complete model of the induction motor will be created for research.

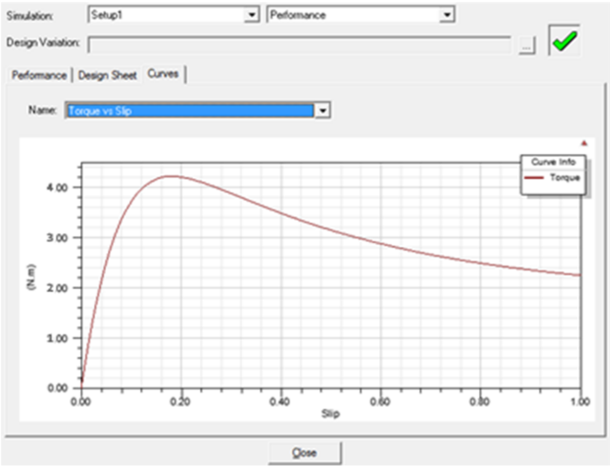


Figure 6. Project calculation results in the form of a characteristic

Figure 7. Maxwell project creation window

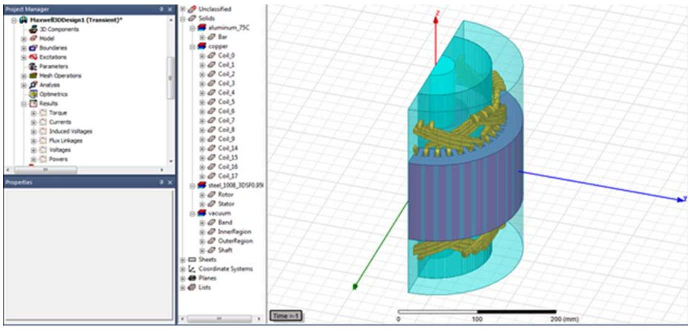


Figure 8. Automatically created Maxwell 3D project

The RMxprt calculation resulted in the following data: Rated electric current: I= 1.5726 A, Rated electric current: I= 1.5726 A, Nominal torque: M= 1.6879 N·m, Nominal speed: 2648.26 rpm. By the data, let's conclude: the calculation in RMxprt software was performed correctly. In the future, it is possible to change various parameters in a short time when investigating IM using this project and calculate the exact values for the selection of optimum values.

3 RESULTS AND DISCUSSION

Calculation of natural frequencies of IM structures in Ansys – Mechanical Ansys. The importance of studying the dynamics of the system of moving elements of asynchronous motor is due to its strong influence on the vibration state of the whole motor. During the development of a stand for the study of motor parameters, the dynamic properties of the whole unit play an important role. In order not to allow the coincidence of operating frequencies with resonance, the calculation of natural vibrations of the structure is carried out.

The purpose of this calculation is to carry out a modal analysis of the motor rotor in combination with other moving elements of the system, taking into account the gyroscopic effect.

A complete CAD model of the induction motor with the possibility of finite element analysis has been developed, so the first step of the calculation will be the conversion of the required elements in the Ansys software. A similar program developed for this purpose is used [Saga 2014]. Imported objects include rotor, impeller, and 2 bearings 6201 ZZ-C3.

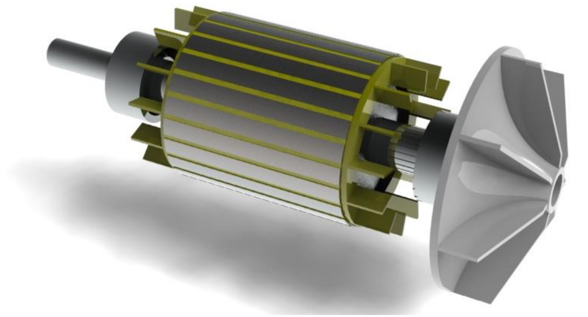


Figure 9. CAD model in SolidWorks software

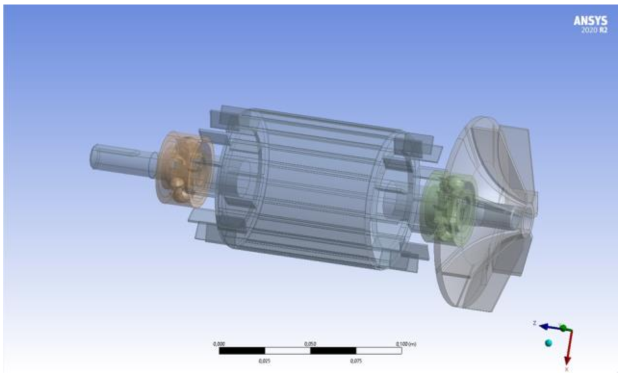


Figure 10. Assembling imported models in Ansys – Design Modeler

When importing in .step .parasolid formats, problems may arise in the form of artifacts on the edges of circles, on protrusions, and on roundings, to solve this problem, the original geometry is corrected. In the Create tab, a Body Operation element is created, in the Type tab, Simplify is selected and all elements of the assembly are marked. Then all elements are renamed according to their purpose. This completes the preparation of parts for calculations.

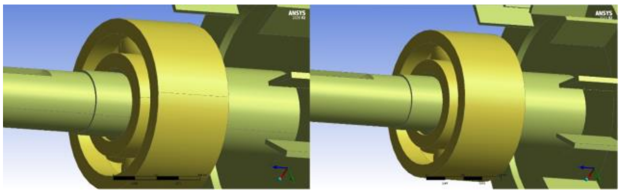


Figure 11. Exclusion of artifacts on the parts

Let's set the materials for all the elements, the rotor will be a composite part and include several materials, the bearing material will be assigned according to the bearing datasheet of the middle series, and the shaft material will be assigned according to the motor datasheet. The impeller will be assigned polycapromide.

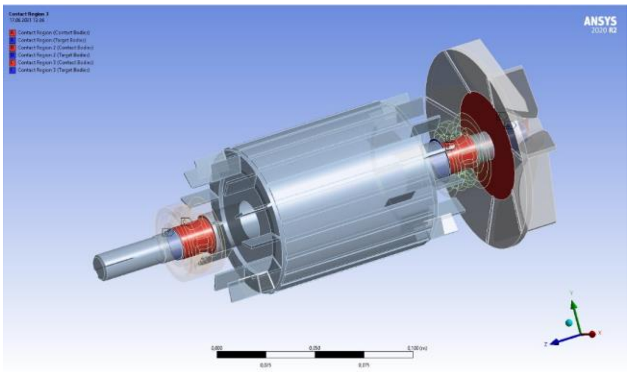


Figure 12. Assigning contact surface

Next, the contact surfaces will be checked or assigned. Since we have the rotor as a single structure, there will be no contact surface assignment to the shaft. This is not a critical aspect because the entire rotor will be calculated as one unit. The next step is to create a mesh of objects to be studied. The more accurate the polygonal mesh - the more accurate the calculation will be, but the more it will be processed. It is worth paying attention to the joints of elements, rounded surfaces, and surfaces of complex geometry, to make local corrections to the mesh and exclude interference.

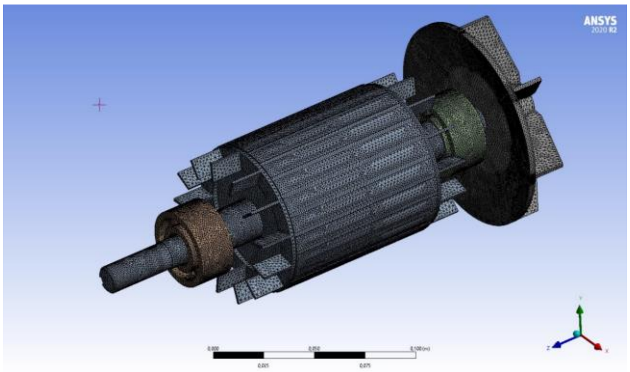


Figure 13. Creating a polygonal mesh of objects

After setting and editing the mesh, the boundary conditions - rigid terminations on the raceways of the inner rings of the bearings - should be set. Simulation of rotor dynamics can be performed in two different reference systems: stationary and rotating. The gyroscopic effect in Ansys is taken into account in the form of a damping matrix. The negative value corresponds to a stable form of oscillation and the positive value to an unstable form. The imaginary part represents the eigenfrequency with damping taken into account. Even though the gyroscopic effect is taken into account in the form of a "damping" matrix, energy dissipation does not occur, so if in the model damping is not set, all real parts of complex frequencies will be zero.

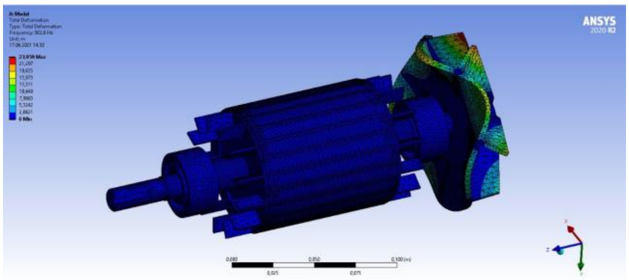


Figure 14. The result of Ansys calculations

To start the calculation, it is necessary to select Solve from the context menu of the Modal element, after successful completion of the calculation the green check mark should appear in the project tree. At that, the graphic window will display a deformed form of anchor corresponding to its frequency with the number specified in the parameters panel in the Mode cell. The result in the fixed reference frame is a frequency range of 922.6 to 1014.6 Hz.

To view the forms of natural vibrations, it may be used the animation tools provided in the mechanical package. Note, that the natural frequency of the motor rotor is from 922 Hz to 1014.6 Hz, therefore it can be concluded - in terms of the calculation of natural frequencies, frequencies 922-1014.6 Hz should be skipped when controlling the motor of this configuration.

The calculation did not take into account the effect of, assembly and temperature stresses, gas forces, or change of material characteristics from the temperature of assembly and temperature stresses were not taken into account. When performing this work, time dependencies of the speed and electromagnetic torque of the asynchronous motor were obtained from the mathematical model. With their help, one can observe the state of the motor at certain moments of time off work. The developed mathematical model in Simulink allows us to correct the data for any configuration of an induction motor and to make further calculations to obtain graphs of dependencies.

In the Ansys software, various data directly affecting the motor operation and its control were obtained experimentally. The obtained values of current, torque and operating speed can be adjusted by changing the internal components of the winding, stator, and rotor structures. Conversely, in case of any deviations in the real motor, it is possible to observe faults, relative to real readings and readings that have been calculated in the Ansys software. The resulting CAD model vibration calculations can be used as a starting point in motor diagnostics. If there are design changes in a real motor, such as a change in air gap or rotor eccentricity, these readings can change dramatically and go out of operating frequency ranges, which will negatively affect the performance of the entire motor as a whole.

When investigating a robot drive, all models can be further augmented with values, for example when using gearboxes, to monitor the available parameters, and in case of unfavorable results, make adjustments to the equipment to ensure optimal motor performance.

4 CONCLUSIONS

In this paper, a study of the influence of defects on the state of induction motors has been conducted with the projected model in Matlab Simulink software, finite-element analysis of CAD models, implemented both in two-dimensional space using the software Ansys Electronic Suite complex Maxwell program RMxprt, and in three dimensions in Ansys Mechanical software. The natural frequency of the motor rotor is between 922 Hz and 1014.6 Hz, so these frequencies must be skipped when controlling a motor of this configuration. The obtained values of electric current, torque, and operating speed can be adjusted by changing the internal components of the winding, stator, and rotor design. All the studies can be modified and used to study IM with other parameters. In particular, the created project in Ansys software can be used to design an IM with its characteristics, optimal for the required tasks.

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