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Investigation of the efficiency improvement on a 1.1 kW three-phase asynchronous motor

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ABSTRACT

In this study, the geometrical dimensions of the operational motor parameters of a three-phase squirrel-cage asynchronous motor were obtained by disassembling it. Operating parameter values and properties of the asynchronous motor were measured and modelled using the Ansys RMxprt tool box. The modelling results and efficiency values were found within 0.3% of the ratings on the motor nameplate. The parameter values (e.g. torque, break-down torque, locked rotor current) obtained from modelling were compared to those on the motor nameplate values. In this model, both the finite element and analytical methods were performed successfully. In this study, only the stator parameters of asynchronous motor are analysed and optimized using motor design equations. The rotor structure has been kept the same during the study. The stator slot parameters were changed over certain intervals for more efficient operation. With these analyses, motor torque, power, efficiency, and stator–rotor magnetic flux values were examined. As a result of these works, the efficiency of the motor was increased by 1.59% and the power factor was enhanced by using the optimal slot parameters and whole-coil stator windings. With the changes made to the stator slot parameters and the type of stator winding, the motor efficiency class has been increased from IE2 to IE3. According to the European Union, the production of motors of the lowest efficiency class is IE3, and lower than this class production is forbidden as of July 1, 2021. It means that the IE2 class motors must be converted into the IE3 class motors. This study presents a simple, fast, and effective way to increase motor efficiency class for the transient operating region of the motor in detail.

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1. INTRODUCTION

In parallel with the development of global industries, the demand for electric motors, which is indispensable for industrial production lines, is increasing. According to the estimates of the International Energy Agency, approximately 45% of global electricity consumption is due to electrical motor systems. Asynchronous motors (AM) are one of the types of motors that have been used in industry for a long time and are estimated to be responsible for 90% of the energy consumed by all-electric motors. This percentage indicates the importance of the AM [1, 2]. By improving the efficiency values of electric motors that have such a high energy consumption rate – especially AM – high rates of energy savings can be achieved. Improving the efficiency of electric motors will reduce gas emissions such as CO2 and SO2 that contribute to climate change and threaten our world [1, 3]. For this reason, increasing the efficiency of AM commonly used in industrial production lines is the main subject of this study.

The main reasons for their widespread use of AM in the industry are:

- Low maintenance
- Not forming an electrical arc during operation
- Can be manufactured to deliver a wide power range from low to very high
- Can be designed with different phases
- Their speeds can be varied over very wide ranges due to their high torque and technological developments [2-5].

However, despite these advantages, they have low efficiency and low power factor disadvantages [6]. For this reason, increasing the motor efficiency and power factor value is one of the most important topics for those involved in asynchronous motor design and optimization [7]. A new standard, which was published by the International Electro-Technical Commission (IEC) in 2008, became the European norm in 2009, and was then adopted by the Turkish Standards Institute in 2010 – introducing

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efficiency classes. These new efficiency classes were defined as IE1, IE2, IE3, and IE4. With the introduction of the IEC 60034-30-1 standard in 2014, the highest efficiency class was IE4, and the scope of efficiency was also extended. In the IEC 60034-30-1 standard, IE4 (international efficiency) classes were defined for all-electric motors classified for sinusoidal voltage operation. Accordingly, these efficiency standards and some motor efficiencies are given briefly in Table 1 [6, 8-9].

Table 1. The electric motor efficiency class and motor efficiencies in the IEC 60034-30-1 Standard [9].

Output	*IE1*				*IE2*			
(kW)	*2 pole*	*4 pole*	*6 pole*	*8 pole*	*2 pole*	*4 pole*	*6 pole*	*8 pole*
0.55	69.0	70.0	65.8	56.1	74.1	77.1	73.1	61.7
0.75	72.1	72.1	70.0	61.2	77.4	79.6	75.9	66.2
1.1	75.0	75.0	72.9	66.5	79.6	81.4	78.1	70.8
1.5	77.2	77.2	75.2	70.2	81.3	82.8	79.8	74.1
2.2	79.7	79.7	77.7	74.2	83.2	84.3	81.8	77.6
3	81.5	81.5	79.7	77.0	84.6	85.5	83.3	80.0
Output	*IE3*				*IE4*			
(kW)	*2 pole*	*4 pole*	*6 pole*	*8 pole*	*2 pole*	*4 pole*	*6 pole*	*8 pole*
0.55	77.8	80.8	77.2	73.0	81.5	83.9	80.9	77.0
0.75	80.7	82.5	78.9	75.0	83.5	85.7	82.7	78.4
1.1	82.7	84.1	81.0	77.7	85.2	87.2	84.5	80.8
1.5	84.2	85.3	82.5	79.7	86.5	88.2	85.9	82.6
2.2	85.9	86.7	84.3	81.9	88.0	89.5	87.4	84.5
3	87.1	87.7	85.6	83.5	89.1	90.4	88.6	85.9

The newest regulation on motor efficiency with the date of 01/07/2021, the energy efficiency of three-phase motors with a rated output equal to or above 0.75 kW and equal to or below 1000 kW, with 2-, 4-, 6- or 8-poles has to correspond to at least the IE3 efficiency level [10]. The 4 poles 1.1 kW, AM used in this study are in the IE2 efficiency class with an efficiency value of 81.4%. Therefore, it has to be increased at least to IE3 class with a minimum efficiency of 84.1%.

The Finite Element Method (FEM) is used in the magnetic analysis of electrical machines. This method is used in many engineering disciplines such as electrical–electronic engineering, machinery, mechatronics, and materials engineering. The method is a way to achieve more efficient structures by numerical analysis through consideration of the material and design sizes of the system to be analyzed. This method allows for the calculation of magnetic magnitudes at any point in the machine, such as air gap flux density, magnetic field density, magnetic field intensity, and magnetic vector potential [11, 12]. There are many software packages, such as ANSYS, COMSOL, FEMLAB, FLUX 2D/3D and INFOLYTICA used to simulate electrical, magnetic, and engineering problems [13]. Electromagnetic analysis of an electric motor, which has been pre-designed using the Ansys RMxprt (Rotation Machinery Expert) program, can be carried out with Ansys Maxwell's 2D/3D [14, 15]. FEMM program can solve low-frequency electromagnetic problems in 2D planar regions and symmetrical axial areas. At the same time, this program addresses linear and nonlinear magneto static problems, harmonic field magnetic problems, linear electrostatic problems, and heat drop problems in stationary materials [16].

Many studies in published literature have been carried out to analyze AMs and improve output parameters. Some of them are Ravi P. et al. (2014) [17], who studied the design of the squirrel cage induction motor and the improvement of its output values. In their study, they made some calculations using the nameplate data of an exemplary induction motor and determined some parameters, such as stator and rotor slot sizes, and the inner and outer diameters of the stator and rotor. According to these values, they calculated the stator–rotor slot values using the Ansys RMxprt simulation program by varying the stator and rotor slot parameters until maximum efficiency, maximum power factor, and maximum torque was achieved. In another study, Şal S. and Ergene L.T. (2010) [11], handle the effect of changes in the rotor geometry of the squirrel cage AM by investigating motor performance values using the FEM. As a result of these analyzes, it is observed that the starting torque of the deep slot design is lower, but the torque value produced by the deep slot asynchronous motor during the first turn was approximately 3 times greater compared to the torque produced by the test motor. In the study conducted by Gao S. and Cai Y (2010) [18], the Radial Basis Function (RBF) method is proposed due to the lack of existing methods for observing stator flux distribution. According to the results obtained, the Radial Basis Function Neural networks-based identification method is a method that increases the accuracy of the induction motor stator flux prediction and reduces the effect of the deterioration factors in the observation process. Gecer B. et al. (2021) [15], the comparison of BLDC, SRM, and Induction motors for electrical vehicles are studied by using ANSYS/Maxwell. Zorlu Partal S. et al. (2022) [19], in their study, a design optimization was made for a 1.8 kW three-phase squirrel-cage, distributed winding induction motor to increase the efficiency class from IE2 to IE4. For this purpose, the induction motor is remodeled using toroidal winding. Eight motor models of the induction motor are constructed with different axial lengths and different amounts of copper. These motor models were analyzed in ANSYS/Maxwell. As a result of these analyzes, it has been seen that the best efficiency value is in the motor model with an axial length of 80 mm. 3.85% in efficiency value, 7.06% in torque value there has been an increase [20], in their study, 5 induction motor designs are used. They analyzed the design parameters, performance data, and losses in each design model. As a result, changing the lamination sheets, extending the package length, and increasing the amount of stator copper increase the efficiency of induction motors. They stated that conductors with better conductivity can be used to reduce rotor conductor losses.

In this study, the geometrical dimensions of a domestic production 4 poles, star connected 3 phase, 1.1 kW power squirrel cage AM have been measured by disassembling it. Modeling of the motor, whose nameplate values and geometric information have been measured and modeled in the RMxprt simulation program in the ANSYS/Maxwell module. The values obtained by modeling have been compared with the nameplate values. To increase the efficiency class from IE2 to IE3, the length values of the stator slot measurement parameters *bs0* and *bs1* have been changed over certain intervals. According to the change in stator *Bs0* and *Bs1* length values, motor output torque, efficiency, and magnetic flux values in stator–rotor teeth are shown graphically and examined. It is known that the AM's rotor parameters affect the efficiency, but the rotor parameters are kept constant for simplicity of operation. As a result of these examinations, *bs0* and *bs1* values are determined for optimum efficiency values and the efficiency class of the motor is increased from IE2 to IE3.

2. METHOD AND ANALYSIS FOR MOTOR DESIGN

A 1.1 kW squirrel cage AM is chosen for the optimization study. The efficiency class of the AM used is IE2. Technical data for the three-phase asynchronous motor used in the study are given in Table 2.

Table 2. Technical data for the AM motor.

Specifications	*Value*
Nominal power	1100 W
Nominal voltage Δ/Y	230 / 400 V
Nominal current Δ/Y	4.3 / 2.5 A
Frequency	50 Hz
Power factor Δ/Y	0.75 / 0.76
Speed of rotor	1425 rpm
Efficiency	83.60%
Standard of efficiency	IE2-81.40
Number of poles	4
Torque	7.40 Nm
Locked rotor current	13.50 A
Locked rotor torque	22 Nm
Breakdown torque	24.90 Nm
No-Load current	1.75 A
No-Load power	130 W

Stator and rotor slot geometries are one of the most important parameters affecting asynchronous motor performance. When slot structures are examined in high-efficiency machines, a classical-type slot structure is seen to be used [21]. The photograph of stator and rotor structures obtained by disassembling the motor values is shown in Figure 1.

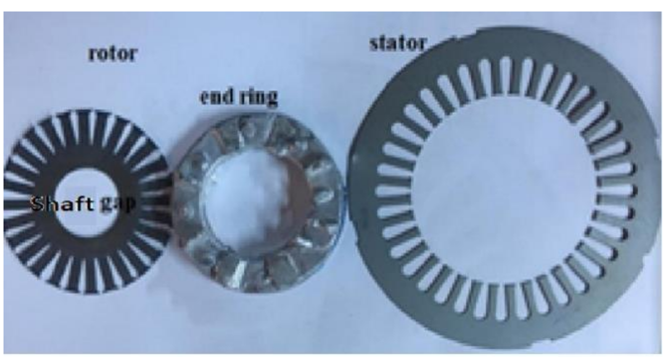

Fig. 1. The geometrics view of the rotor plate, rotor short circuit ring (end ring), and stator sheet plate.

To simulate analyses efficiently, the type and structure of the aluminum material used for the stator, the rotor sheet, and the rotor short circuit bars have been studied in the test lab for material and component testing. The stator and rotor dimensions were obtained as a result of precise measurements. The geometry used in the analysis of the motor is shown symbolically in Figures 2(a) and (b).

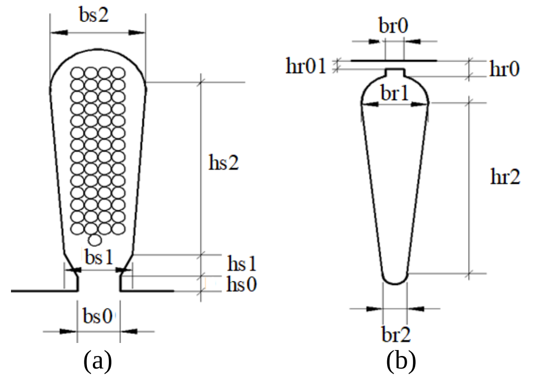

Fig. 2. Stator slot geometry (a), Rotor slot geometry (b).

The rotor and stator slot geometry of AM affects the physical, electrical, and magnetic characteristics of the AM. While determining the AM slot shape, the rotor, and stator slot design are carried out by considering these features. In newly designed motors, slots semi-open and circular are generally preferred to maximize efficiency [22]. The geometric values for the rotor, stator and their material properties are given in Table 3.

Table 3. Stator and rotor dimensions and material information.

Stator dimensions		*Rotor dimensions*	
Outer Diameter	135 mm	Outer Diameter	79.5 mm
Inner Diameter	80 mm	Inner Diameter	30 mm
Core Length	95,5 mm	Core Length	95.5 mm
Packaging Factor	0.95	Packaging Factor	0.95
Number of Slots	36	Number of Slots	28
Core Material	M19_24G	Core Material	M19_24G
hs0	1 mm	hr01	0.1 mm
hs1	1.3 mm	hr0	0.1 mm
hs2	11 mm	hr2	12 mm
bs0	2.5 mm	br0	1.25 mm
bs1	4 mm	br1	4 mm
bs2	6 mm	br2	1.5 mm
-	-	Ring Width	12 mm
-	-	Ring Height	10 mm
-	-	Short Circuit Ring Material	ETIAL-7

The motor used in the study has 57 conductors per slot, and the diameter of each conductor is 0.77 mm. A press band thickness of 2 mm is used as the insulation material between the stator and the conductors. The geometry of the motor, in which parameters are measured, is shown in Figure 3.

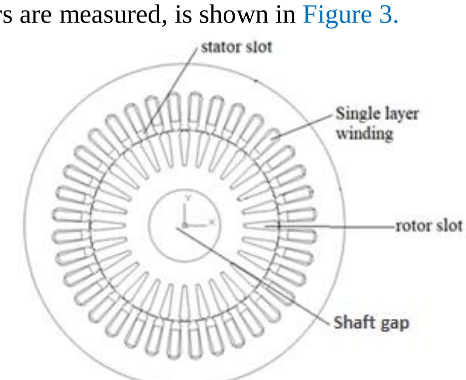

Fig. 3. Schematic of the asynchronous motor.

3. INDUCTION MOTOR ANSYS RMXPRT SIMULATION MODELING

There are three design types in ANSYS/Maxwell simulation software. These are RMxprt, Maxwell 2D, and Maxwell 3D RMxprt (Rotation Machinery Expert), which use design analysis with help of FEM of electrical machines. Maxwell 2D performs the electromagnetic field analysis in XY or RZ planes, and Maxwell 3D uses the volumes with the help of the FEM [23, 24]. Since performing the design analysis of the AM takes a long time in the Maxwell 3D program, the RMxprt module and Maxwell 2D have been used to shorten the analysis process and obtain the parameter values quickly. The model design was created by entering the geometric dimensions of the stator and rotor (given in Table II), the material information, and half-coil windings in the Ansys RMxprt software shown in Figure 4.

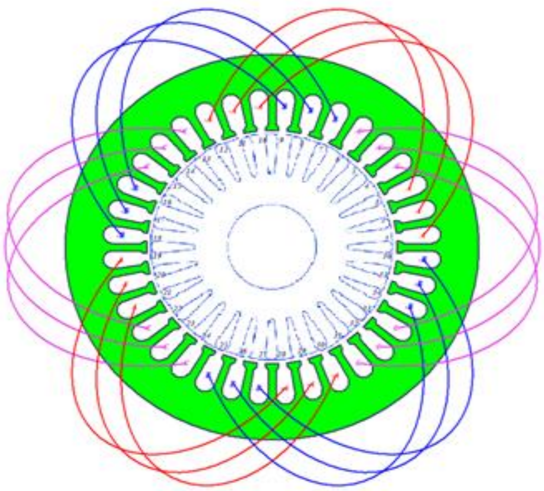

Fig. 4. Half-Coil model of the motor designed using the Ansys RMxprt software.

With the model created in the Ansys RMxprt software, parameters such as efficiency, power factor, torque, locked rotor current and torque, break-down torque, no-load current, and no-load motor power were calculated, and are given in Table 4 and compared to the nameplate values.

Table 4. Parameter values on the motor label and calculated values from the Ansys RMxprt software.

Parameters	*Nameplate Values of Motor*	*Parameter Values Calculated in Ansys RMxprt Program*	*Difference*
Efficiency	83.6%	83.36%	−0.3%
Power factor	0.76	0.73	−4%
Torque	7.40 Nm	7.28 Nm	−1.6%
Stator phase current	2.50 A	2.56 A	+2.4%
Locked Rotor Current	13.50 A	17.16 A	+27%
Locked Rotor Torque	22 Nm	24.33 Nm	+10%
Breakdown Torque	24.90 Nm	28.78 Nm	+15%
No-Load Current	1.75 A	1.71 A	−2.3%
No-Load Power	130 W	114 W	−13%

The magnetic flux values in the stator, rotor and air gap calculated in the Ansys RMxprt software are given in Table 5. When magnetic flux values were examined, it was seen that the constraints were not exceeded [2].

Table 5. Stator, rotor, and air gap magnetic flux values calculated using the Ansys RMxprt software.

Stator, Rotor, and Air Gap Magnetic Flux Description	*Magnetic Flux Density (T)*	*Constraints of Flux Density (T)*
B_{ts} Stator–Teeth Flux Density	1.56	1.40–1.70
B_{tr} Rotor–Teeth Flux Density	1.54	1.50–1.80
B_{sY} Stator–Yoke Flux Density	1.39	1.10–1.45
B_{rY} Rotor–Yoke Flux Density	0.67	1.20
B_{avg} Air–Gap Flux Density	0.69	0.65–0.82

4. DESIGN CONSIDERATIONS TO INCREASE MOTOR EFFICIENCY

The efficiency class was increased to IE3 (Premium Efficiency) by making changes to the parameters of the asynchronous motor stator geometry. These changes were made to the *Bs0* and *Bs1* parameters of the stator slot geometry. If we list the changes, the *Bs0* value was increased from 1.5 mm to 3.5 mm in 0.1 intervals, and the bs1 value was increased from 2 to 5 in 0.2 intervals. The efficiency, magnetic flux density in the stator teeth, stator–yoke flux density, and torque values of the asynchronous motor were calculated as follows.

$$B_{avg} = \frac{P\phi}{\pi D L} \quad (1)$$

B_{avg} is the average magnetic induction flux density in the air gap for a specific magnetic loading in Tesla (T). D is the stator inner diameter in m, L is the core length in m, $\emptyset$ is the flux in weber (Wb) and P is the total number of poles.

$$ac = \frac{I_z Z_{tot}}{\pi D} \quad (2)$$

Where AC is the specific electrical loading, I_S is stator phase current (Ampere) and Z_{tot} is the total number of conductors.

$$Q = C_0 D^2 L n_s \quad (3)$$

where Q is the apparent power in kVA, n_s is synchronous speed and C_0 is the output coefficient which is defined following equation:

$$C_0 = 1.1\pi^2 B_{avg}\, ac\, K_w 10^{-3} \quad (4)$$

where K_w represents the winding factor. With an increasing *bs0* value, stator tooth width decreases, and with a decreasing *bs0* value, stator tooth width value increases. The relationship between stator teeth flux density and average flux density is shown in Equation 5.

$$\frac{B_{ts}}{B_{avg}} = \frac{\pi D}{W_{ts} S} \tag{5}$$

In Equation (5), the air gap average flux density is B_{avg} , the stator slot pitch flux density is B_{ts}, the smallest wide-tooth range of stator is W_{ts}, and S is the tooth or slot number. For AM efficiency optimization, the stator slot type, rotor slot type, and rotor dimensions have been used mostly [25]. Equation (5) is valid within the rotor structure. Since the other parameters are unchanged, the increase in rotor-stator teeth width decreases the flux density in the tooth, and the decrease in the tooth width increases the flux density in the teeth. By changing the *bs0* value from 1.5 mm to 3.6 mm, the resulting change in motor efficiency and change in magnetic flux densities in the stator and rotor teeth are given in Figures 5 and 6. It can be seen from the graph that the motor efficiency has increased significantly with the decrease in the value of *bs0*.

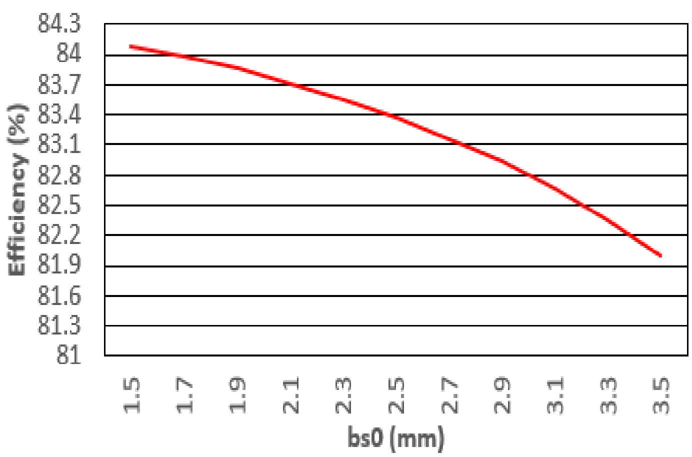

Fig. 5. Motor efficiency according to the change in the stator slot *bs0* value half-coil model of the motor.

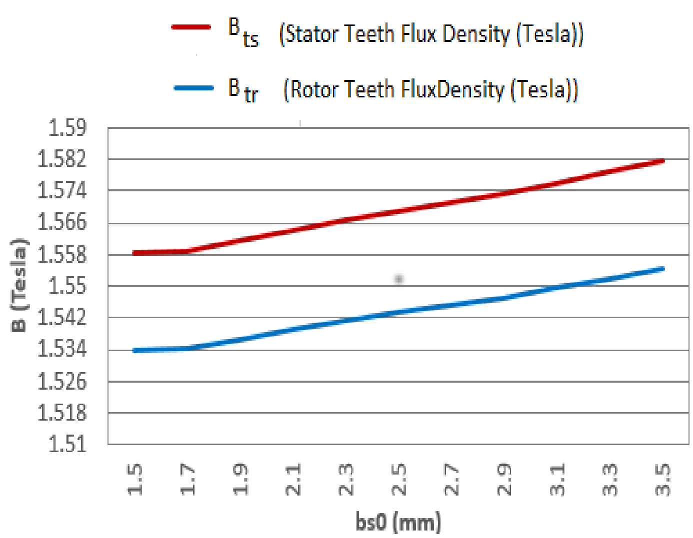

Fig. 6. Stator and rotor tooth magnetic flux density according to the change in the stator slot *bs0* value half-coil model of the motor.

The change in the motor output torque value according to the change of stator slot parameter *bs0* is given in Figure 7. When the value for the *bs0* dimension of the AM is compared to the reference point of 2.5 mm, it is seen that the torque increases with an increase in the *bs0* value, but torque changes little when it decreases.

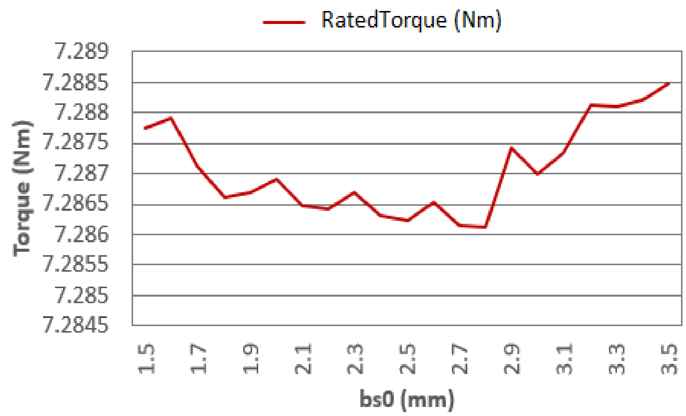

Fig.7. The change of motor output torque value according to the change of *bs0* value of the stator slot.

An optimization study is carried out by keeping the stator slot bs0 value constant at 1.8 mm and changing the *bs1* value from 2.5 mm to 6 mm in 0.1 mm steps. The change in motor efficiency and the changes in the magnetic flux densities in the stator and rotor teeth for these changes are given in Figures 8 and 9. It is understood from the graph in Figure 8 that the efficiency of the asynchronous motor increases with a reduction in the *bs1* value and the efficiency decreases with an increase in the *bs1* value. For *bs1* values below 3 mm, it is seen that the motor efficiency is about 84.8%. When the graph is examined, it is seen that the magnetic current density in the teeth decreases due to the decrease in the bs1 value.

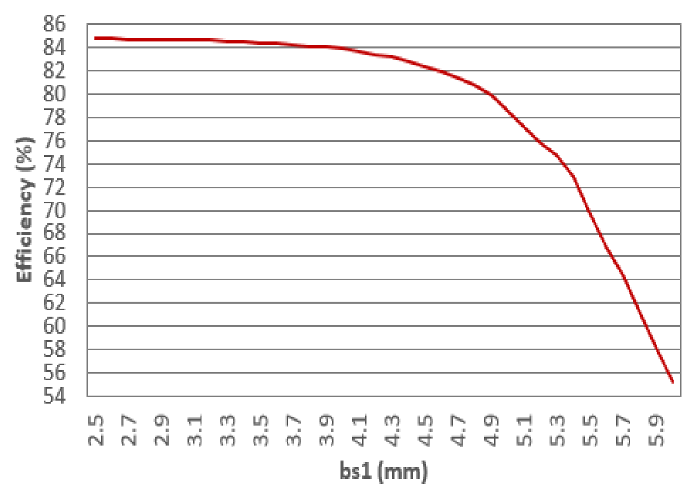

Fig. 8. Motor efficiency according to the change in the stator slot *bs1* value half-coil model of the motor designed using the software.

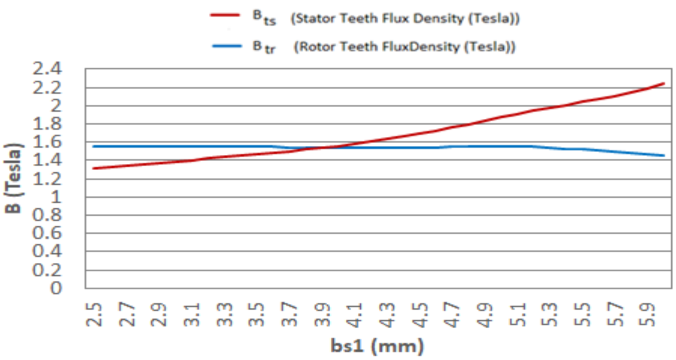

Fig. 9. Stator and rotor tooth magnetic flux density according to the change in the stator slot *bs1* value half-coil model of the motor.

The change in motor torque value with a change in the stator slot parameter *bs1* is given in Figure 10. When the values of the bs1 dimension of the asynchronous motor are compared to the 4mm reference point, it is seen that the torque increases with an increase in the *bs1* value, but the torque changes little when it decreases.

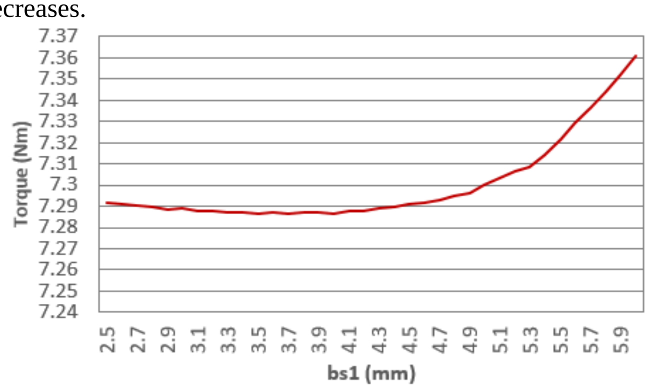

Fig.10. The change in motor output torque values for *bs1* values between 2.5 – 6 mm for the stator slot.

As a result of the changes in the values of the asynchronous motor stator slot parameters over the inspected ranges, the changes in the efficiency, torque, and magnetic flux densities in the stator and rotor teeth have been examined, and the motor efficiency has been improved by increasing the *bs0* value to 1.8 mm and the *bs1* value to 3.3 mm. In addition, when the motor winding type is changed in the simulation program and analyzed with whole-coil windings, it is seen that the motor efficiency rises to 84.95%. The efficiency–speed graph of the asynchronous motor before optimization, following its simulation with whole-coil windings, is given in Figure 11. It is seen that it gives among the best values: 1440 - 1460 rpm.

To examine the change in motor torque value versus the improvement in efficiency, the torque graphic of the asynchronous motor has been obtained – as in Figure 12 – by performing transient analysis in the Maxwell 2D simulation program for 60 ms. If the graphic is examined in Figure 12, it can be seen that there is a minor change in torque value.

Other parameters related to the asynchronous motor are obtained from the Ansys RMxprt simulation program before optimization, after optimization and when the whole-coil winding is used are given in Table 6.

Table 6. Motor parameters obtained from Ansys RMxprt software; with optimization half coiled, with optimization whole coiled and, without optimization.

Motor Parameters Description	*Without Optimization bs0=2,5-bs1=4*	*Optimization Half-Coiled bs0=1,8-bs1=3,3*	*Optimization Whole-Coiled bs0=1,8-bs1=3,3*
Locked-Rotor Torque	24.330 Nm	21.856 Nm	23.751 Nm
Locked-Rotor Phase Current	17.162 A	16.211 A	16.896 A
No-Load Stator Phase Current	1.715 A	1.405 A	1.446 A
No-Load Input Power	114.29 W	95.236 W	94.676 W
Stator Phase Current	2.561 A	2.377 A	2.395 A
Rotor Phase Current	1.840 A	1.842 A	1.833 A
Stator Slot Pitch Deity	1.569 T	1.437 T	1.446 A
Rotor Slot Pitch Deity	1.543 T	1.556 T	1.566 T
Stator-Yoke Flux Density	1.394 T	1.386 T	1.402 T
Rotor-Yoke Flux Density	0.673 T	0.670 T	0.677 T
Air-Gap Flux Density	0.692 T	0.698 T	0.702 T
Stator Omics Loss	117.056 W	98.676 W	93.425 W
Rotor Omics Loss	45.236 W	45.338 W	44.900 W
Iron-Core Loss	29.795 W	28.797 W	29.040 W
Frictional and Windage Loss	16.375 W	16.372 W	16.385 W
Stray Loss	11 W	11 W	11 W
Total Loss	219.464 W	200 W	194.751
Input Power	1319.410 W	1300.210 W	1294.720
Output Power	1100 W	1100 W	1100 W
Efficiency	%83.360	%84.6	%84.95
Power Factor	0.730 W	0.780	0.770
Rated Torque	7.286 Nm	7.287 Nm	7.284 Nm
Rated Speed	1441.58 rpm	1441.26 rpm	1442 rpm
Stator Slot Fill Factor	%48.880	% 51.760	%51.760

When the results are analyzed with optimization and without optimization, it is seen that there are very few changes in the output torque value, rotor phase current, and magnetic flux values of the stator, rotor, and air gap. Approximately 7.5% deal crease occurred in the stator phase current. Due to this decrease, a decrease of 18.38 W occurred in stator ohmic losses. Thanks to this study, an improvement of 1.49% in the asynchronous motor efficiency value and 6.8% in the power coefficient value was achieved. When the winding type was changed to whole coiled, a decrease of 23.63 W occurred in stator ohmic losses. It is observed that the motor efficiency value increased by 84.94% and accordingly, the efficiency value improved by 1.59%.

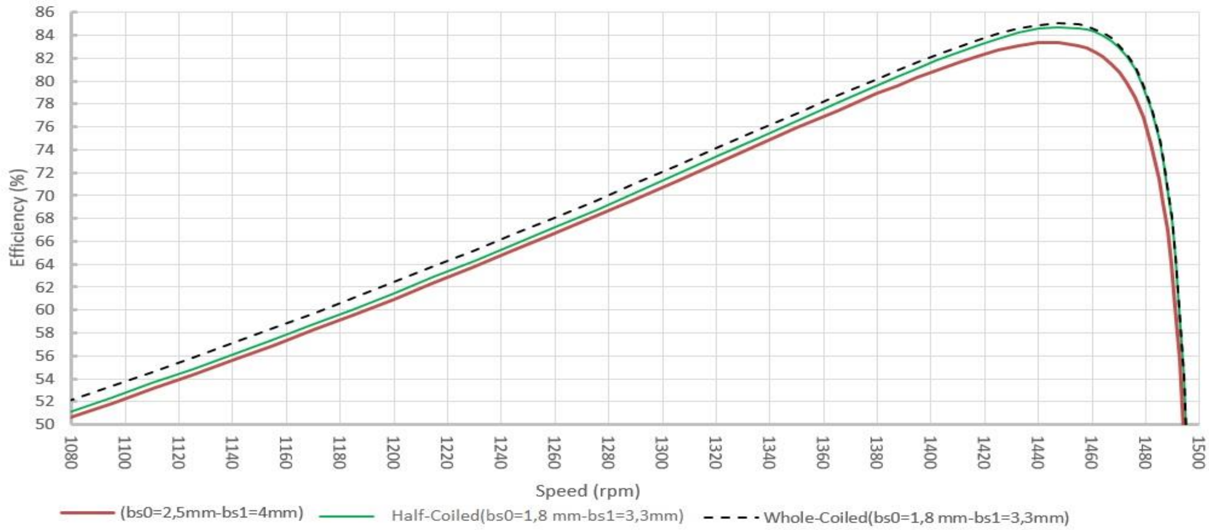

Fig. 11. Efficiency and speed graph with changing parameters.

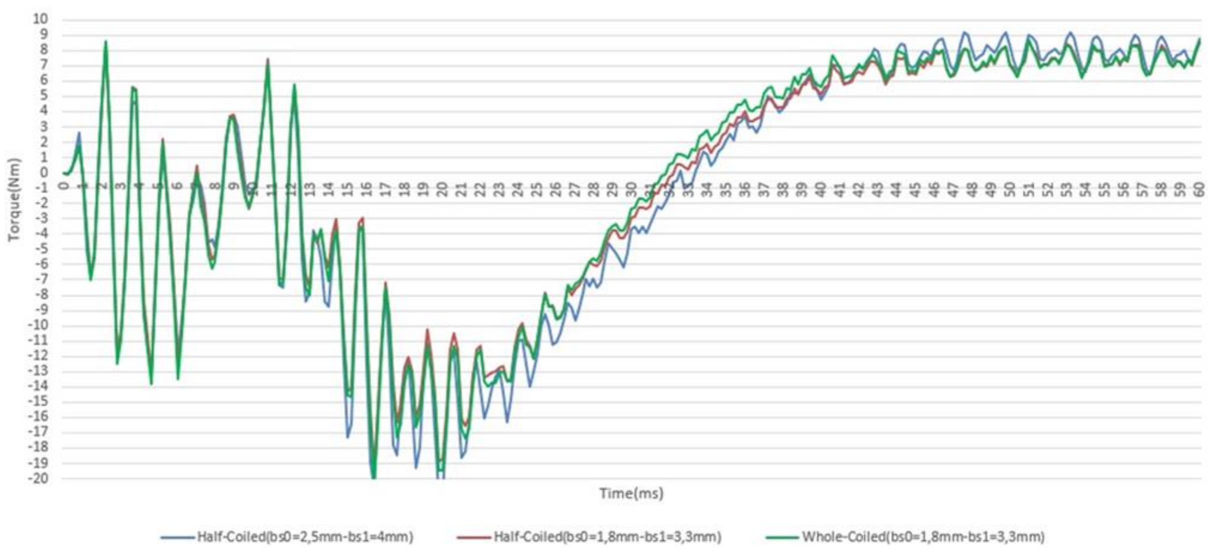

Fig. 12. Torque graph with changing parameters.

5. CONCLUSION

In this study, an asynchronous motor dimension with a power of 1.1 kW is obtained by disassembling. The geometric dimensions and material information has been used to pattern the motor by the Ansys RMxprt software, which is used for the design of electrical machines. The model created in the Ansys RMxprt software is compared with the nameplate values of the motor and the values are very close to the nameplate values. The small deviations between the outputs from the model created in the Ansys RMxprt software and the AM nameplate values are due to the small measurement errors when performing the geometric measurements of the motor parameters.

To increase the efficiency class of the modeled motor from IE2 to IE3, an optimization study has been carried out by changing the values of the stator slot parameters and winding type. In the optimization study carried out, the *bs0* value has been increased from 1.5 mm to 3.5 mm at 0.1 mm intervals, and the *bs1* value was increased from 2 mm to 5 mm at 0.2 mm intervals. By changing the *bs0* and *bs1* values, the efficiency of the AM, magnetic flux density in the stator teeth, stator–yoke flux density, and torque values have been examined. It is observed that the magnetic flux densities in the stator and rotor teeth decreased with a decreasing value of *bs0*. With a decrease in the value of *bs1*, the magnetic flux densities in the stator teeth decrease a great deal, but the magnetic flux densities in the rotor teeth increase slightly. It is observed that the torque values show little change as the values of *bs0* and *bs1* decreased from the reference value. It is observed that the motor efficiency increases as the values of *bs0* and bs1 values decrease within the specified value ranges. By making *bs0*= 1.8 mm and *bs1*= 3.3 mm and using stator winding whole-coil type, the motor efficiency has been increased by 1.59% to 84.95%. As seen from the optimization results the motor efficiency class is increased only by rearranging stator dimensions and winding structure to class IE3. The AM optimization study fulfills new compulsory standards and it is more economical in terms of energy consumption.

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