Squirrel Cage Induction Motor Design and the Effect of Specific Magnetic and Electrical Loading Coefficient

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Abstract: 3-phase induction motors are widely used in industrial applications such as pumps, blowers, compressors, conveyors, etc. In addition, single-phase motors also have domestic use. For this reason, the design of the induction motor is of great importance. During the design, according to the parameters given as input, there are many situations that are contradictory to each other in order to achieve the goal. For example, if high efficiency is required, the motor size and the price will increase, and if lower price is required, other performance characteristics should be ignored. In the practical design of an induction motor, the designer has to comply with a number of constraints because of the large number of input variables. For this reason manual calculation becomes a very long and difficult process. To overcome this tiresome process, it is necessary to create a computer aided program or simulation model to determine the induction motor design parameters. In induction motor design, many parameters directly affect motor performance. Therefore, the selection of these parameters is of great importance. The output coefficient (Co), which takes place in the first steps of the design process, also has a great influence on the motor design. In this paper, a program for optimizing design of 3-phase induction motors written in MATLAB is presented. The structure of the program is modular and therefore can be modified for the various requirements of the induction motor design. Co constant, one of the design parameters, also varies with some other parameters. The most important ones are the specific electrical loading coefficient (A1) and the specific magnetic loading coefficient (Baw), making dramatic effect on the output coefficient. The effect of the variation of the Co constant on the performance of the induction motor was investigated in the study. Stator inner and outer diameter, stack length, stator and rotor slot parameters, equivalent circuit parameters, losses and efficiency was obtained according to the change of Baw and A1 values. The obtained results are given and interpreted in tables and graphs.

Keywords: Electrical loading coefficient, Induction motor design, Magnetic loading coefficient, Output coefficient, Performance analysis.

1. Introduction

Induction machines, which have the most widespread use in today's industry, are usually manufactured as single or three-phase motors. These machines are widely used in various fields ranging from home applications to space technology. For this reason, design of the motor is of great importance in practice. During design, there are many inconsistent situations that are contradictory to each other in order to achieve the desired result according to the given characteristics. For example, if high efficiency is required, the motor size will increase and the price will increase. If lower prices are required, other performance requirements are ignored. While induction motors are examined, the effects of fundamental variables on motor performance are found by using magnetic, electric and thermal models. In the design of induction motors, motor geometry and winding types which are effective in desired performance values are determined. The obtained model in design includes magnetic and electrical models [1].

The main specifications for the design of a three phase squirrel cage induction motor are: rated output power, frequency, voltage, speed, efficiency, power factor and full load current etc. The standard specification for the design of an induction motor are materials (lamination thickness, conductor diameter), performance indexes (efficiency, power factor, starting torque, starting current, breakdown torque), temperature by insulation class, frame sizes, shaft height, cooling types, service classes, protection classes, etc. are specified in national (or international) standards (NEMA, IEEE, IEC, EU, etc.) to facilitate the induction motor for various applications. The main purpose of designing an induction motor is to obtain the complete physical dimensions of all the parts of the machine as mentioned below to satisfy the given specifications [2].

• The main dimensions of the stator
• Details of stator and stator windings
• Design details of rotor and its windings
• Performance characteristics (Iron losses, copper losses, efficiency, no load current, power factor) [3]

The stator and rotor dimensions are determined by independent variables which are: stator slot height, stator tooth width, rotor slot height, rotor tooth width, air-gap length, air gap flux density, stack length, outer stator diameter, stator wire size and electrical steel type. Besides the above independent variables, the design involves some non-linear constraints which concern mainly the motor performances. They are stator winding temperature, rotor bar temperature, flux density in the stator. The type of winding adopted in this design is the squirrel cage type as it is simpler and economical, which consists of a number of bars embedded in the rotor slots and connected at both ends by means of end rings [2].

In this study, the design processes of a 3 phase squirrel cage induction motor are discussed and a sample design is given. In addition, the effects of specific electric loading coefficient and specific magnetic loading coefficients were analysed in the design process which were not taken into consideration but which significantly affected the performance of the motor values. The effects of these two coefficients on motor performance were
investigated. The inner diameter, outer diameter, package length, stator and rotor slot geometries, the change of the equivalent circuit parameters, losses and the change of the efficiency values of the motor were examined.

2. Design Procedure of Induction Motor

Wengerkievicz et al. proposed 5 different methods for the determination of induction motor parameters [4].

1. Calculation from construction data: requires the detailed knowledge of the machine’s geometry and of the properties of the employed materials, besides software for electromagnetic calculation. It is considered to be the most precise procedure, although costly, and it is employed basically by manufacturers, designers and researchers.

2. Estimation based on steady-state motor models: the parameter values are obtained through the solution of equations derived from state-models employing data from tests, measurements or provided by manufacturers. This class includes the standard testing methods.

3. Frequency-domain parameter estimation: the parameter values are estimated from the transfer function observed during tests. It is not a common industry practice.

4. Time-domain parameter estimation: the parameter values are adjusted as the response calculated with a system of differential equations fits the observed time response.

5. Real-time parameter estimation: commonly applied to controllers for continuous tuning of parameters of simplified models, compensating parameter variation due to temperature change, saturation and other effects in the machine.

To design the 3 phase induction motor of the stator, rotor, end rings, and main parts of the induction motor is very difficult by using the manual calculation or software. The design of the induction motors is well established, there are some areas which require special care. The manual design is a lengthy calculation and if any change in the parameters needs to be recalculated. This results in the time and effort is required by the designer to do the calculations accurately. As an example, after doing the calculations of an induction motor design it is observed that performance of the machine is not satisfactory and dimension of the machine is uneconomical. To solve this, the designer has to change some design parameters like electrical loading, magnetic loading, insulation thickness etc. Hence iterative calculation of the entire design procedure is required to achieve a satisfactory result [5].

2.1. Output Coefficient for Induction Machines

As with all electric machines, the design process begins with the calculation of the output coefficient in the induction motor design. The general formulas for design are given below [6].

To calculate the relationship between the \( \text{Dis}^2 \cdot L \) (the standard output coefficient), where stator inner diameter (\( D_0 \)) and stack length (\( L \)), and the machine power and performance, we start by calculating the airgap apparent power \( S_{gap} \).

\[
S_{gap} = 3 \cdot E_1 \cdot I_{In}
\]  

(1)

Also, the input apparent power \( S_{in} \) is

\[
S_{in} = 3 \cdot V_{in} \cdot I_{In} = \frac{P_n}{\eta_n \cdot \cos \phi_{in}}
\]  

(2)

where \( P_n \) is the rated output power and \( \eta_n \) and \( \cos \phi_{in} \) are the assigned values of rated efficiency and power factor based on past experience.

The emf \( E_1 \) may be written as a function of airgap pole flux.

\[
E_1 = 4 \cdot f_1 \cdot K_f \cdot W_1 \cdot K_{wl} \cdot \phi
\]  

(3)

where \( f_1 \) is frequency, \( 1.11 > K_f > 1.02 \) form factor (dependent on teeth saturation), \( W_1 \) is turns per phase, and \( K_{wl} \) is winding factor, \( \phi \) pole flux.

\[
\phi = \alpha_i \cdot \tau \cdot L \cdot B_g
\]  

(4)

where \( \alpha_i \) is flux density shape factor dependent on the magnetic saturation coefficient of teeth and \( B_g \) is flux density in the airgap. The pole pitch \( \tau \) is given in Equation (5).

\[
\tau = \frac{\pi \cdot D_{ls}}{2 \cdot p_i}
\]  

(5)

The number of speed \( n_1 = \frac{f_1 \cdot 60}{p_i} \) and the air gap apparent power are regulated as follows. Finally, \( S_{gap} \) is:

\[
S_{gap} = \frac{K_f \cdot \alpha_i \cdot K_w \cdot \pi^2 \cdot D_{ls}^2 \cdot L \cdot m_1}{60} \cdot A_1 \cdot B_{av}
\]  

(6)

with \( A_1 \) is the specific electrically load (av/c):m).

\[
A_1 = \frac{6 \cdot W_1 \cdot I_{In}}{\pi \cdot D_{ls}}
\]  

(7)

where \( B_{av} \) the specific magnetic load (T),

\[
B_{av} = \frac{\phi}{\alpha_i \cdot \tau \cdot L}
\]  

(8)

We might separate the volume utilization factor \( C_0 \) (Esson’s constant) as

\[
C_0 = k_f \cdot \alpha_i \cdot K_w \cdot \pi^2 \cdot A_1 \cdot B_{av} = \frac{60 \cdot S_{gap}}{D_{ls}^2 \cdot L \cdot m_1}
\]  

(9)

\( C_0 \) gives energy that can be taken in a minute from the unit volume of the machine. It is a measure of how much you have benefited from the material (kVA-minute/m³) [7].

\( C_0 \) is not a constant as both the values of \( A_1 \) (av/c/m) and airgap flux density \( B_{av} \) increase with machine torque and with the number of pole pairs. The \( \text{Dis}^2 \cdot L \) output coefficient may be calculated from (9) with \( S_{gap} \) from Equations (1) and (2).

\[
D_{ls}^2 \cdot L = \frac{1}{C_0 \cdot \eta_n} \cdot \frac{60 \cdot K_e \cdot P_n}{\eta_n \cdot \cos \phi_{in}}
\]  

(10)

Typical values of \( C_0 \) as a function \( S_{gap} \) with pole pair \( p_i \) as parameter for low power induction motors is given in Fig. 1. The \( \text{Dis}^2 \cdot L \) output constant (proportional to rotor core volume) is, in fact, almost proportional to machine rated shaft torque. Torque production apparently requires less volume as the pole pairs number \( p_i \) increases, \( C_0 \) increases with \( p_i \).

It is standard to assign a value \( \lambda \) to the stack length to pole pitch ratio:

\[
\lambda = \frac{L}{\tau} = \frac{2 \cdot L \cdot p_i}{\pi \cdot D_{ls}}
\]  

(6.0 < \lambda < 3.0)

The stator bore diameter \( D_0 \) may now be calculated.
\[ D_{is} = \frac{2 \cdot p \cdot I_r}{\pi \cdot \lambda} \cdot \frac{1}{C_0} \cdot \frac{1}{f_1} \cdot \frac{K_e \cdot P_n}{\eta_r \cdot \cos \phi_{1n}} \] (12)

This is a standard design formula. However, this value is not enough to obtain the total volume of the machine. For this, the stator outer diameter value \( D_{out} \) is standardized in most motor designs.

\[ D_{out} = \sqrt{\frac{2 \cdot p^2}{\pi \cdot \lambda} \cdot \frac{1}{C_0} \cdot \frac{1}{f_1} \cdot \frac{K_e \cdot P_n}{\eta_r \cdot \cos \phi_{1n}} \cdot \frac{1}{D_{is} \cdot f_0(D_{is})}} \] (13)

![Fig. 1. Esson’s constant \( C_0 \) versus \( S_{app} \) [6].](image)

After calculating the stator inner diameter of the induction motor, the ratios given in the Table 1 are used to calculate the stator outside diameter. This formulation provides great convenience for motor designers.

**Table 1. Inner/outer stator diameter ratio [6]**

<table>
<thead>
<tr>
<th>( \frac{D_{out}}{D_{is}} )</th>
<th>2</th>
<th>4</th>
<th>6</th>
<th>8</th>
</tr>
</thead>
<tbody>
<tr>
<td>( \frac{2s}{2s} )</td>
<td>0.54-0.58</td>
<td>0.61-0.63</td>
<td>0.68-0.71</td>
<td>0.72-0.74</td>
</tr>
</tbody>
</table>

After designing the main dimension of the induction motor, stator slot design, rotor slot design, coil design, shaft design, frame design and etc. design are performed. Details of these designs are given in reference [6, 8, 9]. The general cross-section view of the designed motor [10] and the details of the stator and rotor slot structures are given in Figures 2 (a), (b) and (c).

![Fig. 2. a) Cross-section of the motor, b) rotor slot construction c) Stator slot construction.](image)

### 2.2. The Effect of Magnetic and Electrical Loading Coefficients

The first step in the design of rotating electric machines is to obtain the expression \( D_{is}^2 \cdot L \). This expression is possible by selecting appropriate values of specific magnetic and specific electrical loading coefficient and this value is proportional to the volume of the machine.

The total magnetic flux value in the machine’s air-gap is called total magnetic loading. The average flux density value in the machine’s air gap is known as the specific magnetic loading \( B_{av} \). Accordingly, the following expression can be written:

Total magnetic loading \( = p_1 \cdot \phi \) Wb

The specific magnetic loading can be written as in Equation (14).

\[ B_{av} = \frac{p_1 \cdot \phi}{\pi \cdot D_{is} \cdot L} \] (14)

The sum of the amper and conductors around the stator is called the total electrical loading. The number of amper-conductors per meter of stator circumference in the air-gap is known as the specific electrical loading \( A_t \). Accordingly, the following expression can be written:

Total electrical loading = \( I_{1n} \cdot Z \) Amper-conductor

The specific electrical loading can be written as in Equation (15).

\[ A_t = \frac{I_{1n} \cdot Z}{\pi \cdot D_{is}} \] Amper-conductor/metre (15)

Change of the specific magnetic loading \( B_{av} \) affects the maximum flux density in the iron sections, the magnetizing current, the power factor, the size of the machine, the overload capacity, the stray load losses and the core losses [3, 8, 11].

Change of the specific electrical loading \( A_t \) affects the size of the machine, overload capacity, temperature increase and loss of copper in conductors [3, 11-13].

There are some papers in the literature that the magnetic loading coefficient can be used between 0.3 - 0.65 T and the magnetic electrical loading coefficient can be used between 5000 - 450000 A/m [2, 5, 14]. The designer can use these values or use past experience to get approximate values for these coefficients.

The advantages and disadvantages of high specific electrical loading coefficient can be given as [2, 8, 13, 14-18].

**Advantages:**
- Small motor size
- Lower costs

**Disadvantages:**
- Higher use of copper
- More copper loss and stray load losses
- Smaller overload capacity
- High temperature increase
- Lower efficiency
- Increased number of conductors and accordingly increased leakage reactance

The advantages and disadvantages of the high specific magnetic loading coefficient can be given as [8, 13, 15, 18-20].

**Advantages:**
- Small motor size
- Lower costs
- Overload capacity increases

**Disadvantages:**
- Low power factor
- Low efficiency

### 2.3. Specifications of the Designed Motor

Designed motor specifications are [6]:
- Rated power: \( P_r \) [kW] = 5.5
• Synchronous speed: \(n_s\) [rpm] = 1800
• Line supply voltage: \(V_1\) [V] = 460
• Supply frequency: \(f_1\) [Hz] = 60
• Number of phases: \(m = 3\)
• Phase connections: Star
• Targeted power factor: \(\cos \varphi \text{pm} = 0.83\)
• Targeted efficiency: \(\eta_1 = 0.895\)
• p.u. locked rotor torque: \(T_{\text{LR}} = 1.75\)
• p.u. locked rotor current: \(I_{\text{LR}} = 6\)
• p.u. breakdown torque: \(T_{\text{DB}} = 2.5\)
• Insulation class: F
• Temperature rise: class B

### Obtained Results And Discussion
The design values obtained by the written Matlab code are given in Table 2. When the results are examined, it is seen that the obtained values support the reference motor values. It shows that written in Matlab code is working correctly. The algorithm for the design process is given in Fig. 18.

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Variables</th>
<th>Unit</th>
<th>Reference Values [6]</th>
<th>Obtained Values</th>
</tr>
</thead>
<tbody>
<tr>
<td>Apparent Airgap Power</td>
<td>(S_{\text{gap}})</td>
<td>VA</td>
<td>7181.8</td>
<td>7181.8</td>
</tr>
<tr>
<td>Stator Bore Diameter</td>
<td>(D_{\text{st}})</td>
<td>m</td>
<td>0.1116</td>
<td>0.1114</td>
</tr>
<tr>
<td>Stack Length</td>
<td>(L)</td>
<td>m</td>
<td>0.1315</td>
<td>0.13124</td>
</tr>
<tr>
<td>Pole Pitch</td>
<td>(t_o)</td>
<td>m</td>
<td>0.0876</td>
<td>0.087491</td>
</tr>
<tr>
<td>Stator Slot Pitch</td>
<td>(t_{os})</td>
<td>m</td>
<td>9.734 \times 10^{-3}</td>
<td>9.7212 \times 10^{-3}</td>
</tr>
<tr>
<td>Stator Outer Diameter</td>
<td>(D_{\text{out}})</td>
<td>m</td>
<td>0.18</td>
<td>0.17967</td>
</tr>
<tr>
<td>Airgap Length</td>
<td>(g)</td>
<td>m</td>
<td>0.3111 \times 10^{-3}</td>
<td>0.31182 \times 10^{-3}</td>
</tr>
<tr>
<td>Stator Slot Number</td>
<td>(N_s)</td>
<td>36</td>
<td>36</td>
<td>36</td>
</tr>
<tr>
<td>The Zone Factor</td>
<td>(K_{\text{q}})</td>
<td></td>
<td>0.9598</td>
<td>0.9598</td>
</tr>
<tr>
<td>The Chording Factor</td>
<td>(K_{\text{y}})</td>
<td></td>
<td>0.9397</td>
<td>0.9397</td>
</tr>
<tr>
<td>Stator Winding Factor</td>
<td>(K_{\text{w}})</td>
<td></td>
<td>0.9019</td>
<td>0.9019</td>
</tr>
<tr>
<td>The Pole Flux</td>
<td>(f_1)</td>
<td>Wb</td>
<td>5.878 \times 10^{-1}</td>
<td>5.8592 \times 10^{-1}</td>
</tr>
<tr>
<td>Number Of Turns Per Phase</td>
<td>(W_1)</td>
<td>turns/phase</td>
<td>186.8</td>
<td>187.21</td>
</tr>
<tr>
<td>Number Of Conductors Per Slot</td>
<td>(n_{\text{s}})</td>
<td>turns/slot</td>
<td>31.33</td>
<td>31.2</td>
</tr>
<tr>
<td>Airgap Flux Density</td>
<td>(B_g)</td>
<td>T</td>
<td>0.726</td>
<td>0.728</td>
</tr>
<tr>
<td>Rated Current</td>
<td>(I_{\text{Ln}})</td>
<td>A</td>
<td>9.303</td>
<td>9.2927</td>
</tr>
<tr>
<td>Magnetic Wire Cross Section</td>
<td>(A_{\text{co}})</td>
<td>m²</td>
<td>2.6733 \times 10^{-4}</td>
<td>2.0651 \times 10^{-4}</td>
</tr>
<tr>
<td>Magnetic Wire Diameter</td>
<td>(d_{co})</td>
<td>m</td>
<td>1.622 \times 10^{-5}</td>
<td>1.6215 \times 10^{-5}</td>
</tr>
</tbody>
</table>

#### Stator Slot Sizing
| Useful Slot Area | \(A_{\text{sa}}\) | m²  | 155.7 \times 10^{-6} | 154.88 \times 10^{-6} |
| Stator Tooth Width | \(b_{ts}\) | m  | 4.75 \times 10^{-3} | 4.7563 \times 10^{-3} |
| Stator Slot Lower Width | \(b_{s1}\) | m | 5.42 \times 10^{-3} | 5.4012 \times 10^{-3} |
| Stator Slot Upper Width | \(b_{s2}\) | m | 9.16 \times 10^{-3} | 9.1309 \times 10^{-3} |
| Stator Slot Useful Height | \(h_{s}\) | m | 21.36 \times 10^{-3} | 21.315 \times 10^{-3} |
| Airgap mmf | \(F_{\text{mg}}\) | Aturns | 242.77 | 243.45 |
| Stator Tooth mmf | \(F_{\text{mt}}\) | Aturns | 41.99 | 41.915 |
| Rotor Tooth mmf | \(F_{\text{mr}}\) | Aturns | 55.11 | 55.465 |
| Stator Back Iron Height | \(h_{cs}\) | m | 10.34 \times 10^{-4} | 10.322 \times 10^{-4} |
| Back Core Flux Density | \(B_{cs}\) | T | 1.456 | 1.4549 |

#### Rotor Slots Sizing
| Rotor Slot Area | \(A_{r}\) | m² | 81.65 \times 10^{-6} | 81.672 \times 10^{-6} |
| Rotor Slot Pitch | \(t_{or}\) | m | 12.436 \times 10^{-3} | 12.429 \times 10^{-3} |
| Rotor Tooth Width | \(B_{tr}\) | m | 5.88 \times 10^{-3} | 5.8909 \times 10^{-3} |
| Rotor Slot Upper Width | \(d_{1}\) | m | 5.70 \times 10^{-3} | 5.7696 \times 10^{-3} |
| Rotor Slot Lower Width | \(d_{2}\) | m | 1.2 \times 10^{-3} | 1.6977 \times 10^{-3} |
| Rotor Slot Height | \(h_{r}\) | m | 20.10 \times 10^{-3} | 18.07 \times 10^{-3} |
| Rotor Back Core Height | \(h_{cr}\) | m | 13.55 \times 10^{-3} | 13.529 \times 10^{-3} |
| Shaft Diameter | \(d_{\text{shaft}}\) | m | 35.9 \times 10^{-3} | 39.032 \times 10^{-3} |
| Nominal Torque | \(T_{\text{en}}\) | N·m | 29.77 | 29.774 |
| End Ring Depth | \(b_{b}\) | m | 24.445 \times 10^{-3} | 24.533 \times 10^{-3} |
| End Ring Length | \(a_{a}\) | m | 10.02 \times 10^{-3} | 9.9734 \times 10^{-3} |

#### The Magnetization Current
| Stator Back Core mmf | \(F_{\text{mc}}\) | Aturns | 54.22 | 57.803 |
| Rotor Back Core mmf | \(F_{\text{mr}}\) | Aturns | 32.4 | 42.303 |
| Total mmf | \(F_{1\text{m}}\) | Aturns | 853.68 | 880.67 |
| Magnetization Current | \(I_{\text{mu}}\) | A | 3.86 | 4.0169 |

#### Resistances and Inductances
| Stator Phase Resistance | \(R_{s}\) | ohm | 0.468375 | 0.46808 |
| Rotor Cage Resistance Reduced To The Stator | \(R_{\text{c1}}\) | ohm | 1.1295 | 1.1512 |
| Stator Phase Leakage Reactance | \(X_{s1}\) | ohm | 2.17 | 2.1937 |
| Equivalent Rotor Bar Leakage Reactance | \(X_{\text{be}}\) | ohm | 3.1877 \times 10^{4} | 3.2123 \times 10^{4} |
| Rotor Leakage Reactance | \(X_{1}\) | ohm | 3.6506 | 3.6284 |
| Rotor Resistance | \(R_{\text{sn}}\) | ohm | 0.709 | 0.84353 |
| Equivalent Rotor Leakage Reactance | \(X_{1\text{sn}}\) | ohm | 3.938 | 2.418 |
| Magnetization Reactance | \(X_{\text{m}}\) | ohm | 66.70 | 63.921 |

#### Losses and Efficiency
| Stator Winding Losses | \(P_{\text{w}}\) | W | 121.607 | 121.26 |
| Rotor Cage Losses | \(P_{\text{c}}\) | W | 137.417 | 163.13 |
| Stator Tooth Weight | \(G_{s}\) | Kg | 4.168 | 4.0072 |
| Stator Teeth Fundamental Losses | \(p_{s1}\) | W | 36.45 | 36.376 |
| Yoke Weight | \(G_{y}\) | Kg | 5.877 | 5.7154 |
After the design process has been completed, the values of $B_{av}$, $A_1$, and $C_0$ are calculated using Equations (14) and (15). The comparison of the selected values at the beginning of the design procedure with the calculated values are given in Table 3. When the results are examined, it is seen that all three obtained values are close to each other.

Table 3. Comparison of $B_{av}$, $A_1$ and $C_0$

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Chosen</th>
<th>Calculated</th>
<th>% Difference</th>
</tr>
</thead>
<tbody>
<tr>
<td>$B_{av}$</td>
<td>0.67</td>
<td>0.7</td>
<td>4.47 %</td>
</tr>
<tr>
<td>$A_1$</td>
<td>30300</td>
<td>29825</td>
<td>-1.56 %</td>
</tr>
<tr>
<td>$C_0$</td>
<td>147000</td>
<td>146980</td>
<td>-0.013 %</td>
</tr>
</tbody>
</table>

3.1. Change of the $B_{av}$

In this case, the specific electrical loading coefficient $A_1$ is kept constant at 30300 (a-c/m), and the specific magnetic loading coefficient $B_{av}$ is increased from 0.3 (T) to 0.8 (T). The obtained results are given in Figs. 3-7.

Due to the increase of the specific magnetic load coefficient, a decrease in the motor dimensions has occurred. The reduction in outer diameter, caused a reduction in the height of the stator back core. This has resulted in an increase in the value of back core flux density. Stator and rotor slot sizes have also changed. A certain amount of increase in reactance and resistance values has occurred. The decrease in motor size results in a decrease in core weight. Despite the increase in magnetic flux density values, iron losses are reduced. The increase in the used number of conductors resulted in an increase in copper losses.
3.2. Change of the $A_1$

In this case, the specific magnetic loading coefficient is kept constant at 0.67 (T), and the specific electrical loading coefficient $A_1$ (a.c/m) is increased from 10000 to 35000. The obtained results are shown in Figs. 8-12.

The increase in the value of the electrical loading coefficient led to a decrease in the motor outer diameter, inner diameter and package length. This has also caused changes in the stator and rotor slot values of the motor.

In addition, the number of windings has increased in order to be able to provide the required amper-conductor number. This is led to an increase in copper loss.

It is seen that the equivalent circuit parameters also increase due to the increase of the number of windings. Core losses have led to a great decline in the case of decline in motor size and the decrease in core weight. Efficiency value is almost the same.

3.3. Change of the $B_{av}$ and $A_1$

In this case, both the specific magnetic loading coefficient $B_{av}$ value and the specific electrical loading coefficient $A_1$ value are increased. The results obtained are shown in Figs. 13-17.
When the graphs obtained by increasing both the specific magnetic loading and the specific electrical loading coefficients are examined, it is seen that there are similar graphs to the changes of the $B_{av}$ and $A_1$.

4. Conclusion

In this study, the design process is given for 5.5 kW squirrel cage induction motor, and design results are obtained by software written in MATLAB. It was seen that the obtained result is consistent with the value of the reference motor. In the second part of the study, the design effects were investigated by changing the specific magnetic loading and the specific electrical loading coefficients which affect the output coefficient ($C_0$) for the target efficiency. It has been shown that it is possible to design a more efficient but cost effective or less efficient but cheaper motor using the specified design principles and software. In the study, it has been shown that the cost can be reduced by targeting the reference motor.

References