EE564 PROJECT #2

MOTOR WINDING DESIGN AND ANALYSIS

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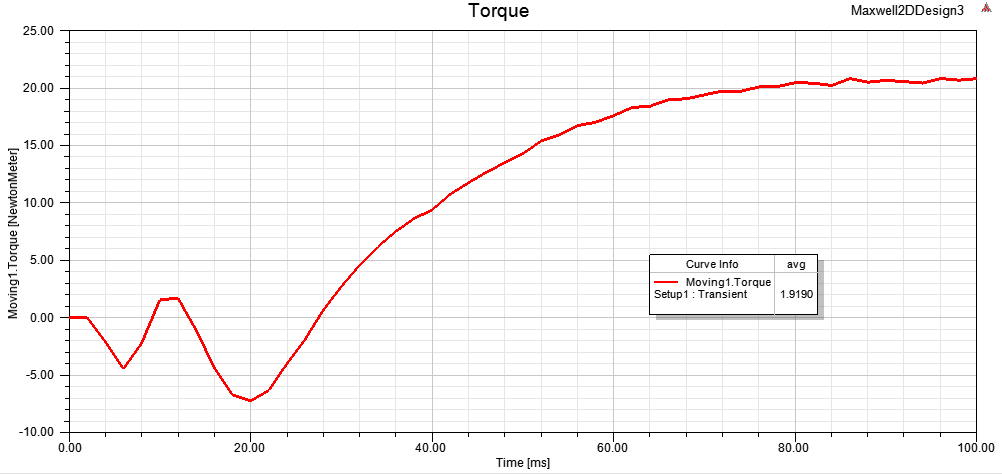
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# 1. INTRODUCTION

The main purposes of project are to design three phase induction motor and then verify it in a FEA program.

# 2. WINDING DESIGN

Firstly, lamination 1 is chosen for induction motor design. All calculation methods can be seen in ‘Winding Design’ excel file.

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **Number of Poles** | 4 |  |  |  |  |
| **Type of Winding** | Integral, Double Layer, Distributed Winding | 3. H | 5. H | 7. H | 9. H |
| **Winding Factors** | 0,9598 | 0,66667 | 0,21757 | -0,1774 | -0,3333 |
| **Number of Turns** | 180 |  |  |  |  |
| **Wire Size** | 14AWG | < | 2,177 | (mm^2) |  |
| **Fill Factor** | 0,7 |  |  |  |  |
| **Winding Connection** | wye |  |  |  |  |
| **Voltage Rating (V)** | 380 |  |  |  |  |
| **Current Rating (A)** | 4,6 |  |  |  |  |
| **Output Power Rating (W)** | 3000 |  |  |  |  |
| **Frequency** | 50 |  |  |  |  |
| **Input Power Rating (W)** | 3308,15 |  |  |  |  |

Table 1 Winding Design Parameters

|  |  |  |
| --- | --- | --- |
| **Number of StatorSlots** | 36 |  |
| **Slots per Pole** | 9 |  |
| **Slot per Pole per Phase** | 3 |  |
| **Slot Angle (degree)** | 20 | 0,34907 |
| **Conductors per Slot** | 30 |  |
| **Nphase** | 180 |  |

Table 2 Winding Design Calculations

|  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **A** | | | **C-** | | | **B** | | |
| a1 | a2 | a3 | c10- | c11- | c12- | b1 | b2 | b3 |
| a10 | a11 | a12 | c7- | c8- | c9- | b10 | b11 | b12 |

|  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **A-** | | | **C** | | | **B-** | | |
| a4- | a5- | a6- | c1 | c2 | c3 | b4- | b5- | b6- |
| a1- | a2- | a3- | c10 | c11 | c12 | b1- | b2- | b3- |

|  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **A** | | | **C-** | | | **B** | | |
| a7 | a8 | a9 | c4- | c5- | c6- | b7 | b8 | b9 |
| a4 | a5 | a6 | c1- | c2- | c3- | b4 | b5 | b6 |

|  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **A-** | | | **C** | | | **B-** | | |
| a10- | a11- | a12- | c7 | c8 | c9 | b10- | b11- | b12- |
| a7- | a8- | a9- | c4 | c5 | c6 | b7- | b8- | b9- |

Table 3 Winding Diagram

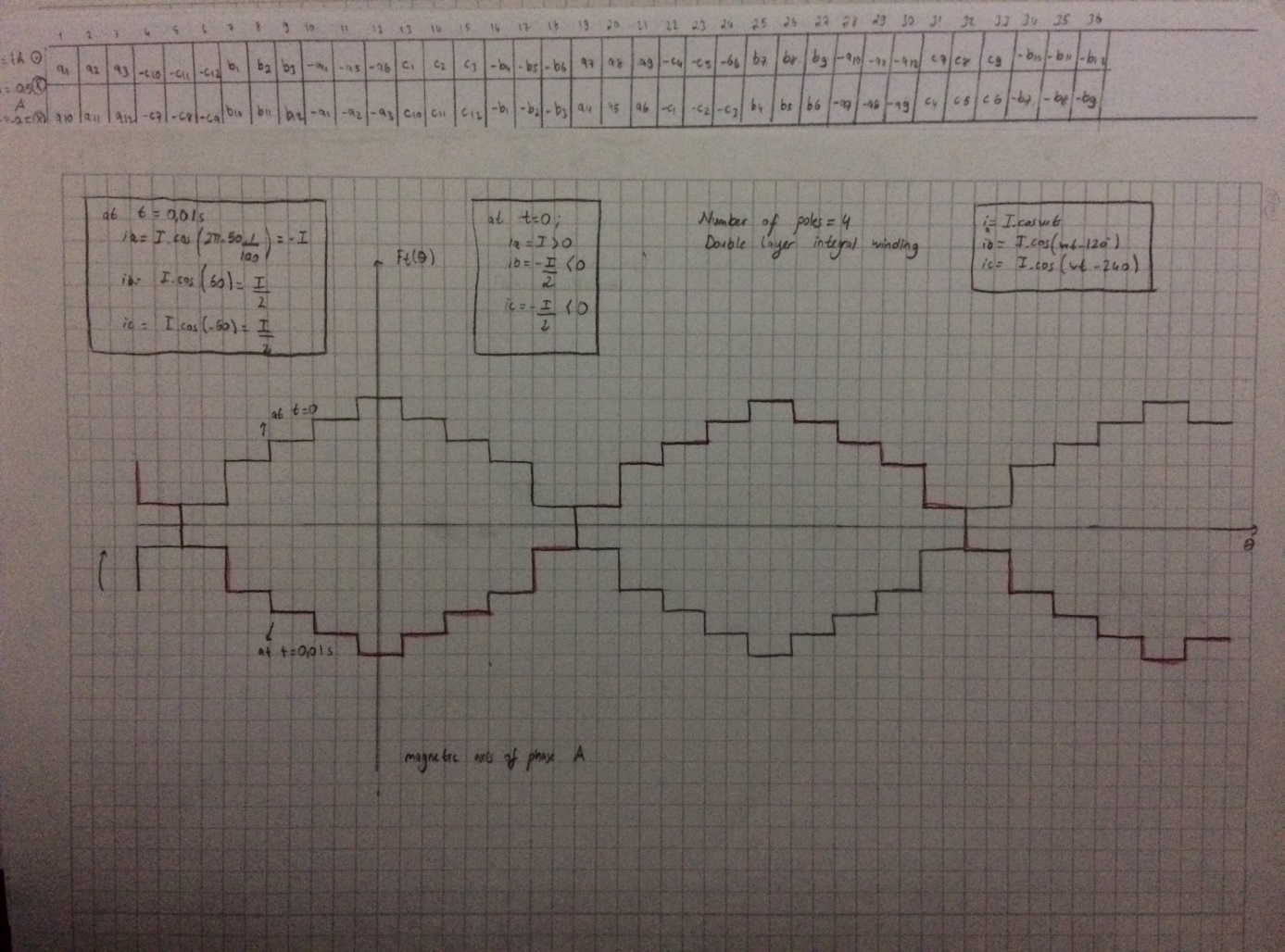


Figure 1 MMF Waveform

# 3. MOTOR PARAMETER ESTIMATION

|  |  |  |  |
| --- | --- | --- | --- |
| **Flux per Pole (Wb)** | 0,00572 |  |  |
| **Bavg (T)** | 0,31667 |  |  |
| **Airgap Clearance (m)** | 0,001 |  |  |
| **Torque (N.m)** | 20,4628 |  |  |
| **Speed (rad/s)** | 146,608 | 1400 | rpm |

|  |  |  |  |
| --- | --- | --- | --- |
| **Axial Length (m)** | **Di (m)** | **Do (m)** | **A (mm^2)** |
| 0,2 | 0,115 | 0,17 | 93,3 |

|  |  |  |  |
| --- | --- | --- | --- |
| **Specific Magnetic Loading (T)** | **Flux Density in Teeth (T)** | **Flux Density in Core (T)** | **Specific Electric Loading-q (A/m)** |
| 0,316665866 | 1,5 | 1,5 | 16962,62751 |

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Full-Load Efficiency** | **Full-Load Power Factor** | **ns (rps)** | **Output Coefficient** | **D^2.L(m^3)** |
| 0,90685043 | 0,8 | 25 | 41,14255258 | 0,002645 |

|  |  |  |  |
| --- | --- | --- | --- |
| **Pole Pitch (m)** | **l\_mt (m)** | **Phase Resistance (ohm)** | **Stator Copper Losses (W)** |
| 0,090320789 | 0,84774 | 3,081200902 | 195,5946332 |
|  |  | (17AWG-1,04mm^2) |  |

|  |  |  |  |
| --- | --- | --- | --- |
| **Phase Inductance (mH)** | **Leakage Inductance (mH)** | **Core Mass (kg)** | **Core Loss (W)** |
| 20,3575204 | - | 35,63587087 | 33,85407732 |

Table 4 Calculation Results

# 4. DETAILED ANALYSIS AND VERIFICATION

## 4.1 INPUTS

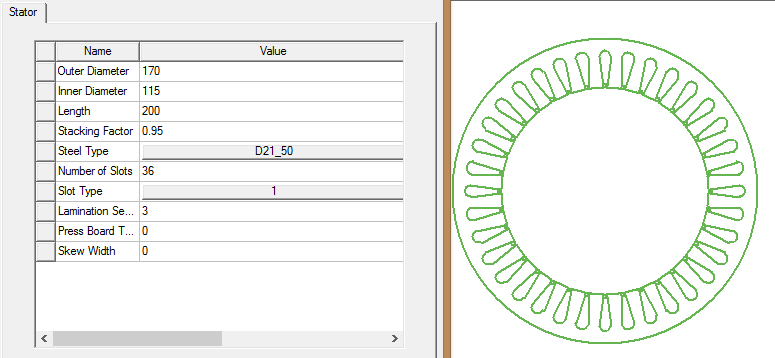


Figure 2 Stator Inputs

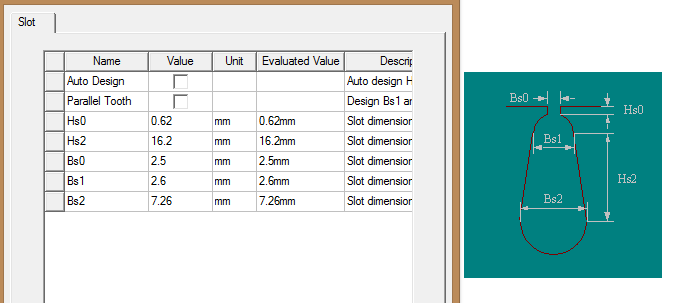


Figure 3 Stator Geometry

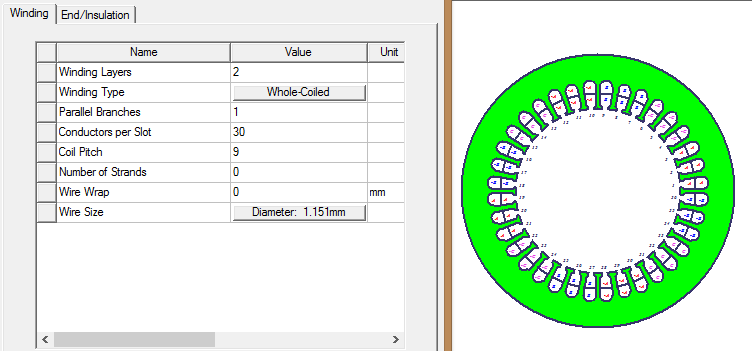


Figure 4 Stator Winding

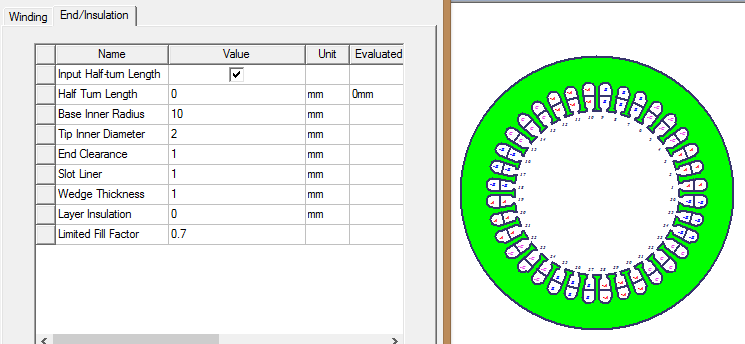


Figure 5 Stator Insulation

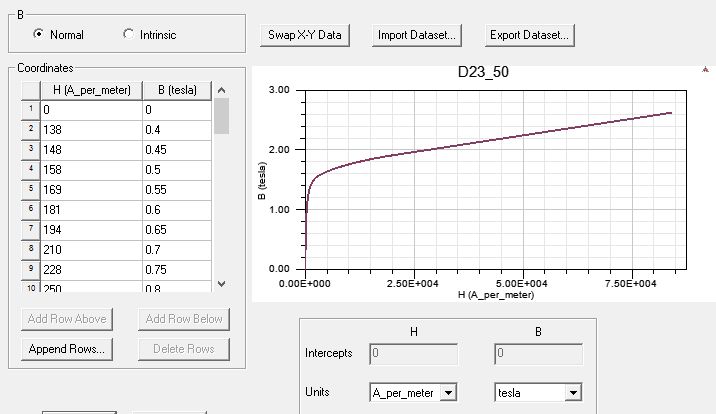


Figure 6 B-H Characteristics

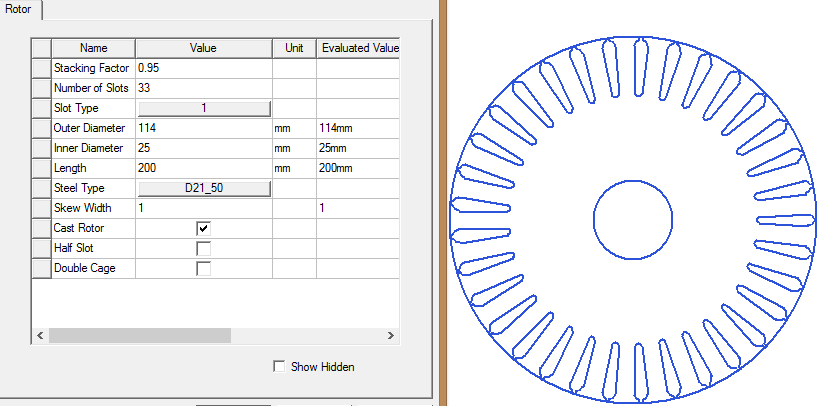


Figure 7 Rotor Structure

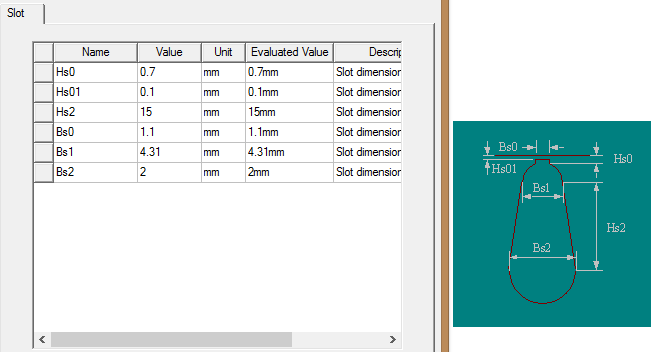


Figure 8 Rotor Geometry

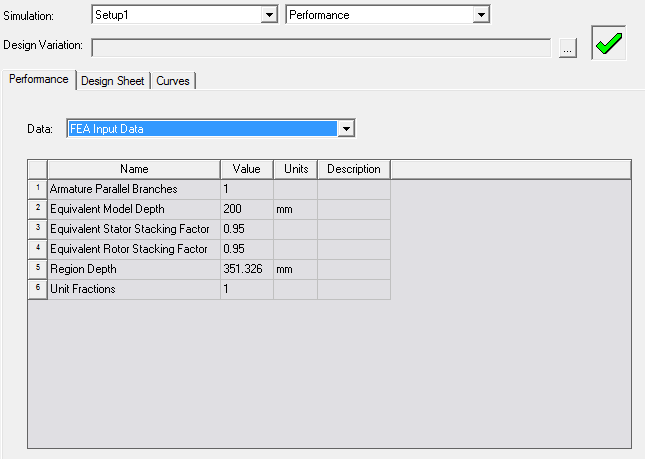


Figure 9 Input Data

## 4.2 OUTPUTS

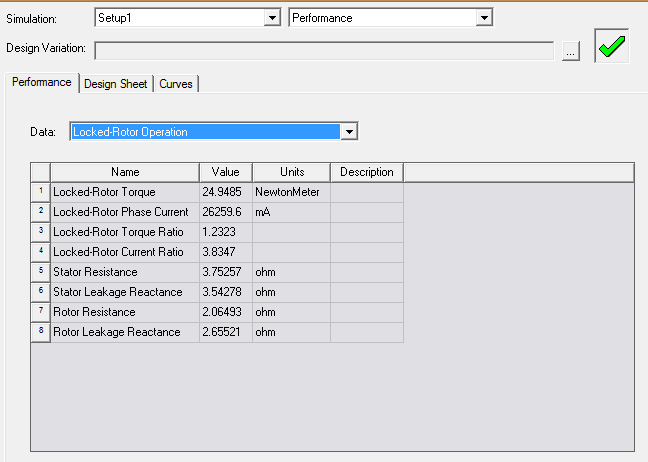


Figure 10 Locked Rotor Operation

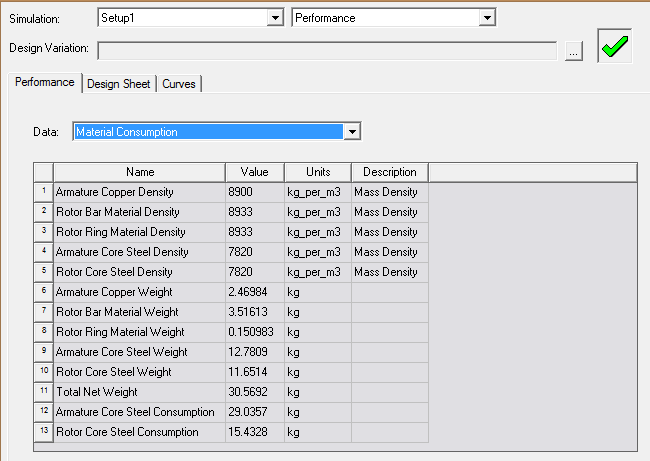


Figure 11 Material Consumption

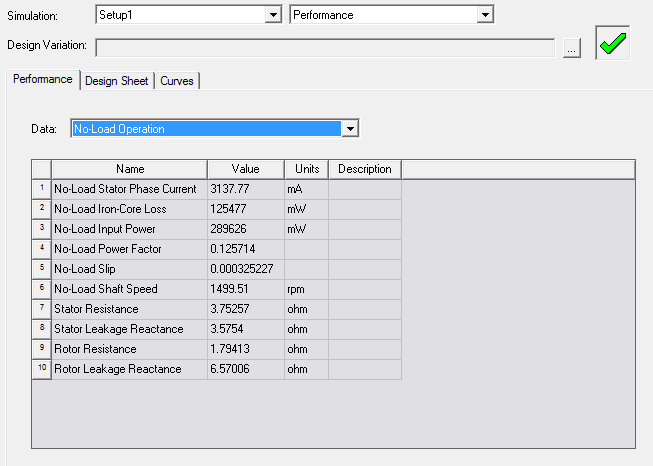


Figure 12 No Load Operation

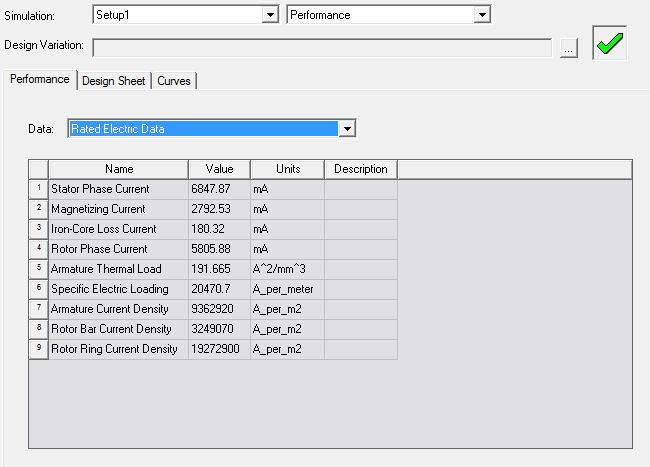


Figure 13 Rated Electric Data

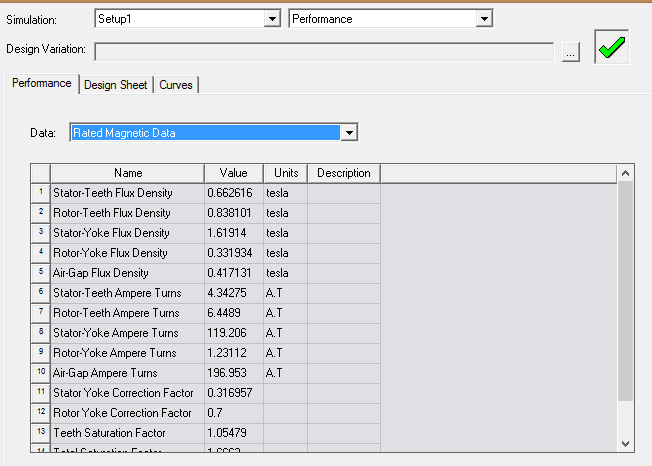


Figure 14 Rated Magnetic Data

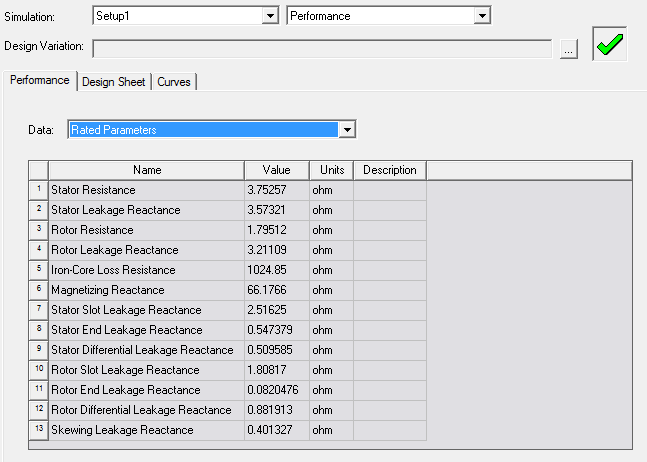


Figure 15 Rated Parameters

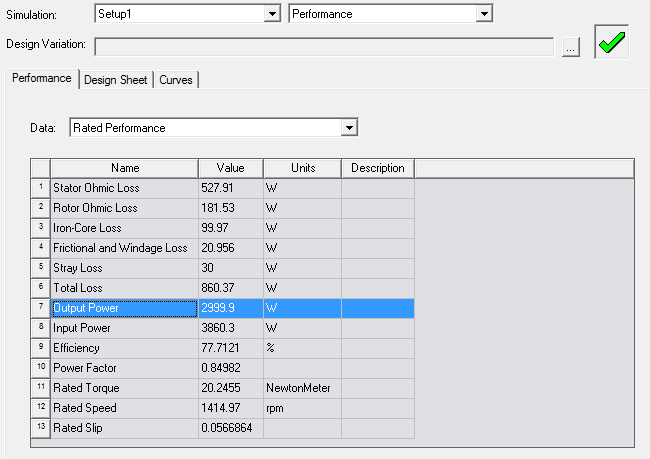


Figure 16 Rated Performance

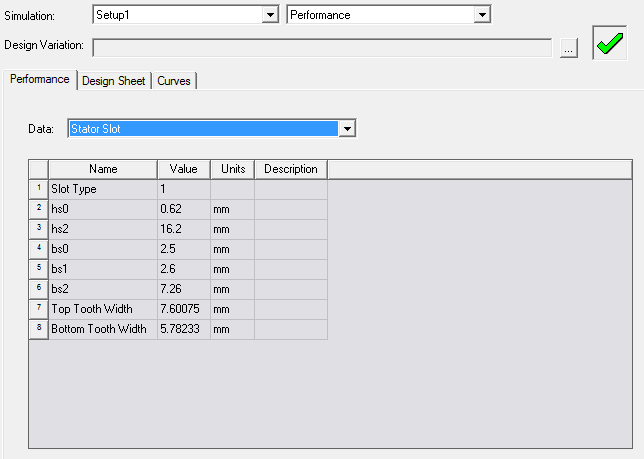


Figure 17 Stator Slot Geometry

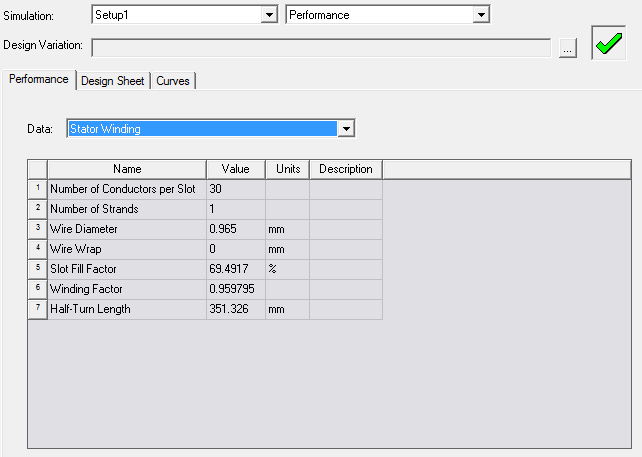


Figure 18 Stator Winding

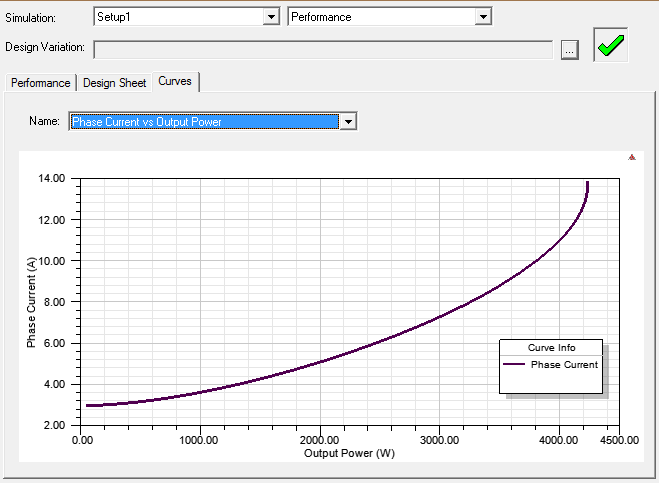


Figure 19 Phase Current vs Output Power

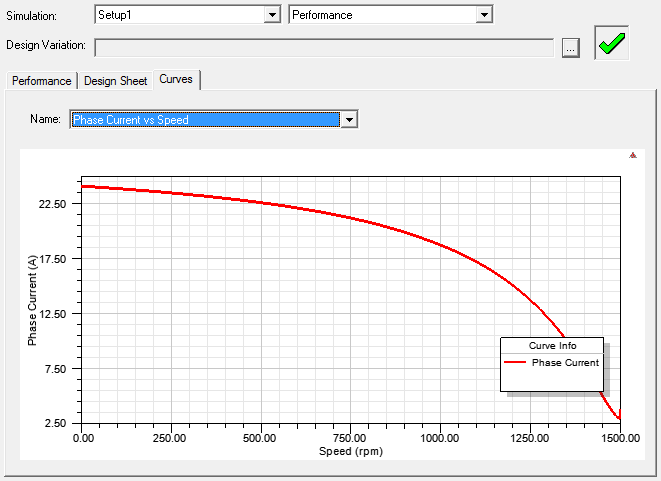


Figure 20 Phase Current vs Speed

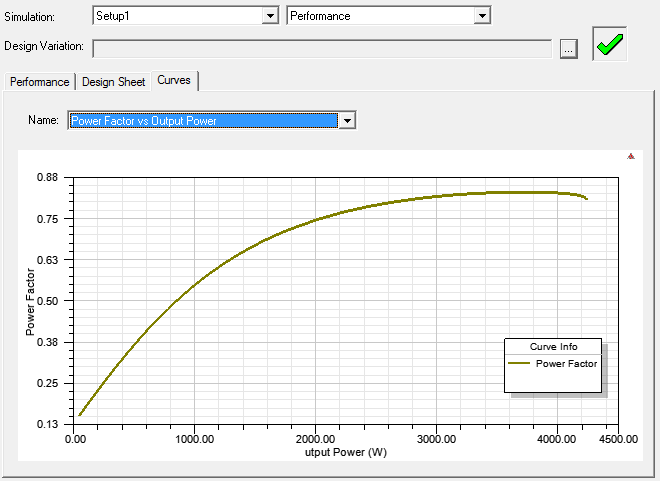


Figure 21 Power Factor vs Output Power

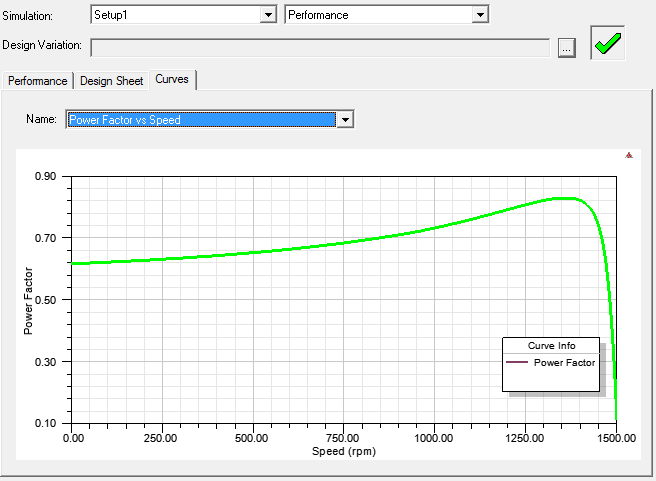


Figure 22 Power Factor vs Speed

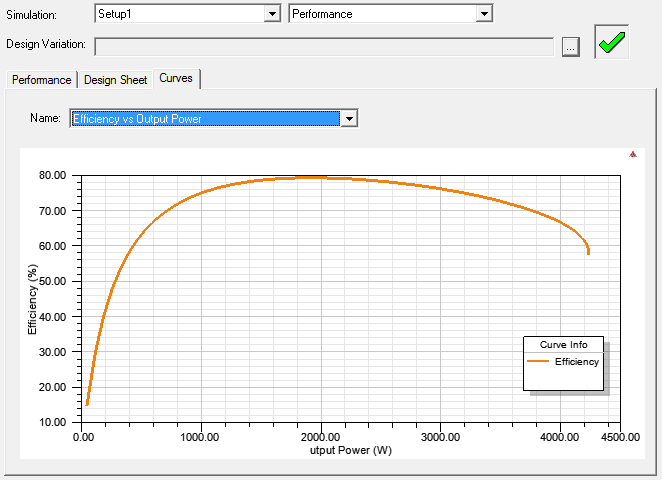


Figure 23 Efficiency vs Output Power

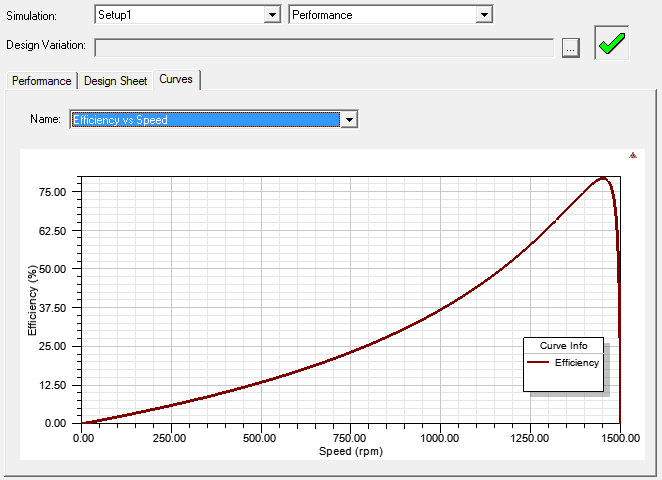


Figure 24 Efficiency vs Speed

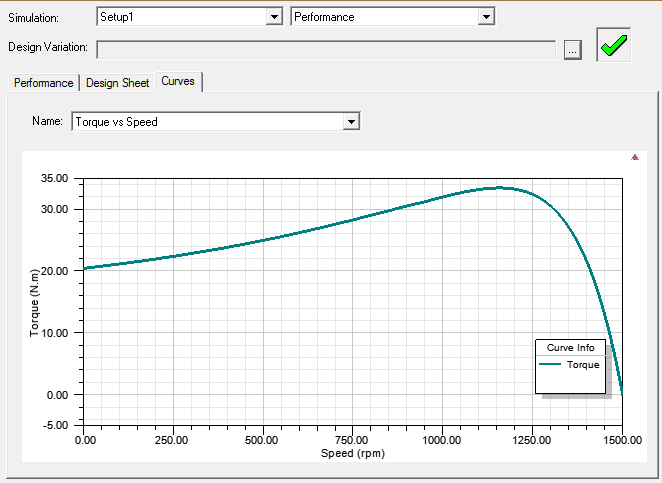


Figure 25 Torque vs Speed

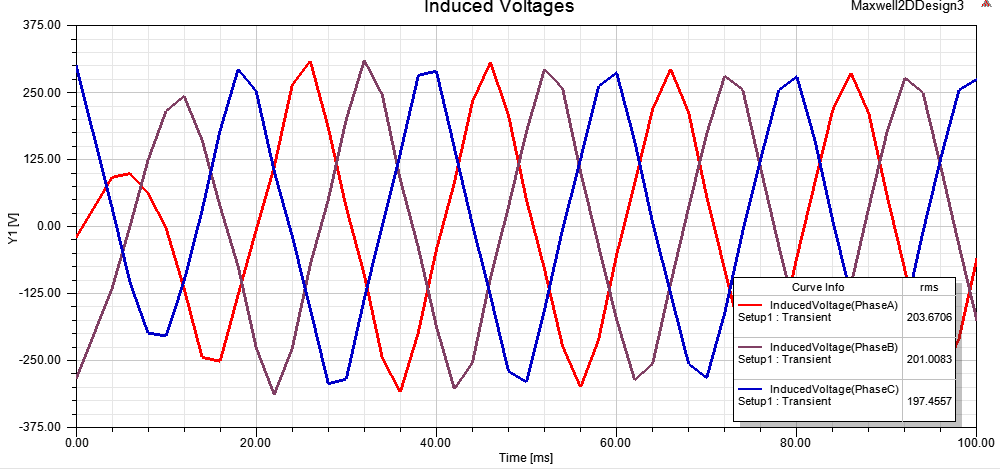
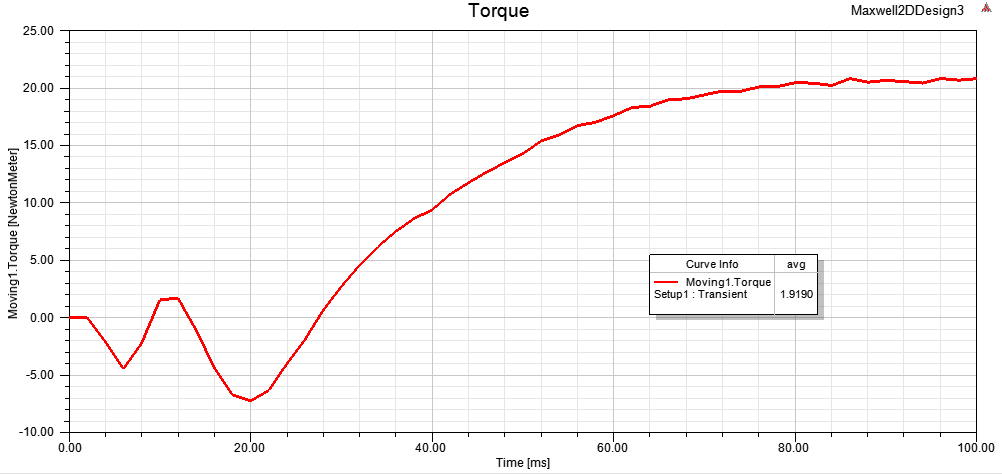


Figure 26 Induced Voltages vs Time

Figure 27 Torque vs Time

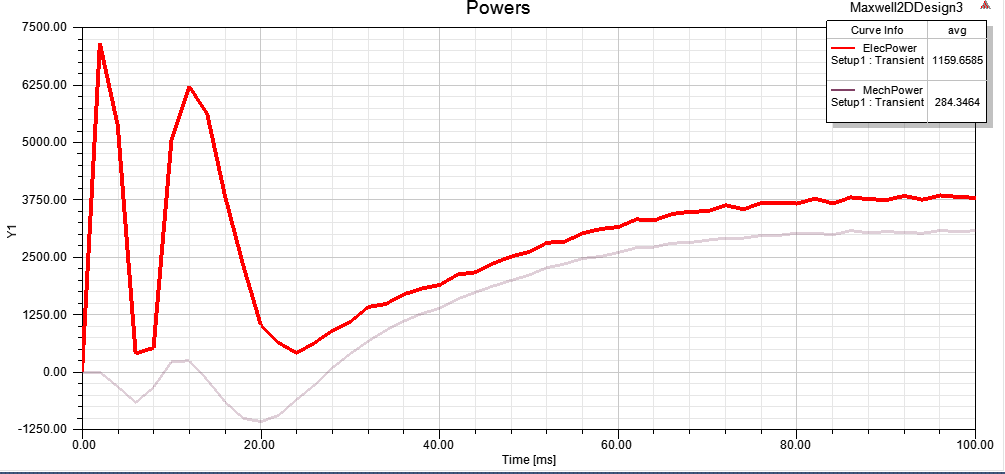


Figure 28 Power vs Time

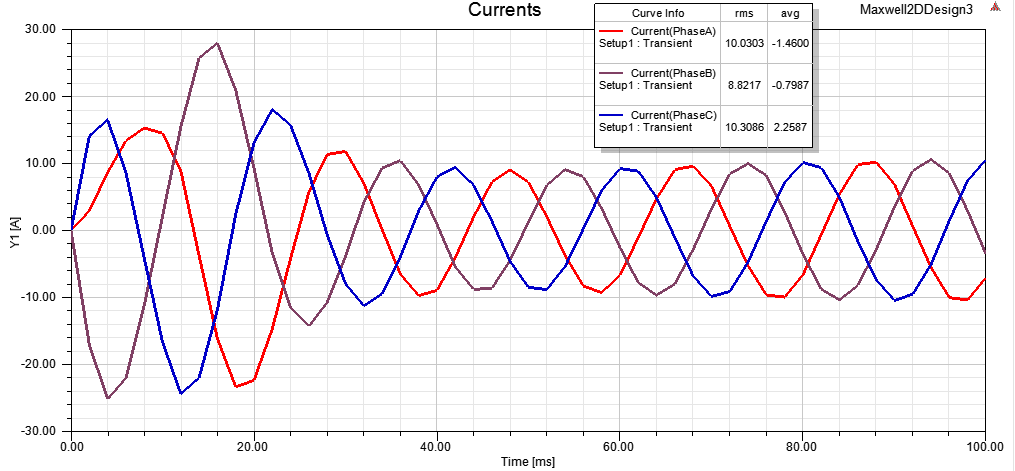


Figure 29 Input Phase Currents

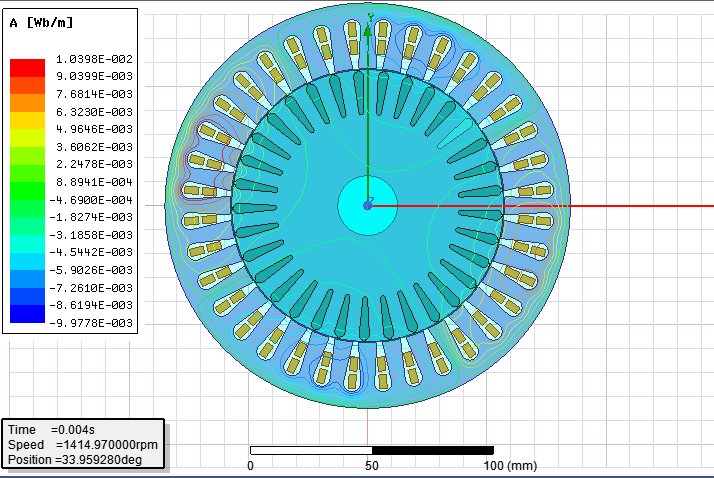


Figure 30 Flux Lines

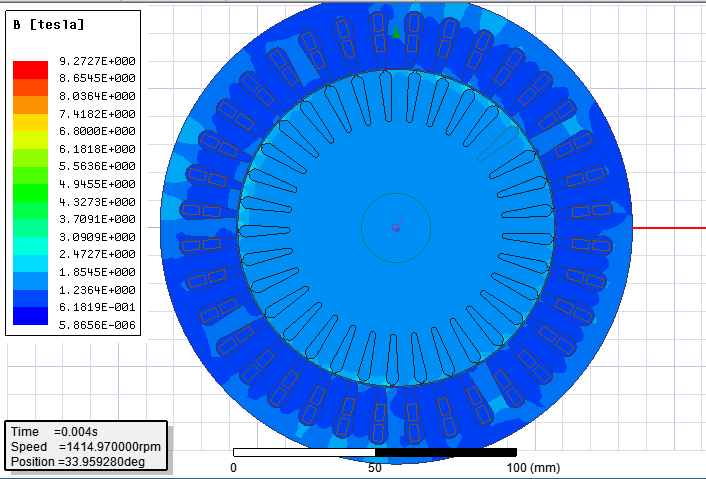


Figure 31 Magnitude of Magnetic Flux Density

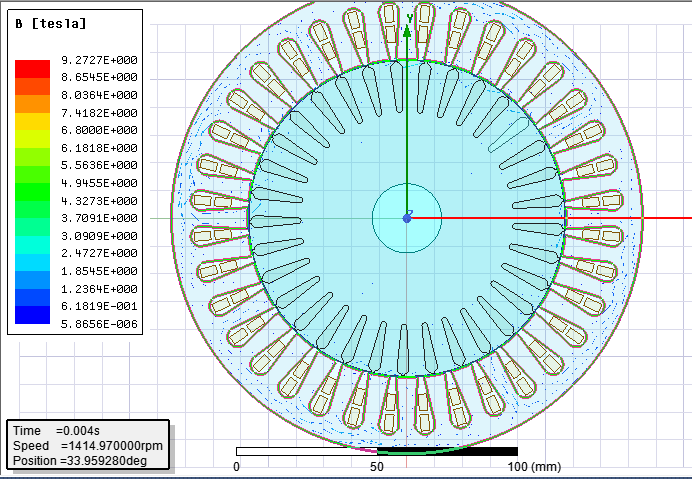


Figure 32 Magnetic Flux Density Vector

# 5. CONCLUSION

There are several significant design goals such as overall system efficiency, weight, cost, size. In order to achieve design optimization goal, the interaction between design parameters must be known well.

Best power factor with maximum efficiency is the main goal of design process. Geometry of the design is already chose. Design steps are based on following algorithm:

1. Calculate magnetic loading to get desired voltage
2. Determine rated torque and speed of induction motor
3. Calculate the approximate core and copper losses at the rated operating conditions by considering friction and windage losses
4. Calculate output coefficient based on geometry and desired output power Q
5. Calculate specific electrical loading

All in all, analytical approach is verified via FEA tool as seen above. All design process such as advantages and disadvantages of different stator designs, choices are referred on ‘Design of Induction Motors’ material [1].

# 6. REFERENCES

[1] Keysan, O. (2018, 03). Design of Induction Motors: Received from http://keysan.me/ee564/