

# Three Phase Induction Motor Design in Windows Programming Platform

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**Abstract**— The paper presents a software development strategy for the design of three phase squirrel cage induction motors in windows programming platform. The software technologies used are Visual Basic 6 for form design and coding, database developed in Microsoft Access comprising information on standards used and layouts of material characteristics used for manufacturing the motor are plotted in Microsoft Excel. The aim of this software lies in reducing the redesign time during the course of learning the design procedure of induction motor. It enables students to verify their design and analyze the performance of machine by changing relevant parameters in less time. The software is made user friendly as it provides a checklist, an easy design data supply and online design tips in each module.

**Index Terms**— Specification Standards, Constructional Features, Performance Analysis, Design Modifications, Computer Aided Design, Front End and Database.

## I. INTRODUCTION

Although the design procedures for induction motors are well established, there are some areas which require special attention. The manual design of motor account for lengthy calculations and any changes in parameters for an acceptable design leads to recalculation. Thus considerable time and effort of the designer is required to carry out the calculations accurately. To cite an example, after the completion of calculations of an IM design it has been 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 electric loading, magnetic loading, insulation thickness etc. Hence iterative calculation of the entire design procedure is required to achieve a satisfactory result. The approximations assumed in the manual calculations also lead to inaccurate results. Computer aided design excel in the fact that computers can perform a very large number of calculations to the required degree of accuracy in short time. The essential thing is that it has to be suitably programmed to arrive at the optimum design. The design features of an induction motor are classified as constructional wise and performance wise and the results are combined. [1] The design software used in manufacturing the motors are expensive and owned by private companies who cannot disclose the details of it. So the demand and requirement of design software for educational purpose is on the rise.

## II. RESOURCE REVIEW

### A. Principles of design

The art of design lies in suitable and economic distribution of space to iron, copper, insulation and air in the machine. Basically the design of electric motor involves the study of the voltages induced in the windings, the load currents and terminal voltages under different loading conditions, the power received or given out by the machine, the speed at which the machine is running under different loading conditions and frequency and the torque produced under different loading conditions as given (Fig1). The interrelations of the above quantities decide the suitability of a machine for a particular application. After designing the size and dimensions of the machine parts, the appropriate magnetic and electric circuits must be calculated. Thus with the details of circuit parameters and dimensions of various parts, performance of the machine is predetermined by

3000 rev/min. 2-Pole. 415V ±10%, 50Hz ±5%, Combined V and F 10%, Ambient 45°C. IP55. Class F Insulation.														
Rated Output	Frame size	Order No. (for Order No. suffixes for voltage and type of construction, see table below)	Operating characteristics at rated output					Locked rotor current	Locked rotor torque	Break-down torque	Rotor Class	G <sup>2</sup> of rotor	Weight approx.	
			Rated Current at 415V	Efficiency %	Power Factor	Rated Speed rev/min.	Rated Torque kgm							
kW	hp		A	%		rev/min.	kgm	current	torque	torque	KL	kgm <sup>2</sup>	kg	
11	15	160M	1LA0 163-2YC.	20	88.0	0.88	2910	3.7	6.0	1.8	2.5	10	0.20	100
15	20	160M	1LA0 164-2YC.	26	89.5	0.88	2910	5.0	6.0	1.8	2.5	10	0.22	115
18.5	25	160L	1LA0 166-2YC.	32	90.5	0.88	2910	6.2	6.0	2.1	2.5	10	0.26	130
22	30	180M	1LA0 183-2YA.	38	91.5	0.87	2940	7.3	6.5	2.4	3.0	16	0.31	165
30	40	200L	1LA0 206-2YB.	51	92.5	0.88	2950	9.9	6.0	2.1	2.7	13	0.56	230
37	50	200L	1LA0 207-2YB.	63	92.5	0.88	2950	12.2	6.0	2.1	2.7	13	0.64	250
45	60	225M	1LA0 223-2YB.	76	93.7	0.88	2955	14.8	6.0	2.1	2.7	13	0.96	310
55	75	250M	1LA0 253-2YB.	92	93.5	0.89	2970	18.0	7.0	2.1	2.7	13	1.80	415
75	100	280S	1LA0 280-2YC.	126	94.2	0.88	2970	24.6	7.0	1.9	2.7	10	3.16	570
90	120	280M	1LA0 283-2YC.	149	94.6	0.89	2970	29.5	7.0	1.9	2.7	10	3.68	610
110	150	315S	1LA0 310-2YC.	181	94.8	0.89	2980	36.0	7.0	1.8	2.7	10	5.20	790
132	180	315M	1LA0 313-2YC.	217	95.2	0.89	2980	43.1	7.0	1.8	2.7	10	6.00	850
160	215	315L	1LA0 316-2YC.	258	95.7	0.90	2985	52.2	7.0	1.8	2.7	10	7.20	990
200	270	315L	#1LA0 317-2YC.	323	95.7	0.90	2985	65.3	7.0	1.8	2.7	10	9.20	1100
250	335	355L	1LA0 356-2YC.	397	96.2	0.91	2985	81.6	7.0	1.6	2.8	10	13.20	1470
315	425	355L	1LA0 357-2YC.	500	96.3	0.91	2985	102.8	7.0	1.6	2.8	10	16.00	1650

Fig (1) Frame size data sheet (Siemens [3]) calculations. The machine is represented by an equivalent circuit and its performance can be determined under different operating conditions. [1, 2]

### B. Specification Standards

The Bureau of Indian Standards (BIS) has prepared standards for various types of electrical machines to cover the requirements of the consumers. Standardization helps in economy and in the comparison of performance of motors from different manufacturers. The customers can mention the additional specifications apart from the standard

specifications to which the equipment must be built and the degree of expected performance accuracy. The standards that summarize the specifications of induction motors are IS 325, IS1231, IS4800 and IS6160. [2] In the given name plate information of Siemens, the IS: 325 standard is mentioned (Fig 2).

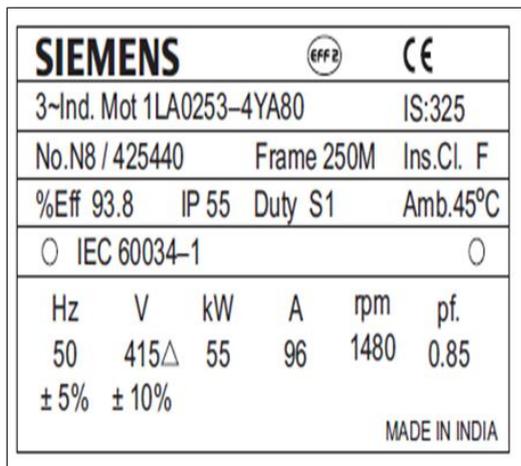


Fig (2) Name plate of 3 Phase Squirrel Cage Induction Motors [3, 4] (Siemens)

C. Computer Aided design – Different approaches

The computer aided design eliminates the tedious and time consuming hand calculations thereby releasing the designer from numerical process to enable him time to handle with physical and logical ideas thus accelerating the design procedure. Heroz et al [1] introduced the concept of two approaches to machine design – Analysis method and Synthesis method. In analysis method the choice of dimensions, materials and types of construction are made by the designer and these are presented to the computer as input data. The performance is calculated by the computer and is returned to the designer with which the performance is checked and if necessary makes another choice of input and recalculates the performance. This procedure is repeated till the performance requirements are satisfied. In synthesis method the desired performance is given as input and the logical decisions required to modify the values of variables to arrive at the desired performance are incorporated in the program as a set of instructions. Thus the program run is not interrupted for designer to take logical decisions. For a given set of performance indices synthesis method should produce an optimum design. The analysis approach is adapted in this software development as it suits the requirements of the students.

D. Technologies used

Visual Basic 6.0 is the front-end for developing the project. It has a graphical user interface that assists people that are not from IT back ground and also provides excellent reporting features with good printing support. It is easy to debug and maintain and gives event driven programming facility.[5,6] MsAccess is the backend for database design due to its multiple user support , efficient data retrieval and

maintenance . The characteristics of different materials used for manufacturing motor are plotted with the help of graphing tool available in Microsoft Excel.

III. IMPLEMENTATION OF MODULES

The module development involves the formulation of constructional features and performance analysis. The functionalities developed in the constructional features are main dimension block, stator design block and rotor design block. The equivalent circuit is completed from the resistance and reactance calculations. The performance functionalities include the estimation of losses and efficiency, full load torque, starting current, starting torque, temperature rise. The Fig (3) is the system architecture depicting the above mentioned details.

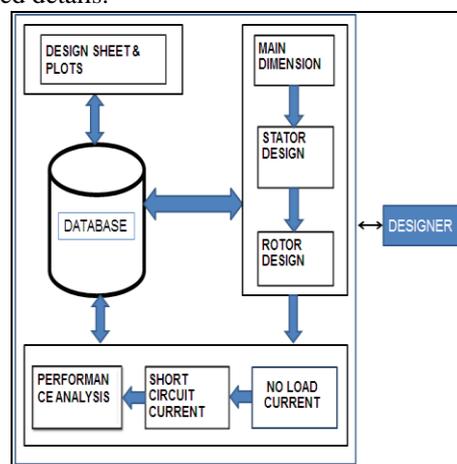


Fig (3) System Architecture

A. Administration settings

A Login form is used to enter authentication credentials to access a restricted page or form. When the login form is submitted its underlying code checks that the credentials are authentic, giving the user access to the restricted page. If a user is not able to provide authentic credentials they will not be able to proceed past the login form as given in Fig (4). This also provides security as once a user is authenticated he can view only his previous design reports.

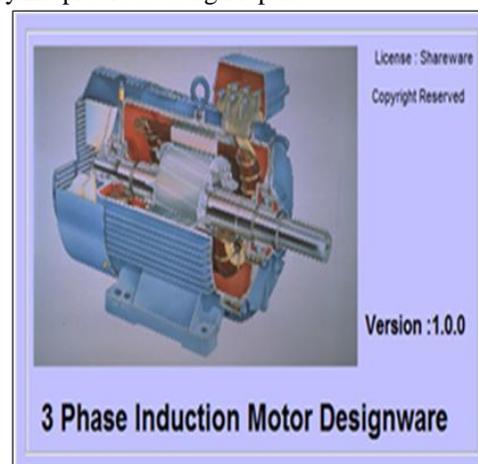


Fig (4) Successful login.

### B. Main Dimension module

Specifications of the motor to be designed have to be entered and then the frame size, stator bore diameter (D) and length (L) are calculated by the software. Frame size is selected from the IS standards for class B and class F insulations. The snapshot of the module is given in Fig (5).

### C. Stator Design Module

The number of stator turns per phase, the number of stator slots, the slot pitch are now found, and the slot width to be taken half of it leaving the tooth width sufficient enough from the mechanical considerations as well as to avoid much saturation. Keeping the flux density within the permissible limits of the material used, the number of conductors per slot are found. The size and shape of the conductor is decided depending on the power rating. The stator winding and winding factor are designed. The snapshots of stator design module and the corresponding layouts are given in Fig (6) to Fig (8).

- For lower values of current, round conductors would be most convenient to use. The current density can be between 3 to 5 A/mm<sup>2</sup>.
- For higher currents, bar or strip conductors should be adopted as anything above 2 or 3 mm in diameter is difficult to wind. Bar and strip conductors gives a better space factor for the slots.

### D. Rotor Design Module

Choose the air gap length (0.3-0.5mm) and find the rotor diameter ( $D_r = \text{stator bore} - 2 * \text{length of air gap}$ ). Select number of rotor slots. Ratio to stator slot number is important to avoid cogging, crawling and magnetic noise for the squirrel cage motor. The rectangular shaped bars and slots are generally preferred in rotor. Select current density in rotor bars and end rings and from rotor bar and end ring currents get their cross sectional areas. For aluminum bar, the range is 2.2 to 4.5 A/mm<sup>2</sup> and a lower value is chosen for small motors. For deep bar rotor, it is in the range of 5.5 to 7.5 A/mm<sup>2</sup>. The snapshots of rotor design module are given in Fig (9) to Fig (11). Rotor bar (width to depth) geometry now depends on the torque-speed characteristic and starting torque needed. Calculate rotor bar and end ring resistances and hence the conductor losses. The rotor resistance is the sum of the resistance of the bars and the end rings. The cross section of the bars and the end rings must be so selected that a compromise between a high resistance rotor which gives a good starting torque and a low resistance rotor which gives a high value of efficiency. Current density in the rotor bars is between 4 to 7 A/mm<sup>2</sup>. The value of slip at full load is determined by the rotor resistance.

### E. No load current Module

To solve the magnetic circuit of motor, the no load current has to be determined. Thus one has to estimate the

magnetizing component ( $I_m$ ) and then core loss component ( $I_c$ ) of current. To calculate magnetizing current, the ampere turns per meter in each part is determined corresponding to the flux density with the help of carters graph and B-H curves as given in Fig. (14) and (15). Then the total mmf in the air gap, stator core & teeth, rotor core & teeth are found. To determine the core loss current, the weight of iron in the stator is found and iron losses are calculated from material data sheets of losses in W/kg as in Fig(13) depending on flux density and frequency. The value of slip is small and, therefore, the iron loss in the rotor is negligible. The snapshots of No load current module and the corresponding graphs are given in Fig(12) to Fig(15).

### F. Performance Analysis Module

Knowing the shape and dimensions of the stator and rotor slots, find the slot leakage reactance for stator ( $X_s$ ) and rotor which is then referred to the stator ( $X_2'$ ). The other components are over hang leakage reactance ( $X_o$ ) and zigzag leakage reactance ( $X_z$ ). Then the total reactance per phase ( $X_{st}$ ) is calculated and the short circuit current is estimated. Refer Fig (16). The equivalent circuit as shown in figure is drawn from the parameters determined and performance calculations are done under full load and starting conditions. Assume friction and windage losses as, typically 1% of input power. Compute efficiency, power factor, full load torque, starting torque, pull out torque and temperature rise from the equivalent circuit. If these do not agree closely with assumed values, redesigning with modifications suggested can be done from the main dimension module. and again verify the performance. If the temperature is not within the satisfactory limits, adjust the loadings of the machine in the main dimension module and again verify the performance.

### G. Design data sheets Module

Once the design is ready, the summary is displayed on module basis as given in Fig(17). The results will be shown as per the selection. Finally the design sheet for a given specification of three phase induction motor is saved in the database and a report is prepared with project name and date. Figure 5-17 are shown in Appendix.

## IV. APPROACHES TO MODIFY THE DESIGN

The results obtained after the initial design may have certain scope for improvement in the following areas.[7,8]

### a) Low Power factor:

Causes: More leakage reactance, small magnetizing inductance and hence magnetizing current is large. Solutions: Reduce the ampere turns per pole to reduce the magnetizing current, If possible reduce the air gap, Reduce flux density B by increasing iron and core length.

### b) Small starting torque:

Causes: Large leakage reactance, small rotor resistance. Solutions: Reduce reactance by decreasing the number of turns per phase or the number of conductors per slot, Decrease the cross sectional area of the rotor bars.

**c) Large starting current:**

Causes: Small leakage reactance

Solutions: Increase leakage reactance by modifying rotor slot shape or use deep slot, Increase stator turns  
Avoid too small value of slots/pole/phase.

**d) Low efficiency:**

Causes: Large stator & rotor copper loss, large core loss and large stray loss. Solutions: Increase size of conductor and use fewer turns per phase, Increase rotor slot area and reduce the rotor current by decreasing stator turns, Decrease flux density by increasing stator turns and increase the length of the core, Use of better steel, Modify stator/rotor slot combination, increase air gap and modify rotor skew to adjust the stray loss.

**e) High temperature rise:**

Causes: Large losses, poor cooling, large thermal load. Solutions: Decrease losses, Check fan design and increase cooling gas flow, Increase surface heat rejection capability, like fins and design proper ventilation system for large machines, Increase heat conductivity from winding to core, Improve contact between core and frame, Decrease current density, Increase axial length, Decrease stator turns, Increase the insulation level. [1, 2, 8]

**V. CONCLUSION**

The demand of motor design software for educational purposes was the motivation behind this study. The scope of the project is featuring software for the design of squirrel cage induction motor in its basic form useful to designing and teaching field. The developed software provides good support for the students who are learning the design process as a part of their curriculum where they first master the design procedure and with the different parameter modifications they arrive at the optimized solution. This helps them to analyze the effects of different parameter variations easily and learn the design of induction motor effectively. The present work has concentrated on the design of standard squirrel cage induction motor which can be extended for designing energy efficient machines as a future scope. Also the software can be evolved to produce the optimized results for the given specification of induction motor without the intervention of the designer.

**REFERENCES**

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**AUTHOR'S PROFILE**

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APPENDIX

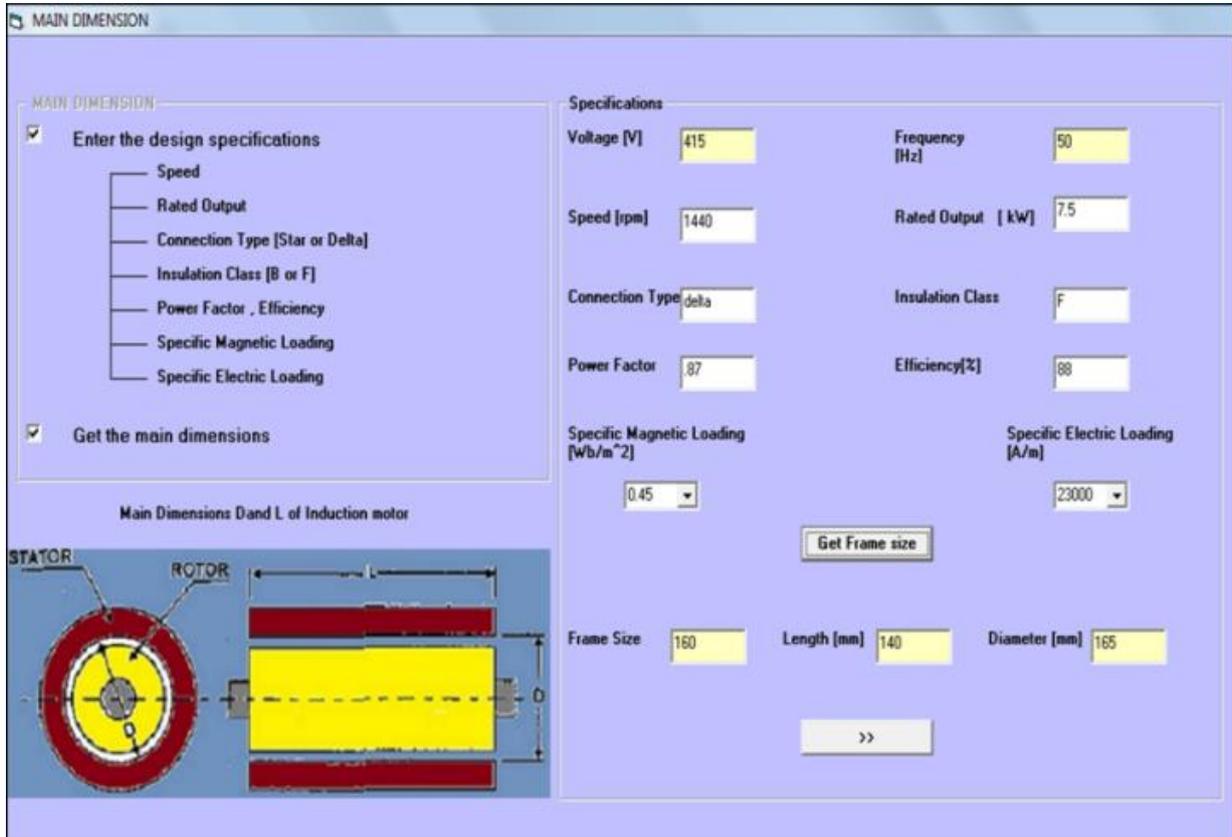


Fig (5) Main Dimension Module

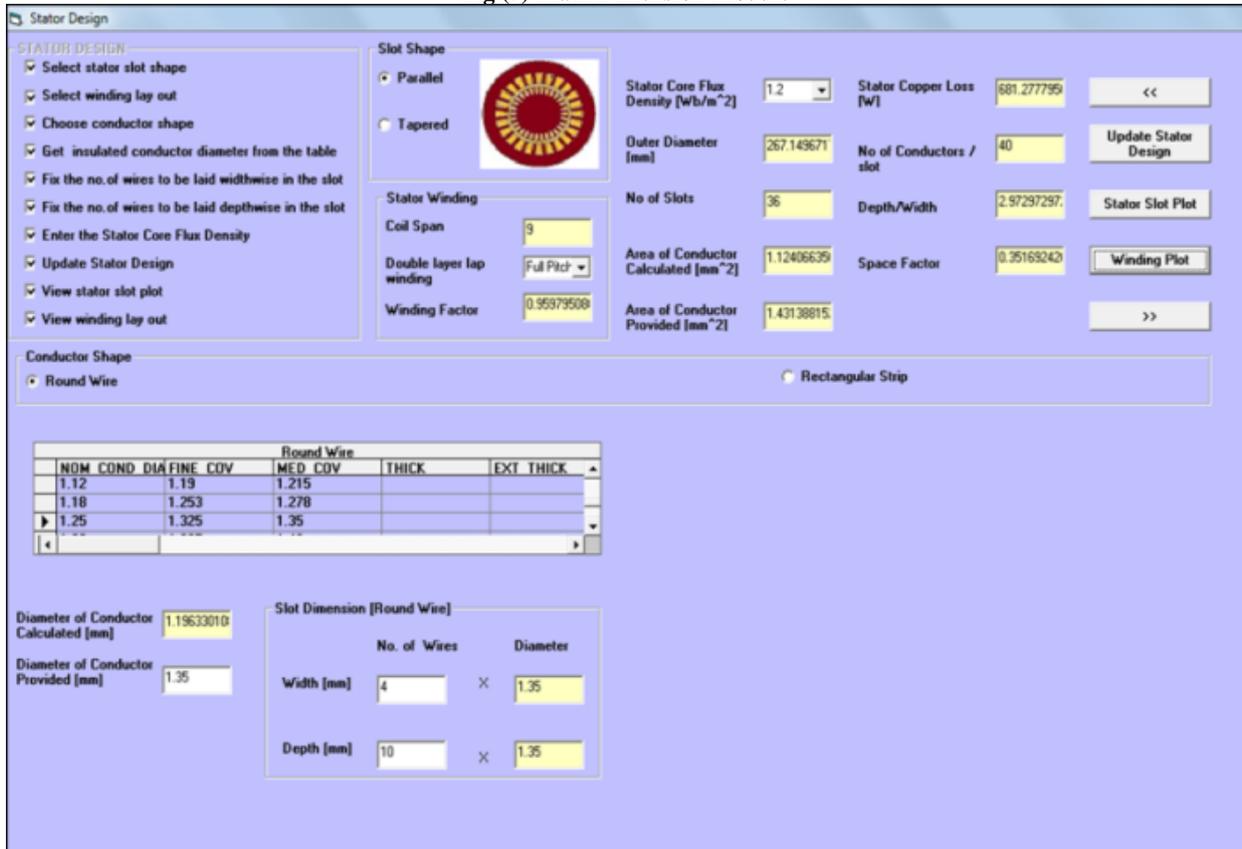
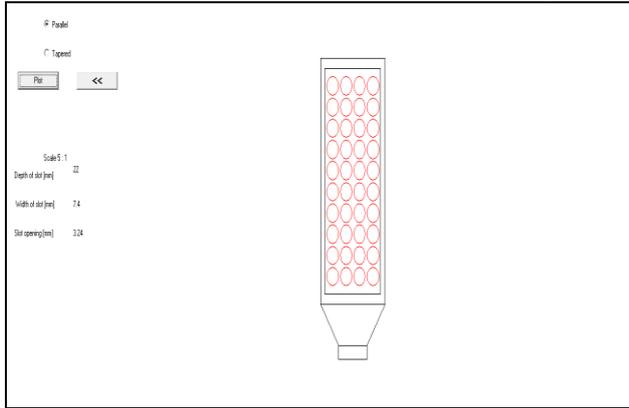
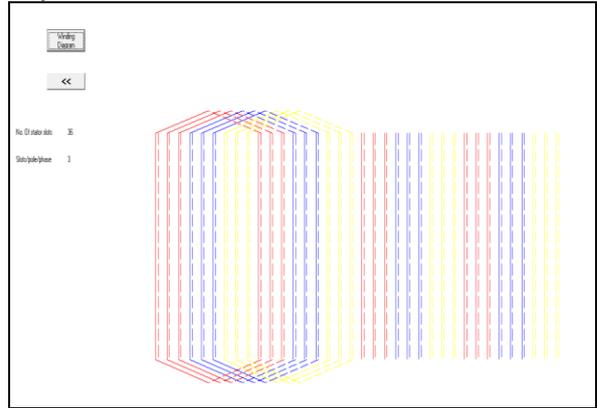


Fig (6) Stator Design



Fig(7) Stator slot plot



Fig(8) Winding layout

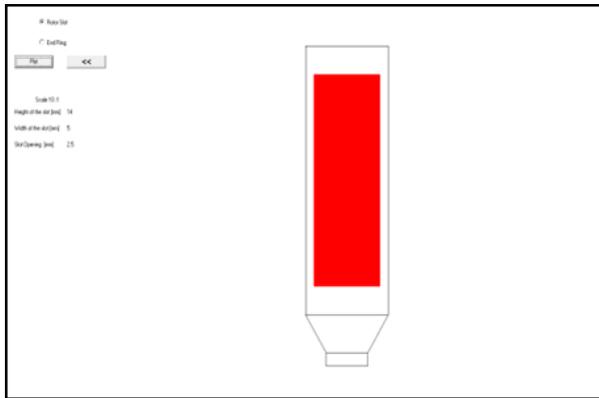


Fig (9) Rotor slot plot

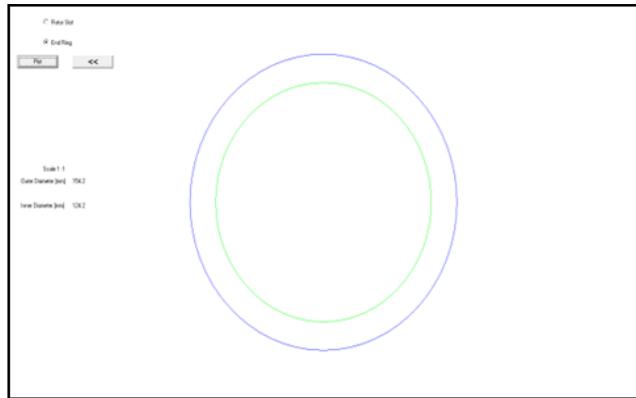


Fig (10) End ring plot

**Rotor Design**

**ROTOR DESIGN**

- Select Rotor slot shape
- Choose the number of rotor slots (ratio given)
- Decide the airgap length
- Assume the rotor current density
- Area of Bar
- Fix the width of bar from the table (area given)
- Fix the depth of bar accordingly
- Update Dimension
- Decide the bar length extension
- Fix the thickness of end ring (area given)
- Update rotor design
- View rotor slot plot

**Rotor Slot and Bar Dimensions**

Slot Shape: Parallel

Number of Slots: 44 (36/444pole, 36/284pole)

Length of Airgap [mm]: 3

Area of Bar [mm<sup>2</sup>]: 42.79099870

Rotor Current Density [A/mm<sup>2</sup>]: 5

Width Of Bar Selected [mm]: 2.2

Width Of Slot [mm]: 3.2

Depth Of Bar Selected [mm]: 20

Depth Of Slot [mm]: 23

Extended bar length [mm]: 15

Skew Length [mm] one slot pitch: 12

Length of Bar [mm]: 182

Rotor Teeth Flux Density[Wb/m<sup>2</sup>]: 1.00907874

**Copper Loss In Bars [W]: 174.958687**

**Copper Loss In Endings [W]: 67.2161007**

**Total Copper Loss In Rotor [W]: 342.174798**

**Full Load Slip [%]: 3.12795487**

**End Ring Dimension**

Area of Ending[mm<sup>2</sup>]: 149.828777

Thickness Selected [mm]: 7

Depth Calculated [mm]: 22

Rectangular Strip											
T 2.2	T 2.5	T 2.6	T 3.0	T 3.2	T 3.5	T 4.0	T 4.5	T 5.0	T 5.5	T 6.0	T 7.0
39.1	44.5	49.9	53.5	56.7	62.1	71.1	80.1	89.1	98.1	107	116
125	134	143	152	161	170	182	193	204	215	226	237

**Update Rotor Design**

**Rotor slot Plot**

Fig 11 Rotor Design



Fig 12 No load current

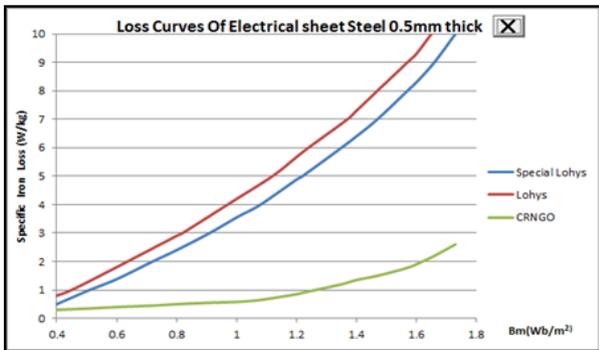


Fig 13 Loss curves of electrical steel sheet

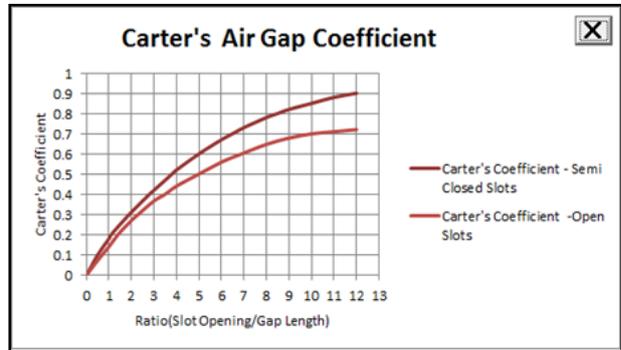


Fig 14 Carters Air gap Coefficient

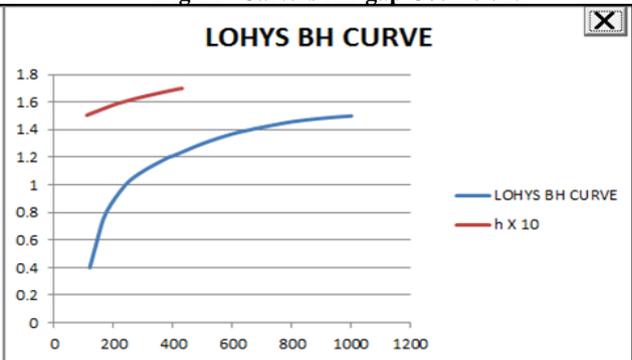
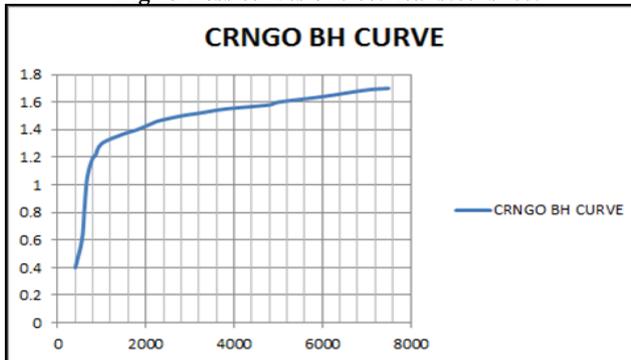


Fig 15 B-H curves for different steels

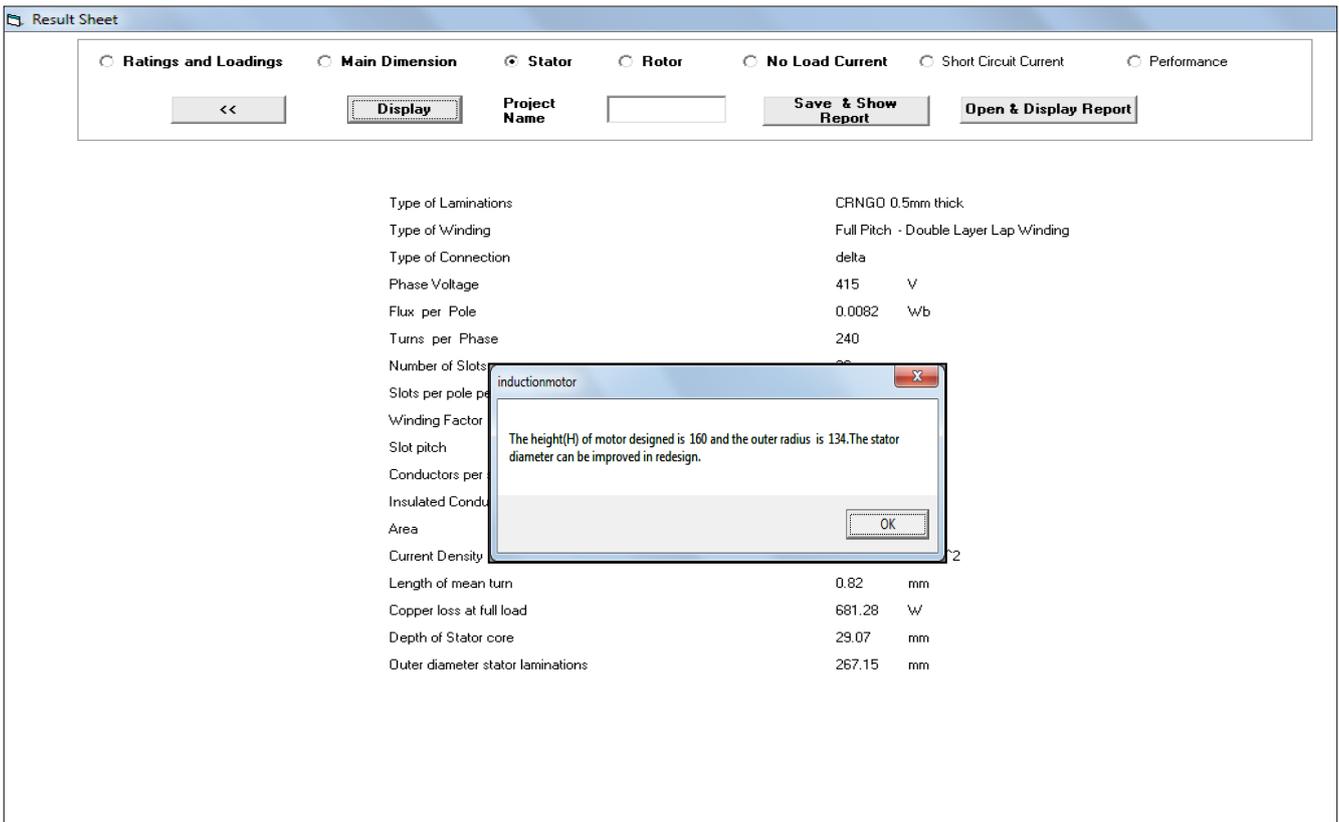
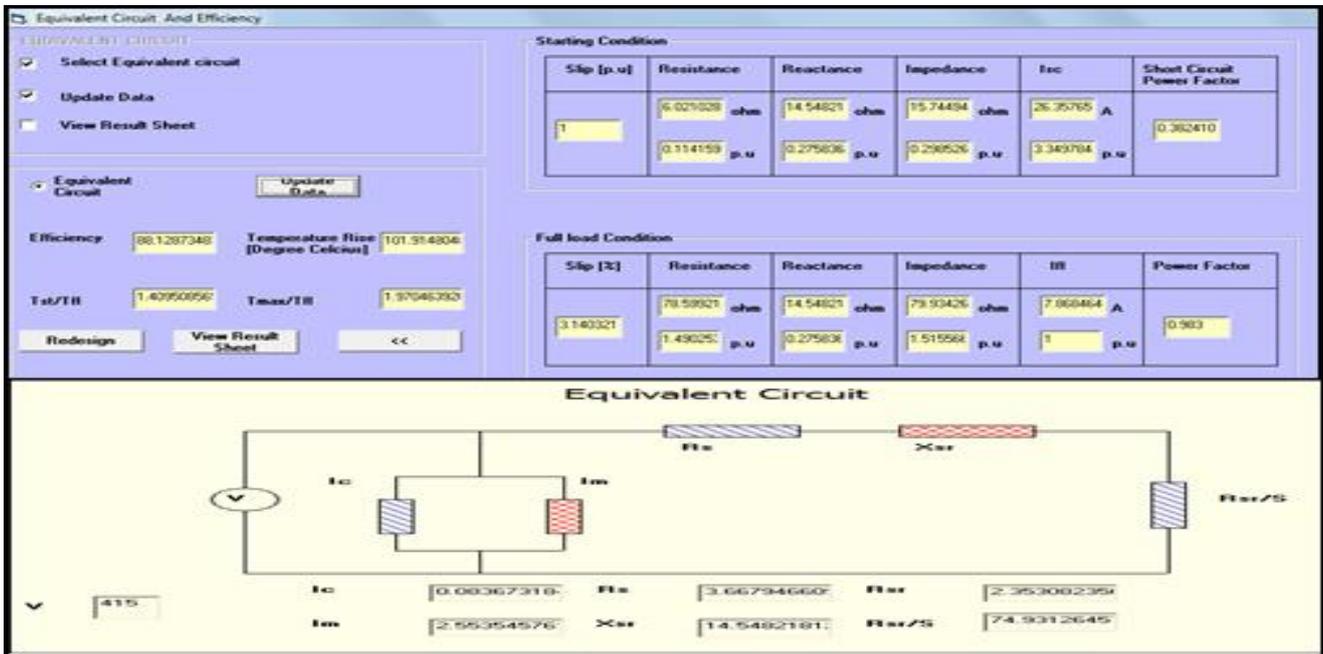


Fig 17 Design data sheets