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COMPUTER-AIDED DESIGN OF ELECTRICAL MACHINES TOOLKIT (GUI) USING MATLAB

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Abstract: With the advent of technology, many designers, academicians and researchers have been intrigued about the role of computers in the design of electrical machines. More aspects of the design process can be assisted by and taken over by computers as processors get more powerful. It is a common strategy to formulate the design of an electrical machine, or parts of it, as a multi-criteria optimization problem since the goal in designing electrical machines is to have a device that operates at the maximum possible performance, with the help of computer variable design parameters can conveniently be used for arriving at an optimum design. The Computer-Aided Design eliminates the tiresome and lengthy calculations and accelerates the process of designing. This work aims to eliminate the complications involved in the manual hand calculations of designing the machines, by using computer the selection of most suited data can be used to get the optimum design. To give it an aesthetic look Graphical user interface are made in the in-built App Designer of MATLAB.

Keywords: GUI, Computer-Aided Design of Electrical Machine, MATLAB, Optimization

I. INTRODUCTION

Numerical techniques are used across the board in research and engineering to analyze complex problems. The highly mathematical nature of the discipline and its strong association with computer science, however, makes electrical engineering particularly suited to computational solutions. Professional engineers also employ the computers themselves to aid in their own design (a process known as bootstrapping,). In fact, the development and enhancement of software tools to allow the implementation of immensely complicated designs is the prime objective of the entire discipline of computer-aided design (CAD). It is the responsibility of a designer to model and simulate designs as much as we can before they are manufactured to obviate defects and reduce the number of iterations required to create the final product. On similar lines, this work is aimed to alleviate human intervention and to achieve optimum design in minimum possible time. The toolkit will be a reliable software to perform complex calculations required for designing various electrical machinery.

II. DESIGNING THE TOOLKIT

The advantage of using computers is that it can carry out many calculations in a fraction of a second. However, to leverage this power, one needs to write a set of instructions i.e. a program or algorithm. Depending on the type of machine, an algorithm/program was formulated using the MATLAB software. Graphical User Interfaces (GUIs) were designed for different electrical machines using MATLAB App Designer. The GUI was later packaged as a MATLAB App.

Beginning with a literature survey, since Computer-Aided Design of Electrical Machines is a relatively avant-garde approach of the conventional Design of Electrical Machines, the literature survey was aimed to provide a bird's eye view on the research done so far in the field of interest. Several textbooks & journals served as the basis for the theoretical and conceptual framework; these previous works also discussed numerous conflicts and challenges experienced by machine designers and are vital sources of programming techniques.
There is a market gap for software that allows a user to customize a product to their own tastes. As a result, the need to create more user-friendly tools arises that would demonstrate simple modifications to parts of a machine or the machine as a whole at the click of a button.

There are broadly two methods of Electrical Machine Design — Analysis Approach & Synthesis Approach. The latter approach has been utilized during the course of this work. In this method, the computer is used only for the purpose of analysis and reference. If the design is not satisfactory, the designer can manually make other suitable choice of the parameters to recalculate the performance. Various Objective Parameters/Functions in an Electrical Machine are:
(a) Higher Efficiency
(b) Lower weight for given kVA output (Kg/kVA)
(c) Lower Temperature-Rise
(d) Lower Cost
(e) Any other parameter like higher power factor for induction motor, higher reactance etc. [4]

III. MACHINE DESIGN & GUIS

A. NAVIGATION PAGE


UI Figure

COMPUTER-AIDED DESIGN OF ELECTRICAL MACHINES
ENGINEER'S TOOLKIT

Select an Electrical Machine to design:

● Transformer
○ DC Machine
○ Induction Machine
○ Synchronous Machine

Figure 1 | Navigation Page

The Navigation GUI page acts as a bridge, connecting the user to the individual pages of Machine design viz., Transformer, DC Machine, Induction Machine, and Synchronous Machine GUI pages. This page also makes use of buttons to enable browsing of Data Sheets/References for choosing suitable values of variables like Specific Magnetic Loading (Bav), Specific Electrical Loading (ac), Ratio of core length to pole pitch etc. depending on the machine. The Data Sheets serve as a guide for the machine designers in order to easily achieve optimum design & swiftly undertake iterations instead of repeatedly referring textbooks.

The flowchart followed for the overall design of electrical machines is shown in figure 2.

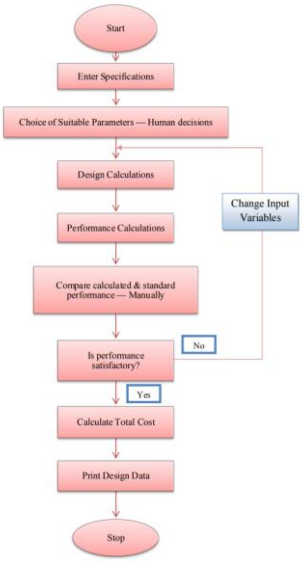


Figure 2 | Overall Design Flowchart

B. COST ANALYSIS

The final step in the design is Cost/or Economic Analysis. A simple cost model has been developed that allows the calculation of various costs viz. material, labour, etc The model has been normalized as a function of weight of components in order to accommodate different power ratings and sizes. The simplest case is when the cost of the component in question is a direct function of its size/weight; then cost is simply the product of its specific cost/market price (₹/weight or size) and the weight or size.

The Electrical Machine is broken down into its main constituting elements, the cost of each element as per current market prices are determined and related to a simple yet significant parameter such as weight (in kg).
The selling price is worked as under-
The cost of the complete machine is determined by adding the individual element costs plus the cost of assembly, testing, labour, factory overhead, etc.
COST ANALYSIS
Selling Price = Cost of Production + Profit
Cost of Production = Prime Cost (Direct material cost + Direct Labour cost + Direct Expenses) + Factory Overhead/Expenses

IV. RESULTS

A. Induction Machine

The induction motor especially three-phase Induction motors are widely used AC motors to produce mechanical power in industrial applications. Almost 80% of the motor is a three-phase induction motor among all motors used in industries.
A three-phase induction motor is a type of AC induction motor that operates on a three-phase supply compared to the single-phase induction motor where a single-phase supply is needed to operate it. The three-phase supply current produces an electromagnetic field in the stator winding which leads to generate the torque in the rotor winding of the three-phase induction motor having a magnetic field.
This 3-phase motor is also called an asynchronous motor. These AC motors are of two types: squirrel and slip-ring type induction motors.

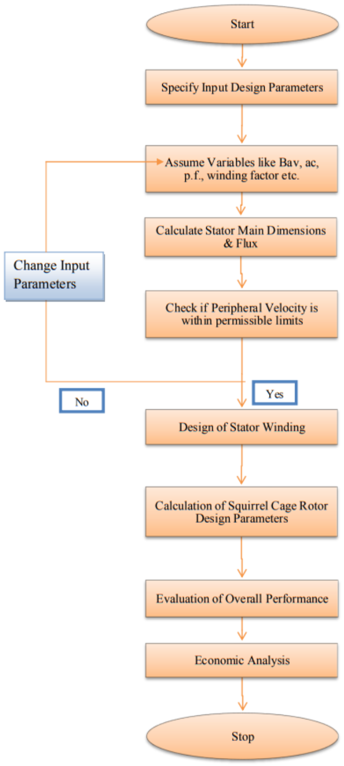


Figure 31 | Flowchart for Induction Machine Design

The principle of operation of this motor is based on the production of a rotating magnetic field. These three-phase motors consist of a stator and a rotor and between which no electrical connection exists. These stator and rotors are constructed with the use of high-magnetic core materials in order to reduce hysteresis and eddy current losses.

COMPUTER-AIDED DESIGN OF INDUCTION MACHINE

TYPE OF M/C : Three Phase

Cross-sectional view of induction motor and its parts

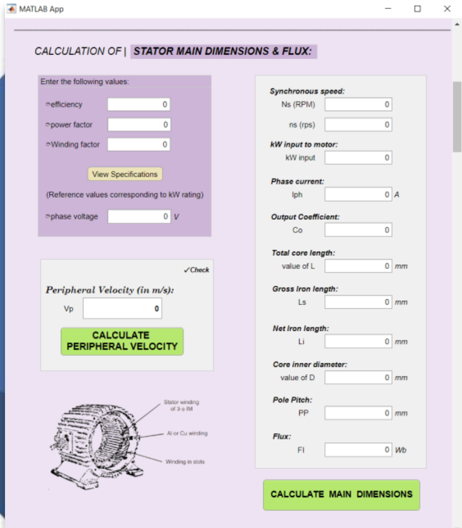
Design Parameters:

Enter the following values:

kW Rating 0 kW
Voltage Rating 0 V
Frequency 0 Hz
No. of Poles 0
Average gap density 0 T
Specific Electric loading 0 ac/m

(Reference values of average gap density and specific electric loading corresponding to kW Rating)

Figure 32 | GUI for Induction Machine



CALCULATION OF | **STATOR MAIN DIMENSIONS & FLUX:**

Enter the following values:

efficiency 0
power factor 0
Winding factor 0

(Reference values corresponding to kW rating)

phase voltage 0 V

Peripheral Velocity (in m/s):
Vp 0

Synchronous speed:
Ns (RPM) 0
ns (rps) 0

kW input to motor:
kW input 0

Phase current:
Iph 0 A

Output Coefficient:
Co 0

Total core length:
value of L 0 mm

Gross Iron length:
Ls 0 mm

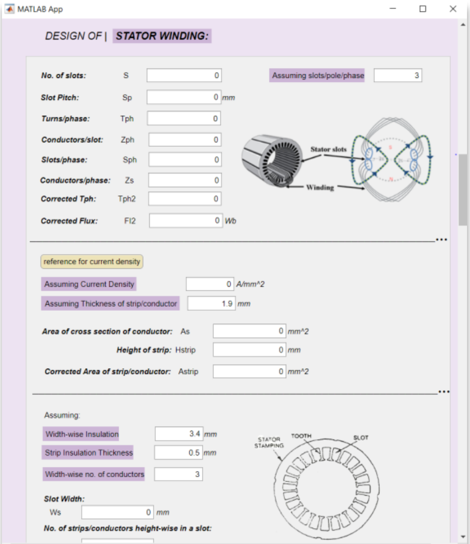
Net Iron length:
Li 0 mm

Core inner diameter:
value of D 0 mm

Pole Pitch:
PP 0 mm

Flux:
Fl 0 Wb

Figure 33 | Calculation of Stator Main Dimensions



DESIGN OF | **STATOR WINDING:**

No. of slots: S 0
Assuming slots/pole/phase 3
Slot Pitch: Sp 0 mm
Turns/phase: Tph 0
Conductors/slot: Zph 0
Slots/phase: Sph 0
Conductors/phase: Zs 0
Corrected Tph: Tph2 0
Corrected Flux: Fl2 0 Wb

Assuming Current Density 0 A/mm^2
Assuming Thickness of strip/conductor 1.9 mm

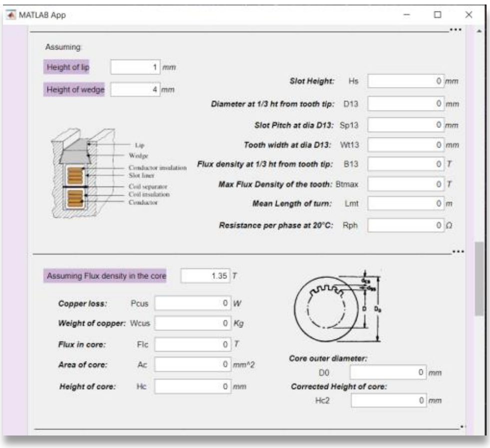
Area of cross section of conductor: As 0 mm^2
Height of strip: Hstrip 0 mm
Corrected Area of strip/conductor: Astrip 0 mm^2

Assuming:
Width-wise Insulation 3.4 mm
Strip Insulation Thickness 0.5 mm
Width-wise no. of conductors 3

Slot Width:
Ws 0 mm

No. of strips/conductors height-wise in a slot:

Figure 34 | Design of Stator Winding



Assuming:
Height of lip 1 mm
Height of wedge 4 mm

Slot Height: Hs 0 mm
Diameter at 1/3 ht from tooth tip: D13 0 mm
Slot Pitch at dia D13: Sp13 0 mm
Tooth width at dia D13: Wt13 0 mm
Flux density at 1/3 ht from tooth tip: B13 0 T
Max Flux Density of the tooth: Btmax 0 T
Mean Length of turn: Lmt 0 m
Resistance per phase at 20°C: Rph 0 Ω

Assuming Flux density in the core 1.35 T

Copper loss: Pcus 0 W
Weight of copper: Wcus 0 Kg
Flux in core: Flc 0 T
Area of core: Ac 0 mm^2
Height of core: Hc 0 mm

Core outer diameter:
D0 0 mm
Corrected Height of core:
Hc2 0 mm

Figure 35| Stator Winding Parameters

Iron loss in tooth corresponding to Btmax = 1.5966T 23.92
Iron loss in core corresponding to Bcmax = 1.35T 18.32

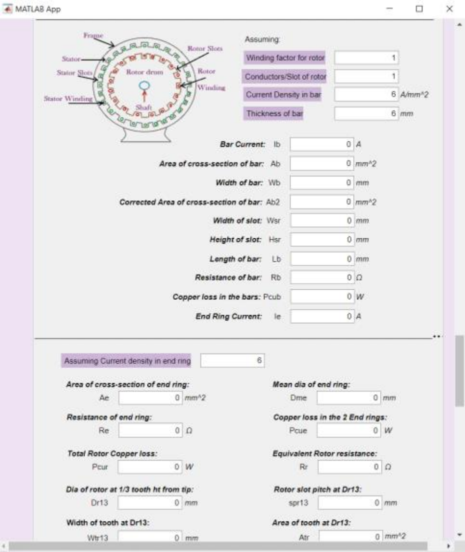
Weight of tooth: Wt 0 Kg
Mean dia of the core: Dmcs 0 mm
Weight of core: Wc 0 Kg
Iron loss in tooth: Pit 0 W
Iron loss in core: Pic 0 W

DESIGN OF | **SQUIRREL CAGE ROTOR :**

Air gap length: Lg 0 mm
Rotor diameter: Dr 0 mm
No. of Rotor Slots: Sr 0
Slot pitch: sp2 0 mm
Equivalent Rotor Current: Ir 0 A

Assuming:
Winding factor for rotor 1
Conductors/Slot of rotor 1
Current Density in bar 6 A/mm^2
Thickness of bar 6 mm

Figure 36 | Design of Squirrel Cage Rotor



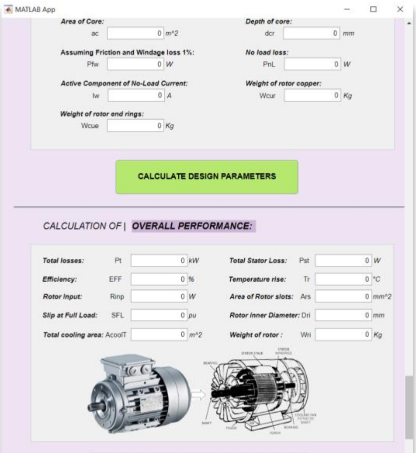
Assuming:
Winding factor for rotor 1
Conductors/Slot of rotor 1
Current Density in bar 6 A/mm^2
Thickness of bar 6 mm

Bar Current: Ib 0 A
Area of cross-section of bar: Ab 0 mm^2
Width of bar: Wb 0 mm
Corrected Area of cross-section of bar: Ab2 0 mm^2
Width of slot: Wsr 0 mm
Height of slot: Hsr 0 mm
Length of bar: Lb 0 mm
Resistance of bar: Rb 0 Ω
Copper loss in the bars: Pcub 0 W
End Ring Current: Ie 0 A

Assuming Current density in end ring 6

Area of cross-section of end ring:
Ae 0 mm^2
Mean dia of end ring:
Dme 0 mm
Resistance of end ring:
Re 0 Ω
Copper loss in the 2 End rings:
Pcue 0 W
Total Rotor Copper loss:
Pcur 0 W
Equivalent Rotor resistance:
Rr 0 Ω
Dia of rotor at 1/3 tooth ht from tip:
Dr13 0 mm
Rotor slot pitch at Dr13:
spr13 0 mm
Width of tooth at Dr13:
Wtr13 0 mm
Area of tooth at Dr13:
Atr 0 mm^2

Figure 37 | Squirrel Cage Rotor Parameters (contd.)

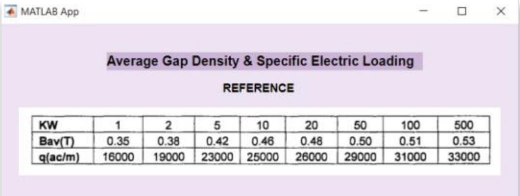


Area of Core: ac 0 m^2
Depth of core: dcr 0 mm
Assuming Friction and Windage loss 1%: Pfw 0 W
No load loss: PnL 0 W
Active Component of No-Load Current: Iw 0 A
Weight of rotor copper: Wcur 0 Kg
Weight of rotor end rings: Wcue 0 Kg

CALCULATION OF | **OVERALL PERFORMANCE:**

Total losses: Pt 0 kW
Total Stator Loss: Pst 0 W
Efficiency: EFF 0 %
Temperature rise: Tr 0 °C
Rotor Input: Rinp 0 W
Area of Rotor slots: Ars 0 mm^2
Slip at Full Load: SFL 0 pu
Rotor inner Diameter: Dri 0 mm
Total cooling area: AcoolT 0 m^2
Weight of rotor : Wri 0 Kg

Figure 38 | Overall Performance

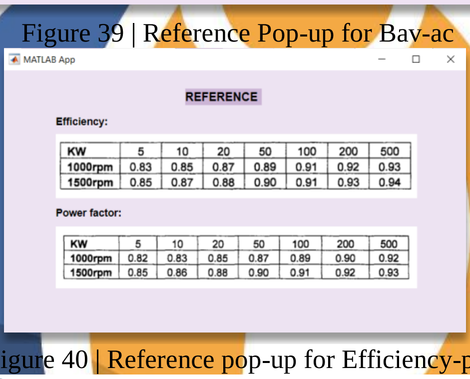


Average Gap Density & Specific Electric Loading

REFERENCE

KW	1	2	5	10	20	50	100	500
Bav(T)	0.35	0.38	0.42	0.46	0.48	0.50	0.51	0.53
q(ac/m)	16000	19000	23000	25000	26000	29000	31000	33000

Figure 39 | Reference Pop-up for Bav-ac



REFERENCE

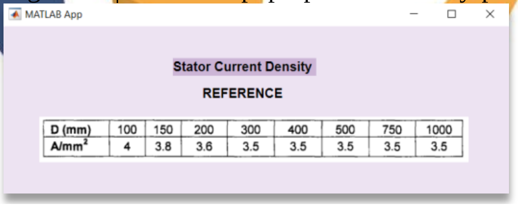
Efficiency:

KW	5	10	20	50	100	200	500
1000rpm	0.83	0.85	0.87	0.89	0.91	0.92	0.93
1500rpm	0.85	0.87	0.88	0.90	0.91	0.93	0.94

Power factor:

KW	5	10	20	50	100	200	500
1000rpm	0.82	0.83	0.85	0.87	0.89	0.90	0.92
1500rpm	0.85	0.86	0.88	0.90	0.91	0.92	0.93

Figure 40 | Reference pop-up for Efficiency-p.f



Stator Current Density

REFERENCE

D (mm)	100	150	200	300	400	500	750	1000
A/mm^2	4	3.8	3.6	3.5	3.5	3.5	3.5	3.5

Figure 41 | Reference pop-up for Stator Current Density

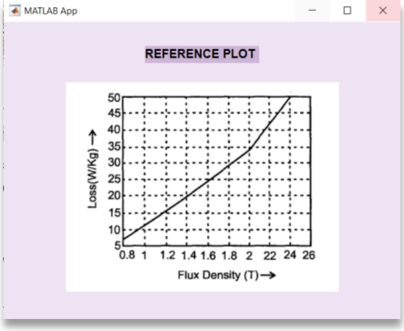
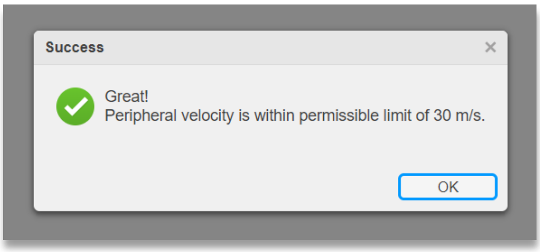


Figure 42 | Reference plot : Flux density v/s Loss/kg



Great!
Peripheral velocity is within permissible limit of 30 m/s.

Figure 43 | Check/Warning for Peripheral Velocity

The three-phase induction motor GUI enables the user to calculate the following parameters:
Stator main dimensions: synchronous speed, kW input to motor, phase current, output coefficient, total core length, gross iron length, net iron length, core inner diameter, pole pitch, flux, and peripheral velocity.

Design of stator winding: no. of slots, slot pitch, turns/phase, conductors/slot, slots/phase, conductors/phase, area of cross-section of conductor, height of strip, slot width, no. of strips/conductors height-wise in a slot, slot height, maximum flux density of the tooth, mean length of turn, resistance per phase at 20ºC, copper loss, weight of copper, flux in core, area of core, height of core, core outer diameter, weight of tooth, mean diameter of core, weight of core, iron loss in tooth, iron loss in core.

Design of squirrel cage rotor: air gap length, rotor diameter, no. of rotor slots, slot pitch, equivalent rotor current, bar current, area of cross-section of bar, width of bar, width of slot, height of slot, length of bar, resistance of bar, copper loss in the bars, end ring current, area of cross-section of end ring, mean diameter of end ring, resistance of end ring, copper loss in the 2 end rings, total rotor copper loss, equivalent rotor resistance, maximum flux density in tooth, area of core, depth of core, no-load loss, friction and windage loss, active component of no-load current, weight of rotor copper, weight of rotor end rings.

Overall performance: total losses, total stator loss, efficiency, temperature rise, rotor input, area of rotor slots, slip at full load, rotor inner diameter, total cooling area, weight of rotor.
Economic analysis: total weight of machine, prime cost, cost of production, selling price.

V. CONCLUSION

Several Graphical User Interfaces (GUIs) were successfully designed and were found to be fully functioning. Design parameters and results were corroborated by performing manual calculations. The Toolkit was eventually packaged as a MATLAB App. Such apps can be utilized not only in industrial applications but also in educational institutions to provide holistic and pragmatic ways of teaching Computer-Aided Design of Electrical Machines. The toolkit provides a great amount of flexibility and success in designing an electrical machine not only from the limited available information/specifications but also in a short span of time. To complete the designing procedure of any Electrical Machine, the toolkit enables the designer predict the machine's overall expenditure.

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