MATLAB BASED COMPUTER-AIDED DESIGN OF DC MACHINES TOOLKIT (GUI)

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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, Optimizatio*n

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 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]
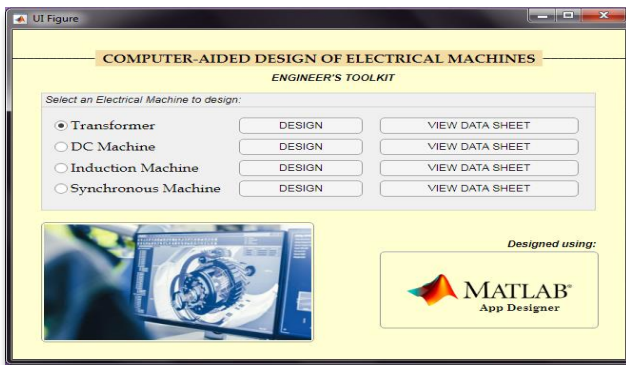
III. MACHINE DESIGN & GUIS

A. NAVIGATION PAGE

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.
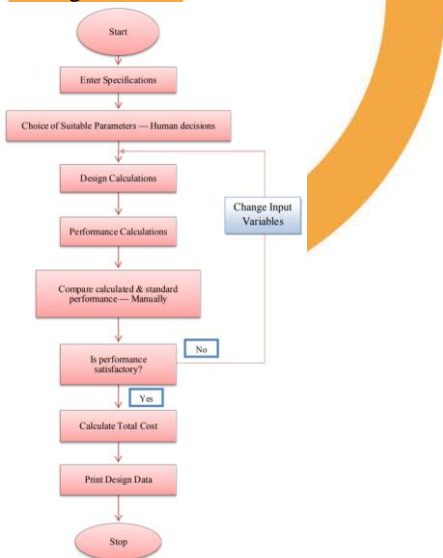
Figure 2 | Overall Design Flowchart

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

DC Machine

A DC machine is an electromechanical energy conversion device. When mechanical energy is being converted into electrical energy by the machine, it is called a generator and when electrical energy is being converted into mechanical energy then it is called as motor. Based on winding type of armature, DC machines are categorized as lap wound and wave wound. Since the machine is the same for both operations of Generator and Motor, same design is applicable for both. Choice of Specific Electric Loading, Specific Magnetic Loading, Poles, Speed, etc can be made using the Data Reference Pop-ups as shown.

For all electrical machines, the estimation of main dimensions is the primary step of designing. An output equation is formulated, output coefficient Co is calculated based on which Armature Diameter (D) and Core Length (L) are calculated.

Let Pa = Power developed by armature, D = Armature Diameter, L = Armature core length in m, n = Speed in rps. Therefore, output coefficient =

$$Co = \frac{Pa}{D^2 \times L \times n} = \pi^2 \times Bav \times ac \times 10^{-3}$$

Where Bav = Specific Magnetic Loading and ac = Specific Electric Loading.

The value of maximum magnetic flux density in the air gap (Bm) usually varies from 0.55 to 1.10 Wb/m2 and corresponding value of average flux density (Bav) in the air gap is from 0.4 to 0.8 Wb/m2. [2]

The value of specific electric loading i.e., ampere-conductor per m peripheral length along the air gap of machine varies between 15,000 to 51,000 ampere-conductor/m. Low rating machines have lower value of ac and higher rating machines have high value of ac. [2]

The frequency of flux reversal in the armature core generally lies between 25 and 50 Hz. Lower values (25 to 35 Hz) frequency should be used for large machines and high frequency in the range of 50-75 Hz may be used for smaller machines.
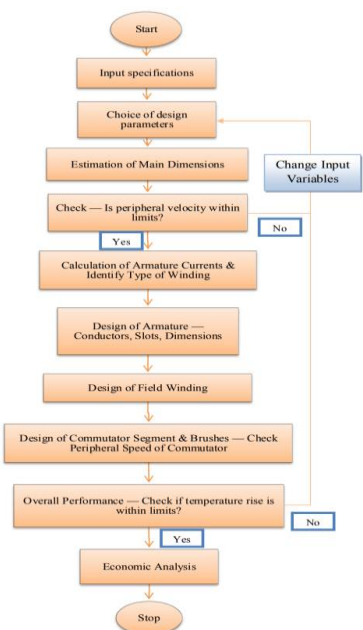

Figure 3 | Flowchart for DC Machine Design

The range of peripheral speed is 15–30 m/sec without special construction of the machine. If special construction is done then the peripheral speed can be taken upto 50 m/sec.
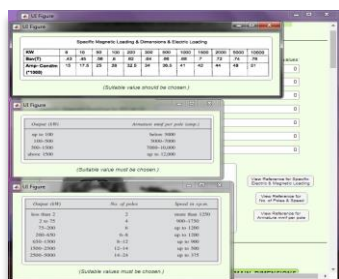

Figure 4 | GUI for DC Machine

Figure 5 | Reference Pop-ups
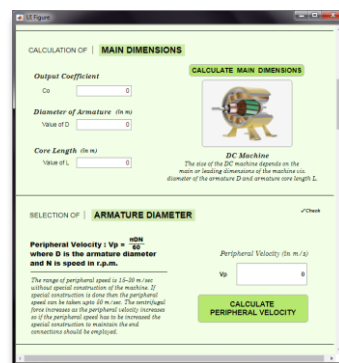
Figure 6 | Main Dimensions Calculations
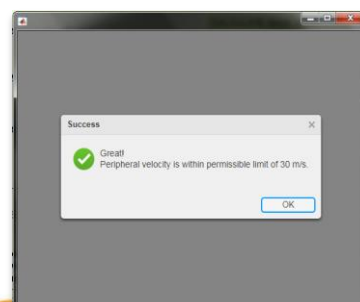
Figure 7 | Check/Warning for Peripheral Speed
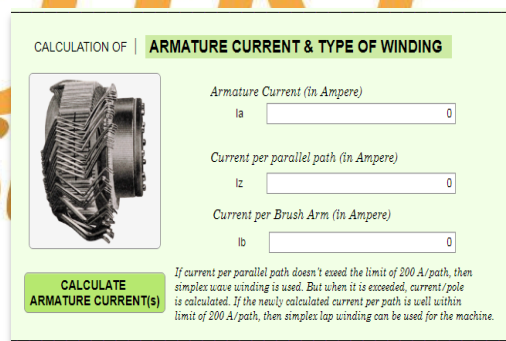
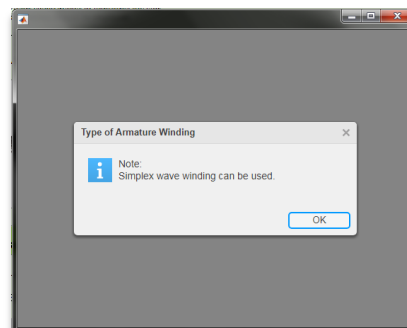Figure 8 | Calculation of Armature Current & Identifying Type of Armature Winding

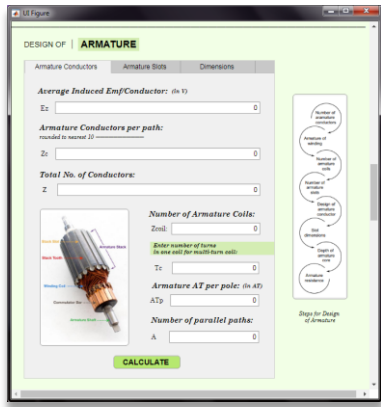Figure 9 | Identifying Type of Winding
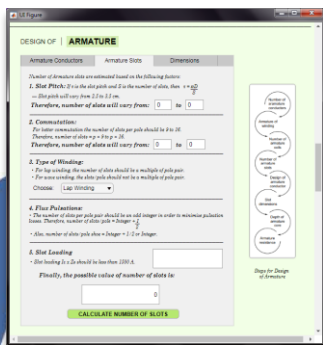
Figure 10 | Design of Armature — Conductors

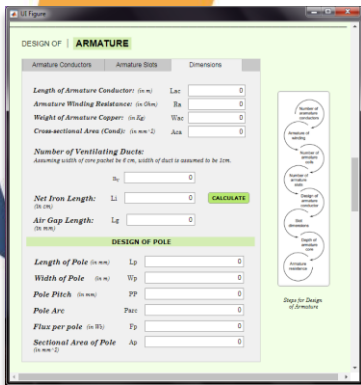Figure 11 | Design of Armature — Armature Slots

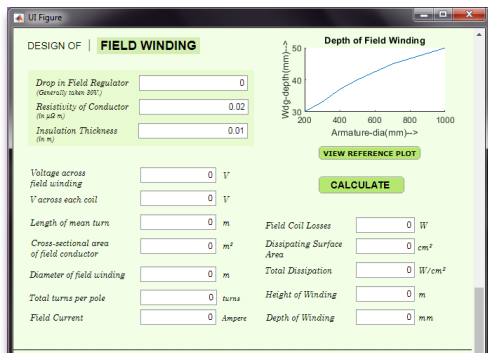Figure 12 | Design of Armature — Dimensions
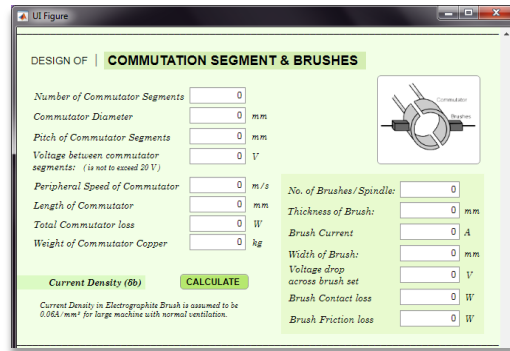

Figure 13 | Design of Field Winding

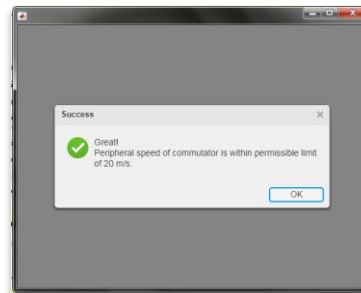Figure 14 | Design of Commutation Segment & Brushes

Figure 15 | Check/Warning for Commutator Peripheral Speed

Figure 16 | Overall Performance

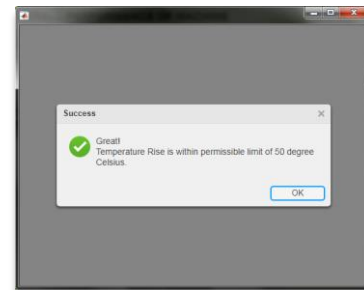Temperature-rise should ideally be below 50o C.

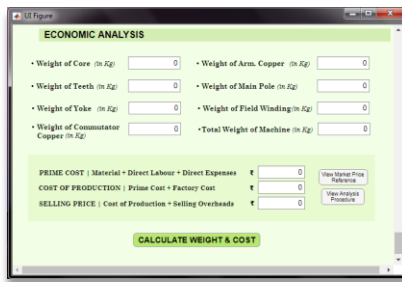Figure 17 | Check/Warning for Temperature-Rise
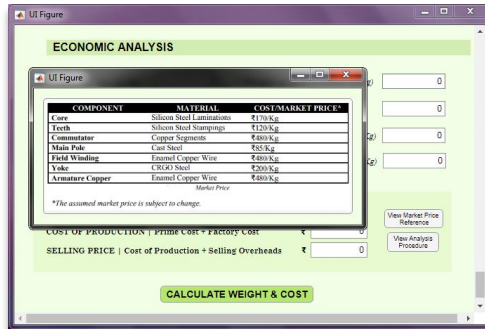
Figure 18 | Economic Analysis

Figure 19 | Nominal Market Price Reference

The DC Machine GUI enables the user to calculate the following parameters:

Main Dimensions — Output coefficient, Diameter of Armature in m, Core Length in m, Peripheral Velocity in m/s.

Calculation of Armature Current in ampere, Current per parallel path in ampere, Current per brush arm in ampere.

Design of Armature

Armature Conductors — Average Induced Emf/Conductor in V, Armature Conductors per path, total no. of conductors, No. of armature coils, Armature AT per pole, Number of parallel paths.

Armature Slots — Range of number of slots based on slot pitch, good commutation, type of winding and flux pulsations, Check for Slot loading within permissible limits.

Dimensions — Length of Armature Conductor in m, Armature Winding Resistance in Ohm, Cross-sectional area of conductor in mm2, No. of ventilating ducts, Net iron length in cm, Air gap length in mm.

Pole Design — Length of pole in mm, Width of pole in m, Pole Pitch in mm, Pole Arc, Flux per pole in Wb, Sectional Area of Pole in mm2.

Design of Field Winding — Voltage across field winding in V, Voltage across each coil, Length of mean turn in m, Cross-

sectional area of field conductor in m2, Diameter of field winding in m, Total turns per pole, Field current in A, Dissipating Surface Area, Total dissipation, Height of winding in m, depth of winding in mm.

Design of Commutation Segment & Brushes — No. of commutator segments, commutator diameter in mm, Pitch of commutator segments in mm, Voltage between commutator segments in V, Peripheral speed of commutator in m/s, Length of Commutator in mm, Total Commutator loss in W, Weight of commutator copper in kg, No. of brushes/spindle, Thickness of brush, Brush Current, Width of Brush, Voltage drop across brush set.

Overall Performance of Machine — Bearing Friction & Windage losses, Brush friction loss, brush contact loss, iron loss at teeth, iron loss at core, armature copper loss, field copper loss, efficiency.

Slot & Tooth Dimensions — slot height in mm, slot width in mm, mean width of tooth in mm, flux density of tooth in Wb/m2, width of teeth at 1/3 height from root in mm.

Temperature Rise — Armature, Field winding, Commutator, Cooling Surface in m2.

Weight Calculation — Weight of core in kg, weight of teeth in kg, weight of yoke in kg, weight of commutator copper in kg, weight of armature copper in kg, weight of main pole in kg, weight of field winding in kg.

Economic Analysis — Prime cost (material and direct labour expenses), Cost of production (prime cost and factory expenses), Selling price (cost of production and selling profit & overheads).

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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