An Expert System for Automated Hub Motor Designs of a Light Electric Vehicle

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Abstract

This paper aims to develop an expert system for the automated design process of the hub motor on a light electric vehicle. Hub motor designs must satisfy the propulsion system specification (like wheel dimensions) and preset constraints (assembly space and controller specification). The structure of this design system includes the user interface, the inference processor, the CAD system and the knowledgebase. Initial parameters and boundary conditions can be simply input, and then the hub motor is automatically designed by the inference processor on the CAD system. Finally, this design system is able to produce a customized hub motor effectively and correctly.

Keywords: Expert System, Automated Design System, Light Electric Vehicle, Hub Motor

1 Introduction

At present, environmental protection becomes a major concern for customers to purchase a vehicle. Zero (low)-emission and high efficiency are two major factors (Figure 1) in the automotive industry for developing a vehicle [1].

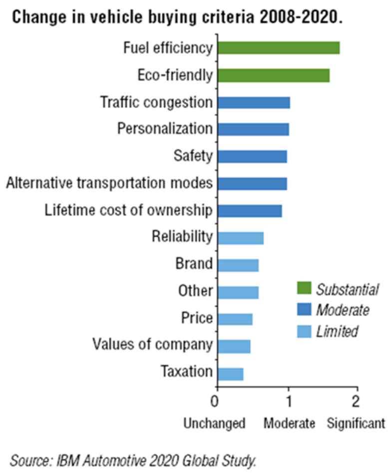

Figure 1: Change in vehicle buying criteria 2008-2020.

An electric vehicle is an apposite candidate for the above factors, and a Permanent Magnet Synchronism Motor (PMSM) plays an important role on an electric vehicle. The PMSMs are classified into two types based on the structure of the rotor, i.e. inner-rotor and outer-rotor. The outer-rotor PMSM, which is capable of larger output torque than the inner-rotor in low speed can be installed in the wheel, that is so-called a hub motor or a wheel motor. An ITRI-conceived light electric vehicle (LEV) has a restricted space for the inner wheel; hence, the hub motor is a suitable selection for the propulsion system (Figure 2). Because there are a lot of constraints in designing a hub motor, such as the wheel size, control methods and the shape of the magnet, ~~so~~ the dimensions of the skeleton of the motor have to follow the design pattern strictly.

Figure 2: Hub Motor for ITRI LEV

The automated design process consists of the standardization procedure, the skeleton, and the expert system. The expert system, commonly used in specific design domain, includes the user interface, the inference processor, the CAD system and the knowledgebase, which can reproduce expert intelligence on the computer [2] to assist users in designing a hub motor. The PMSMs, composed of the rotors, stators, magnets and windings, have standard structures. Therefore, a sample CAD model of the motor can be created as that of the drawing dies pre-built by B.T. Lin and S.H. Hsu [3], and then utilize the expert system to establish an automated design system.

In this system, the input conditions are the diameter and the thickness of the inner wheel. The output conditions are the specification of the motor performance, for example, the maximum torque, the cogging torque and the torque ripple. The back-electromotive force (Back-EMF) of the motor affects the performance of the motor, which varies with different Back-EMF waveforms. From the finding of the paper [4], if the control waveform current is the same as the back-EMF waveform of the motor, the motor can render the best performance. On the other word, to obtain the best performance of the motor, the inverter has to generate the waveform current similar to that of the back-EMF. In this study, the back-EMF waveform is the sine waveform current, so the inverter of the hub motor has to provide the waveform analogous to the sine waveform. Since the back-EMF waveform relates with the rotor, stator and the shape of the magnet, their relationship can be assembled into formulas and rules for building the knowledgebase and the inference of the motor design.

2 System Structure

The structure of the expert system contains the four parts including the User Interface, the Inference Processor, the CAD System and the Knowledgebase (Figure 3).

2.1 User Interface

The user interface comprises the heuristic dialogue and the parameter input windows. The heuristic dialogue provides user hints about the hub motor design method, and the parameter input windows provide concise window interface for users to input the initial parameters and the boundary conditions. The user interface is programmed by the Visual Basic for Applications. The interface has six parameters, slot number, pole number, maximum external diameter, airgap distance, motor stack distance and slot gap (Figure 4).

2.2 Inference Processor

When the system receives input parameters, the parameters are delivered to the inference processor. The inference processor is composed of model build method and rationale diagnosis. The model build method provides the building procedure and the method of the hub motors. The rationale diagnosis can diagnose a parameter if it is reasonable or not, if not, the heuristic dialogue will be displayed on the user interface.

2.3 CAD System

This system is based on CATIA V5R16 in WONDOWS XP operating system. CATIA V5R16 provides the development environment for customized design system. The part design module can produce the 3D-model, and the knowledge advisor module can create the user interface and the knowledgebase, then the automation and scripting module can build the inference processor.

2.4 Knowledgebase

The knowledgebase consists of hub motor design experiences, design rules and constraints. The user interface, the inference processor and the CAD system operate according to the knowledgebase, which provides the design guideline and the experience of experts. This base offers the development procedure and method of the hub motor. For example, the pole number, the slot number, and the hub motor diameter are chosen via this knowledgebase system.

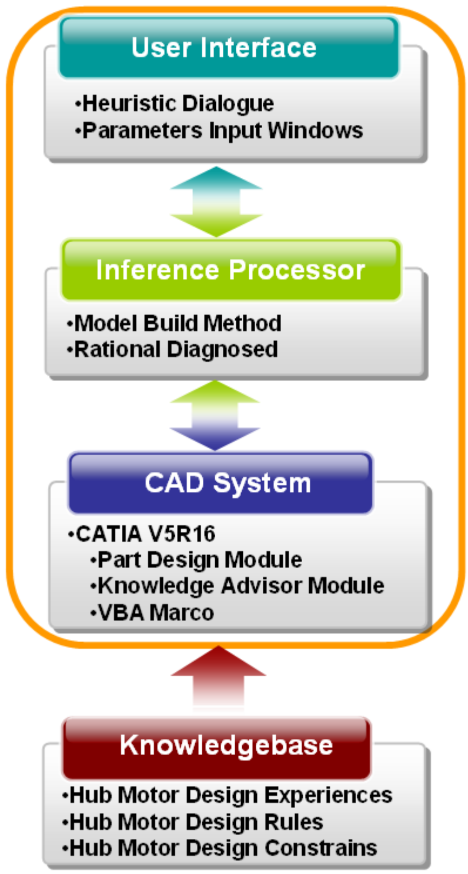

Figure 3: System structure

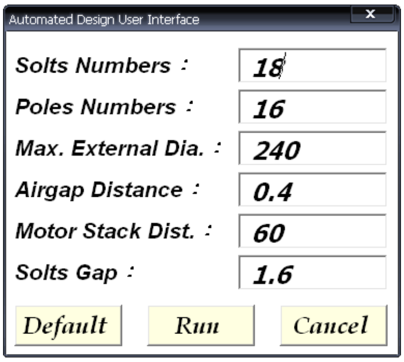

Figure 4: User Interface

3 System Procedures

The system is based on CATIA V5R16, the building procedure as shown in Figure 5. Each step of the modeling procedure is explained in the following contents. The building procedure has six steps: the Motor Structure Analysis, the Motor Process Standardization, the Sample Motor Construction, the Parameters Setting, the Programming, and the Interface Building.

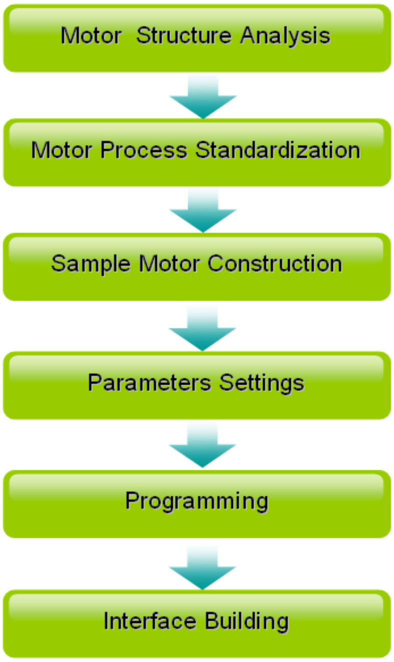

Figure 5: Procedures for constructing system

3.1 Motor Structure Analysis

The analyzed parameters and the structure of a motor include the rotor, the stator, the magnets and the windings (Figure 6). All structures of the hub motor are based on the following skeletons. Their functionality and all the possible structure building method have to be studied before the system is built. Part of the knowledgebase is created in this step.

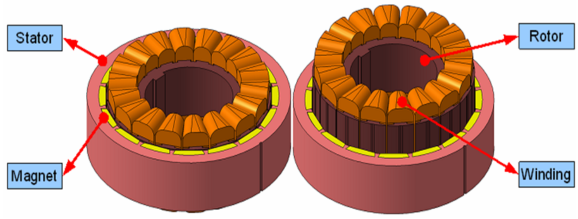

Figure 6: Hub Motor main Skeletons (3D Model)

3.2 Motor Process Standardization

In the CAD, the structure building has rules and procedures. In this step, the purpose of the design process standardization provides a systematic method for designing hub motors. The motor process standardization can be provided to build the inference processor.

3.3 Sample Motor Construction

Once the motor process standardization has been created, the sample motor construction and the parameters will be developed in the sample motor model (Figure 7). In this process, the model must be constrained by the parameters. For example, the outer diameter of the stator must be smaller than that of the rotor. According to the preset constraints, the design parameters will be changed if the input parameters are modified to fit such constraints. Further, the input parameters are the independent variable and the other variables depends on the input parameters.

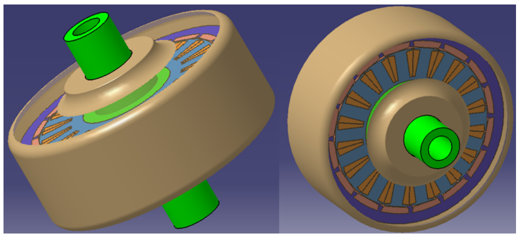

Figure 7: Sample Motor Model

3.4 Parameters Setting

The parameters are classified into two types including independent parameters and dependent parameters. The independent parameters are from the input parameters and are independent of other parameters such as the wheel dimensions. The dependent parameters are related to the independent parameters.

3.5 Programming

CATIA V5R16 provides three functions, the rule editor, the formula editor and VBA Macro (Figure 8). The rule editor is used to build rational diagnosis and the formula editor is used to create model building method. VBA macro provides programming environment to modify the 3d-model of the hub motor.

3.6 Interface Building

The interface has two parts including heuristic dialogue and parameter input windows. Both of them are built by VBA macro based on the knowledgebase.

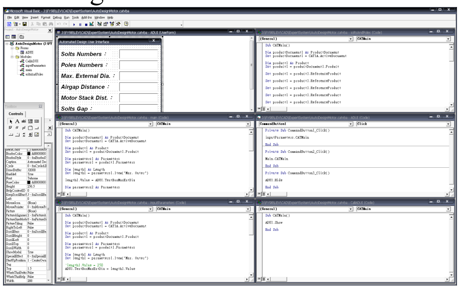

Figure 8: VBA Code Environment

4 Case Study

The final, we develop an expert system for automated hub motor designs. We use the expert system to design three hub motors automatically. Firstly, we input the parameters of three external diameters, 120mm, 240mm and 480mm respectively with the same thickness (60mm) and airgap (0.5mm). After all, the system will produce three 3D models, and then utilize the finite element method software, like Ansoft Maxwell 2D, to verify their electromechanical characters. The results are demonstrated below in Figure 9, Figure 10, Figure 11 and Table 1, the average cogging torque under the five percent of the maximum torque and the torque ripple under the ten percent of the maximum torque. The results achieve the goal of the expert system.

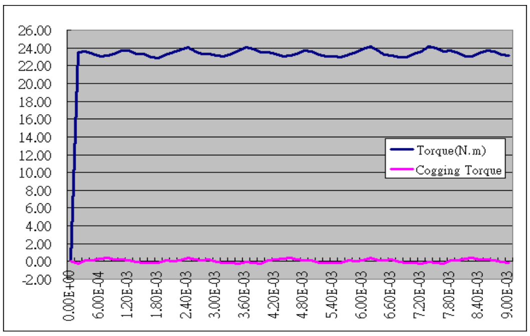

Figure 9: The wheel inner diameter 120mm

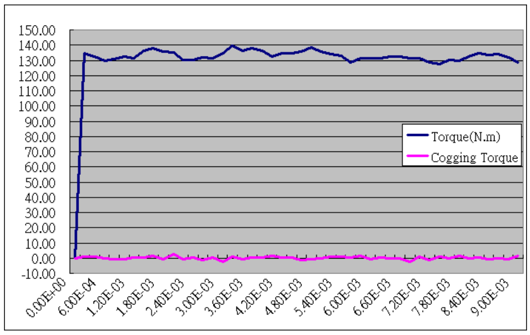

Figure 10: The wheel inner diameter 240mm

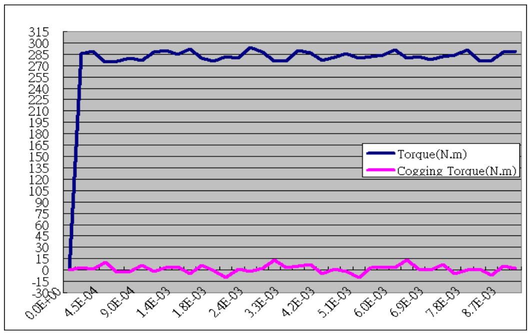

Figure 11: The wheel inner diameter 480mm

Table 1: The motor performance specification

	Avg. (Max. Torque)	Max. Cogging Torque	Torque Ripple
Dia.120	23.43 N.m	0.43 N.m	5.30%
Dia.240	133.03 N.m	2.43 N.m	8.86%
Dia.480	282.90 N.m	13.12 N.m	6.57%

5 Conclusion

This paper aims to develop an expert system for the automated design system for the hub motor on a light electric vehicle. This system provides an interface for users without experience to design a hub motor. And, experimental results show that this system has dramatically reduced the design hours from several working days to within a day. Furthermore, the system operates with CATIA V5R16, which can transform the 3D-model (Figure 12) to STEP, IGS or CATIA format, then the result is directly delivered to the electromechanical analysis software, like Ansoft Maxwell 3D, to process the motor performances (Figure 13). The final, the rapid and accurate design result and a qualified hub motor for specification of the propulsion system are acquired effortlessly.

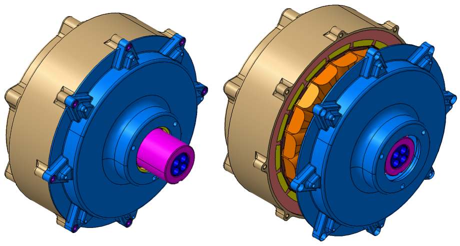

Figure 12: Hub Motor 3D Model

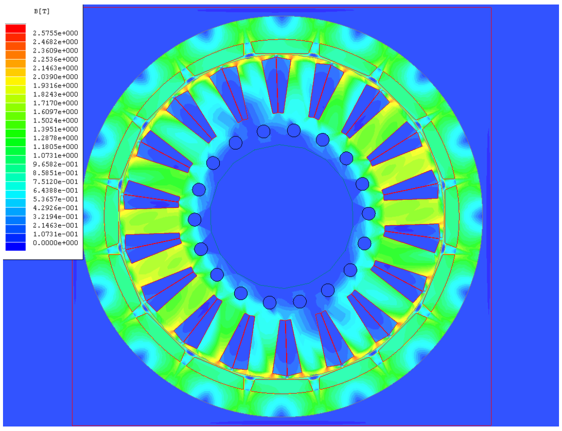

Figure 13: Flux Density Analysis

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