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OR-HEFSM D-DRIVE DEVELOPED STRUCTURE BASED ON ACTUAL PROTOTYPE ANALYSIS (APA) PROCESS

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ABSTRACT

Recently, direct-drive motor for in-wheel electric vehicle application become an interested research topic due to their advantages of directly torque control and elimination of transmission gear system. In conjuction, flux switching machines (FSMs) are among a good candidate to fulfil direct-drive application due to excellent of high starting torque, constant power over wide speed range, low torque ripple and high durability. With all components located on the stator, the machine is extremely robust as compared with interior permanent magnet motor (IPMSM) that conventionally employed in existing EV/HEV. This paper presents the development of actual prototype of outer-rotor hybrid excitation flux switching machine (OR-HEFSM) based on finite element analysis (FEA) and actual prototype analysis (APA). The prototype development procedures are described in details to have excessive visualization and precise prediction results. Through a 3D-Model developed by SOLIDWORKS software, the final design motor has been constructed and fabricated accordingly. Finally, further experimental investigation on final design motor should be implemented to verify the results obtained from simulation works.

Keywords: outer-rotor, flux switching machine, direct-drive.

INTRODUCTION

Flux Switching Machine (FSM) (E. Sulaiman, 2013) is one of the machines being used others than four kind machines such as Direct Current (DC) motor, Induction Motors (IMs), Switch Reluctant Motors (SRMs) and Permanent Magnet Synchronous Motors (PMSMs). Utility every machine had their own used in a specific practice area and in counter certain problem, the FSM being created and study to replace others machine with more practical application to achieve green world concept through electric machine. The major drive concept used in FSM either internal or outer which being decide either the solid part called as rotor being driven by excited part called as stator in internal or outer position.

Finite element analysis (FEA) is a numerical concept used in virtual analysis to prove the theory are adequate to move to another's stages. As OR-HEFSM theory (E. Sulaiman, 2012), the JMAG Designer software was used to analyze the core of theory from design to optimize processes. The process varies with the design process, so the final result of FEA comparison will be validated the theory or otherwise. Even the FEA from JMAG Designer be main analysis in OR-HEFSM, the FEA from experimental is vital to prove the theory itself more crucial in deciding either the design is able to adapt goal application.

To achieve the goal application, the experimental approach requires from theoretical visualization to acquire the base of application projection and in realizing the prototype unit (Beaney, 2015). The actual prototype analysis (APA) was used as guide with five stages from complete design, select material, machining, assembly and test. APA is floor plan design for general electric machine (GEM) fabrication where all stages designated with objective and flow chart in how it's supposed to act from front line to end line process. This approach will guide the prototype fabrication of OR-HEFSM D-Drive from FEA of JMAG Designer into goal application with more practical method.

Industrial application stakes on motor can't avoid using coupling as a method to drive the application in linear, rotary and flexible position. There's too many coupler had been presented to fulfill all application in the world such rigid coupler, sleeve coupler, flange coupler and clamp coupler. Each coupler will drive the application based on their characteristic and had pros and cons if used for specific applications such as in electric vehicle (EV), so D-Drive being introduced as a direct coupler to OR-HEFSM. Using the direct coupler to EV application will reduce the tension between the join without use any bridge type coupler such clamp or belt that will increase the cost and future maintenance.

D-DRIVE STRUCTURE

Introduction of direct drive structure

Direct drive (D-Drive) structure was proposed for OR-HEFSM to fulfill significant the outcome of outer-rotor design in term of power transition between motor and application unit. Structure design always depends on the goal application of design where concluded by three factors of simple, robust and functional.

This factor will be guided on the first stage and the first phase of APA process as illustrated in Figure 1 in which the design is created by SOLIDWORKS 2014 (Yang Song, 2010). The flowchart in Figure 1 demonstrated design guideline of first stage APA strat from beginning till the end process involved by considering the sequence aim in each steps. In fact, the three factors of manufacturing cost, the size of the

machine and efficiency should be take into consideration as a major impact in designing a new machine.

There is a decision maker on each phase to decide either the process fulfill the objective that has been drawn. The continuity from one phase to another phases is arranged sequentially from the rotor to the end of developing their housing. The flow makes the next sequence gain dimension information to be matched in structural design.

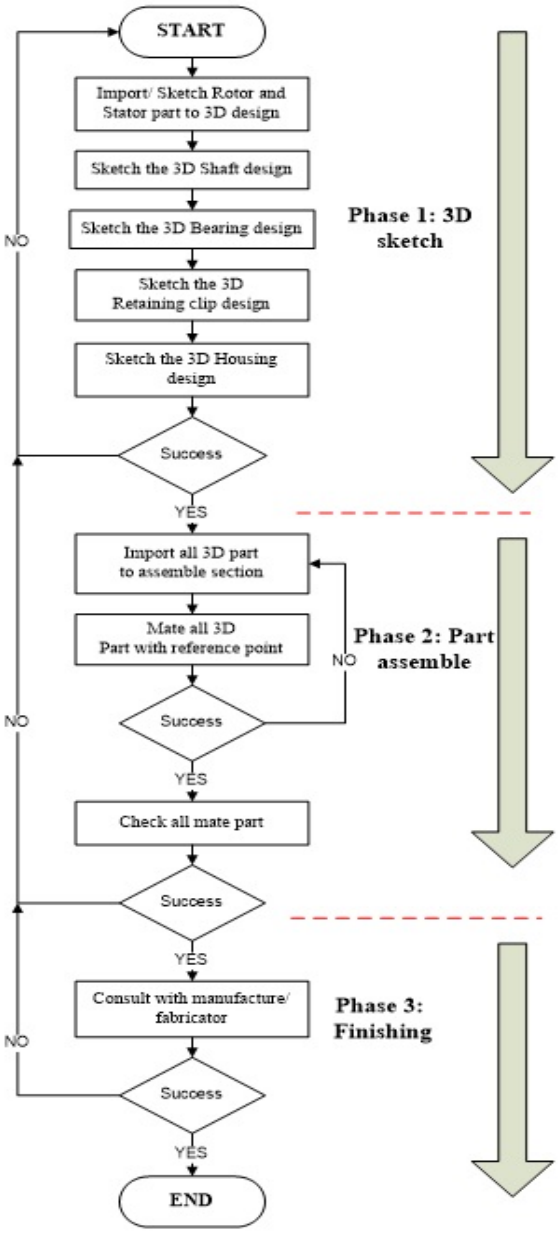

Figure-1. Complete design first stage APA flowchart.

The process at each phase is quite similar from beginning to the end, but will be saved with different format. Each phase will be save as .SLDPRT, .SLDASM, and .2D/3D for phase 1, phase 2, and phase 3, respectively. At the end of the process, the complete final drawing of the machine will be sent to a manufacturer for fabrication and they will give an advice to be improved if any error regarding mechanical bahaviour occurs. Thus, the suggestion is to ensure the data given to them must match the minimum standard requirement for fabrication process.

The design comes with two visualizations separated part which is labeled as main and support parts to easily create analytical approach. The approach used to break the sketch structure into smaller part in easily create the design for the next phase of the first stage APA process. Main part consists rotor and stator that fundamental part in electric machine which being aided by FEA used JMAG Designer to validate the design function as a project objective before fabricating used APA. As support parts, from the shaft, direct coupler, bearing, housing and fastener are created by visualizing the goal application directly in first phase APA.

Analytical approach of main part

Stator design

The parameters of the stator used in FEA of JMAG-Designer are also used to sketch the stator in SOLIDWORKS, to have a comparable outcomes. The details dimension of the stator is illustrated in Figure-2 having 12 stator teeth to hold the excited mechanism such as permanent magnet (PM) and field excitation coil (FEC). The dimension of rectangular PM made by neodymium (NeFeb) magnet grade N35 is 35(H)mm, 10.77(W)mm, 3.66(D)mm with fillet 0.1mm on each corner has created as in simulation. To ensure the assembly process is easily managed, all parameters are take into consideration with ±0.03mm tolerance.

Figure-3 shows 3D assembly design of the stator complete with the armature and FEC windings. The armature winding indicated by number 1, 2, and 3 is demonstrates the three-pahse coil of U, V, and W phase, respectively. The three-phase generated flux with 120 degrees phase different obtained from simulation is illustrated in Figure-4.

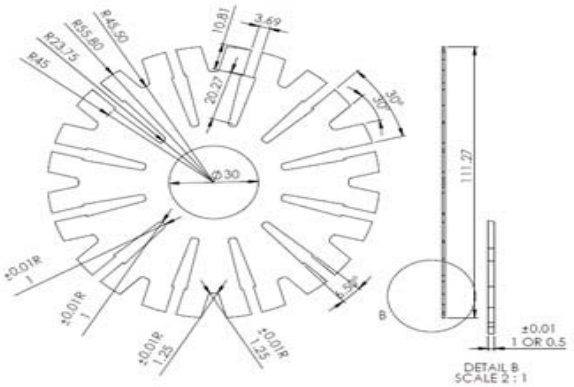

Figure-2. Stator dimension of 12S-14P OR-HEFSM in mm unit.

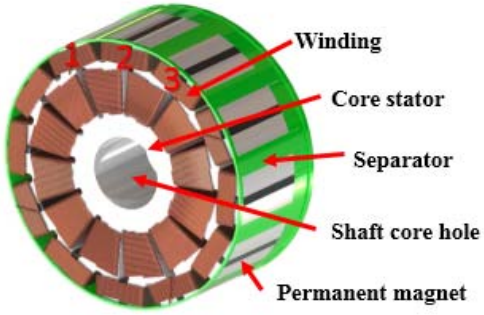

Figure-3. 3D assembly design.

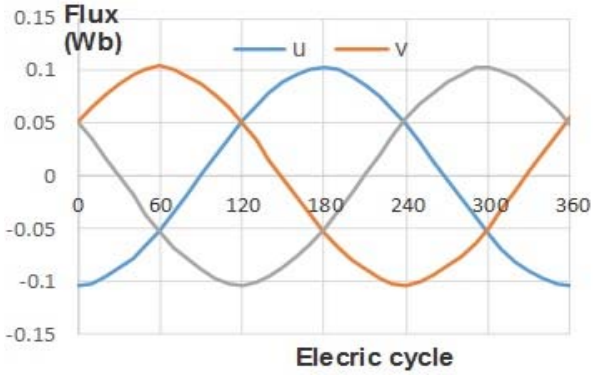

Figure-4. Three-phase flux linkage characteristic 12S-14P OR-HEFSM.

Rotor design

The procedures of rotor design is almost similar as explain in stator design above. The rotor with salient structure and no PM or winding makes the structure extremely robust and suitable for high speed application. The dimension is collected from the simulation has been done in JMAG-Designer and redraw in SOLIDWORK. In SOLIDWORK design, the additional lobe with a srew hole of 5mm diameter has been designed to attach the rotating part directly to the wheel.

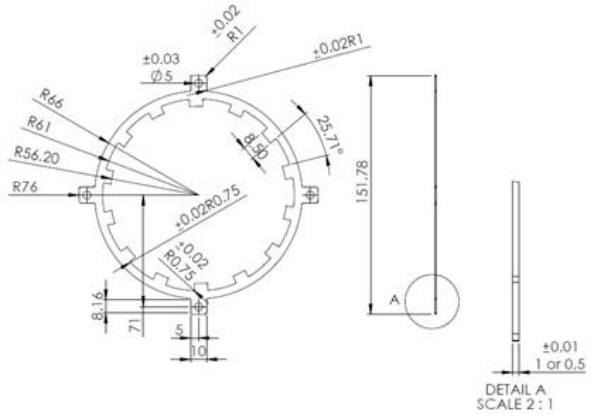

Figure-5. Design rotor of 12S-14P OR-HEFSM (All units in in mm).

Analytical approach of support part

Shaft design

Once the design of rotor and stator has been completed, shaft to hold the motor is then required to be designed. The shaft which is a long cylinder rigid body widely used in motor fabrication as a stabilizer to support the whole parts of the motor. The structure helps the rotor move along in the same axis of stator after being excited and produce rotation power to be transferred to an application unit. The overall shaft structure complete with a round shape connector is illustrated in Figure-6.

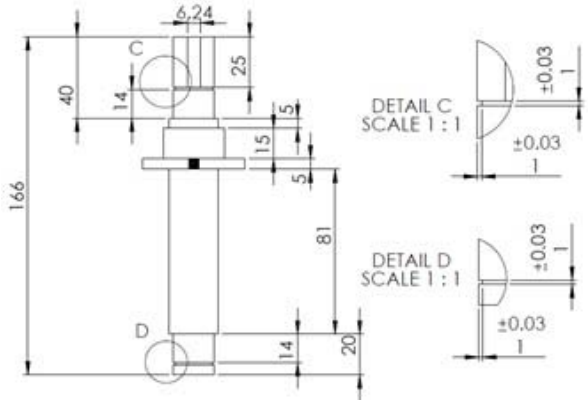

Figure-6. Design shaft of 12S-14P OR-HEFSM (All units in mm).

Direct coupler design

The theory how the design will drive directly are based on the shaft and the rotor design in how the coupler should be attached while fulfill the coupler objective. The direct coupler structure is a simple coupler compare used bridge coupler such as belt and chain with aim to deliver the direct rotation power through simple robust coupler. The structure as Figure-7 act not just for power transmission, but also act as cover for the main structure and as direct connects to goal application. A few element was added on direct coupled to match with goal application such as bolt type fastener and disc brake.

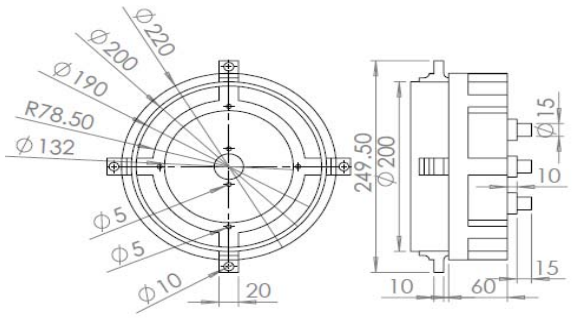

Figure-7. Design direct coupler of 12S-14P OR-HEFSM (All units in mm).

Bearing design

To realize the D-Drive structure, the bearing used in the design should fulfill three criteria which are able to hold the rotating part, simple to integrate and robust function. Figure-8 shows the design of bearing with two separated parts of internal and external part of bearing for direct coupler side. On the other hand, normal ball bearing is used to hold the shaft on the right axis with housing of the motor. With eight combination of bearings around the motor housing and ball bearing on the middle housing, the direct coupler should rotate together with the shaft.

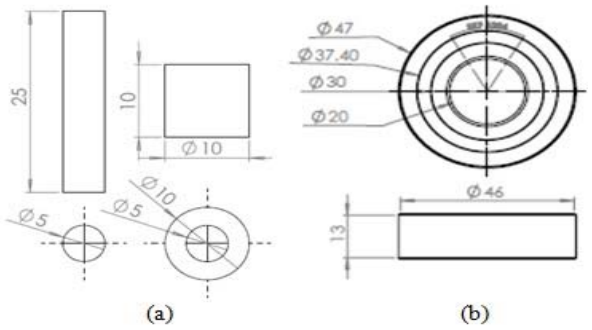

Figure-8. (a) Design internal and external bearing of 12S-14P OR-HEFSM (b) Design ball bearing of 12S-14P OR-HEFSM (All unit in mm).

Housing design

Motor housing is designed at the end of the design process to ensure the dimension is appropriate for motor that has been designed. Besides, all related components and accessories are also took into consideration. Generally, the housing structure is much depends on the application. For D-Drive application which the motor is attached directly to the wheel, the housing structure must has reliability with vibration when mounted on the direct coupler component. Figure-9 shows the motor housing from the side view.

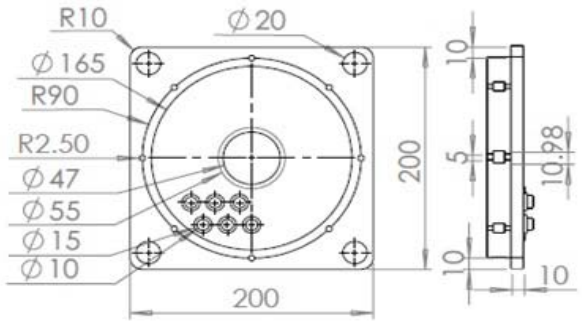

Figure-9. Design housing of 12S-14P OR-HEFSM in mm unit.

Fastener design

The complete main and support part is designed with a few hook type such as hole to accomplish the last part from the whole design structure. The last design is to complete all components have been designed and assembled making a D-Drive structure using fastener to join between two or more components.

The most widely used of fastener is from couple type, such as crimping, welding, tapping, gluing, clipping and bolting. In order to reduce cost and make it simple, the D-Drive structure has been design using fastener of pen bolt, cap nut, 'c' clip and rubber holder type as illustrated in Figure-10(a), ((b), 10(c) and 10(d), respectively.

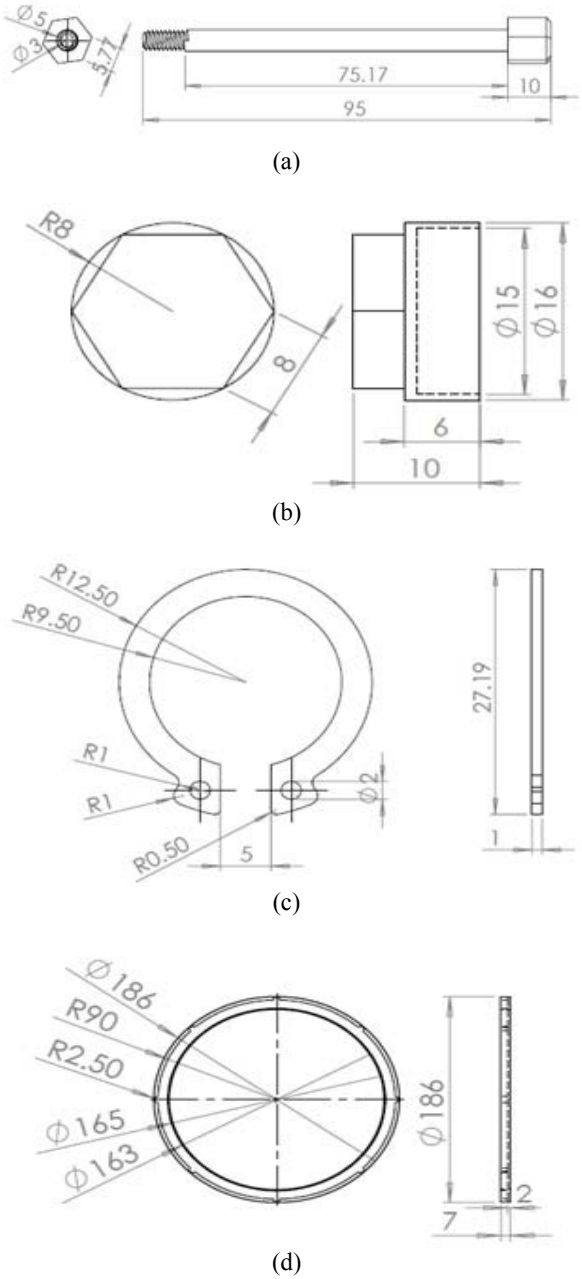

Figure-10. (a) Design structur pen bolt, (b) Design structure cap nut, (c) Design structure 'c' clip, (d) Design structure rubber holder (All units in mm).

Based on the given criteria, the pen bolt type was used because it has better result in fastener joint in term of vibration and joint type. Similar to cap nut, the joining used based on goal application which to join between motor and tyre with aim to hold and reduce the vibration. The 'c' shape clip made from aluminum material is then combine with a groove on the shaft to hold and rotate with the shaft. With rubber holder made from thermoplastic polymer material the fastener is used to hold the motor housing.

D-Drive motor for electric vehicle application

Complete design motor attached to wheel

The precision and tolerance in sketching design dimension show the rescale dimension has been obtained from JMAG-Designer to be fabricated and validated. Thus, the dimension should be matched with the assembly process of designing the D–Drive structure. The Figure-11(a) and (b) illustrates the whole structure of OR-HEFSM to be integrated as a D-Drive system. The motor is located in the middle, while the direct holder and housing is placed at the outer side. By assemble all the components, the D-Drive is capable to be installed directly to the wheel.

Structure of application unit

Main and support part assemble make complete OR-HEFSM and ready to be assembled to application unit. The application unit which electric vehicle being chosen as the end product will prove the ability of D-Drive structure to drive the tyre directly or otherwise. To keep the simple assemble production, regular type ring tyre was chosen in easily future assembly. The application unit will connect directly to OR-HEFSM as a common tyre connector to bridge car coupler body using standard tools. Figure-12 show complete assembly D-Drive ORHEFSM to ring tyre structure.

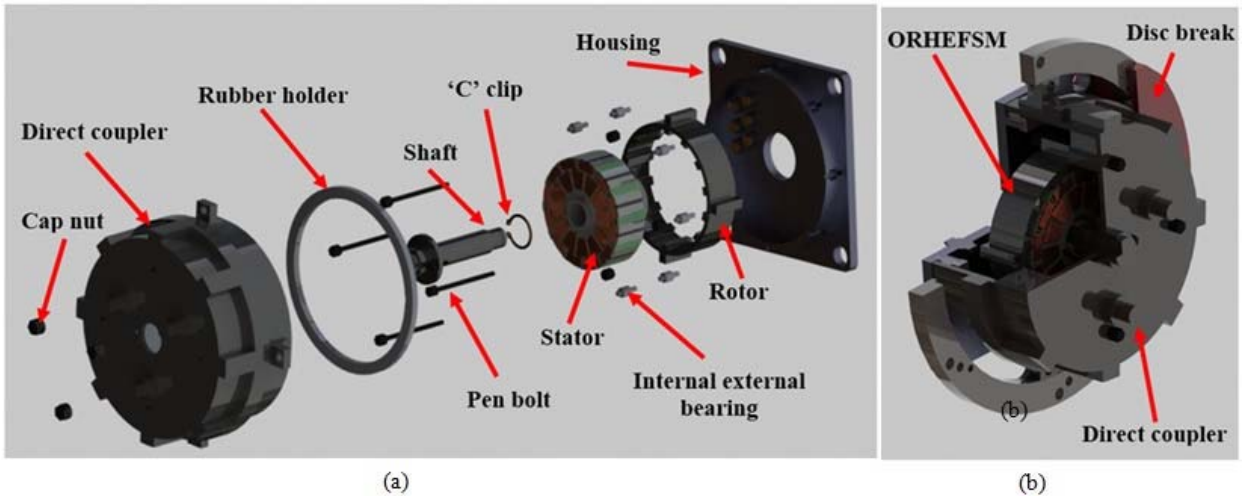

Figure-11. (a) Assembly process D-Drive structure. (b) Internal section view complete assembly process D-Drive structure.

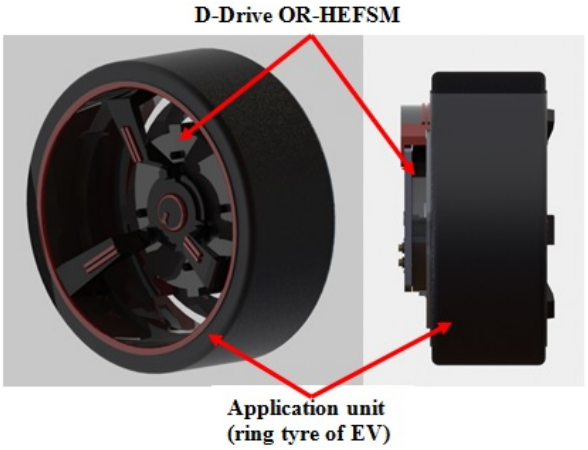

Figure-12. Complete design D-Drive structure.

CONCLUSIONS

In this paper, the design and development of D-Drive OR-HEFSM for in-wheel application has been presented. The design analysis of the proposed motor has successfully implemented using 2D-FEA and 3D analysis of JMAG-Designer and SOLIDWORK software, respectively. The APA method applied in SOLIDWORK has simplified the design time frame and meet the design standard. Finally, the proposed design motor complete with the housing and drive coupler has been approve for fabrication and experimental validation can be proceed for future investigation.

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