DEVELOPMENT OF WHEEL HUB MOTOR DRIVE APPLICATION IN ELECTRIC VEHICLES

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Abstract

At most 100-word summary of the problem and the findings.

In order to choose the optimum type of electric motor for Formula Student type race car applications, literature review has been conducted. Electric motor types such as AC Induction Motor (ACIM), Brushless DC (BLDC) Motor, Permanent Magnet Synchronous Motor (PMSM) and Stepper Motor & Switched Reluctance (SR) motors are compared. Results have shown that Permanent Magnet Synchronous Motor is the best option with its 95 percent efficiency. Further research has done comparing sub categories of PMSMs which are Interior Permanent Magnet motor (IPM) and surface mounted PM machines (SPM) in which IPM motors are selected as the best candidate for traction applications with their higher capacity of torque production. Finally, SolidWorks design of wheel assembly parts comprising planetary, upright and motor has been done using design parameters and dimensions.

Keywords: Hub motor, FSAE, Permanent Magnet Synchronous Motor, Interior Permanent Magnet Synchronous Motor.

1 Introduction

Electric motor concept revolutionized the industry by their extensive advantages over the internal combustion engines (IC) by means of low environmental effect and efficiency (Çakır, 2004, p.1). As an alternative solution to non-renewable fossil fuels, electric vehicles gained popularity in the automotive industry (Kucinski, Liang, Davis, &Masucci, 2017, p.10). The electric motor under this project was designed for the Formula SAE competition which is an international university student design competition (Carraro, Degano, Morandin & Bianchi, 2013). Four-wheel independent drive configuration concept is considered in which every wheel is controlled by its own torque source which is the motor (Çakır, 2004, p.2).

Figure 1: In Wheel Motor (Retrieved from https://motorwallpapers.org/protean-hub-motor/)

Today private companies make use of wheel motors since most of the race winning cars adapted this technology (Çakır, 2004, p.1). Electric vehicles (EVs) outrun internal combustion engines by many aspects. As mentioned above EVs have zero emission, fast response, and provide high torques at low speeds. In addition, differential gear boxes which are used to regulate the speed of the wheels are used in every car in today's world. However, differential gear boxes can not control the torque which makes in wheel electric motors desirable. Because these motors have a direct drive motor in each wheel. Apart from differential box, it eliminates the usage of gearbox and drive shaft that are a big part of a conventional car (Çakır, 2004, p.3). Also, the power loss that is caused by those gearboxes and drive shafts is minimized since the driving torque is directly on the road.

Formula SAE is an international competition for university students to design and build a race car (Hooper, 2011, p.31). The purpose of this project is to select a wheel hub motor for Formula Student type race car applications. Various options are possible for the selection of an electric motor such as AC Induction machine, Reluctance Machine and Permanent Magnet Synchronous Machine (PMSM).

AC induction motors, so called "squirrel cage motors" make use of an AC current running through the coils of stator that generates a rotating magnetic field (RMF). RMF induces a current in the rotor and creates a magnetic field in it. Thus, rotor follows the field on the stator making itself rotate (Zhao &Yu, 2011, p.10). Synchronous reluctance motors have a stator with coil windings and a rotor with no windings nor permanent magnets. This motor makes use of magnetic reluctance to create torque. While energized stator coils create magnetic flux on rotor, rotor is forced to align with the path of least reluctance, creating the motion (Hooper, 2011, p.29). Lastly, PMSM motors consist of two main parts which are stator that carries a number of electrical coil windings and a rotor with permanent magnets attached on its surface. Coil windings of stator is given an AC current which creates a revolving magnetic field (RMF). RMF interacts with the fields of PMs on the rotor creating a force for the rotor to rotate.

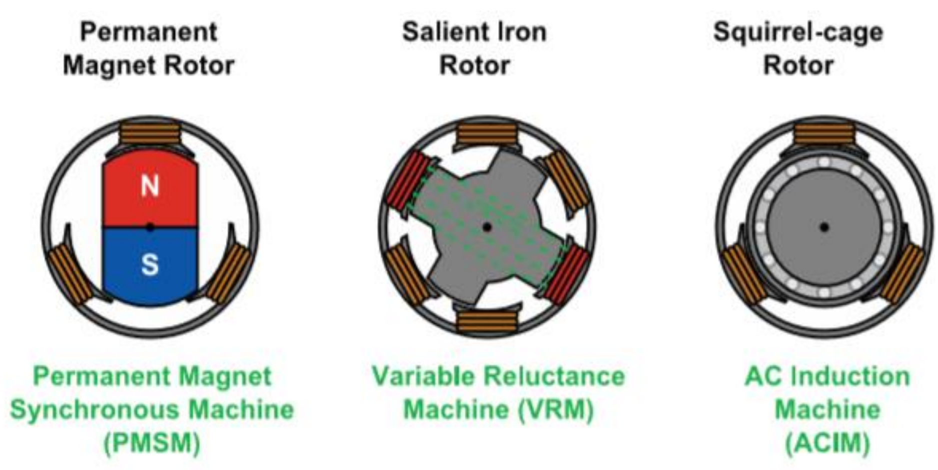

Figure 2: Electric Motor Types (from Hooper, 2011)

2 Motor Selection

2.1 Induction Motor vs PMSM

Puranen (2006) stresses that conventionally an induction motor can have a higher air gap flux density than a PMSM motor (p.34). However, modern high energy density magnets make it possible to have flux densities greater than 1 T. Although induction motors can provide many levels of flux densities, flux densities greater than 1 T creates excessive saturation of iron path (permeability of the iron drops) for both of the motors which can be solved by a PM material with extra magneto-motive force. Therefore, in a PMSM high dynamic performance that are caused by high flux densities can be provided by an increased number of PMs. Modern NdFeB with air flux densities greater than 1 T along with high linear current densities result in tangential stresses creating high torque densities for PMSMs.[1] In addition, required amount of copper needed for torque production is lower in PMSMs than IMs (p.34).

Research of Torrent, Perat, & Jimenez (2018) on comparing three different PMSM rotor structures[2] and IM has shown that air gap flux densities of all PMSMs are higher than of IM. Also, in all PMSMs power density and nominal efficiency was slightly higher (Torrent, Perat, &Jimenez, 2018, p.12)

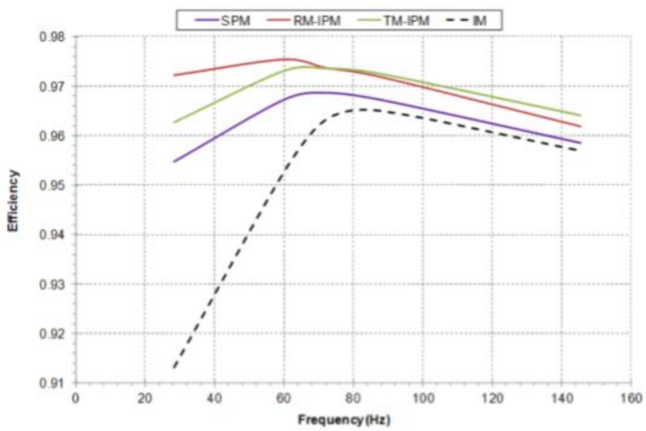

Figure 3: e 17. Efficiency at different operation frequencies: comparative between the three PMSM rotor structures with respect to the IM (from Torrent, Perat, &Jimenez, 2018)

For all the operating frequencies (see Figure 3), efficiency of PMSM rotor structures is slightly higher than IM excluding low frequencies where the difference is much greater (p.12).

[1] The tangential stress σ tan that produces the torque in cylindrical electric machines is proportional to the product of the stator linear current density As and the air gap flux density Bδ.

[2] Surface magnets (SPM) - interior magnets with radial magnetization (RM-IPM) - interior magnets with tangential magnetization (TM-IPM)

All requirements considered including; high air gap flux density, high power-to-weight ratio, large torque-to-inertia ratio, high-speed operation, high overloading torque, high efficiency and high-power factor, PMSM outran IM except high-speed operation which might be a problem depending on field weakening capability of the motor (Puranen, 2006, p.34). PMSM machines offer twice the power density of IM, thus makes it a better option compared to IM (Hooper, 2011, p.40).

2.2 Permanent Magnet Synchronous Motor (PMSM)

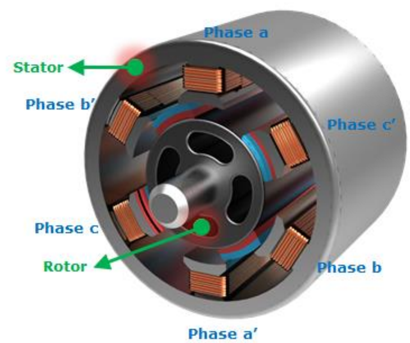

Figure 4: PMSM (Retrieved from http://www.functionbay.co.kr/documentation/onlinehelp/default.htm#!Documents/pmsmpermanentmagnetsynchronousmachine.htm)

Carraro, Degano, Morandin, &Bianchi (2013) emphasize that the best electric motor candidate for traction applications is the Permanent Magnet Synchronous Motor because of its high torque density, high efficiency, freedom in the design process of the motor (p.1142). Hooper (2011) also stresses that PMSMs have the highest power density and efficiency, numerically around 95% (p.31). PMSMs have one drawback which is the high cost of their permanent magnets. One possible solution that is presented by Carraro is to use a synchronous reluctance machine which has no windings nor magnets attached on its surface thus eliminates the cost of PMs (Carraro et al., 2013). However, it is disadvantageous in terms of efficiency which drops from 95% to <90% with the use of this engine (Hooper, 2011, p.29).

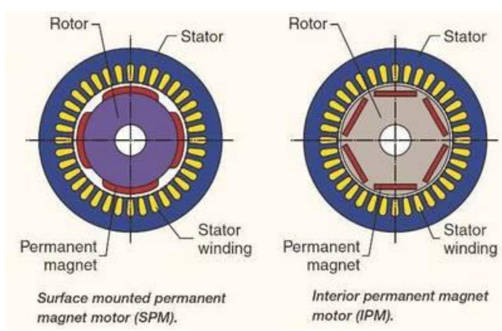

Figure 5: SPM vs IPM (Retrieved from https://www.controleng.com/single-article/understanding-permanent-magnet-motors/345972809e774096c1b1eeec350f0168.html?tx_ttnews%5BsViewPointer%5D=1)

PMSMs are categorized in terms of different stator geometries which are surface mounted permanent magnet synchronous motor (SPM) and interior permanent magnet motor (IPM). While permanent magnets place on the surface of the rotor in SPM, PMs place inside of the rotor in IPM (see Figure 5).

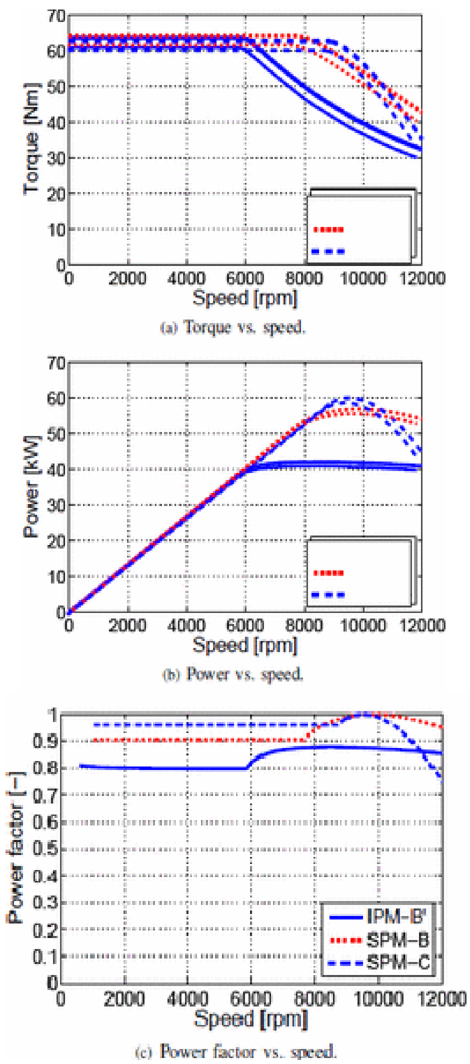

Figure 6: (from Carraro et al., 2010)

Based on Non-dominated Sorted Genetic Algorithm (NSGA) analysis that is conducted on two different stator geometries with same number of slots and poles (36-slot, 4-pole) but different outer diameters (IPM-A - 337mm, IPM-B – 276mm) minimum torque ripple of 12% is observed in IPM-B. In addition, regardless of their different diameters, both machines are equal in mass proving that there are not big advantages in choosing higher stator geometries thus making IPM-B the optimum stator geometry (Carraro et al., 2013, p.1144). When Constant Power Speed Range (CSPR) characteristics compared of both machines (see Figure 6), IPM-B produces better CSPR than IPM-A As can be observed from graph (b) and (c) (p.1144). The selected IPM-B machine is compared with two other SPM machines of equivalent size (276mm) which are SPM-B with 36-slot and 4-pole rotor and SPM-C with 12-slot and 8-pole. The evaluation on masses reveals that the lowest values are in IPM-B and SPM-C. Furthermore, unless IPM machines, the mass of SPM machines can be reduced even more. Up to 30% reduction is pssible in SPM machines (p.1145). Carraro emphasizes that the results show that best candidates are IPM-B showing best torque and power trends and SPM-C with a possible reduction in the motor mass (Carraro et al., 2013).

Vagati, Pellegrino & Guglielmi (2010) also conducted a research comparing IPM and SPM permanent magnet machines in which having the same diameter and stack length both machines have shown similar characteristics of continuous torque and power (p.5).

When iron and copper losses are compared, at base speed SPM machine has a little less overall loss. However, at high speed operations iron losses[3] and copper losses[4] including PM losses reveal that total loss is the same for both machines (p.6). Lastly, IPM machine outran the SPM machine in terms of overload capability as stated by Pellegrino & Guglielmi (2010) which makes the IPM machine the obvious choice (p.6).

[3] The loss of available energy by hysteresis and eddy currents in an electromagnetic apparatus (from merriam-webster.com)

[4] Copper loss is the heat produced by electrical currents which is an undesirable tarnsfer of energy.

2.3 SolidWorks Wheel Assembly Design

Wheel assembly of a Formula Student in wheel electric motor car is composed of sequentially hub motor, upright, hub bearings, planetary, wheel center and brakes (see Figure 7).

Figure 7: Wheel assembly (Kucinski, Liang, Davis, & Masucci, 2017)

First part of the assembly is called planetary in which it is composed of a sun gear in the middle, three planet gears around the sun gear and a ring gear outmost.

Second part is upright which carries all the load inside of a wheel. The last part is the cage of a motor which is suitable for the selected upright design. Sun gear in the middle is attached to the motor end axle. Propulsion coming from the motor is transferred through the end axle of the motor to the sun, planet and ring gears. Ring gear is attached to the next part which is the wheel center where also the next part, brake system is attached. The reason why planetary is used is that an electric motor can reach excessive RPM (rotation per minute) values. If the original RPM value of the motor is not reduced, it would cause wheel-spinning. In addition to wheel-spinning, the target tractive force couldn't have achieved. For these reasons, motor RPM value is reduced using a planetary gear system.

For the final step of the Development of Wheel Hub Motor Drive Application in Electric Vehicles Project, considering necessary scales and parameters, SolidWorks design of the wheel assembly comprising of planetary system, upright and motor cage is done. Firstly, upright design is constructed. Taking upright design parameters as reference, planetary with a gear ratio of 5.4:1 and motor cage are constructed (see Figure 8 & Figure 9).

- Front upright outer diameter is 152.4mm,
- The outer diameter of the three planet bearing locations is 40.9mm,
- Diameter of sun gear location on upright 22.7mm,
- Gear number of sun gear is 15, planets gears are 33.

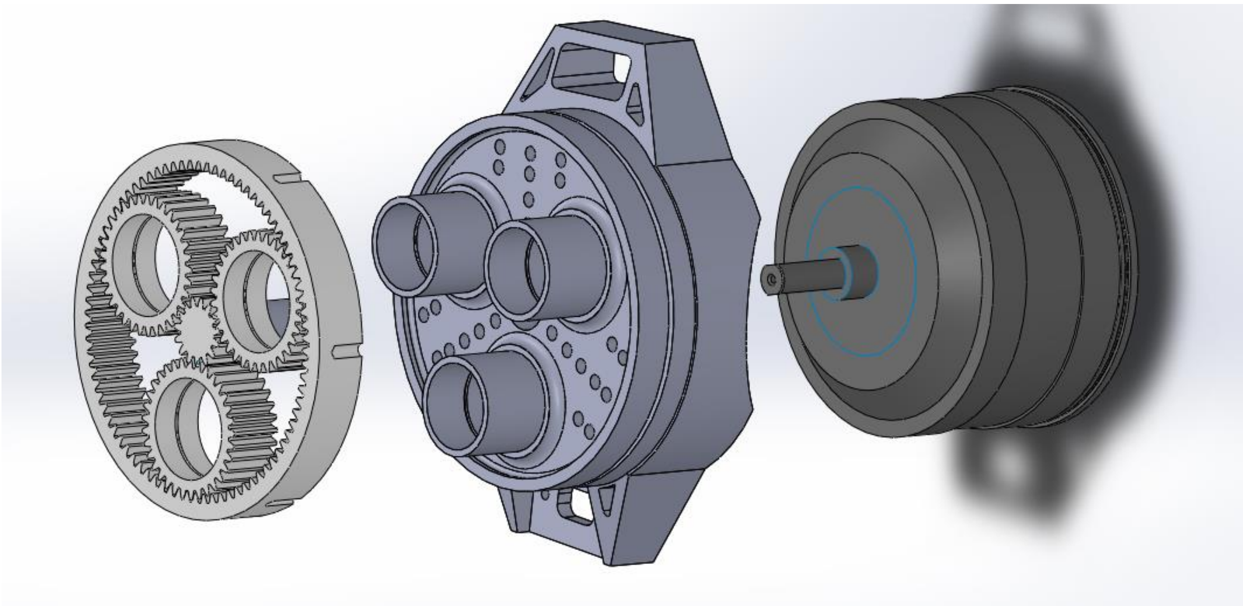

Figure 8: Exploded view of constructed wheel assembly

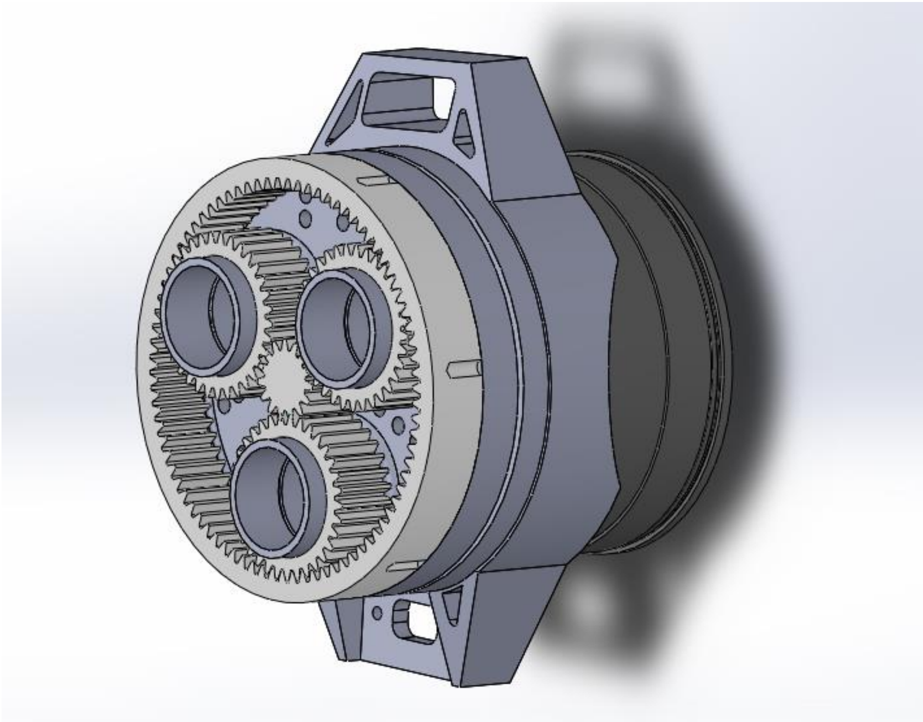

Figure 9: Constructed wheel assembly

3 Conclusion and Future Work

In conclusion, literature review on the best candidate for an electric motor for traction application is done starting with the comparison of AC Induction motor and a Permanent Magnet Synchronous Motor where PMSM chosen to be the obvious choice in between. After the selection of PMSM, sub categories of this motor with different geometries namely Interior Permanent MAGNET Synchronous Motor (IPM) and Surface Mounted Permanent Magnet Synchronous Motor (SPM) are compared. Results have shown that Interior Permanent Magnet Motor (IPM) is a better option in traction applications. After the selection of the motor type, SolidWorks design of wheel assembly of planetary, motor and upright was constructed.

Due to time constraints, many researches and tests have been left for the future. Future work encompasses a deeper analysis of the selected motor type (IPM), study on stator and rotor geometries for the design of the inner sections of the motor, if rotor and stator are designed, FEA (Finite Element Analysis) can be done. This research is mainly focused on selection of an electric hub motor type and constructing its wheel assembly on SolidWorks. By the end of the project presentations, 3D printing of the 2:3 scaled wheel assembly parts will be done to show the prototype of the assembly.

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