DESIGN OF FLYWHEEL ROTOR AND MOTOR FOR HIGH SPEED AUTOMOBILE APPLICATIONS

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ABSTRACT
To provide continuous and constant power supply to the load side in the automobile applications flywheel is proposing in this article, Flywheel not only stores energy and also it can maintain stability of the system indirectly, this article deals with design of different shapes of flywheel and electrical motor suitable for high speed automobile applications, initially theoretical calculation, simulation of the flywheel rotor is simulated using Powerful FEA packages, finally simulated flywheel, electrical motor is tested with experimental setup.

Key words: Flywheel; Electric Motor; FEA packages; Experimental setup.

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1. INTRODUCTION
Flywheel concept is ancient technique developed from potter wheels and spindle wheel, Egyptians in the year 2400 BC rotating wheels used for handcraft pottery, after 1985 flywheel concept is widely used in water pumps and also in power generation stations, flywheel can be used for multiple things, some of the advantages of flywheel is storing mechanical energy in the form of rotation, smoothening the output load side by providing constant and uninterrupted output for certain period of time, electric automobiles commonly required battery, electric motor, power electronic components, generator and gearbox, in addition to
this flywheel is placed inside the automobiles means stability, output continuity can also increased. Figure 1, shows the block diagram of Flywheel placed in automobile.

![Block diagram of Electric vehicle with flywheel](image)

**Figure 1** Block diagram of Electric vehicle with flywheel

basically flywheel is depends on mechanical system, it is most commonly used along with the motor or generator for maintaining smooth output, evacuated containment is preferred for high speed rotor spinning flywheel, windage losses is minimum once entire setup is placed inside the evacuated containment [1], hybrid electric power can be fed from the battery, fuel cell or super capacitors are most commonly used in low speed applications, hybridization like diesel-electric vehicles can be useful for heavy duty as well as high speed vehicle applications [2], for flywheel rotor highly reliable, high starting torque motor is proffered for good performance [3], motors like induction motor, permanent magnet synchronous motor, brushless DC motor, brushed DC motor, Switched Reluctance motor, Synchronous reluctance motor can also use for flywheel rotor, new flywheel energy storage system is proposed with multiple motors coupled together to make efficient input to flywheel, this prototype is proposed with typical three stages[4].

![Flowchart for flywheel and motor analysis](image)

**Figure 2** Flowchart for flywheel and motor analysis
Design of Flywheel Rotor and Motor for High Speed Automobile Applications

During power generation station side also flywheel is preferred, in wind power generation station also flywheel can be placed in another side, so that power from the wind generator as well as flywheel power together coupled together for higher efficiency [5]. so in this article mainly focused on optimized design of flywheel for high speed applications followed by stress analysis of flywheel at last thermal analysis of flywheel is simulated using FEA software's, simulated design is tested with experimental setups

2. DESIGN OF FLYWHEEL

FEA carried out based on some steps, first preprocessing of the flywheel design, followed by solution of the flywheel, finally post processing of the flywheel is carried out. Design of different types of flywheel is drawn using FEA packages, Mesh and nodal analysis for different types of flywheel is simulated, stress and thermal analysis of flywheel is important for performance improvement in the electric vehicles, best simulated design of flywheel is proposed for practical testing for electric vehicles. Design specifications of flywheel is shown in table 1, based on this design specifications different types of flywheel is constructed using FEA software packages.

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Unit</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mass of the flywheel</td>
<td>Kg</td>
<td>8</td>
</tr>
<tr>
<td>Outer diameter of flywheel</td>
<td>mm</td>
<td>110</td>
</tr>
<tr>
<td>Inner diameter of flywheel</td>
<td>mm</td>
<td>90</td>
</tr>
<tr>
<td>Speed of rotation of flywheel</td>
<td>RPM</td>
<td>1400</td>
</tr>
<tr>
<td>Material of flywheel</td>
<td></td>
<td>Steel</td>
</tr>
<tr>
<td>Thickness of the flywheel</td>
<td>mm</td>
<td>20</td>
</tr>
</tbody>
</table>

For a flywheel angular velocity \( (\omega) \) is the moment of inertia about its own axis of symmetry. It is the measure of resistance to the torque applied on a spinning object.

For moment of inertia

\[
I_m = \frac{m}{2} (r_0^2 + r_i^2)
\]  

(1)

Stored energy = sum of kinetic energy of individual mass elements that comprise the flywheel

Kinetic energy in a rotating system is

\[
E_k = \frac{1}{2} I_m \omega^2
\]  

(2)

\[
= \frac{1}{2} I_m (\omega_{max}^2 - \omega_{min}^2)
\]  

(3)

Speed fluctuations in flywheel

\[
F = \omega_{max} - \omega_{min}
\]  

(4)

Coefficient of the speed fluctuation

\[
C_f = \frac{\omega_{max} - \omega_{min}}{\omega_{avg}}
\]  

(5)

Stress calculation:
A physical quantity that expresses the internal forces that neighbouring particles of a continuous material exert on each other. It is represented by sigma.

\[ \sigma = \frac{\text{force}}{\text{cross sectional area}} = \frac{f}{a} \]  \hspace{1cm} (6)

3. SIMULATION OF DIFFERENT TYPES OF FLYWHEELS

Based on the above formulas design of three different types of flywheel is proceeded, dimensions are fixed, inner and outer diameter of flywheel is drawn using FEA packages, based on the air gap ducts space allocation is defined in the core of the flywheel rotor, dimension is constant for all Rim, Disc and Spoke type flywheel, once wire frame model is developed, material selection, mass of the flywheel and thickness of flywheel is applied for all three types, figure 3.a, 3.b, 3.c. shown the solid model of flywheel, steel material is used for core of the flywheel, thickness of in the post processing the simulation is run by giving fixed values.

![Figure 3 (a) Solid model of Rim type flywheel](image1)

![Figure 3 (b) Solid model of Disc type flywheel](image2)

![Figure 3 (c) Solid model of Spoke type flywheel](image3)

3.1. Stress Analysis

By using FEA software packages simulation for stress and thermal analysis is carried out for Rim type, disc type and spoke type flywheel, once solid model is finished, stress analysis is carried out, Fixing the speed of the flywheel rotation and mass of the flywheel is fixed, dynamic stress analysis simulation is simulated by using Ansys software, from the stress analysis simulation, stress occurred in the rim type flywheel is predominantly low compared...
to other two types disc and spoke type flywheels. In Rim type flywheel more stress occurred in the thin area supporting joints area of the rotor, less stress only occurred in the place of outer core and shaft region indicated in the blue colour, red colour places indicated high value of stress, in disc type flywheel stress occurrence is spread uniformly in the region of core places of flywheel rotor, it indicates that lifespan and stress in more places is not healthy for running flywheel for long time and also stress occurrence in the more leads to increase of temperature, in spoke type flywheel because of excess of spokes presence near to the shaft material withstand capability reduces and also stress occurred in the spokes leads to broken level.

Figure 4 (a) Stress analysis of Rim type flywheel  
Figure 4 (b) Stress analysis of Disc type flywheel  
Figure 4 (c) Stress analysis of Spoke type flywheel

3.2. Thermal Analysis
Thermal analysis of flywheel is important to analysis, once thermal performance of rotor is poor means, aging factor of flywheel occurs, it heatup the core of the motor, performance of rotor gets affected, heating of the rotor can be avoided by changing the material of the rotor, changing the physical appearance of the rotor, by changing the physical appearance also stress ability should not goes to worst case, it has to satisfy all the limitation of stress and thermal analysis of flywheel, In the Rim type structure thermal occured in the area of exterior core of the flywheel, it can be cooled by external atmosphere air itself, so need for external cooling device to cool down surface of flywheel, in disc type flywheel produces more heat near to the center of the core areas, once time increases thermal level increases and started to spread all over the area of rotor, core gets heated up means shaft everything gets heated up, it leads to
reduce lifespan of rotor, it indicates that cooling is difficult for disc type flywheel, in spoke type flywheel more heat producing area is spoke, spoke get heated up means material with stand ability reduces, if flywheel running for long time means chancess for getting broken also, atlast by concluding Rim type flywheel is better for running for high speed application, it have capable for running for long time.

Figure 5 (a) Thermal analysis of Rim type flywheel  Figure 5 (b) Thermal analysis of Disc type flywheel

Figure 5 (c) Thermal analysis of Spoke type flywheel

Table 2

<table>
<thead>
<tr>
<th>Types of flywheel</th>
<th>Stress Analysis</th>
<th>Thermal Analysis</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rim type flywheel</td>
<td>3.67 Pa</td>
<td>32.45 deg Celsius</td>
</tr>
<tr>
<td>Disc type flywheel</td>
<td>3.94 Pa</td>
<td>33.20 deg Celsius</td>
</tr>
<tr>
<td>Spoke type flywheel</td>
<td>4.26 Pa</td>
<td>33.65 deg Celsius</td>
</tr>
</tbody>
</table>

4. DESIGN OF INDUCTION MOTOR

For automobiles like battery powered vehicles required Direct current motor/ or Alternating current Motor, based on torque, battery requirement, power rating, motor controller, design specifications choice of motor can be made, in this article design simulation for single phase induction motor is simulated, induction motor have various good advantages compared to other motors available, Induction motor cost is low comparably, life span of motor is high. Induction motor works on the principle of mutual induction, capacitor start induction motor is used for starting the motor.
Table 3

<table>
<thead>
<tr>
<th>Specification</th>
<th>Value</th>
<th>units</th>
</tr>
</thead>
<tbody>
<tr>
<td>Inner diameter</td>
<td>26.03746</td>
<td>mm</td>
</tr>
<tr>
<td>Outer diameter</td>
<td>49</td>
<td>mm</td>
</tr>
<tr>
<td>Thickness</td>
<td>16.15753092</td>
<td>mm</td>
</tr>
<tr>
<td>Rated Speed</td>
<td>1400</td>
<td>Rpm</td>
</tr>
<tr>
<td>Shaft diameter</td>
<td>20</td>
<td>mm</td>
</tr>
<tr>
<td>No of stator slots</td>
<td>12</td>
<td>--</td>
</tr>
<tr>
<td>No of rotor poles</td>
<td>8</td>
<td>--</td>
</tr>
<tr>
<td>Material used for stator core</td>
<td>Cold rolled steel</td>
<td>--</td>
</tr>
<tr>
<td>Material used for rotor core</td>
<td>Cold rolled steel</td>
<td>--</td>
</tr>
<tr>
<td>Material used for coil</td>
<td>Copper</td>
<td>--</td>
</tr>
<tr>
<td>Number of turns</td>
<td>43</td>
<td>--</td>
</tr>
<tr>
<td>Type of coil</td>
<td>Concentrated double layer winding</td>
<td>--</td>
</tr>
</tbody>
</table>

4.1. FEA Analysis of Induction Motor

Single phase Induction motor of squirrel cage type rotor is designed for high speed electric powered automobile applications, once Electric energy is given to the motor means motor started to produce mechanical energy, this mechanical energy is given to the flywheel. flywheel stores rotational energy and also it resist change in speed, at last flywheel is connected to the wheels of the vehicle, some basic design details of flywheel is shown in table 3, twelve stator slots, eight rotor poles are used in this induction motor, solid model of single phase induction motor is shown in figure 6, it shows that stator core and rotor core has cold rolled steel material, rotor has made up of bars and end rings, end rings shorted by the copper material, once solid model of induction motor is designed, mesh analysis for designed Induction motor is carried out, reduction of mesh size increases the output accuracy, mesh of 2mm dimension is used, nodal values of 2547 is obtained in simulation, mesh analysis is simulated only when there is no leakage in the design, if there is any leakage in the design means mesh analysis is aborted during simulation, during preprocessing flux linkage, current distribution of Induction Motor is shown in figure 7 and figure 8, from that diagram it shows clearly maximum flux density occurs in the motor is 0.855 Wb/m² indicates in the red colour, figure 8 shows maximum current density occurs in the stator slots of 5.05 A/m². Input voltage of 72 volts is given to the stator of Induction Motor, input voltage waveform is shown in figure 9, Motor attain maximum speed of 1400 rpm, it slips with the percentage of 6.67 with the synchronous speed. slip speed is shown in figure 10. torque value of the motor is shown in the figure 11, maximum of 0.25 N-m value is obtained during simulation of Induction Motor.

Figure 6 Solid model of Induction Motor
Figure 7 Flux linkage of Induction Motor

Figure 8 Current density of Induction Motor

Figure 9 Input Voltage waveform
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Figure 10 Efficiency of Induction Motor

Figure 11 Torque value of Induction motor

From the table 4 designed IM simulation values are shown, from the figure 7 shows there is no flux linkage in the machine, current density is also higher value, overall simulation of IM is suitable to operate for automobile application

Table 4 Simulation results of IM

<table>
<thead>
<tr>
<th>S.No</th>
<th>FEA analysis of IM</th>
<th>Values</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Flux linkage</td>
<td>0.855 Wb/m²</td>
</tr>
<tr>
<td>2</td>
<td>Current density</td>
<td>5.05 A/m²</td>
</tr>
<tr>
<td>3</td>
<td>Maximum Torque</td>
<td>0.25 N-m</td>
</tr>
<tr>
<td>4</td>
<td>Slip percentage</td>
<td>6.667%</td>
</tr>
<tr>
<td>5</td>
<td>Efficiency</td>
<td>69%</td>
</tr>
</tbody>
</table>

4.2. Thermal Analysis of Induction Motor
Thermal analysis of Induction Motor is simulated using powerful FEA software, from this thermal analysis thermal performance of machine at various conditions can be simulated, Thermal
thermal analysis plays a vital role to improve the performance of machine, heat occurs in the machine is low means efficiency of the machine also good, once heat producing in the coils or core of the machine increases means efficiency of the machine also reduces, from the thermal simulation indicates that more heat occurs the place of stator coils, initially room temperature of the machine kept at 30 degree Celsius, simulation of the machine carried out up to 57 minutes, Thermal simulation of the machine is shown in figure 12, from the table 5 shows that thermal value of the machine not exceeds 50 degree Celsius, so designed Induction Motor is suitable to operation.

Table 5 Thermal results of Induction Motor

<table>
<thead>
<tr>
<th>S.No</th>
<th>Components of Induction Motor</th>
<th>Maximum Temperature (Deg Celsius)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Stator coil side</td>
<td>40.4</td>
</tr>
<tr>
<td>2</td>
<td>Stator tooth</td>
<td>39.5</td>
</tr>
<tr>
<td>3</td>
<td>Rotor tooth</td>
<td>37.9</td>
</tr>
<tr>
<td>4</td>
<td>Rotor bar</td>
<td>37.9</td>
</tr>
<tr>
<td>5</td>
<td>Shaft</td>
<td>36.5</td>
</tr>
</tbody>
</table>

5. HARDWARE DEVELOPMENT
Based on the simulation results of designed different types flywheel, effective flywheel is chosen for prototype modeling, Rim type flywheel have good stress and thermal withstand ability compared to other two types, similarly simulation results of IM is chosen because of its good performance of torque power and speed values.

Prototype model of flywheel and IM is coupled by using belt conveyors with the V-Belt ratio of 1:4 range, one end of IM is coupled with the Flywheel connected common shaft, so from this setup one rotation of IM gives 4 rotation of flywheel, speed produced by the flywheel 4 times higher than speed coming from the motor, figure 13, shows the setup designed flywheel and IM ,this multiplied speed can be given to the transmission drive shaft of the vehicle, but in prototype model another end also coupled with the IM to make the flywheel rotate faster than normal speed to make more effective performance.
Design of Flywheel Rotor and Motor for High Speed Automobile Applications

![Prototype model of flywheel and Induction motor](image)

**Figure 13** Prototype model of flywheel and Induction motor

Practical testing is tested for two minutes, from this testing machine with and without flywheel is tested by turned off after reaching sixty seconds, machine without flywheel reaches zero speed once it reaches 80 seconds, machine with flywheel can run maximum speed of 1404 RPM, it takes extra 24 seconds to reach zero speed, machine with flywheel can be suitable to operate at all conditions.

![Time Vs speed curves with and without flywheel](image)

**Figure 14** Time Vs speed curves with and without flywheel

6. CONCLUSIONS

This work focuses on the design and analysis of flywheel and Induction motor for automobile applications, usually instead of depending on gear system for multiplying speed of the vehicle flywheel can be use, flywheel not only increase the speed, it can also helps to maintain stability of the vehicle and also it stores mechanical energy in the form rotation energy, this article deals with design of three different types of flywheel by following design algorithm method for optimization and improve performance of the flywheel, some of the main simulation testing like stress, thermal analysis is carried out for all three types of flywheel, among three types, Rim type flywheel have better performance characteristics, simulation is tested with powerful FEA software's. Electrical Motor plays a vital role for Electric Vehicles, Compared to other Electric Motors, Induction Motor have some good features, so design of IM is designed using flowchart, designed IM is simulated using FEA software, once
simulation results of IM and flywheel is good means taken for prototype developing, Prototype model is tested in the experimental testing laboratory, prototype model is suitable to operate for automobile applications, future scope of the research is carried out with BLDC motor, different materials for flywheel, stress and thermal analysis for flywheel in prototype.

REFERENCES


