Design and fabrication of axial flux ferrite magnet brushless DC motor for electric two-wheelers

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Design and fabrication of axial flux ferrite magnet brushless DC motor for electric two-wheelers

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Background - Importance of improved ferrite magnets to the growth of electric vehicle

• There is a demand for electric vehicle (EV) propelled by environmental causes and fuel price fluctuations

• At present, performance/price factor compared to IC engine vehicles are holding back the growth of EVs
Background - Importance of improved ferrite magnets to the growth of electric vehicle

• There is a demand for electric vehicle (EV) propelled by environmental causes and fuel price fluctuations

• At present, performance/price factor compared to IC engine vehicle are holding back the growth of EV

• The cost of batteries used in electric vehicles (EVs) has been falling fast and is almost certainly well below the estimates made by many analysts in the past decade¹.

• A low cost powertrain could lead to affordable, efficient and performing EVs in market earlier than expected!

• Introduction of improved energy density ferrite magnet based PM motors is a possible solution to low-cost powertrain

Outline

- Background
- Specification of electric motor powertrain for two-wheeler
  - Challenges in substituting rare earth magnet with ferrite in electrical machines
- Design details of ferrite magnet motor
- Mechanical assembly of motor
- Fabrication of the motor
- Conclusion
Specification of electric motor powertrain for two-wheeler

Emmo electric scooter
[Existing motor: Sintered rare earth permanent magnet motor]

<table>
<thead>
<tr>
<th>S.N</th>
<th>Name</th>
<th>Unit</th>
<th>Value</th>
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<tbody>
<tr>
<td>1</td>
<td>Maximum vehicle mass including load</td>
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<td>130</td>
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<tr>
<td>2</td>
<td>Maximum (Rated) vehicle speed</td>
<td>kmph</td>
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<td>3</td>
<td>Time to reach rated speed of vehicle</td>
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<tr>
<td>4</td>
<td>Rated speed of motor</td>
<td>rpm</td>
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<tr>
<td>5</td>
<td>Rated power of motor</td>
<td>W</td>
<td>700</td>
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<tr>
<td>6</td>
<td>Rated torque</td>
<td>Nm</td>
<td>20</td>
</tr>
<tr>
<td>7</td>
<td>Rated voltage</td>
<td>V</td>
<td>48</td>
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</table>
Challenges in substituting rare earth magnet with ferrite in electrical machines

![Graph showing the relationship between residual flux density and intrinsic coercivity force for different types of magnets. The graph indicates that ferrite has lower residual flux density and intrinsic coercivity force compared to bonded NdFeB (RE), sintered SmCo (RE), and sintered NdFeB(RE).](image-url)
Challenges in substituting rare earth magnet with ferrite in electrical machines

- **What others are doing**
  - **Motor without any magnets**
    - Switched reluctance motors
    - Synchronous reluctance motors
  - **Motor with magnets**
    - New topologies that allow putting more magnet in an efficient way such as axial flux machines, dual rotor machines

- **Nanopyme motor topology and configuration offer**
  - Low cost position sensing and simple controller
  - Easy to wound and easy to repair modular concentrated winding
  - Direct drive with no gears offers lesser components and improved reliability

[Atallah2012]
Design details

**Design constraints**
- Number of stator slots: 18
- Number of rotor poles: 16
- Length of airgap: 0.4 mm
- Outer diameter of stator: 260 mm
- Gross slot fill factor: 50%
- Width of slot opening: 1 mm
- Depth of slot lip: 2 mm
- Depth of slot mouth: 2 mm
- Current density of coil: 4.5 A mm\(^{-2}\)
- Ratio of pole arc to pole pitch: 1

**Optimised designs**

<table>
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<tr>
<th>Design</th>
<th>63</th>
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<th>124</th>
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<th>158</th>
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<td>8</td>
<td>7</td>
<td>7</td>
<td>7.5</td>
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<td>(b) (%)</td>
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<td>10</td>
<td>5</td>
<td>0</td>
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<td>(\lambda_d) (%)</td>
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<td>50</td>
<td>47.5</td>
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<td>(P_{Cu}) (W)</td>
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![Design diagram with labels](image-url)
Mechanical assembly of the motor

- Coils
- Stator
- Magnets
- Rotor yoke
- End Plate
- Tooth
- Magnets
- Wheel
- End Plate
- Rotor yoke
Fabrication of motor - stator tooth

Material: M400-50A
Fabrication of motor - stator coils
Fabrication of motor – tooth mounting assembly

Tooth holder

Shaft

Tooth holder
Fabrication of motor – tooth mounting assembly
Fabrication of motor – Completed stator and rotor position sensor mounting
Fabrication of motor – Rotor yoke and magnet assembly
Completed motor on vehicle
Conclusion

- Introduction of improved energy density ferrite magnet based PM motors could improve the adoption rate of electric vehicles by offering low-cost powertrain

- DTU along with Nanopyme partners has fabricated and successfully completed first trial assembly of axial flux ferrite magnet motor for electric two-wheeler application

- In coming weeks DTU will fine-tune the motor assembly and integrate the motor to wheels of vehicle

- The on-board vehicle test of powertrain according to ISO 13064 standard is scheduled for October 2015. This will be followed by test bench evaluation of motor
Consortium

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