Motor Summit 2020 International

Efficient Motor Technology with Low Loss Soft Magnetic Material

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Hirooki Tokoi

Research & Development Group
Hitachi, Ltd.
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1. Introduction of Amorphous Motor
1-1 Demands of High-efficiency of Motor

High efficiency motors are required to decrease electric power consumption.

References:
1) IAE-0919107 (2009), Agency for Natural Resources and Energy
2) Energy-efficiency policy opportunities for electric motor-driven systems, IEA (’11)

World’s electric power consumption

*1EJ=10^{18}J
Amorphous metal has a very small iron loss. High Bs nanocrystal has both low loss and high magnetic flux density.
## 1-3 Issues when using amorphous metal in motors

Amorphous metal is difficult to make into a motor core due to its “hardness” and “thinness”.

### Characteristics of materials

<table>
<thead>
<tr>
<th>Material appearance</th>
<th>Electrical steel sheet</th>
<th>Amorphous metal</th>
</tr>
</thead>
<tbody>
<tr>
<td>Loss (ratio)</td>
<td>1</td>
<td>1/10</td>
</tr>
<tr>
<td>Thickness (mm)</td>
<td>0.1~1.0</td>
<td>0.025</td>
</tr>
<tr>
<td>Hardness (ratio)</td>
<td>1</td>
<td>5~10</td>
</tr>
</tbody>
</table>

### Issues when using motors

① Increased processing times (15-20 times)
② Reduced mold life (1/50)
③ Thin film strip post-processing
④ Degradation of magnetic properties due to processing

Amorphous materials require a “new iron core structure” that can be easily processed.
Established a method to laminate amorphous metal by shearing
1-5 Hitachi’s Amorphous Motor

Axial-flux type motor with amorphous core leads to high efficiency.

Motor structure: Axial-flux type

Laminated core: Amorphous metal

Structure of amorphous motor

Motor efficiency of trial motor (11 kW)

Conventional induction motor

Prototype in 2012

Prototype in 2014

Motor efficiency (%)

Load torque (%)

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We had developed a new compressor with integrated amorphous motor. The package size had reduced to 37% of the previous model.

**Conventional**

IE3 Induction motor

Drive belt

**Developed**

IE5 Amorphous motor

- Shortening the motor shaft by 40%
- Cutting motor loss by 40%

**Graphical Comparison**

- **Volume** -63%
- **Height** -34%
- **Depth** -14%

**Reference**

2. Study for Further High Efficiency
To further increase efficiency, it is necessary to reduce the loss of (a), (b) and (c).

11kW prototype in 2014

- **Coil** (DC copper loss) 123.7
- **Coil** (AC copper loss) 37 (Calc.)
- **Bearing and others** (Mechanical loss) 70
- **Stator core** 65.6
- **Housing** (at no load) 10 (Calc.)
- **Housing** (at load) 70 (Calc.)
- **Rotor** 35 (Calc.)
- **Cooling board** 15 (Calc.)
- **Others** 11.4

Total loss: 437.7 W
2-2 Loss Reduction Measures

Loss reduction of IE5 amorphous motor by new material and structure

<table>
<thead>
<tr>
<th>Type of loss</th>
<th>Countermeasure policy</th>
<th>Concrete means</th>
</tr>
</thead>
<tbody>
<tr>
<td>(a) DC copper loss</td>
<td>Decrease of current:</td>
<td>High-Bs nanocrystal</td>
</tr>
<tr>
<td></td>
<td>- Increase of magnetic flux</td>
<td>High-Br bond magnet</td>
</tr>
<tr>
<td>(b) AC copper loss</td>
<td>Decrease of electrical resistance:</td>
<td>Low loss coil using multiple fine wires</td>
</tr>
<tr>
<td></td>
<td>- Increase of coil diameter</td>
<td></td>
</tr>
<tr>
<td></td>
<td>- Decrease of number of coil turns</td>
<td></td>
</tr>
<tr>
<td>(c) Housing loss</td>
<td>Decrease of eddy current:</td>
<td>Non-magnetic and non-conductive ceramic housing</td>
</tr>
<tr>
<td></td>
<td>- Increase of electrical resistance</td>
<td></td>
</tr>
</tbody>
</table>
We reduced copper loss by increasing magnetic flux and reduction of resistance.

<table>
<thead>
<tr>
<th></th>
<th>Conventional</th>
<th>Developed</th>
</tr>
</thead>
<tbody>
<tr>
<td>Magnet</td>
<td>Ferrite sintered magnet</td>
<td>Bond magnet</td>
</tr>
<tr>
<td></td>
<td>((Br = 0.46\text{T}))</td>
<td>((Br = 0.8\text{T}))</td>
</tr>
<tr>
<td>Core</td>
<td>Amorphous metal</td>
<td>High-Bs nanocystal</td>
</tr>
<tr>
<td>Coil</td>
<td>(\Phi1.6\text{-}2\text{parallel} \times 98\text{turn (2\Delta)})</td>
<td>(\Phi1.0\text{-}6\text{parallel} \times 80\text{turn (4Y)})</td>
</tr>
</tbody>
</table>

Increasing magnetic flux (Reduction of input current and number of coil turns)

Reduction of winding resistance
Ceramics is an excellent material for both resistivity and strength.

Since it is difficult to make the leakage flux zero, we focused on housing material.
The test motor is the same size as the IE5 11kW-amorphous motor in 2014.

- Ceramic housing
- Mold stator
- Bond magnet rotor
- High-Bs nanocrystal core
- Resin
- Mold stator
- High Br bond magnet
- External view

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Total loss is reduced by 40%, mainly in coils and housing.

<table>
<thead>
<tr>
<th>Rotor</th>
<th>Amorphous motor '14</th>
<th>Nanocryatal motor</th>
</tr>
</thead>
<tbody>
<tr>
<td>(1) Magnet</td>
<td>Ferrite sintered magnet</td>
<td>High-Br bond magnet</td>
</tr>
<tr>
<td>(2) Core</td>
<td>Amorphous metal</td>
<td>High-Bs nanocrystal</td>
</tr>
<tr>
<td>(3) Coil</td>
<td>Φ1.6X2X98turn-2Δ</td>
<td>Φ1.0X6X80turn-4Y</td>
</tr>
<tr>
<td>(4) Housing</td>
<td>ADC12</td>
<td>Al₂O₃</td>
</tr>
<tr>
<td>(5) Resin</td>
<td>BMC</td>
<td>High thermal conductivity resin</td>
</tr>
</tbody>
</table>

η=96.2%

η=98.3%
3. Deployment to Radial Gap Type Motor
Amorphous laminated teeth are constructed by following the shearing method.

Motor structure with teeth made of amorphous metal

- Amorphous metal
- Laminated teeth
- Axially Insert
- And assemble
- Magnetic steel sheet yoke
- Resin Bobbin
- Amorphous metal
- Laminated teeth
- Magnetic steel sheet yoke is assembled in brick shape
3-2 Target specifications of motor

11kW industrial motor (equivalent to 2P machine) was set as the target value

<table>
<thead>
<tr>
<th>Item</th>
<th>Specifications</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rated power</td>
<td>11kW</td>
</tr>
<tr>
<td>Rated speed</td>
<td>3000r/min</td>
</tr>
<tr>
<td>Rated torque</td>
<td>35N·m</td>
</tr>
<tr>
<td>Structure</td>
<td>Radial gap type, SPM (Surface Permanent Magnet)</td>
</tr>
<tr>
<td>Voltage</td>
<td>3Ph 200Vrms  (DC288V)</td>
</tr>
<tr>
<td>Rated current</td>
<td>35Arms</td>
</tr>
<tr>
<td>Volume</td>
<td>Φ240mm × L120mm</td>
</tr>
<tr>
<td>Efficiency</td>
<td>95% or more (IE5)</td>
</tr>
</tbody>
</table>
3-3 Calculation results of iron loss of stator

If amorphous metal is used only for the teeth, the iron loss can be reduced to about 1/3.

All stator cores are magnetic steel sheets

Teeth part is amorphous metal
3-4 Structural design of amorphous motor

Motor volume achieved the target specification

Magnet (HIDENSE® Br=0.8T @Hitachi metals)

FRP-FW Axial retaining ring

Amorphous Teeth (2605SA1 @Hitachi metals)

Yoke (35A300)

Coil (1AIW-φ1.0mm×72 turn @Hitachi metals)

Bearing

φ215mm

80mm

φ140mm

Appearance of prototype motor
3-5 Detailed structure of each part

Yoke Core (35A300)

Teeth part (2605SA1)

Teeth part (Bobbin)

Teeth part (Inserted state)

Rotor assembly (Magnet : HIDENCE®)

Terminal connection

Motor assembly
3-6 Efficiency evaluation of prototype motor

Prototype motor
SiC Invertor
Water
DC Input line
Torque meter, Load device

Efficiency of prototype motor

Efficiency (%)

80%  90%  95%  96.0%  96.6%  97.1%  97.2%

Comparison with IE5 axial type

<table>
<thead>
<tr>
<th></th>
<th>IE5 (axial gap type)</th>
<th>Amorphous teeth(Radial)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Appearance</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Rated Power</td>
<td>3000r/min 11kW</td>
<td>3000r/min 11kW</td>
</tr>
<tr>
<td>Specification</td>
<td>10P-12S (SPM) Magnet: NMF-12G (Br=0.48T)</td>
<td>16P-24S (SPM) Magnet: HIDENCE (Br=0.8T)</td>
</tr>
<tr>
<td>Volume</td>
<td>6.9L Φ260×130</td>
<td>3.6L (1/2) Φ215×100</td>
</tr>
<tr>
<td>Weight</td>
<td>36kg</td>
<td>18kg (1/2)</td>
</tr>
<tr>
<td>Efficiency</td>
<td>96.2% (measured)</td>
<td>97.2% (measured)</td>
</tr>
</tbody>
</table>

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4. Conclusion
In this presentation, we explained the technology for further improving the efficiency of amorphous motors and the technology for expanding the applications.

**High efficiency technology**
- We proposed new axial gap type motor with high-Bs nanocrystal core and ceramic housing to reduce copper loss and housing loss which dominate in axial gap type amorphous motor.
- The motor efficiency was improved from 96% to 98%.

**Expanded application technology**
- We proposed radial type amorphous motor consisting of amorphous teeth and electrical steel sheet core back.
- The amorphous teeth can be manufactured with relatively simple processing.
- The prototype motor achieved an efficiency of 97%.

Some of these developments are granted by the New Energy and Industrial Technology Development Organization (NEDO) through the “Funding program for development of realization technology for replacement and reduction of rare-earth metal.”
Hirooki Tokoi

Hitachi, Ltd. Research & Development Group
1-1, Omika-cho 7-chome, Hitachi-shi, Ibaraki-ken, 319-1292 Japan
Tel: +81-70-4267-3578
E-mail: hirooki.tokoi.fe@hitachi.com
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