Novel Single-Drive Bearingless Motor with Wide Magnetic Gap and High Passive Stiffness

Hiroya Sugimoto
Seiyu Tanaka
Akira Chiba
Tokyo Institute of Technology
Advantages of the bearingless motors

- No contact
- No wear
- No lubricant
- Non polluting
- Maintenance-free

Possible Applications

- Highly pure water pump in semiconductor industries
- High speed motor such as a compressor
- Cooling fan requiring long life-time

Significant issues for industry application

Magnetic suspension cost is high!
Thus, cost reduction is strongly required.

Reducing number of active positioning axes is the most effective.
1-2. A number of active positioning axes

One-axis actively positioned bearingless motor can realize to reduce four active positioning axes.

<table>
<thead>
<tr>
<th>5-axis active positioning</th>
<th>2-axis active positioning</th>
<th>1-axis active positioning</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bearingless motor units</td>
<td>Thrust magnetic bearing</td>
<td>Bearingless motor</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Passive magnetic bearing</td>
</tr>
</tbody>
</table>

Passive magnetic bearing
1-3. Advantages of 1-axis bearingless motor

A single-drive bearingless motor is focused.

<table>
<thead>
<tr>
<th>The number of active positioning axes</th>
<th>5</th>
<th>2</th>
<th>1: Thrust magnetic bearing motor</th>
<th>1: Single-drive bearingless motor</th>
</tr>
</thead>
<tbody>
<tr>
<td>Required number of units</td>
<td>six-IGBT inverter</td>
<td>Sus.:2, Mot.:1</td>
<td>Sus.:1, Mot.:1</td>
<td>Mot.:1</td>
</tr>
<tr>
<td></td>
<td>four-IGBT inverter</td>
<td>Sus.:1</td>
<td>0</td>
<td>Sus.:1</td>
</tr>
<tr>
<td></td>
<td>displacement sensor</td>
<td>5</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>PM cost ratio</td>
<td>$6</td>
<td>$6</td>
<td>$13</td>
</tr>
<tr>
<td></td>
<td>Cost ratio</td>
<td>1</td>
<td>0.46</td>
<td>0.35</td>
</tr>
</tbody>
</table>

Single-drive bearingless motor needs only one three-phase inverter and one displacement sensor for the suspension and motor regulations.
Two functions of the motor and the thrust magnetic bearing are magnetically integrated in the single motor.
2. Purpose

- Important issues in the single-drive bearingless motor are presented.

- A novel single-drive bearingless motor with wide magnetic gap and high passive stiffness is proposed.

- The 3D-FEM analyses and experiment results are presented.
High passive stiffness for reducing vibrations in the radial and tilting directions

Wide magnetic gap for centrifugal pump applications

3-1. Important research issues

- Johannes Kepler Univ. in 2014
- National Taipei Univ. of Tech. in 2009
- Univ. of São Paulo-USP in 2011
- Shizuoka Univ. in 2013
- Toyama Univ. in 2011

Proposed SDBM in 2013

Radial stiffness, $k_r$ (N/mm)

Gap factor, $g/R$
3-2. Proposed structure

Increasing permanent magnets and the number of layers are effective to enhance the passive stiffness.
3-3. Requirement of the wide magnetic gap

Plastic can must be installed on the rotor and stator surfaces to avoid the damage from chemical fluid.
Active axial force to overcome the unstable thrust force must be generated for stable magnetic suspension.
Active axial force is generated in one side of the coil-end by a shifting rotor in the axial direction.

Structure (a)
Unfortunately, the axial force of structure (a) is quite low.

Several structures have been investigated.

Active axial force, $F_{z_i}$ (N)

Target value 6.28 N

$d$ axis current, $i_d$ (A)
3-7. Investigation of several structures

Structure (b)

Structure (c)
The active axial force is increased although structures (a) – (c) can’t achieve the target axial force.

A novel structure without magnetic saturation is proposed.
3-9. Proposed stator and rotor structures

- The stator core is constructed with six bars.
- The rotor is two-pole cylindrical permanent magnet.

The permanent magnet flux is distributed sinusoidal wave between the rotor and stator cores.
When the suspension flux is superimposed on the PM flux, flux density in the air-gap in positive z-direction is high compared with that in negative z-direction.
Virtual two-pole concentrated winding is generated by novel V-shaped winding structure.

Fold angle $\phi$ is key parameter for torque generation.
Prototype machine with the rotor and divided cores

PM for detecting angular position

Rotor

Two-pole PM

One of the divided cores with V-shaped winding

RPMB

Two-pole PM

RPMB

RPMB

Housing

Windings

Displacement sensor

4-1. Test machine
4-2. Demonstration movie
4-3. Test machine

The rotor is served to the reference position after the d-axis current is excited.

Touch down length ±0.2 mm

Suspension control is activated

\[ i_d = -2.98 \text{ A} \]

\[ i_q \]
The regulations of the axial position and the rotational speed are realized in the experiment.

Static magnetic suspension

Acceleration up to 3600 r/min

± 0.95 A
± 22 μm

$\omega$ ($10^3$ r/min)

$z$ (mm)

$i_d$ (A)

Time (s)

3600 r/min

0 1 2 3
5. Conclusion

- A novel single-drive bearingless motor with wide magnetic gap and high passive stiffness is proposed.
- Design process of the proposed single-drive bearingless motor is shown.
- In the experiments, stable magnetic suspension and speed regulations are confirmed.