Permanent Magnet Synchronous Motor for Traction Systems

Efficient

Smarter

Quieter

Reliable
Toshiba’s PMSM (Permanent Magnet Synchronous Motor) offers various benefits to railway services compared to our traditional Induction Motor (IM)*1.

- **Efficient**
  Saving more energy, thanks to a high efficiency of 97%*2

- **Smarter**
  Smarter maintenance operations, thanks to the unique structure.

- **Quieter**
  Reduced by about 12dB* compared to our conventional open self-ventilating type motors.

**Efficient**

Global activities are underway to reduce CO₂ emission, and railway companies also face considerable expectations to reduce electric consumption of train cars. The Toshiba Permanent Magnet Synchronous Motor (PMSM) achieved higher efficiency than traditional Induction Motor (IM) due to the elimination of secondary loss. Toshiba’s technology appropriately exploits the advantages of this PMSM system, and boasts a high efficiency of 97%.*2

As shown above, PMSM propulsion system achieves 39%*5 energy saving for commercial trains compared to conventional systems. After implementing the PMSM traction system, the customer measured their new energy consumption and the result was significant savings in terms of cost and energy.

To calculate the energy savings, Toshiba compared the electric power consumption and electricity expense between PMSM and IM for one year and eight years. The following table shows the comparison.

<table>
<thead>
<tr>
<th>Loss (kW)</th>
<th>PMSM</th>
<th>IM</th>
</tr>
</thead>
<tbody>
<tr>
<td>Iron loss (kW)</td>
<td>0.12</td>
<td>0.92</td>
</tr>
<tr>
<td>Primary copper loss (kW)</td>
<td>0.07</td>
<td>0.57</td>
</tr>
<tr>
<td>Secondary copper loss (kW)</td>
<td>0.05</td>
<td>0.35</td>
</tr>
<tr>
<td>Other loss (kW)</td>
<td>0.05</td>
<td>0.35</td>
</tr>
</tbody>
</table>

Comparison between loss of PMSM and IM*7

As shown in the table, PMSM saved 39%*5 energy compared to IM for commercial trains.

Example estimations of the energy-saving effect by achieving high efficiency *9

<table>
<thead>
<tr>
<th>Year</th>
<th>Electric power consumption (MWh)</th>
<th>Electricity expense(M$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>One year/One train set</td>
<td>953</td>
<td>0.12</td>
</tr>
<tr>
<td>Eight years/One train set</td>
<td>7,623</td>
<td>0.92</td>
</tr>
<tr>
<td>Eight years/24 train sets</td>
<td>182,958</td>
<td>22.6</td>
</tr>
<tr>
<td>Twenty-four years/24 train sets</td>
<td>548,874</td>
<td>67.9</td>
</tr>
</tbody>
</table>

Comparison between energy consumption of PMSM and IM*5

- **Induction Motor**
  - Electric power consumption (MWh)
  - Electricity expense(M$)*4

- **PMSM**
  - Electric power consumption (MWh)
  - Electricity expense(M$)

- **Effect**
  - Electric power consumption(MWh)
  - Electricity expense(M$)

- **Quantity of reduced CO₂ (t-CO₂)*6**
  - Eight years/One train set: 158.0
  - Eight years/24 train sets: 1,263.5
  - Eight years/24 train sets: 30,325.3
  - Twenty-four years/24 train sets: 90,975.9

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*1 AC Induction Motor (Asynchronous Motor)

*2 The motor efficiencies were calculated with loss measurement based on IEC 60349-2 at the temperature below 40°C from 8/25/2009 to 9/25/2009 for PMSM.

*3 Type tests including noise are carried out according to JIS E6102 with the first product.

*4 Toshiba estimated annual electricity expense of urban subway cars with 12.7(¥/kWh) provided by TEPCO in 2012. $1 = ¥102.7 as of 06/05/2014.

*5 The figure includes the effect of enhanced regenerative braking force by applying regenerative braking as a fleet and by utilizing adhesion limit relaxation control.

*6 Toshiba calculated with CO₂ emission coefficient 0.425 (t-CO₂/MWh) in case of TEPCO, provided by Ministry of the Environment Government of Japan.

*7 IM is manufactured in 1996 and output power is 120kW. PMSM is manufactured in 2009 and output power is 120kW. Both of motors are tested according to JIS E 6102.

*8 Based on measurement on commercial trains from 5/21/2012 to 5/26/2012 for PMSM and from 4/12/2012 to 4/20/2012 for IM.

*9 Toshiba in 1992 and output power is 205kW. PMSM is manufactured in 2010 and output power is 205kW. Both of motors are tested according to JIS E 6102.
**Smarter**

Railway systems are constantly striving to make periodic maintenance simple and cost effective, which is essential for stable operation. The maintenance of conventional open self-ventilating type IM systems is time consuming, mostly due to the nature of its construction. For conventional motors, the case has to be opened with a dedicated jig to remove the rotor, the inside cleaned, and the bearing regreased. Toshiba has developed a totally-enclosed structure to make maintenance operations smarter compared to our conventional Induction Motor (IM) in terms of cost and time. We have successfully eliminated potential internal contamination, which makes cleaning no longer required through the PMSM’s service life. We have also engineered a structure allowing the bearing unit to be replaced without disassembly of the entire motor. Consequently, while improving the maintenance of bearing crucial for stable operation, Toshiba successfully eliminated the conventional 3D (Dirty, Demanding, and Dangerous) maintenance.

**Quieter**

Demands to ensure low noise operation have been intensifying year by year, especially for the traction of subway trains. Toshiba has succeeded in reducing ventilation noise by about 12dB throughout all speed ranges compared to our conventional open self-ventilating type.

Additionally, since exhaust air and heat are also reduced as well as noise, this limits the temperature increase in subway tunnels, helping conserve electricity used to power air conditioning in the tunnels.

*10 Estimated maintenance hour.
Toshiba developed an inverter equivalent to the size of a typical traction inverter for the conventional IM drive, and in most cases made it possible to smoothly update the IM drive to the PMSM drive.

**Reliable Driving the PMSM**

Since permanent magnets are implanted in the rotor core of PMSM, the magnetic force is not leaked from inside the motor even if an Nd-Fe-B magnet is used. The magnetic force is selected to achieve necessary performance even at the end of the design life. Toshiba’s totally-enclosed structure requires no disassembly through its service life, hence no strong magnetism is perceptible during normal handling.

**Simple and lightweight**

Toshiba’s PMSM has a lighter weight than that of conventional open self-ventilating type IM as well as a simple, totally-enclosed and natural cooling structure without radiation fins and ventilating fans. Despite the totally-enclosed natural cooling structure, its appearance is equivalent to that of the conventional open self-ventilating type IM, and its size and mass are generally equivalent to less than an IM. Therefore, in most cases the PMSM can be installed in existing bodies as-is. When under the same cooling condition as an IM, reduced weight or increased output of approximately 20% is also achieved*11.

**Implanted permanent magnet**

Toshiba’s PMSM rotors are the IPM (Interior Permanent Magner) type. Toshiba interior magnets have an improved shape to accomplish a structure that is easy to manufacture, simple, and reliable in terms of strength, and are arranged to effectively exploit the reluctance torque.

**High-performance permanent magnets**

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*11 Output power of the IM is 190 kW and its weight is 690 kg. Output power of the PMSM is 205 kW and weight is 565 kg.

Almost 1000 PMSMs*12 have already been delivered by Toshiba, and so far, no traction motor failure has been reported. It shows the high reliability of Toshiba’s technologically advanced traction motor.

**Driving the PMSM**

Based on our expertise, we have developed an improved traction inverter for the PMSM drive and established PMSM control technology, validated and verified by service operation. Toshiba provides several options to drive the traction motor. The inverter configuration can be chosen among the following options:

- **4 in 1 traction inverter (1.5 kV)**: 4 inverters integrated in 1 unit driving 4 traction motors at 1.5 kV.
- **2 in 1 traction inverter (750 V)**: 2 inverters integrated in 1 unit driving 2 traction motors at 750 V.

For the same size, these inverters can be combined, giving a 4 in 1 times 2 at 1.5 kV or a 2 in 1 times 2 at 750 V.

However, by improving the parts arrangement and developing a highly efficient and compact cooling unit, we have accomplished a size equivalent to the conventional IM drive inverter. Toshiba will continue to develop our advanced PMSM drive while ensuring a compact and highly reliable traction inverter systems for subway, commuter cars, high speed railcars and locomotive.

*12 As of August 1, 2014
Our Goal
Over 100 years of Toshiba’s experience in railways were put together to design a technologically advanced traction motor, the PMSM. Toshiba started developing the PMSM system in the early 1990s.

The goals have been the following two:
- developing an environment-friendly new system and reducing significantly the running costs for the operator.

Using data accumulated through research, development and field tests during the development phase, we established the PMSM traction system technologies for railway cars. The PMSM’s advantages such as energy savings, noise reduction and easier maintenance were verified through pilot service tests with the customers. Since then, PMSM systems have been deployed in mass produced commuter/subway trains and have been operated since 2007.

Using this technological breakthrough as a starting point, Toshiba continues to innovate and improve this environment-friendly PMSM system to allow its use by more customers.

It also contributes to the larger system called the Energy Management System. By regenerating more energy than conventional traction motors, it allows other trains to receive more regenerated power®. As part of this system, the regenerated energy may also be stored in highly capable batteries or be used by other devices, such as lighting the stations or charging an electric bus.

Toshiba’s commitment to constant, environment-conscious, safe and dream-inspiring innovation for railways is our pledge to ensure that we pass on the beautiful and irreplaceable Earth to future generations.

Driven by Toshiba’s PMSM
Already 2500 PMSM have been delivered.

Tokyo Metro 02 series
Customer: Tokyo Metro Co., Ltd.
Type: 8-vehicle
Number of Cars: 800 series
Starting year of delivery: 2012

Tokyo Metro 1600 series
Customer: Tokyo Metro Co., Ltd.
Type: 8-vehicle
Number of Cars: 1600 series
Starting year of delivery: 2012

Tokyo Metro 1000 series
Customer: Tokyo Metro Co., Ltd.
Type: 8-vehicle
Number of Cars: 1000 series
Starting year of delivery: 2012

JRF HD300 series
Customer: Japan Freight Railway Company
Type: High Density
Number of Cars: 300 series
Starting year of delivery: 2012

Kita-Osaka Kyuko 9000 series
Customer: Kita-Osaka Kyuko
Type: 8-vehicle
Number of Cars: 9000 series
Starting year of delivery: 2012

Hankyu 1000 series
Customer: Hankyu Electric Railway
Type: 8-vehicle
Number of Cars: 1000 series
Starting year of delivery: 2012

Keisei N1000 series
Customer: Keisei Electric Railway
Type: 8-vehicle
Number of Cars: N1000 series
Starting year of delivery: 2012

SMART C151 series
Type: 8-vehicle
Number of Cars: 151 series
Starting year of delivery: 2012

Hanshin 5700 series
Customer: Hanshin Electric Railway Co., Ltd.
Type: 8-vehicle
Number of Cars: 5700 series
Starting year of delivery: 2012

Find out more on http://toshiba-railway.com

Permanent Magnet Systems
Efficient
Smarter
Quieter
Reliable

PMSM-1の表紙と同じ（なので不使用）
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- Tokyo Metro 02 series
  - Manufacturer: Tokyo Metro Co., Ltd.
  - Type: Subway
  - Order Date: 2002
  - Size: 82 sets
  - Starting year: 2010

- Tokyo Metro 16000 series
  - Manufacturer: Tokyo Metro Co., Ltd.
  - Type: Subway
  - Order Date: 2009
  - Size: 56 sets
  - Starting year: 2013

- Tokyo Metro 1000 series
  - Manufacturer: Tokyo Metro Co., Ltd.
  - Type: Subway
  - Order Date: 2015
  - Size: 23 sets
  - Starting year: 2017

- JRF HD300 series
  - Manufacturer: Japan Freight Railway Company
  - Type: Suburban
  - Order Date: 2011
  - Size: 15 sets
  - Starting year: 2012

- Kita-Osaka Kyuko 9000 series
  - Manufacturer: JR West
  - Type: Subway
  - Order Date: 2015
  - Size: 3 sets
  - Starting year: 2017

- Hankyu 1000 series
  - Manufacturer: Hankyu Electric Railway Company
  - Type: Subway
  - Order Date: 2020
  - Size: 2 sets
  - Starting year: 2023

- Keikyu N1000 series
  - Manufacturer: Keikyu Corporation
  - Type: Subway
  - Order Date: 2011
  - Size: 1 set
  - Starting year: 2012

- SMART C151 series
  - Manufacturer: SMART ELEKTROBAHN KOBLENZ GmbH
  - Type: Subway
  - Order Date: 2018
  - Size: 1 set
  - Starting year: 2020

- Hanshin 5700 series
  - Manufacturer: Hanshin Electric Railway Company
  - Type: Subway
  - Order Date: 2020
  - Size: 2 sets
  - Starting year: 2023

For more information, visit http://toshin.com