Contribution to Carbon Neutrality Using Brushless Motors

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The Paris Agreement, adopted at the 2015 United Nations Climate Change Conference (COP21), sets a goal of "limiting the increase in the global average temperature to well below 2 degrees Celsius above pre-industrial levels while pursuing efforts to limit to 1.5 degrees"[(1)]. Countries around the world are engaged in activities to achieve carbon neutrality by the second half of this century. To achieve carbon neutrality, it is essential to reduce energy consumption along with the use of clean energy and the reuse of CO_2 emitted. Looking at global energy consumption, since motors account for 53 %[(2)], replacing the motors currently in use with high-efficiency motors will lead to reduction in global energy consumption and achievement in carbon neutrality. This report explains the reduction effect of energy consumption for the high-efficiency brushless motor among various motors.

1. Introduction

To achieve the goal of limiting the increase in the global average temperature to 2 degrees Celsius while striving for 1.5 degrees, all parties have created a reduction target of greenhouse gas and engaged in activities to reduce energy consumption. To reach carbon neutrality in 2050, Japan set a target of reducing greenhouse gas emissions by 46 % by 2030 from 2013 levels[(3)]. In the "Sustainable Development Goals (SDGs)" adopted at COP21, Goals 1, 2, 11, and 13 include the mitigation of risks posed by climate change[(4)] (see Figure 1).

Figure 1. SDG icons: Goals 1, 2, 11, and 13

Activities to prevent global warming are required on a global scale, and carbon neutrality is essential to achieving the goal. In order to achieve carbon neutrality in the industrial field, it is necessary to use renewable energy with low CO_2 emissions, to store and reuse CO_2, and to reduce CO_2 emissions by reducing energy consumption. Focusing on the reduction of energy consumption in particular, motors account for 53 % of global energy consumption (see Figure 2), and replacing them with high-efficiency motors leads directly to carbon neutrality.

Many countries have introduced energy-efficiency regulations for electrical equipment, and motors are also subject to regulation because they account for more than half of global energy consumption. Motors used in continuous operation, such as compressors, pumps, and fan motors, account for 70 % of the total energy consumption of motors, and the scope of regulations is expanding from the present induction motors to include synchronous motors[(5) (6)].

This report compares induction motors and brushless motors (synchronous motors) sold by Oriental Motor, and explains how to contribute to carbon neutrality in addition to the reduction effect of energy consumption by using brushless motors.

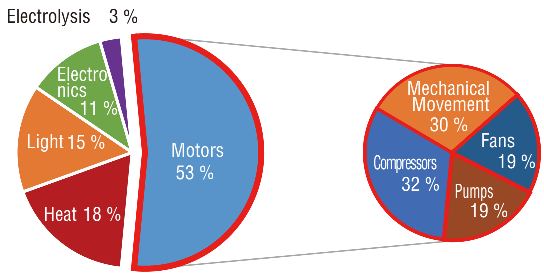


Figure 2. Breakdown of Global Energy Consumption[(2)(6)]

2. Structure, Drive System, and Loss for Each Motor

2.1. Induction Motors

2.1.1. Motor Structure

Figure 3 shows the structure of an induction motor. A stator has windings (coils) of copper wire inserted into a core of laminated electrical steel sheets, and the passage of alternating current through the windings creates a rotating magnetic field. A rotor consists of a core of laminated electrical steel sheets and a squirrel cage conductor (aluminum) (see Figure 4). The rotating magnetic field of the stator and the induced current of the rotor generated by the rotating magnetic field of the stator interact to rotate the rotor. This induced current creates secondary copper losses, which are the major factor in reducing efficiency (see Figure 5).

In addition, since magnetic flux must be generated in both the stator and the rotor, the electrical power required to rotate an induction motor is greater than that of a brushless motor described below. As a result, the efficiency deteriorates especially in the low-speed, low-torque operating range.

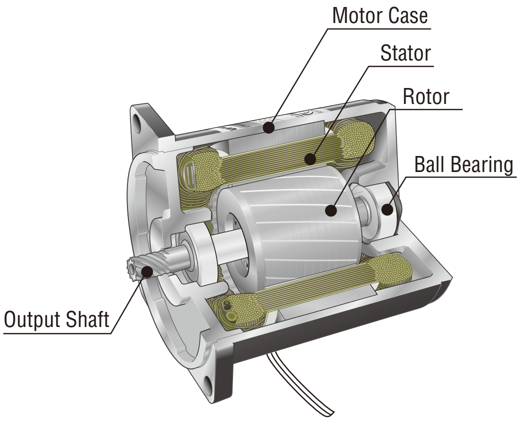


Figure 3. Structure of Induction Motor

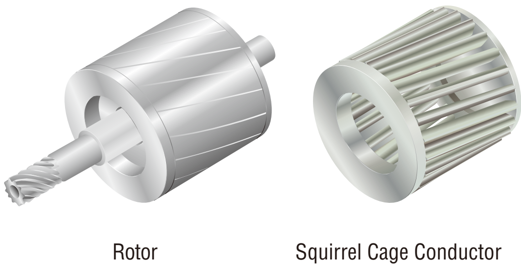


Figure 4. Squirrel Cage Rotor

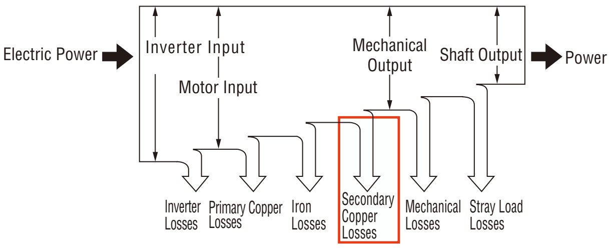


Figure 5. Breakdown of Loss for Induction Motor
(When driving with an inverter)

2.1.2. Variable-Speed Drive of Induction Motors

There are two methods of variable-speed control for driving induction motors, inverter control and phase control. Inverter control is a method of controlling the motor speed by changing the voltage and frequency applied to the motor, and is used for three-phase induction motors. Phase control is a method of controlling the motor speed by changing only the voltage applied to the motor. It is used for single-phase induction motors with a tachogenerator and is used in conjunction with closed-loop control. (7)

2.2. Brushless Motors

2.2.1. Motor Structure and Drive System

Figure 6 shows the structure of a brushless motor. Windings are wound around the stator, and permanent magnets are fixed on the rotor surface. Hall ICs are installed as a sensor to detect the position of the rotor, and closed loop control is performed by controlling the current to the stator windings based on the position and speed information of the rotor (see Figure 7). A drive circuit (driver) controls the current flowing through the stator windings to create a rotating magnetic field in the stator, thereby rotating the rotor. There is no induced current through the rotor and no secondary copper losses in the rotor as in an induction motor because a brushless motor uses permanent magnets for the rotor. Using permanent magnets makes the electrical power required to rotate a brushless motor less than that of an induction motor, resulting in lower losses (see Figure 8). In addition, the accuracy of detecting the rotor poles is improved by surface mounting the hall ICs used for the sensor, and the technology of controlling the motor current in the driver is further developed, enabling a high-efficiency drive. In recent years, further improvements in efficiency have been achieved by using low-loss electrical steel sheets, increasing the winding area by optimizing the stator shape, and using thicker electrical wires. (8)

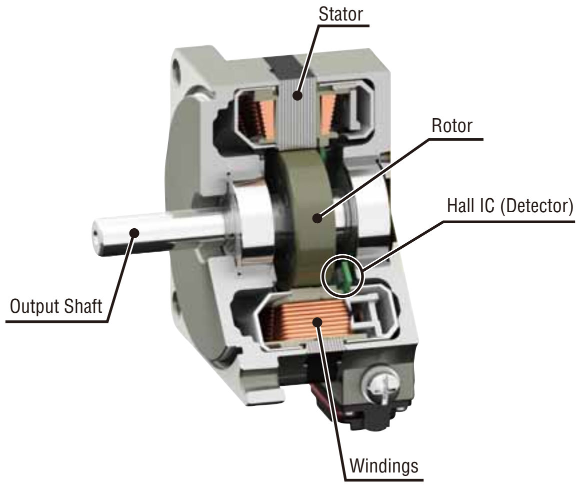


Figure 6. Structure of Brushless Motor

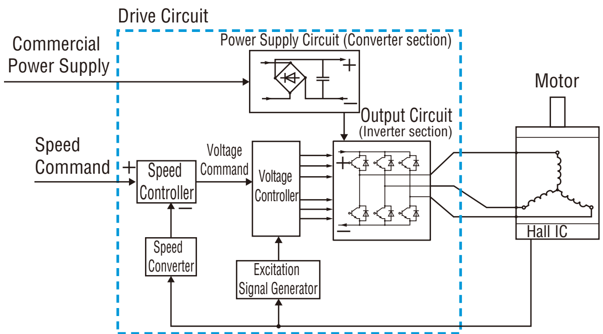


Figure 7. Basic Driver Circuit of Brushless Motor

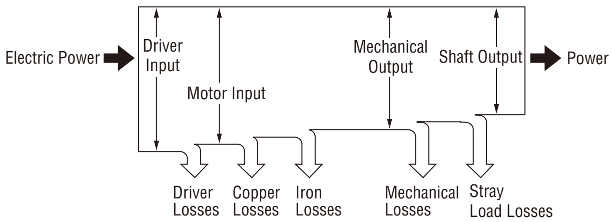


Figure 8. Breakdown of Loss of Brushless Motor

3. Efficiency Comparison of Each Motor

3.1. Efficiency Measurement Method

A method to measure the efficiency is when a constant load is applied to the motor by a torque load device and the input power to the equipment at each operating point is read by indication of a power meter (see Figure 9). Based on this measured value, the efficiency is calculated by formula (1).

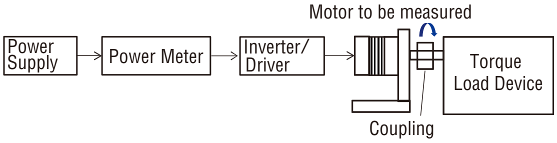


Figure 9. Efficiency Measurement System

$$\eta = \frac{Pout}{Pin} \quad \cdots\cdots (1)$$

η: Efficiency [%]

Pout: Motor output power [W]

Pin: Input power to inverter and driver [W]

3.2. Comparison of Power Consumption at the Same Output Power

The following example shows a comparison of power consumption when driving an induction motor with a rated output power of 90 W and when driving a brushless motor under operating conditions where the output power becomes 90 W (see Table 1). It indicates that the power consumption of a brushless motor is lower when the motor output power is equal.

Table 1. Comparison of Power Consumption at Output Power 90 W

Measuring product	Induction Motor with Inverter 	Brushless Motor 
Model	**5IK90A-SW2** (Motor) with inverter	**BLM5120HP-AS** (Motor) **BMUD120-A2** (Driver)
Power supply voltage	Three-phase 200 VAC	Single-phase 100 VAC
Torque [N·m]	0.570	0.287
Rotation Speed [r/min]	1550 (60Hz)	3000 (Rated speed)
Power Consumption [W]	154.6	110.0

3.3. Comparison by Efficiency Maps

When a motor is operated with variable speed drive, efficiency must be compared over the entire operating range since it changes according to the load factor and rotation speed. Therefore, an efficiency map showing the efficiency at each operating point within a range of continuous operation is often used. Figure 10 shows the comparison by the efficiency maps of the induction motor and brushless motor described in Table 1.

In this example, the load factor for the induction motor is the ratio of the load torque to the rated torque when the rated torque is 100 % at 60 Hz. The load factor for the brushless motor is the ratio of the load torque to the rated torque when the rated torque is 100 % (see Figures 11 and 12).

It shows that the brushless motor is more efficient over a wider range.

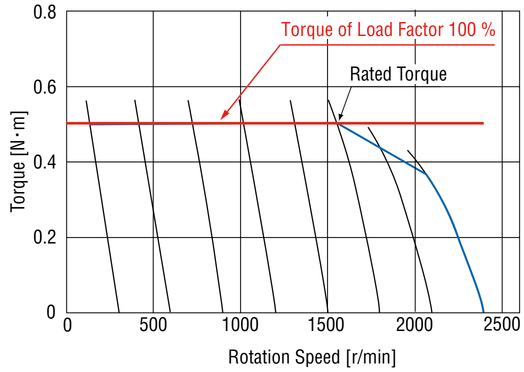


Figure 11. Concept of Load Factor for Induction Motor

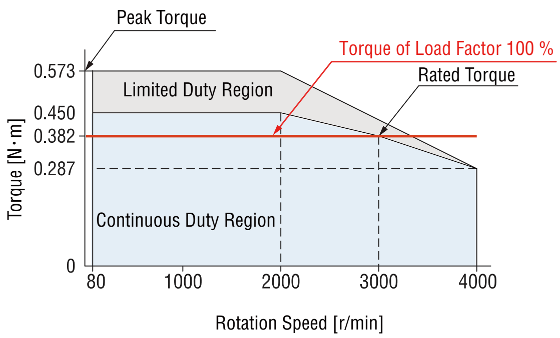


Figure 12. Concept of Load Factor for Brushless Motor

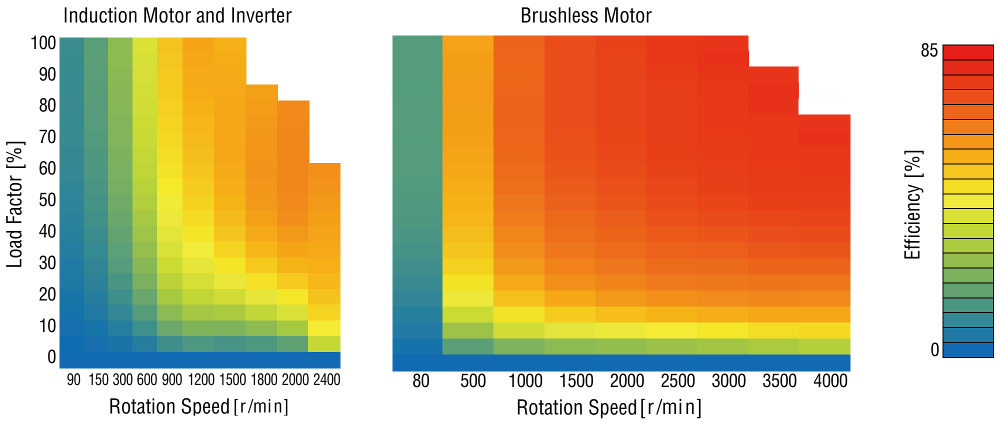


Figure 10. Comparison by Efficiency Map

4. Comparison of Power Consumption Using Conveyor as an Example

4.1. Power Consumption at Constant Speed Drive

Power consumption is compared when a gearhead is assembled with an induction motor and brushless motor described in Table 1 to drive a conveyor at a constant speed (see Table 4). Table 2 shows the torque and rotation speed of the gearhead output shaft, and Table 3 shows the operating conditions of equipment.

Table 2. Driving Conditions

Torque of Gearhead Output Shaft [N·m]	4
Rotation Speed of Gearhead Output Shaft [r/min]	100

Table 3. Operating Conditions of Equipment

Operating Conditions	
Number of Motors	1 unit
Operating Days per Year	300 days 12 hours / day
Energy Charge Rate[1]	16.38 yen / kWh
CO_2 Emission Factor[2]	0.441 kg-CO_2/kWh

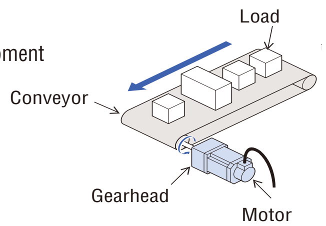


Table 4. Comparison of Induction Motor and Brushless Motor

	Induction Motor	Brushless Motor
Motor Combination	**5IK90GE-SW2** (Motor) **5GE15S** (**GE** parallel shaft gearhead) with Inverter	**BLM5120-20B** (Motor: With **GFV** parallel shaft gearhead) **BMUD120-A2** (Driver)
Gear ratio	15	20
Motor rotation speed [r/min]	1500	2000
Annual Energy Consumption [kWh/year]	346.0	219.7
Annual Electricity Rate [Yen]	5,668	3,599
Annual CO_2 Emissions [kg-CO_2]	152.6	96.88
Mass [kg]	4.7*	3.1

*Excluding an inverter mass

A comparison under the above conditions shows that using the brushless motor reduces power consumption and CO_2 emissions by 37 % per year.

The efficiency of a geared motor is reduced compared to a motor by itself because of losses caused by the internal load of the gearhead. Transmission efficiency represents a ratio (%) of the output power from a motor and that from a gearhead output shaft through gears (see Table 5). It varies depending on the gear type or the gear ratio due to structural differences, such as the number of gear stages. In the case of a geared motor, it is necessary to calculate the load factor of the motor output shaft, taking into account the transmission efficiency of the gearhead.

Table 5. Example of Gearhead Transmission Efficiency (Normal ambient temperature)

Transmission Efficiency [%]

Motor Output Power	Gearhead Type	Gear Ratio 5	10	15	20	30	50
BMU/BLE2 120 W	Parallel Shaft (**GFV**)	90	90	90	90	86	86
	Hollow Shaft Flat (**FR**)	85	85	85	85	85	85
	Right-Angle Hollow-Shaft Hypoid (**JH**)	65	65	65	65	65	65

4.2. Effect on Power Consumption due to Rotation Speed Change

Based on the conveyor drive described on 4.1, this section compares power consumption when a load is repeated to transport at 100 r/min and to decelerate to 30 r/min for inspection (see Table 6). The operating time at high-speed and low-speed is 50 % each and the total operating time is the same as that in Table 3.

Table 6. Change of Driving Conditions

Torque of Gearhead Output Shaft [N·m]	4
Rotation Speed of Gearhead Output Shaft [r/min]	From 100 to 30

A comparison of power consumption under these conditions shows that both power consumption and CO_2 emissions are reduced by 69 % per year for the brushless motor (see Table 7). Compared to the constant speed drive described on 4.1, the difference in efficiency between the induction motor and the brushless motor becomes greater. This is because the efficiency of the brushless motor is slightly reduced, while that of the induction motor is greatly reduced by changing the operating point (see Figure 13). As a result, the brushless motor can operate with higher efficiency even in applications where speed and torque vary.

Table 7. Change in Power Consumption due to Driving Conditions Change

Combinations of Products	**5IK90GE-SW2** **5GE15S** with Inverter	**BLM5120-20B** **BMUD120-A2**
Annual Energy Consumption [kWh/year]	258.9	81.22
Annual Electricity Rate [Yen]	4,240	1,330
Annual CO_2 Emissions [kg-CO_2]	114.2	35.82

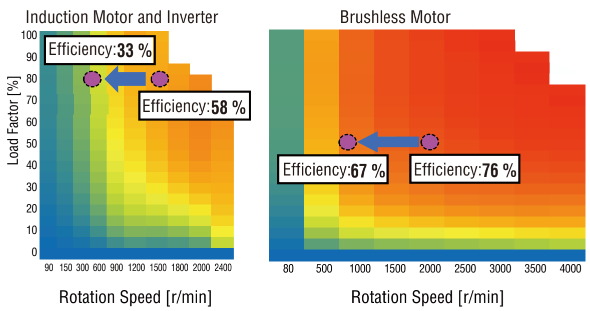


Figure 13. Change in Efficiency by Speed Change

1. TEPCO (Tokyo Electric Power Company) Energy Partner Website, "Commercial Electricity (Contract electric power 500 kW or more) Energy Charge - Other Season" as of October 2022
2. TEPCO (Tokyo Electric Power Company) Energy Partner Website, "CO_2 Emission Factor in Fiscal 2020"

5. Comparison of Motor Size and Mass

Changing from an induction motor to a brushless motor can reduce the motor size and mass (see Figure 14). Although the frame size is the same, the total length of the motor and gearhead for the induction motor is 200 mm, while that of the brushless motor is 95.4 mm, or 104.6 mm shorter.

The mass of the induction motor is 4.7 kg, while that of the brushless motor including the motor and driver is 3.1 kg, which is 1.6 kg lighter, even including the driver. Therefore, a brushless motor contributes to downsizing of equipment, reducing CO_2 emissions during transportation, and waste.

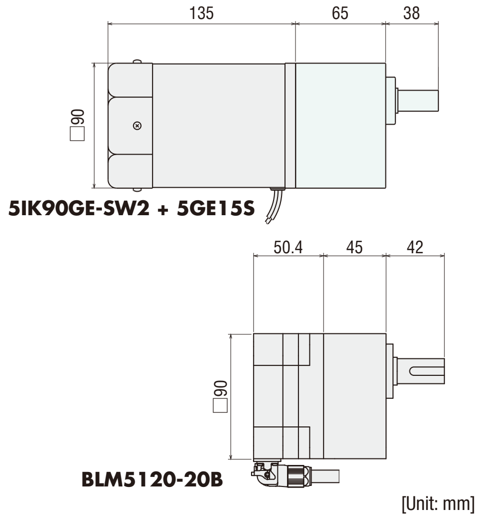


Figure 14. Comparison of External Dimensions

6. Improvement in Efficiency of Fans by Brushless Motor

High-efficiency fans using a brushless motor are also available (see Figures 15 and 16). Compared to conventional models that use an induction motor, it is possible to significantly reduce power consumption (see Table 8). In addition, since it is possible to change the speed using external analog settings or PWM signals, adjusting the airflow based on a load of equipment in the control panel can reduce not only power consumption but also noise (see Table 9).

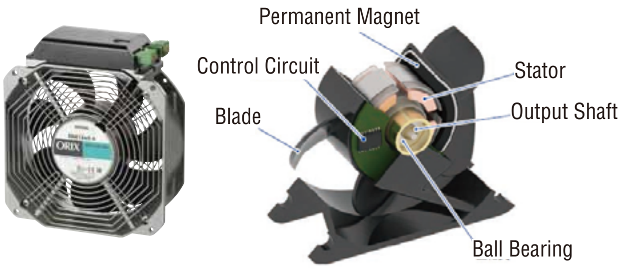
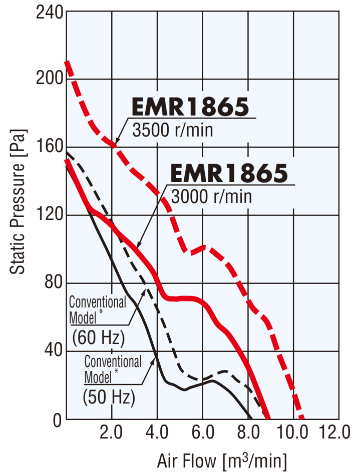


Figure 15. EC Fan **EMR** Series



* When the finger guards (**FG18D**) are installed on both sides of **MR18-BC**

Figure 16. Characteristics Comparison with Conventional Model

Table 8. Performance Comparison between **EMR** Series and Conventional Model

Model Designation	Conventional Model **MR18-BC***	**EMR1865**
Annual Energy Consumption (Maximum air flow) [kWh]	88.8	69.6
Annual Electricity Rate [Yen]	1,455	1,140
Annual CO_2 Emissions [kg]	39.2	30.7
Mass [kg]	3.9	1.3

Operating conditions: 12 hours / day, 300 days
*When the **FG18D** finger guard is installed on both sides of the fan to operate

Table 9. Rotation Speed and Noise Level of **EMR1865**

Rotation Speed [r/min]	Maximum Air Flow [m^3/min]	Maximum Static Pressure [Pa]	Power consumption (Maximum air flow) [W]	Noise level [dB (A)]
3500	10.4	211	38	59
3000	9.0	154	26	55
2500	7.2	105	17	50
1500	4.4	38	7	37

7. Summary

We provide brushless motors as a high-efficiency motor that contributes to carbon neutrality, and explained the effects of reducing energy consumption. A brushless motor is higher in efficiency than an induction motor and can significantly reduce energy consumption and CO_2 emissions.

Oriental Motor will continue to accurately assess society's needs and develop products and services to meet those needs.

References

(1) United Nations “Report of the Conference of the Parties on its twenty-first session”, (2015), p.4

(2) IEA “World Energy Outlook 2016”, (2016), pp.297-298

(3) Ministry of Economy, Trade and Industry, “The 6th Strategic Energy Plan”, (2021), p.4

(4) Oriental Motor Co., Ltd., Naoto SHOYAMA, “Latest Status of Energy Efficiency Regulations for Induction Motors and Fan Motors”, RENGA No. 2110, (2021)

(5) CEL 038-2020 Implementation Rules for Energy Efficiency Labeling of Permanent Magnet Synchronous Motors

(6) IEA “Walking the Torque: Proposed Work Plan for Energy-Efficiency Policy Opportunities for Electric Motor-Driven Systems ”, (2011), p.15

(7) Oriental Motor Co., Ltd., Masahiro TAKIMOTO, “Feature and control technology of the MSC-1 speed controller”, RENGA No. 176, (2012), pp.14-20

(8) Oriental Motor Co., Ltd., Shinya KUWATA, Ayuka HORI, “Features of the NexBL BMU Series Brushless Motor and Driver Package”, RENGA No. 179, (2014), pp.5-8

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