Low Starting Current Motor Developed for Top Runner Model

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Abstract

In April 2015, the Top Runner Standard (equivalent of IE3) for 3-phase induction motors started in Japan. The applicable category objective items of this system are 3-phase low-voltage induction motors with capacities of 0.75kW to 375kW (referred to as "the Top Runner motors"). These motors are stipulated to improve the energy consumption efficiency from IE1 to IE3.

A Top Runner motor generally tends to have an increased starting current to raise its efficiency. Such a feature can affect our customers who want to have a low starting currents specification motor.

As such, we developed low starting current type Top Runner motors.

1 Preface

It is estimated that about one hundred million motors are currently used in Japan and 97% of these motors belong to the IE1 efficiency class ("IE1" hereafter). If all 3-phase induction motors are improved to the IE3 efficiency class ("IE3" hereafter), it is estimated that about 1.5% of total power consumption in Japan (i.e. 15.5 billion kWh/year) could be reduced[(1)]. Fig. 1 shows efficiencies of IE1 and IE3 for 4-pole induction motors.

In 2011, AC motors were the applicable machines for the Top Runner Standard. In April 2015, the Top Runner Standard for 3-phase induction motors began. As a result of this expansion of the applicable range, the efficiency class of 3-phase induction motors had to be improved to IE3. When the efficiency class is improved, some energy saving can be expected. On the other hand, however, the starting current tends to be increased as a result. It is, therefore, necessary to take some appropriate measures for the customers who call for low starting current specifications. Given the aforementioned, we developed Top Runner motors that feature low starting currents. This paper introduces our low starting currents technology for Top Runner motors.

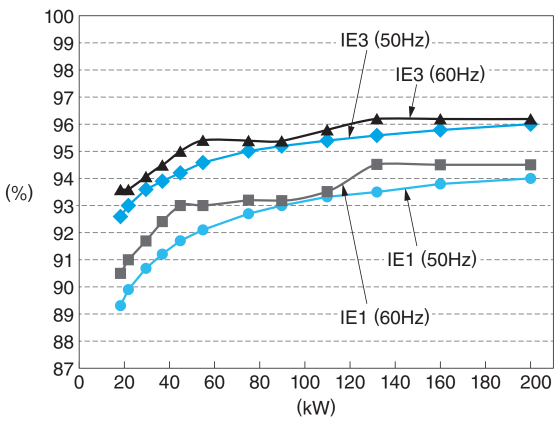

Fig. 1 Efficiencies of IE1 and IE3

Efficiencies of IE1 and IE3 are shown. These efficiencies are the values defined in JIS C 4213-2014 and JIS C 4034-30-2011.

2 Changes in Characteristics Due to Migration to IE3

When an electrical input is converted into a mechanical output in the motor, part of the energy is consumed in the form of losses. Motor efficiency is defined as a value that is the input minus the losses (=output) divided by the input. To improve the efficiency class from IE1 to IE3, a required amount of losses may be deducted. Fig. 2 shows the definition of motor losses and Table 1 shows the measures to reduce motor losses.

When the efficiency class is improved to IE3, there will be characteristic changes in the IE1 motor as described below.

(1) Compared with motor size of a totally enclosed motor of IE1, the total length becomes longer. Compared with drop-proof motors, the frame number becomes larger.

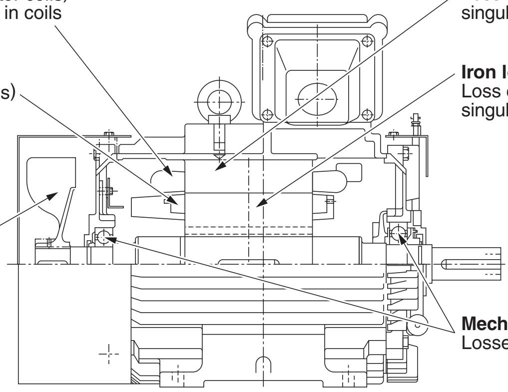

Fig. 2 **Definition of Motor Losses**

Types of motor losses are shown.

Table 1 **Measures to Reduce Motor Loss Reduction**

Measures to reduce motor losses reduction are shown.

Loss	Measures to reduce losses
Primary copper loss	· Increase in conductor cross section · Improvement of space factor for coils · Reduction of coil end length
Secondary copper loss	· Increase in conductor cross section
Iron loss	· Adoption of low loss electrical steel laminations · Adoption of thin electrical steel laminations · Optimization of magnetic flux density
Mechanical loss	· Reduction of cooling fan diameter · Adoption of low loss grease
Stray load losses	· Optimization of gap length · Optimization of the number of rotor slots · Optimization of rotor skew · Insulation of rotor slots · Iron core annealing

(2) The motor's starting current is greater.
(3) The rated speed of the motor becomes higher.
(4) Generated torque of the motor becomes greater.

For IE1 motors, the starting current value is 6 to 8 times the rated current. For IE3 motors, this value becomes 7 to 10 times. This is because motor impedance (consisting of ohmic component and inductance component, and the former is related to loss generation) is reduced in order to curtail losses, and this treatment results in an increase in starting current.

When the starting current is reduced, motor impedance is increased and motor losses are also increased. To realize a low starting current, it is necessary to reduce losses inclusive of the increased component. As a result, the frame number becomes greater compared with Top Runner motors.

3 Techniques for Reducing Starting Currents

To reduce starting currents, the following measures are generally taken:

(1) Utilizing the skin effect (a phenomenon where the current distribution is concentrated at the upper part of slots due to a high secondary frequency at the time of starting), the starting secondary resistance is raised. For this purpose, the slot cross section on the gap side is decreased in the case of a double cage rotor construction.

(2) In the case of full-voltage starting (a method of starting by applying the rated voltage directly to motor terminals), the effect of magnetic saturation is minimized in the vicinity of rotor core gaps. For this purpose, semi-closed slots are adopted.

(3) The number of coil turns is increased in order to raise motor impedance.

As a result of above measure (1), however, secondary copper loss is increased. As a result of above measure (2), the harmonic component of magnetic flux in gaps is increased. Influenced by these results, stray load losses (eddy current losses caused by harmonic magnetic flux) are increased. Still more, by virtue of above measure (3), primary and secondary copper losses are greatly increased. It is difficult for the Top Runner motors to carry out motor design where the starting current is suppressed.

As a technique to reduce the starting current while securing high efficiencies, we would like to introduce a rotor with a double cage rotor type construction as below.

This type of rotor has a slot structure as shown in Fig. 3 by applying a technique of the above measures (1) and (2). The starting current can be decreased by minimizing the cross section of each round slot part near the gap surface. At that time, however, a proper distance between round slot part and trapezoidal part is adequately taken into consideration in order to reinforce the effect of the skin effect at the time of starting. If the cross section of each trapezoidal part, distant from the gap surface, is increased, secondary copper loss can be suppressed during motor operation. Regarding round and trapezoidal slot sizes together with length and width of slit grooves, we are working on the optimum design by numerical analysis method.

In regard to the above measure (3), the conductor cross section is increased (making the iron core size larger) so that the resistance value can be decreased. By such a treatment, the increased amount of copper losses is cancelled. For the stator, measures specified in Table 1 were taken.

As an approach to reduce losses, insulation may be applied to the rotor slots and/or no treatment may be applied to the outer periphery of the rotor as follows:

(1) Rotor slot insulation

The inner surface of slots in the rotor iron core is insulated by a heat-resisting coating. By this treatment, short-circuit currents among rotor bars can be suppressed. It is, therefore, possible to suppress the interbar current loss that is one of the stray load losses. Since the surface is exposed to a high heat of molten aluminum at about 700°C during aluminum die cast treatment, it is necessary to use a heat-resisting coating material. Immersion treatment is carried out in an inorganic coating material that is superb in terms of heat resistant properties.

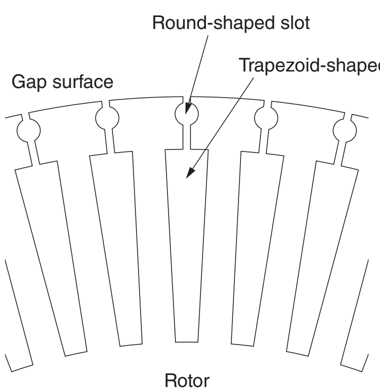

Fig. 3 Gap Structure of a Low Starting Current Motor

The gap structure of the rotor is shown.

(2) No treatment to the outer periphery of the rotor

Since the outer periphery of the rotor is processed after aluminum die cast treatment, this outer periphery is inevitably short-circuited. This eventually gives rise to surface losses consisting mainly of eddy current loss, generated by the effect of high frequency flux around air gaps. If no treatment is applied to the outer periphery of the rotor, it is possible to reduce the surface loss that is one of the stray load losses. To realize this no surface treatment, a high level of manufacturing expertise is required to produce high-level dimensional accuracy without the need for additional processing of the rotor external surface. This is required in the process of aluminum die cast treatment and shaft press-in (or shrink fitting).

4 Prototype Evaluation of a Low Starting Current Type Top Runner Motor

Using approaches introduced in Sections 2 and 3, we manufactured and evaluated a prototype 40kW 6-pole low starting current motor with the IE3 class efficiency. Since the inrush current at the time of starting the motor tends to be reduced as the starting power factor is raised higher, configuration of slots has been determined in consideration of this fact at the time of designing the prototype.

Table 2 shows characteristics of the demonstration unit. In regard to efficiencies, the machine attained almost the same level of energy consumption efficiency of 94.5% that is stipulated for the Top Runner motor. As a result of adopting the semi-closed slots, the effect of magnetic saturation upon the starting current has been found to be almost 1/3 compared with the totally closed slots. It was suppressed to be about 5 times of the rated current. The starting power factor was raised approximately by 20% compared with regular machines of the company with the same capacity. In addition, the

Table 2 Characteristics of the Demonstration Unit

Efficiency and starting current values of the low current starting Top Runner motor are shown.

	40kW-6P 440V-60Hz Result of prototype model
Frame No.	225SX
Rated current	62.9A
Starting current	464%
Efficiency	94.4%

inrush current at the time of starting could be reduced by about 10%. The overall length of this type of motor is also longer than that of standard Top Runner motors.

5 Postscript

This paper introduced our technologies for the development of low starting current Top Runner motors. When such technologies are applied, we can expect to realize high efficiencies for other range motors which are not covered by the Top Runner Standard. In the future, we will work on developing high-efficiency motors to meet applications not limited to top runner motors. In so doing, we will meet the various requirements of our customers.

《Reference》

(1) Agency for Natural Resources and Energy (2009 Report of Investigation into Actual Conditions of Energy Consuming Equipment), JAE-091907, Introduction of Top Runner Standards (draft) for JEMA 3-Phase Induction Motors