

# On the Study of Different Rotor Geometry Configuration for use in High-Speed Induction Motors

**Abstract** – In recent years, improvements in manufacturing, transportation and process industry technologies bring about an increase in optimal operation speed in drive systems. In this respect, recently developed high speed gear-less or direct-drive electrical drives have seen an increase in interest based on the reduction in the total structural volume of the drive system. Due to the significant development of cost-effective, fast switching and compact variable frequency drives technology, wide speed range operations of different type AC motors has become feasible. The speed definition of an induction motor can be seen in

quency drives. However, voltage qualities of these are not satisfactory due to limited switching frequency of high-power IGBT technology. Thus, high-speed levels might be calculated for frequencies in the range of 100 to 400 Hz are considered to be high-frequencies [2]. Owing to brush and commutator structure causing mechanical and electrical problems, DC drives are not allowed to be used for high-speed applications. In addition to the aforementioned statement, the structure is not appropriate for large centrifugal forces. Nevertheless, as high-speed drive applications, there are different type of AC motor concepts proposed in literature [1], [2], [3], [4]: Laminated/solid induction, permanent magnet synchronous and switched reluctance synchronous motors.

## I. Introduction

In recent years, improvements in manufacturing, transportation and process industry technologies bring about an increase in optimal operation speed in drive systems. In this respect, recently developed high speed gear-less or direct-drive electrical drives have seen an increase in interest based on the reduction in the total structural volume of the drive system. Due to the significant development of cost-effective, fast switching and compact variable frequency drives technology, wide speed range operations of different type AC motors has become feasible. The speed definition of an induction motor can be seen in Eq. 1

$$n = \frac{120f}{p}, \quad (1)$$

In literature, there are several descriptions for the term "high-speed". As a mechanical engineer, peripheral speed over  $150 \text{ m s}^{-1}$  is considered to be high speed [1]. From the motor manufacturer's point of view, a two-pole machine which is supplied higher than 50 to 60 Hz, can be considered as a high-speed machine. However, the most important point of view for the high-speed term is explained by development at power electronics. Nowadays, up to few hundreds hertz frequencies can be produced by variable fre-

quency drives. However, voltage qualities of these are not satisfactory due to limited switching frequency of high-power IGBT technology. Thus, high-speed levels might be calculated for frequencies in the range of 100 to 400 Hz are considered to be high-frequencies [2]. Owing to brush and commutator structure causing mechanical and electrical problems, DC drives are not allowed to be used for high-speed applications. In addition to the aforementioned statement, the structure is not appropriate for large centrifugal forces. Nevertheless, as high-speed drive applications, there are different type of AC motor concepts proposed in literature [1], [2], [3], [4]: Laminated/solid induction, permanent magnet synchronous and switched reluctance synchronous motors.

Below are the advantages of SRIM compared to CRIM:

- Structural and Mechanical integrity, Rigidity, Reliability and Strength of Material
- High thermal properties
- High speed in high power applications (high moment density)
- Low noise and vibrations in high speed applications
- Simple to protect against aggressive chemicals
- Ease of Manufacturing

- Low level of noise and vibrations (If the rotor has no slots)
- Linearity of torque-speed characteristics throughout the entire speed range
- The possibility of obtaining steady-state stability.

In 1950s, Solid-Rotor topologies for induction machines operating at high speeds have gained a lot of interest. From its inception to 1970s, various scientists and engineers have contributed to the development and the theory of solid rotor construction, where significant interest was seen the 1990s for using solid rotor structure for high speed applications.

As the rotor does not contain any trace of copper<sup>1</sup>windings, the eddy currents roam in the rotor without any conductive path restriction and cause the motor to have different characteristics compared to a Cage Rotor Induction motor (CRIM), an industry standard construction. While eddy currents are the main principle of its operation, these currents also causes the motor to have lower efficiency in slow speed applications and this indirectly decreases its power factor. But in high speed application where the speed is around 30000 rpm the losses become far less and SRIM becomes the better choice for high speed applications.

## I.1. Report Structure

In this report for Drive Technologies, the high-speed performance of the four different types of rotors are investigated and compared using finite element analysis: cage, smooth solid, axially slitted, coated is designed using a finite-element analysis (FEA). All rotors are designed with similar geometries and construction parameters to minimise the effect of unwanted effects.

```
1 // C++ program to find all string
2 // which are greater than given length k
3
4 #include <bits/stdc++.h>
5 using namespace std;
6
7 // function find string greater than
8 // length k
9 void string_k(string s, int k)
10 {
```

```
11 // create an empty string
12 string w = "";
13 // iterate the loop till every space
14 for (int i = 0; i < s.size(); i++) {
15     if (s[i] != ' ')
16
17         // append this sub string in
18         // string w
19         w = w + s[i];
20     else {
21
22         // if length of current sub
23         // string w is greater than
24         // k then print
25         if (w.size() > k)
26             cout << w << " ";
27         w = "";
28     }
29 }
30 }
```

The number of turns per stator slot is selected so as to obtain the same stator current in rated operation. All four motors were analyzed using FEA tools for 20 different speeds in order to obtain the combined torque-speed characteristics. To illustrate visually the differences in the distributions of the magnetic flux and the eddy current the results for 11300 rpm are presented and the core loss, the total loss and the efficiency for the specific speed are compared for all the motors. The designed four motors will be also compared for winding currents, induced voltages, flux linkages, electromagnetic torque, copper losses, iron losses, solid rotor losses and efficiency.

## Bibliography

- [1] J. F. Gieras and J. Saari, "Performance calculation for a high-speed solid-rotor induction motor", *IEEE transactions on industrial electronics*, vol. 59, no. 6, pp. 2689–2700, 2011.
- [2] J. Pyrhönen, "The high-speed induction motor: Calculating the effects of solid-rotor material on machine characteristics", *Acta Polytechnica Scandinavica, Electrical Engineering Series;(Finland)*, vol. 68, 1991.
- [3] J. Lähteenmäki et al., *Design and voltage supply of high-speed induction machines*. Helsinki University of Technology, 2002.

<sup>1</sup>the rotor consists of a solid body of steel or similar ferromagnetic material

- [4] J. Saari et al., *Thermal analysis of high-speed induction machines*. Helsinki University of Technology, 1998.