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Development of Self Bearing Machine Using a Specialized Stator Winding

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Abstract

Self-bearing machines have a combined characteristic of magnetic bearings and electrical motors. They are capable of generating torque in the machine while suspending the rotor. This suspension is achieved by the presenceof a net electromagnetic force which is produceddue to an unbalanced magnetic flux distribution in the air gap created by means of supplying additional currents in the stator winding. This paper discusses the development of such aself-bearing machine equipped with a specialized type of stator winding scheme capable of achieving direct control on the unbalanced components of the stator magneto-motive force (MMF) without affecting the torque producing components.These machines have applications in minimizing vibration, offsetting deflections due to external loads, alleviating bearing loads and enabling intelligent condition monitoring.

Keywords: Self-bearing, Stator Winding

1. Introduction

During the last few decades electrical machines are widely used for high speed operations. So in order to improve their productivity and quality of work efforts are being made to convert them into self-bearing machines. This is achieved by integrating magnetic bearing characteristics in a conventional electrical motor. The unbalanced magnetic force in an electrical machine is exploited in so-called self-bearing or bearing-less electrical machine where, as well as functioning as a motor, the machine can also produce transverse forces or bearing forces perpendicular to the rotation axis. Currently, it is common to take a standard motor and replace the mechanical bearings with magnetic bearings to obtain very high speed operation. Self-bearing machine treat motor and bearing as an integral unit. Such machines operate by creating an unbalanced flux distribution in the air gap by supplying variable currents in the stator windings.

Chiba et al.[1] introduced a bearing-less (self-bearing) concept in AC machinery. In this self-bearing machine, the rotor position is controlled by controlling the magnetic flux density at the air gap. Two separate sets of winding schemes have been incorporated in this type of winding; the primary sets carries the motor currents while the secondary set carries levitation currents. However, they inherently suffer from poor specific power rating.

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Arkkio et al.[2] deployed two discrete sets of windings in the motor and this allows the use of a standard supply. Normally the supplementary winding is distributed to the stator slots in the wedge area and occupies about 10% of the total cross-sectional area of a single slot, which otherwise would have occupied by the primary windings. Again Takemoto et al.[3] demonstrated self-bearing capabilities in a switched reluctance motor where the main winding was responsible for rotation of the motor and the secondary winding for providing suspension force to the rotor.However, in 2005 a single set of winding called bridge configured winding (BCW) was introduced by Khoo[4,6] for polyphase self-bearing machines which could generate both torque and transverse force using the same winding. The nature of this winding was such that the currents responsible for producing torque was divided into two parallel paths and an isolated power supply called bridge currents in the midpoint of the path could produce a net lateral force. With no bridge current supply, the motor could operate as a normal torque producing machine. This design was an elegant development where no additional windings were used to produce the net lateral forces like in dual set of winding. Later Khoo and Garvey[5] demonstrated this capability of controllable transverse force production by using bridge configured winding (BCW) in a three phase 1.1 kW brushless permanent magnet motor.

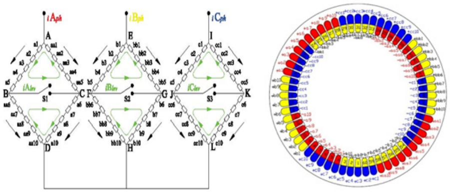
This present study demonstrates the use of bridge configured winding scheme for the development of a self-bearing machine. It is achieved by replacing the original stator winding of a conventional 37 kW induction motor with the BCW. The developed machine is then experimentally investigated for lateral force production and the obtained results are presented.

2. Bridge Configured Winding In Self Bearing Machine

Bridge configured winding (BCW) is a double layered, single set of winding consisting of two parallel paths. The principle feature of this winding is that the parallel path currents can be utilized for the production of force by using an isolated supply at the midpoint of these two paths. In this present study, BCW scheme, as shown in Figure 1(a), has been applied in place of conventional stator winding in an induction motor in order to demonstrate the self-bearing possibilities.

This winding achieves self-bearing operation by the superimposition of the torque and the force producing components of the stator MMF, having a pole-pair number difference of one.

An uneven flux density distribution due to rotor eccentricity present in the system can produce an additional flux of pole pair (p±1), (where, p is the number of fundamental pole pairs).Any one of this additional flux pole pair interacts with the fundamental pole pair flux and as a result a significant net transverse force (UMP) can be produced. BCW scheme works on this principle. An additional 2-pole field has been introduced purposefully with the 4-pole fundamental field by short circuiting the bridges. By superimposing this 2-pole field and 4-pole field, a levitation force can be produced to counteract the UMP which is already present in the system. The induced bridge currents have the capability of producing an additional 2-pole and 6-pole magnetic flux density components. These 2-pole and 6-pole fields can interact with the 4-pole main field and thus a radial magnetic flux density can be produced in the air gap.

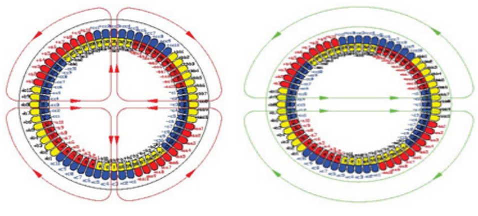


(a) (b)

Figure 1. (a) Bridge configured winding scheme for three phases. (b) A winding scheme of a distributed, double layered bridge configured winding

Consider the Phase A winding connection of the induction machine shown in Figure 1(a). When the induction machine is supplied with the main supply, the current will flow through the arm AB and BD in one path as well as AC and CD in an another path. A four pole field has been formed according to the winding pattern as shown in Figure 2(a). It has been realized that the with the presence of unbalance in the system, current will flow through the arm BC as soon as it is being short circuited and it is called as levitation current i_{Alev}. The levitation current i_{Alev} will flow in the arm AB through the arm CA in order to make a closed loop path. Similarly, the levitation current i_{Alev} will flow in the arm DB through CD. It has been observed in the arms AC and BD that the levitation current i_{Alev} flows in the opposite direction to the direction of main supply current i_{Aph} shown in Figure 1(a). The polarity of the current flowing in the arms AC and BD have been reversed due the opposite direction of flow of levitation current and thus the 2-pole field has been formed as shown in Figure 2(b). The super imposed levitation field is a pole pair different with the main pole pair field. As a result, a net transverse force called levitation force is exerted on the rotor. Therefore, a levitation force can be produced in any arbitrary direction with the combination of bridge connections.

This levitation force can then be utilised for converting the induction motor into a self-bearingmachine.

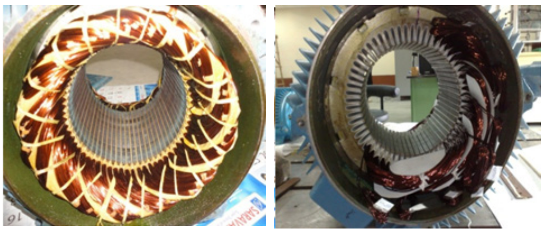


(a) (b)

Figure 2. (a) 4 pole field formation. (b) 2 pole field formation.

3. Development of the Self Bearing Machine

In this present study the machine under consideration, as shown in Figure 3(a), is a three-phase, 4-pole, 37kWinduction motor with 60 stator slots. The original winding ofthe machine was removed as shown in Figure 3(b). The stator was then rewound with anew set of coils based on the bridge configured scheme presented in Figure 1(a). The existing stator winding was a double layered full pitch winding having 4 strands and 11 turns with a coil pitch of 15. The existing main coil winding was modified to 3 strands and 11 turns of same wire diameter in order to accommodate the search coil winding over the main coil winding. The new bridge configured winding is a distributed, double layered; chorded winding as shown in Figure 1(b). The fact that the bridge configured winding requiresa number of terminal locations for bearing currents injectionmeans that a continuous slot-to-slot distributed winding methodcannot be implementedas in conventional machines. Instead,several discrete preformed coils were prepared at the outset beforebeing inserted into the stator slots. The rewinding processwas carried out manually. Figure 4 (a) shows the induction motor after being rewound according to the bridge configured winding scheme.

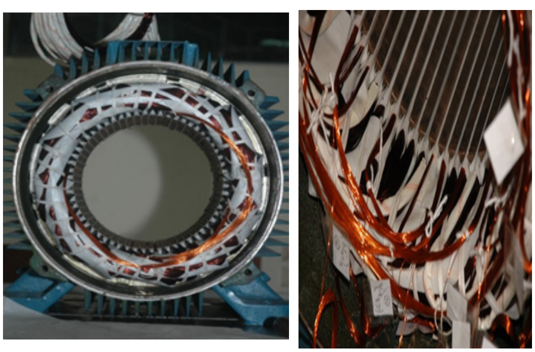


(a) (b)

Figure 3. (a) Induction motor with conventional winding. (b) Induction motor during rewinding.

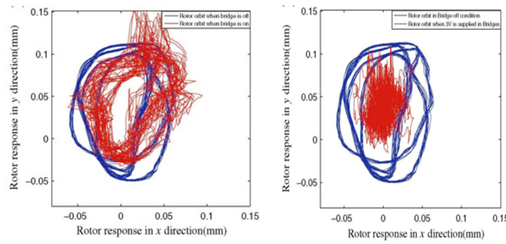
4. Results

The developed self-bearing machine has been experimentally examined. Figure 5(a) and 5(b) gives a comparision of the rotor orbits with and without bridge currents suggesting that anelectromagnetic force is generate which can be utilised for levitation of the rotor.



(a) (b)

Figure 4. (a) Induction motor after rewinding with BCW. (b) Exploded view of the stator windings.



(a) (b)

Figure 5. (a) Rotor orbit when bridge is off and on (b)Rotor orbit when bridge is off and on at 3 V supply.

5. Conclusion

A conventional 4 pole induction motor has been rewound with the specialized bridge configured winding. In this new scheme the three phase motor terminals have been retained and a separate terminal has been given for transverse force generation. The developed test rig has then been utilised to experimentally demonstrate its transverse force producing capability which is proposed to be utilised for self-bearing operation of the induction machine.

6. References

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