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Review Article

Design, Development, FEM Analysis of Hybrid 12/14 BSRM for Saispandan- Bearing-Less Magnetic Indian Total Artificial Heart for Destination Therapy (DT)

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Abstract

Rotor vibration control during start-up, acceleration and deceleration phases are one of the key problems besides stable levitation, in high-speed applications of bearing less switched reluctance motor (BSRM) [1-3]. Global sliding mode controller (GSMC) is proposed to control the speed and position of BSRM. Sensor less operation is achieved with sliding mode observer. Rotor displacement tracking error functions were used in the sliding mode switching functions. New sliding mode displacement control and speed tracking equations obtained using extra exponential fast decaying nonlinear function and conventional linear sliding mode switching. Simulation is carried on hybrid 12/14 BSRM with the proposed controller and observer. 12 stator poles and 14 rotor poles were selected. Pole arc was 25.71. FEM analysis showed Torque pole arc was 12.85. Air gap length was 0.25 - 0.5 mm. Stator diameters -112/60.2, stator yoke thickness 7.7 mm, shaft diameter of 18 mm, coil width of 4 mm, rotor pole arc of 12.85, axial stack length of 40 mm, rotor yoke thickness of 9.7 mm-were the major design parameters. FEM of motor parameters under different loads for speed, torque load, switching angle, voltage, phase resistance and moment of inertia was performed. Separated single winding, wide suspending force region, higher power density, natural decoupling of torque from suspending force, low magnetic motive force, low core cost of hybrid 12/14 BSRM makes it ideal as motor for total artificial heart as destination therapy.

Keywords: *Bearing Less Switched Reluctance Motor (BSRM); Global Sliding Mode Controller (GSMC); FEM Analysis; Destination Therapy (DT)*

Introduction

Maglev motors can be bearing or bearingless. Bearingless switched reluctance motors have inherent fault tolerance, rotor robustness and reliability at higher speeds as there is no rotor winding. These types of motors can be used in electrical energy storage systems, electric vehicles and space missions. When motors are used as heart pumps motor breakdown due to failure of mechanical bearings can be avoided. They are compact, clean, maintenance free and can be manufactured at lower costs [4-6]. Sensorless BSRM was thought of to reduce the complexity, size and cost of the complete drive system. Torque ripple due to non-linearity was still a cause for concern. Advanced sliding mode controllers like GSMC and DSMC to make the system more stable and healthy was thought of sliding mode torque observer was used to reduce torque ripple. New SMTO based square currents control method and iterative learning compensation method was used. Miniaturization and high speed is easy to attain. The output power is higher. Number of wires and inverter is less and so is the cost. They are seal free and no lubrication is needed.

Two types of winding are needed on each stator pole one is the torque winding and the other is the suspending force winding. Torque control needs to be decoupled from the suspending force control [7-10]. A novel method for the same had to be resorted to. Usage of two windings could result in a higher cost. If axial length increases then the speed of the rotor is reduced. It was important to avoid the high reverse torque needed to maintain the rotor at the centre. Reduction of stator poles would lead to lower power density, longer flux paths, flux reversals and increased magnetic motive force with higher core losses. We used a simple 12/14 BSRM to get a decoupled nature between the suspending force and motor torque. Two types of windings were used. Suspension force winding for suspension force and torque winding to provide the reluctance torque. No windings exist in the rotor. 2 self-regulated DC supply achieves a decoupled performance [11-14].

Design of 12/14 BSRM

12 stator and 14 rotor pole numbers. For steady levitation 4 stator poles act as suspending force poles. Due to short flux path and symmetry of structure number of torque poles should not be less than 8. So the total number of stator poles is 12. Two stator poles that are diametrically opposite should have the same phase. The mutual inductance of phase winding is thus minimized. For the rotor in any position the rotor poles should match the number of stator poles that gives the motor a self-starting capacity in positive and negative direction. So, Ns/ Nr = 12/14.

Increasing self-starting capability results in lower average torque due to decreasing positive inductance slope. Critical to design are suspending force pol arc, torque pole arc and rotor pole arc. Torque pole arc is slightly smaller than rotor pole arch that makes the assigned position inductance as large as possible with a slight increase in slot area. For continuous torque the torque pole arc should be smaller than the step angle. The derived torque and rotor pole arc are equal and is 12.85 degrees. To have enough space for the winding the suspending pole arc was selected as 25.7 degrees. Any decrease in air gap results in increase of electromagnetic torque and radial force. Aligned inductance is very sensitive to air gap length. Range selected was 0.25 mm to 0.5 mm (Figure 1).

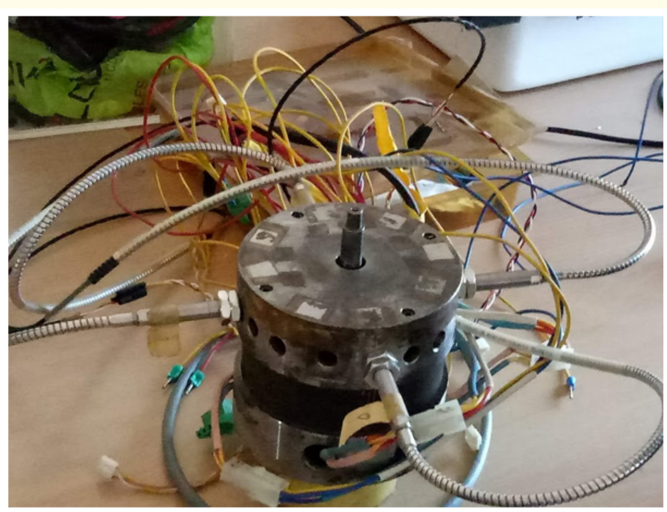

Figure 1: *Hybrid 12/14 BSRM 1 KW model. Miniaturisation of this model is being done.*

Unique design advantages

Significant advantages of this design is that one winding on each stator pole makes it relatively easier to manufacture. Separated windings on separate torque and suspending force pole is good for decoupling torque from radial force. There is a constant overlap area between suspending force pole and rotor pole at any rotor position. In this design compared with conventional bearing less SRM the suspending force region is wider. This design naturally decouples torque from suspending force control. Torque produced by the suspending force winding is small with fixed excitation current. This happens due to the constant overlapping area between suspending force pole and rotor pole. Power density of this design is higher as ⅔ stator poles are used for torque. Shorter flux paths reduce the magnetic motive force. Lower flux reversal reduces core loss also.

Operating parameters and principles

Operating Parameters are given in table 1. Uniqueness lies in salient poles both in the stator and rotor, with excitation being limited to stator alone. Torque adopts configuration of minimum reluctance. Suspending force pole and torque pole forms the two types of stator poles. Suspension force winding and torque winding provide the corresponding forces. Two self-regulated DCV supplies achieves a net decoupled performance between net levitation and motor torque. Radial force is generated by suspension winding coils in X and Y axis. Stator main phase coils produce the resultant rotational torque.

Sl. no	Design Parameters of BSRM	Dimensions in mm
1	Outer diameter of stator (mm)	112
2	Stator yoke thickness (mm)	7.7
3	Stator inner diameter (mm)	60.2
4	Axial stack length (mm)	40
5	Rotor pole arc (deg) (Br)	12.85
6	Rotor yoke thickness (mm)	9.7
7	Diameter of shaft (mm)	18
8	Coil width (mm)	4

Table 1: *Design parameters of hybrid 12/14 BSRM.*

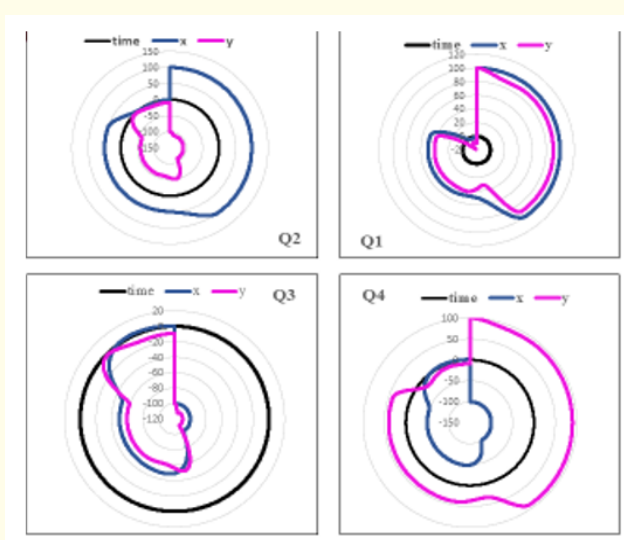

Figure 2: *Stable rotor position on varying parametric loads.*

Switching control strategy

Here the BSRM is a six phase drive. 8 power switches control four phase suspension winding and four power switches for two phase torque winding coils. Independent control can be achieved by asymmetric converters. Mode 1 is magnetization and Mode 4 is demagnetization mode, with 3 and 4 being freewheeling modes. Switching state 1 is magnetization mode, 0 freewheeling mode and -1 is the demagnetization mode [15-18].

FEM analysis

2D Magnet software to observe the short flux paths, no flux reversal and decoupled nature of suspension force and main torque. Performance analysis of BSRM under different eccentric positions were noted.

Magnetic flux distribution, inductance, torque and suspending force vs position and current was analysed. Eccentric faults can cause the rotor to rub against the stator poles and cause deterioration of the motor. Sensorless method was used to reduce the manufacturing complexity. Closed loop torque control is needed for better torque profiles. Torque sharing function may lead to loss of robustness. Smooth torque profiles needs square current control method and iterative learning compensation techniques along with GSMC based sliding mode torque observer [19-24].

New robust controllers DSMC and GSMC were used to control rotor displacements and speed and SMO for avoiding mechanical sensors and reduce the complex controlling processes.

Conclusion

Excellent decoupling environment between stator torque control and suspension force control is found at different values of currents. Suspension force and motor torque increases with increase of rotor eccentric displacements in the Y direction. In addition to the improved performance characteristics GSMC cancels the reaching mode, reduces chatting and overcomes the disturbance and time delay. The closed loop operation of BSRM system with conventional and global sliding mode controllers were found to be working very well under different loading conditions [25-27]. GSMC based SMO offers less chattering greater stability and accurate rotor displacement, position and speeds under unexpected changes of reference and loading conditions.

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