

A. Khargade, S. B. Bodkhe and A. K. Rana, "Closed loop control of axial flux permanent magnet BLDC motor for electric vehicles," *2016 IEEE 6th International Conference on Power Systems (ICPS)*, New Delhi, 2016, pp. 1-6.

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Abstract: Compact motor with high torque and wide speed range is the primary requirement for in-wheel electric vehicle application. Axial flux permanent magnet (AFPM) brushless direct current (BLDC) motors are an interesting solution for electric vehicles, because of their shape, flexibility, compactness, robustness, high efficiency, wide speed range and high torque. In this paper, a slotless AFPM BLDC motor is proposed. It has single side configuration with 24 stator poles and 36 permanent magnets (PM) on rotor disc. In most of the applications of AFPM BLDC motor, the speed control is very important. To achieve accurate speed control, closed loop control using microcontroller is proposed in this paper. Microcontroller is used to drive the motor by sensing rotor position using Hall sensors. The effective braking scheme is also proposed. To verify the performance of the proposed AFPM BLDC motor, simulation is carried out and results are presented. A prototype of AFPM BLDC motor is designed and fabricated in order to validate the performance of the motor.

keywords: {angular velocity control;brushless DC motors;closed loop systems;electric vehicles;microcontrollers;permanent magnet motors;rotors;stators;AFPM brushless direct current motor;Hall sensors;axial flux permanent magnet BLDC motor;braking scheme;closed loop control;electric vehicle;in-wheel electric vehicle application;microcontroller;permanent magnets;rotor disc;rotor position sensing;speed control;stator poles;Brushless DC motors;Permanent magnet motors;Rotors;Stator cores;Stator windings;Axial flux machine;BLDC motor;Hall sensor;closed loop control;electric vehicle;microcontroller;permanent magnet motor},

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W. Gruber, T. Nussbaumer, H. Grabner and W. Amrhein, "Wide Air Gap and Large-Scale Bearingless Segment Motor With Six Stator Elements," in *IEEE Transactions on Magnetics*, vol. 46, no. 6, pp. 2438-2441, June 2010.

doi: 10.1109/TMAG.2010.2043820

Abstract: In recent years, the demand for high purity spinning processes has been growing in certain industry branches, such as the semiconductor, biotechnological, pharmaceutical, and chemical industry. Therefore, the cleanness specifications have been tightened, and hermetically sealed process chambers are preferred. This paper presents an advantageous solution for such an application featuring a large scale, wide air gap, and a high accelerating bearingless segment motor. Bearingless slice motors allow complete magnetic levitation in combination with a very compact and economic design. The disc-shaped rotor holds permanent magnets generating magnetic flux in the air gap. Hence, three degrees of freedom are passively stabilized by reluctance forces. Thus, only the radial rotor position and the rotor angle have to be controlled actively. The announced bearingless segment motor is a subtype of the bearingless slice motor, featuring separate independent stator elements. This leads to a reduction of stator iron, cost, and weight and, in addition, leaves space for sensors and electronics enabling a very compact system design.

keywords: {air gaps;magnetic levitation;permanent magnet motors;rotors;stators;synchronous motors;disc-shaped rotors;largescale bearingless segment motor;magnetic levitation;permanent magnet motors;stators;wide air gaps;Chemical elements;Chemical industry;Hermetic seals;Large-scale systems;Permanent magnet motors;Pharmaceuticals;Reluctance motors;Rotors;Spinning;Stators;Electromagnetic forces;magnetic levitation;nonlinear systems;permanent-magnet motors;synchronous machines},

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T. Stallinger, W. Gruber and W. Amrhein, "Bearingless segment motor with a consequent pole rotor," *2009 IEEE International Electric Machines and Drives Conference*, Miami, FL, 2009, pp. 1374-1380.

doi: 10.1109/IEMDC.2009.5075382

Abstract: Bearingless motors combine contactless levitation and rotation in a preferably compact system design, because the bearings as well as the motor windings are located on the same lamination stack. Using a permanent magnet excited disc shaped rotor, three of the six degrees of freedom can be passively stabilized by means of reluctance forces. The bearingless segment motor features concentrated windings on separated stator segments. However, such motors usually require the measurement of the rotor angle and the rotor position for a proper operation. An advantage of the bearingless consequent pole motor is the radial force generation by direct current (dc). Thus, no angular sensors are needed in this concept. A combination of the bearingless segment motor and the consequent pole motor leads to a new type of bearingless motor. In this case the radial force generation becomes independent from the rotor angle and a decoupled generation of motor torque is possible. This investigation focuses on the optimization of the operation characteristics, the control scheme and the comparison of the simulation results with the measurement data of a manufactured prototype.

keywords: {electric motors;machine control;rotors;stators;torque;bearingless segment motor;consequent pole rotor;contactless levitation;lamination stack;motor windings;radial force generation;stator segments;torque generation;DC motors;Force sensors;Lamination;Levitation;Permanent magnet motors;Permanent magnets;Position measurement;Reluctance motors;Rotors;Stator windings},

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K. C. Tripathi, P. Lal, P. R. Sarma, A. K. Sharma and V. Prakash, "A Battery-Run Pulsed Motor with Inherent Dynamic Electronic Switch Control," in *IEEE Transactions on Industrial Electronics and Control Instrumentation*, vol. IECI-27, no. 1, pp. 29-34, Feb. 1980.

doi: 10.1109/TIECI.1980.351658

Abstract: A new type of battery-run brushless ferrite-magnet dc motor system is described. Its rotor part consists of a few permanent ceramic (ferrite) magnets uniformly spread on the rim of a disk (wheel) and the stator part consists of electromagnets placed in such a way that when energized, they always form a repulsive couple to rotate the disk. A sensor coil is placed to give an induced pulse signal, which acts as an inherent dynamic switching time control for the automatic electronic control system. Control of speed, brake system, and safety measures are also discussed. Experimental values for the present system are given. Some possible applications are suggested.

keywords: {Automatic control;Brushless DC motors;Ceramics;Control systems;DC motors;Ferrites;Permanent magnet motors;Rotors;Switches;Wheels},

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H. K. Jussila, A. V. Mityakov, S. Z. Sapozhnikov, V. Y. Mityakov and J. Pyrhönen, "Local Heat Flux Measurement in a Permanent Magnet Motor at No Load," in *IEEE Transactions on Industrial Electronics*, vol. 60, no. 11, pp. 4852-4860, Nov. 2013.

doi: 10.1109/TIE.2012.2222853

Abstract: Heat transfer is a limiting factor in the performance of electrical machines. Measuring the heat flux in an electrical machine is traditionally carried out indirectly with temperature measurements as there are only a few sensors for heat flux measurements. This paper

describes a new experimental method to measure the local heat flux inside an electrical machine. The measurement was proven successful in the air gap of the permanent magnet machine, 37 kW 2400 min⁻¹, under an influence of the air gap magnetic flux. The heat flux was measured by using sensors based on the transverse Seebeck effect. The test machine was an axial flux permanent magnet machine with two stator stacks and one internal, ironless rotor disc. A gradient heat flux sensor was installed in the air gap on the stator side. Local Nusselt and Reynolds numbers were calculated according to the measured heat flux results and compared with the results given by traditional methods to verify the new measurement method.

keywords: {Seebeck effect;air gaps;heat transfer;permanent magnet motors;stators;temperature measurement;temperature sensors;air gap magnetic flux;axial flux permanent magnet machine;electrical machines;gradient heat flux sensor;heat transfer;ironless rotor disc;local heat flux measurement;permanent magnet motor;power 37 kW;stator stacks;temperature measurements;transverse Seebeck effect;Magnetic sensors;Resistance heating;Temperature measurement;Temperature sensors;Axial flux permanent magnet (AFPM) machine;concentrated tooth winding;heat flux;heat flux measurement;permanent magnet machine},

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