A Novel Five-Phase Double-Stator Tubular Fault-Tolerant Flux-Modulation Permanent Magnet Motor

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Summary

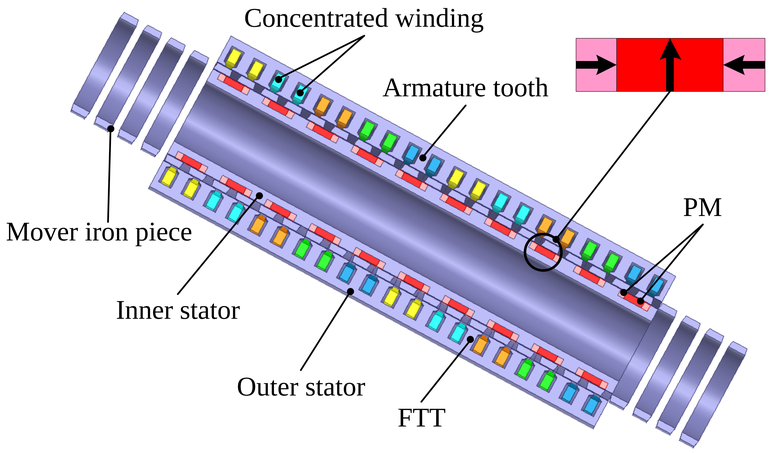
Tubular permanent magnet motors have been applied to many direct drive systems. This paper proposes a novel double-stator tubular fault-tolerant (DSTFT) flux-modulation permanent magnet (FMPM) motor for electromagnetic suspension system. The key of the proposed motor is the special double-stator and flux-modulation structure. The double-stator structure can make best use of the inner space of motor. The flux-modulation structure is based on magnetic gear effect, which can use effective harmonic components of magnetic field. Thus, the thrust force density is improved. Additionally, the idea of single-layer fractional-slot concentrated windings and fault-tolerant teeth is used to enhance fault-tolerant capability. The electromagnetic performance is analyzed by using the time-stepping finite-element method, verifying the effectiveness of the theoretical analysis.

Conclusion

- A novel five-phase DSTFT-FMPM motor for electromagnetic suspension has been proposed, in which the special structure of double-stator and flux-modulation is the key to improve thrust force density.
- The introduction of single-layer fractional-slot concentrated windings and FTT is designed to enhance fault-tolerant capability.
- It has been shown that the proposed motor exhibits high thrust force density, low thrust force ripple and good fault-tolerant capability.
- The merits and performance of the proposed motor have been verified by FEM.

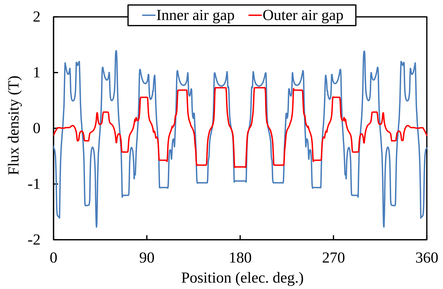
Proposed motor

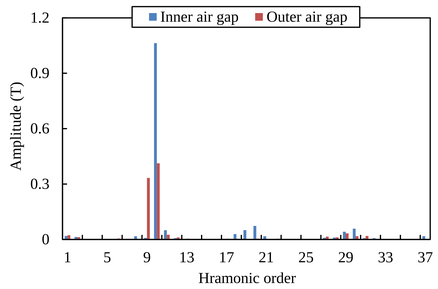
Proposed DSTFT-FMPM motor incorporates the double-stator and flux-modulation structure. The windings are arranged in the outer stator slots and all PMs are inserted in the surface of the inner stator. The mover is composed of partitioned iron pieces, and it acts as flux modulation. The quasi-Halbach PM array is used to reduce PM fringing leakage flux and to improve air-gap flux density.. Additionally, the introduction of the single-layer concentrated winding and FTT is to designed to improve fault-tolerant capability.



Performance

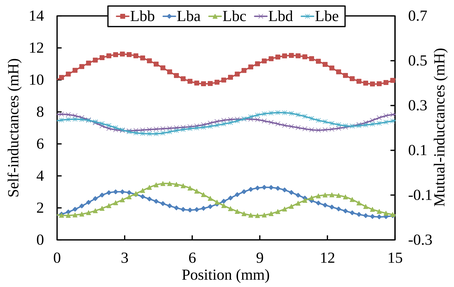
Air-gap flux density





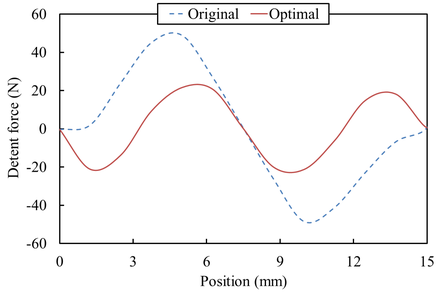
The largest harmonic component in inner air-gap is 10th, which is produced by PMs directly. However, the 10th harmonic component in the outer air-gap becomes smaller and 9th harmonic component is generated by the modulation of the mover iron pieces. The 9th harmonic component is effective, which has major influence on the performance of the motor.

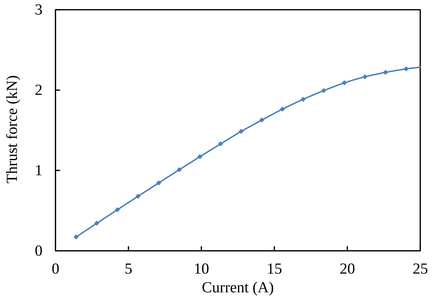
Inductance and fault tolerance



The ratio of mutual-inductance of self-inductance is only 2.1%. It further indicates that the magnetic fields of two adjacent phases are decoupled with each other. Therefore, the proposed motor can offer good fault-tolerant capability.

Detent force and thrust force





Optimizing the stator end teeth width can minimize the detent force. The average thrust force is up to 844 N while the phase current is the rated value of 7 A. The thrust force density is 398 kN/m^3 predicted by FEM. Additionally, it can be seen that the thrust force increases gradually due to magnetic saturation effect when the current exceeds 15 A. Thus, the motor has merits of high thrust force density and strong overload capability.