Design, Analysis, and Prototyping of a Novel-Structured Solid-Rotor-Ringed Line-Start Axial-Flux Permanent-Magnet Motor

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***Abstract*-- This paper presents the design process, detailed analysis, and prototyping of a novel-structured line-start solid-rotor based axial-flux permanent-magnet (AFPM) motor capable of auto-starting with solid-rotor rings. The preliminary design is a slot-less double-sided AFPM motor with 4 poles for high torque density and stable operation. Two concentric unilevel spaced raised rings are added to the inner and the outer radii of the rotor discs for smooth line-start of the motor. The design allows the motor to operate at both starting and synchronous speeds. The basic equations for the solid rings of the rotor of the proposed AFPM motor are discussed. Non-symmetry of the designed motor led to its 3D time-stepping finite element analysis (FEA) via Vector Field Opera 14.0, which evaluates the design parameters and predicted the transient performance. To verify the design, a prototype 1hp, 4-pole, 3-phase line-start AFPM synchronous motor is built and tested the performance in real-time. There is a good agreement between experimental and FEA based computed results. It is found that the prototype motor maintains high starting torque and good synchronization.**

***Index Terms*— axial-flux permanent-magnet motor, finite element analysis, line-start, solid-rotor.**

NOMENCLATURE

A	*linear current density*
B_{dr}	*rotor ring tooth flux density*
B_{ga}	*axial air-gap flux density*
B_{gr_max}	*radial air-gap maximum flux density*
b_r	*rotor ring slot width*
B_{rr}	*peak flux density of rotor ring*
C	*machine constant*
C_v	*damping coefficient*
D_{so}	*stator outer diameter*
D_{si}	*stator inner diameter*
D_{ro}	*rotor-ring outer diameter*
D_{ri}	*rotor-ring inner diameter*
E_0	*magnet back-EMF*
e	*electromotive force (EMF) per phase*
f	*frequency*
F_{tan}	*tangential force*
g_a	*axial air-gap length*
g_r	*radial air-gap length*
i_{sd}	*d-axis component of stator current*
i_{sq}	*q-axis component of stator current*
i'_{rd}	*d-axis component of rotor current referred to stator*
i'_{rq}	*q-axis component of rotor current referred to stator*
$\vec{J}$	*current density*
j_m	*rotor moment of inertia*
j_L	*load inertia*
i	*phase current*
k_{W1}	*winding factor of fundamental harmonic*
k_{rFe}	*space factor of the iron*
L_{cr}	*rotor-yoke thickness*
L_{cs}	*stator-yoke thickness*
L_e	*end winding inductance per phase*
l	*radial length of iron core*
l_e	*equivalent rotor ring core length*
l_{ea}	*equivalent stator core length*
l_{er}	*equivalent stator core thickness*
l_m	*length of one turn of the winding*
L_{sd}	*d-axis component of stator self-inductance*
L_{sq}	*q-axis component of stator self-inductance*
L'_{rd}	*d-axis component of rotor self-inductance*
L'_{rq}	*q-axis component of rotor self-inductance*
L_{md}	*d-axis component of stator mutual-inductance*
L_{mq}	*q-axis component of stator mutual-inductance*
L_{pm}	*magnet's axial length*
L_r	*rotor ring axial length*
L_{WS}	*end winding leakage inductances*
L_{SW_in}	*end winding leakage inductances at inner radius*
L_{SW_out}	*end winding leakage inductances at outer radius*
l_w	*winding thickness*

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