IN-WHEEL MOTOR DESIGN
FOR ELECTRIC VEHICLES

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FOR ELECTRIC VEHICLES

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ABSTRACT

In this thesis an in-wheel electric motor prototype has been designed for experimental purposes. In-Wheel Motor (Hub motor) can be used in electric cars with 4 wheel independent drive configuration. Within every wheel, there can be one "Direct-Drive In-Wheel Motor" to generate the necessary torque per wheel. Unlike conventional "central drive unit" systems, torque as well as the power and speed can be supplied to each tyre independently.

The difference in this work is the design of a direct drive electric motor which is able to carry transverse loading acts on the tyre. Type of the motor is called inverted configuration or outer rotor structure in the literature, in which the rotating element is the casing of the motor.

The electric machine designed in the thesis is Switched Reluctance Machine. First a 3D solid model was created. Necessary strength analyses have been done. Simultaneously, electromagnetic FEA have been done, when it is necessary either of the designs were modified until it converged to a set of consistent dimensions for both mechanic and electromagnetic design.

Last, the results of the electromagnetic analysis were embedded into a hybrid simulation model, in order to check the coherency between the design and the analysis. The results were coherent.

ÖZET

Bu tezde yapılan deneysel amaçlı bir “tekerlek-içi motor” prototipidir. Tekerlek-içi motorlar 4 tekerlekten bağımsız çekişli elektrikli taşıtlarda kullanılır. Bu araçlarda her tekerleğin içine ‘doğrudan-sürüş’ yapısında birer tekerlek-içi motor yerleştirilir. Merkezi güç birimli yapıların aksine bu taşıtlarda güç, tork ve hız her bir tekerleğe kontrollü bir biçimde bağımsız olarak sağlanabilir.

Bu tezin içerdiği farklılıklardan birisi şaft eksenine dik, yani radyal, yükleri kaldırabilen doğrudan-sürüş yapısında bir elektrik motorunun tasarımıdır. Tasarlanan motor türü literatürde terslenmiş motor, ya da dış rotor tasarımı şeklinde geçmektedir.

Tasarım temel olarak ‘Anahtarlamalı Reluktans Motor’ tipindedir. İlk olarak mekanik tasarımın parçası olarak 3-Boyutlu katı modeller yaratılmış, ve gerekli dayanılılıkta olup olmadıkları sınanmıştır. Eş zamanlı olarak elektromanyetik tasarımın da sonlu-eleman-analizi yürütülmüş, gerektiği zaman her iki tasarımda yenilenerek sonuçta birbiriyle tutarlı boyut ve özellikler elde edilmiştir.

Son olarak elektromanyetik analizden edilen veriler melez bir simulasyon modeline girilerek tasarım ve analizin sonuçaları karşılaştırılmıştır. Sonuçlar tutarlıdır.

"for GONDOR…"

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A_s	:	Specific loading (A-turns/m)
A_v	:	Vehicle's frontal projection area (m)
B	:	Flux density (Weber/m^2 = Tesla)
b_{sr}	:	Stator yoke thickness (back-iron)
b_{sy}	:	Rotor yoke thickness (back-iron)
C_d	:	Air-drag coefficient
Error! Objects cannot be created from editing field codes.	:	Bore diameter (mm)
D_o	:	Rotor outer diameter (mm)
D_s	:	Shaft diameter (mm)
D_{wire}	:	Magnet-wire diameter (m)
i	:	Current (A)
I_p	:	Peak current (A)
I_{RMS}	:	RMS current (A)
F	:	Force (N)
F_{air}	:	Air-drag (N)
F_{N_tyre}	:	Normal force acting on a tyre (N)
F_{roll}	:	Friction force due to the rolling (N)
H	:	Flux intensity (A/m)
h_{cs1}	:	Height of winding clearance from the top of the pole (m)

h_{cs2} : Height of winding clearance from the bottom of the pole (m)

h_r : Rotor pole height (m)

h_s : Stator pole height (m)

k_d : Duty ratio

k_e : Efficiency

L : Inductance (H)

Error! Objects cannot be created from editing field codes. : Air-gap thickness (mm)

L_s : Stack length (m)

L_{aa} : Self inductance (H)

L_{ab} : Mutual inductance between phase a and b (H)

n : Safety factor

P_d : Power developed (W)

P_r : Number of rotor poles

P_s : Number of stator poles

R : Resistance (Ω)

R_s : Phase resistance (Ω)

R_{wire_m} : Magnet wire resistance per meter (Ω/m)

T : Torque (Nm)

T_e : Electromagnetic torque (Nm)

T_f : Fall time (s)

T_{ph} : Number of coil turns per phase

v : Vehicle speed (m/s)

W_c : Co-energy (joules)

w_{coil} : Width of the coil (m)

w_{sp} : Stator pole width (m)

λ	:	Flux-linkage (V/s)
ϕ	:	Flux (weber)
μ_r	:	Rolling friction coefficient
τ	:	Shear stress (N/m^2)
σ_y	:	Yield stress (N/m^2)
ω_n	:	Rotor speed (rad/s)

TABLE OF ABBREVIATIONS

ABS	Anti Blockage System
EV	Electric Vehicle
FEA	Finite Element Analysis
SRM	Switched Reluctance Motor
VRM	Variable Reluctance Motor
ZEV	Zero Emission Vehicle