Design method of an ultra-high speed PM Motor/Generator for Electric-Turbo Compounding System

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Background

In various industries, ultra-high speed motor is actively studied and developed for diverse industrial applications like generators/starters for micro gas turbines, turbo-compressor, vacuum pump and turbine generator. Electric Turbo Compounding System (E-TCS), which operates with motor/generator unit at a very-high speed, is the most realistic alternative technology that can respond to fuel efficiency regulation by applying an electrical system to the existing turbocharger. This paper presents the design of an ultra-high speed PM motor for applying E-TCS.

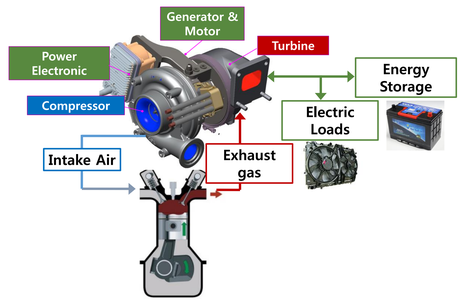
Objectives

- ❖ Design of an ultra-high speed PM motor driven by 10kW at the rated speed 70,000 rpm and the maximum speed 100,000 rpm for applying E-TCS
- ❖ The optimal design of PM motor to not only reduce the eddy-current loss, prominently occur at very-high speed, but also ensure the structural safety using RSM with the results of FEA and structural analysis.

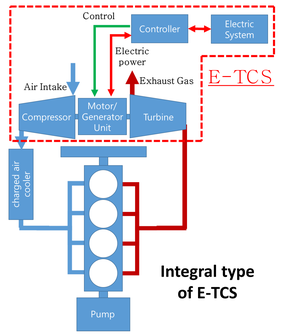
Conclusion

- ❖ This paper presents the design of an ultra-high speed PM motor driven by 10kW at the rated speed 70,000 rpm for applying Electric -Turbo Compounding System(E-TCS)
- ❖ The optimal design of the ultra-high speed PM motor is performed with Finite Element Method(FEM) and structural analysis. Especially, Carbon fiber is used as a material of sleeve, the electromagnetic and structural and characteristics by material of sleeve are analyzed.
- ❖ The optimal design method of PM motor, using carbon fiber is proposed to not only reduce the eddy-current loss, prominently occur at very-high speed, but also ensure the structural safety.

E-TCS Unit



E-TCS



Integral type of E-TCS

- **THE OPERATION OF E-TCS**

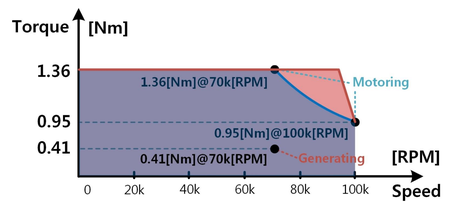
(1) Operate Turbine using engine exhaust gas
(2) Supply Intake Air to the engine using turbine & motor
(3) Generate the power using the rotational force of the turbine
(4) Use the power generated by the generator and the spare power is stored in the energy storage

- **THE ADVANTAGES OF E-TCS**

(1) Improvement of the fuel efficiency by recovering more than 30 % of the exhaust energy from the diesel engine
(2) Improvement of the dynamic characteristics of the engine and increase the output with the motor in the low-speed region
(3) Improvement of the energy efficiency with the energy of the excess exhaust gas, recovered by the generator in the high-speed region

Motor Spec.

Required output characteristics



Contents	Value	Unit
Torque@rated speed	1.37 @ 70,000	Nm@rpm
Torque@max speed	0.96 @ 100,000	Nm@rpm
Power	10	kW

Constraints

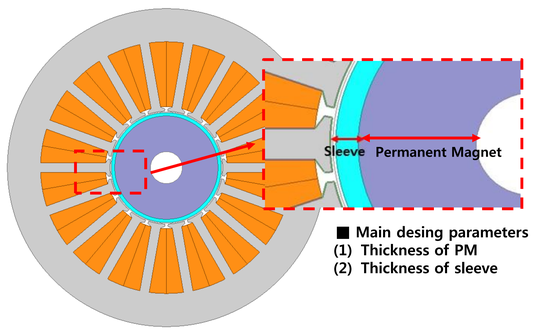
Contents	Value	Unit
Voltage limit	400	V_{dc}
Current limit	80	A_{peak}
Operating temperature	150~200	°C
Number of poles	2(1)	-
Magnet	SmCo(2:17)(2)	-

- **Design Constraints**

(1) Consider the electrical frequency for control
The electrical frequency by poles @ 100,000rpm
1666Hz (2 poles), 3333Hz (4 poles)
➔ if, switching frequency 20 kHz, Number of switching : 12 (2 poles), 6 (4 poles)
(2) Consider the demagnetization at very-high operating temperature

Results of FEA & Structural analysis

Design of Rotor

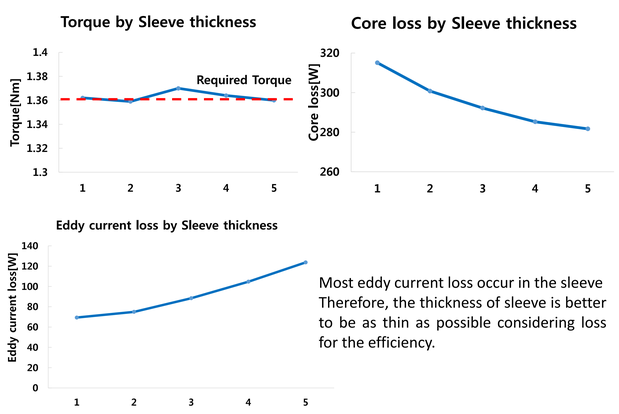


■ Main desing parameters
(1) Thickness of PM
(2) Thickness of sleeve

- **Main design parameters**

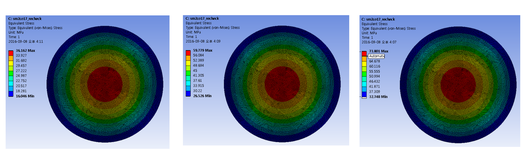
(1) The thickness of the Permanent magnet (the diameter of the rotor)
(2) The thickness of the sleeve
➔ These parameters are influential design parameters of rotor for the ouput characteristics and structural safety factor

Output characteristics



Most eddy current loss occur in the sleeve Therefore, the thickness of sleeve is better to be as thin as possible considering loss for the efficiency.

Structural analysis



70,000rpm 90,000rpm 100,000rpm

The forces caused by pressure : F
Total tension in the wall : T.

$$F = pA = PDL \qquad pDL = 2(\sigma_t tL)$$

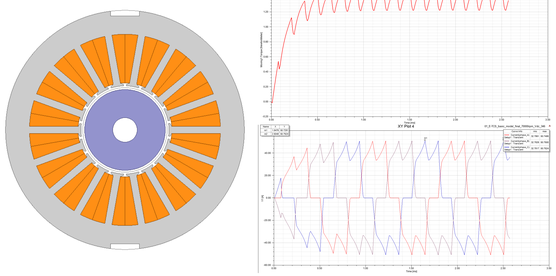
$$T = \sigma_t A_{wall} = \sigma_t tL \qquad \sigma_t = \frac{pD}{2t}$$

$$\sum F_H = 0$$

$$F = 2T$$

To reduce the thickness of the sleeve and eddy current loss, occurred in the sleeve, the carbon fiber is used as the material of the sleeve

Final model



Speed [rpm]	Vdc [V]	Adv_ang [deg]	Torque [Nm]	Efficiency [%]
70,000	342	10	1.39	95.69
100,000	400	35	1.17	95.29

The PM motor for E-TCS, driven by 10kW at ultra-high speed is verified using FEA. The required torque at the rated speed and max speed is satisfied.

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