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Thermal optimization of a totally enclosed forced ventilated permanent magnet traction motor using lumped parameter and partial computational fluid dynamics modeling

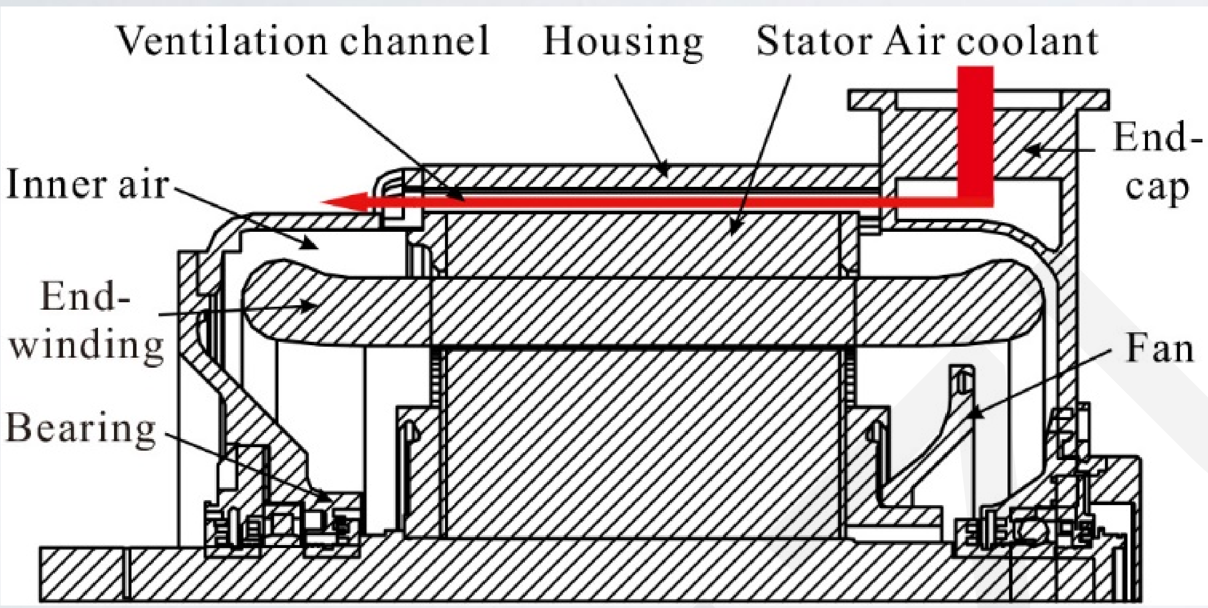
Key words:
Computational fluid dynamics;
Lumped parameter model;
Permanent magnet synchronous motors;
Totally enclosed forced ventilated motor

Research Background

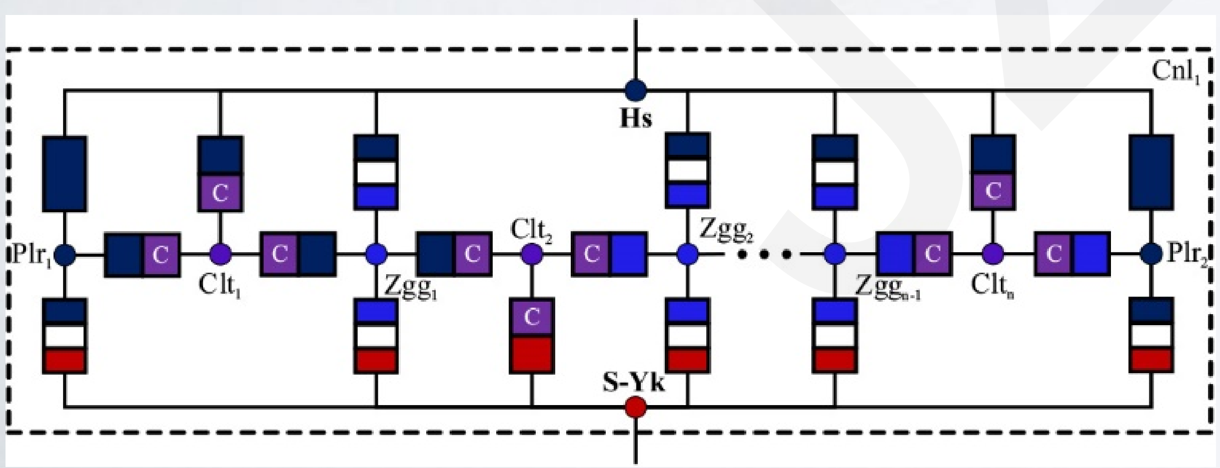
- Permanent magnet (PM) motors are particularly suitable for high-speed trains owing to their superior power density and efficiency, low noise, and low maintenance costs. Over the last decades, the application of PM motors in rail vehicles has been extensive (e.g., in France, Japan, Germany, and Canada). For high-speed trains, PM motors with totally enclosed self-cooling structure were first put into commercial operation on AGV Italo trains by the French company Alstom.
- This study sets out to develop a 600-kW **totally enclosed forced ventilated (TEFV)** PM traction motor (power density up to **1 kW/kg**) for Chinese high-speed rail trains. Compared to the motors on AGV Italo, challenges are posed to electro-magnetic and thermal design to reach the same power density level with the smaller space of CRH380A bogies.
- The **lumped parameter (LP) mode**l is introduced to preliminary design and optimization of ventilation channels because of its low computing requirements with acceptable accuracy. The **computational fluid dynamics (CFD) method** is applied and a partial CFD model of the ventilation channels is built to simulate the flow condition and compute convection coefficients for optimization. Moreover, a complete 3-D CFD model is modeled to calculate the maximum temperature at local points.

Overall LP and partial CFD model

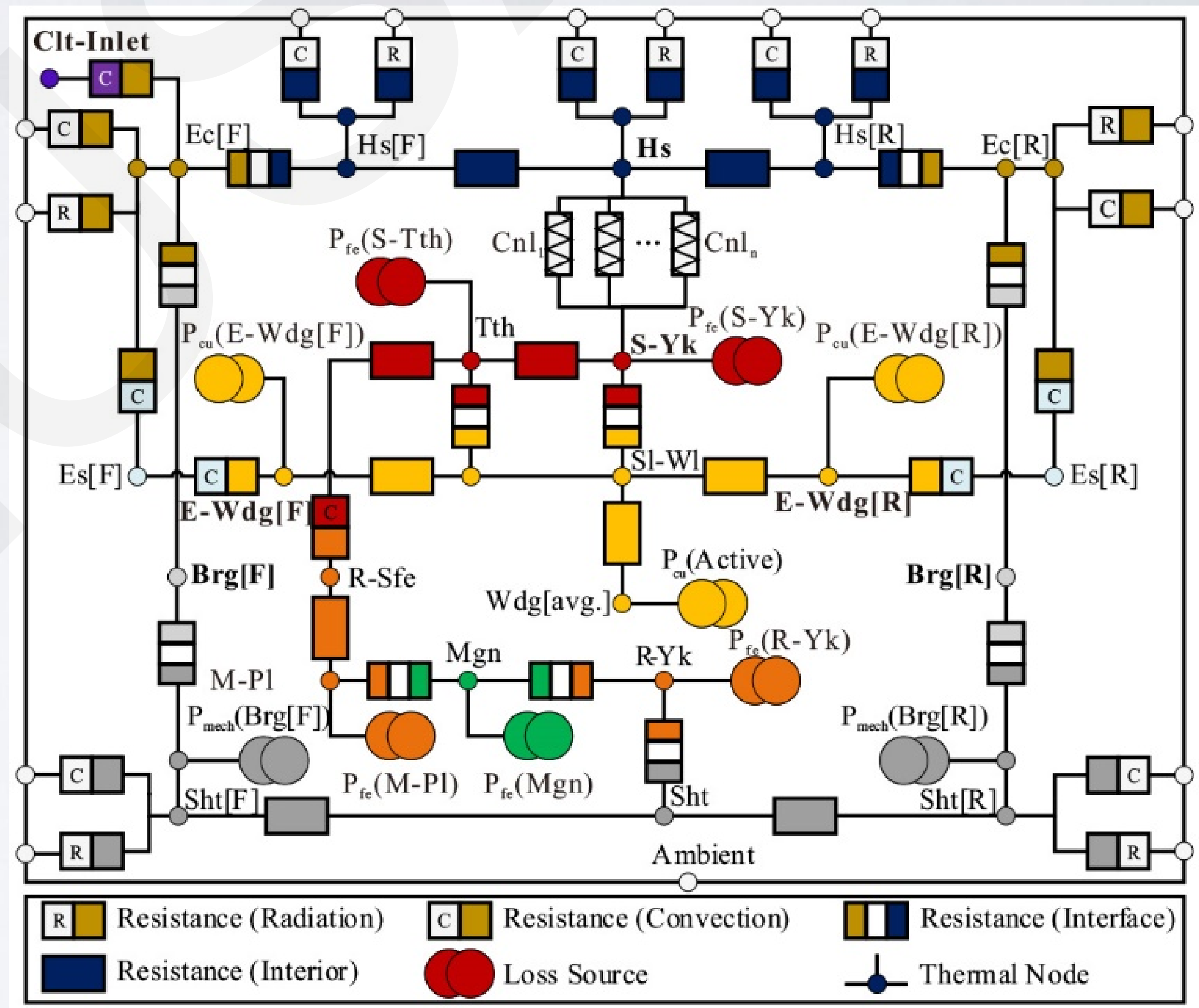
- Since the motor is TEFV, the partial CFD model is able to simulate the simulate the explicitly unknown coolant flow conditions by modeling the coolant area and its attached solid walls. The influence of the thermal field on the coolant is considered with the coupling solution of LP and CFD models.



Sketch of the motor and coolant path



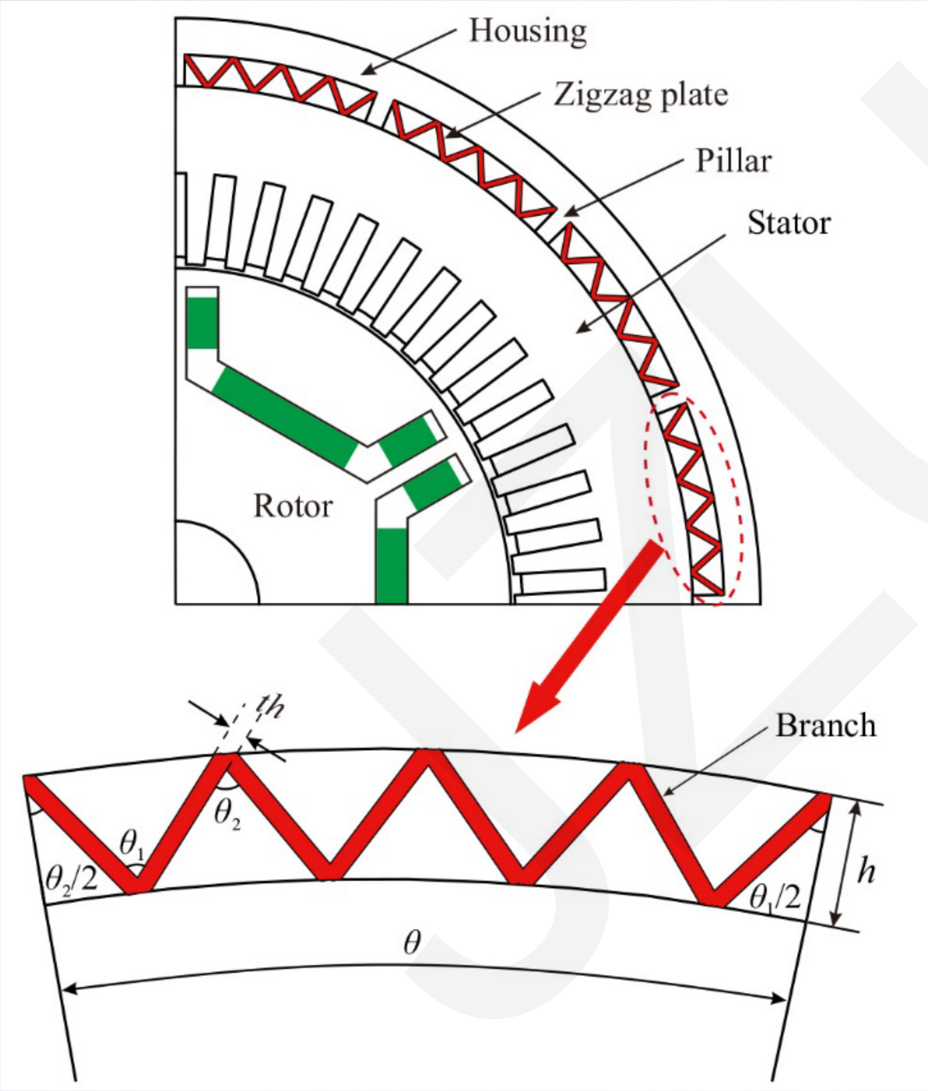
LP model of one ventilation channel



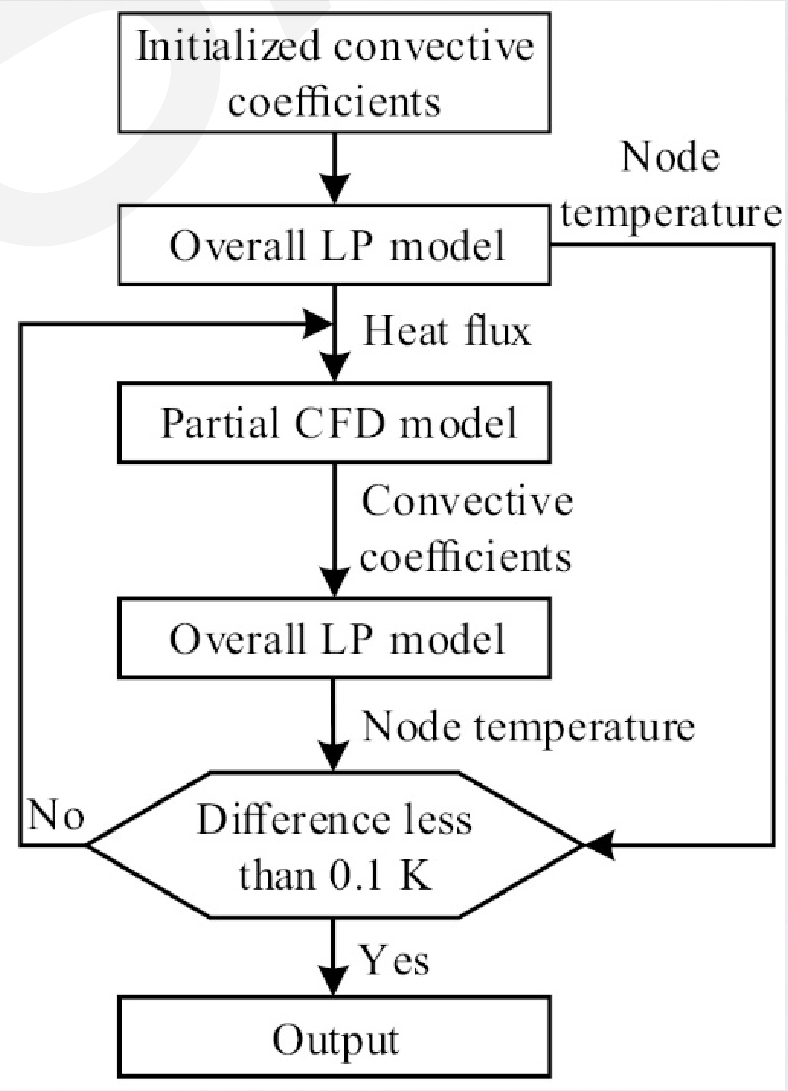
LP model of the motor

Overall LP and partial CFD model

- The coupling solving of the LP and CFD is achieve by exchanging the data of heat flux, convective coefficients and node temperature using the user defined functions.
- Using the Taguchi design, the optimal parameters are determined as Case 15 (*n*=10, *h*=15, and *th*=1).



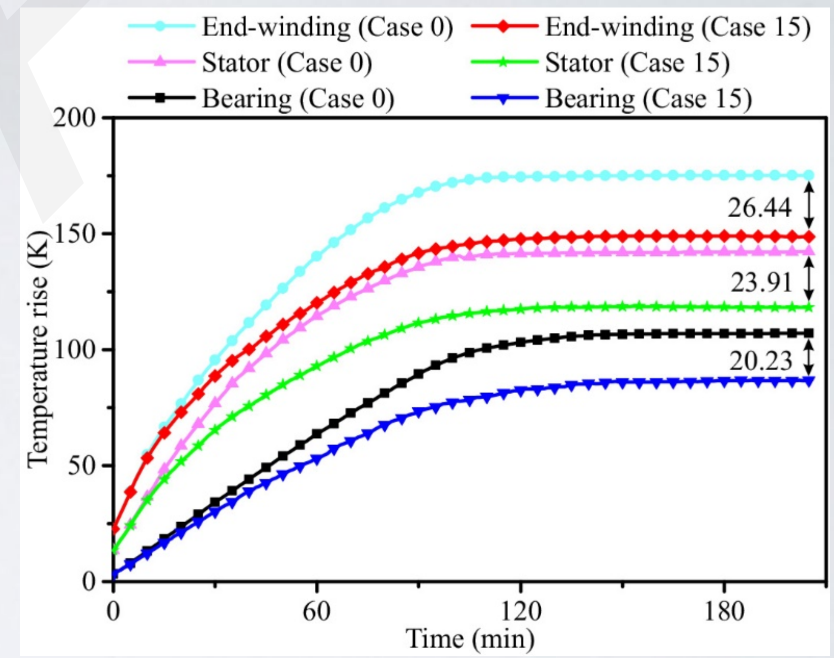
Design parameters



Coupling progress

Results

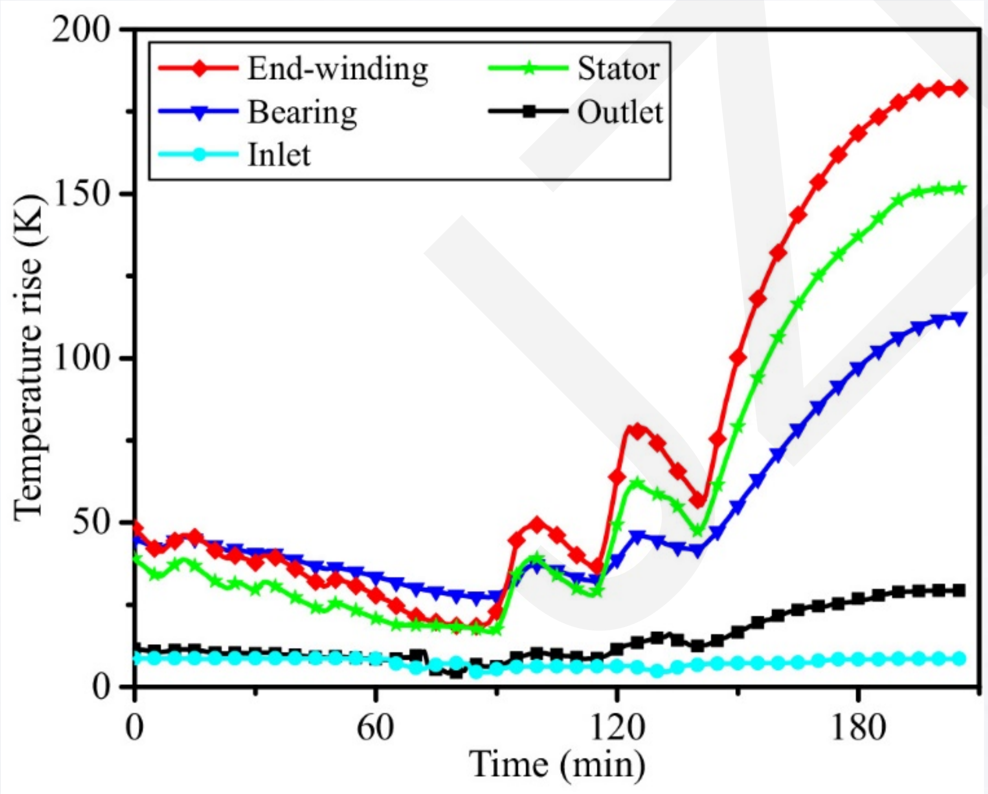
- Tests were conducted by a twin drag system including the proposed PM motor and an induction motor at the same rated power.
- The results of LP model and complete CFD model are verified with errors less than 6%. The thermal performance is improved by more than 15%.



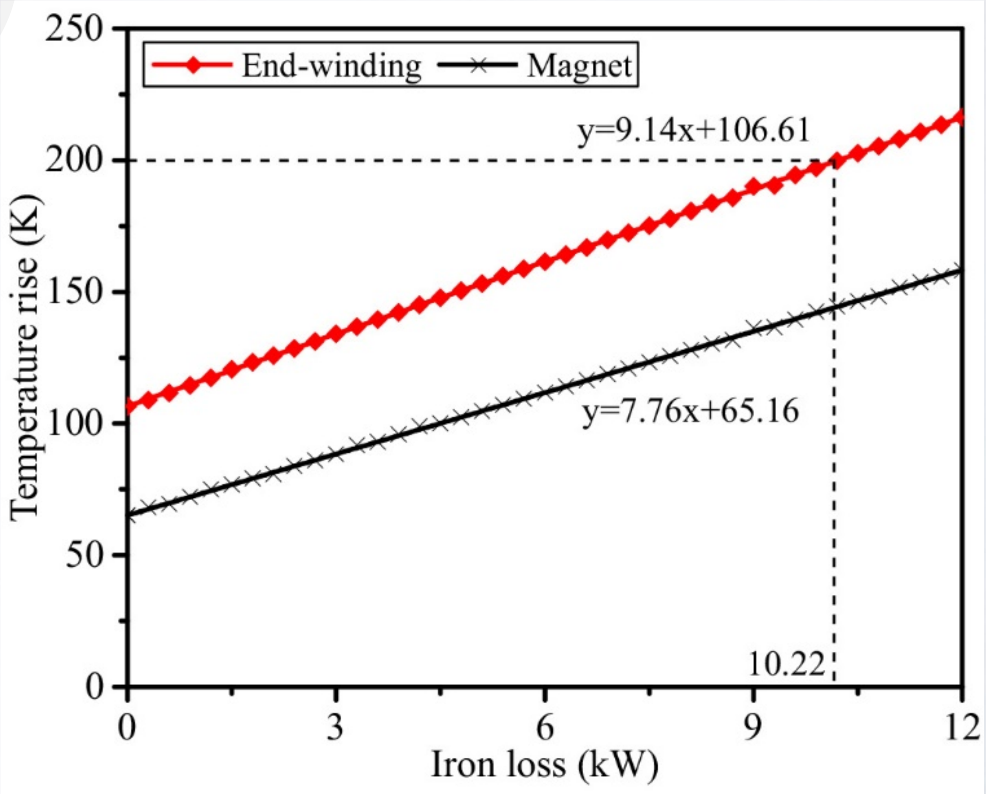
Component		End-winding	Winding	PM	Stator	Bearing
Case 0	LP (K)	182.45	176.07	140.74	150.65	108.32
	CFD (K)	181.43	173.28	138.82	148.33	108.54
	Meas. (K)	175.14	169.01	/	142.21	107.04
Case 15	LP (K)	151.27	142.12	112.32	122.62	90.53
	CFD (K)	153.86	145.96	111.25	121.45	88.96
	Meas. (K)	148.70	141.14	/	118.30	86.80
Benefit (%)		15.10	16.49	/	16.81	18.91

Results

- Although much work has been carried out on iron loss prediction in this kind of interior permanent magnet synchronous motor, there is still no precise method to indicate iron loss with an inverter involved.
- An engineering method is proposed to estimate the iron loss constraint by assuming that extra harmonic iron losses in the stator yoke, stator teeth, and rotor are proportional to the volume-weighted average value of the flux density.
- The iron loss under the rated traction operation was estimated to be 8.21 kW, while the measurement was 8.47 kW.



Temperature rises with an inverter



Estimation of temperature rises vs. iron losses

Conclusions

- Within the specification limit of the CRH38A bogie, zigzag plates are introduced to ventilation channels of a 600-kW TEFV PM traction motor and optimized using the overall LP model, in which detailed convective heat transfers were studied by the coupled partial CFD model.
- The optimized ventilation structure ensures a normal operation of the traction motor as well as improving the thermal performance by more than 15%.
- The thermal analysis method using overall LP with partial CFD modeling was proposed for cooling structure optimization of TEFV machines or water-cooling machines, in which cooling structure can be extracted from the overall model for thermal coefficient calculation.