

ANSYS



仿真
新时代

2017 ANSYS用户技术大会

中国·烟台

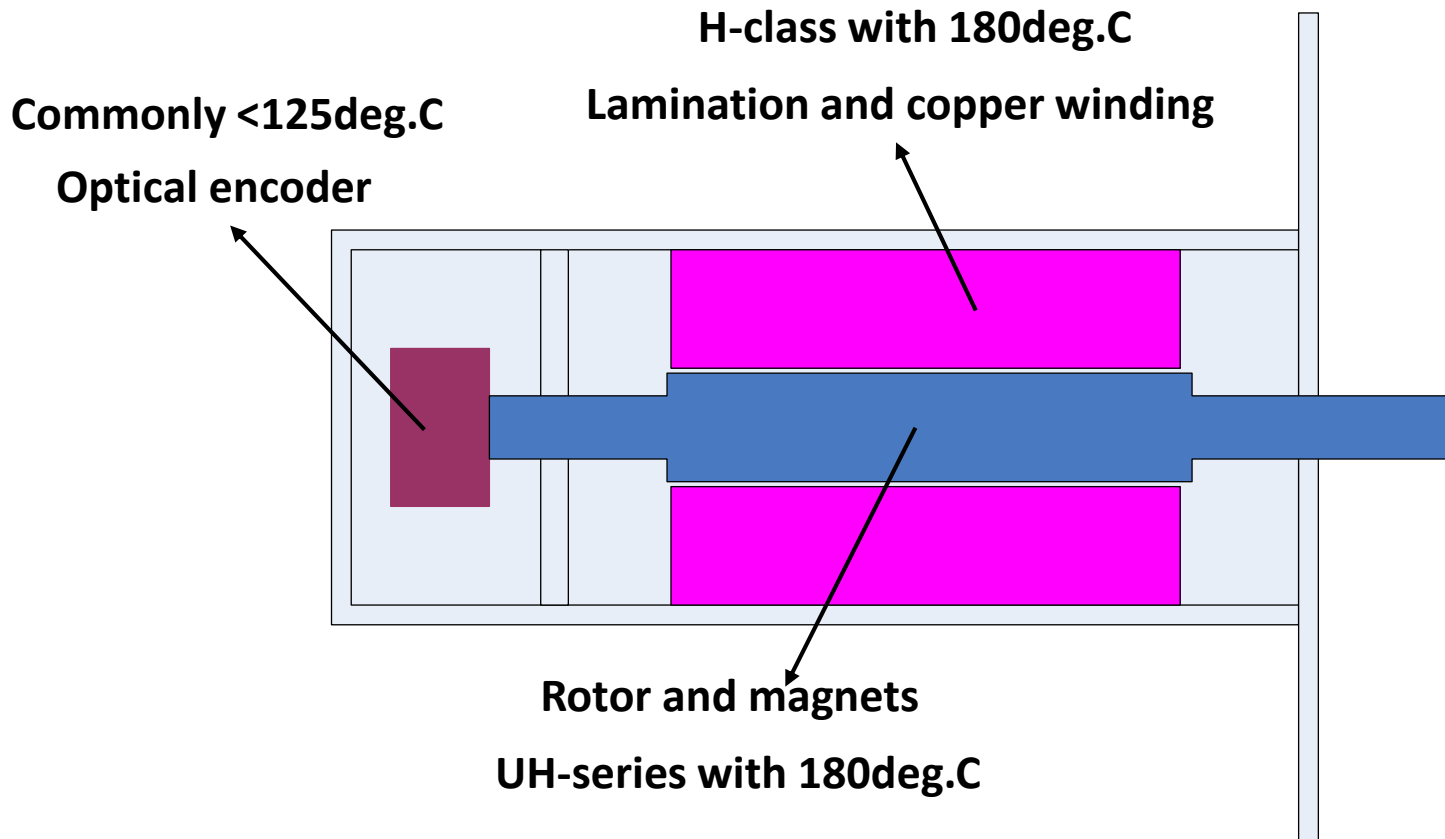
Active Cooling for On-machine Device

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Research Engineer

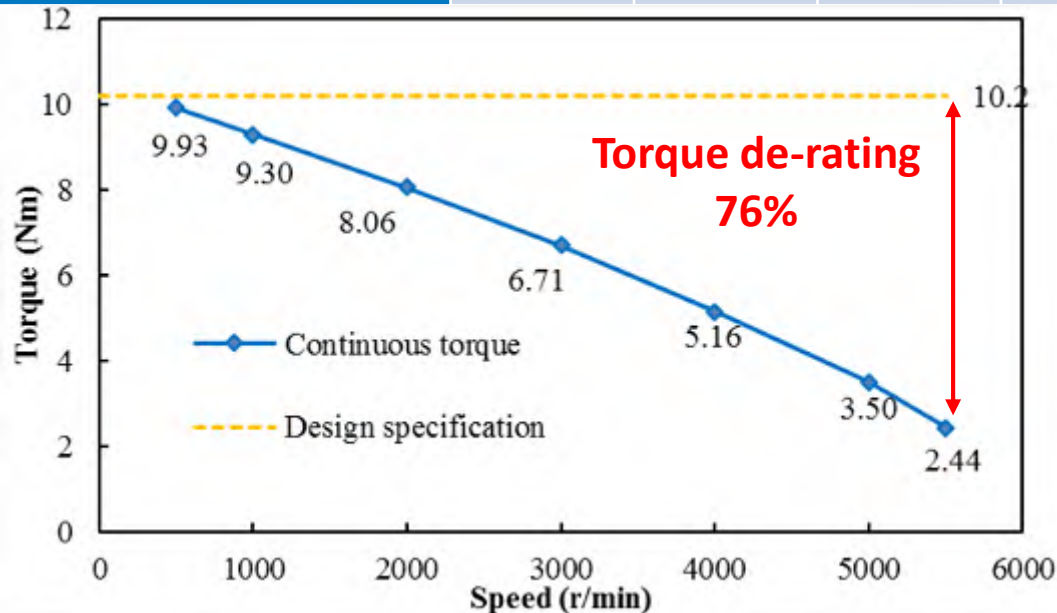
Advanced Technology-Rockwell Automation

Temperature Limitation of A Servo Motor



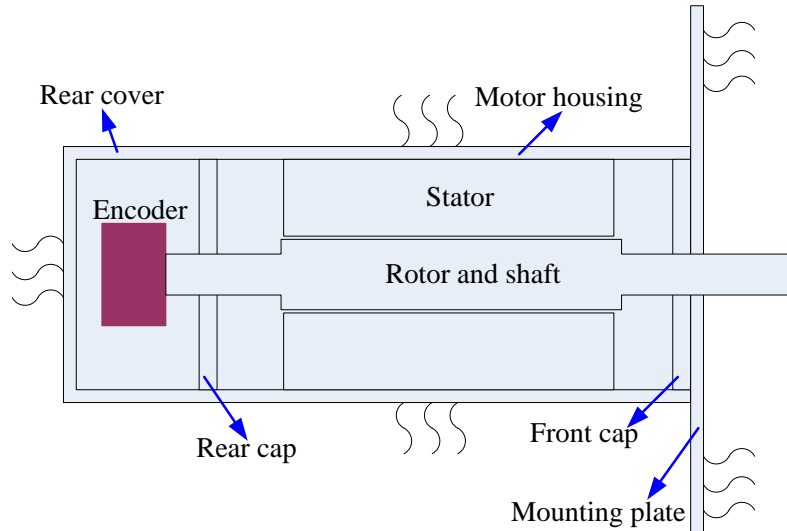
Temperature Limitation of A Servo Motor

Steady state temperature	Windings	Windings	Windings	Encoder	Encoder Air	Housing	Ambient
Temperature Limits (°C)	140	140	140	100	100	165	
Temperatures at 500 rpm (°C)	113.5	119.1	117.6	97.6	92.6	100.3	23.0
Margin at 500 rpm (°C)	26.5	20.9	22.5	2.4	7.4	39.7	
Temperatures at 2000 rpm (°C)	105.0	112.5	111.2	97.5	91.0	97.3	22.5
Margin at 2000 rpm (°C)	35.0	27.5	28.8	2.5	9.0	42.7	
Temperatures at 3999 rpm (°C)	96.9	104.7	103.9	97.4	89.4	94.7	23.1
Margin at 3999 rpm (°C)	43.1	35.3	36.1	2.6	10.7	45.3	
Temperatures at 5500 rpm (°C)	93.6	101.5	101.0	98.4	89.4	94.6	22.1
Margin at 5500 rpm (°C)	46.4	38.5	39.0	1.6	10.6	45.4	

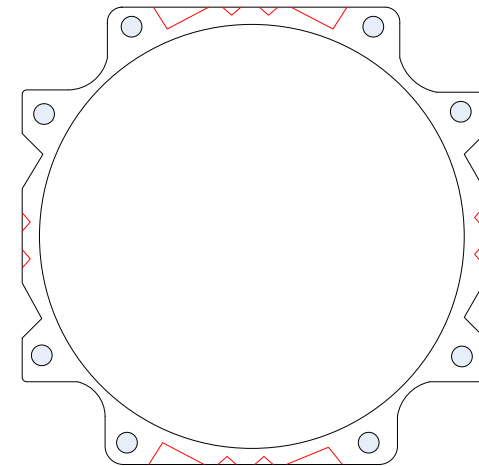


33UH magnet
F-class insulation winding
115deg.C 18 bit single turn encoder

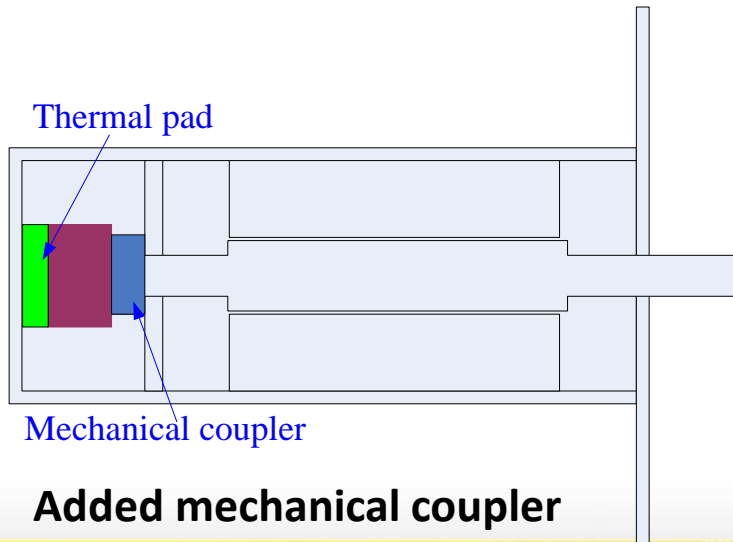
Cooling system-Passive cooling



Increased radiation



Increased cooling area

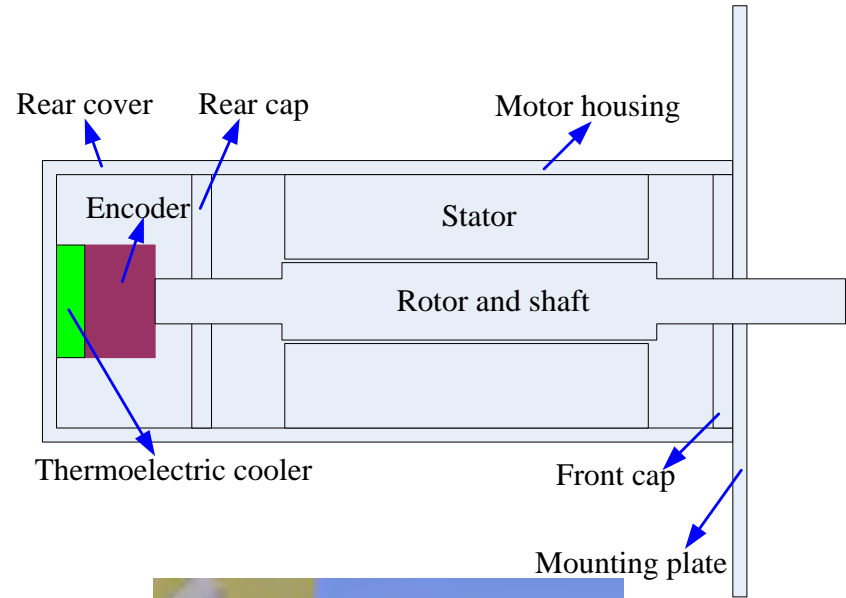
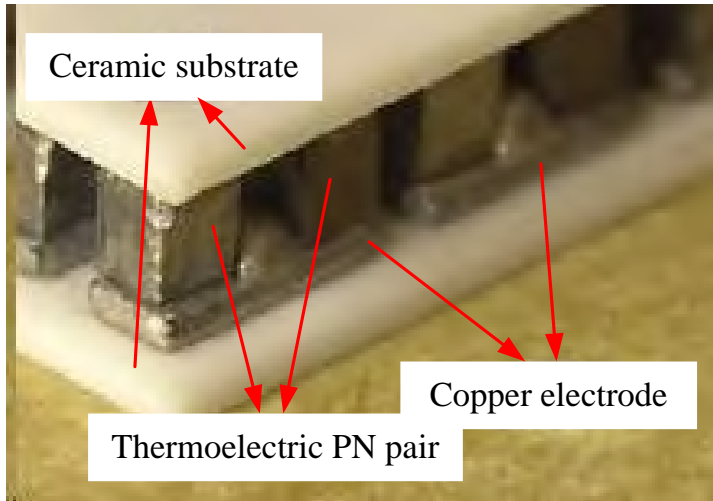


Added mechanical coupler

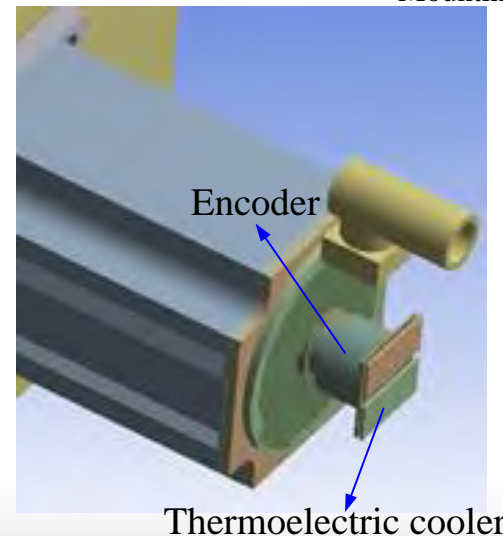


Added heat path

Cooling system-Active cooling

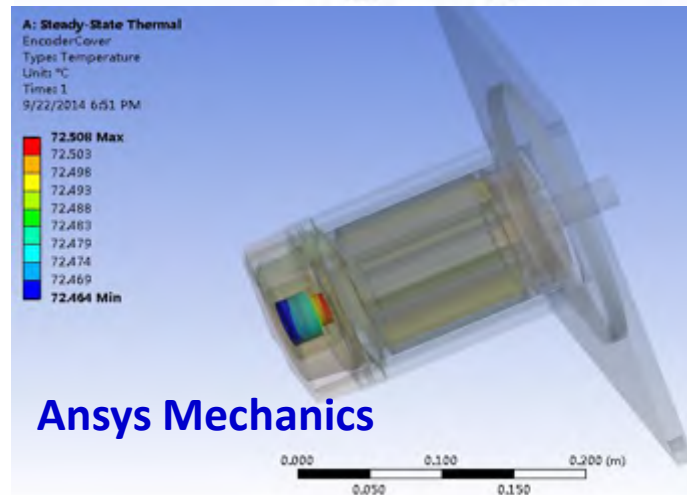
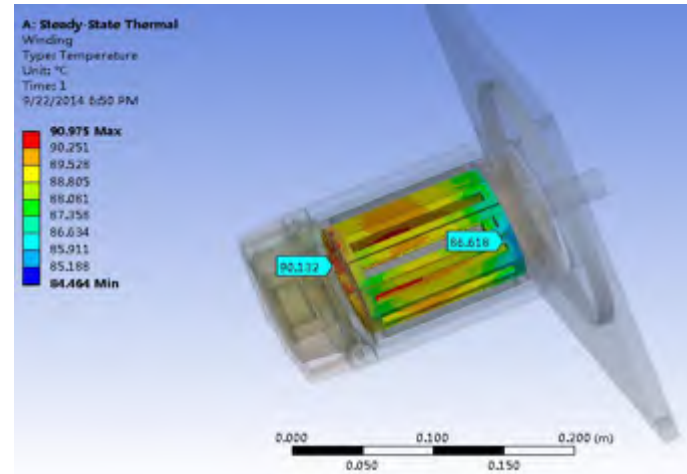
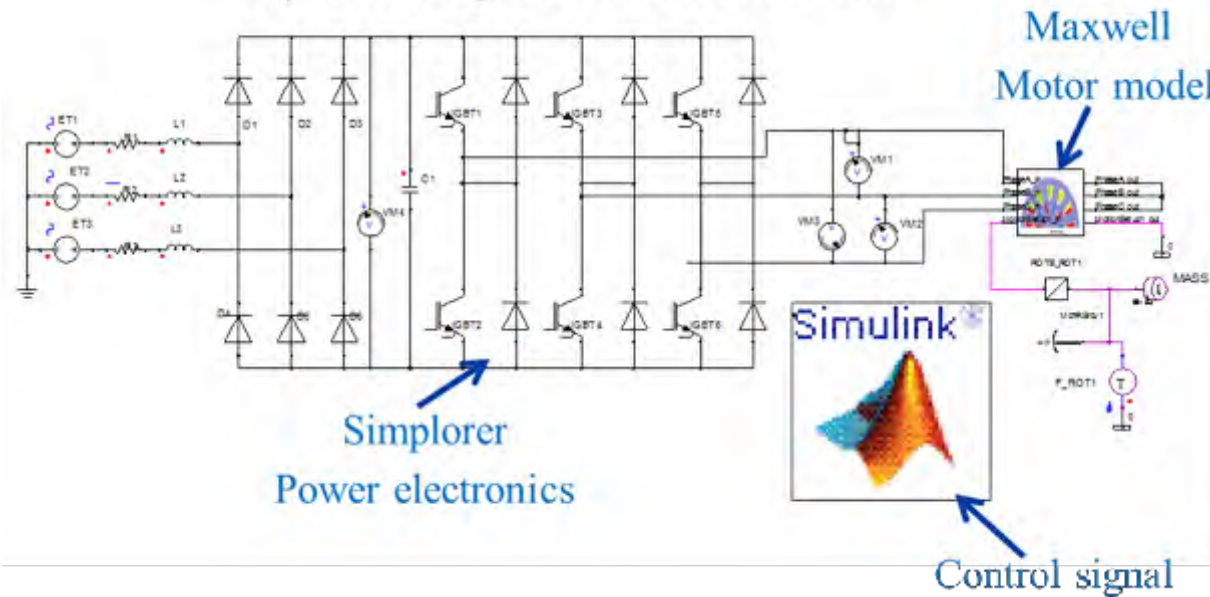


Can we add an active cooling system with thermoelectric cooler to reduce the temperature rise of the encoder?



System co-simulation

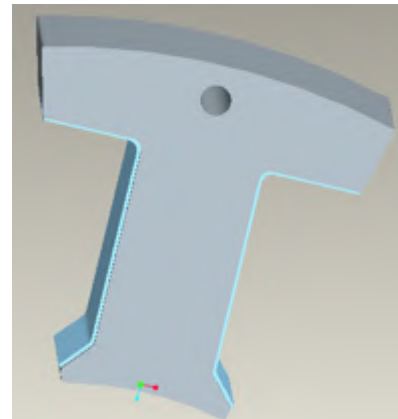
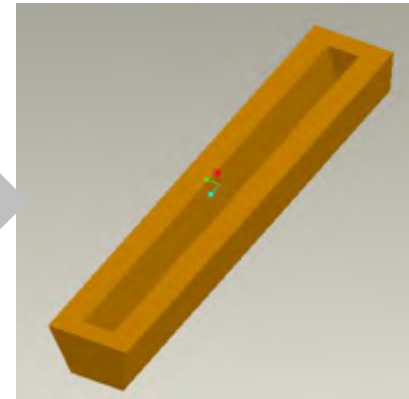
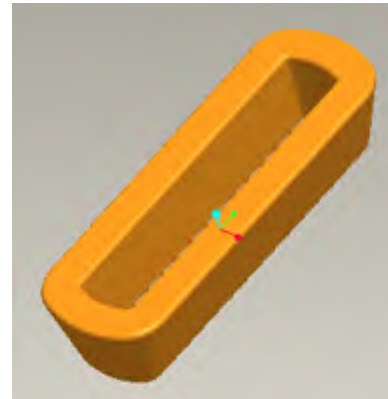
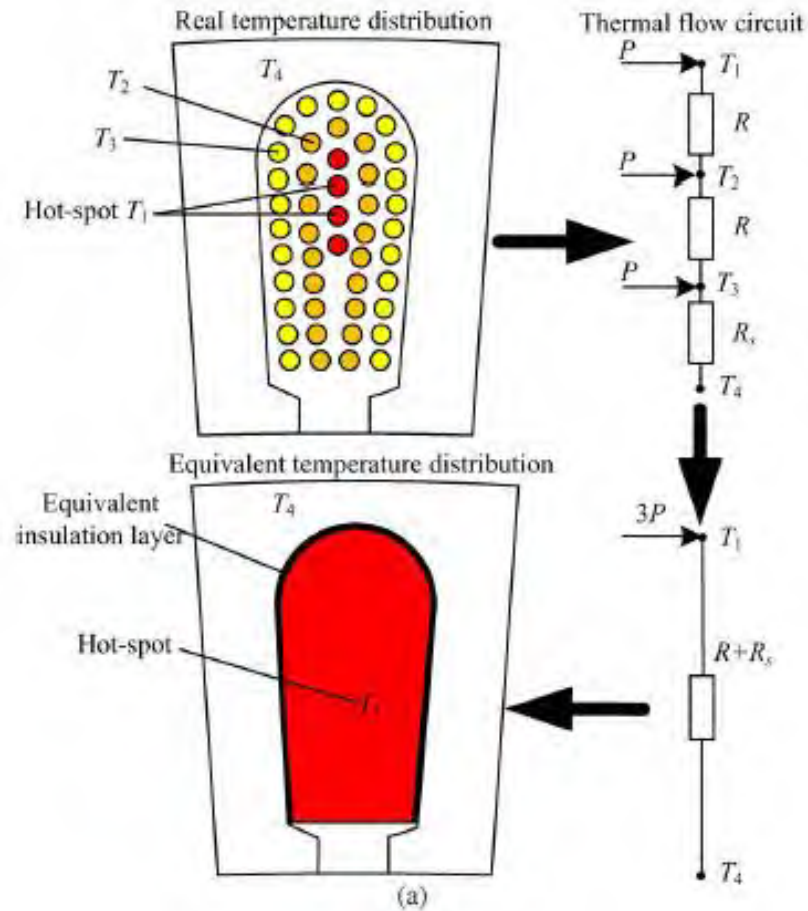
System Diagram of Co-Simulation



ANSYS Mechanics

Thermal simulation model building

Modeling of the winding



Thermal simulation model building

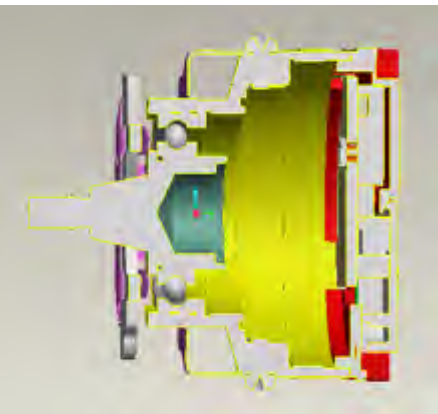
Modeling of the encoder



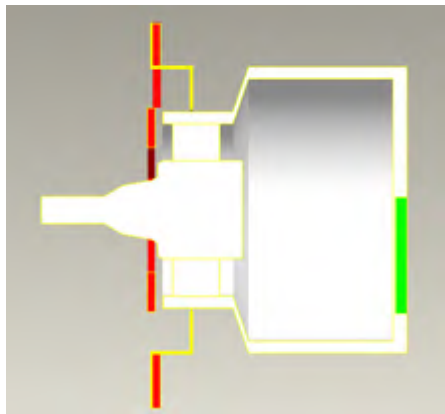
Actual encoder



PCBA

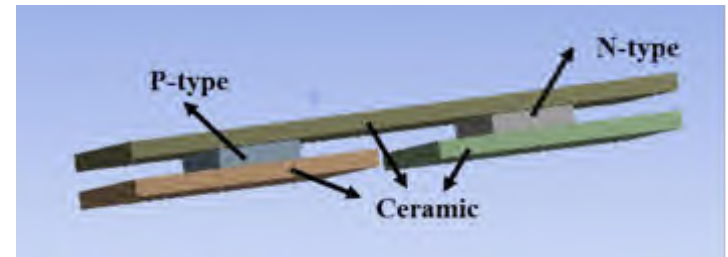
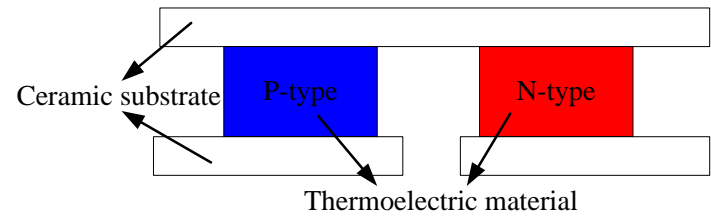
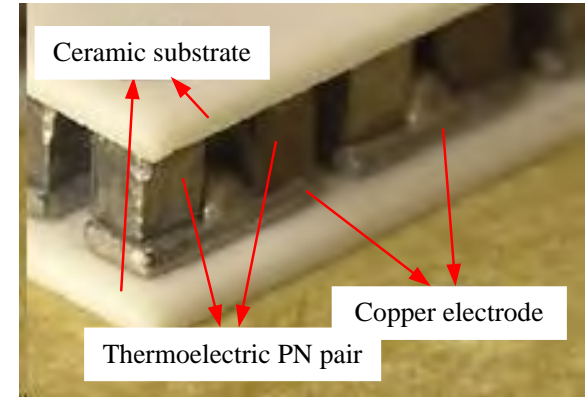


Actual model

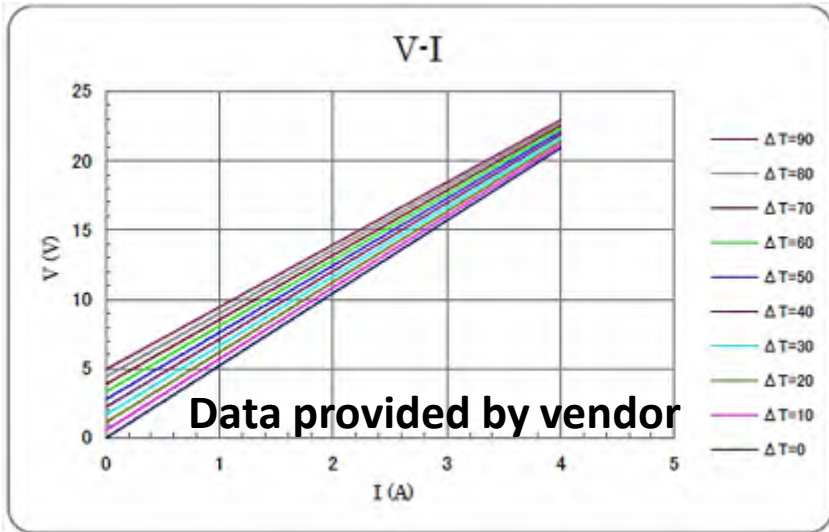


Simplified model

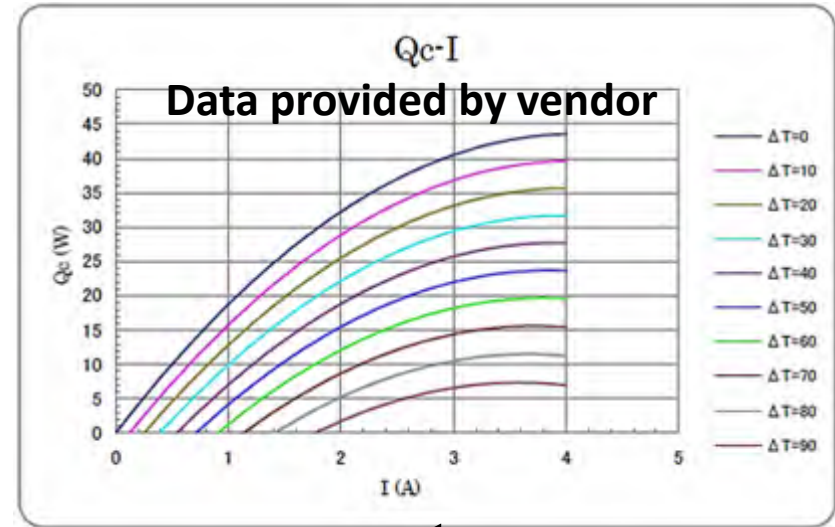
Modeling of the thermoelectric cooler



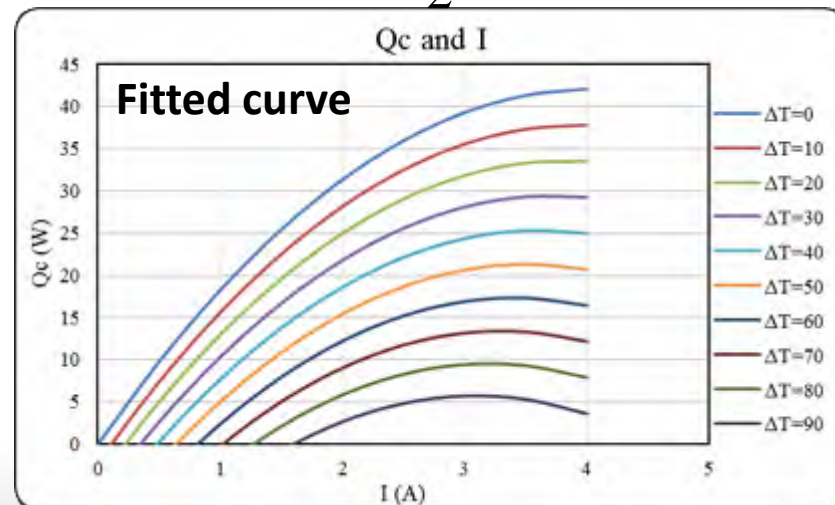
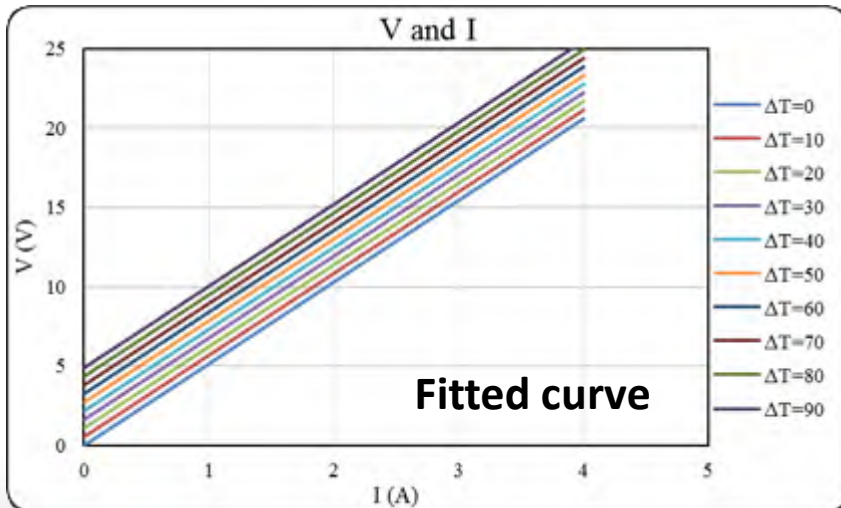
Thermal simulation model building



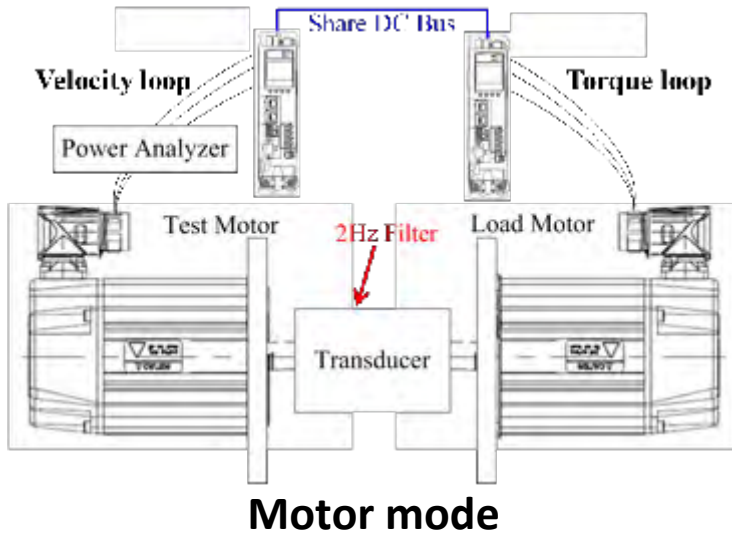
$$V = \alpha(\Delta T) + IR$$



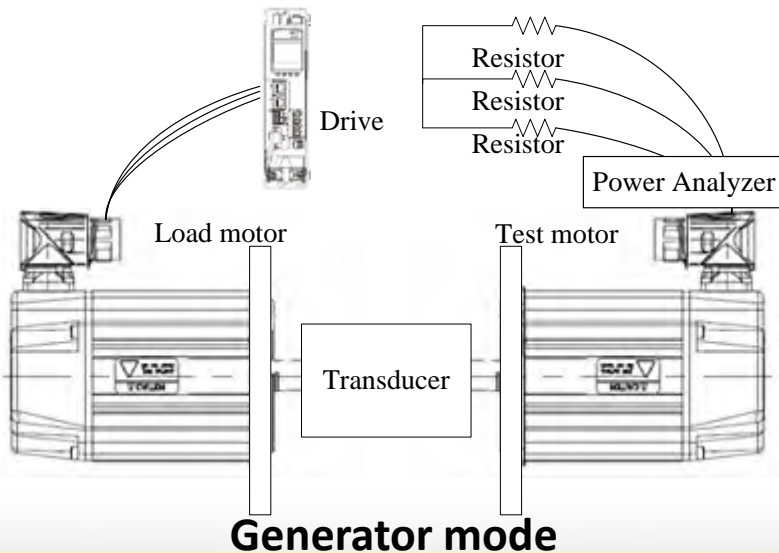
$$Q_c = \alpha T_c I - \frac{1}{2} I^2 R - K \Delta T$$



Thermal simulation model tuning by tests



Loss results @5500rpm	
Gross Loss (W)	181.54
Copper Loss (W)	18.34
Iron Loss (W)	154.5
Mechanical Loss (W)	7.7
Encoder Loss (W)	1



Simulation results @ 5500rpm

Temperature (°C)	Test	Simulation	Error
Winding (max)	101.5	102.6	-1.1
Winding (min)	93.5	98.5	-5.0
Housing	94.6	95.4	-0.8
Rear end cap	89.4	93.8	-4.4
Encoder	98.4	103.2	-4.8
Rear cover (middle)	91.5	93.4	-1.9
Rear cover (edge)	86.5	91.3	-4.8

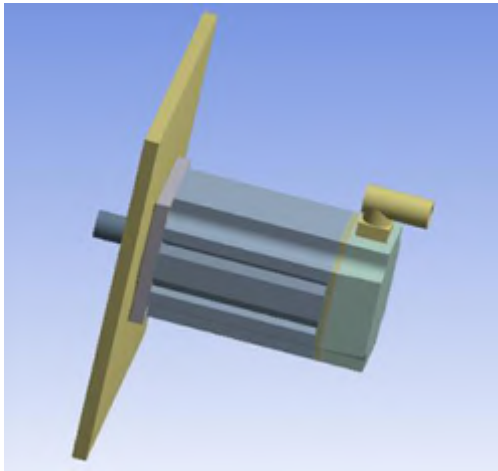
Cooling strategies-High radiation Nano Paint

Temperature (°C)	Black paint radiation 0.9	Nano paint radiation 0.98	Reduction
Winding (max)	102.6	100.9	-1.7
Winding (min)	98.5	96.9	-1.6
Housing	95.4	93.8	-1.6
Rear end cap	93.8	92.1	-1.7
Encoder	103.2	101.5	-1.8
Rear cover (max)	93.4	91.7	-1.7
Rear cover (min)	91.3	89.4	-1.9

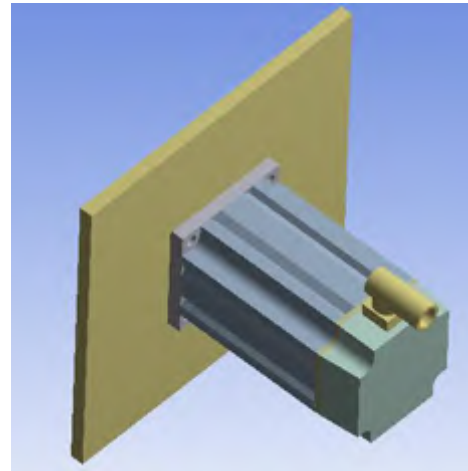
With Nano paint, the encoder temperature can drop 1.8K.

Cooling strategies-Added grooves

Original model



Added grooves

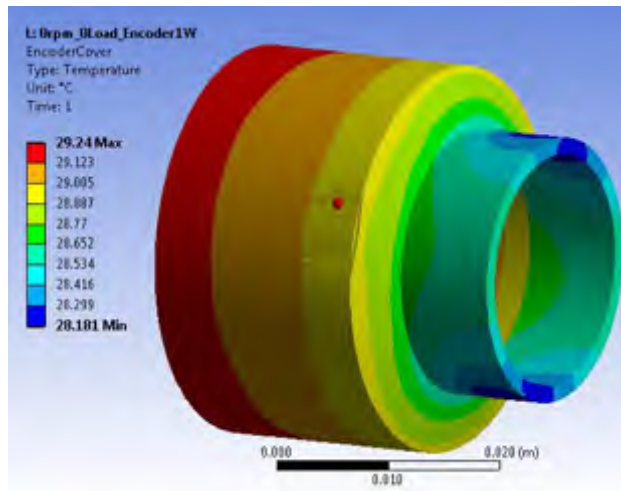


With added grooves, the encoder temperature can drop 0.5K.

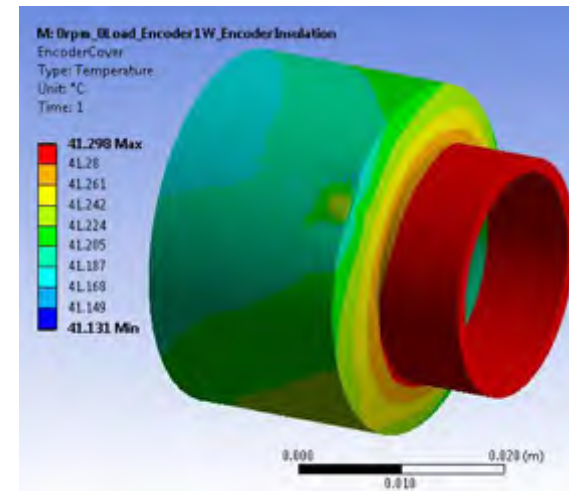
Temperature (°C)	Original	With four grooves	Reduction
Winding (max)	102.6	102.2	-0.5
Winding (min)	98.5	97.9	-0.6
Housing	95.4	95.1	-0.3
Rear end cap	93.8	93.6	-0.2
Encoder	103.2	102.7	-0.5
Rear cover (max)	93.4	93.0	-0.4
Rear cover (min)	91.3	90.8	-0.5

Cooling strategies-Thermal insulation

No load w/o thermal insulation



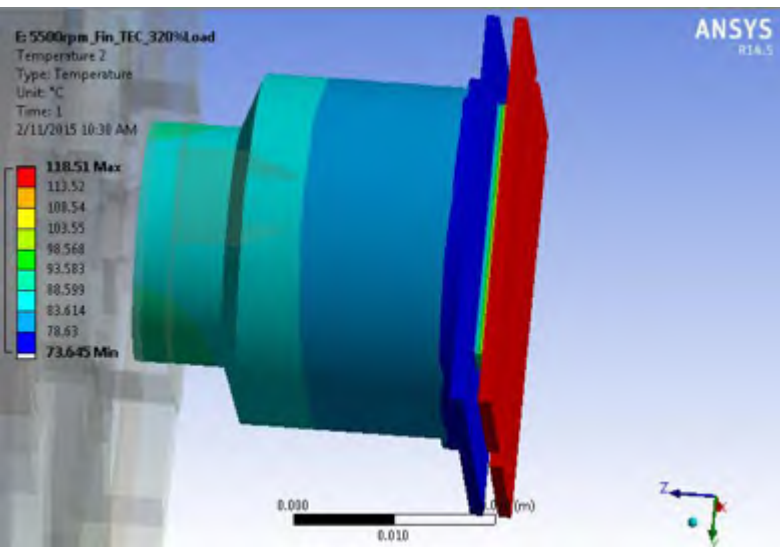
No load w/ thermal insulation



When encoder has certain power loss and the encoder is thermally insulated from the rotor shaft by a mechanical coupler, the encoder temperature will increase 16.1K.

Temperature (°C)	No insulation	w/o encoder loss	w/ encoder 1W
Winding (max)	102.6	102.1	102.6
Winding (min)	98.5	98.0	98.5
Housing	95.4	94.7	95.4
Rear end cap	93.8	93.3	93.9
Encoder	103.2	90.7	119.3
Rear cover (max)	93.4	92.9	93.5
Rear cover (min)	91.3	90.0	91.3

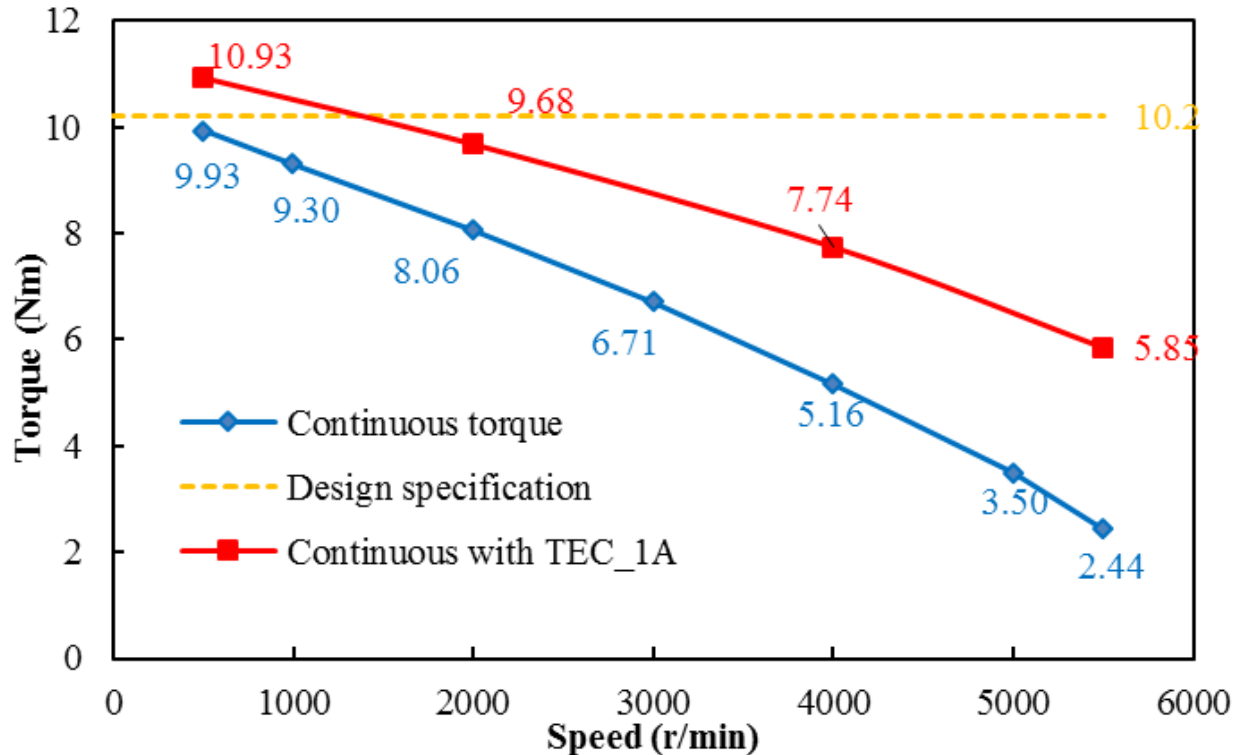
Cooling strategies-Thermoelectric Cooler



5V/1A DC power is supplied to the TEC. When the TEC is working, the temperature difference between the hot side and the cold side can be 45K, and the encoder temperature rise can be lower.

Temperature (°C)	Qualification tests 100% load	w/ TEC, 0A 100% load	w/ TEC, 0A 240% load	w/ TEC, 1A 240% load	Variation
Winding (max)	101.5	100.9	137.9	141.4	3.5
Winding (min)	93.5	96.8	131.6	135.5	3.9
Housing	94.6	93.9	126.4	130.5	4.1
Rear end cap	89.4	91.9	122.6	130.3	7.7
Encoder	98.4	99.2	128.6	93.5	-35.1
Rear cover (max)	91.5	91.2	121.8	134.6	12.8
Rear cover (min)	86.5	87.8	116.1	125.6	9.5

Cooling strategies-Thermoelectric Cooler



The continuous torque at 5500 rpm can be increased from 2.44Nm to 5.85Nm with TEC. The encoder has 6.5°C temperature margin at this new continuous torque rating. However, the windings start to get to the temperature limit with the larger continuous torque rating.

Prototyping



**Without paint
With black paint**

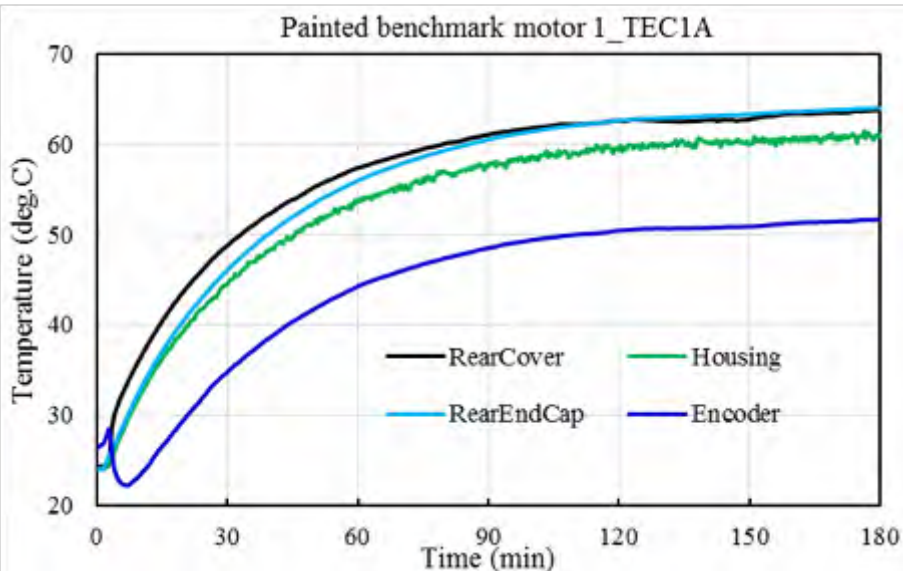
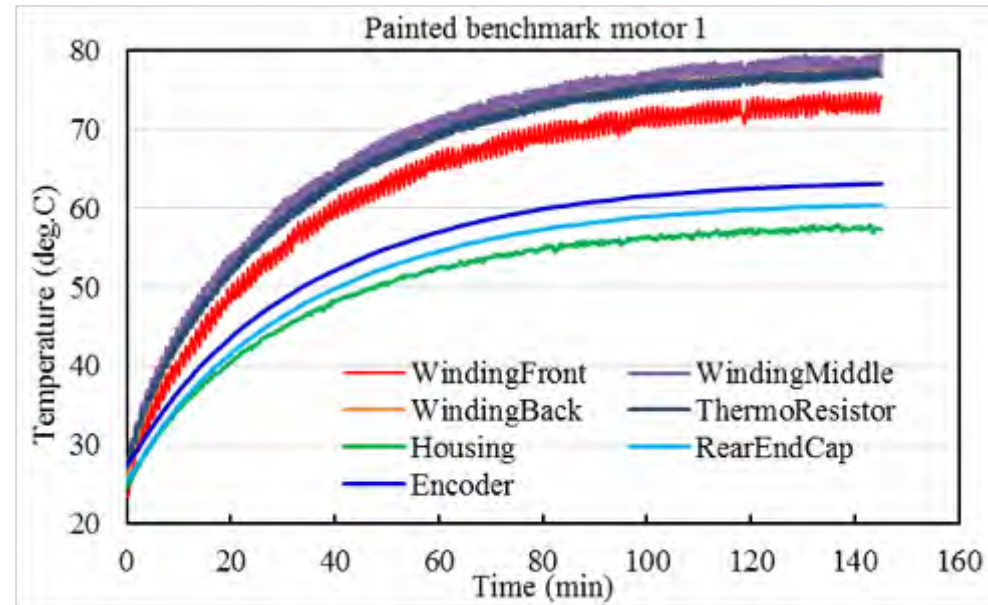


**With Nano paint
With TEC**



Prototyping

With 5V/1A DC power supply, the encoder temperature can be 12K lower for this test.



The test results are not as good as the simulation, but the tests do validate the effectiveness of using TEC active cooling.

Production motors would have more precise assembly of the TEC and thermal pad and may have better results.

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Thanks!



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