Anna Poms

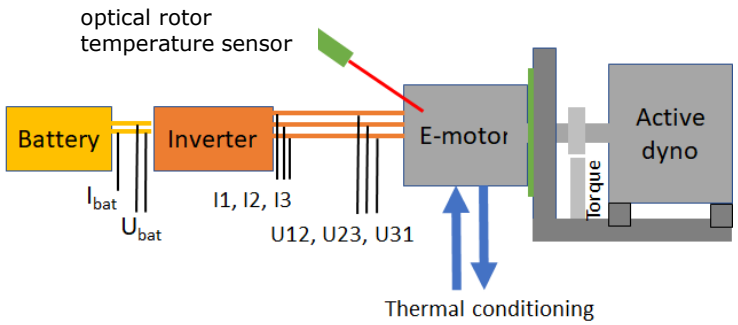
Optical Rotor Temperature Measurement

Optical Rotor Temperature Sensor

„Give me a non-contact rotor temperature sensor without any thermal inertia“

The need to exploit an e-motor‘s thermal capabilities arises from

- Protection from thermal damage
- Creation and calibration of temperature – torque maps
- Exploiting the thermal limits even in transient operation
- Simulation and fine tuning of a digital twin



Needed:

A simple to use and robust sensor with minimum installation requirements for contiuos real-time temperature measurement

Temperature Torque dependence - PMSM

Torque equation:

$$T_\mathrm{i} = \frac{3}{2} p \cdot \left(\psi_\mathrm{d} \cdot i_\mathrm{q} - \psi_\mathrm{q} \cdot i_\mathrm{d}\right)$$

Electrical power:

$$P_\mathrm{el} = \frac{3}{2}\left(u_\mathrm{d} \cdot i_\mathrm{d} - u_\mathrm{q} \cdot i_\mathrm{q}\right)$$

$$u_\mathrm{d} = R_\mathrm{S} i_\mathrm{d} + \frac{\mathrm{d}\psi_\mathrm{d}}{\mathrm{d}t} - \omega_\mathrm{el}\psi_\mathrm{q}$$

Flux linkage:

$$\psi_\mathrm{d} = L_\mathrm{d} i_\mathrm{d} + \psi_\mathrm{PM}(T)$$

Rik De Doncker, Duco W.J. Pulle, Andre Veltman-Advanced Electrical Drives_ Analysis, Modeling, Control (Power Systems)-Springer (2011)

Temperature Torque dependence – ASM

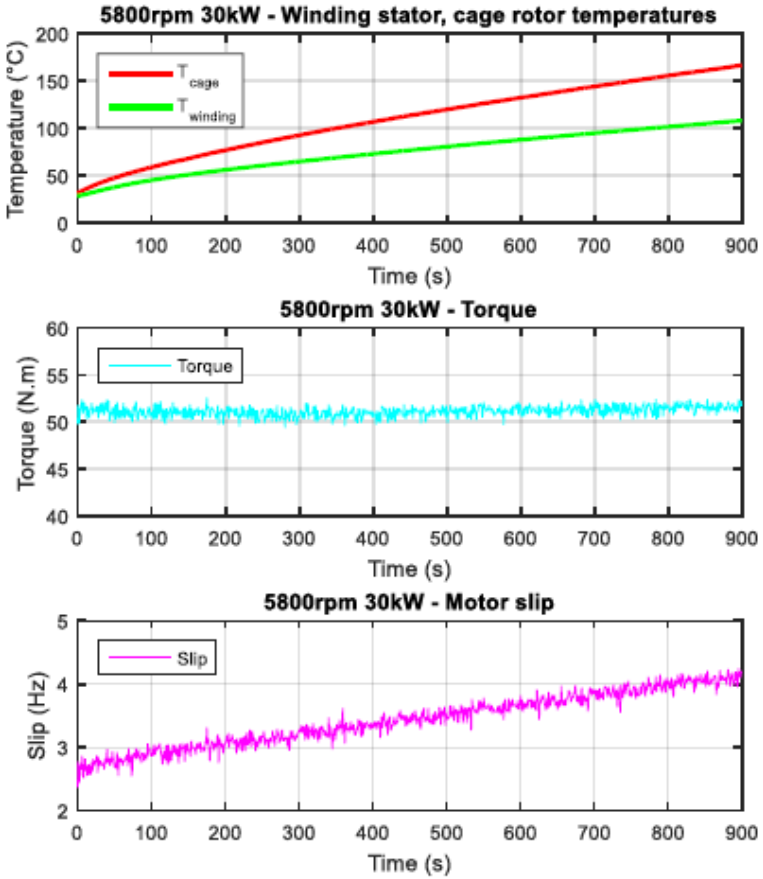


Figure 1. The 30 kW operating point with slip compensation using infrared pyrometer for measurement of rotor cage temperature.

Tran, Tuan-Vu; Nègre, Eduard, (Renault) *Electronics* 2020

DC Rotor resistance changes with temperature

- Direct effect on torque
- Slip compensation to keep torque stable as offered by Renault
  - IR measurement for rotor cage temperature

$$R_{\mathrm{R}}(T) = R_{\mathrm{R}}(20°\mathrm{C}) \cdot \left(1 + \alpha \cdot (\vartheta - 20°\mathrm{C})\right)$$

α: temperature coefficient for aluminum or copper [%/°C]

  - AC component is not considered

Rotor Temperature Sensor

Measurement technique	Characteristics	Result	Comment
Telemetry	Sensor installation in rotor	Local temperature	High mechanical effort and cost
Pyrometer	Space and free optical path needed	Only front surface of non-cooled rotors	Cheap
Back-EMF	Only at synchronous motors	Average rotor temperature	Only in free-wheeling mode possible
Fiber optic pyrometer	For all type of e-motors	Rotor surface temperature	Minimum installation effort

Our solution

Rotor Temperature Sensor

Innovation

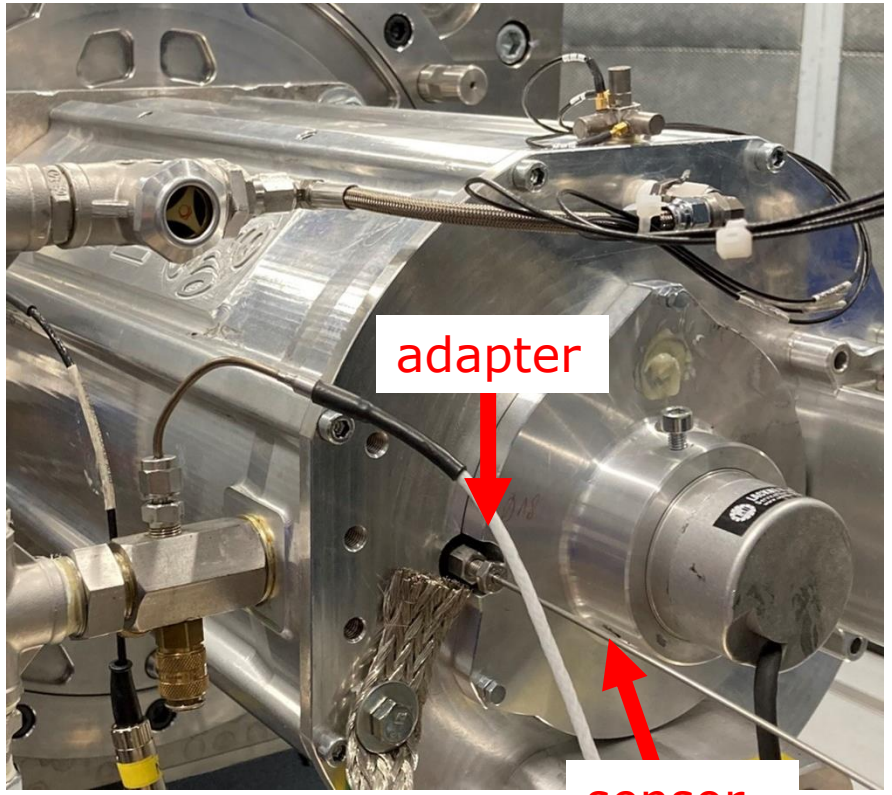
+ Small sensor diameter (≤ 5 mm)

+ Low installation effort

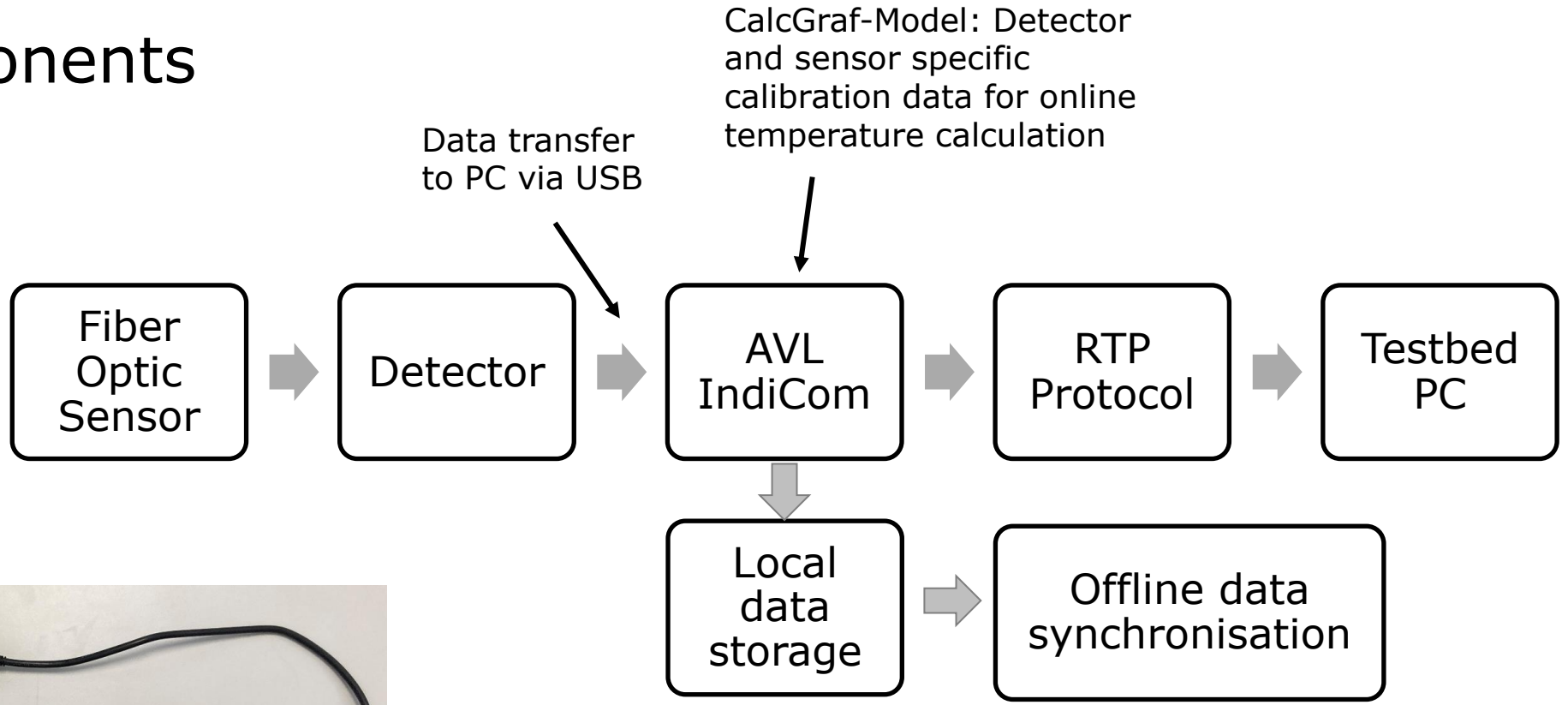
+ data transfer via AVL IndiCom™ to AVL PUMA™

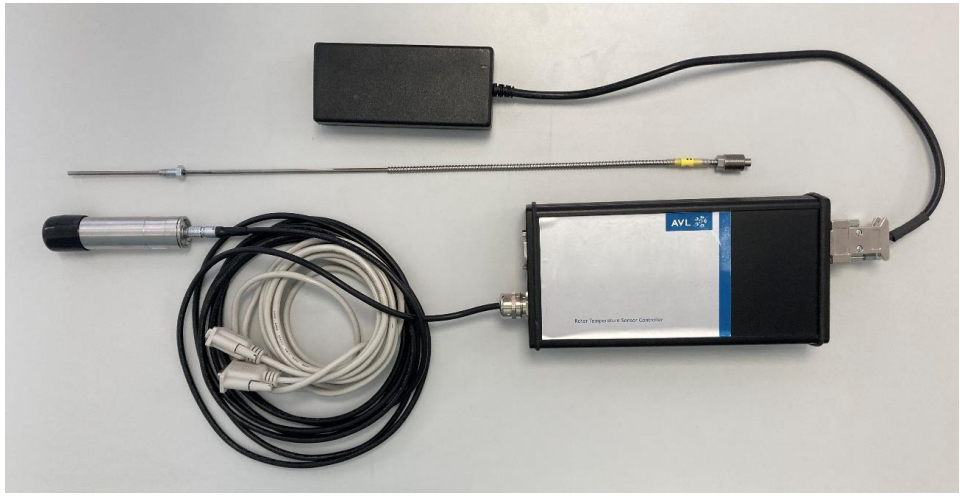
+ No mechanical machining or painting of the rotor

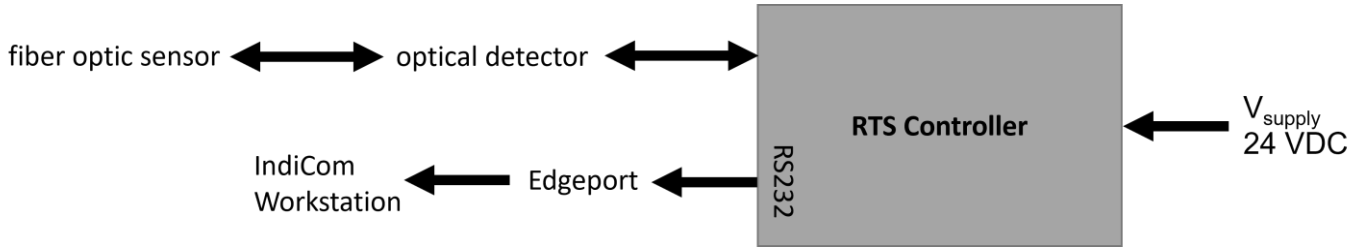
+ Applicable on all types of e-motors
  + PMSM, EESM, ASM, induction motor,…
  + cooled / non-cooled



System components



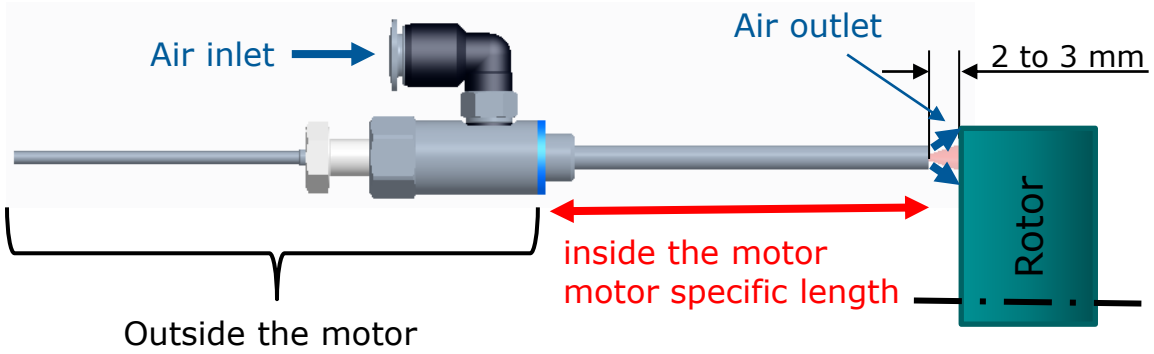


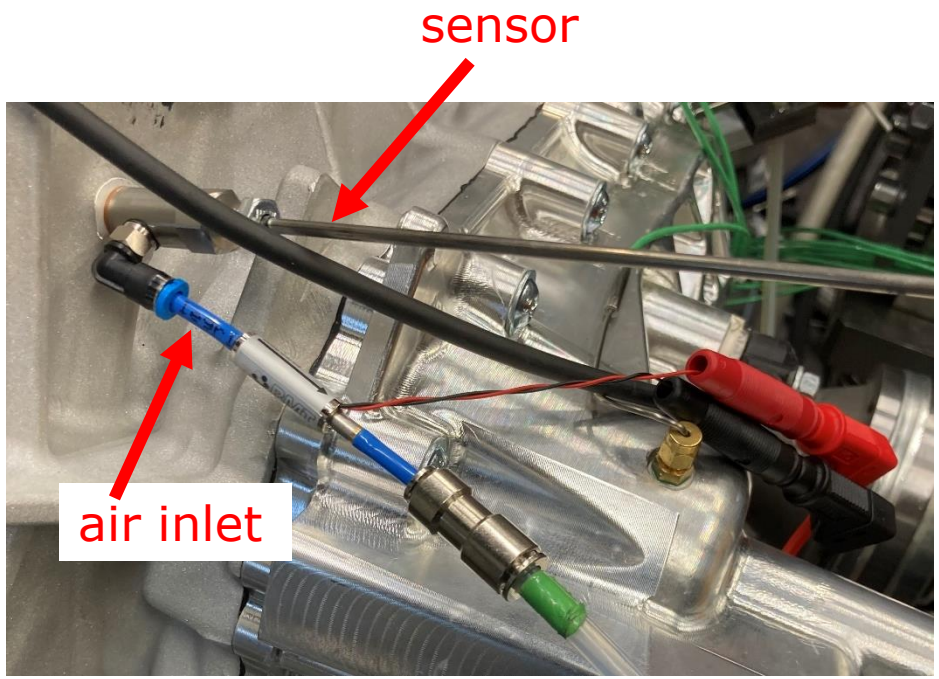


Rotor Temperature Sensor

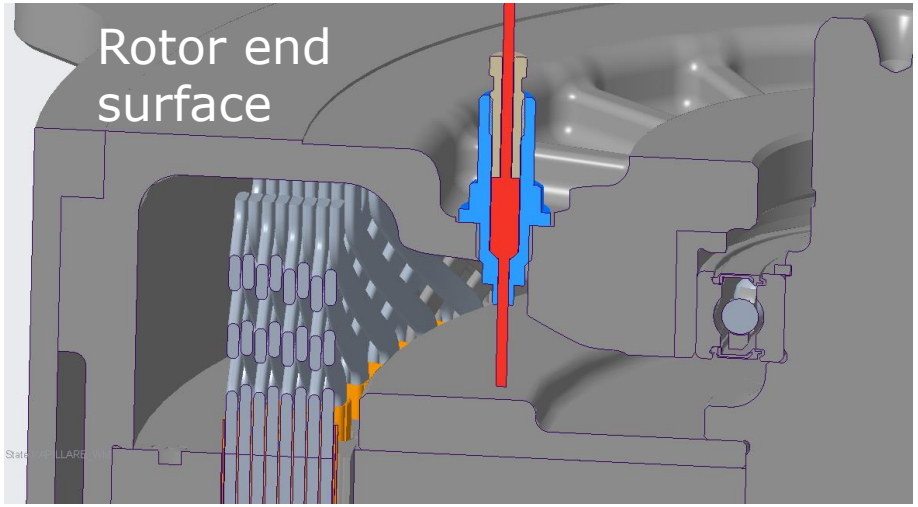
Our Solution and Patent

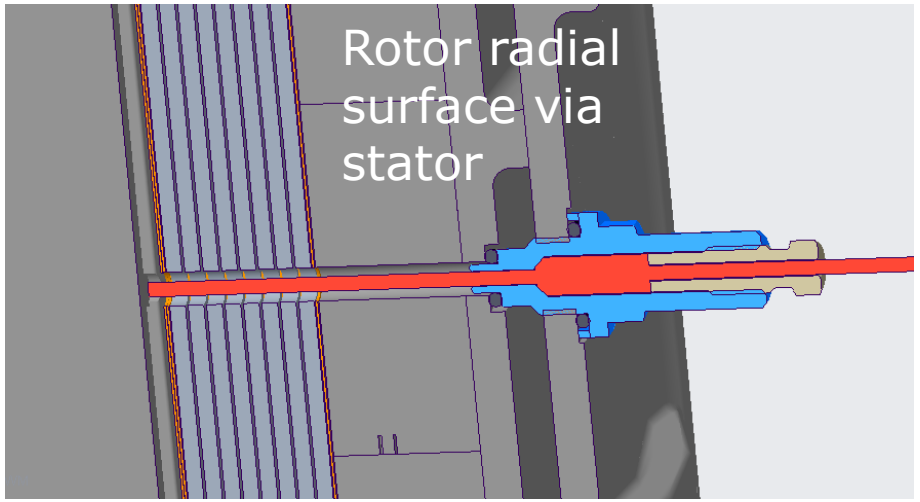
Directly oil-cooled rotors ➔ patent pending sensor

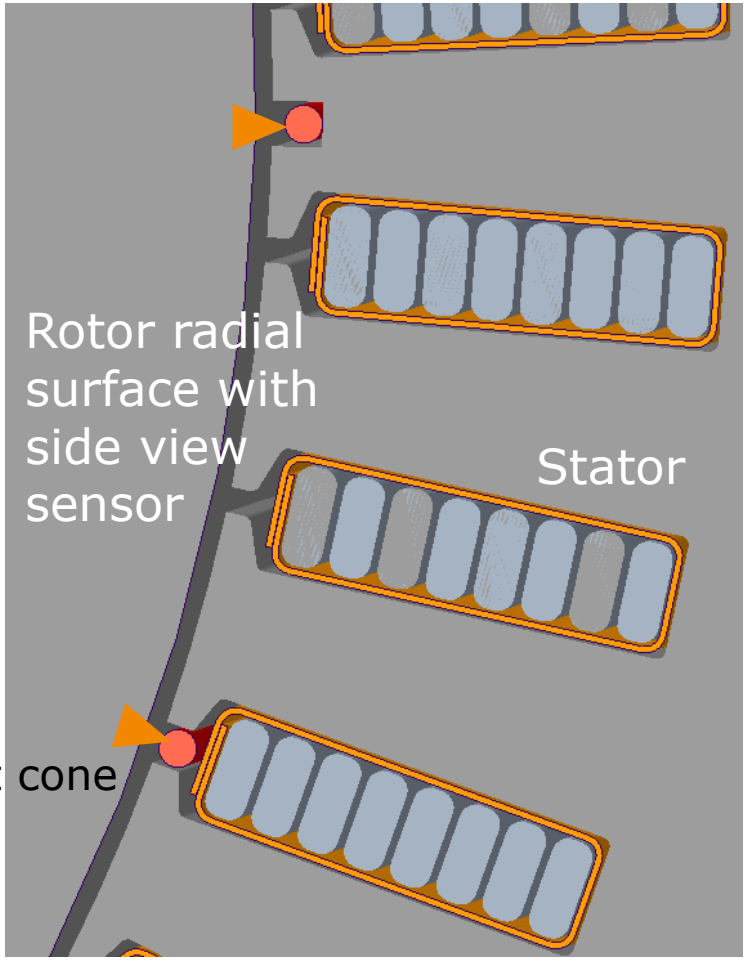




3 adaption examples





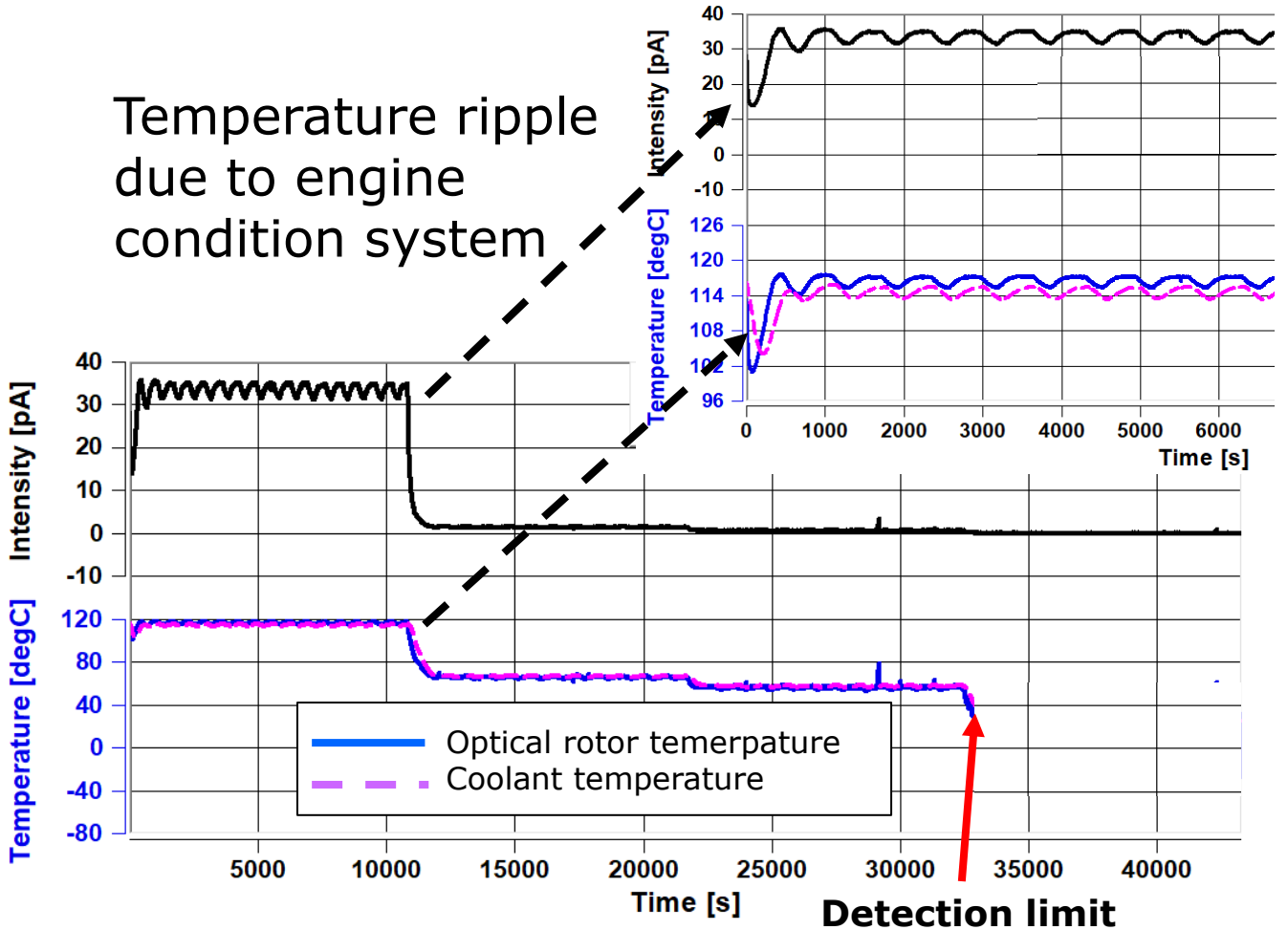


Calibration for oil cooled rotor

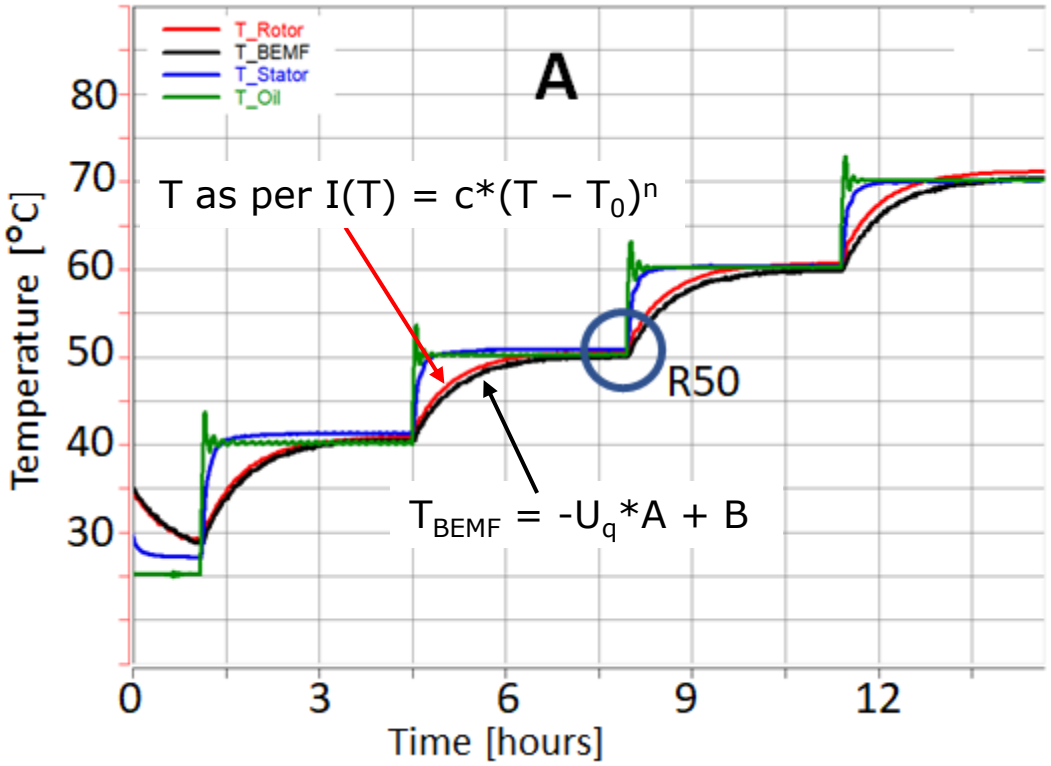
Procedure:

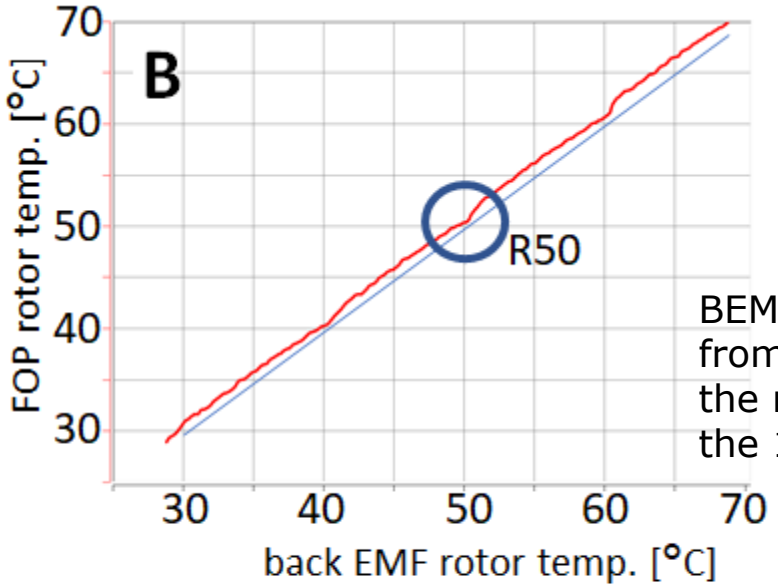
- Condition the motored engine to at least 3 different temperatures
- Operate the motor until the temperature is stable
- Measure intensity and temperature
- Determine intensity-temperature relation

Temperature ripple due to engine condition system



FOP calibration: confirm FOP calibration along temperature steps



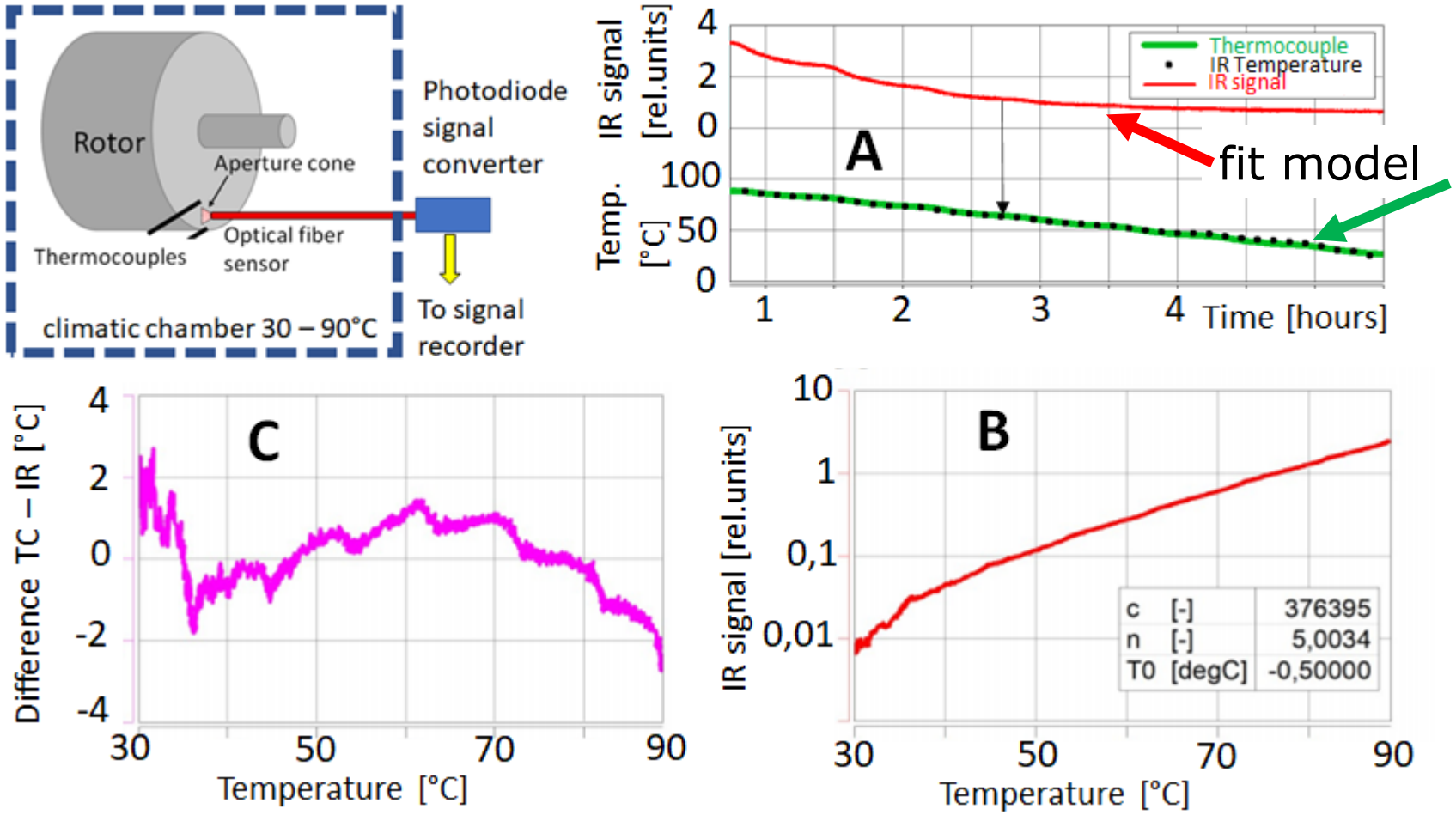


BEMF signals are evaluated from continuously operating the motor at 1000 rpm over the 14 hours test period

Result: reliable and precise real time pyrometer signal at temperatures > 30°C

Notice that model coefficients (A, B, and c, T_0, n) for BEMF and radiation signal evaluation provide independent confirmations of rotor temperature response to heat input from stator conditioning.

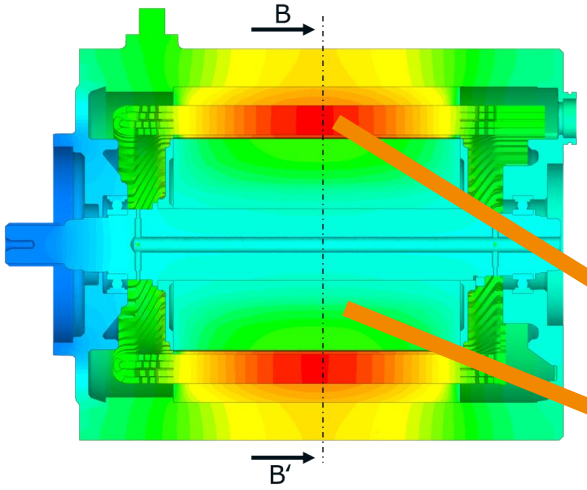
FOP calibration step 1: establish radiation to temperature relation



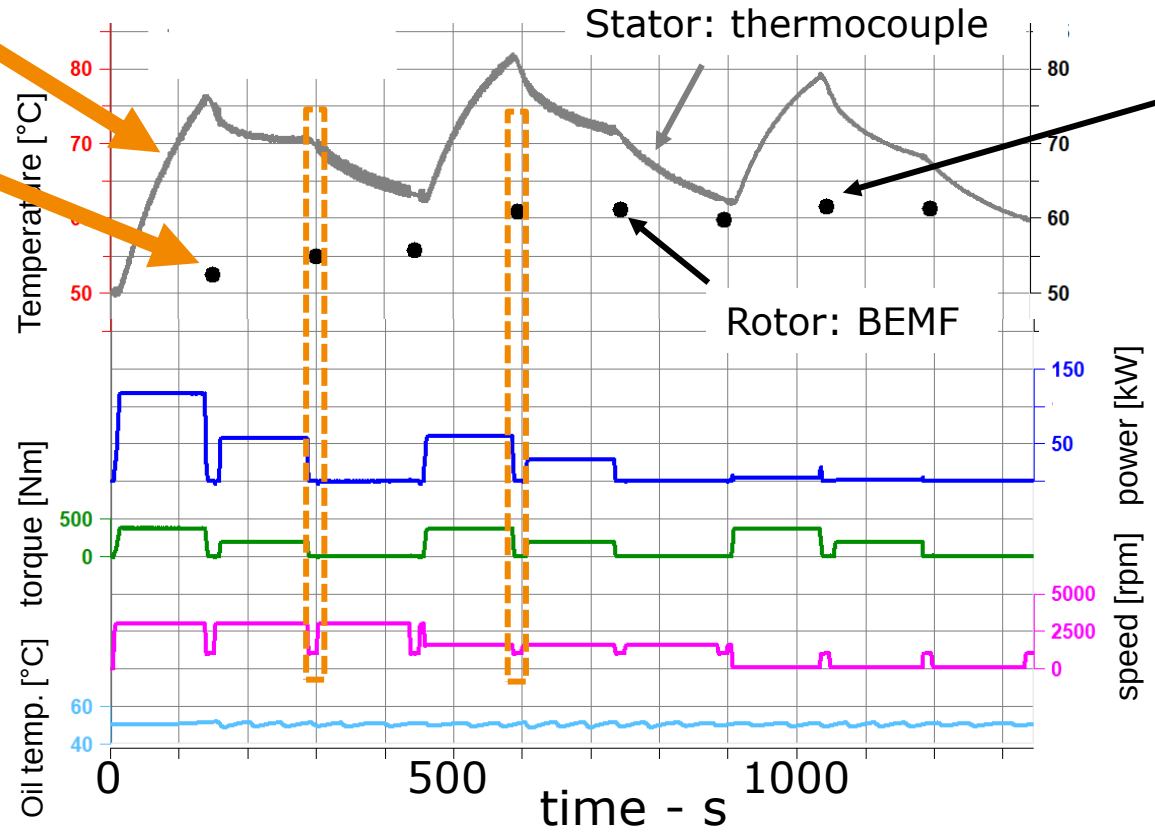
Primary FOP calibration: Establish the radiation to temperature relationship and derive the fit parameters

A: Intensity and temperature measurement
B: Intensity – temerpature relation
C: Quality of intentisty temperature relation

Test example: BEMF temperature after each test point



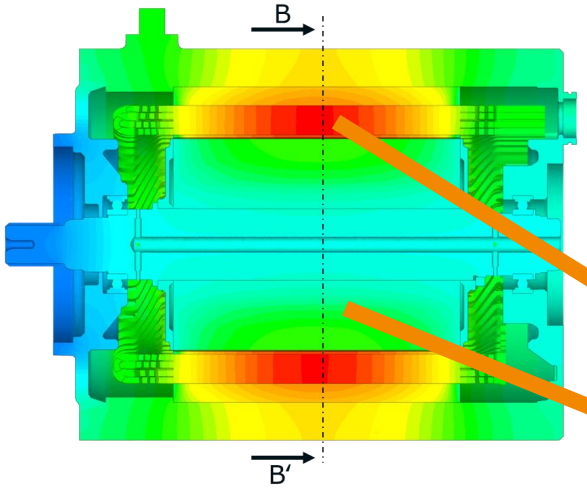
PMSM example



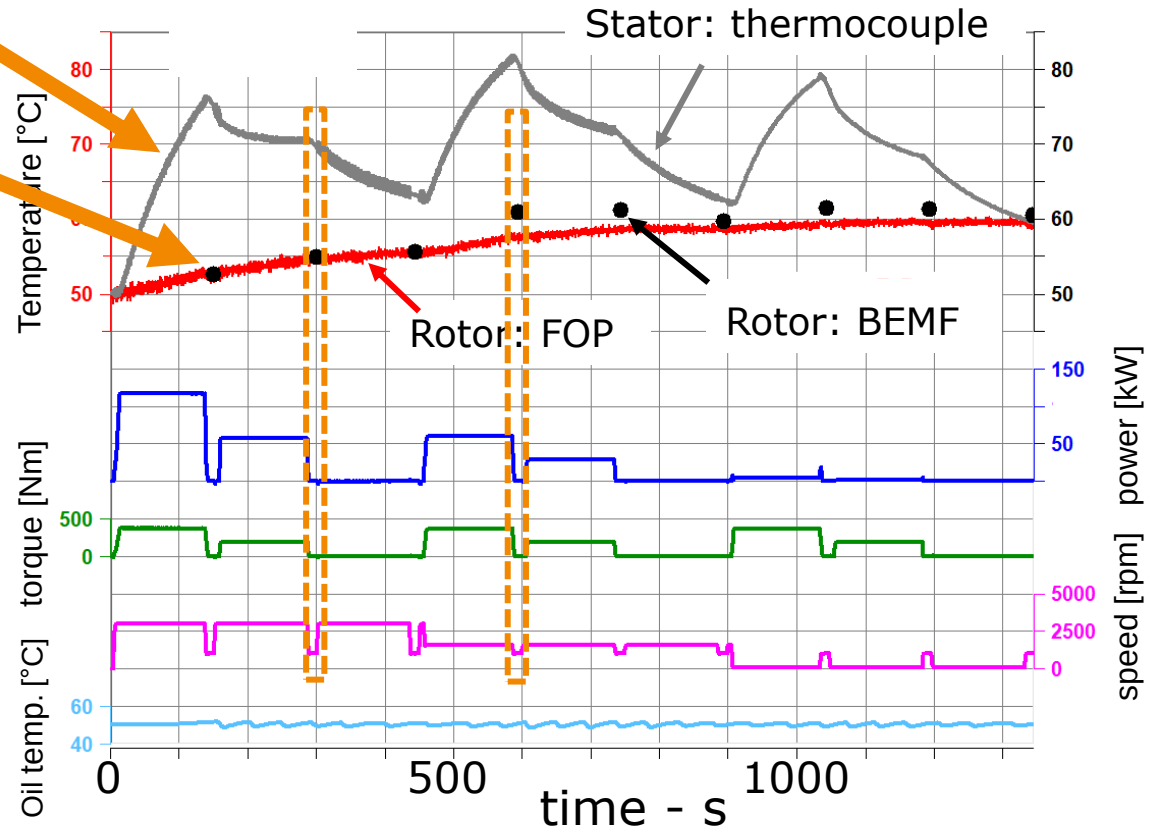
The back-EMF method needs regular test periods:

- 1000 rpm
- Zero load
- Open stator voltage lines

Test example: the real time FOP temperature signal



PMSM example

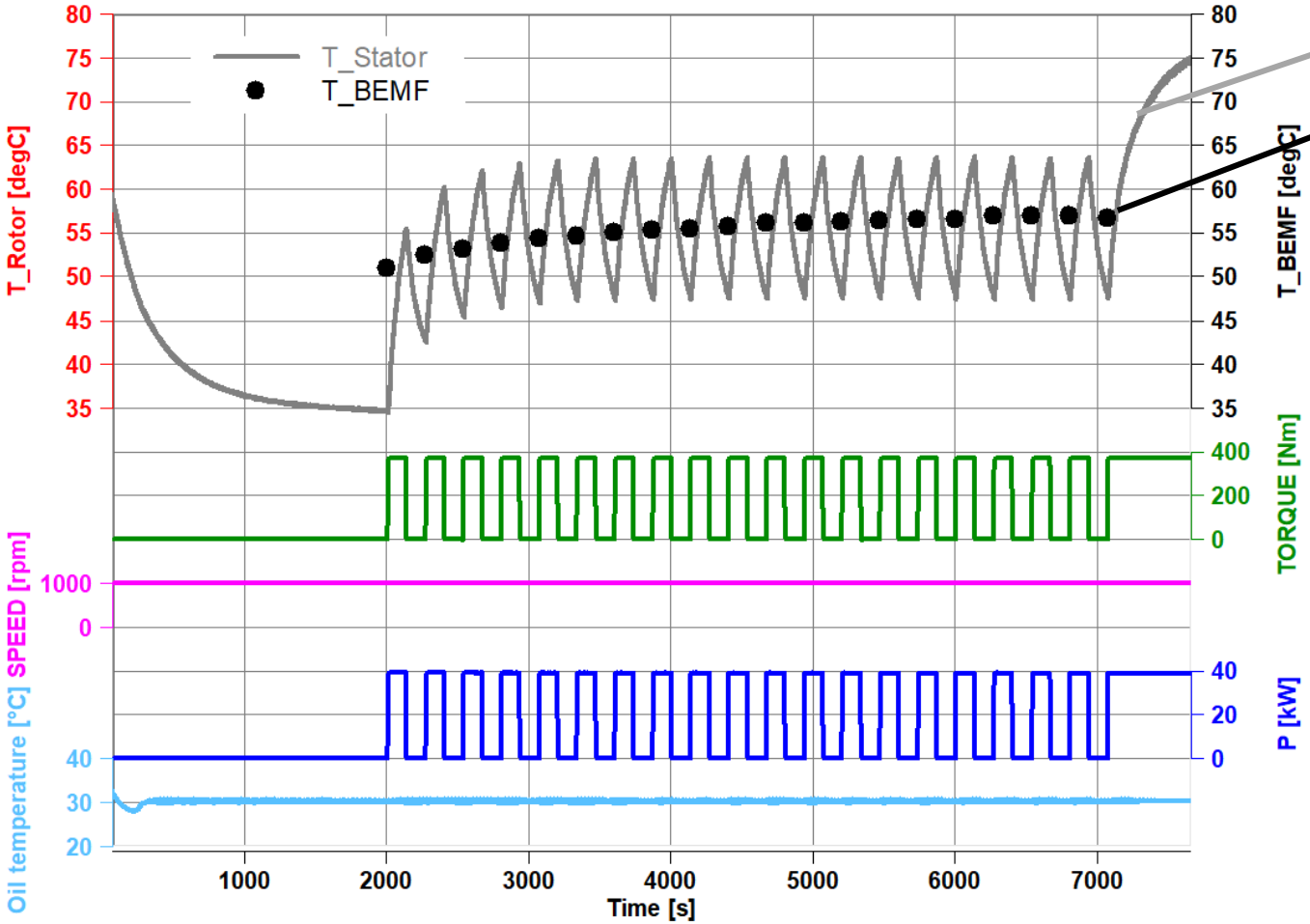


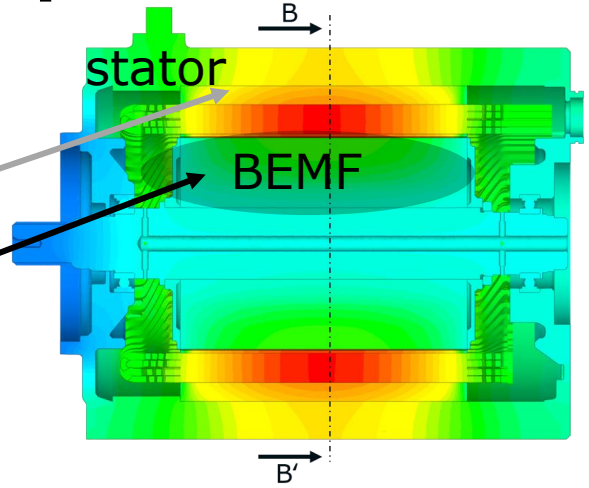
BEMF temperature: is an integral for the rotor's magnetic field effect

FOP: shows the local surface temperature near the sensor front

Differences are due to heat transfer effects in the rotor body

A time response test at moderate temperatures



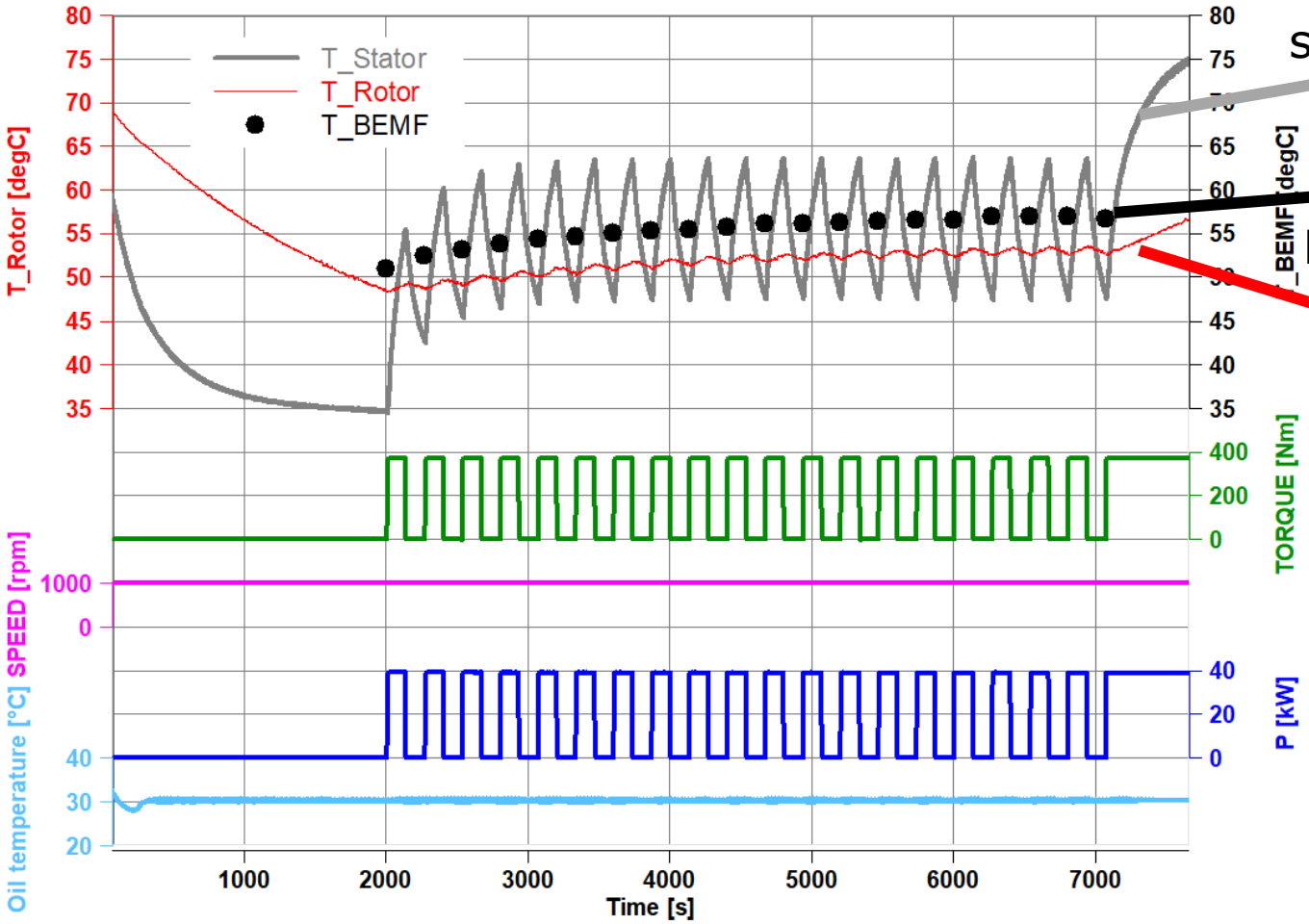


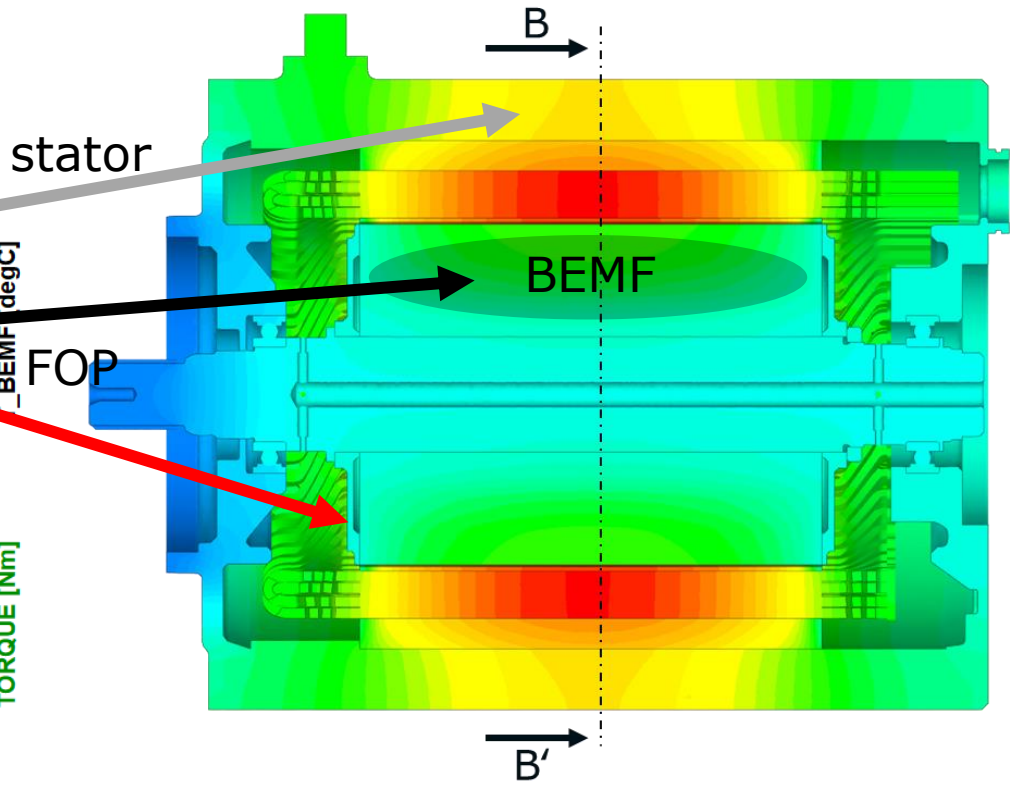
Motor response to load repetitions:

Stator temperature sweeps with 15 °C amplitudes

Any response of the rotor ?

A time response test at moderate temperatures





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Thank you

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