Electric Motor Temperature Prediction

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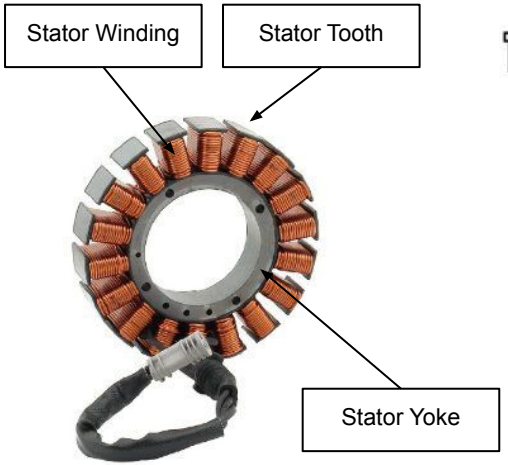
Outline

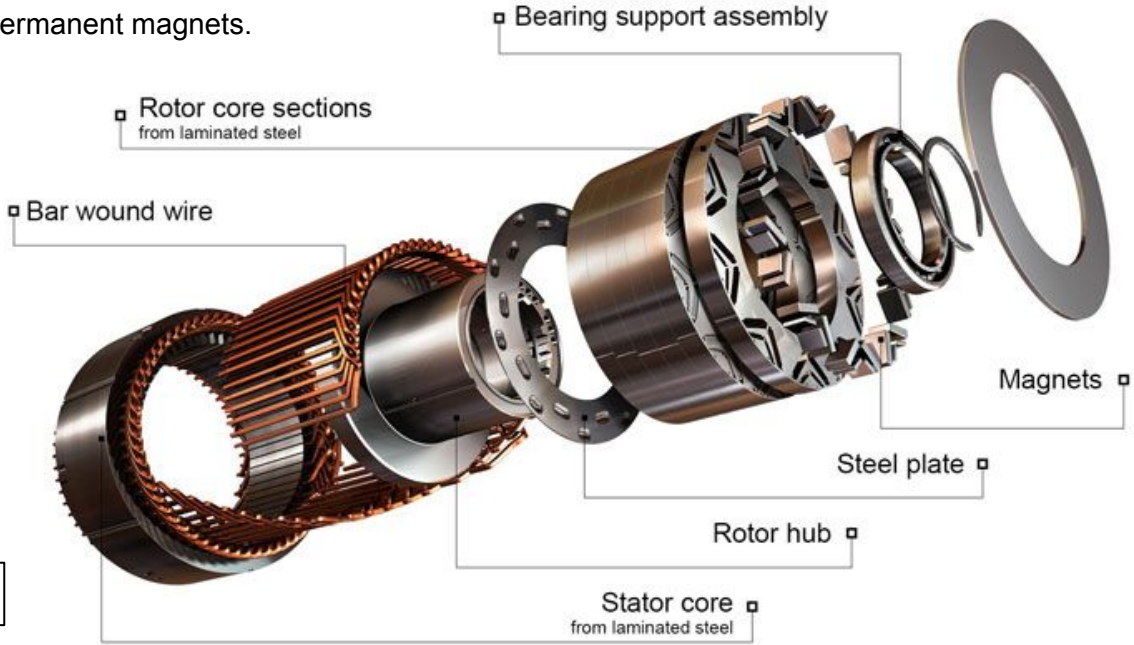
The Permanent Magnet Synchronous Motor (PMSM)

According to Levkin, D:

- A PMSM's inductor consists of permanent magnets.
- The stator is the fixed part.
- The rotor is the rotating part.



The Stator



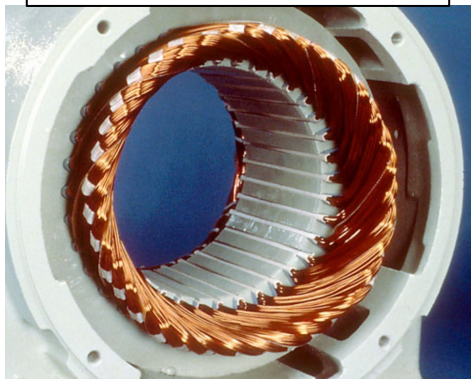
The Permanent Magnet Synchronous Motor

Why Temperature Prediction Matters

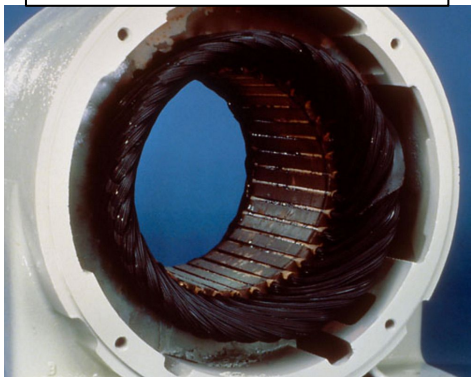
According to Anjian Zhou, et al:

- The temperature determines the PMSM's load capacity.
- Excessive temperature will introduce potential thermal safety problems.
- Accurate temperature prediction is crucial to improve the motor performance and system operation safety.

Healthy Winding



Winding Damage due to Thermal Deterioration



Images from Leos, N. D.

Why Torque Prediction Matters

According to W. Nawae and K. Thongpull:

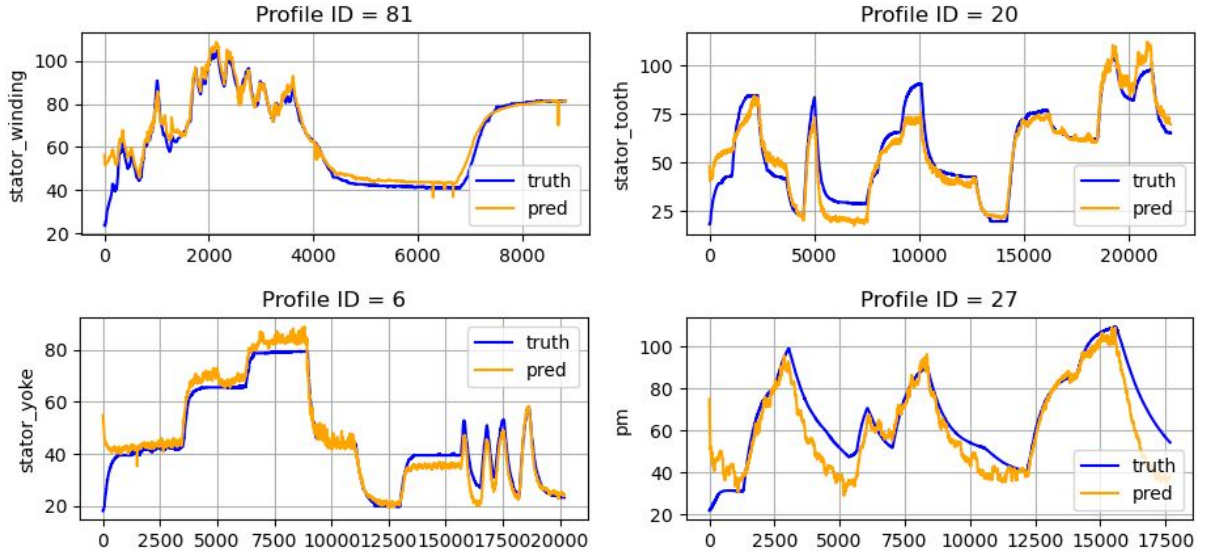
- Rotor torque is conventionally acquired by a torque transducer.
- However, using such device requires extra cost, bulky mechanical installation, and data acquisition electronics.

Accurate torque predictions can save time, money, and space

Temperature Prediction Results

The trends and magnitudes of the temperature can be captured through predictive machine learning models

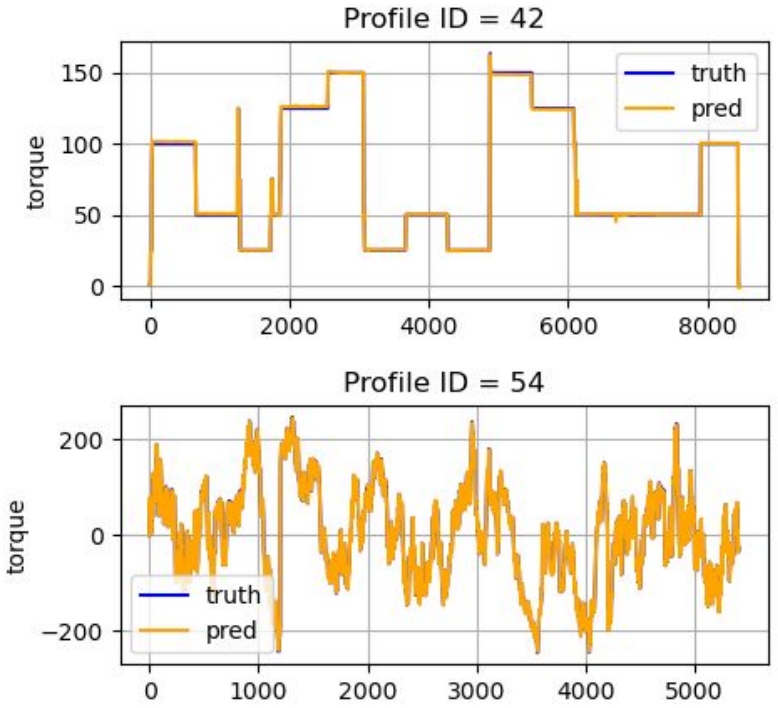
Target	RMSE (°C)
Stator Winding	8.2
Stator Tooth	6.3
Stator Yoke	4.4
Pm	8.5



Torque Prediction Results

The trends and magnitudes of the torque can be captured through predictive machine learning models

Target	RMSE (N·m)
Torque	1.0



Temperature Prediction Model

The target temperatures are estimated using an Exponentially Weighted Moving Average (EWMA) Regression model.

- This model uses 4 custom features:
  - 1 minute window of recorded sensor history
  - 2 minute window of recorded sensor history
  - 3 minute window of recorded sensor history
  - 19 minute window of recorded sensor history
- The recorded sensor history includes the following measurements sampled at 2 Hz:
  - Voltage measurement in dq-coordinates
  - Current measurement in dq-coordinates
  - Motor speed
  - Coolant temperature
  - Ambient temperature

Torque Prediction Model

The torque is estimated using a Polynomial Regression model.

- This model uses a 3rd degree polynomial expansion of sensor data.
- The sensor data includes the following measurements:
  - Voltage measurement in dq-coordinates
  - Current measurement in dq-coordinates
  - Motor speed
  - Coolant temperature
  - Ambient temperature

Future Work

This information strongly suggests that the target variables of the motor could indeed be predicted from measurements. Although, this is clearly not a perfect solution. There are sometimes high prediction inaccuracies at the beginning of a measurement session due to a history of data not existing for the creation of EWMA features in the temperature model.

Future work can include:

1. Exploring methods to lower error spikes at the beginning of each new motor session.
2. Optimizing the predictive models to be fast enough for real time application on a vehicle's computer.

If the motor temperature predictions are accurate enough for a given PMSM manufacturer, then there will be no need to rely on temperature sensors within the system if adequate model training can be done prior to commercial production. This will greatly benefit scenarios where sensors fail and are inaccessible due to the nature of the motor design.

Bibliography

Anjian Zhou, Changhong Du, Zhiyuan Peng, Qianlei Peng, Datong Qin, "Rotor Temperature Safety Prediction Method of PMSM for Electric Vehicle on Real-Time Energy Equivalence", Mathematical Problems in Engineering, vol. 2020, Article ID 3213052, 10 pages, 2020. https://doi.org/10.1155/2020/3213052

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W. Nawae and K. Thongpull, "PMSM Torque Estimation Based on Machine Learning Techniques," 2020 International Conference on Power, Energy and Innovations (ICPEI), Chiangmai, Thailand, 2020, pp. 137-140, doi: 10.1109/ICPEI49860.2020.9431433.