Electrified power train optimisation with iCARe®

iCARe® electrical steels for enhanced machine performance: Save, Torque, Speed

Save is steel with very low losses, to save weight, to save energy, to improve efficiency.

Save is in particular useful for stators of high frequency machines.

Torque is steel with high permeability, to improve air-gap flux, to obtain high motor torque or to generate high current.

A stator using Torque improves the motor's break-away torque.

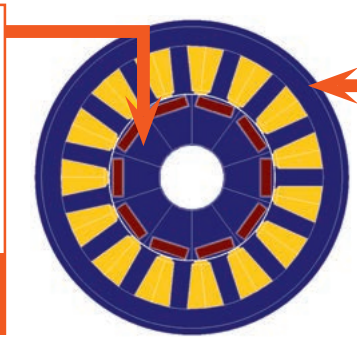
Speed steel has high strength for high speed rotors which maintain high levels of magnetic performance.

These grades allow the machine to be more compact and have a higher power density.

Rotor ES:
high mechanical solicitation due to

1. thin steel bridges between buried magnets and air-gap
2. high speed for high power density

Speed



Stator ES:

1. high air-gap flux for high torque
2. low energy dissipation for high efficiency

Save or Torque

iCARe® steels are optimised for high frequencies (>400Hz)

- Optimal grain size (δ) gives best trade-off between hysteresis and excess losses at 400Hz and above (this is quite different than the optimum for 50Hz industry grades)

$$\frac{P_{Fe}(J_p,f)}{f} = k_{hyst}J_p^2 + k_{eddy}J_p^2 f + k_{exc}J_p^{1.5}f^{0.5}$$

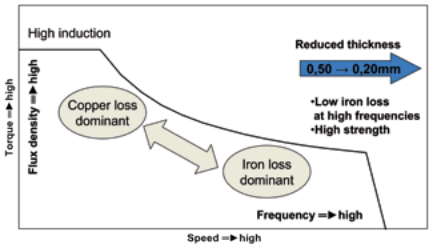
$$k_{hyst} = k'_{hyst}.\frac{1}{\delta} \quad \& \quad k_{exc} = k'_{exc}.\delta$$

- Alloying content is either chosen for lowest eddy current losses (Save) or highest polarisation (Torque)
- Optimised texture and structure to maximise ease of magnetisation
- Apart from these magnetic optimisations, optimal mechanical properties are achieved via alloying and structure choices

iCARe® advanced technical support: optimal electrical steel use

Electric traction motors: operating over wide speed and torque range
- conflicting requirements for electrical steels over such wide range
- compromise needed between high polarisation and low iron losses

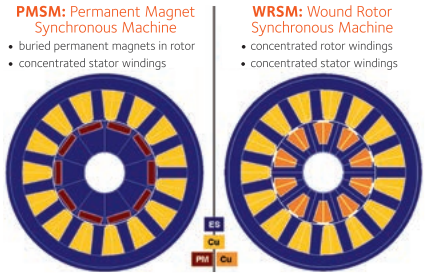
→ Numerical comparison of electrical steel grades in different types of machine topologies for vehicle traction (cars and trucks)



STUDY 1: synchronous machines (permanent magnet/wound rotor)

- Traction motors for hybrid and electric cars
- P_{nom} = 31kW; f_{nom} = 400Hz
- Numerical approach: material comparison for equal mechanical power, with varying axial length

* Two synchronous motor topologies under study (same stator): the WRSM produces less torque per meter, but is less costly (no rare-earth materials involved)



PMSM	Industry Standard M330-35A	Industry High Permeability M330P-35A	iCARe® - Save			iCARe® - Torque			
			Save 20-13	Save 30-14.5	Save 30-15	Torque 25-12.5	Torque 27-13.5	Torque 30-14.5	Torque 30-15
Torque density (Nm /m axial length)	Ref.	+2.2%	-0.4%	+0.7%	+0.4%	+1.1%	+0.8%	+1.3%	+1.6%
Compactness (m³)	Ref.	-2.1%	+0.4%	-0.7%	-0.4%	-1.1%	-0.8%	-1.3%	-1.6%
Active material loss (nominal)	Ref.	+15%	-21%	-16%	-15%	-21%	-19%	-16%	-14%
Active material efficiency (nominal)	Ref.	-0.52%	+0.77%	+0.56%	+0.54%	+0.72%	+0.68%	+0.55%	+0.52%

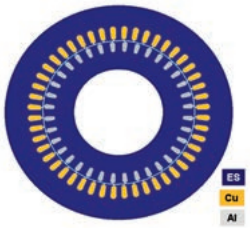
WRSM	Industry Standard M330-35A	Industry High Permeability M330P-35A	iCARe® - Save			iCARe® - Torque			
			Save 20-13	Save 30-14.5	Save 30-15	Torque 25-12.5	Torque 27-13.5	Torque 30-14.5	Torque 30-15
Torque density (Nm /m axial length)	Ref.	+4.4%	-1.7%	+0.5%	+0.2%	+1.0%	+0.6%	+1.5%	+2.1%
Compactness (m³)	Ref.	-4.2%	+1.8%	-0.5%	-0.2%	-1.0%	-0.6%	-1.5%	-2.1%
Active material loss (nominal)	Ref.	+8%	-17%	-12%	-12%	-17%	-15%	-13%	-13%
Active material efficiency (nominal)	Ref.	-0.33%	+0.67%	+0.49%	+0.47%	+0.66%	+0.61%	+0.50%	+0.51%

Electrical steel comparison at nominal speed and drive cycle averaged. All values are relative compared to the values for M330-35A, except the efficiency values are absolute changes compared to the reference grade.

The efficiency when using the reference grade is 96.4% for the PMSM and 96.1% for the WRSM.

STUDY 2: induction machine

- Traction motor for trucks
- P_{nom} = 78 kW; f_{nom} = 200Hz
- Numerical approach: material comparison for equal torque (~mechanical power), with varying slip



IM: Induction Machine (= asynchronous machine)
- Aluminium squirrel cage rotor
- distributed stator windings

IM	Industry Standard M330-35A	Industry High Permeability M330P-35A	iCARe® - Save		iCARe® - Torque		
			Save 20-13	Save 30-15	Torque 27-15	Torque 30-17	Torque 30-15
Stator current (at nominal operation)	Ref.	-7.4%	+2.9%	-0.7%	-1.3%	-2.8%	-4.3%
Energy losses due to active materials (at nominal operation)	Ref.	+11%	-18%	-14%	-16%	-9%	-14%
Active material efficiency (at nominal operation)	Ref.	-0.44%	+0.72%	+0.53%	+0.61%	+0.37%	+0.53%

Electrical speed comparison at nominal frequency. All values are relative compared to the values for M330-35A, except the efficiency values are absolute changes compared to the reference grade.
The efficiency when using the reference grade is 96.1% for the IM.

Conclusion

iCARe® Save: high efficiency (= best use of battery power)
- **high efficiency** due to low iron losses
- **smaller batteries** possible for same drive range
- if best efficiency is important, regardless extra cost, then Save 20-13 comes first
- change of torque density is limited

iCARe® Torque: less copper windings
- good compromise between **high torque production** and **low iron losses**
- higher torque density enables **smaller machines**, hence saving on copper and magnets

iCARe® Save and Torque grades in 0.3 mm: the market reference today
- appear to be effective materials
- best value/cost ratio (during construction and exploitation)
- higher performance machines benefit from 0.27 or 0.25 mm grades