Energy Efficiency of Induction Machines – Normative Requirements, Technical Potential, Comparison with Other Types of Electrical Machines

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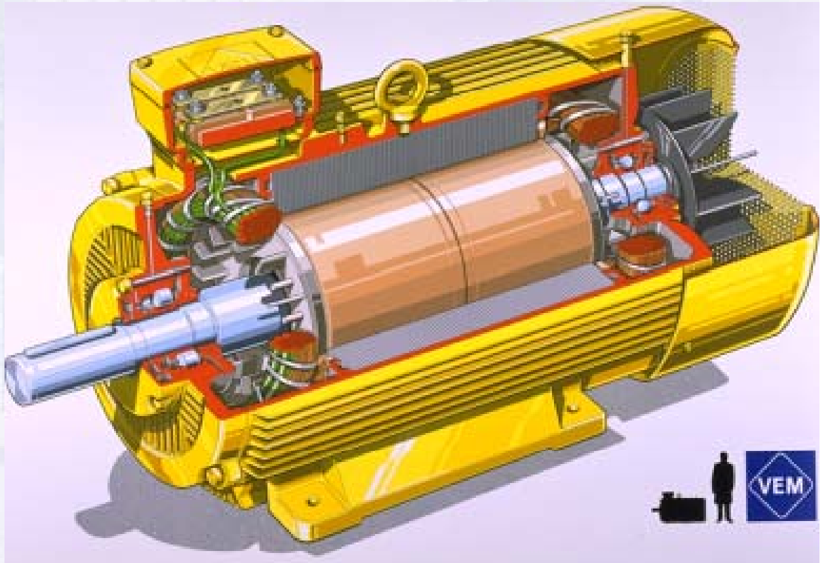
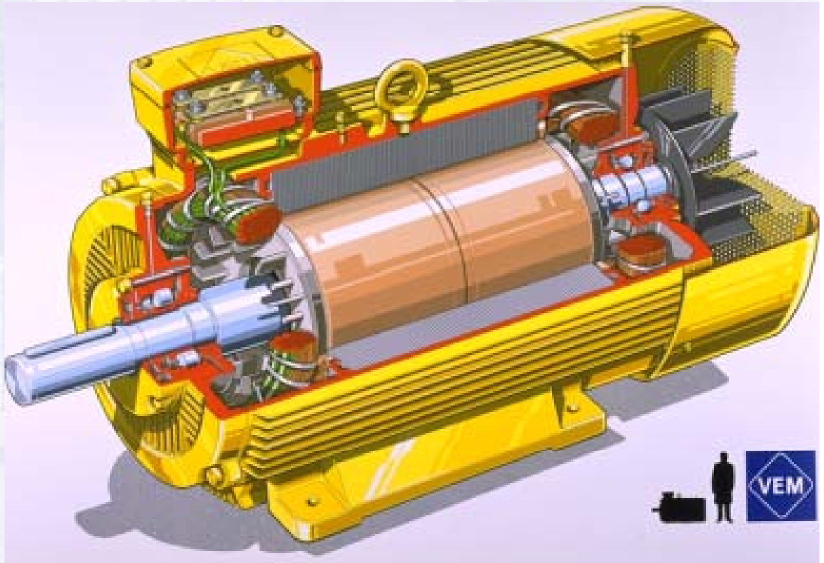


Energy Efficiency of Induction Machines

Contents

Overview

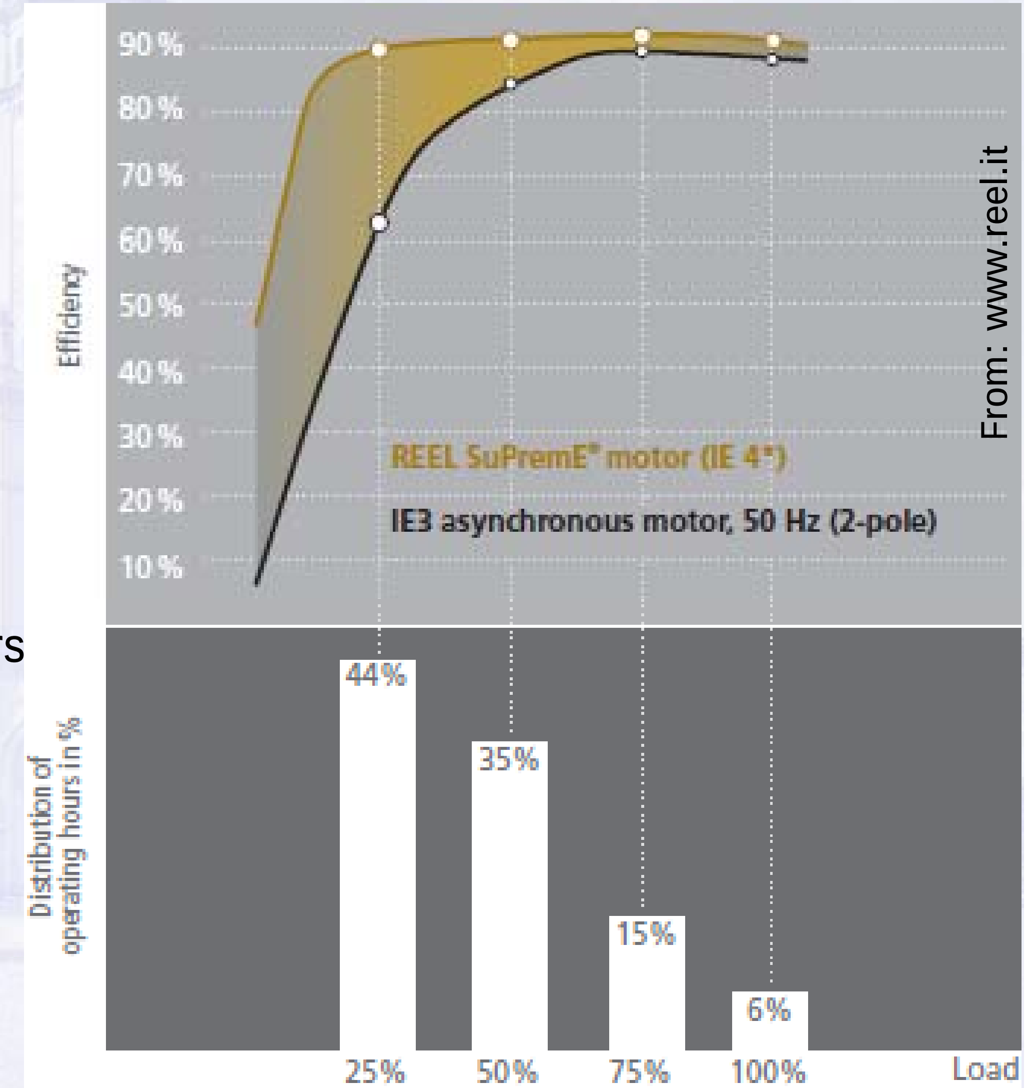
- Introduction
- Normative Requirements
- Technical Potential
- Comparison with Other Types of Electrical Machines
- Conclusion



Challenges for Standard Induction Motors

- Increasing legislative requirements on energy efficiency
- Increasing demand for outstanding torque or power density in some applications
- "New" motor technologies:
  - PM synchronous motors
  - Synchronous reluctance motors
  - Switched reluctance motors
  - Flux switching synchronous motors

Will cage induction motors have a future?

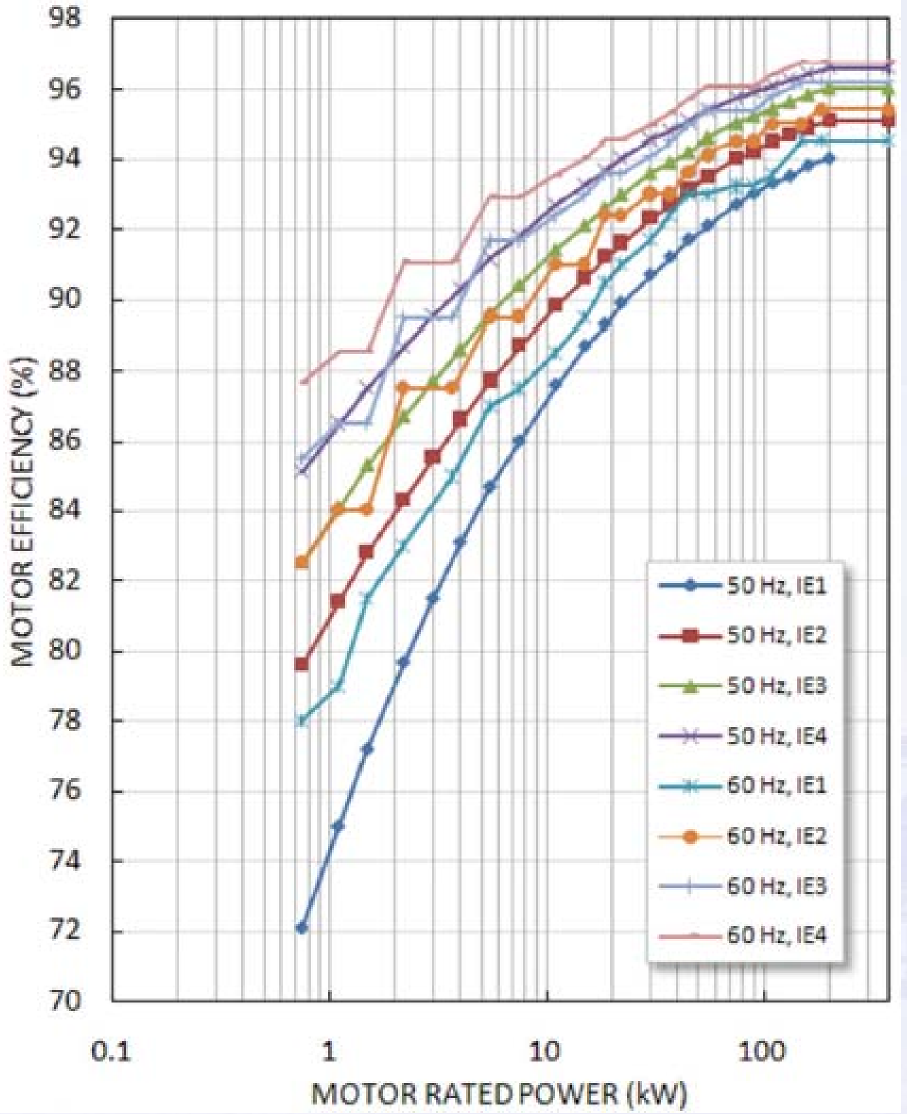


From: www.reel.it

International Standardization of Efficiency Classes in 2009

IEC 60034-30 defines efficiency classes IE1 … IE3 – but only for line-fed cage induction motors with

- U_N < 1000 V
- 0,75 kW < P_N < 375 kW
- f_N = 50 Hz or 60 Hz
- 2, 4 or 6 poles
- no pole change
- S1 or S3 operation
- normal conditions
- line start, …
- 60 Hz limits identical to DOE-EPACT or NEMA Premium
- 50 Hz limits based on CEMEP: EFF2 → IE1, EFF1 → IE2



From: ISR-UC, Prof. de Almeida

IE limits for 4pole motors

EuP Legislation for the EU based on IEC 60034-30 (2009)

EU directive 640/2009:

- IE2 mandatory from 2011-06-05
- IE3 or IE2 with converter supply for P_N > 7,5 kW mandatory from 2015-01-01
- IE3 or IE2 with converter supply for P_N > 0,75 kW mandatory from 2017-01-01

Different reactions on the motor market:

- ‘Work arounds‘: Misleading labeling, e. g. S9 instead of S1
- Demand of IE4 motors, even though IE4 hasn‘t been standardized yet
- Demand of motors outside scope, but with IE classification

Prior to further legislation steps, normative basis must be developed:

- EU mandate M/470 EN for motors
- EU mandate M/476 EN for converters and power drive systems

Consequence of EU Mandates

New IEC 60034-30-1 with extended scope for single speed motors:

- Rated power down to 120 W and up to 1000 kW
- Rated voltage down to 50 V and up to 1000 V
- 2, 4, 6 or 8 poles
- Designed for sinusoidal supply
- Efficiency classes are independent from motor technology

New IEC 60034-30-2 for variable speed motors maximum speed between 100 rpm and 10.000 rpm (independent of no. of poles) is currently being drafted

⇒ *Legislation on minimum efficiency classes for variable speed motors cannot be released before 2016*

Options for Improvement of Induction Motor Efficiency

a) Technology:

Improved slot fill factor in stator;

rotor cage from casted copper

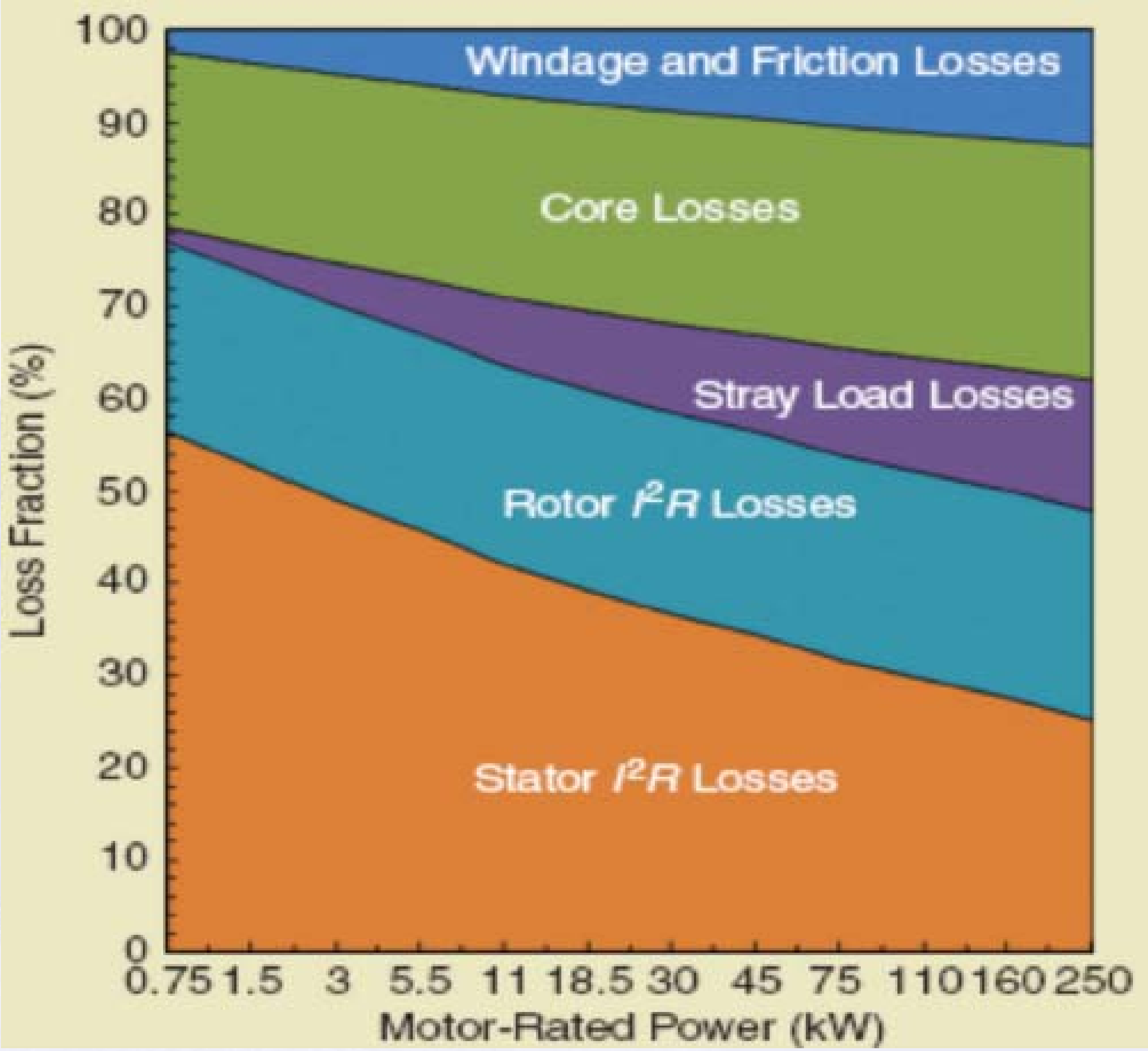
b) Material:

Improved lamination

c) Design:

Reduction of stray load losses

But: Restriction due to limited starting current for single speed motors!



From: ISR-UC, Prof. de Almeida

Example 1: Design Alternatives for Efficiency Improvement of Induction Motor

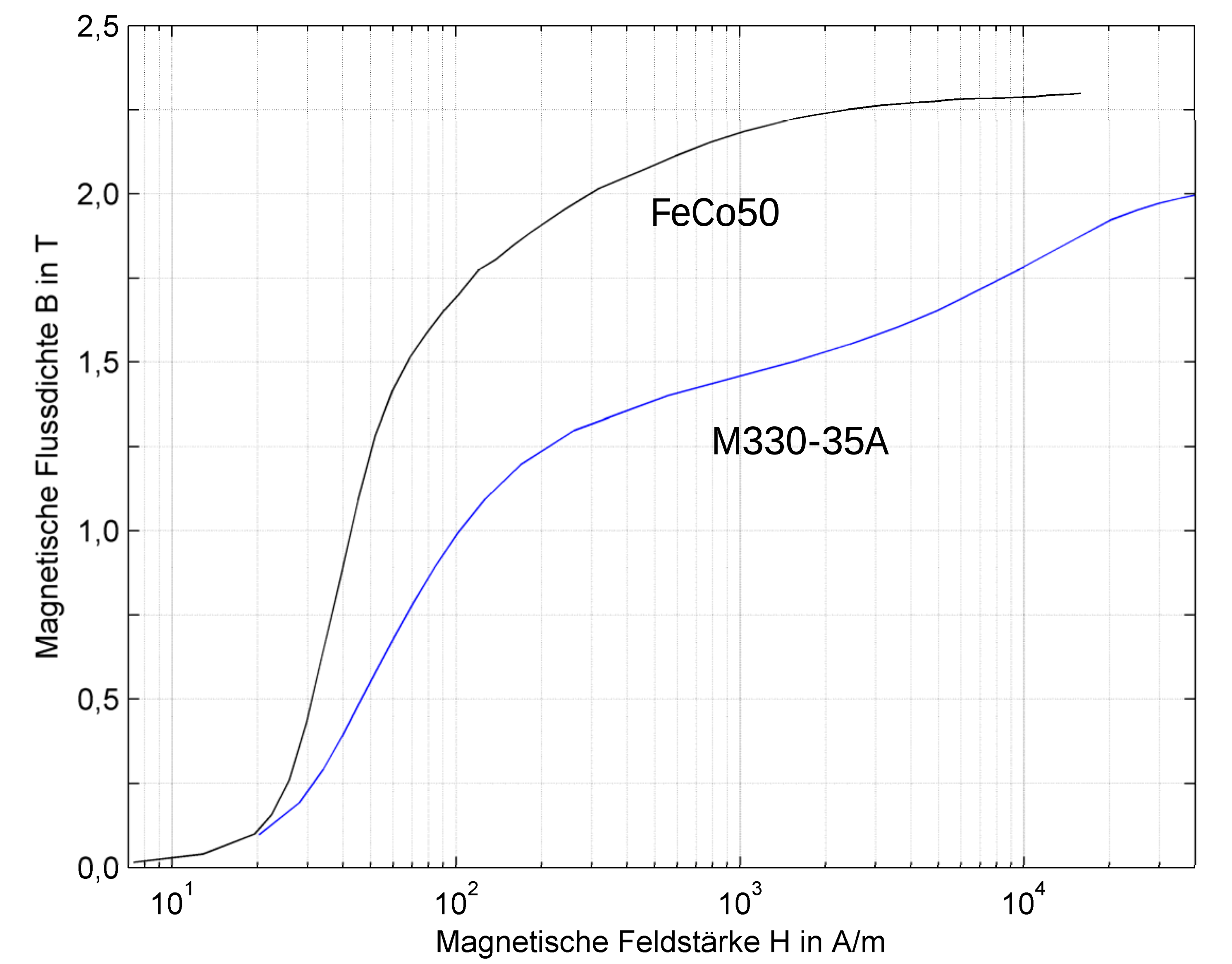
- 1,5 kW, 3000 rpm single speed cage induction motor

	poles	*f* / Hz	*l* / mm	cos φ	η / %
Original design	2	50	90	0,82	81,1
Increased core length			135	0,89	81,5
Improved core material (M330-50A)			135	0,87	84,4
Copper for rotor cage			135	0,87	85,9

- 1,5 kW, 3000 rpm motor with converter supply

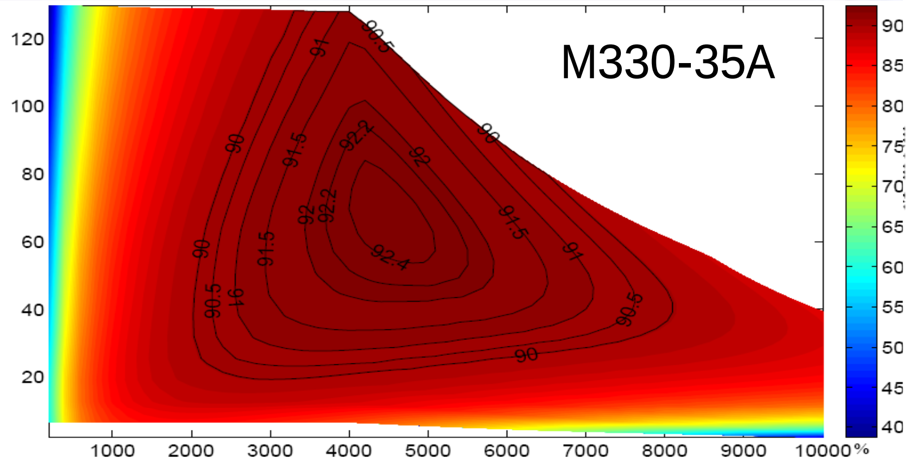
	poles	*f* / Hz	*l* / mm	cos φ	η / %
Original design	2	50	90	0,82	81,1
4 poles, reduced core length	4	100	75	0,82	85,0
Improved core material (M330-50A)			75	0,81	85,6
Original core length			90	0,77	86,3
Copper for rotor cage			90	0,77	86,9
Slightly increased core length			100	0,82	87,4

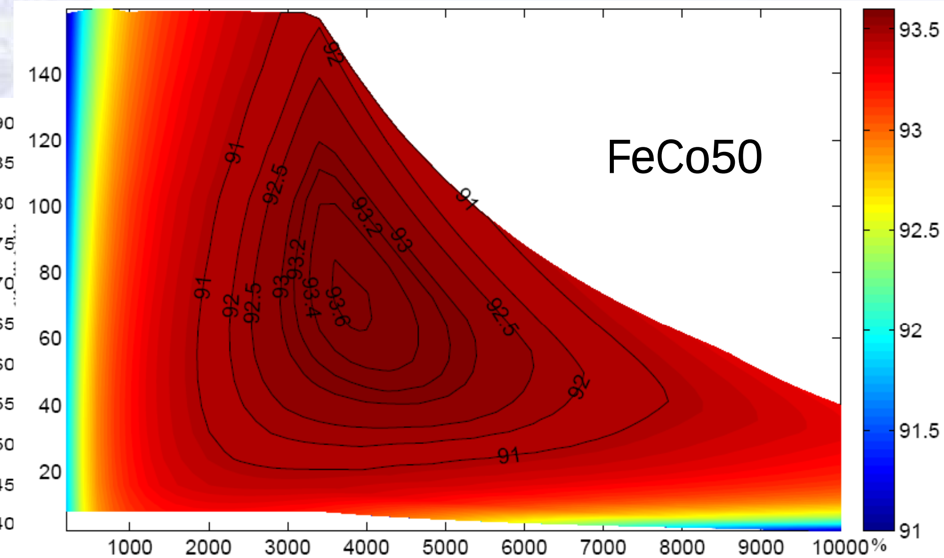
Example 2: Influence of Lamination Material on Maximum Torque and Efficiency



Example 2: Influence of Lamination Material on Maximum Torque and Efficiency

- 55 kW, 4 pole cage induction motor

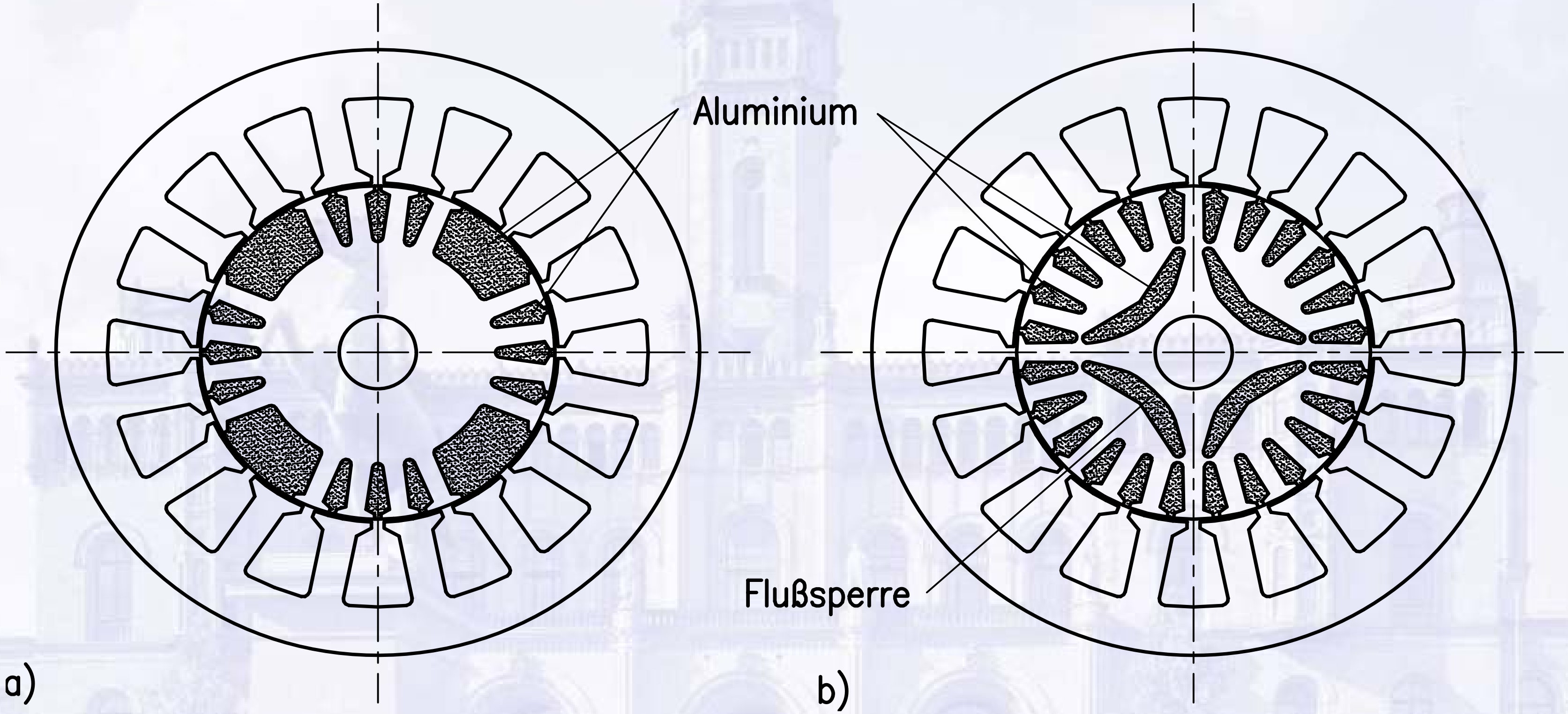




Efficiency maps in the torque in Nm vs. speed in rpm plane

- High end material reduces magnetizing current by 25%
- With optimization of geometry, high end material increases maximum torque by 20% AND efficiency by 1% for identical stator current

Alternatives to Induction Machines: Synchronous Reluctance Machines



“Classical” Line Start Synchronous Reluctance Motors

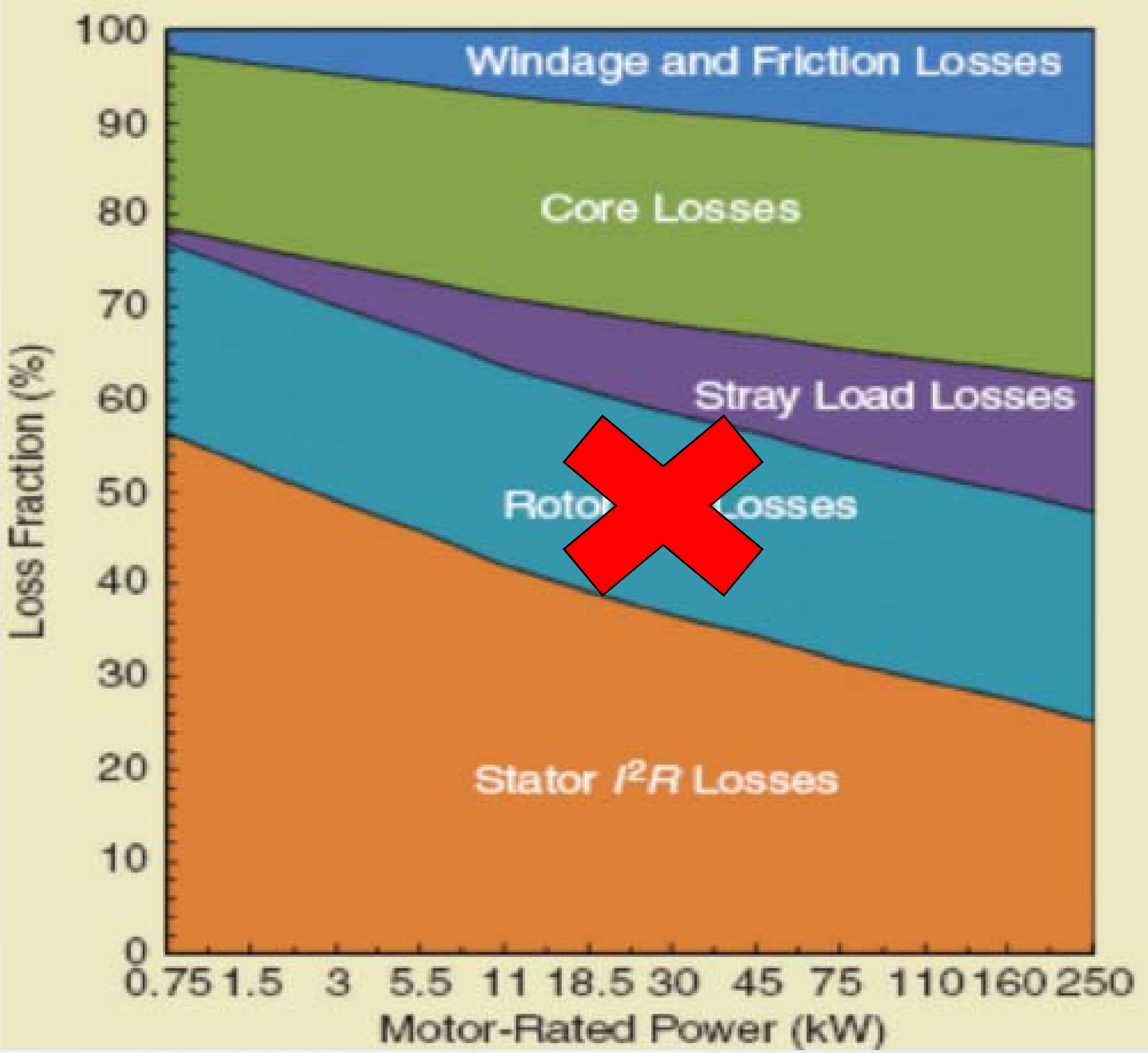
Alternatives to Induction Machines: Synchronous Reluctance Machines

From: www.abb.de

"New" Converter-fed Synchronous Reluctance Motors

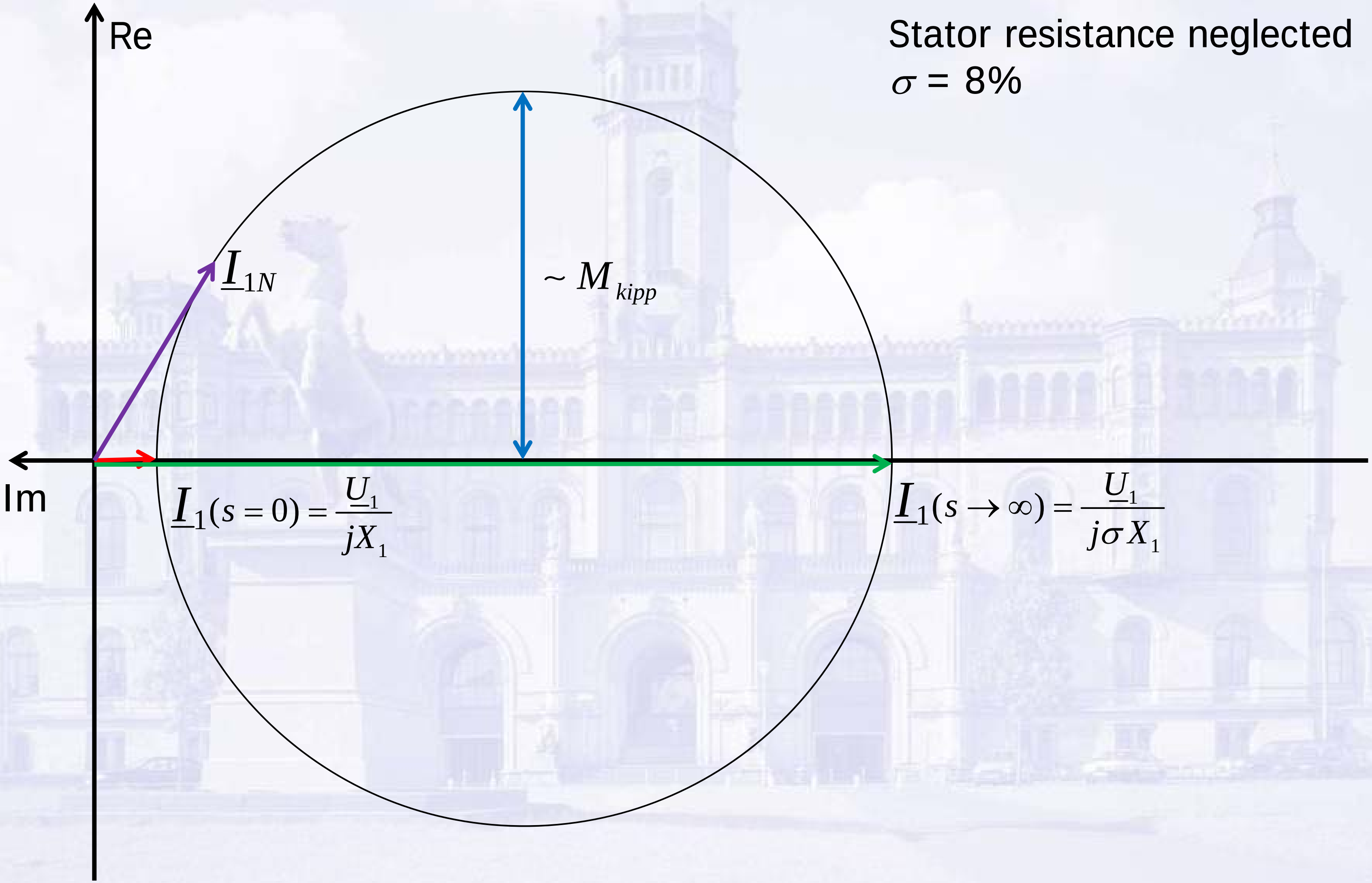
Alternatives to Induction Machines: Promise of Synchronous Reluctance Machines

- No rotor losses
- Improved efficiency
- Higher torque density



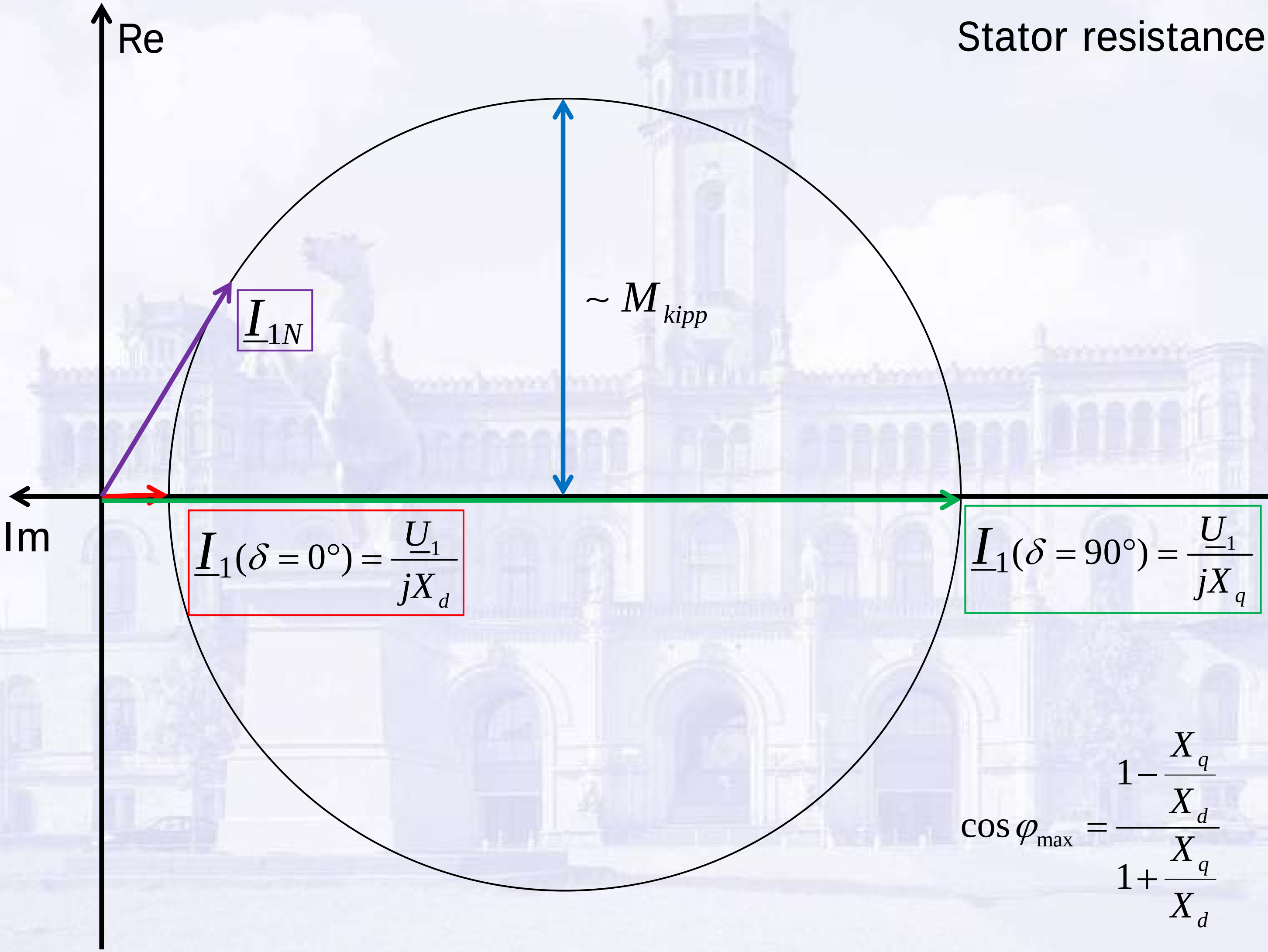
Current Locus of Induction Machine

Stator resistance neglected
σ = 8%



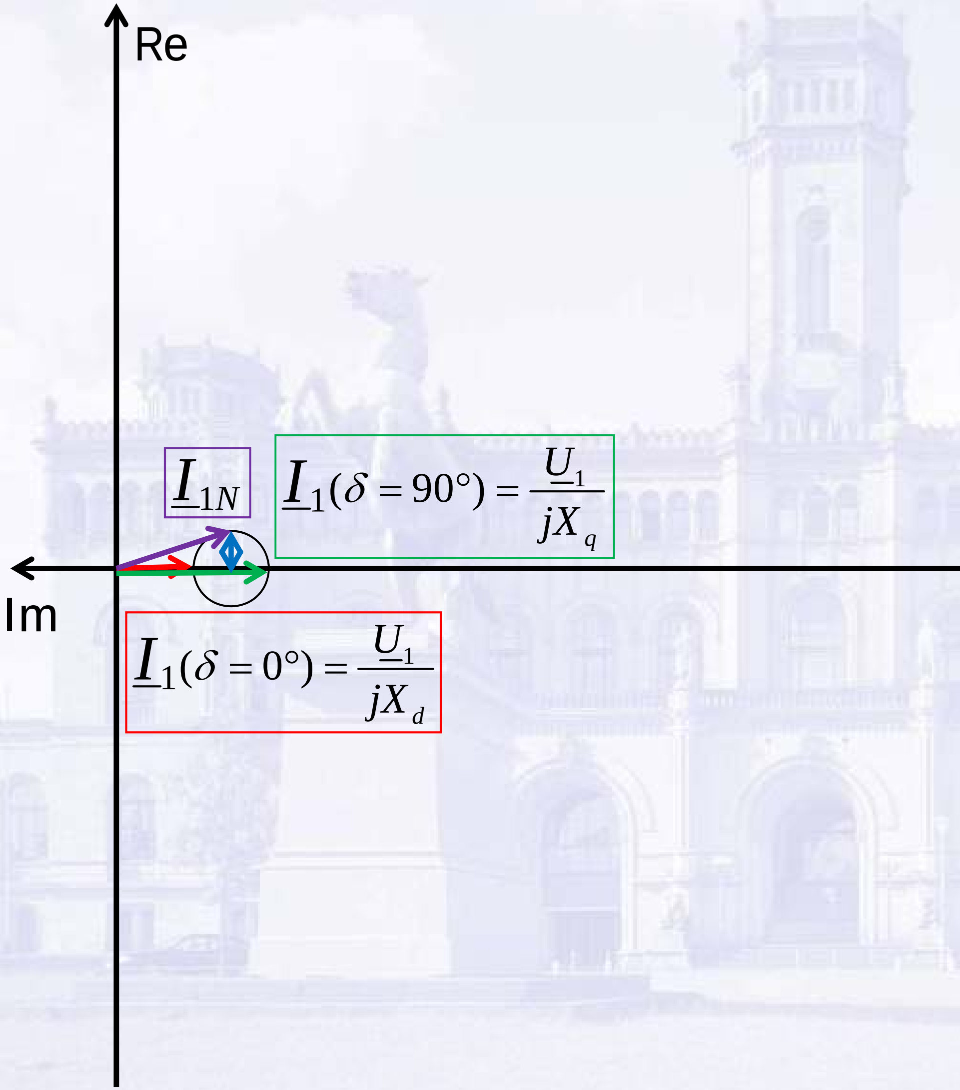
Current Locus of Synchronous Reluctance Machine

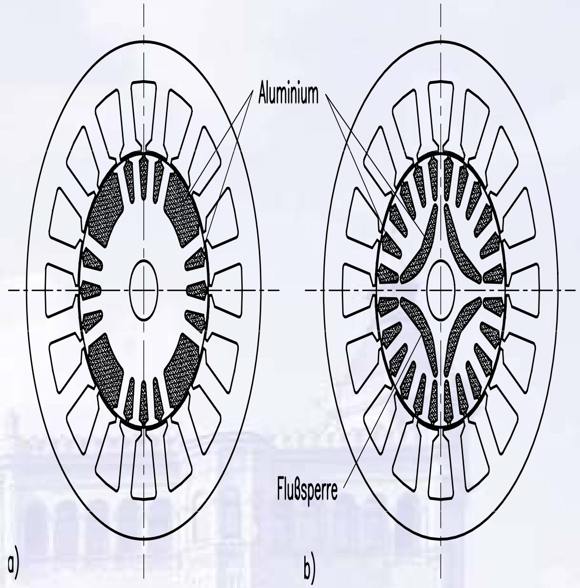
Stator resistance neglected



$$\cos\varphi_{\max} = \frac{1 - \frac{X_q}{X_d}}{1 + \frac{X_q}{X_d}}$$

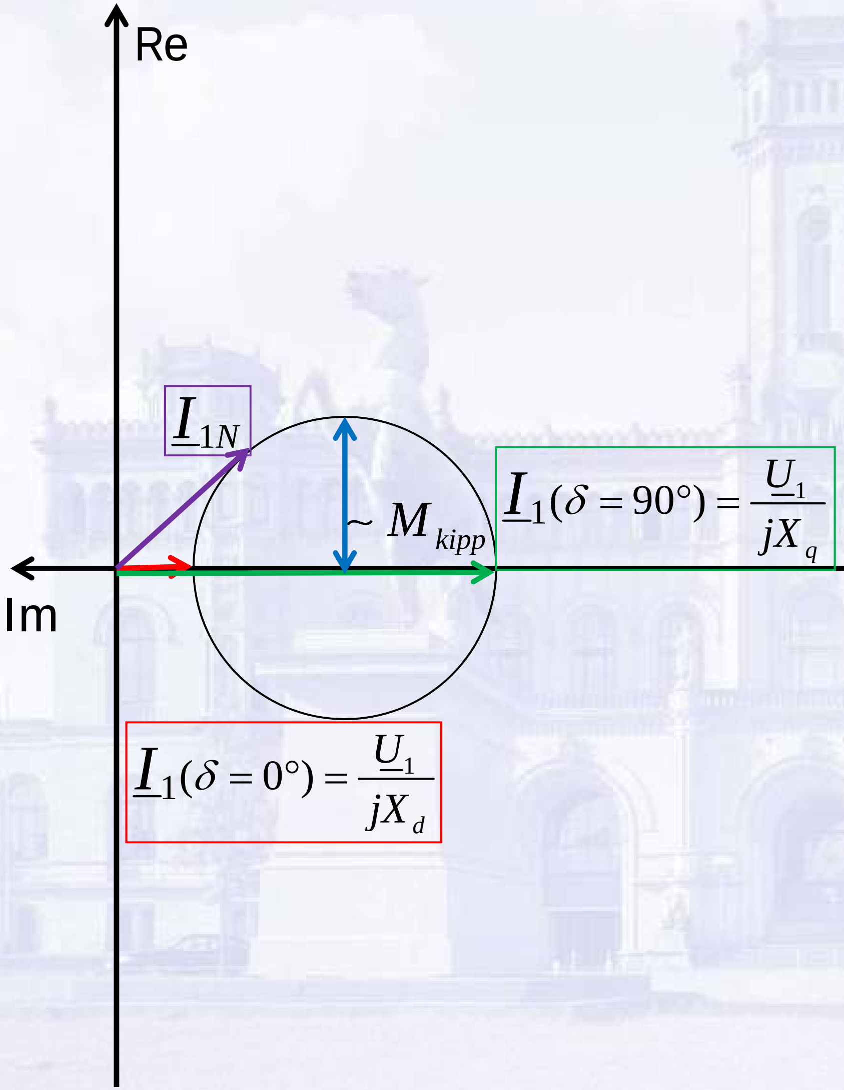
Current Locus of Simple Line-Start Synchronous Reluctance Machine ($X_d / X_q = 2$)

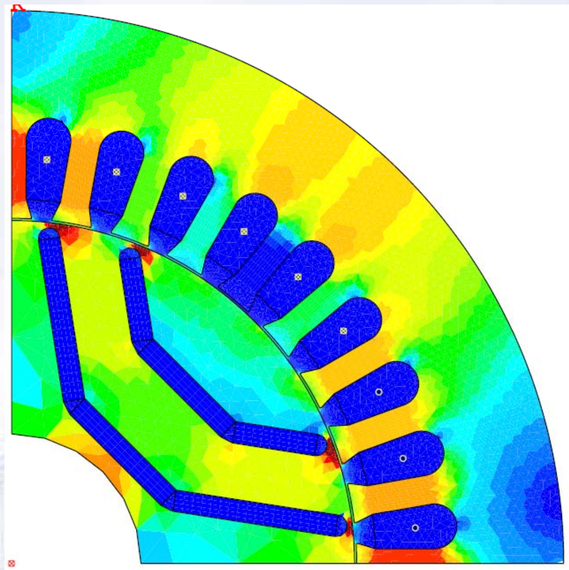




$$\cos\varphi_{\max} = \frac{1 - \frac{X_q}{X_d}}{1 + \frac{X_q}{X_d}} = \frac{1 - \frac{1}{2}}{1 + \frac{1}{2}} = 0,33$$

Current Locus of Variable Speed Synchronous Reluctance Machine ($X_d / X_q = 5$)

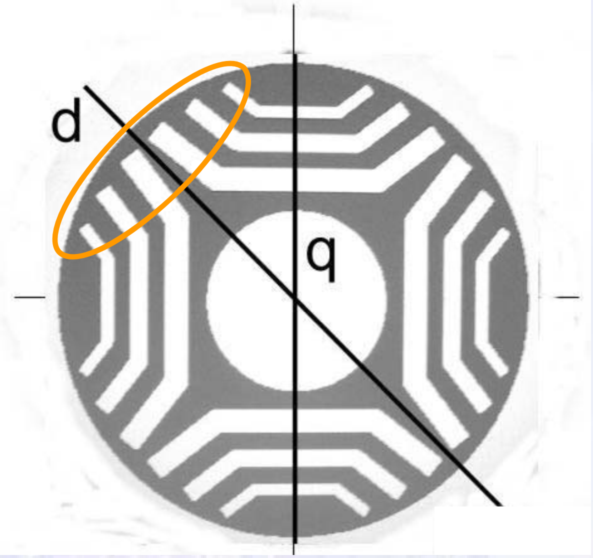




$$\cos\varphi_{\max} = \frac{1-\frac{X_q}{X_d}}{1+\frac{X_q}{X_d}} = \frac{1-\frac{1}{5}}{1+\frac{1}{5}} = 0,67$$

Challenges for Synchronous Reluctance Machines

- Thickness of rotor leakage paths vs. mechanical robustness
- Permeability of rotor core vs. permeability of stator core
- Influence of manufacturing on permeability of rotor leakage paths
- Negative influence of stator saturation on X_d and thus on $\cos \varphi$
- High torque oscillations during asynchronous starting



Conclusion

- Standardization and legislation on efficiency classes won‘t care about motor technology in the future
- For single speed motors, induction motors remain – besides line start PM synchronous motors for small ratings – the only option
- In many variable speed applications, induction motors can easily reach IE4
- High end lamination material will significantly improve torque density and efficiency
- Converter-fed synchronous reluctance motors are – contrary to switched reluctance motors – an alternative to induction machines for variable speed applications, but not their grave-digger