

Efficiency: Technology Evolution

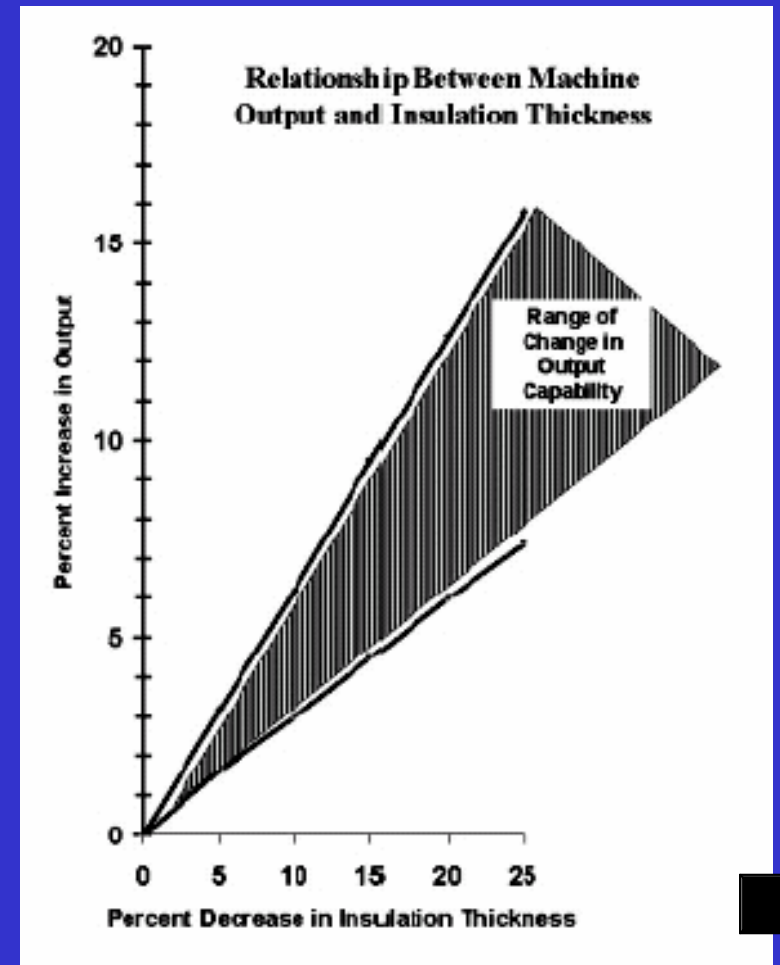
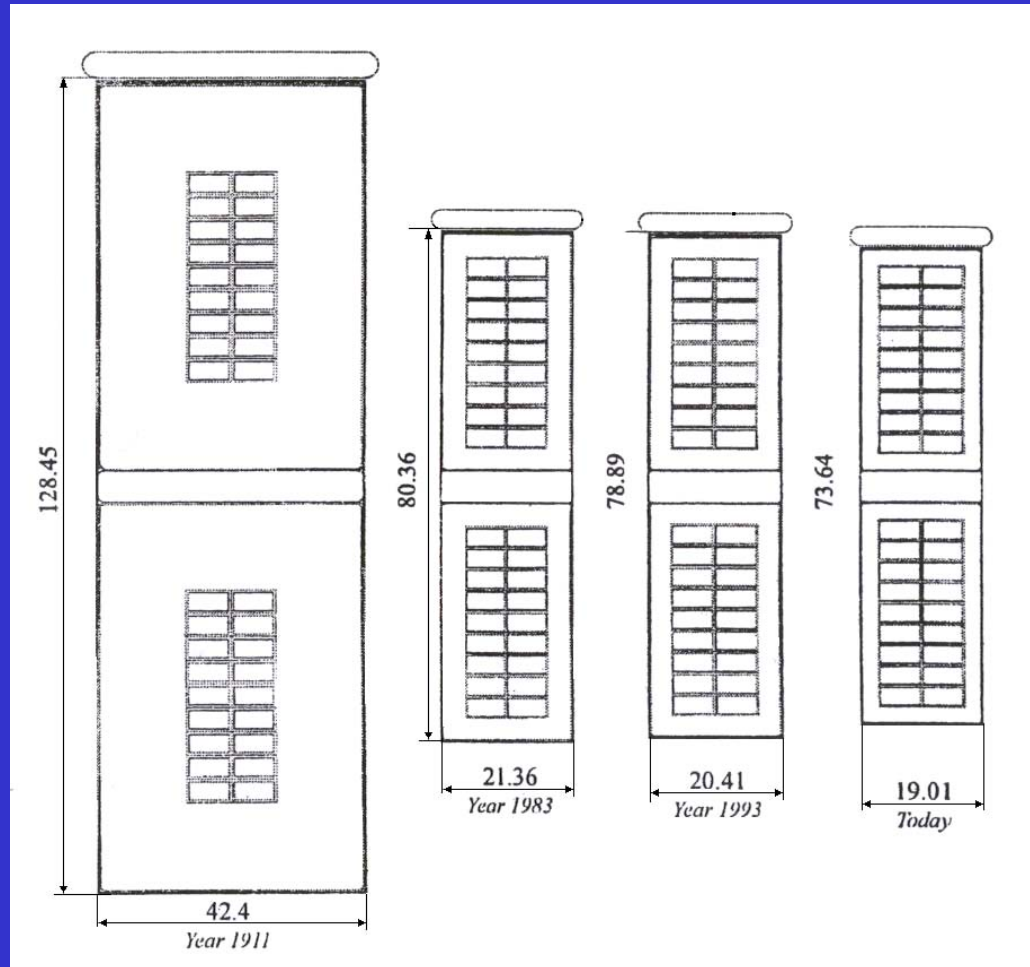
Output coefficient (kW / unit size)

- Cooling Methods
- Insulation Material
- Conductor Material
- Core losses and flux density
- IEC 34 tests

Cooling Methods

- Air Cooling
- Hydrogen Cooling (*30% higher OC than Air cooled generator*)
- Combined Hydrogen/Water Cooling (*Highest OC*)

Insulation Material



Core steel

- Ordinary magnetic materials typically have a yield strength of 200 MPa
- Cobalt-iron Yield strength: 683 MPa

Core steel ...2

- Total iron losses consists of two parts
- Hysteresis losses
 - Proportional to frequency
 - Dependant on the area of the hysteresis loop
 - This is a characteristic of the material
 - Function of flux density

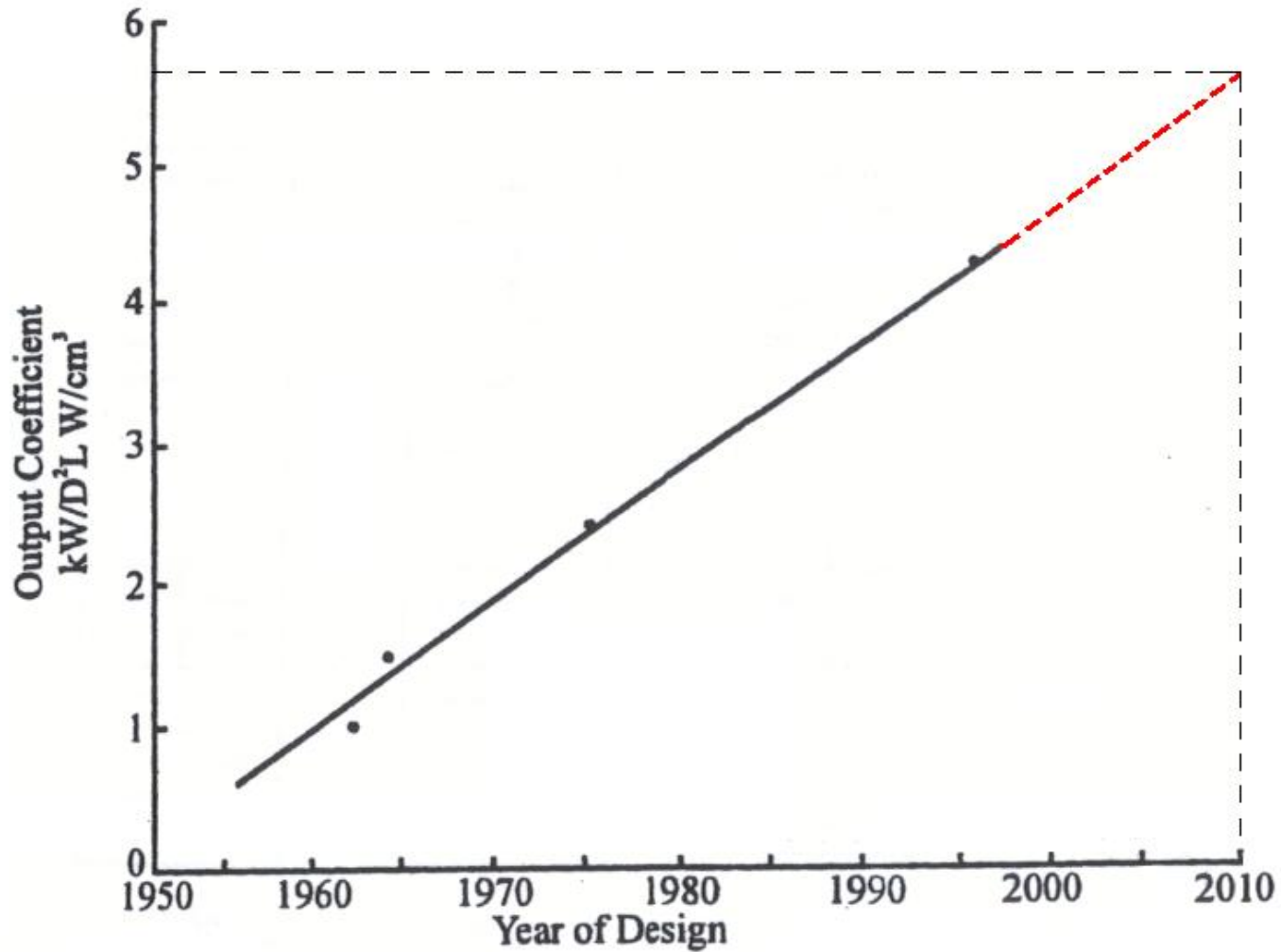
Core steel ...3

- Eddy current losses
 - Proportional to the square of the thickness of the material
- Specialised electrical steels made from 1900
- Small quantities of silicon or aluminium are added
- Silicon limited to $< 4,5 \%$
- Quality of the steel depends on the alignment of the grain structure

Core steel ...4

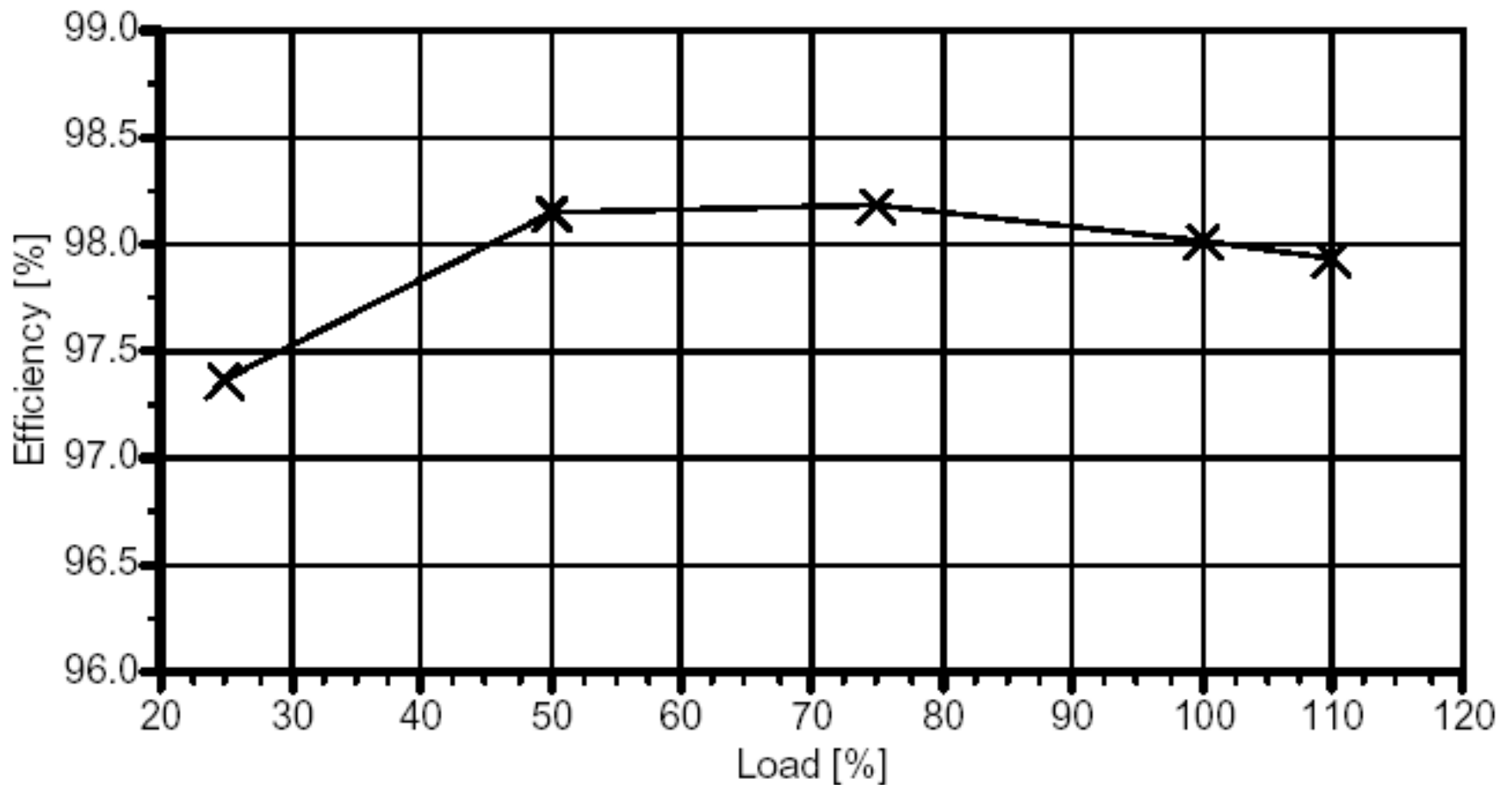
- Types of core steel
 - Hot rolled steel - 7 W/kg at 1,5 T
 - Grain-oriented steel - 0,32 mm & 1,5 W/kg at 1,7 T
 - High permeability steel
 - Domain-refined steel - 0,23 mm & 0,85 W/kg at 1,7 T
 - IEC 404 defines core steels

Output Coefficient (OC) Improvements



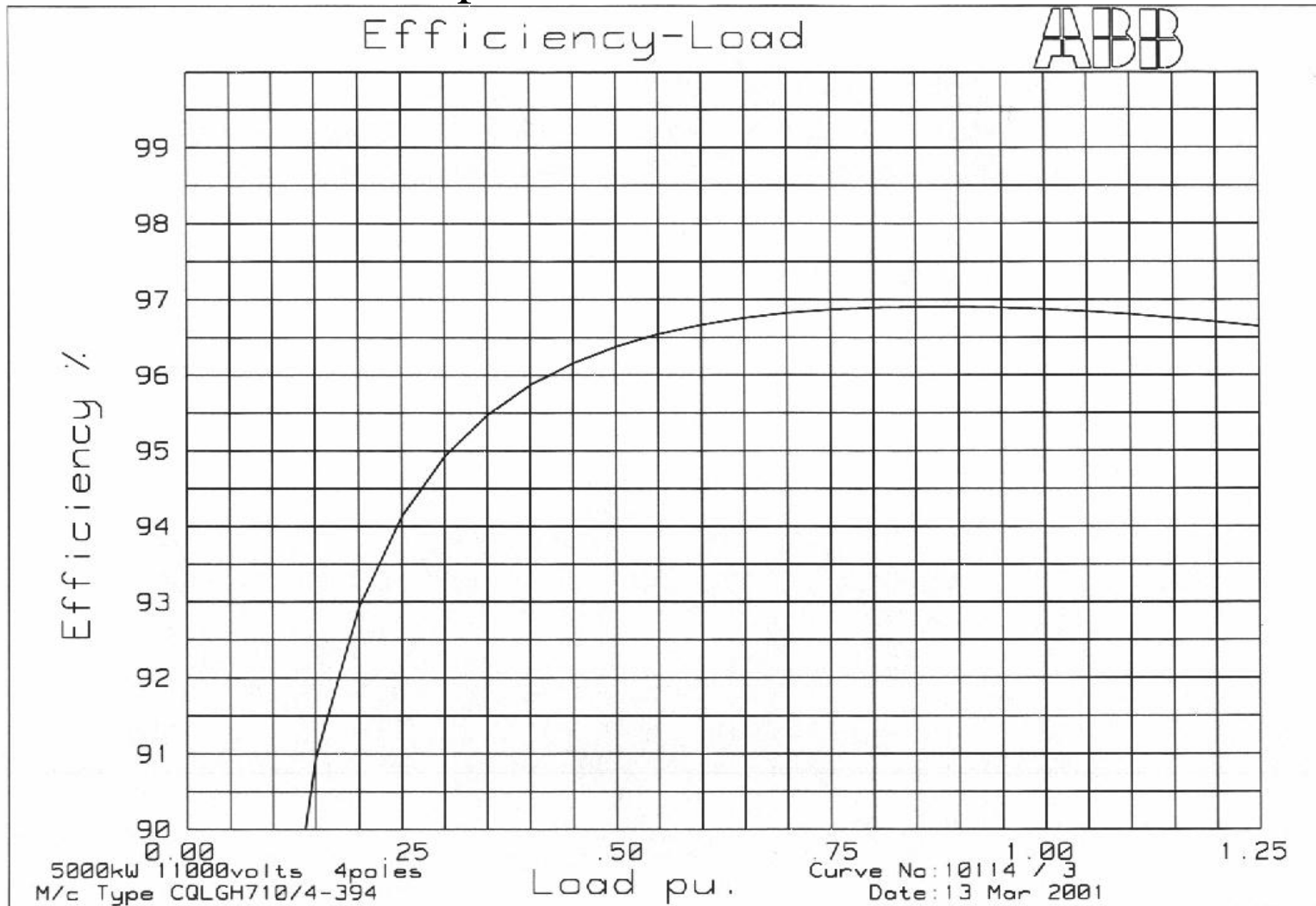
Efficiency vs slip ...1

17 MW 28 pole 11 kV synchronous motor



Efficiency vs slip ...2

5 MW 4 pole 11 kV induction motor



Type of losses

Stator winding temperature in °C

Stator copper losses in kW

Rotor winding temperature in °C

Rotor copper losses in kW

Core losses in kW

Windage losses in kW

Friction losses in kW

Stray-load losses in kW

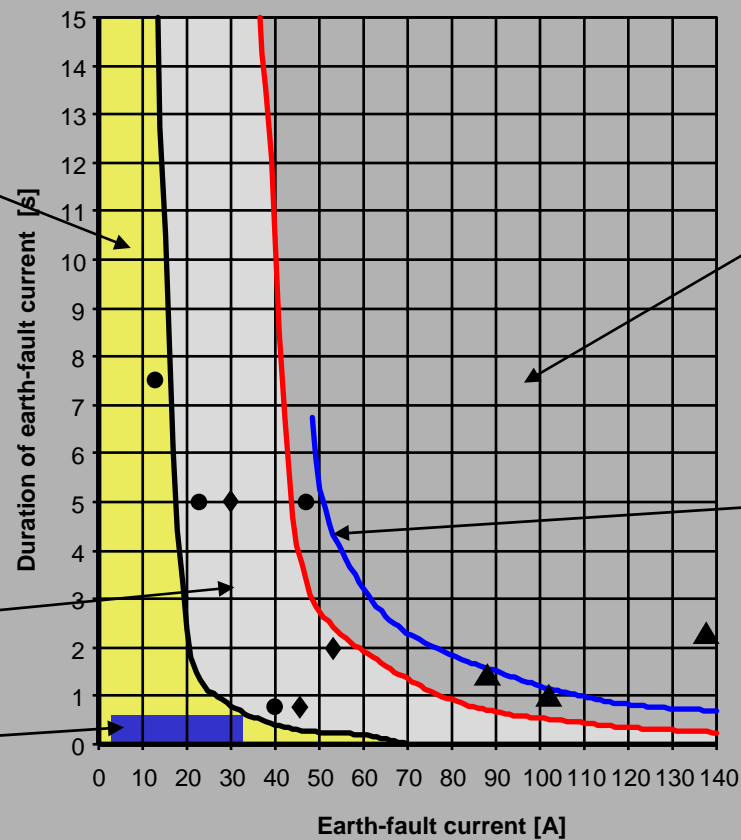
Total losses

Efficiency in %

Losses in Standards

Stator earth-fault current damage

Earth-fault duration curve of a stator plate



No damages
Small welding scars on surface

Bad burning scars (▲)

Dimension of burning scars is 10 mm.

Small welding scars (●)
Small burning scars (◆)

Setting in the example