Cryogenic challenges for different superconductive motor topologies

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customized motors / generators

10 kW … 3 MW

… 300.000 Nm

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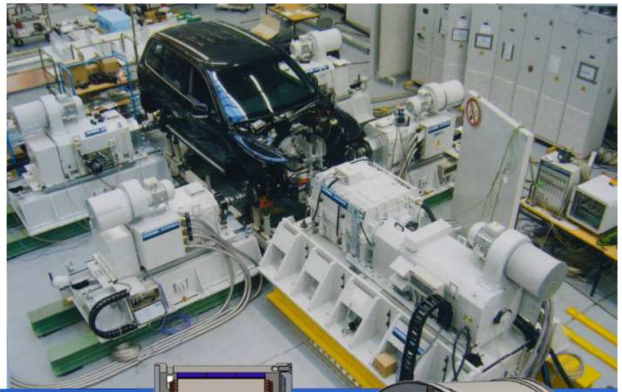
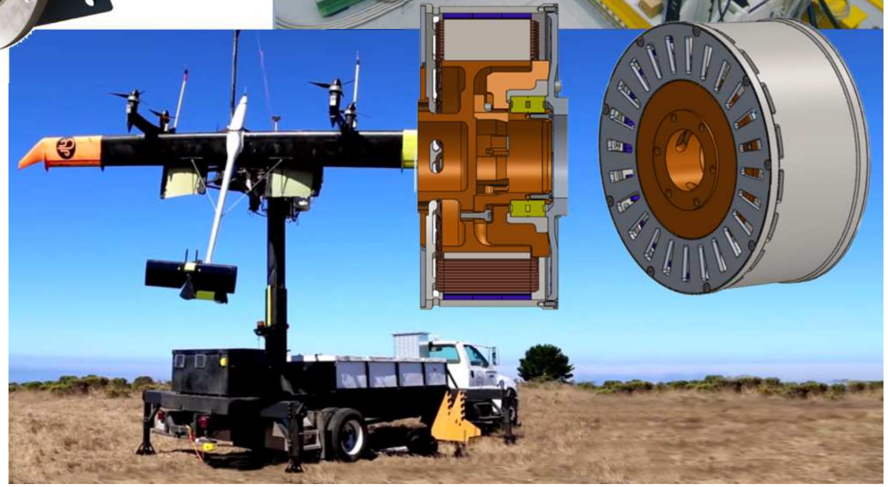
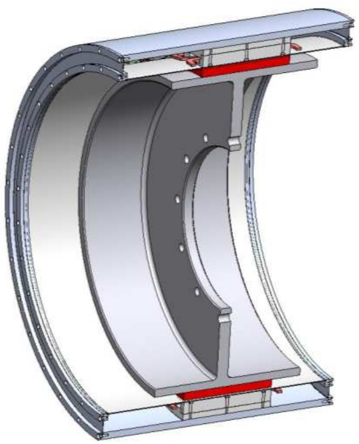




Cryogenic challenges for different superconductive motor topologies

outline



principle properties of motors.

where can SC be used in a motor?

topologies and examples

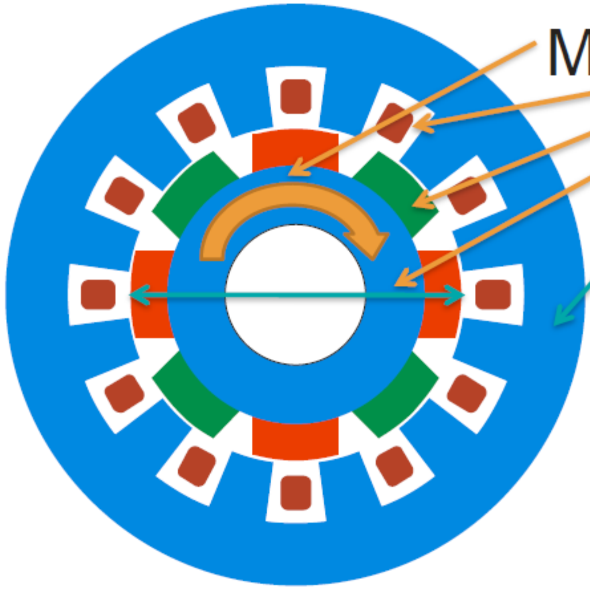
how are cryogenics integrated in motors?

solutions for rotor and stator

motor / generator

Only few parameters specify motor

$M \sim A \cdot B \cdot d^2 \cdot l$



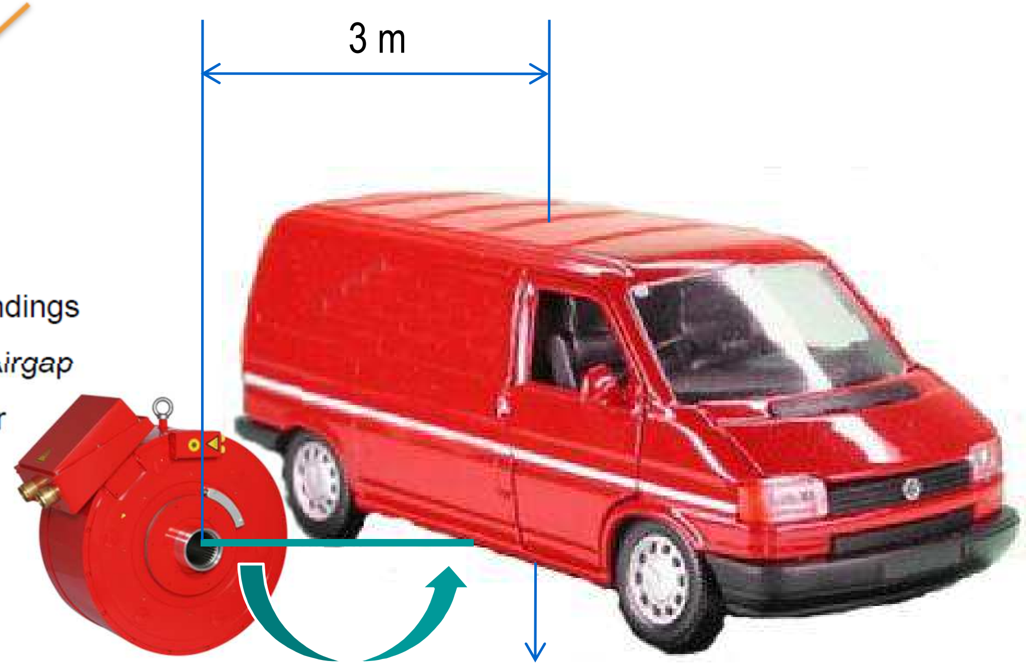
M:Torque

A: Amp-windings

B: Flux in Airgap

d: Diameter

l: Length



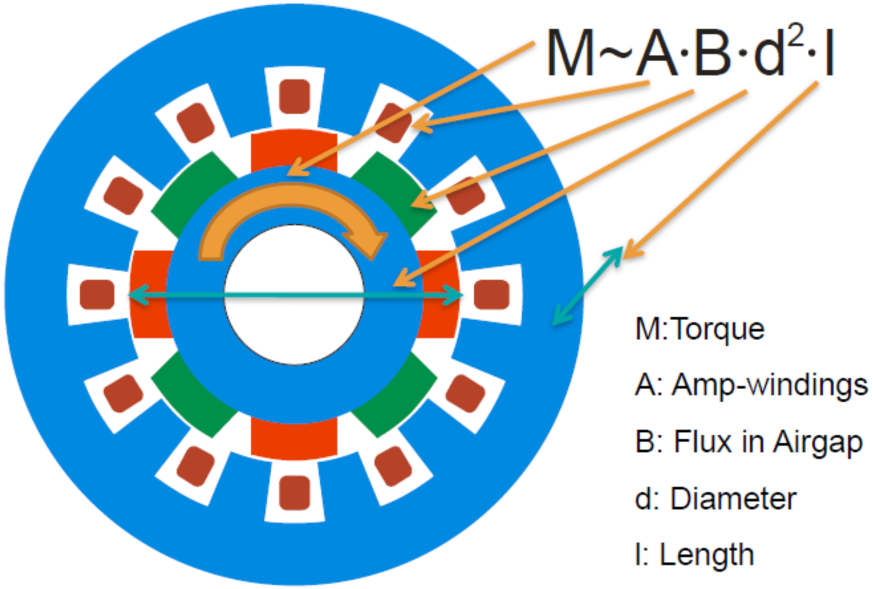
60.000 Nm

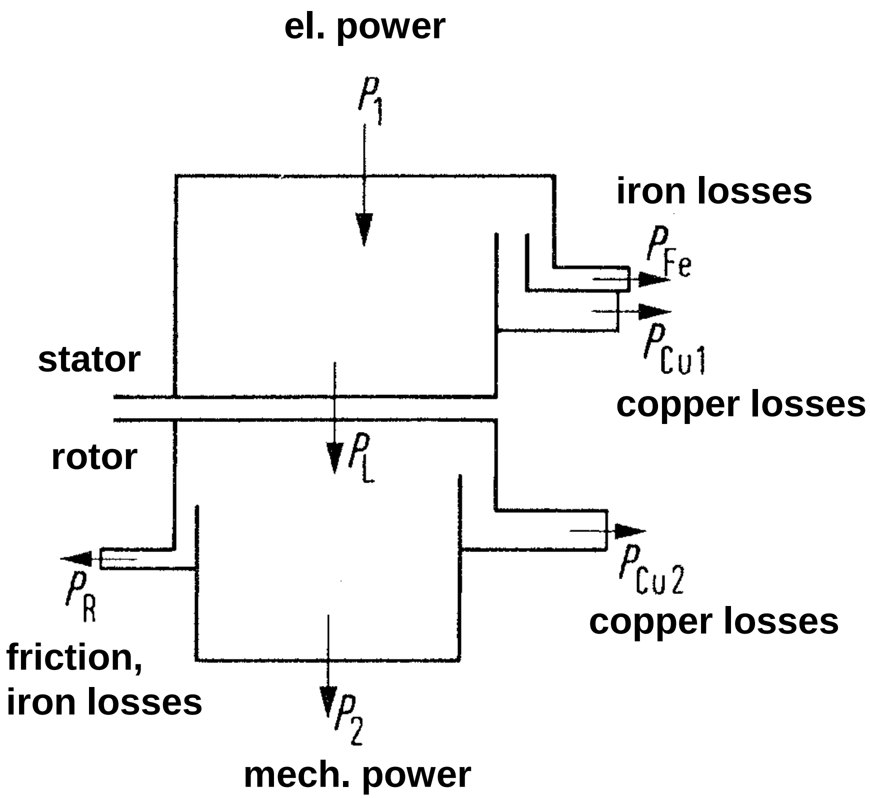
2 tons

$P \sim M \cdot f/p$

P: Power
f: Frequency
p: number of pole pairs

SC in motors





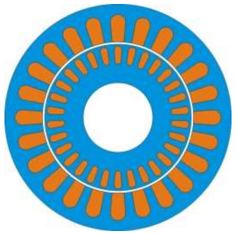
A: sc AC-winding, …

B: sc DC-winding, bulk, stack, …

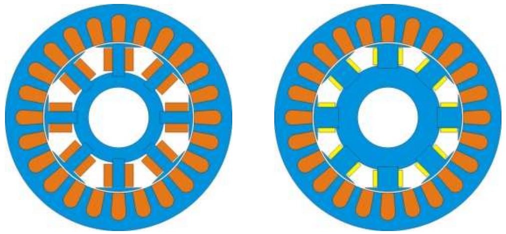
motor topologies

blue: iron
orange: nc winding
yellow: sc winding
red/green: Magnets

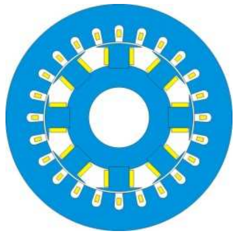
AC – nc asynchronous rotor



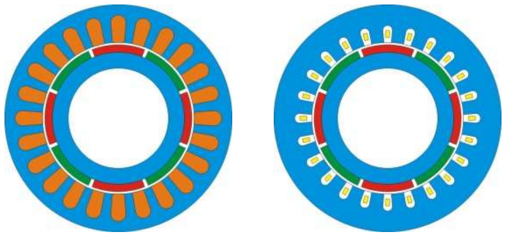
nc – rotor sep. excited– sc



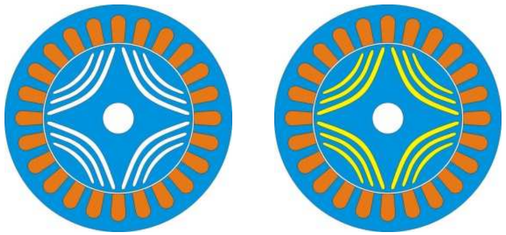
all sc motor



nc – PM-Rotor – sc



nc – reluctance rotor – sc

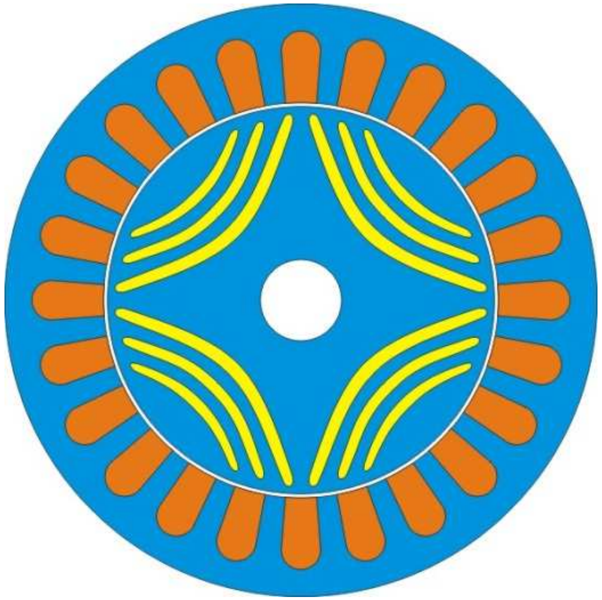


reference: 100% power density

… and some more:

homopolar
axial flux
transversal flux
…

reluctance motor

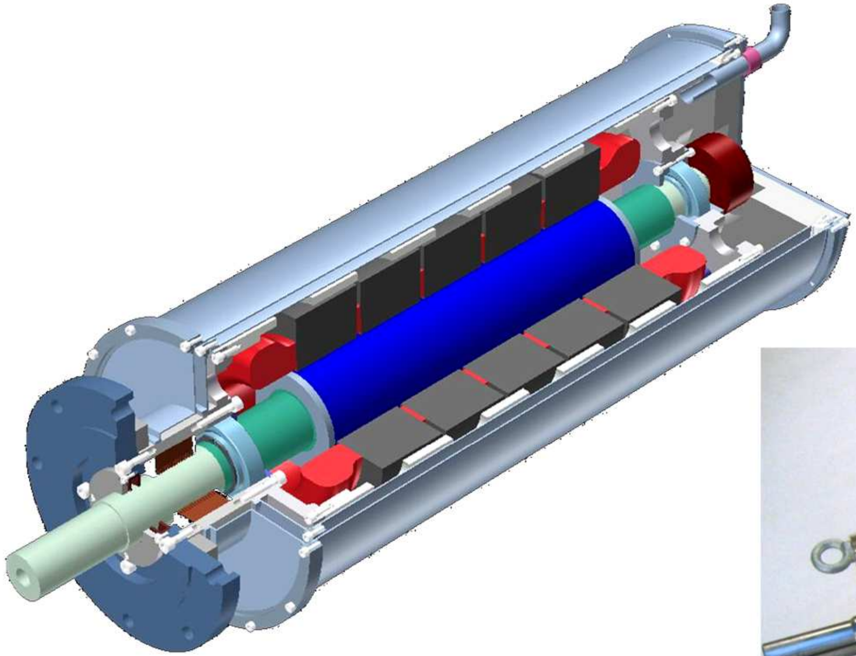


- Diamagnetic rotor
- Passive rotor – no power transmission
- Cold rotor
- Iron in rotor obligational and close to SC
- Relative low force density
- No limitations in operation
- Complex rotor structure – speed limitations

Force density:

130% compared to nc PM-Motor

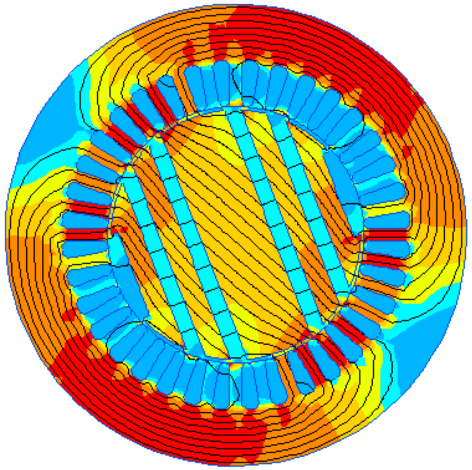
reluctance motor
Oswald



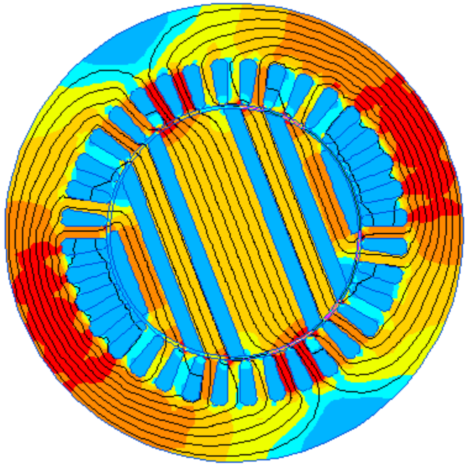
SDYN110:

400 kW
77 K, IN_2
reluctance type motor
power density 130%
compared to nc PM-motor

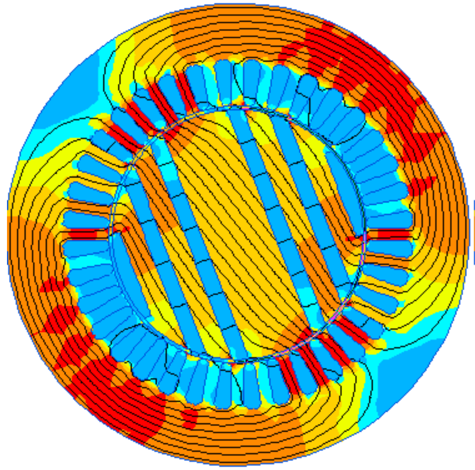
reluctance motor
Oswald



Plastic:
P_o = 229 kW
P_a= 470 kVA
power factor: 0,5



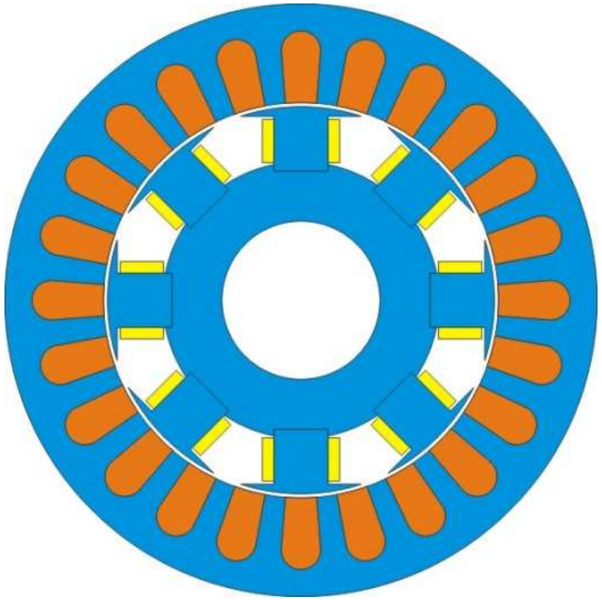
Ideal SC:
P_o = 345 kW
P_a= 400 kVA
power factor: 0,86



Real YBCO:
P_o = 256 kW
P_a= 420 kVA
power factor: 0,61

still very low power factor

excited synchronous Motor



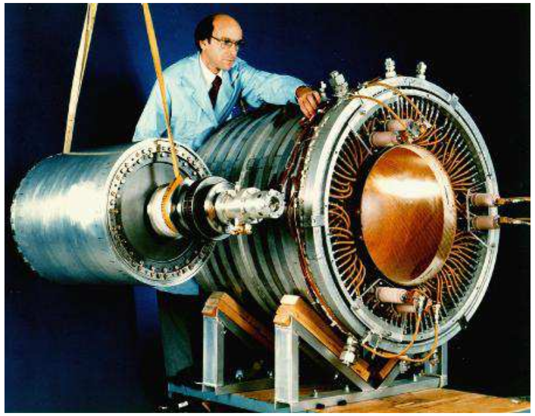
- Active SC coils in rotor (DC application)
- power transmission (many kA!)
- Cold rotor
- Iron in rotor (partially) useless (>2T?)
- Active influence on excitation
- Complex rotor structure – speed limitations and minimum sizing (-> MW)

Force density:

> 200% compared to nc PM-Motor

excited synchronous Motor
General Electric

1970's - Westinghouse
5 MW, 4.5 K
NbTi Superconductor



1980's -General Electric
20 MW, 4.5/8 K
NbTi/Nb3Sn Superconductor

1990's – Westinghouse STC
1 MW, 20 K
BSCCO Superconductor

excited synchronous Motor Siemens


Quelle: Siemens

HTS I:

1999 - 2002
400 kW
1500 rpm

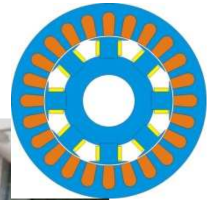
technology demonstrator


Quelle: Siemens

HTS II:

2002 - 2007
4 MVA
3600 rpm

high speed
longterm operation
since 2009

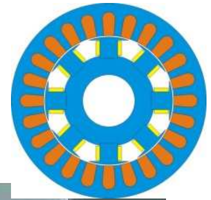



Quelle: Siemens

HTS III:

2006 - 2010
4 MW
120 rpm
high torque: 300 kNm

excited synchronous Motor
Siemens

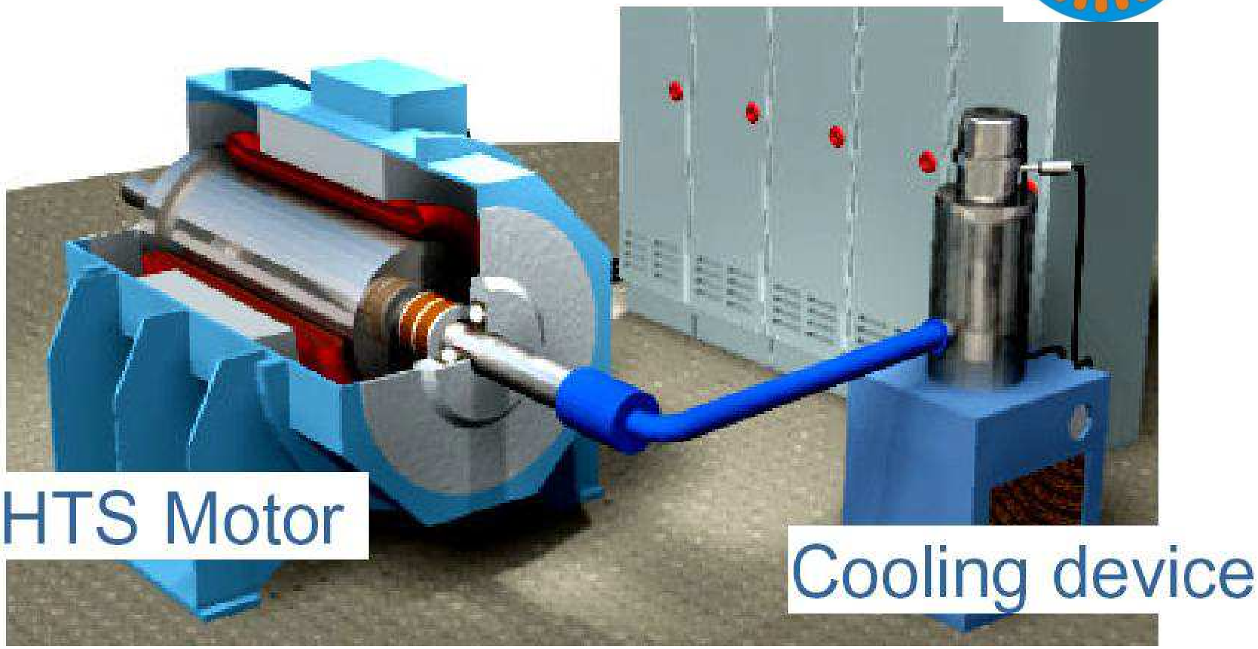


Quelle: Siemens

HTS I:

1999 - 2002
400 kW
1500 rpm

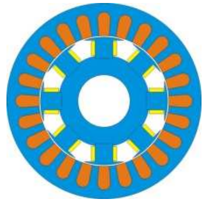
technology demonstrator



Synchronous motor
Bi2223/AG tape
Air gap copper stator

Operating temperature 27K
„plug and play“
Ne cooling system

excited synchronous Motor
Siemens

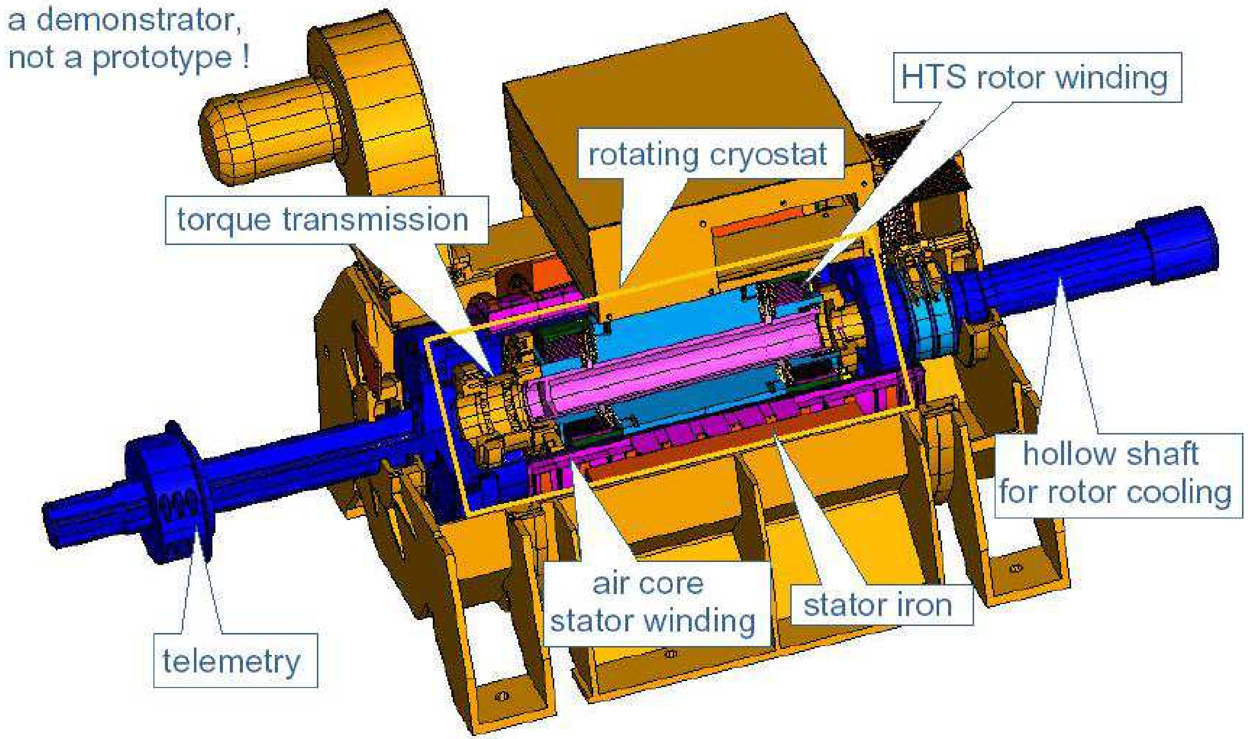


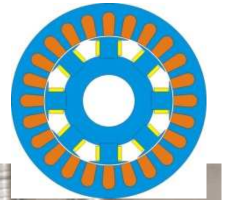
Quelle: Siemens

HTS I:

1999 - 2002
400 kW
1500 rpm

technology demonstrator

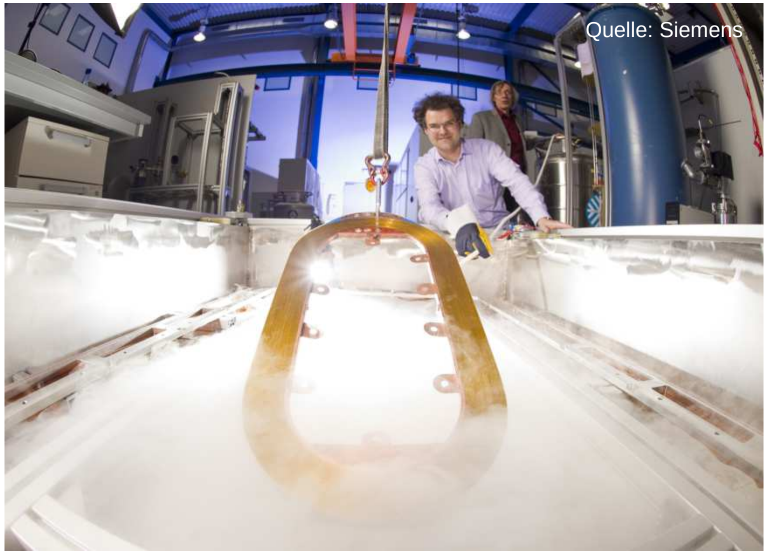




excited synchronous Motor Siemens

Siemens 4MW HTS II 2007 at test rig:

- **rotor at 25K (liq. Ne)**
- **motor weight -30%**
- **coils made of Bi-2223**


Quelle: Siemens

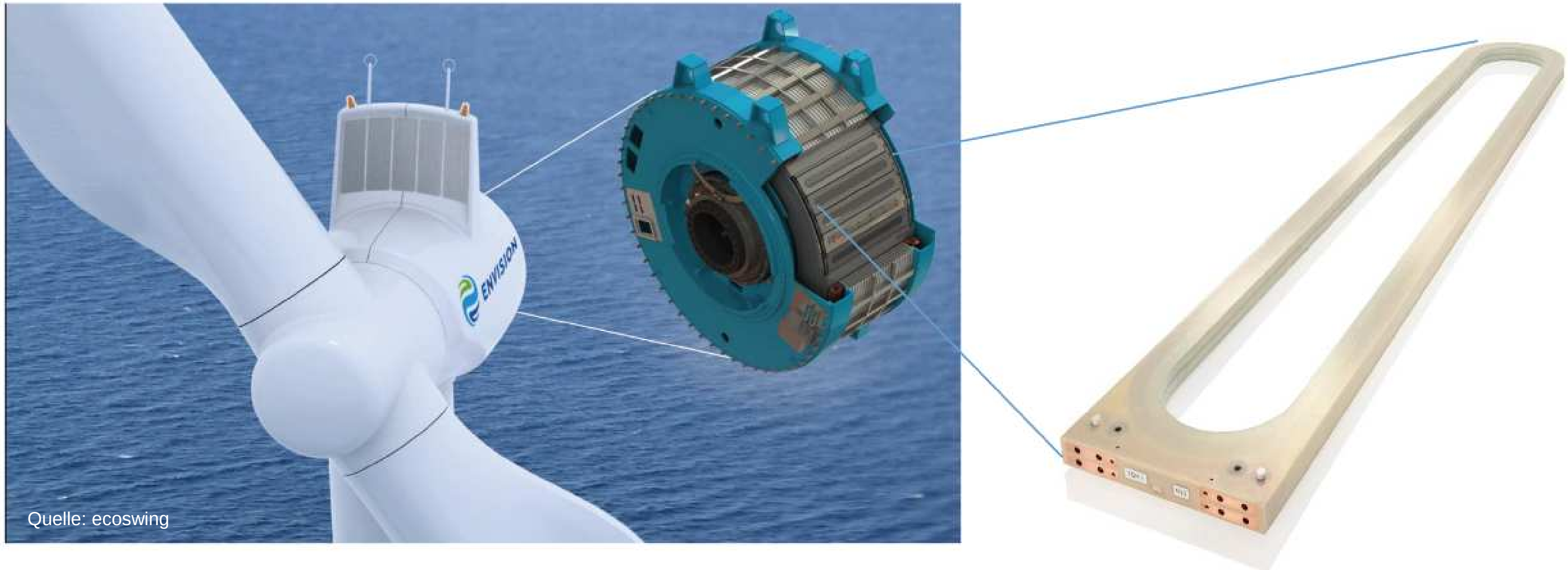

Quelle: Siemens

- **first grid synchronization 2009**
- **efficiency +2%**
- **losses -50%**
- **> 5000 hours of operation without degradation of SC**

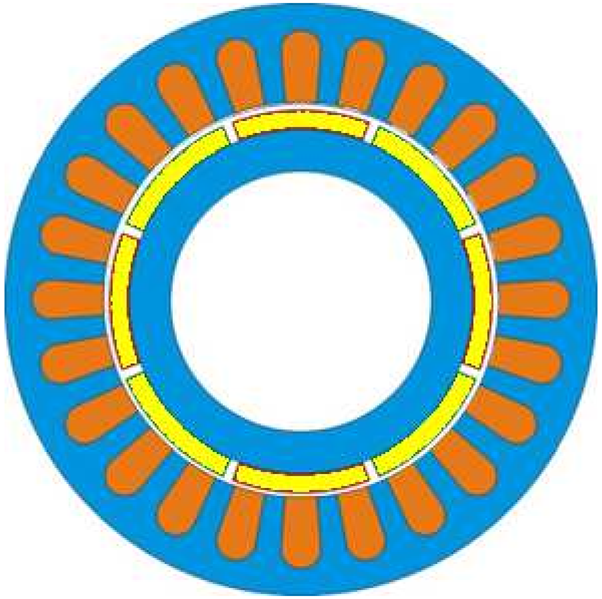
excited synchronous Motor
ecoswing project

2015 - 2019
Retrofit for 3MW class
rotor coils with GdBaCuO tapes

active cooling (coldhead) of rotor DC-coils
rotating He (gas, high pressure) feedthrough



PM(sc) synchronous motor

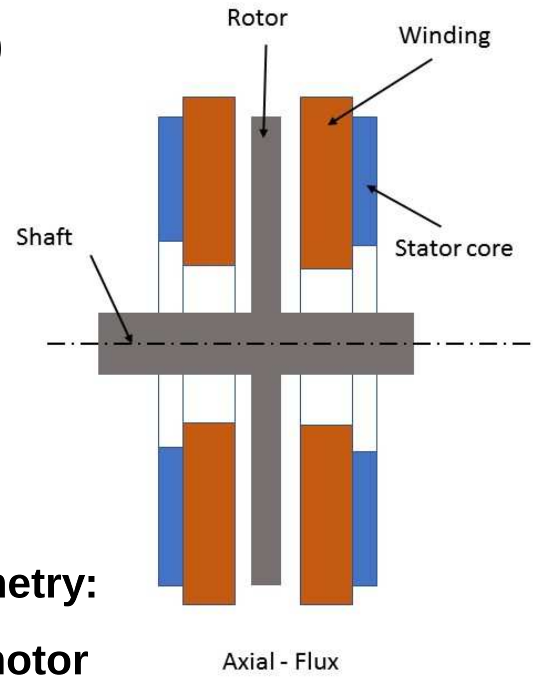


- SC bulk or stack in rotor (DC application)
- magnetizing system needed
- Cold rotor
- Iron in rotor (partially) useless (>2T?)

Force density:

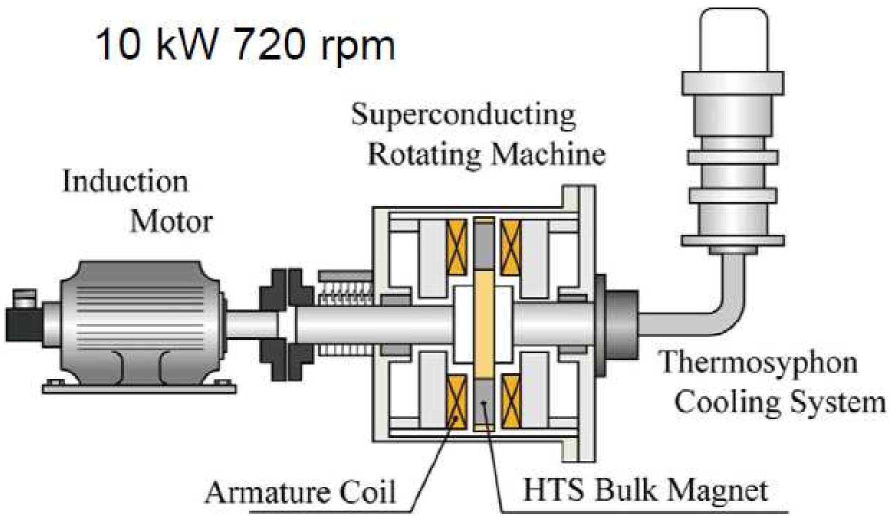
> 200% compared to nc PM-Motor

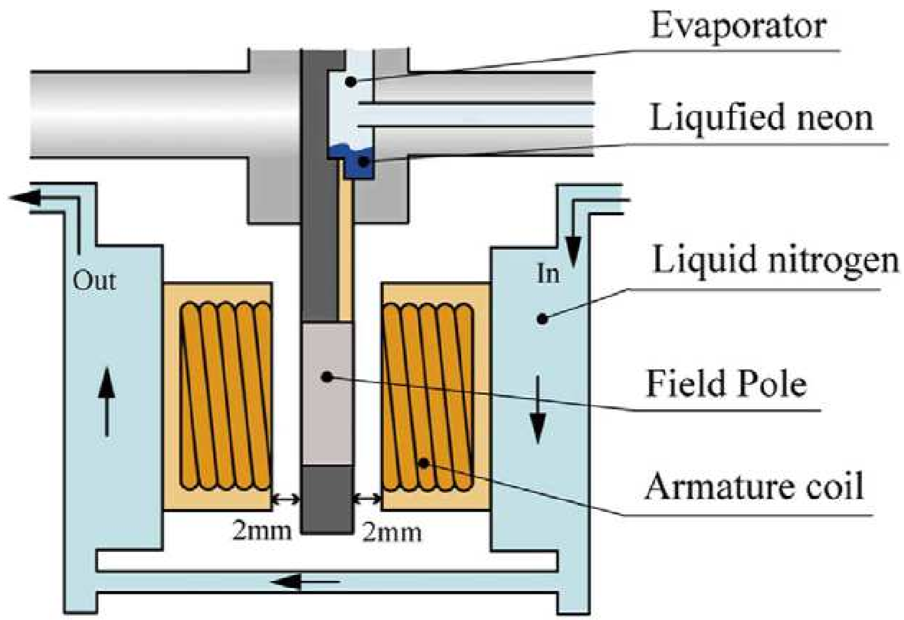
special geometry: axial flux motor



Quelle: phi-power.com

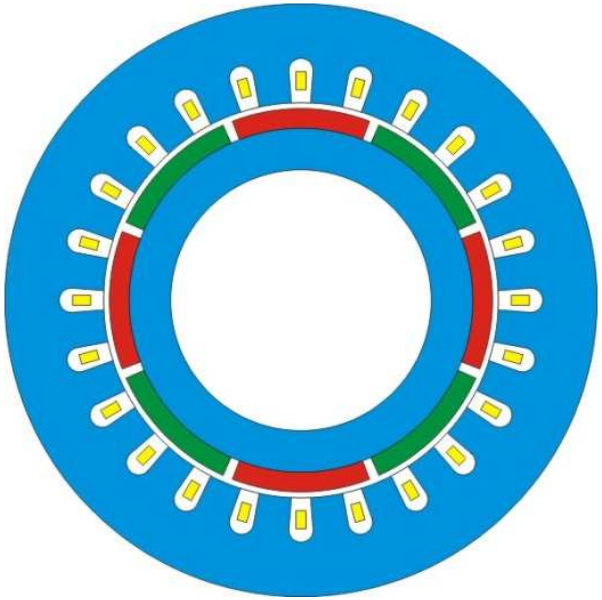
PM(sc) synchronous motor
Tokyo University of Marine Science and Technology





Quelle: IEEE Trans Appl. Supercond. 23 6397585 (2013)

PM synchronous motor

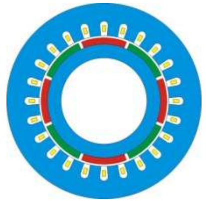


- Active SC coils in stator (AC application)
- Passive rotor system
- Cold stator
- Iron in stator (partially) useless (>2T?)
- Flux control for high speed
- Cryostat for rotating fields

Force density:

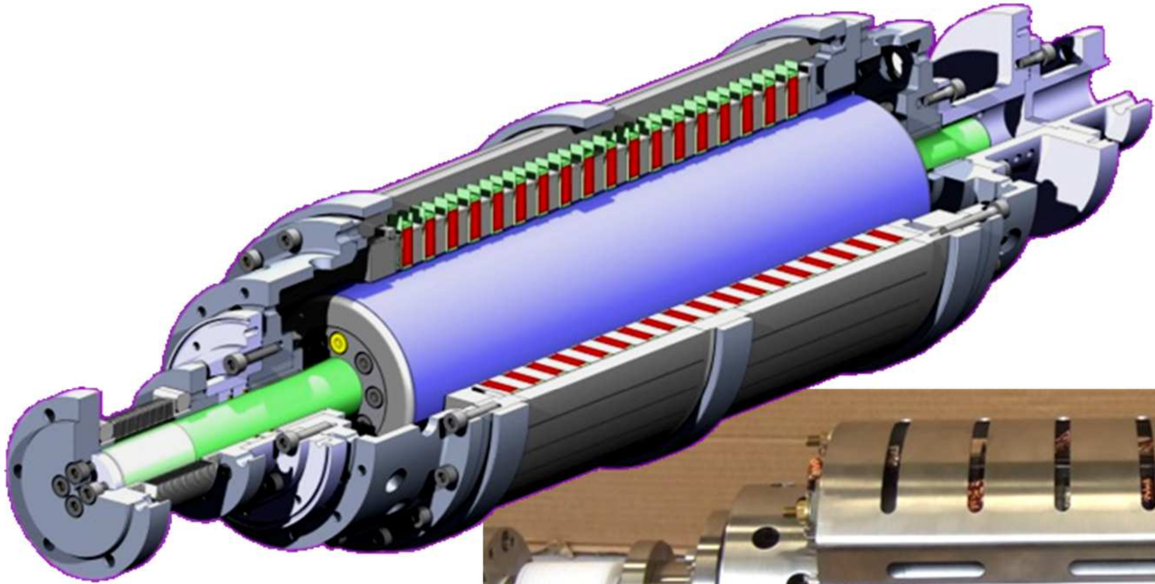
> 250% compared to nc PM-Motor

PM synchronous motor
Oswald

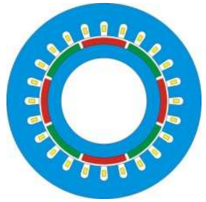


SLIN:

45 kN
77 K, lN_2
stator coils BSCCO
power density and
acceleration: 200%

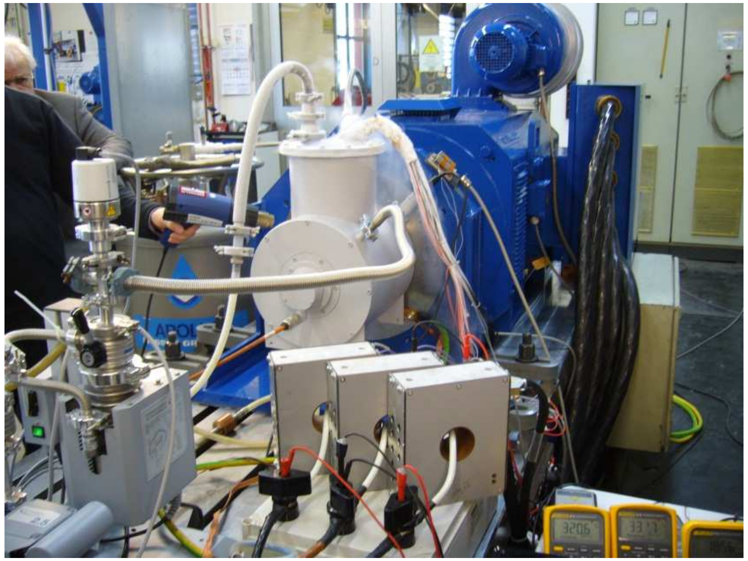


PM synchronous motor
Oswald

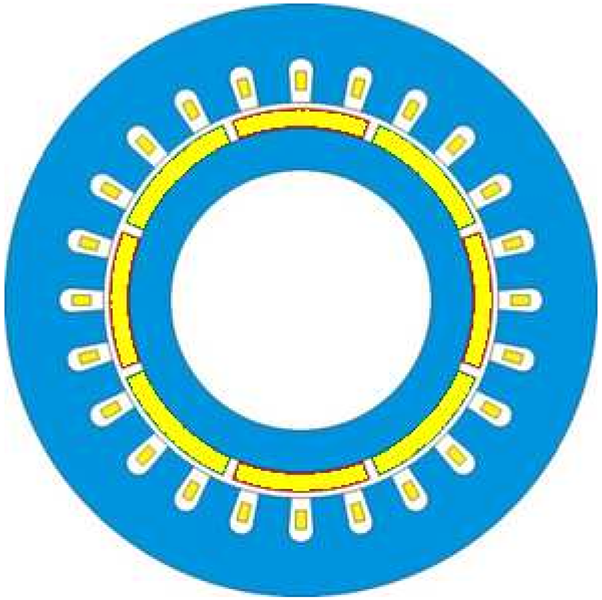


SMFS:

40 kW, 665 rpm, 575 Nm
77 K, lN_2
PM-motor with SC stator winding (YBCO)
power density 250%
compared to nc PM-motor



fully SC motor (bulk rotor)

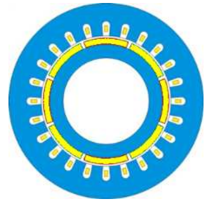


- Active SC coils in stator (AC application)
- Bulk SC in rotor (DC application)
- Cold stator and rotor
- Iron in stator and rotor (partially) useless
- Passive rotor
- Magnetizing device needed
- Flux control for high speed or dynamic adaption of magnetization

Force density:

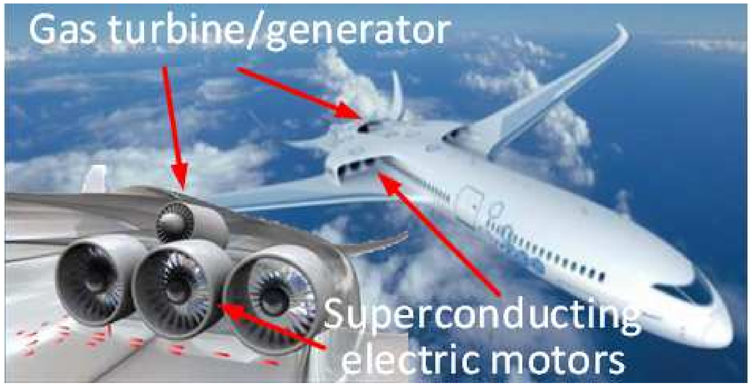
> 300% compared to nc PM-Motor

fully SC motor (bulk rotor)
ASuMED

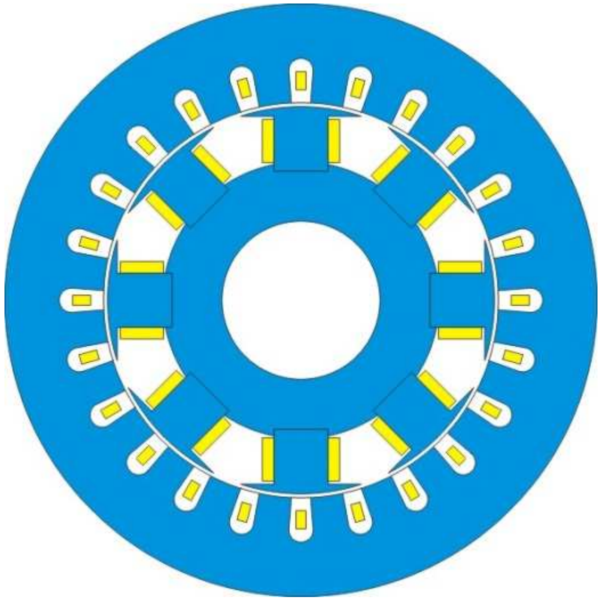


EU funded project (2017-2020)

- **SC stator winding**
- **SC rotor stack**
- **1MW at 6000rpm**
- **light weight for airborne application**



fully SC motor (exc. rotor)

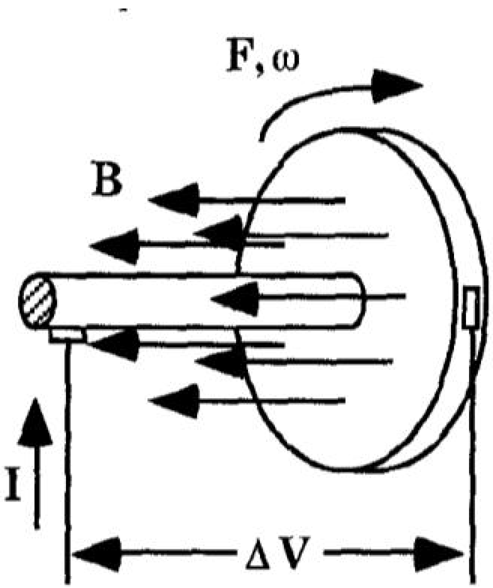


- Active SC coils in stator (AC application)
- Active SC coils in rotor (DC application)
- Cold stator and rotor
- Iron in stator and rotor (partially) useless
- Power transmission to rotor (many kA!)
- Active influence on excitation
- Complex rotor structure – speed limitations and minimum sizing (-> MW)

Force density:

> 300% compared to nc PM-Motor

Homopolar motor

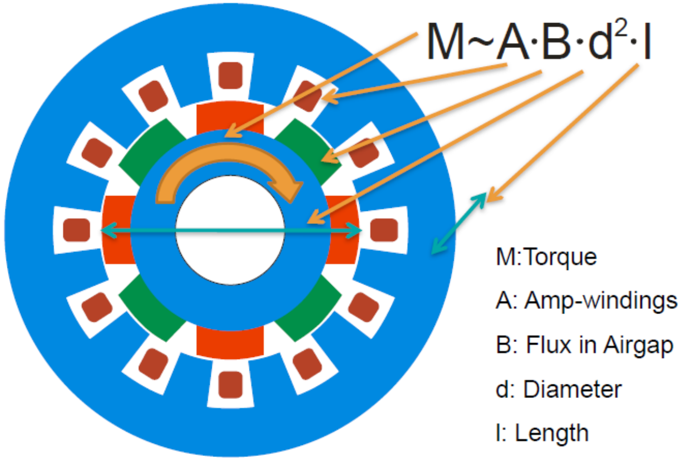


- Active SC coils in stator (DC application)
- Rotor made of conductive material
- Cold stator
- Iron in stator and rotor (partially) useless
- Power transmission (many kA!)
  at least one at large diameter !!!
- Easy speed control

Force density:

> 200% compared to nc PM-Motor

cryogenic aspects



increase of „A":

cryogenic cooling of SC stator winding

pro's:

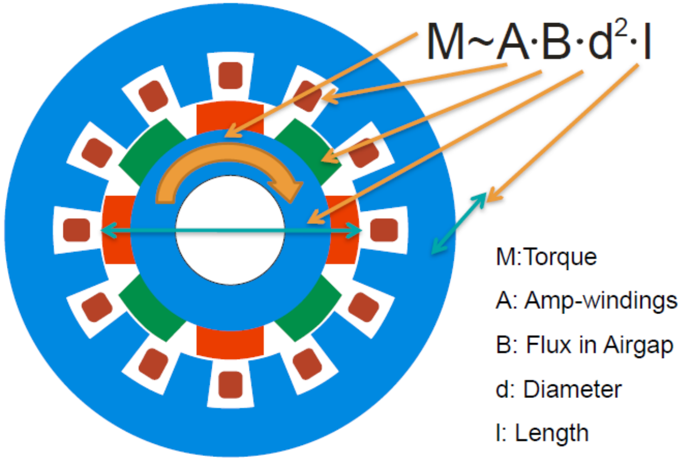
- static cryostat
- static supply

con's:

- AC losses in SC are remarkable (up to 1% of system power)
  -> cooling capacity
- if cryostat is between stator and rotor:
  wall fully penetrated by moving magnetic flux
  -> eddy currents

- only few systems were tested
- often stator is immerged in liquid cryogen
- closed system in presentation OR8-2 on Friday

cryogenic aspects



increase of „B":

cryogenic cooling of SC rotor components

pro's:

- **low thermal losses (SC in DC application)**

con's:

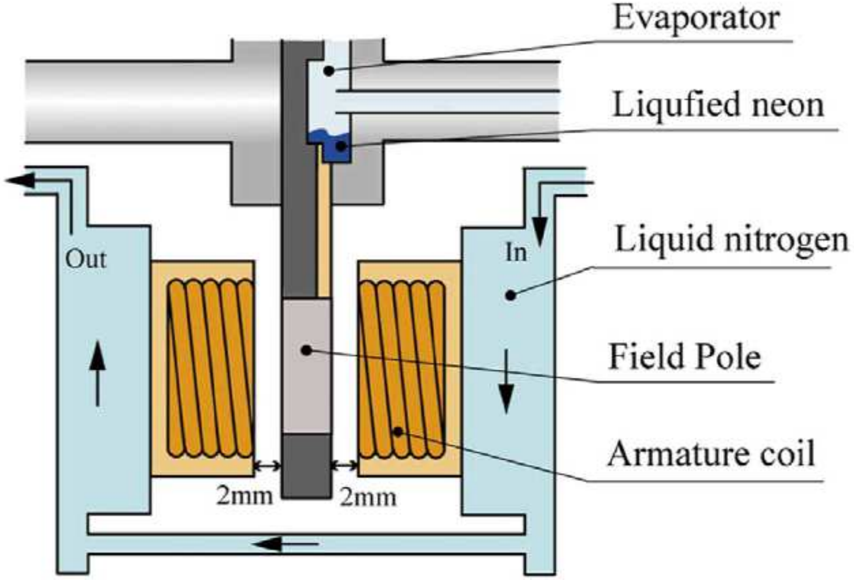
- **coolant feed through to rotating system**
- **(parts) of cryostat are rotating**
- **combination of cryogen, sealing and bearing…**

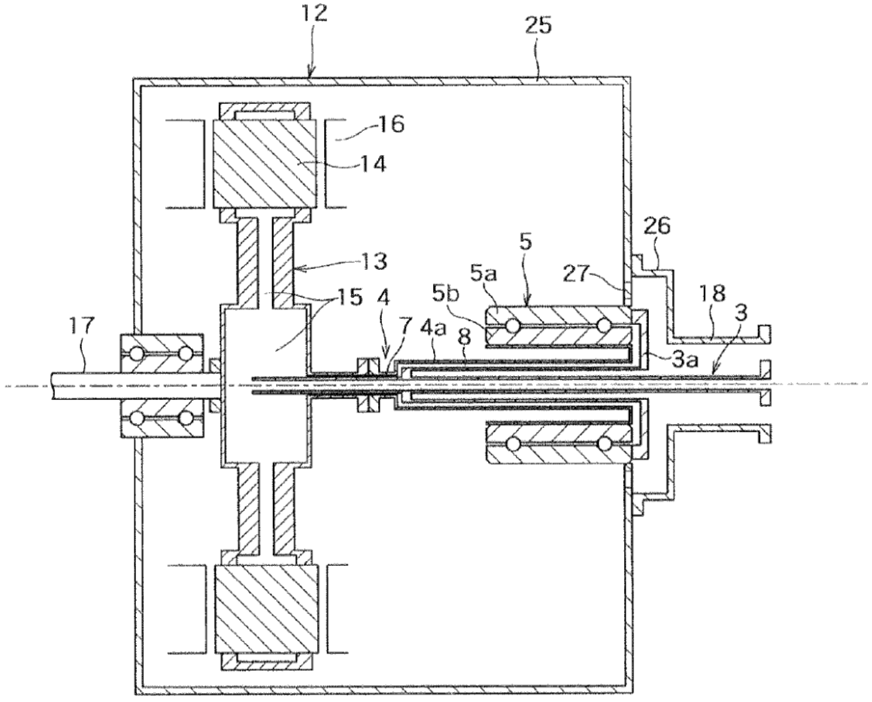
- **most sc motors/generators have cold rotor**
- **many cryostat topologies were tested**

-> two promising solutions…

cryogenic aspects
Thermosyphon … in axial flux motor with sc bulk material in rotor

- **major tasks are solved (sealing, bearing, …)**
- **applicable for all motor topologies with SC in rotor**
- **numerous publications and patents…**





Quelle: Tokyo University of Marine Science and Technology, Patent US8616587B2

cryogenic aspects
Thermosyphon

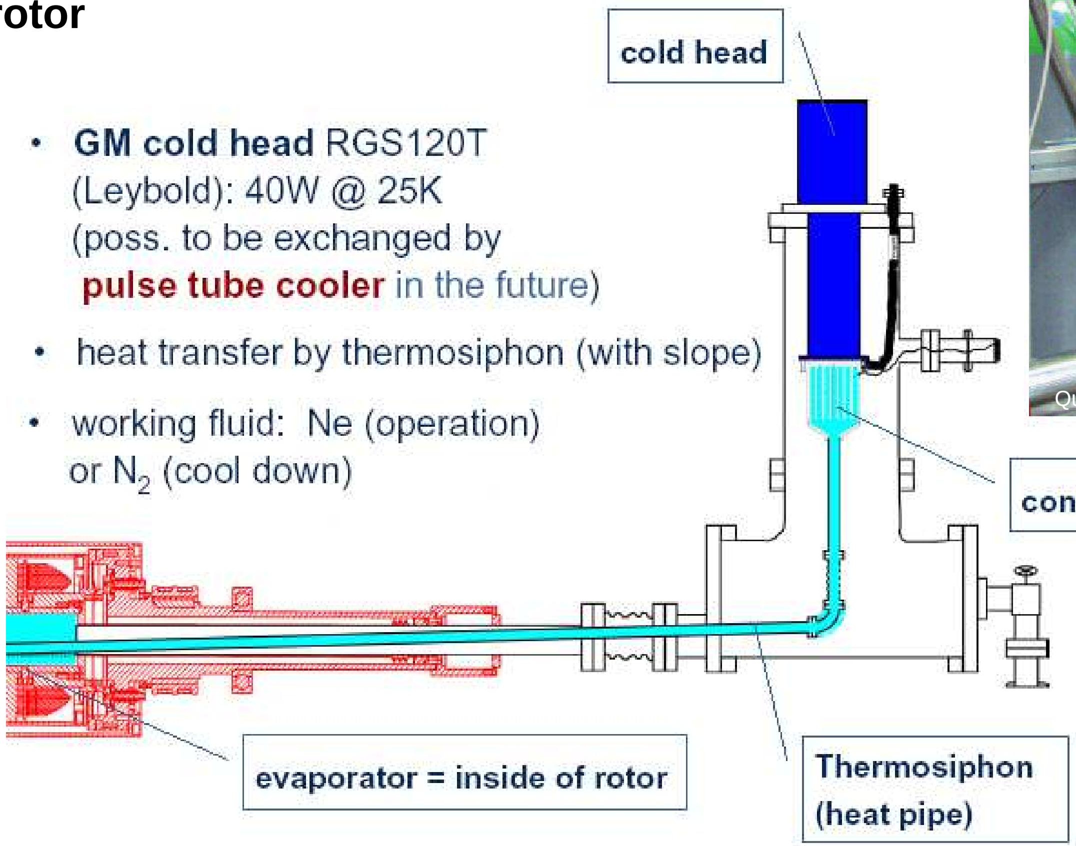
… in synchromous excited motor with sc coil in rotor

Siemens HTS I:

1999 - 2002
400 kW
1500 rpm

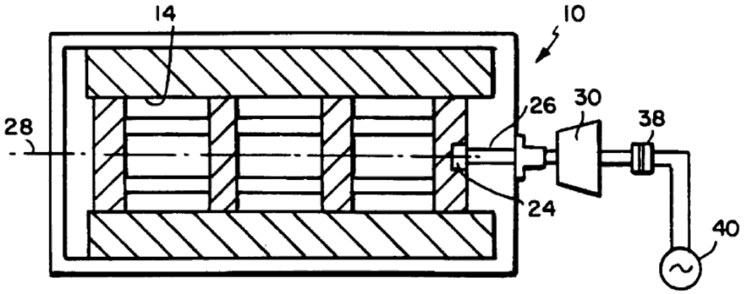
technology demonstrator

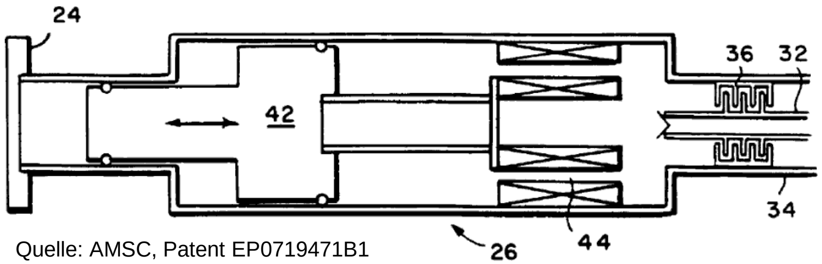
- **GM cold head** RGS120T (Leybold): 40W @ 25K (poss. to be exchanged by **pulse tube cooler** in the future)
- heat transfer by thermosiphon (with slope)
- working fluid: Ne (operation) or N_2 (cool down)



cryogenic aspects
active cooling with coldhead

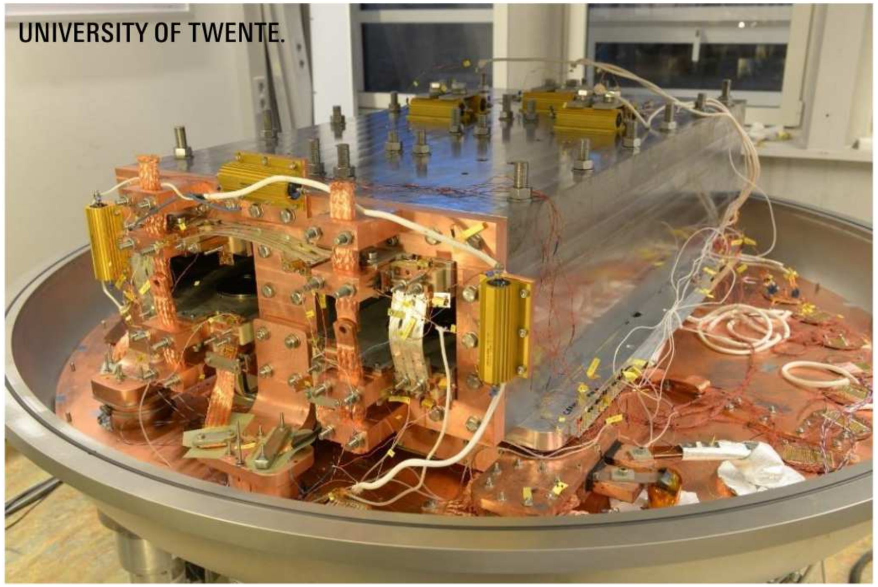
- **coldhead integrated in rotor**
- **compressor is usually not moving**
- **solution for working gas feed through available since 90's**





Quelle: AMSC, Patent EP0719471B1

will be integrated in ecoswing project: coils are tested at University of twente with Cu coldbus and similar forces



Thank you!

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