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DIEF Dipartimento di Ingegneria Industriale
DINFO Dipartimento di Ingegneria dell'Informazione

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The S.T.I.G.E. Project

Development of innovative drilling machines for geological activities with electric power supply

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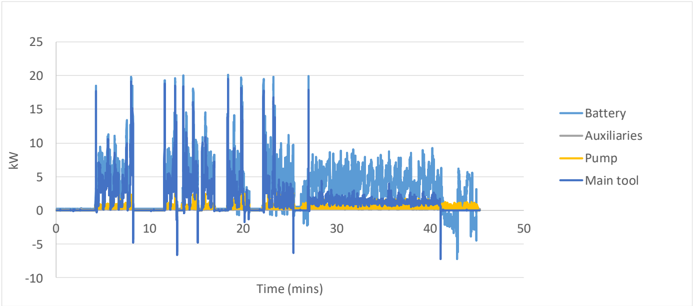
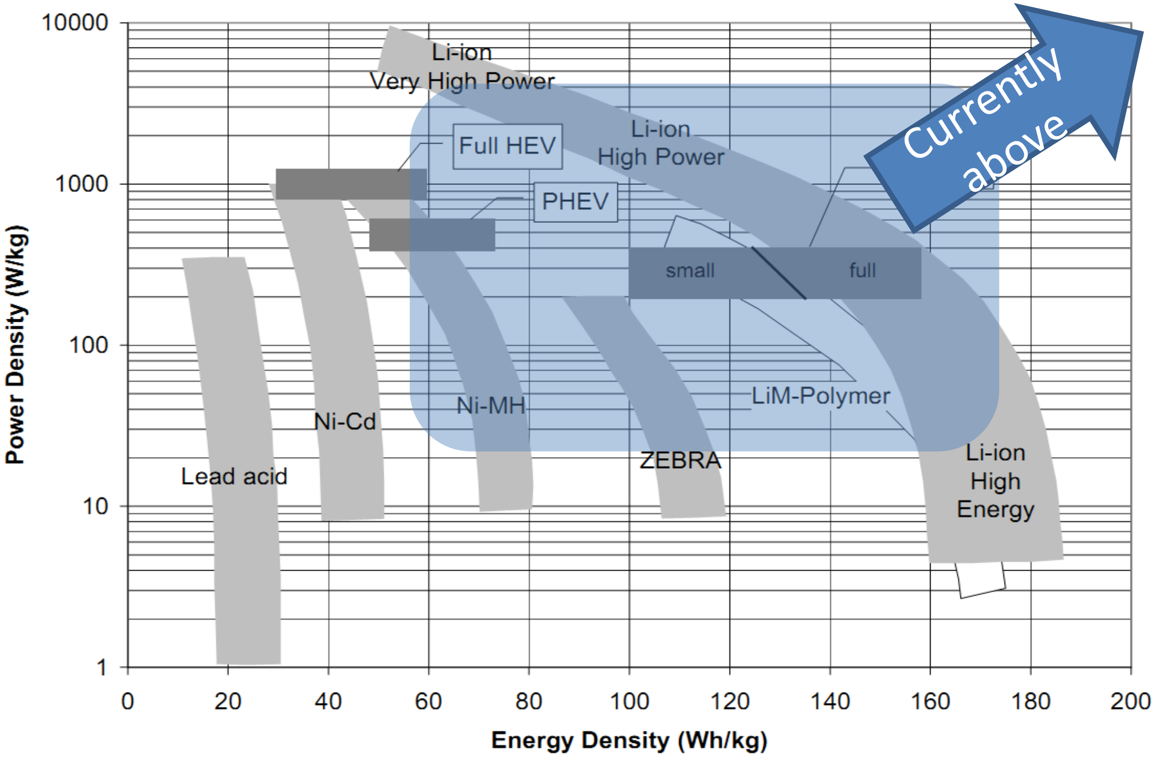
The S.T.I.G.E. project - Why Electric?

- Sustainability
  - No air pollution
  - No noise
  - Higher efficiency
    - Lowest GHG emissions

- Opportunities
  - Automation possibility
  - Precise measurements & telemetry
    - Remote diagnostics
    - Industry 4.0
  - Reduction of maintenance



The S.T.I.G.E. project - Why today?



So, why EV?

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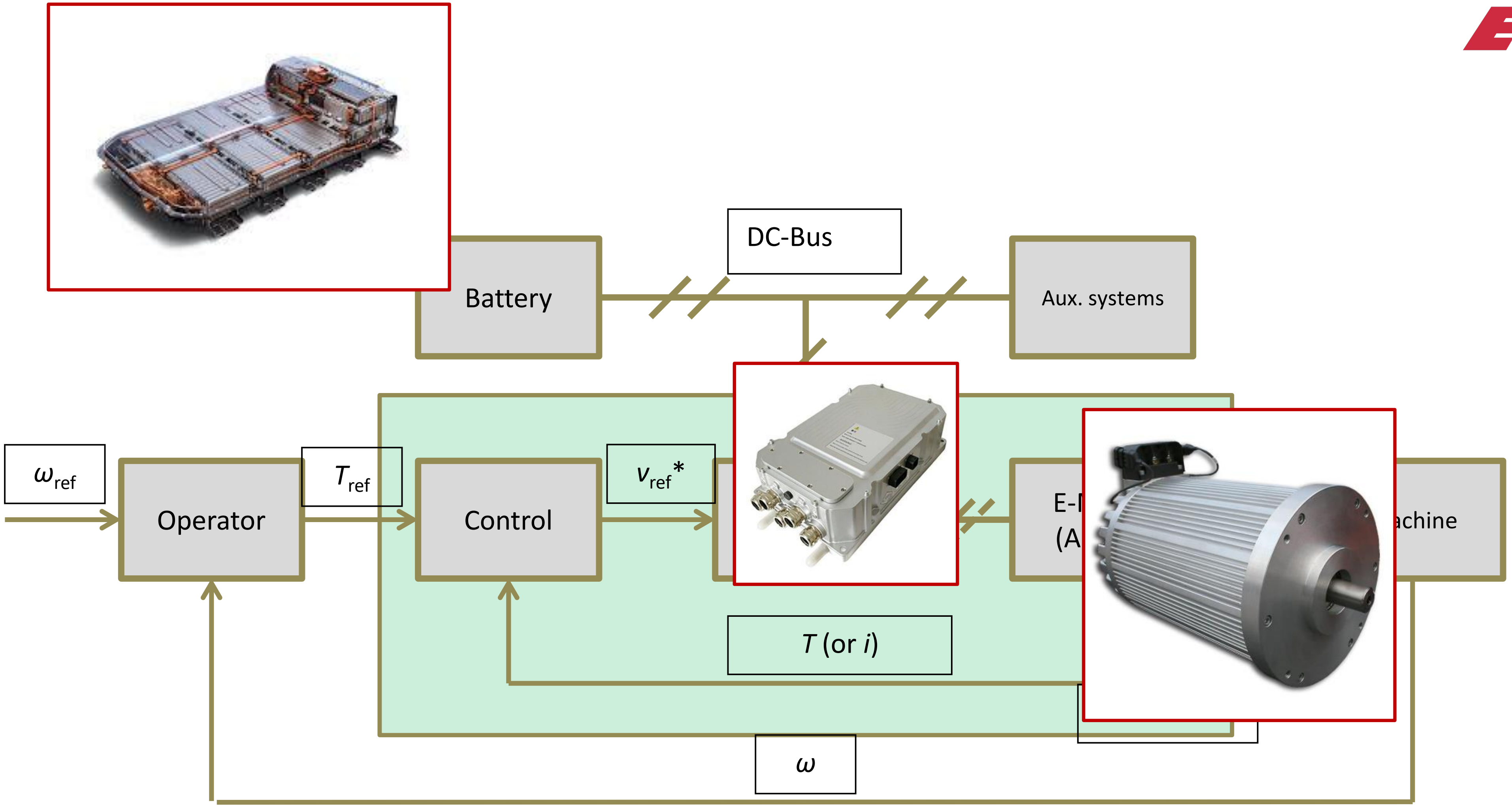
- An analysis on Prius Adopters…
  - it's technological
  - it's comfortable
  - there are advantages in the city
- State of the art EV: TESLA
  - Luxury
  - **Power !!!!**

Factor	Variables/codes	Ozaki, 2011
Factor 1	• Comfort of driving • Quietness • Ease of driving • Automatic transmission	
Factor 2	• New or innovative technology • Level of specification • Performance • New ways of energy use	
Factor 3	• Socially desirable behaviour • Good recommendation from friends and family	
Factor 4	• Reliability • Manufacturer's name	
Factor 5	• Design • Fashion	
Factor 6	• Lower tax • Congestion charge exemption • Company car	
Factor 7	• Economic driving • Lower fuel bills	
Factor 8	• Better for the environment • Reduced emissions	
Factor 9	• Lower running costs	
Factor 10	• The size of the car	

Costruzione di veicoli elettrici ed ibridi – Lesson 1 - 30/09/2019 64


DC-Bus
Battery
Aux. systems
ω_{ref}
Operator
T_{ref}
Control
v_{ref}*
E-M
(A
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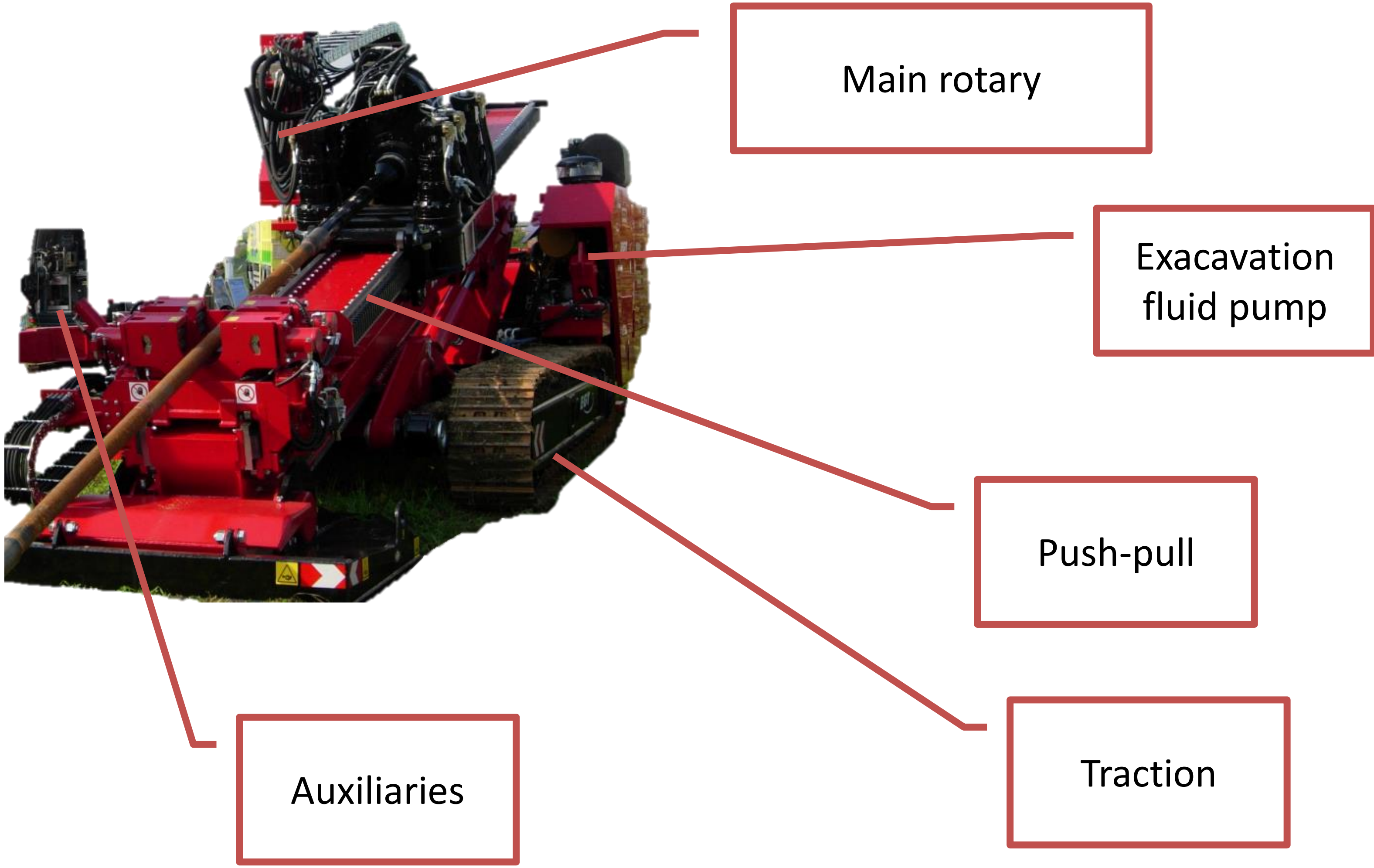
The S.T.I.G.E. project – Which drives?

- Target
  - Target: 100% full electric
  - Duration: up to 8 hours
  - Working cycle: similar as diesel ones



Energy consideration

Efficiency

Conventional «driveline» efficiency

- Oleodinamic transmission: 60-65%
- Overall mechanical : 85%

Final efficiency:
=< 50%

Full electric drive

- Motor- inverter unit: 85-90%
- Overall mechanical: 80%

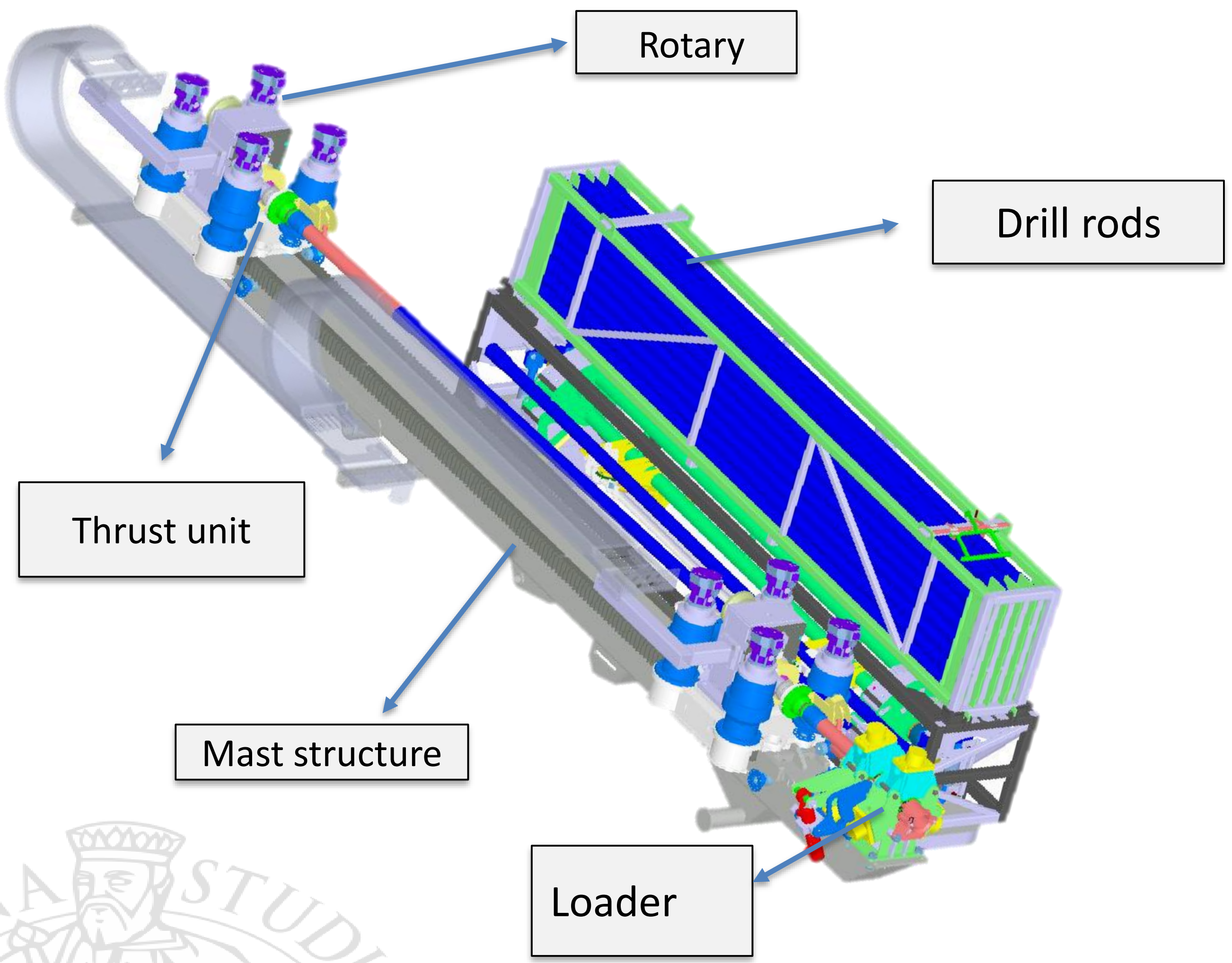
Final efficiency:
> 70%

Single drive characterization

Drive	Max load	Minimum load
Rotary	45 kW	0,5 kW
Thrust	12,5 kW	0,35 kW
Excavation fluid pump	23 kW	-
Auxiliary oleodinamic pump	10 kW	-

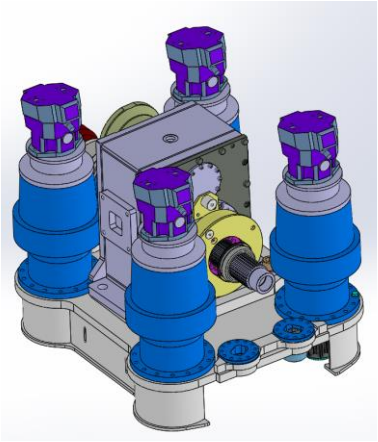
Example – design of MAST unit

Main drilling unit
MAST

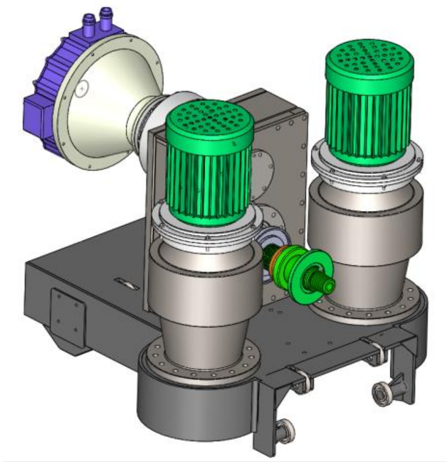


Update of existing components

Motor assessment

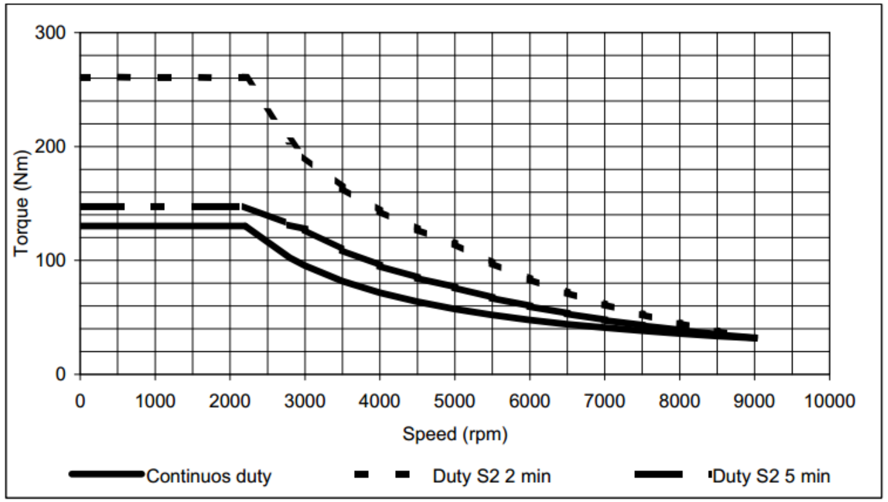


- **Engineering of new Electric unit**



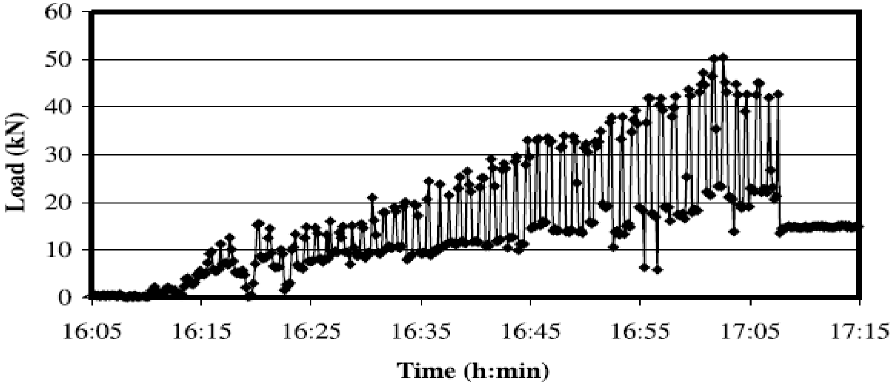
Load cycle assessment

- How to choose components?
  - Energy storage: cost, mass and volume balance
  - Drive units: use nominal/maximum/typical torque?

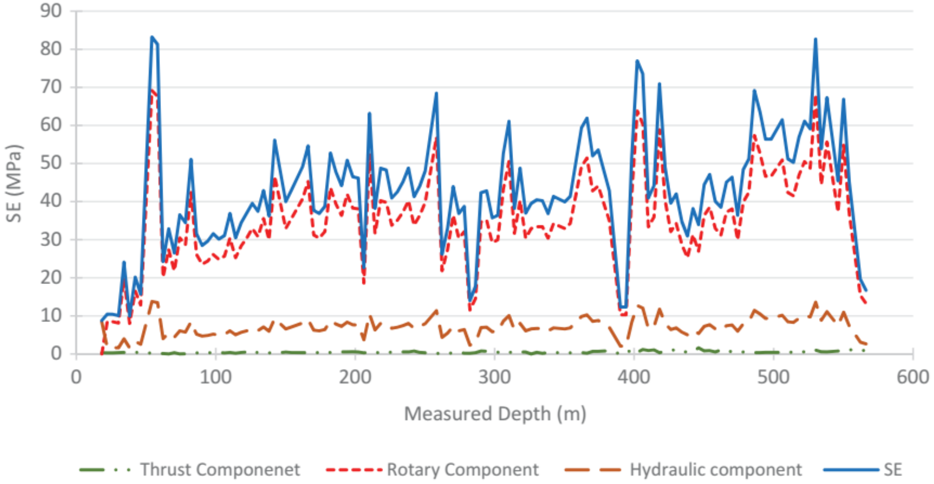


Torque assessment model

$$M = c' * P^{ap} * n^{b} * L^{d} * e^{p*K_L} * D_i^{f} * W^{g} * V^{h} \quad [Nm]$$



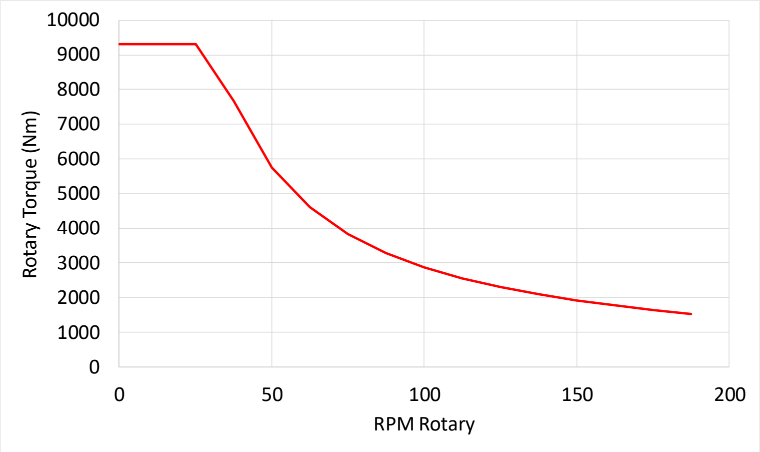
Baumert, 2004



Faghigh, 2017

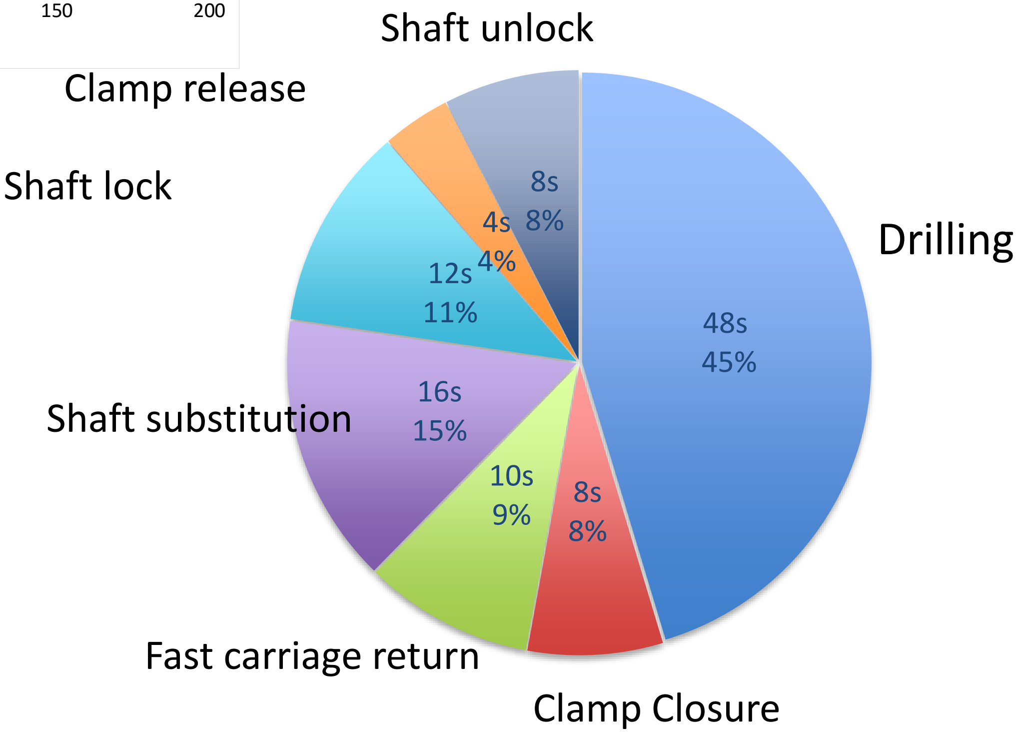
Typical cycle proposed for sizing

- Working cycle



Shaft torque

- **6000 Nm - 30 rpm**
- **1500 Nm - 180 rpm**

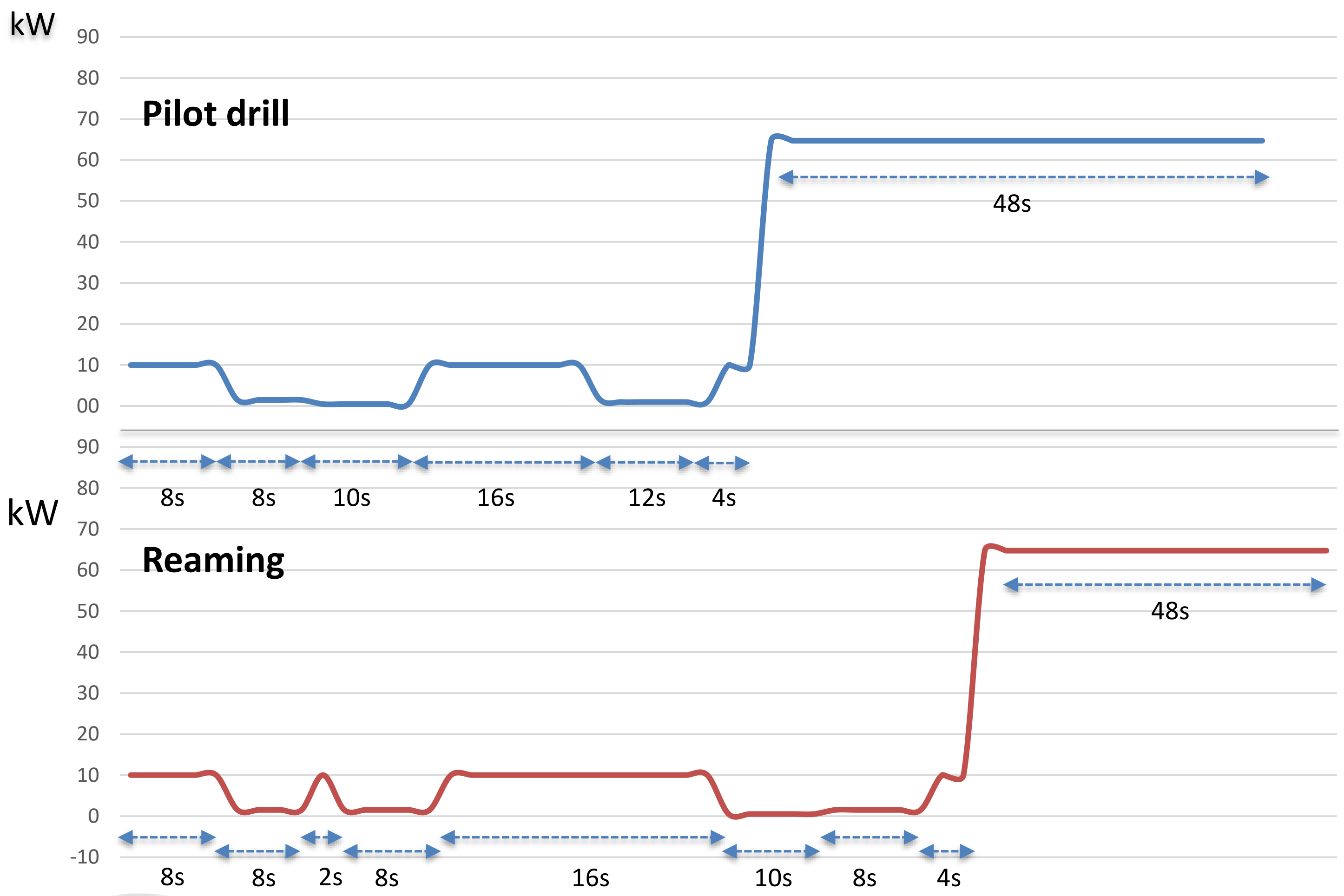


Thrust expectations

- **100 kN @ 5m/min**
- **Fast movement: 50 m/min**

Estimation of expected power cycle

Cycle per a single shaft



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Energy needed for a workcyle (rotary and trust, 40 rods)

$$\boldsymbol{W_t} = \left(W_{thrust} + W_{shaft}\right) * n_{shafts} = \mathbf{97\ kWh}$$

+

Energy necessary for traction, pumps, auxiliaries..

Battery LiFePO₄

Minimal energy needed (rotary): 100 kWh
With traction and auxiliary units: +60 %
Battery energy reserve: +10%
Total: 180 kWh - minimum

- Final mass: 1800 Kg
- Cell volume: delle celle 0,8 m^3

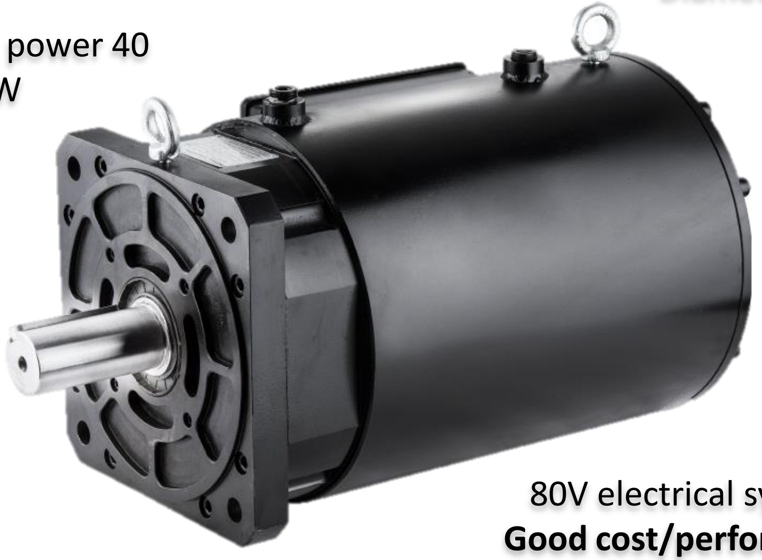
Alternatives for motor drive

Three phase Induction (rare earths free)

Peak torque600 Nm
Max speed 3500 rpm
(limited by reducer)

Mass 230 Kg
Depth 670 mm
Diameter 385mm

Continous power 40 kW



80V electrical system
Good cost/performance quality

Permanent magnet sinchronous machine
Axial flux type

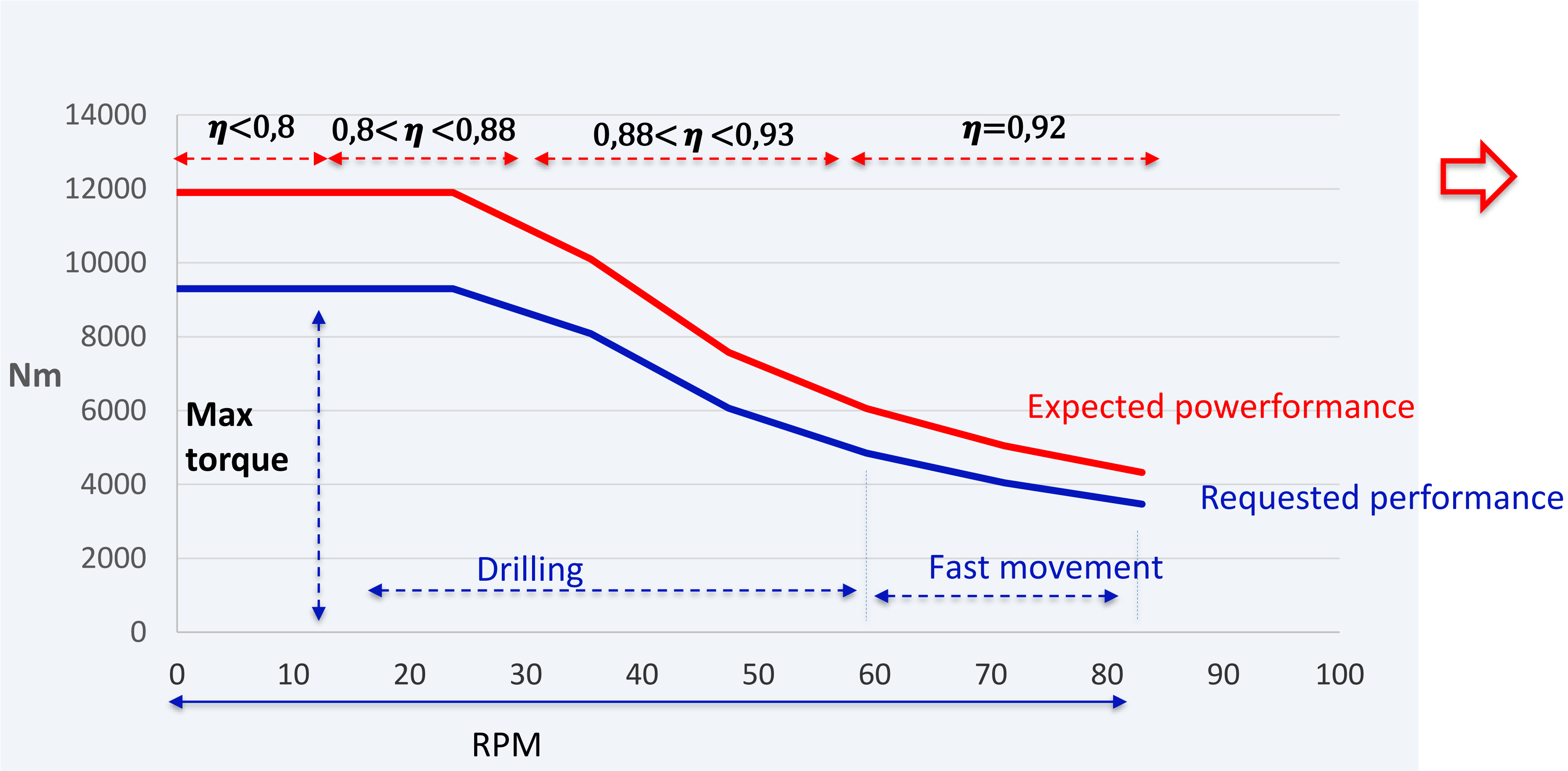
Peak torque 790 Nm
Max speed 3250 rpm

Mass 37 kg
Diameter 368 mm
Depth 98 mm

Continous power 70kW

High voltage bus 350/700 V
Cost increase

Motor and drilling unit matching



Permanent Magnet synchronous machine

High efficiency

Fit typical heavy geared reducers RPM (3500 RPM)

New components for drilling units

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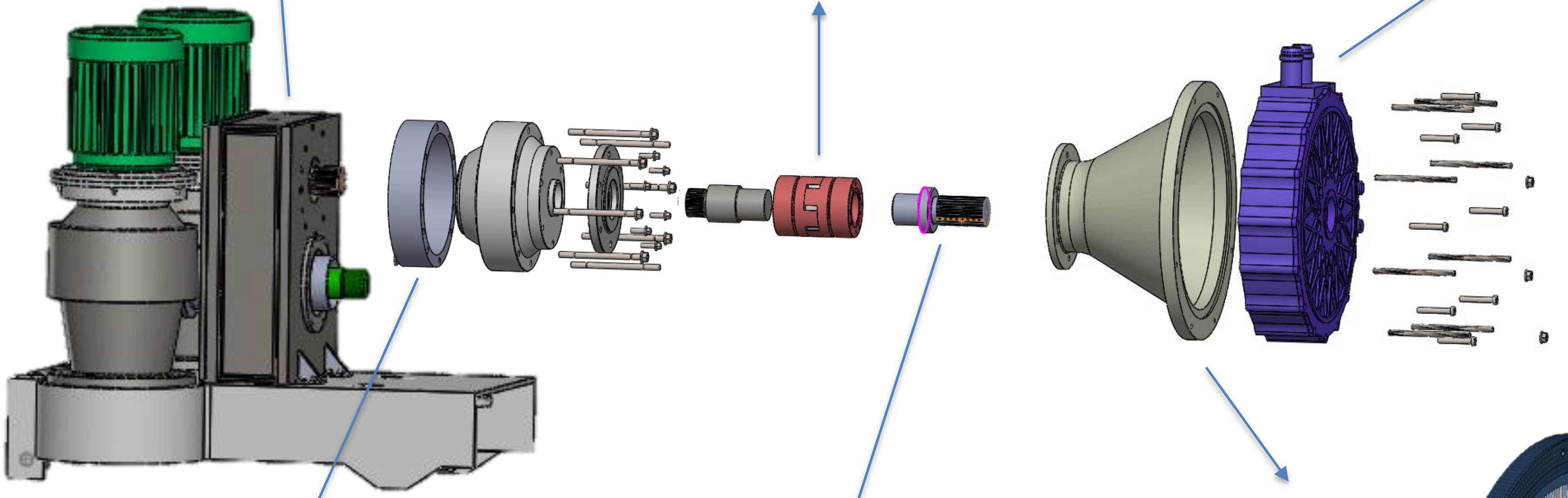
Gearbox E.G.T. $\boldsymbol{\tau} = 3.1$

Joint

YASA 750 V

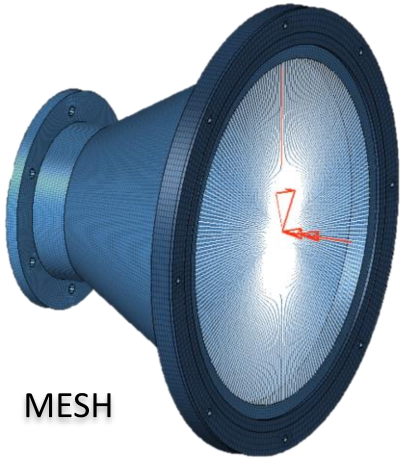
Motor flange



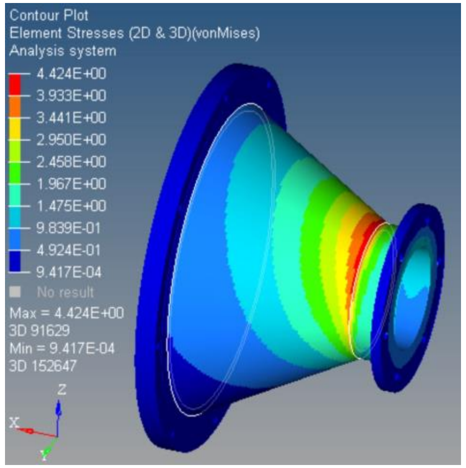
2-stage planetary gear RR510D
$\boldsymbol{\tau} = \mathbf{13.6}\ \ T_{nMAX} = 3700\ Nm$

Intermediate shaft

FEM verification

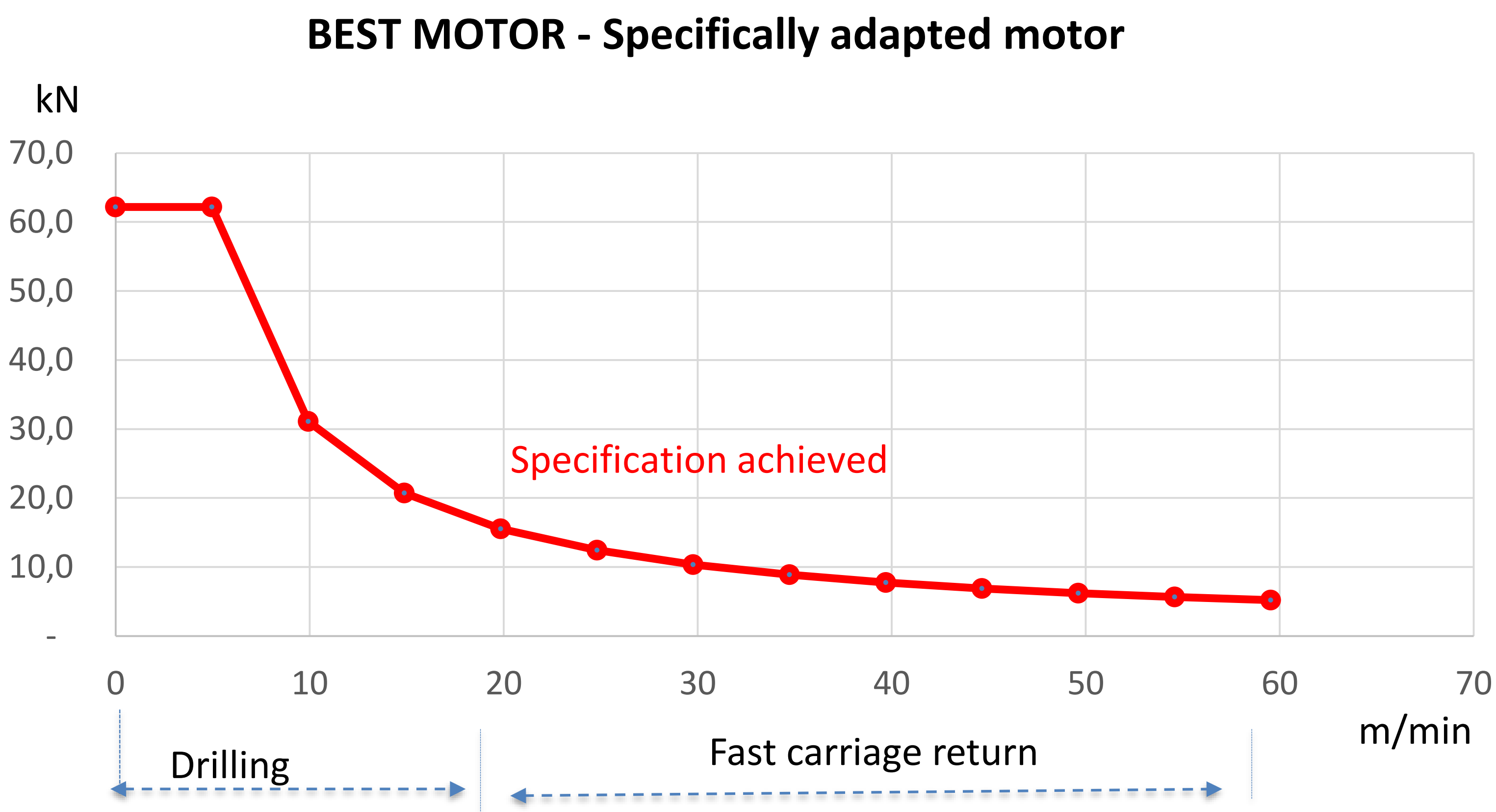


MESH



Von Mises @ 3.5g, vertical

Thrust unit

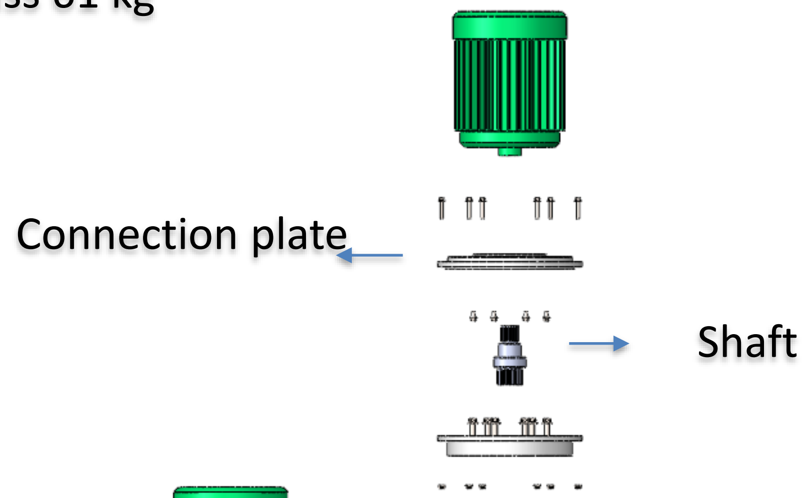


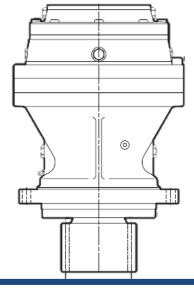
Induction motor

Nominal power 12 Kw

Max 2450 rpm

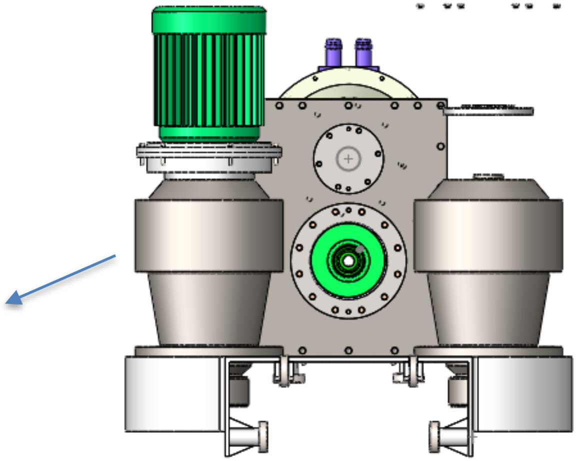
Mass 61 kg



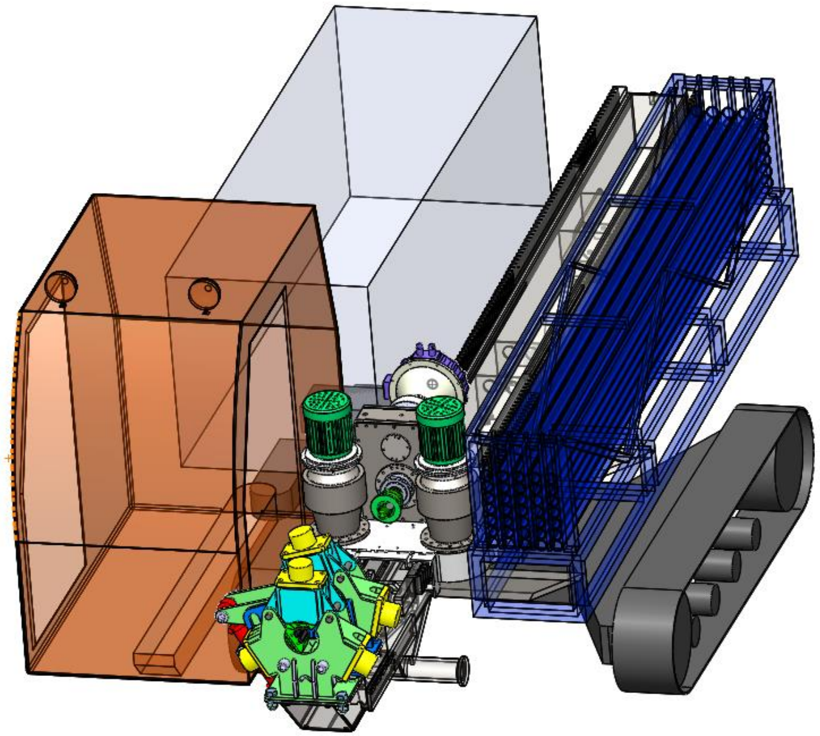


2-stage planetary gear RR810

τ=27,35



Final observation



- Noise & air pollution reduction
- Reduction of oleodinamic devices
- Increase machine efficiency
- New possibility for control, measurements and peak performances

Next steps

- Prototype build up
- Real-world testing and data validation
- Design revision
- …production?

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