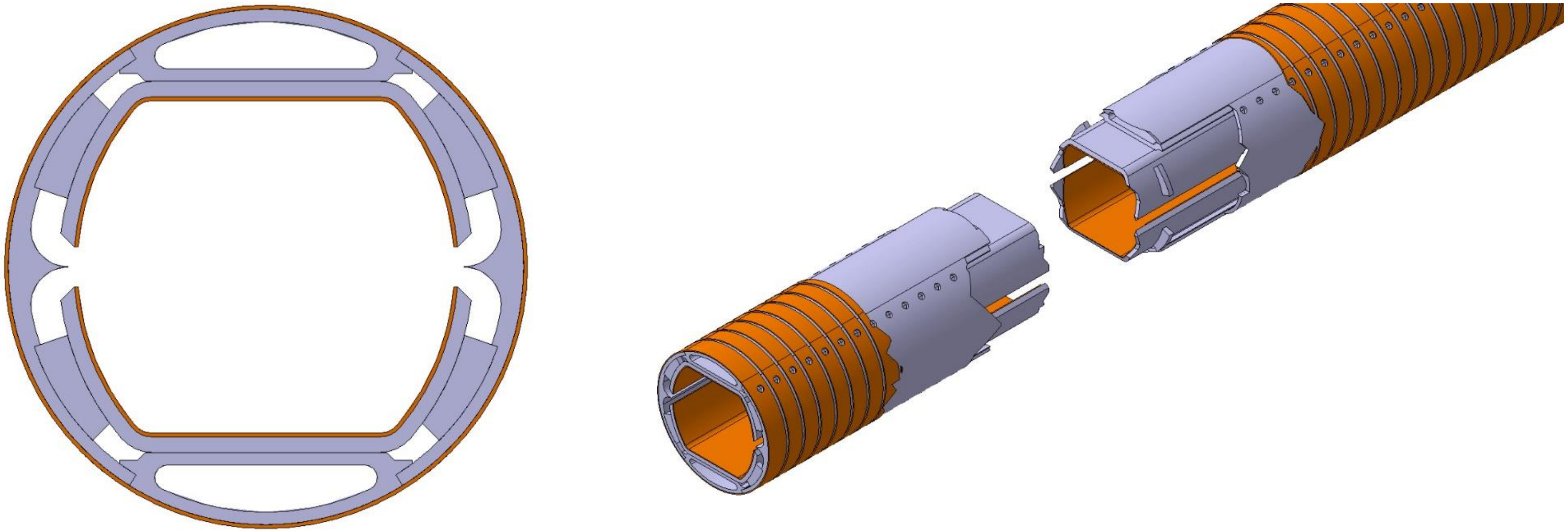
CERN

FCC-hh beam screen design

EuroCircol task 4.5

C. Garion

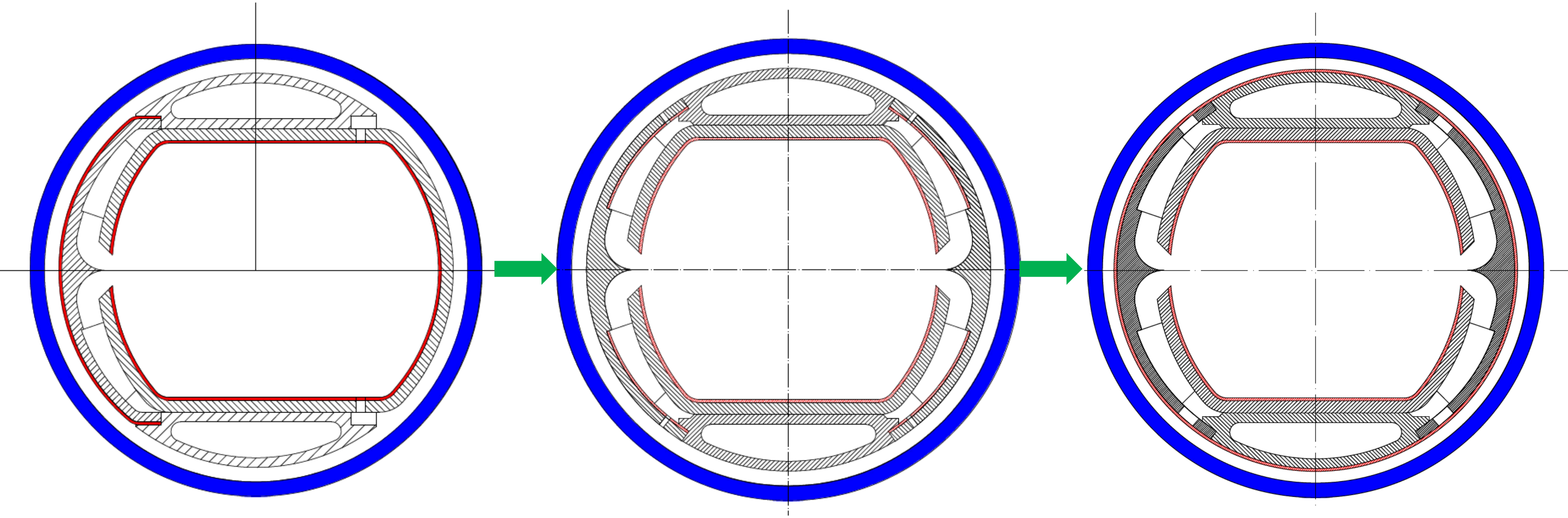


Cross section and 3D model of the beam screen

Outline

- Design update
- Mechanical design
  - Internal pressure in cooling channel
  - Quench model & mechanical behaviour
  - Material properties
- Thermal study
  - Material properties
  - Nominal heat transfer
  - Off-plane beam heat transfer
- Prototyping
- Summary

Design Updates



- Symmetrical design
  - → Better impedance
  - → Pumping holes hidden by the screen
- Thermal copper coating on the outer side
- Bigger pumping holes – no constraint for the distribution

Design – Main dimensions

Cold bore diameter: 44/47 mm

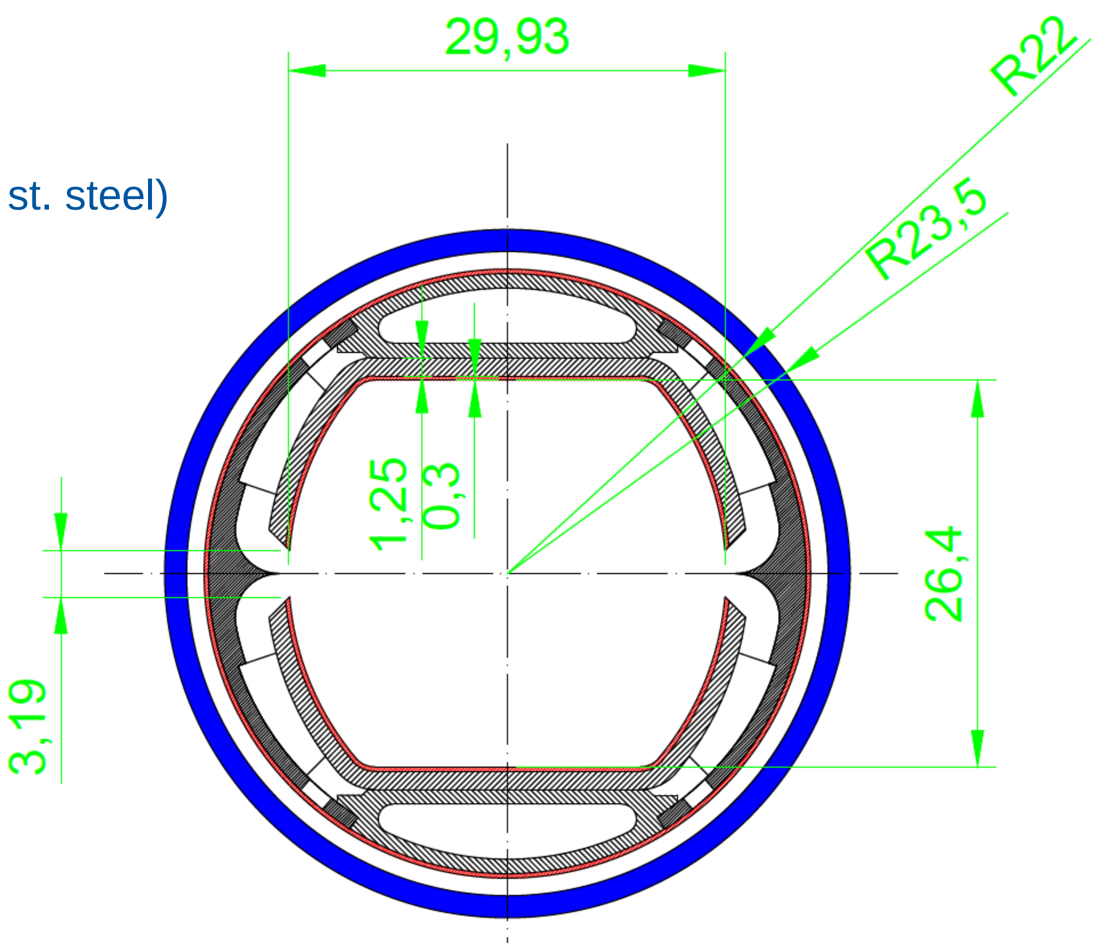
Beam screen wall:
- 1.25 mm P506 (high-Mn high-N st. steel)
- 0.3 mmcopper

Nominal aperture:
- H:~ 29.9 mm
- V:~26.4 mm

Slit height: ~ 3.2 mm

Cooling channel:
- Thickness 1 mm
- Internal 53.58 mm^2
- Hydraulic diameter: 5.61 mm

Copper for heat transfer: 0.3 mm



Mechanical analysis

Cryogenic considerations

Minutes of the FCC Hadron Collider General Design Meeting

12th November 2015

Participants : M.I. Besana, X. Buffat, F. Burkart, A. Chance*, H.R. Correira Rodriguez, B. Dalena*, J. Double*, C. Kotnig, R. Martin, F. Petrov*, L.S. Stoel, L.J. Tavian
(*Vidyo connection)

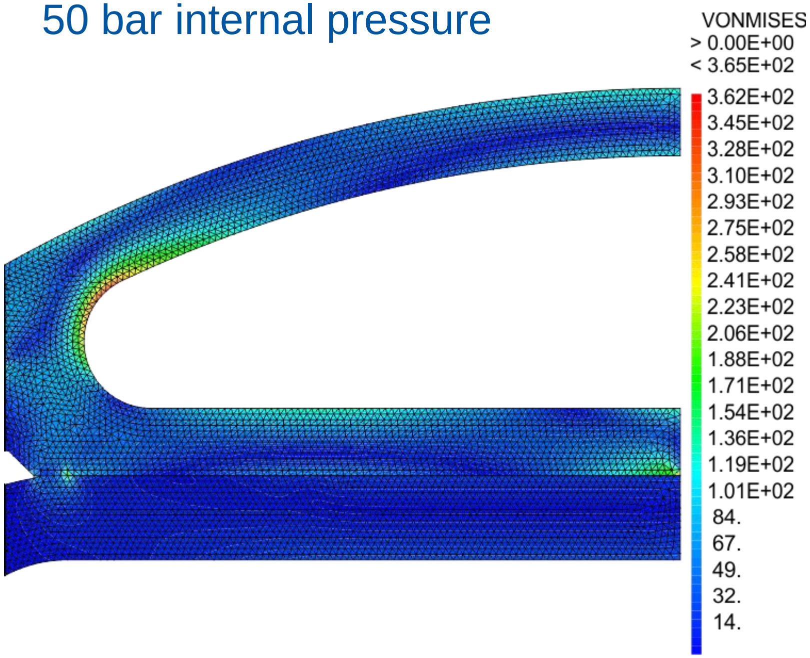
F. Kotnig presented the beam screen cooling for the FCChh. He showed that the hydraulic performance of the current beam screen design is a among the best that they have studied.

→ Present design is compatible with cryogenic requirements.
→ Assumption of a working pressure of 50 bars!

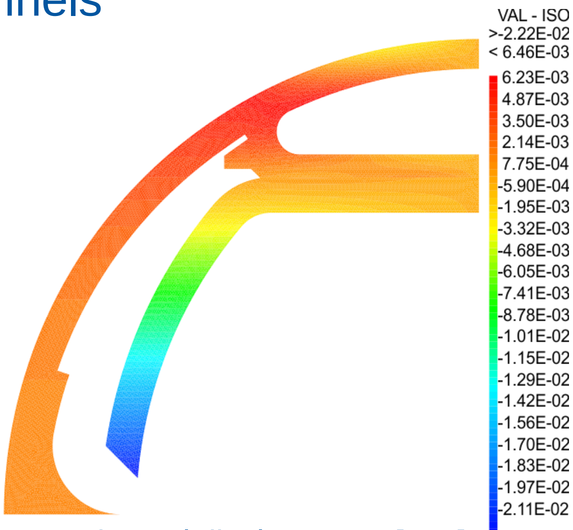
Mechanical analysis

Internal pressure in the cooling channels

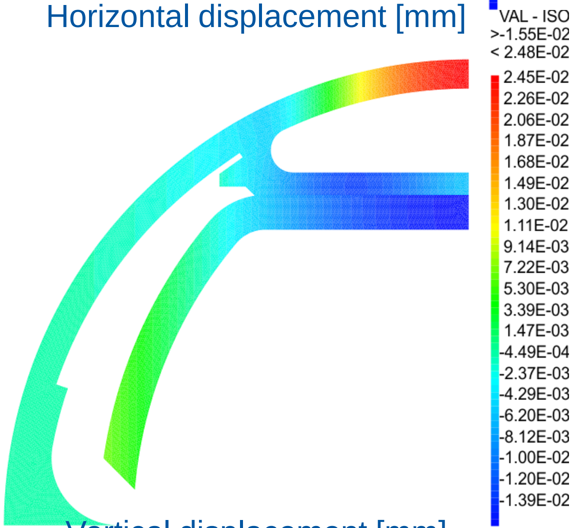
- Cooling channel thickness: 1 mm
- 0.5 mm weld width
- 50 bar internal pressure



Von Mises stress field [Mpa]



Horizontal displacement [mm]



Vertical displacement [mm]

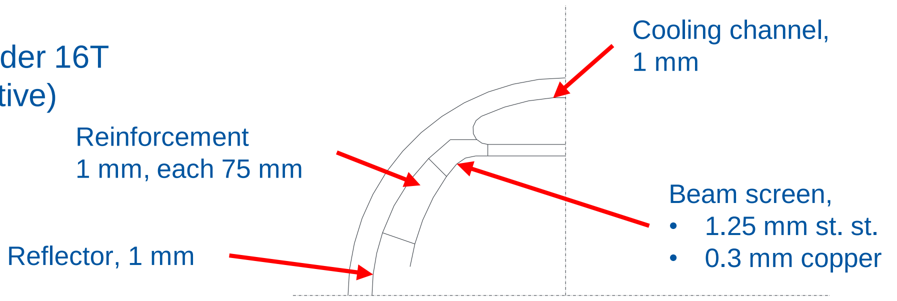
→ OK for nominal operation.
→ Pressure test to be checked.

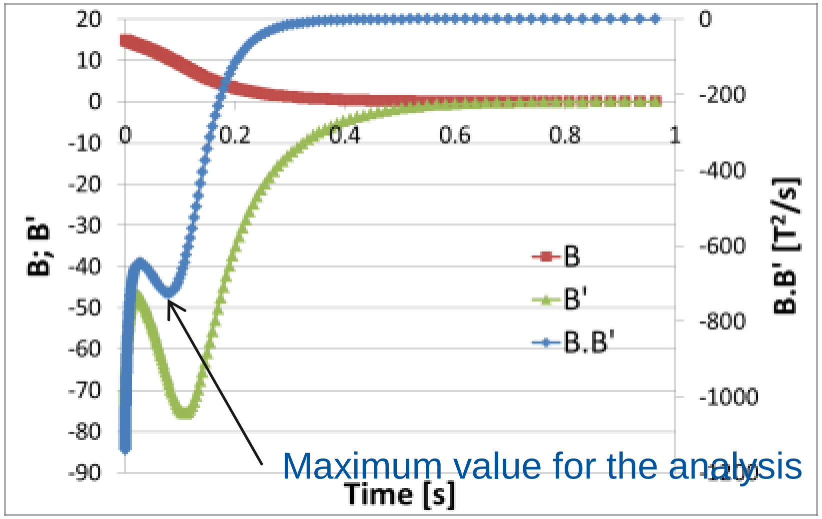
Mechanical analysis

Magnet quench

Simplified model:

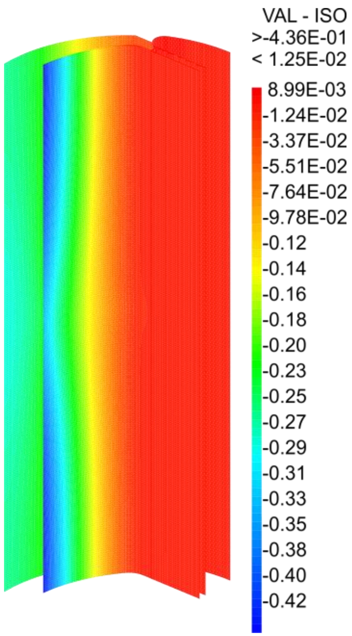
- Quarter of beam screen, shell elements
- Electrical conductivity of copper estimated at 50 K and under 16T
- Heat dissipation by Joule effect not considered (conservative)
- Eddy currents in the reflector neglected
- Static analysis
- Lorentz force driven by the parameter B.B' ~ -725 $T^2.s^{-1}$



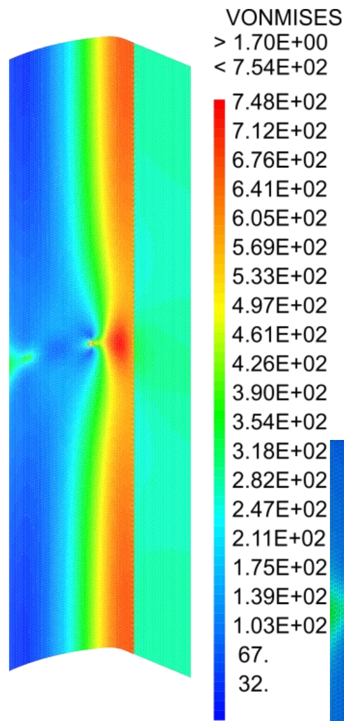


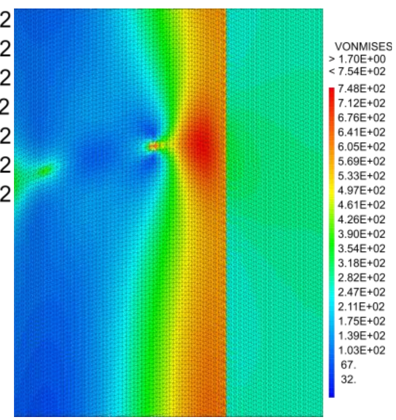
Mechanical analysis

Magnet quench

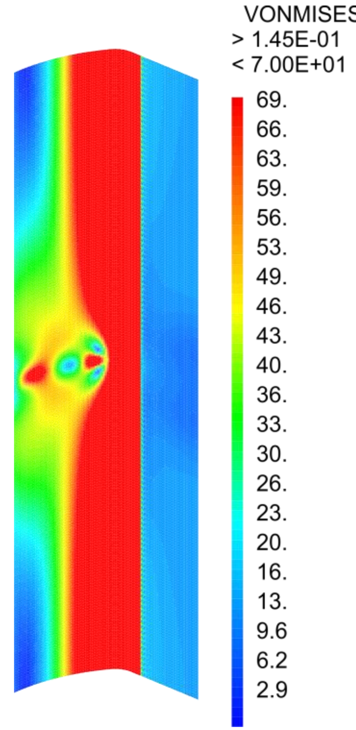


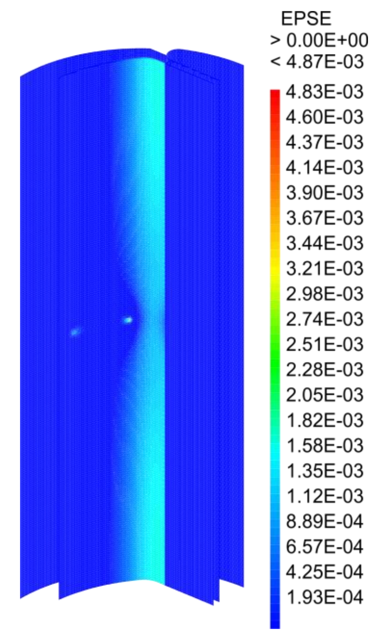
Horizontal displacement: ~ 0.5 mm





Maximum Von Mises stress in the beam screen: ~ 750 MPa





Plastic strain in the copper layer: ~ 10^{-3}

Even if the model has to be refined, results of the beam screen behaviour during a quench are promising.

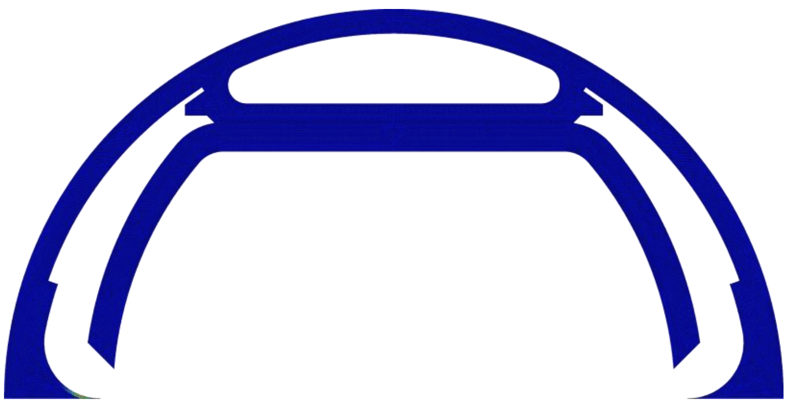
Thermal analysis

Nominal behavior

Model:

- 2D massive model
- Heat deposition of 31 W/m centrered w.r.t. beam screen
- Heat deposition field based on SynRad simulation
- Thermal conductivity of copper estimated at 50 K and under 16T ~ 700 $W.m^{-1}.K^{-1}$ (need to be measured)
- Thermal conductivity of stainless steel at 50 K ~ 6 $W.m^{-1}.K^{-1}$
- Convection coefficient of 150 $W.K^{-1}.m^{-2}$

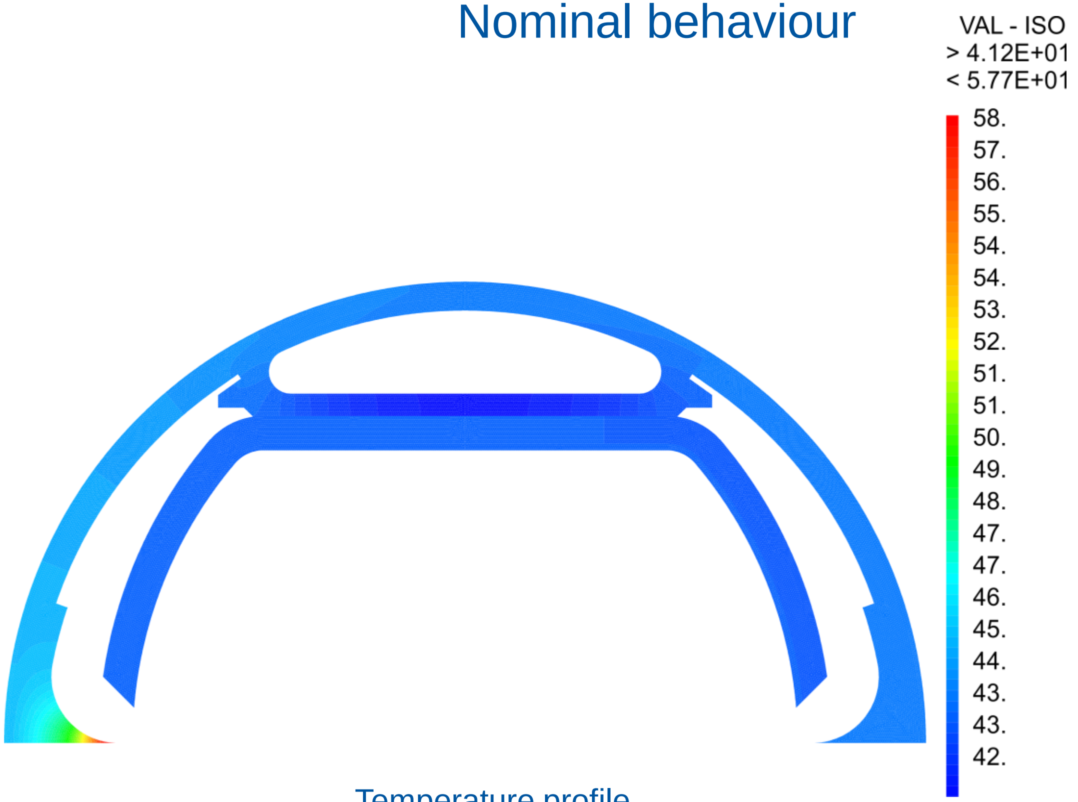
Model



Heat deposition field

Thermal analysis

Nominal behaviour



Temperature profile

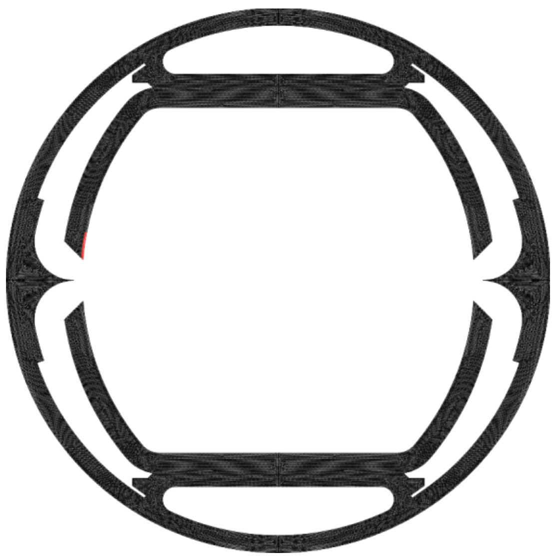
Local temperature increase (reflector tip)
Screen temperature a few K higher than the helium temperature

Thermal analysis

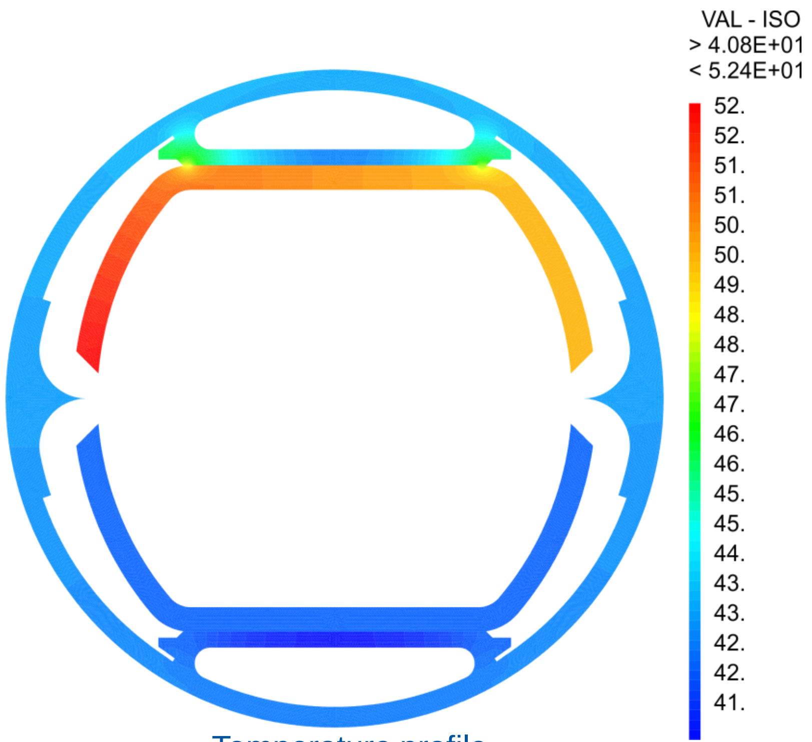
Nominal behavior

Model:

- 2D massive model
- Heat deposition of 31 W/m on one beam screen edge
- Thermal conductivity of copper estimated at 50 K and under 16T ~ 700 $W.m^{-1}.K^{-1}$ (need to be measured)
- Thermal conductivity of stainless steel at 50 K ~ 6 $W.m^{-1}.K^{-1}$
- Convection coefficient of 150 $W.K^{-1}.m^{-2}$



Heat deposition



Temperature profile

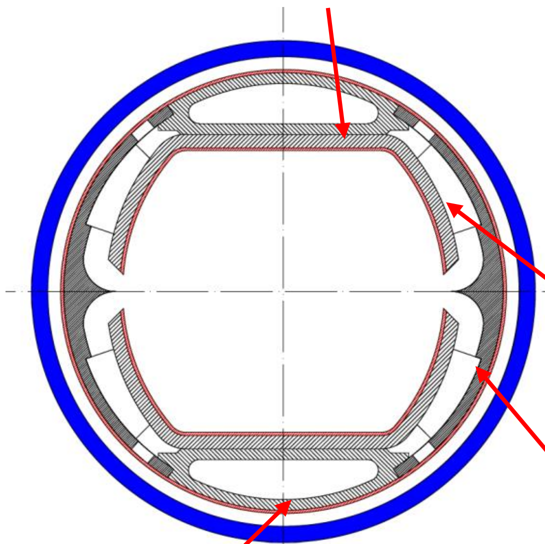
Prototypes

Series vs prototype #1

Sub-component manufacturing:

Series

Beam screen wall:
- P506, 1.25 mm
- copper colamination, 0.3 mm



Reinforcement:
- P506
- punching

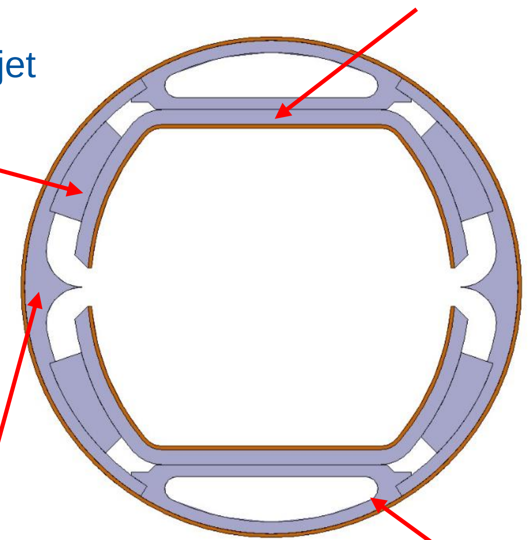
Cooling channel:
- P506 stainless steel
- Extruded

Reflector:
- P506 stainless steel
- Extruded + finishing

1st prototype

Beam screen wall:
- 304L, 1. 5 mm
- copper electrodeposition, 0.05 mm

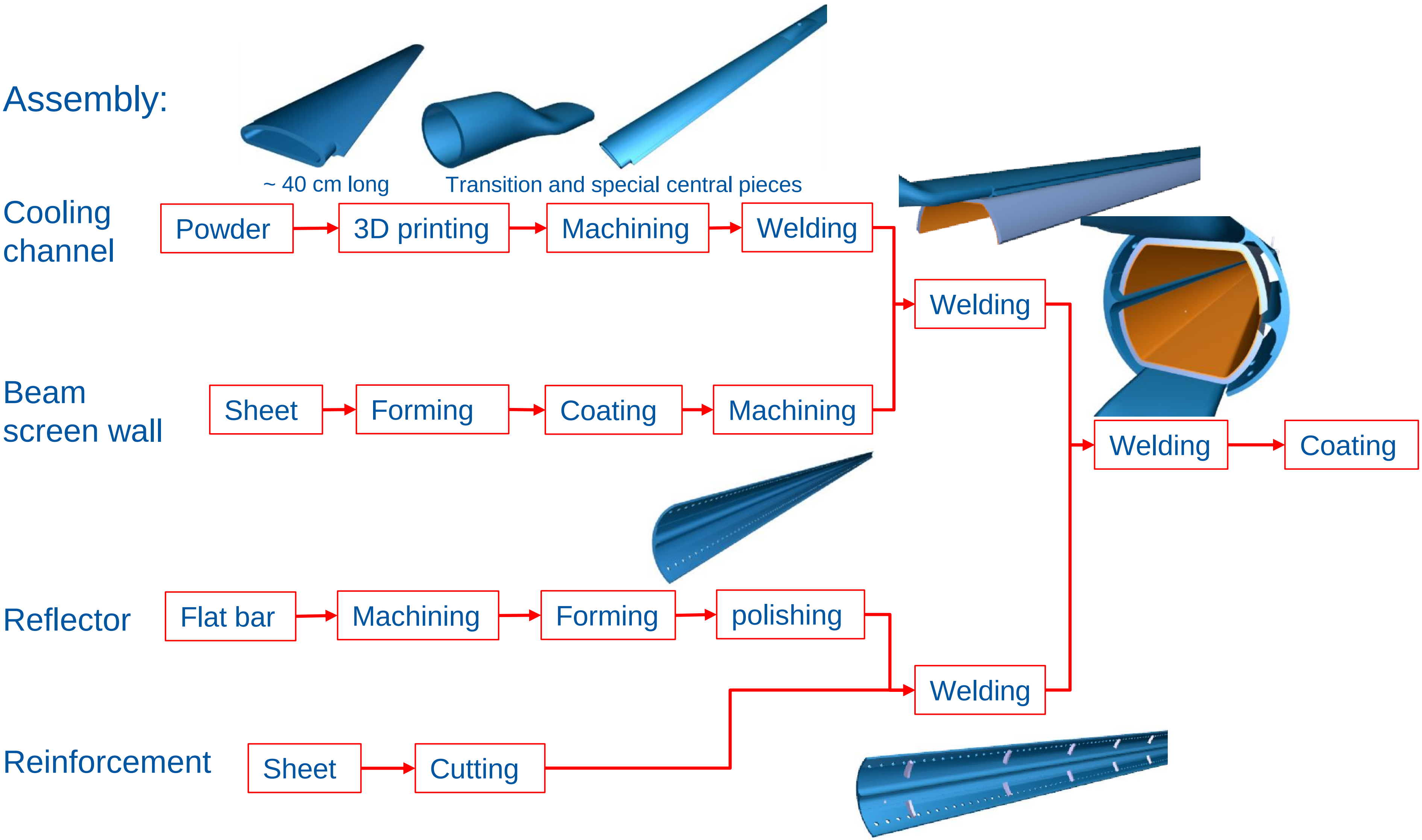
Reinforcement:
- 304L
- EDM or water jet cutting



Reflector:
- 304,
- Machined + forming + finishing

Cooling channel:
- 316L,
- 3D printed + machined

Prototypes


Assembly:
~ 40 cm long
Transition and special central pieces
Cooling channel
Powder
3D printing
Machining
Welding
Welding
Beam screen wall
Sheet
Forming
Coating
Machining
Welding
Coating
Reflector
Flat bar
Machining
Forming
polishing
Welding
Reinforcement
Sheet
Cutting

Next steps

From the design point of view:

- Check the design of the cooling channels for pressure test conditions
- Refine the model for the quench analysis:
    - Joule effect
    - Influence of the copper strip (3D model for the current field)

From the prototyping point of view:

- First samples to qualify the different processes involved in the manufacturing (Q1/2016)
- Manufacture ~2m long prototypes

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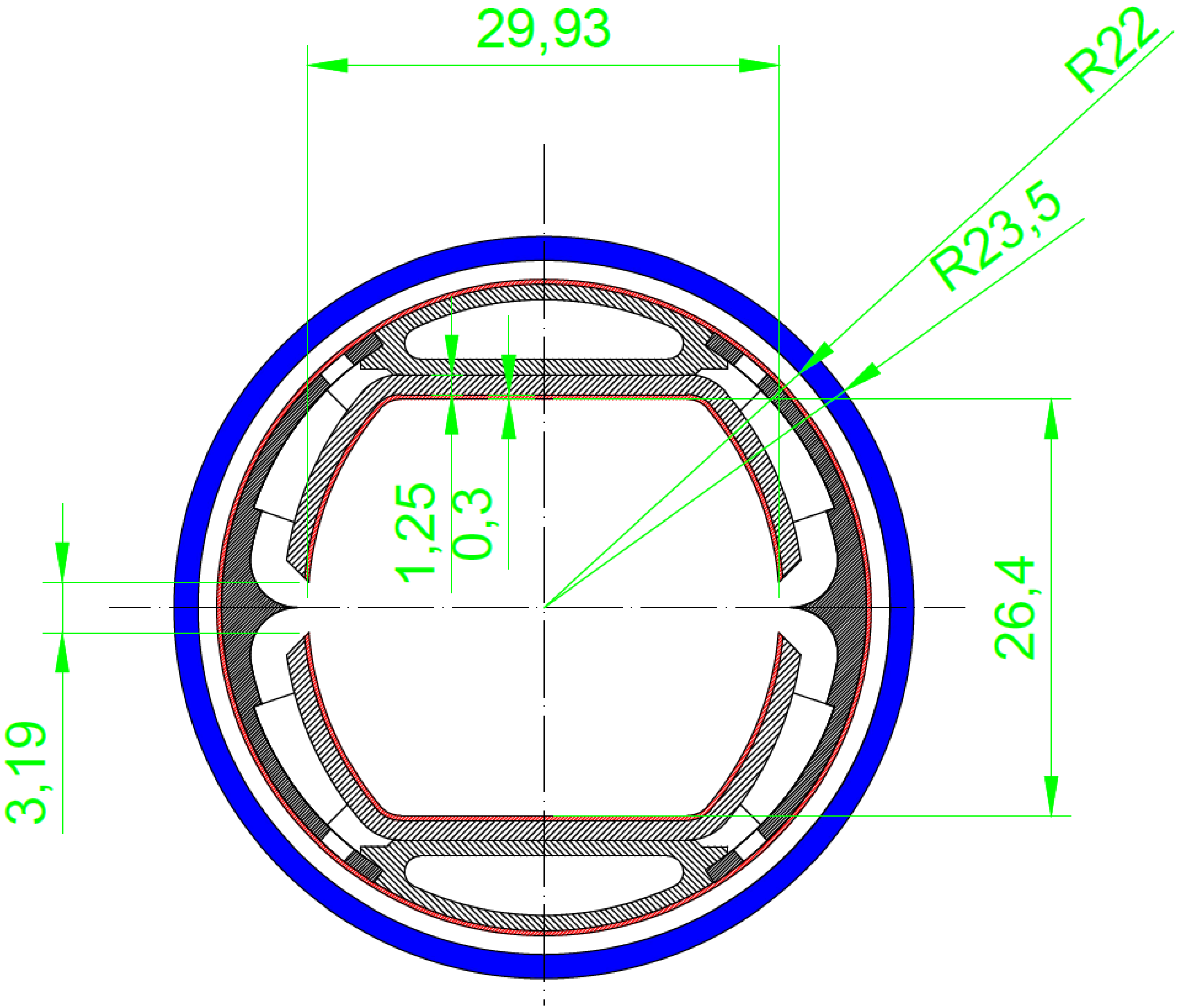
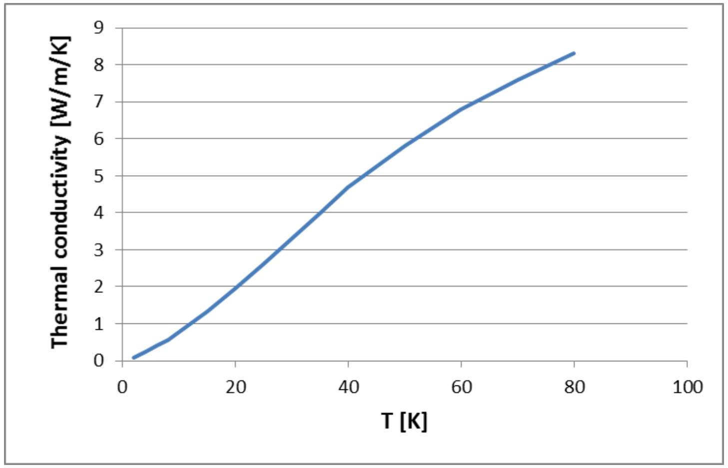

29,93
R22
R23,5
1,25
0,3
26,4
3,19

Material properties

Stainless steel*:

Electrical resistivity (50 K) ~ 5.10^{-7} Ω.m

Thermal conductivity (50 K) ~ 6. $W.m^{-1}.K^{-1}$



316LN:

Yield strength:

σ_y (4K)** ~ 860 MPa

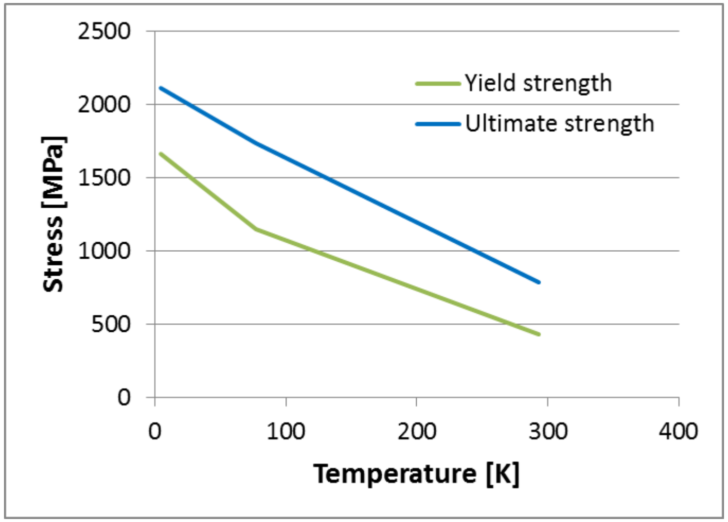
σ_y (293 K) ~ 300 MPa

P506 (high-Mn high-N austenitic stainless steel):

Yield strength***:

σ_y (50K) ~ 1350 Mpa

Magnetic susceptibility ~3.10^{-3}



P506 properties

*Jensen et al. Selected cryogenic data notebook, BNL, vol. 1

** Sa et al., Mechanical Characteristics of Austenitic Stainless Steel 316LN Weldments at Cryogenic Temperature, Fusion Engineering 2005

***Sgobba, S. and Hochörtler, G., A new non-magnetic stainless steel for very low temperature applications, Stainless Steel Science and Market, 1999; 2; 391-401