CERN

Shape Memory Alloy Connectors for UHV Applications

Outline

The concept and operation principle

Material properties and comparison NiTiNb – NiTi

Material response

Ring behaviour

Leak tightness

Irradiation tests

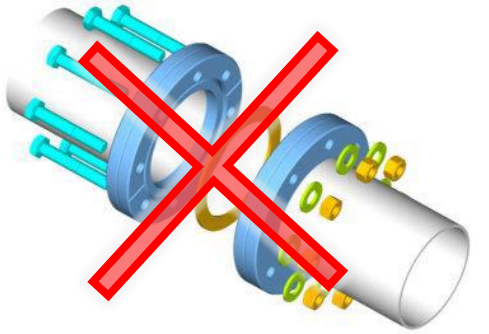
Constitutive model

Conclusions

* In collaboration with University of Calabria, Rende, Italy

Concept of SMA Connectors for UHV Applications

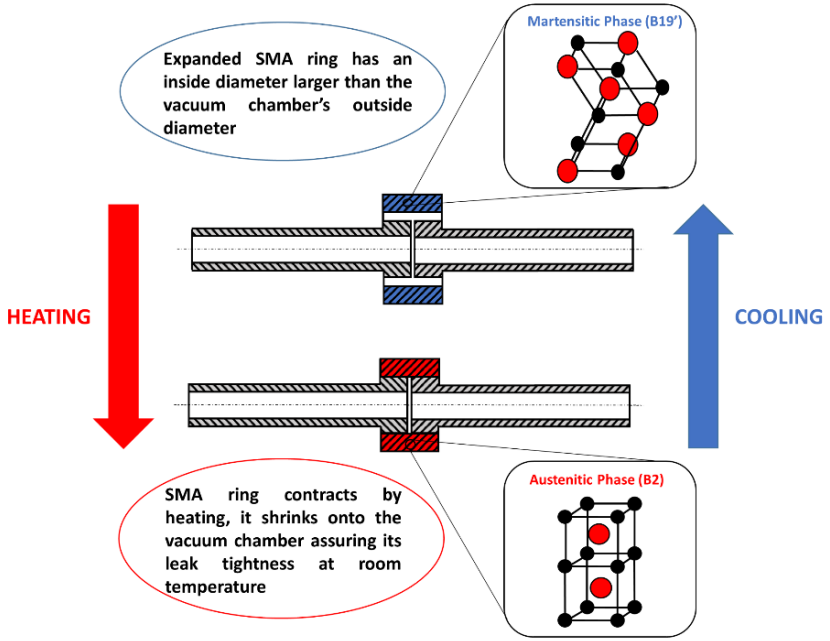
Current system



Typical ConFlat flange

New concept

Proof of concept of SMA connectors for Ultra High Vacuum (UHV) chambers.

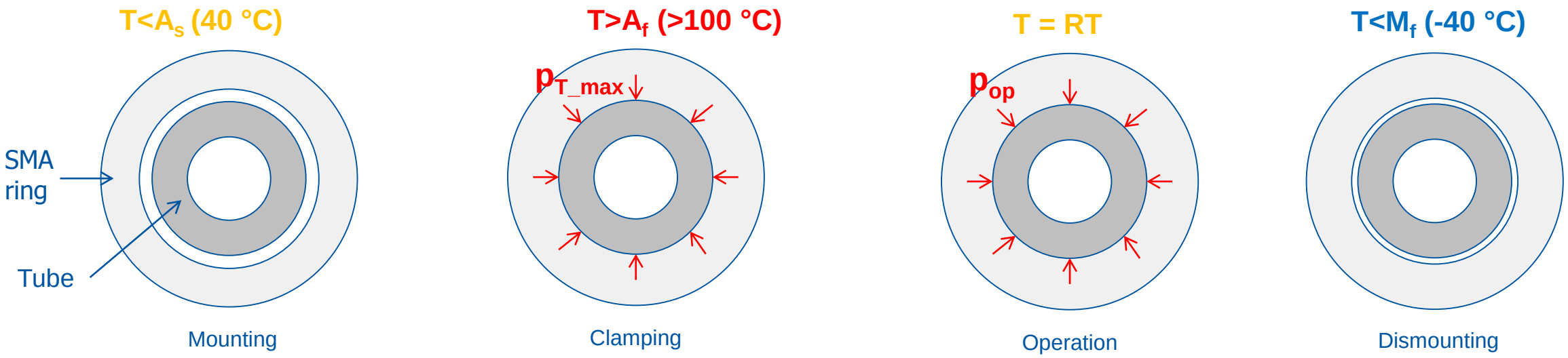


Soft/hard materials + mechanical force

Soft/hard materials + temperature control

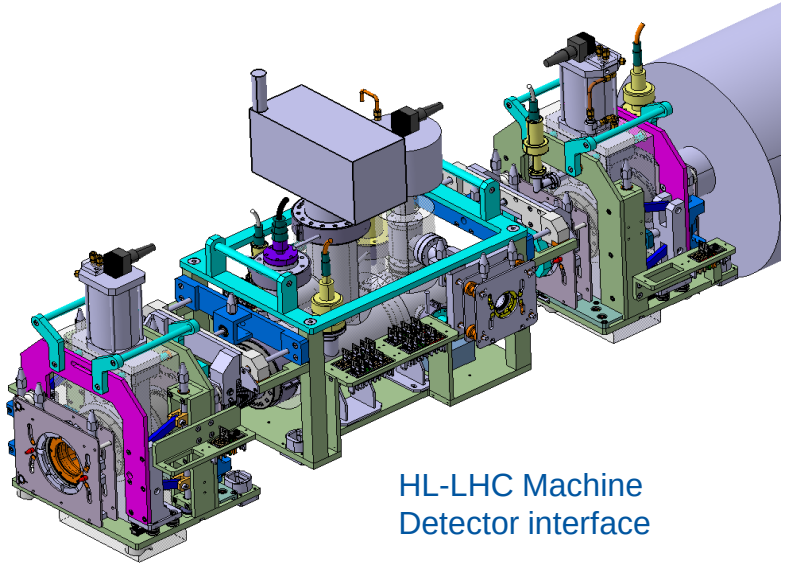
Operation Principle

1. Mounting at room temperature
2. Tightening by heating above 100 °C
3. Leak Rate < 10^{-10} mbar·l·s^{-1} at room temperature
4. Dismounting by cooling down to -40°C

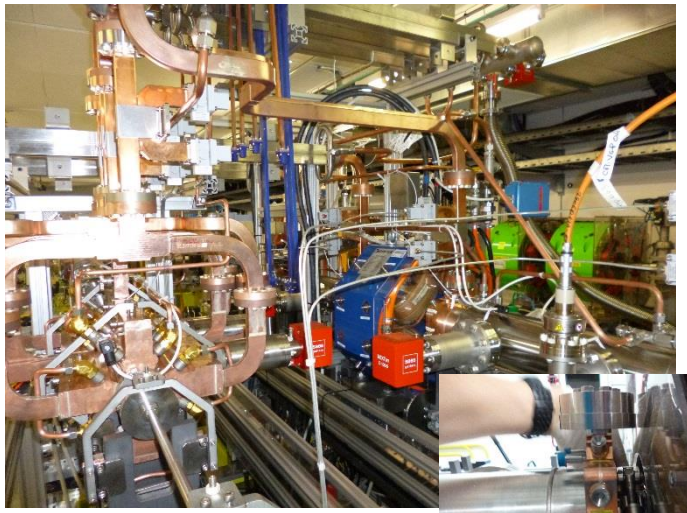


Advantages and Potential Applications

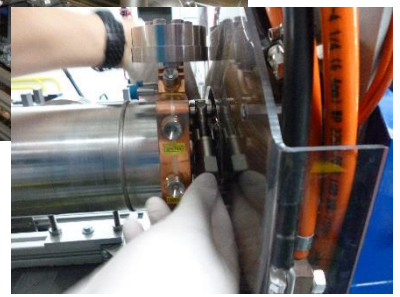
- A compact, leak tight and easily mountable\dismountable connection system
- Possibility of remote controlling\activation
- Possibility to connect dissimilar materials
- Possibility to use in high demanding areas (e.g. collimator areas, machine/detector interface)



HL-LHC Machine
Detector interface



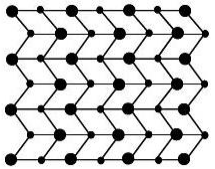
CLIC main linac



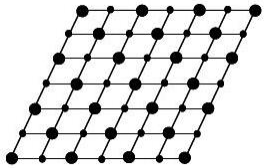
CLIC module installed in CLEX

Shape Memory Alloy Behavior

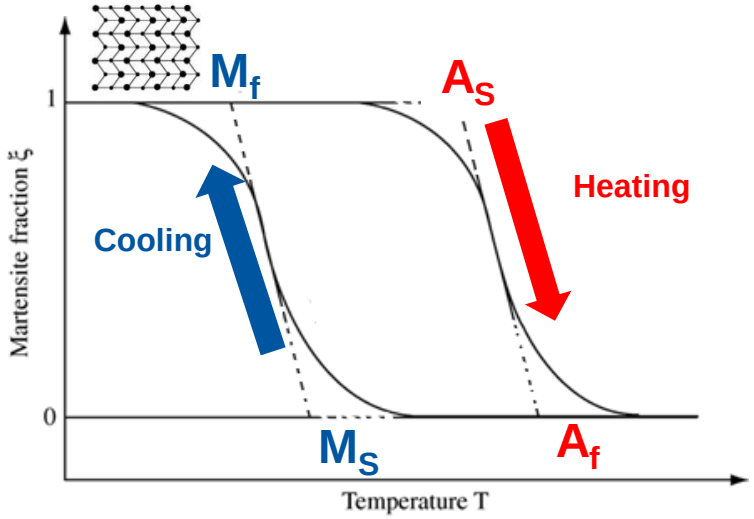
Martensite: stable at low temperature and high stress

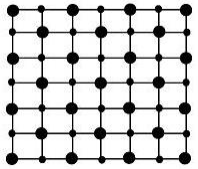


Twinned martensite (low stress)



Detwinned martensite (high stress)





Austenite: stable at high temperature and low stress

Reversible phase transformation: displacive transformation without diffusion process

- **A_s**: Austenite start temperature
- **A_f**: Austenite finish temperature
- **M_s**: Martensite start temperature
- **M_f**: Martensite finish temperature

Transformation Temperatures (TTs) depend on:

- Chemical composition
- Internal stress/strain field (dislocation arrays/precipitates)
- Thermo-mechanical cycling

Material Selection - Comparison NiTi / NiTiNb

NiTi Rings
Small Hysteresis
Ni55Ti45 (wt.%)

A_s=40°C
A_f= 50°C
M_s= -25°C
M_f= -50°C

Thermal Hysteresis: A_f – M_S = 75 °C

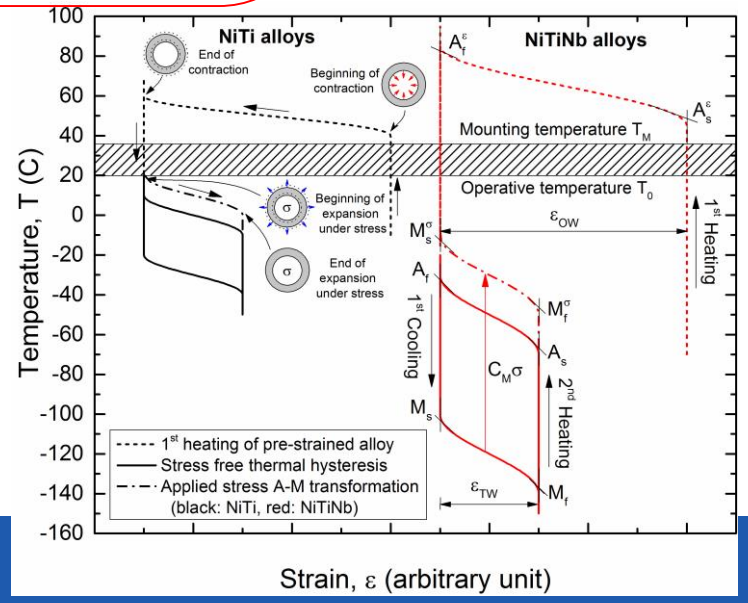
- High clamping pressure in a narrow thermal range: **from 0 to 200 °C**
- Dismounting at higher temperatures **T_{dism} ≈ -40 °C**

NiTiNb Rings
Wide Hysteresis
Ni48Ti38Nb14 (wt.%)

A_s=50°C
A_f= 60°C
M_s= -100°C
M_f= -150°C

Thermal Hysteresis: A_f – M_S = 160 °C

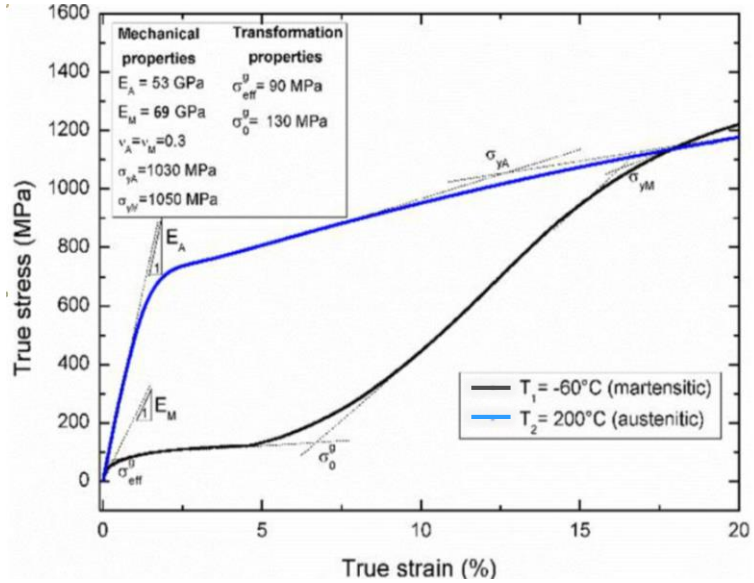
- High clamping pressure in a wide thermal range: **from -100 to 200 °C**
- Dismounting at very low temperatures **T_{dism} ≈ -150 °C**



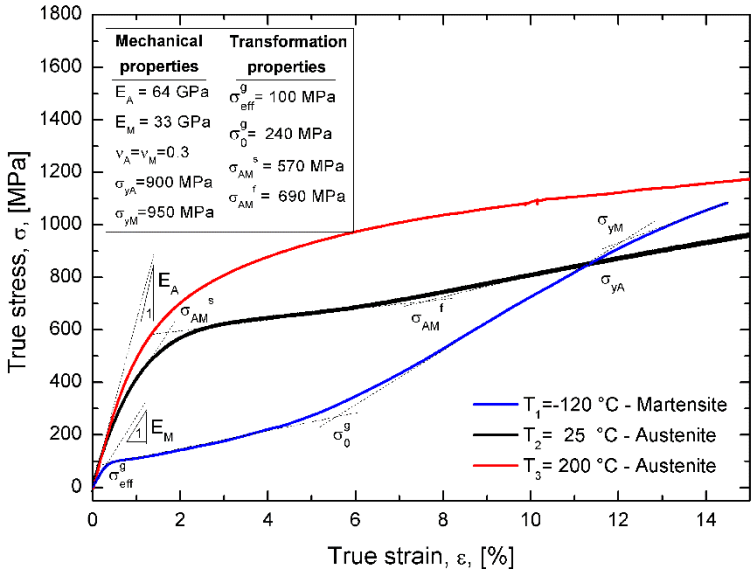
Material Selection - Properties

Material properties:

- NiTi based alloys
- Magnetic permeability < 1.002
- Thermal outgassing: < 10^{-13} mbar.l.s^{-1}.cm^{-2}
- Radiation hard



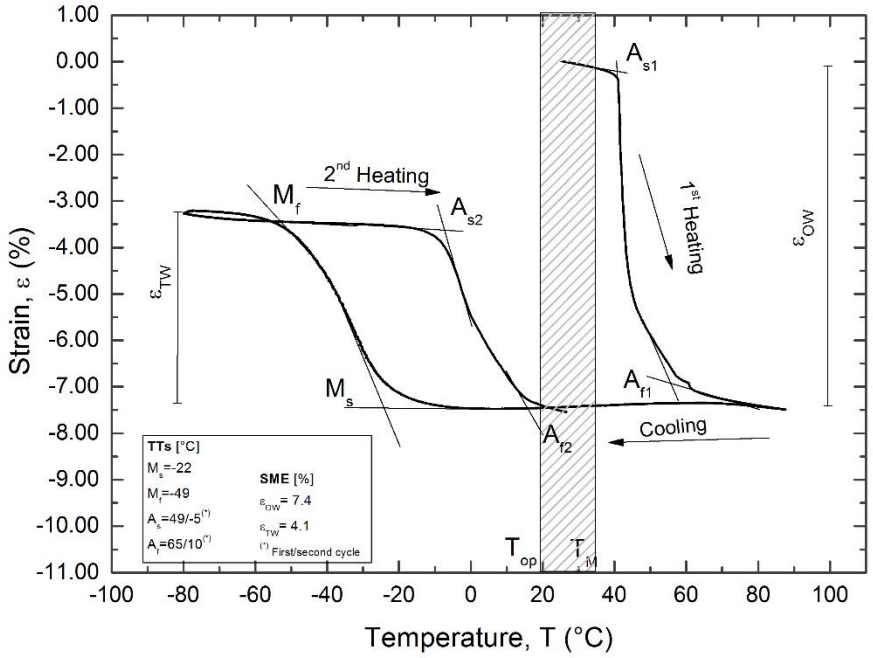
Typical tensile curves of NiTi



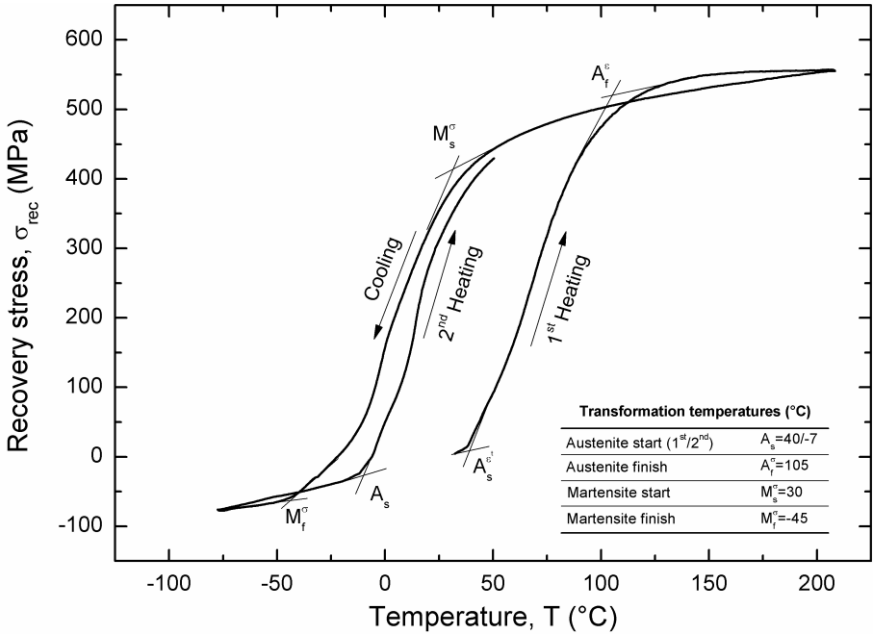
Typical tensile curves of NiTiNb

Mechanical Behaviour of Materials

Stress free and stress applied curves



ε-T curve obtained from a stress-free thermal cycle between the TTs (mechanical pre-strain (ε_{tot}) equal to 19.4%)

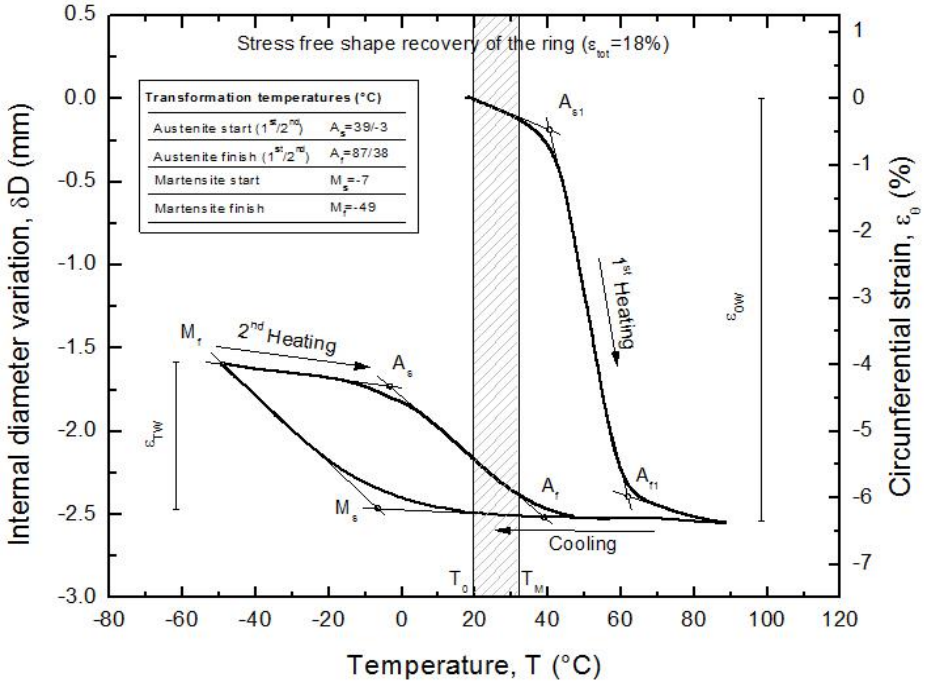


Recovery stress (σ_{rec}) under constrained ($\varepsilon=\varepsilon_{res}$) thermal cycles (mechanical pre-strain (ε_{tot}) equal to 19.4%)

Mechanical Behaviour of Rings

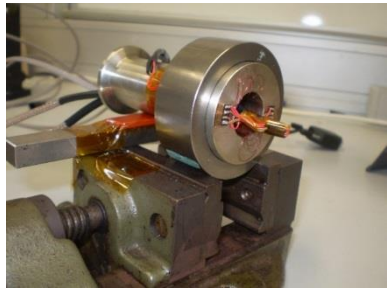
Stress free behaviour is measured with an extensometer.

Extensometer

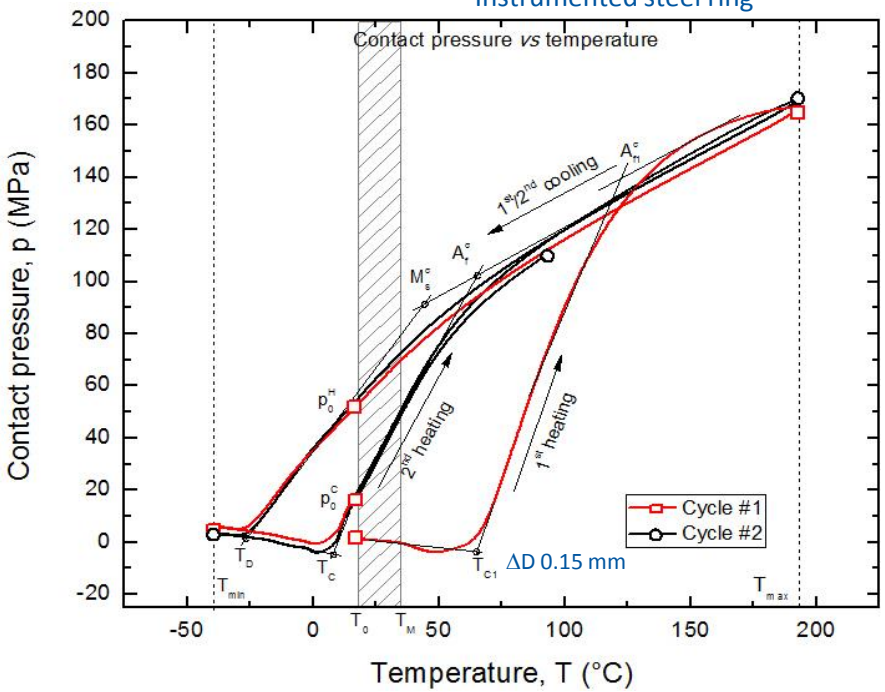


Clamping pressure is assessed with instrumented ring under external pressure.

$$P = -\frac{E}{2(1+\nu)}\frac{De_{steel}^2 - Di_{steel}^2}{De_{steel}^2}(\varepsilon_\theta - \varepsilon_z)$$



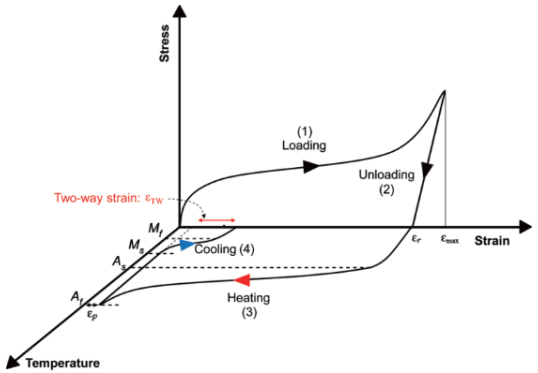
Instrumented steel ring



Materials and Ring Training

By mechanical deformation (and giving preferred orientation to the martensite variants), the training aims at:

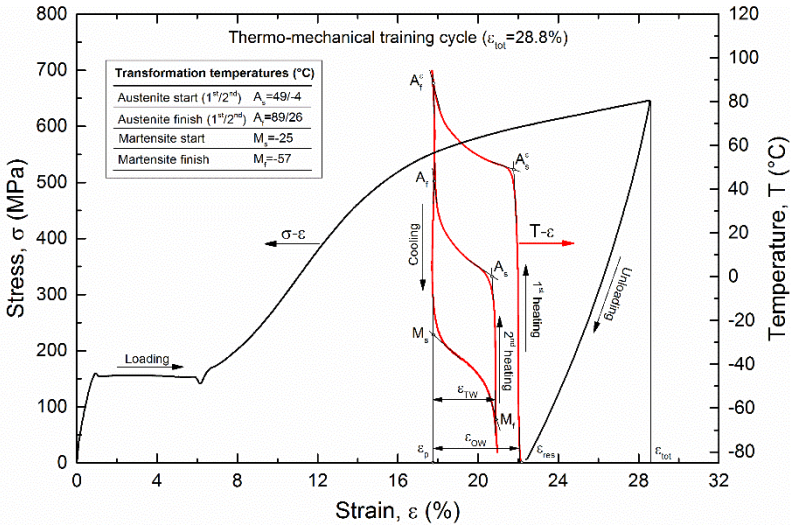
- Increasing the As
- Inducing the OW and TW effects



A_s^0= -3°C
A_f^0= 12°C
M_s^0= -22°C
M_f^0= -33°C

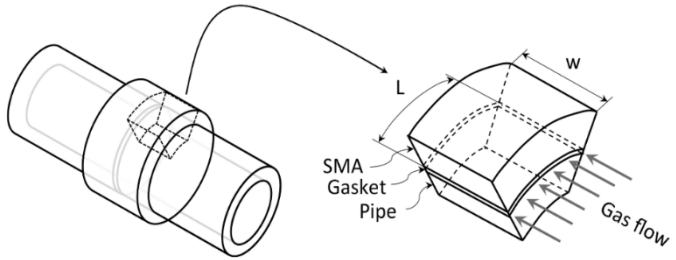
Training

A_s^t= 49°C
A_f^t= 89°C
M_s^t= -25°C
M_f^t= -57°C



Leak Tightness of Rings

The conductance C (free molecular flow) of a gas throughout a sealing surface can be calculated as follows [Roth, 1972]:



Effective length

Contact pressure

$$C = K \frac{L_e}{w_e} \exp(-3P/R)$$

K=Cst(T,M,…)

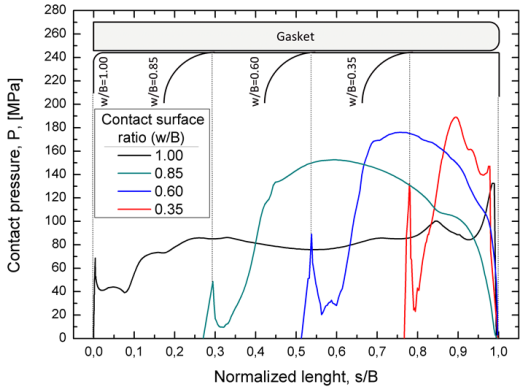
Effective width

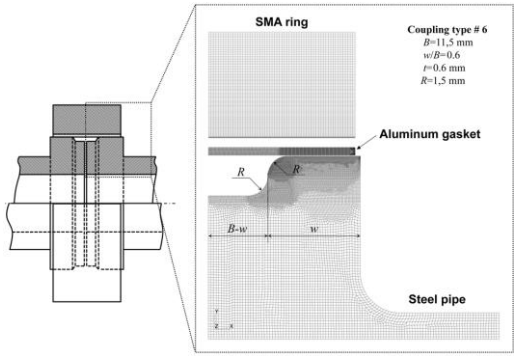
Sealing ability of the material

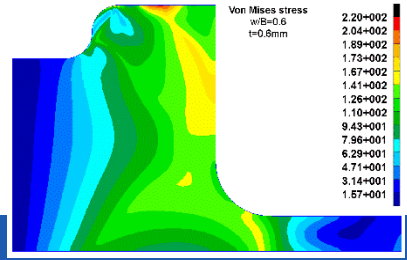
A sealing performance parameter is defined:

$$S = \left(\frac{C}{K}\right)^{-1} = \frac{w_e}{L_e} \exp(3P/R)$$

By FE simulations, the contact pressure is determined along the gasket /pipe contact.



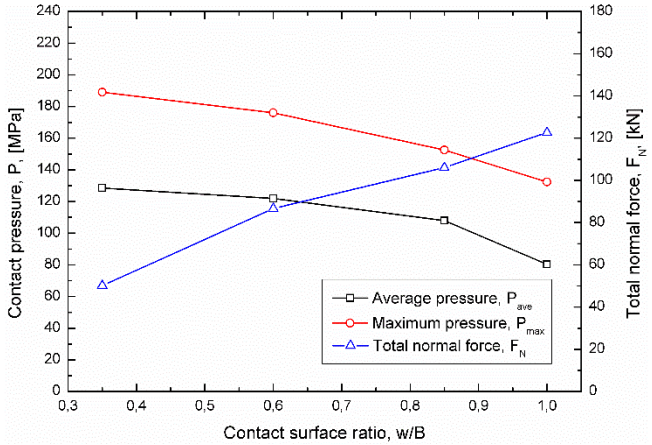


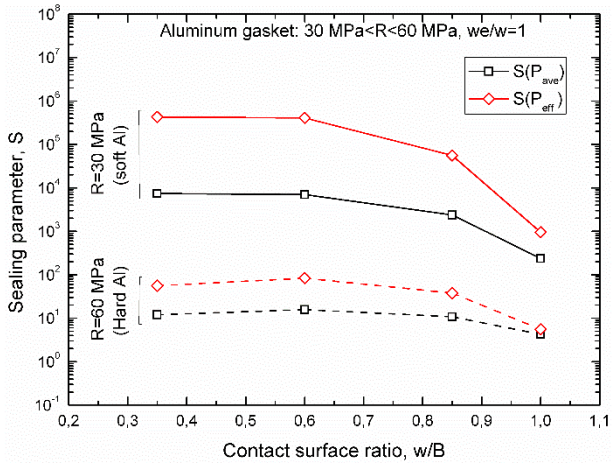


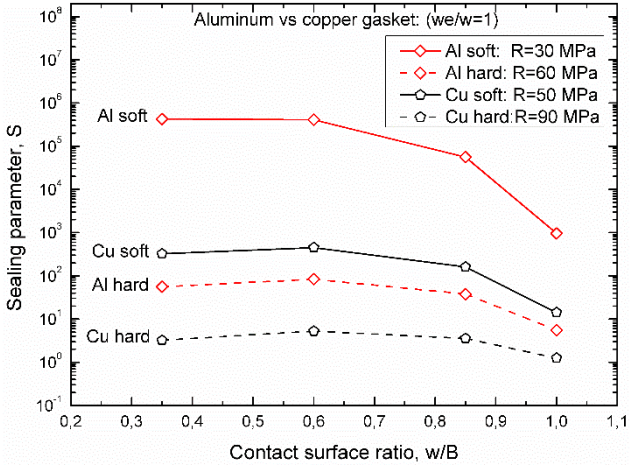
By integration along the gasket /pipe contact, assuming conductance in series, the sealing performance parameter reads:

$$S = (1/\pi d_e) \int_0^w exp(3\,P/R) ds$$

Leak Tightness of Rings



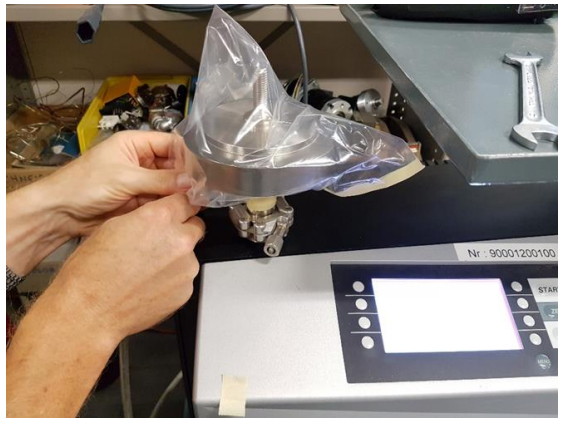




Pressure, sealing parameter as a function of the contact surface ratio

→ The optimum contact surface ratio is around 0.6.

Assembly for leak detection



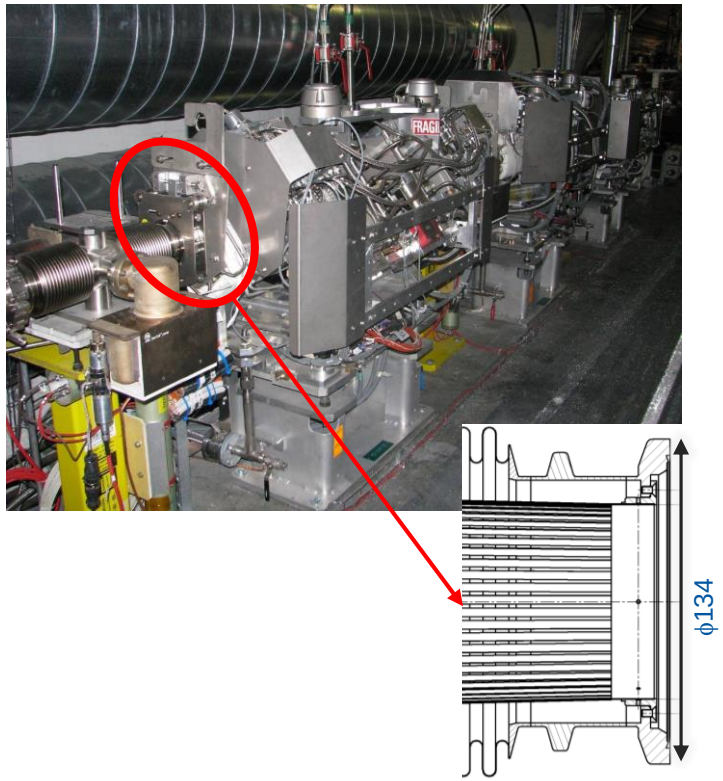
Leak detection

All assemblies (about 20 assemblies tested in total) are leak tight ($<10^{-10}$ mbar·l·s^{-1}), even after 1-year aging and complete thermal cycles.

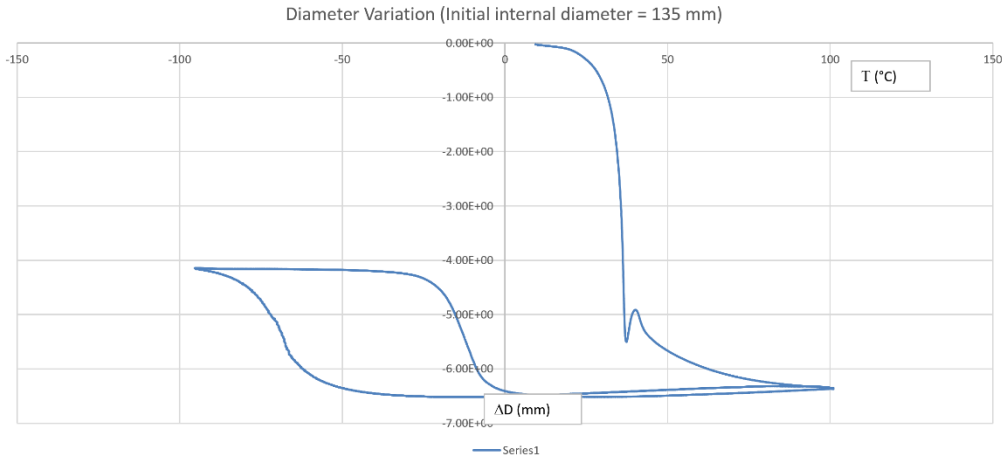
Large Rings

Most of the tests have been done with rings of ID ~ 45 mm.

Rings with ID, after training, of around 135 mm have been produced and are compatible with LHC collimator flanges.



Large rings before and after training



Stress free curve of large rings, ~ 10 mm thick

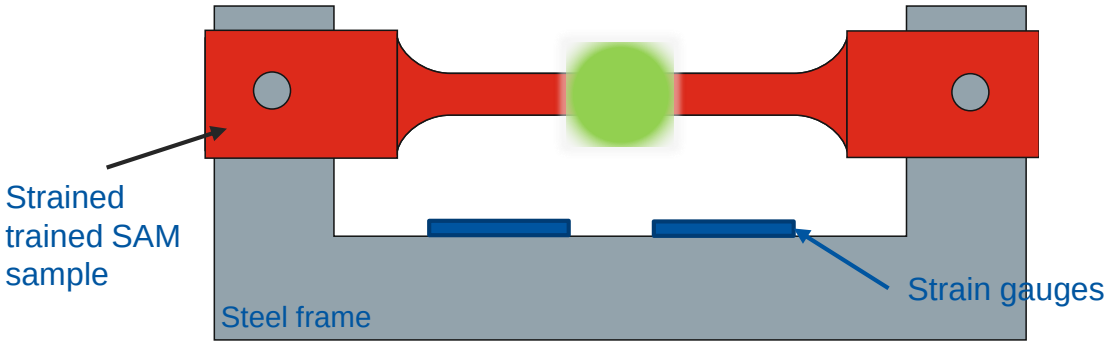
Training has been successfully done (ongoing optimization). Leak tests on SMA-based assemblies are foreseen in the next weeks.

Irradiation Test #1

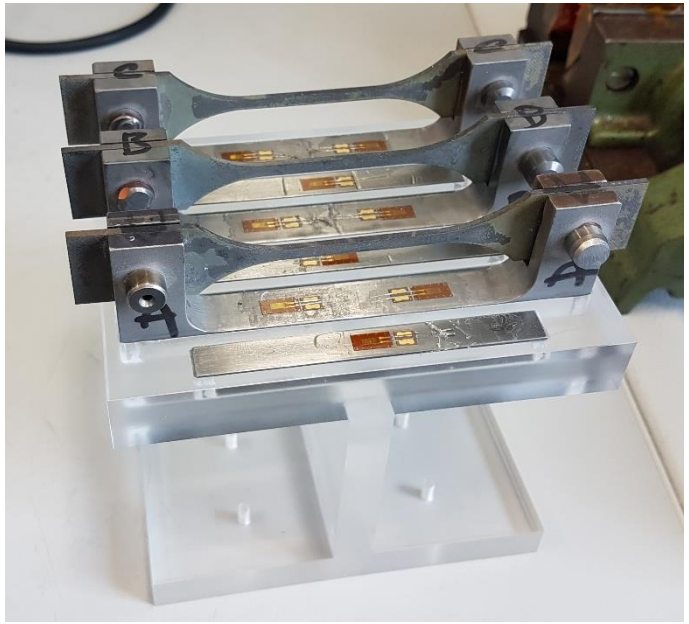
Influence of proton radiation on material response: Phase transformation? Creep like behaviour?

The IRRAD proton facility uses primary proton beams with a momentum of 24GeV/c, extracted from the PS ring:

- Small irradiated zone (~12*12mm2).
- 3.10^{10} p+/cm^2/s.



Test set-up used in IRRAD



Continuous monitoring of strain/stress.

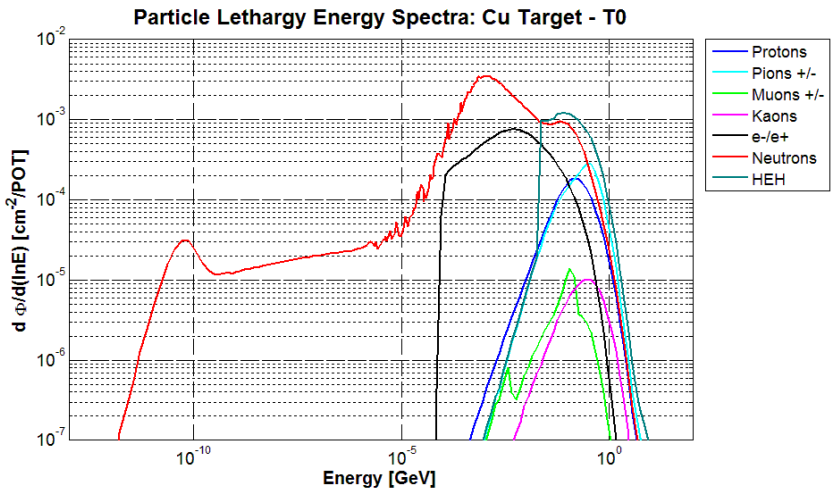
Expected dose1 MGy (2 weeks).

Irradiation Test #2

Influence of mixed field on ring response?

Tests are be done at CHARM (Cern High energy AcceleRator Mixed field/facility).
The radiation field is generated through the interaction of a 24 GeV/c proton beam extracted from the PS with a metallic target.

Test set-up used in CHARM



Particles Lethargy Energy with Cu target in correspondence of the SMA position.

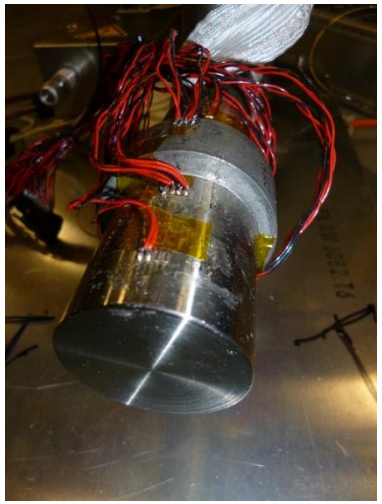
Online monitoring of strain/stress.

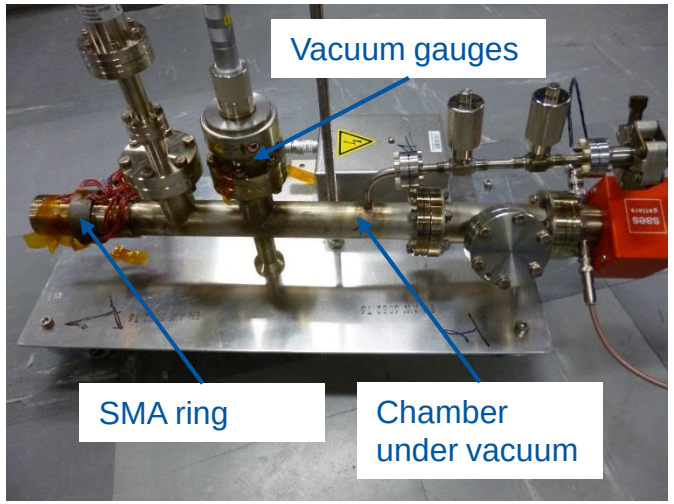
Expected dose 200-250 kGy (up to Dec 2018).

Irradiation Test #3

Influence of mixed field on ring response?

Tests are done in high irradiation areas, namely in SPS north area. SMA clamped rings are placed in the vicinity of a collimator.





Test set-up used in SPS

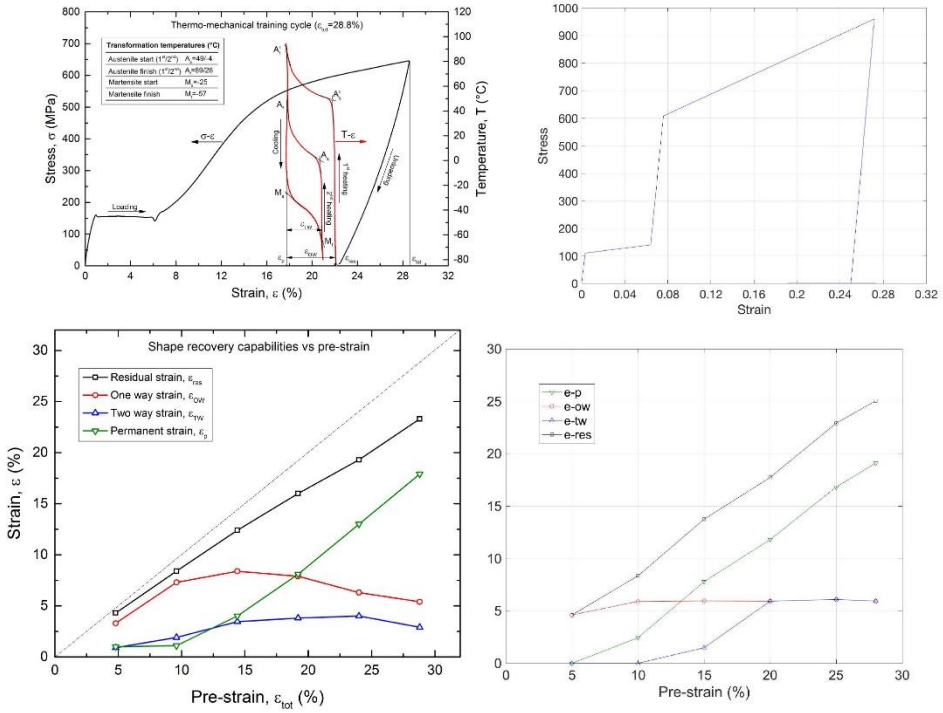
Off-line measurement of strain/clamping pressure and leak rate.
Online monitoring of pressure.

Expected dose 200-250 kGy (up to Dec 2018).

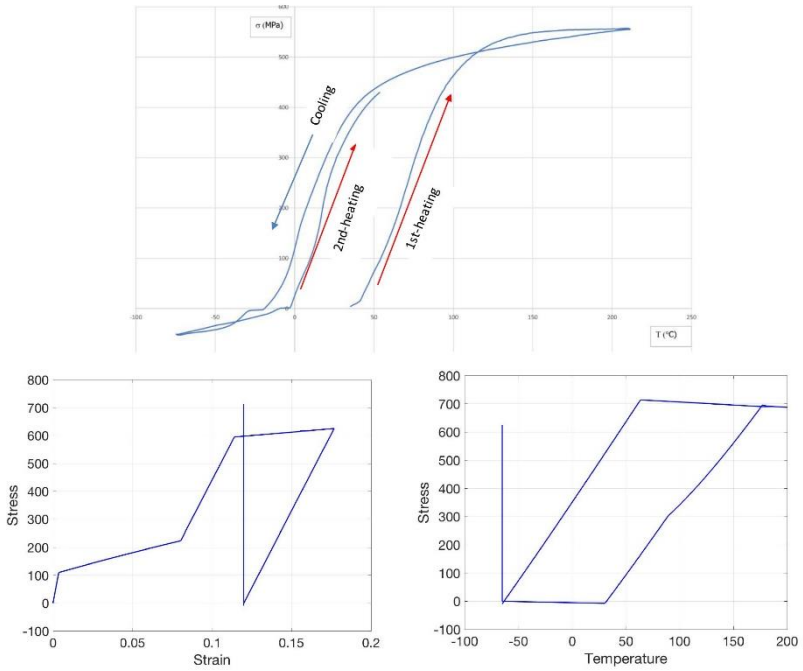
Simulations

Development of a constitutive model suitable for training, OWE and TWE*:

- Kinematic: $\varepsilon = \varepsilon^e + \varepsilon^{th} + \varepsilon^p + \varepsilon^{tr}$ (decomposition of the strain).
- Constitutive equation: $\sigma = E \cdot \varepsilon^e$ (Hooke's law).
- Yield surface (plasticity based on Von Mises criterion).
- Memory surface in the strain space.
- Evolution laws for plasticity and phase transformation.
- Consistency equations.



Training simulations compared to measurements



Stress applied and stress free behaviour

*: In collaboration with University of Calabria and University of Pavia

Conclusions

A new UHV connector has been proposed at CERN and is presently studied.

Based on SMA, it is a compact, easily mountable and temperature-controlled solution.

Mechanical tests have been carried out on materials and SMA rings.

Leak tightness tests have been successfully done.

A new campaign to characterize the materials and the connectors under irradiation are ongoing.

Work is ongoing to propose a constitutive model suitable for the training, OW and TW effects.

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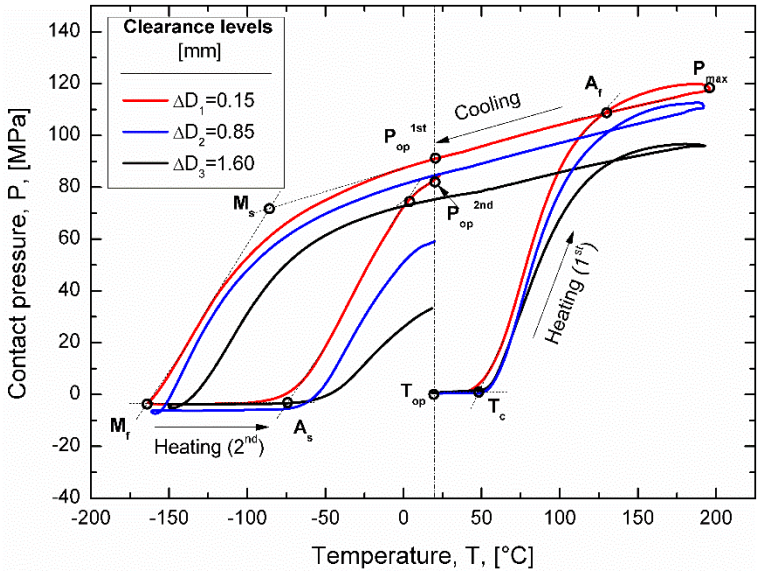
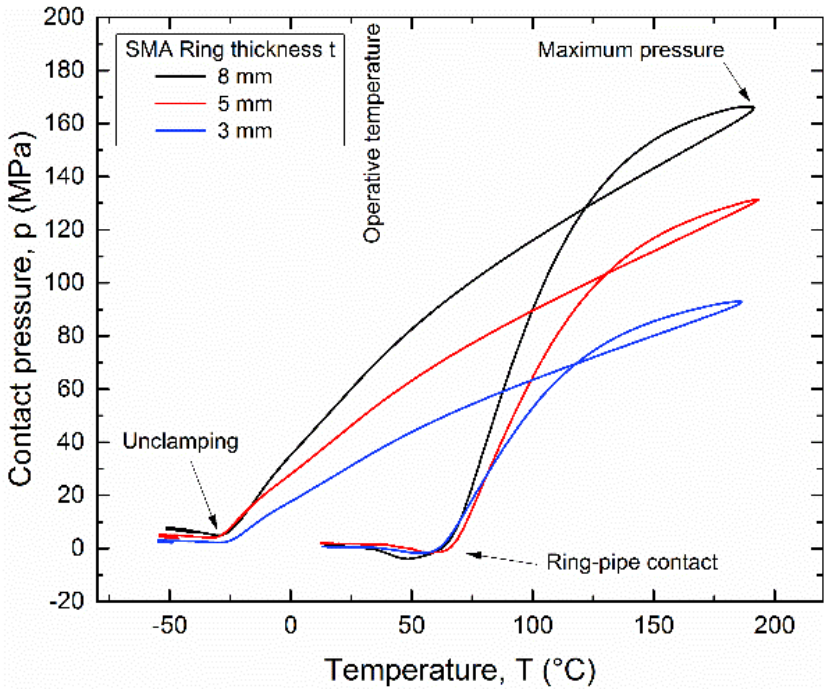
Influence of initial gap and ring thickness



NiTiNb



NiTi