Valve packing optimization through use of dedicated characterization test procedures and calculation rules

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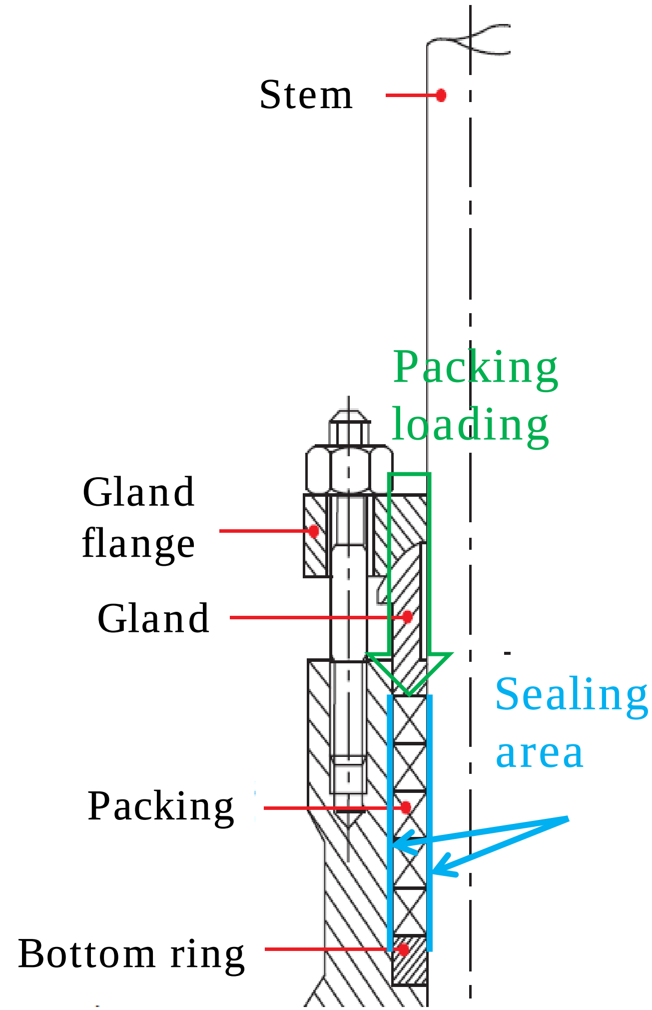
Context

- Environmental requirements for:
  - Emissions reduction

    ➔ *For industrial valves: ISO15848 classification*
  - Energy consumption reduction

    ➔ *For industrial valves: reduction of the force required to move the stem for opening/closing*
- The stem packing tightening level has a contrary effect on these two requirements

➔ *Need for a tool defining optimal packing tightening involving the best compromise*



Source: « Guide de la ROBINETTERIE INDUSTRIELLE» (PROFLUID)

Context

- Development of a tool package for the design and optimization of valve packing:
  - Initiated by the Fluid Equipment Committee of CETIM (composed of French valve and sealing product manufacturers)
  - In collaboration with ESA (European Sealing Association) and FSA (Fluid Sealing Association)

- The tool package aims at :
  - Ensuring a tightness class in operation
  - Limiting the friction during stem movements
  - Insure the system mechanical integrity

Presentation overview

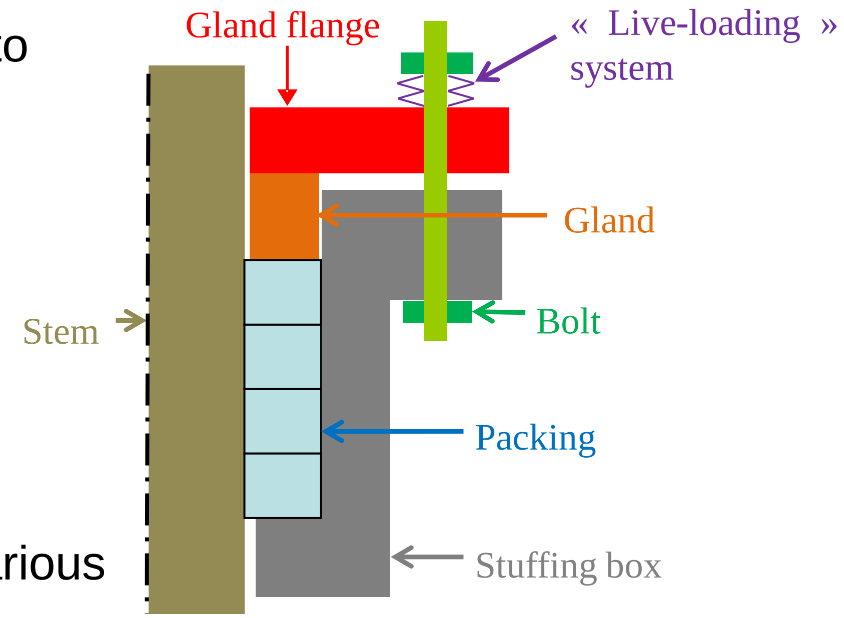
- Short description of the proposed calculation model

  For more details, see previous IVS2015 presentation , “Tool development for design and optimization of valve packings.” Industrial Valve Summit, 28/05-2015”

- Description of the packing parameters generation required for the calculation model:
  - Characterization test procedures
  - Test rigs
  - Results obtained on a first test campaign on:
    - braided PTFE
    - die formed graphite rings

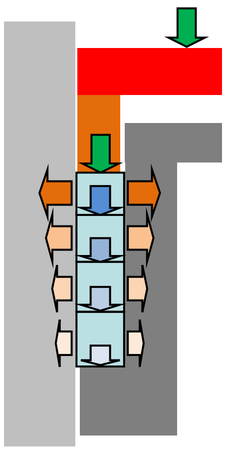
Short description of the proposed calculation model

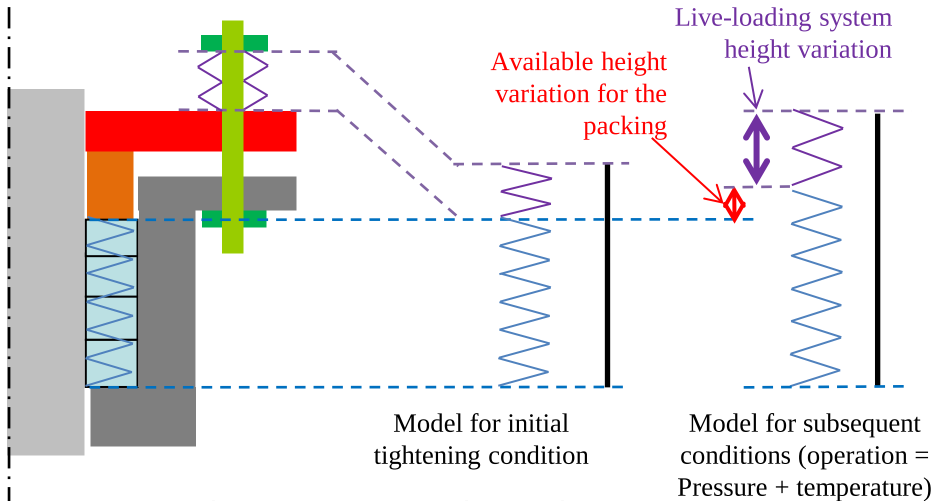
- 2 main steps:
  - Initial required bolt tightening force to meet the tightness criteria (for the various considered valve operating conditions)
  - Check of mechanical integrity and friction level acceptability (for the various considered valve operating conditions)



Short description of the proposed calculation model

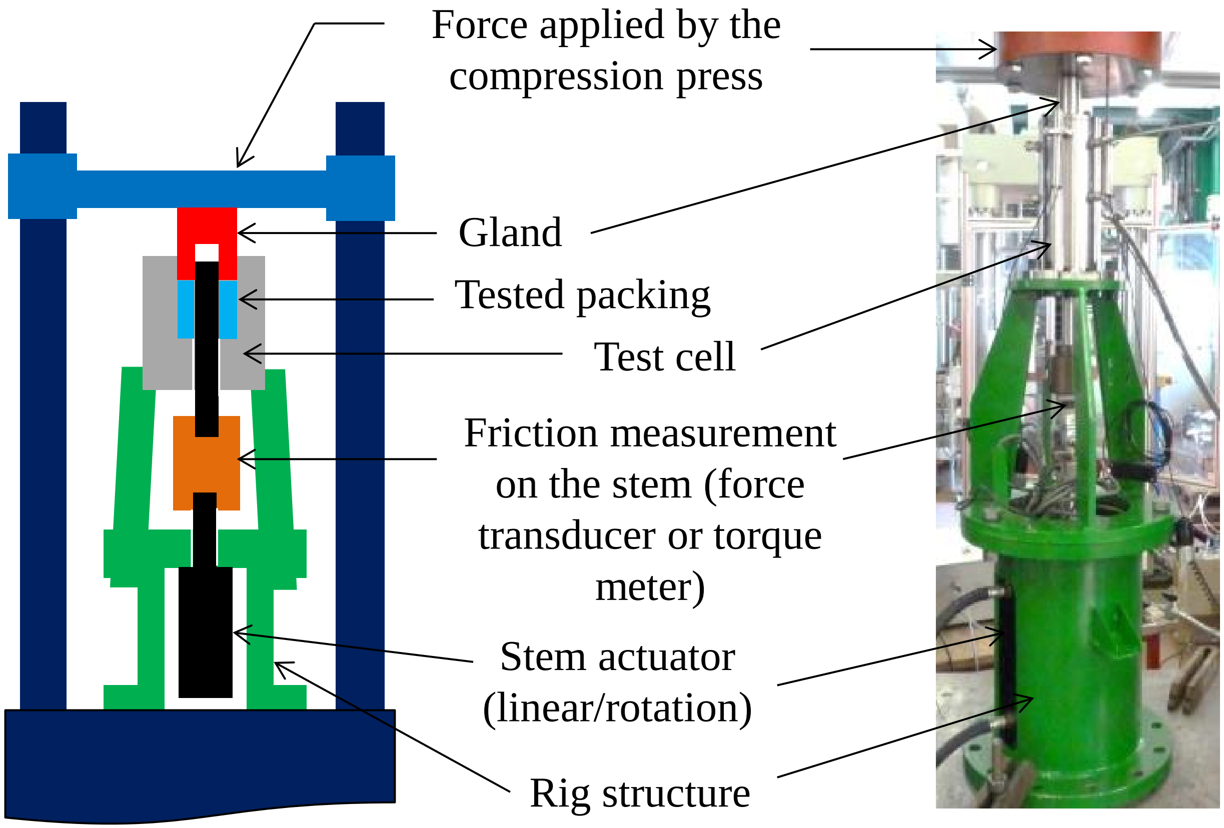
- Covered aspects
  - Transmission of loading force through the packing stack
  - Variation of available height for the packing between tightening phase and operation due to:
    - Differential thermal expansion
    - Packing creep/relaxation





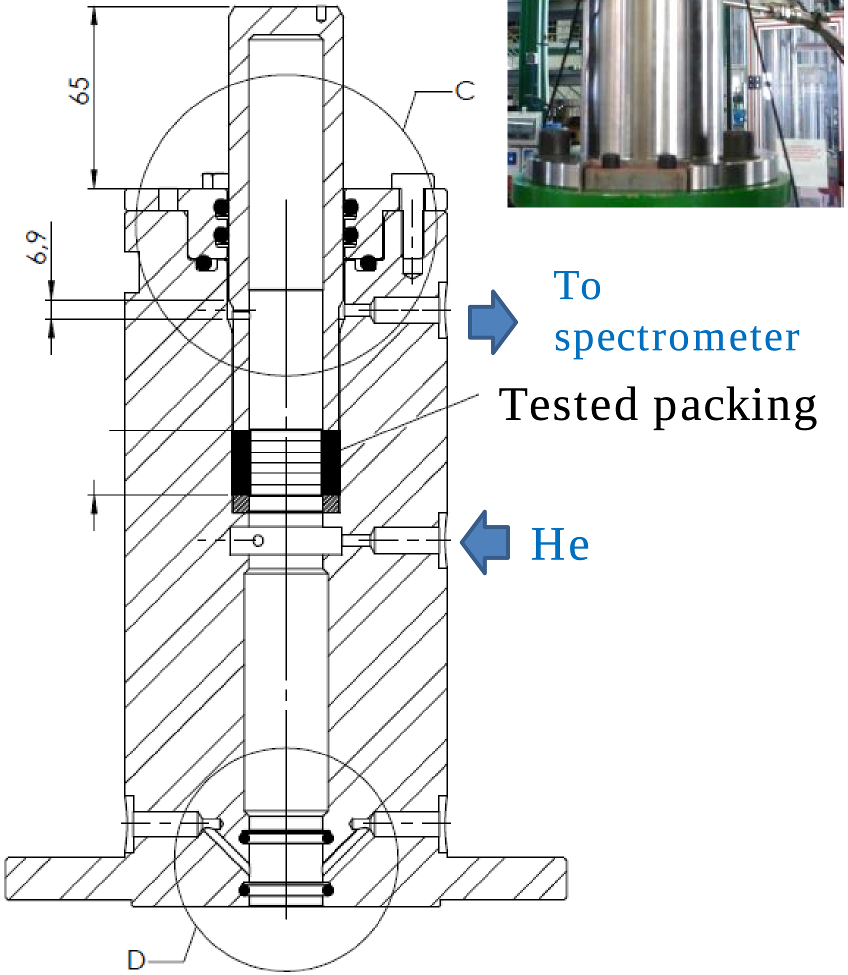
Test rig

- Test rig structure



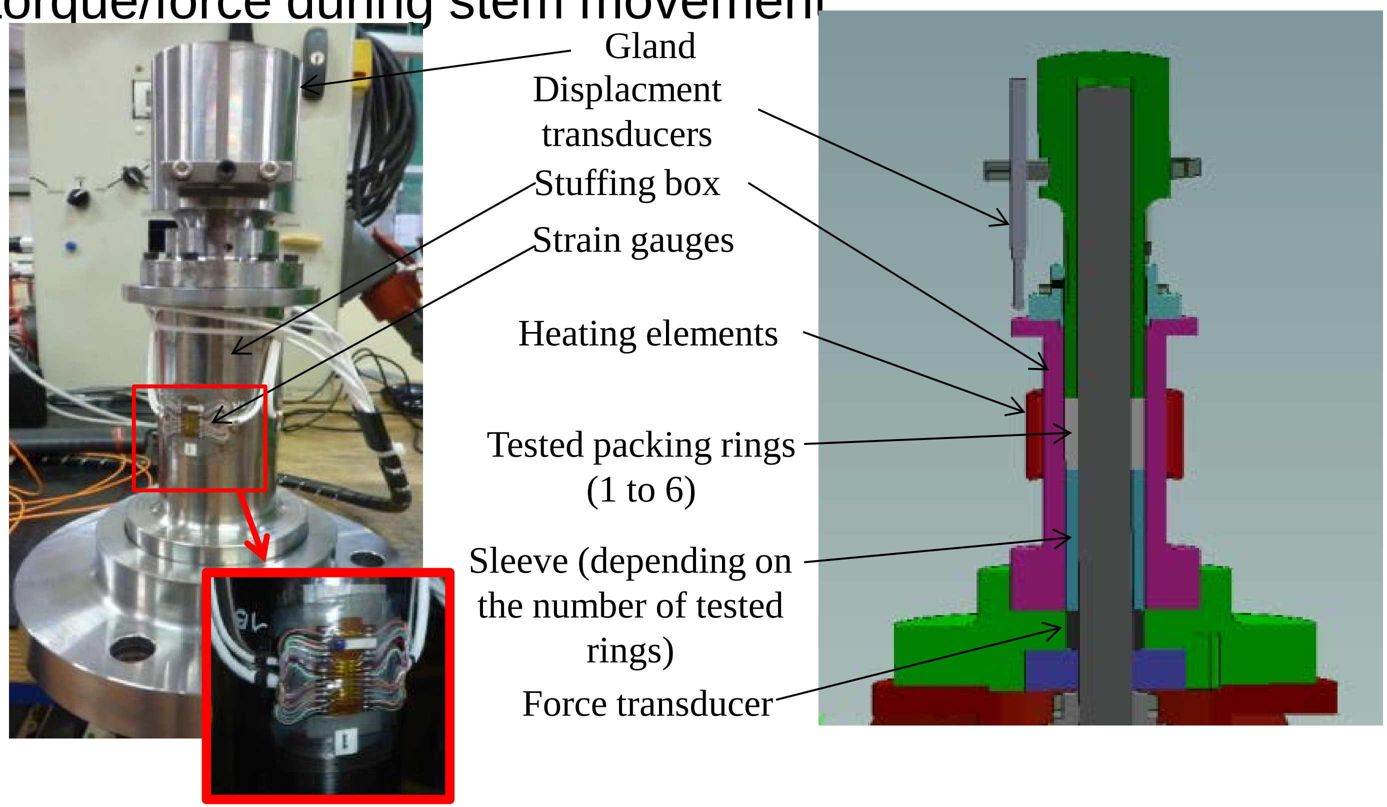
Test rig: Sealing test cell

- Based on API622 (4'' valve based design) for dimensions, tolerances and surface finish
- From 1 to 6 rings stack
- Helium pressure up to 80bar
- Leak measurement through Helium spectrometry (global vacuum)



Test rig : Mechanical Test Cell

- Packing deflection
- Stuffing box external diameter deformation due to packing loading
- Axial load transmitted to packing bottom face
- Friction torque/force during stem movement



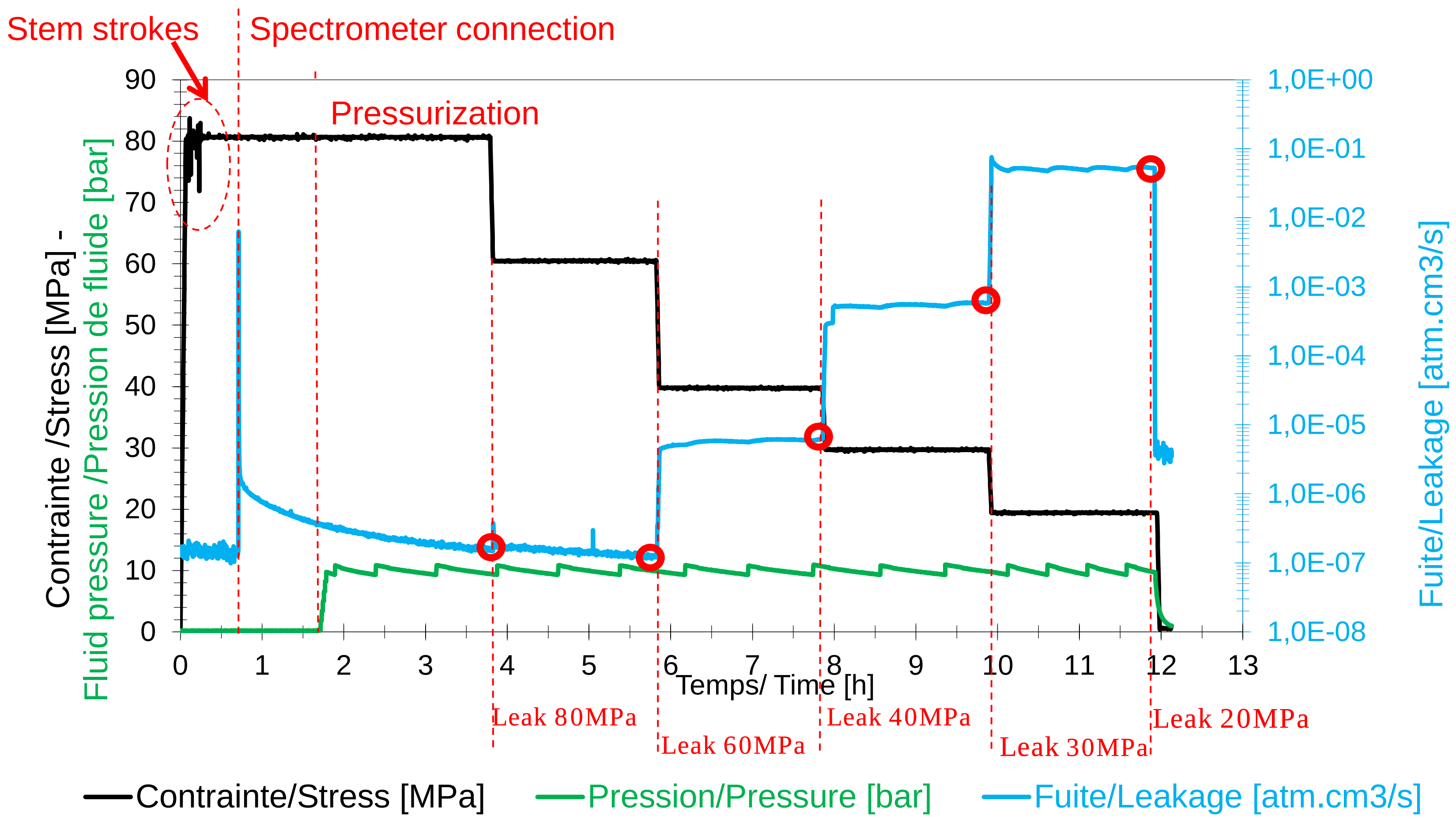
Sealing test results

14 tests performed on 4 rings packing stacks with following parameters variation:

- Packing type : die formed graphite / braided PTFE rings
- Stem movement: linear or rotation
- Packing initial loading
- Helium pressure

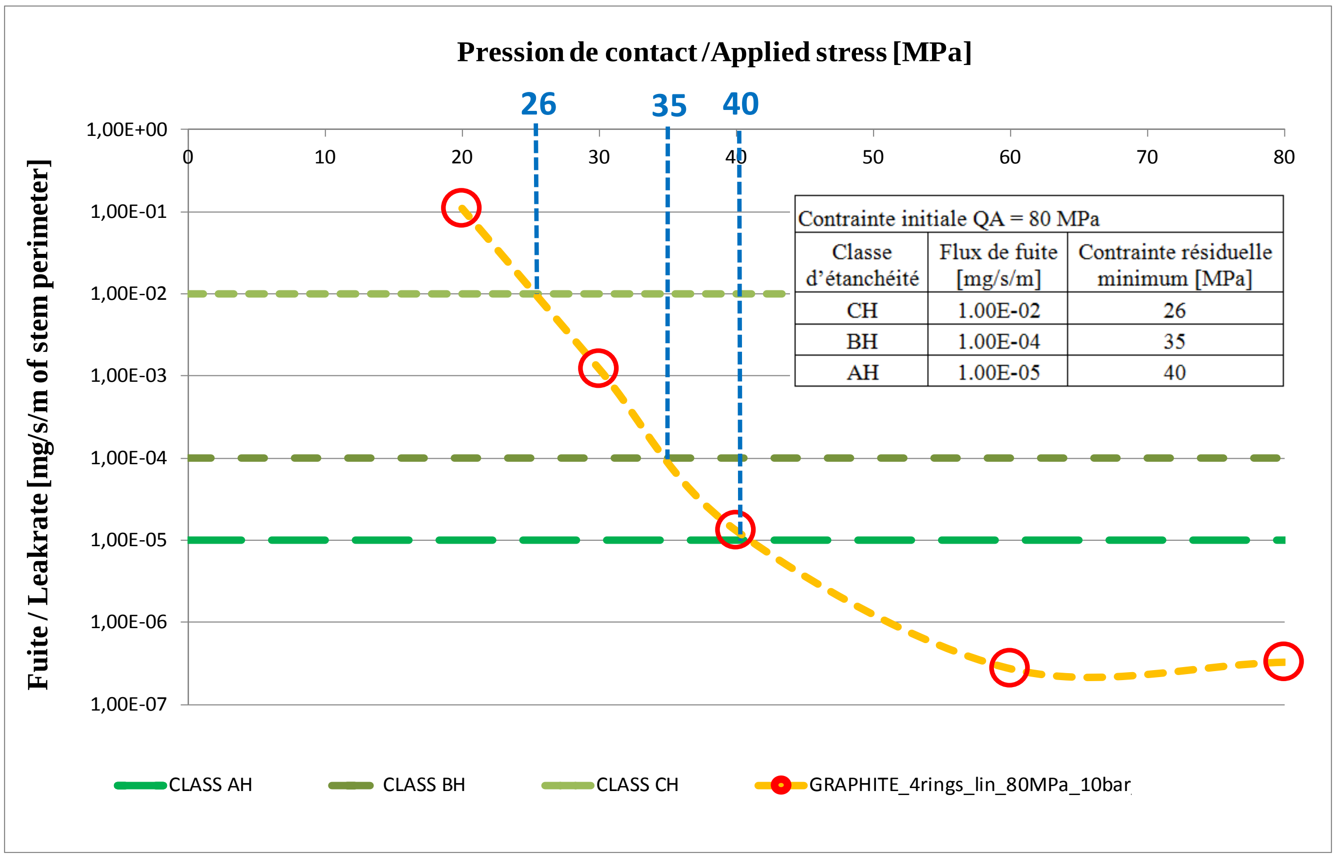
Sealing test results

- Sealing test result example (graphite packing)



Sealing test results

- Sealing test result example (graphite packing)

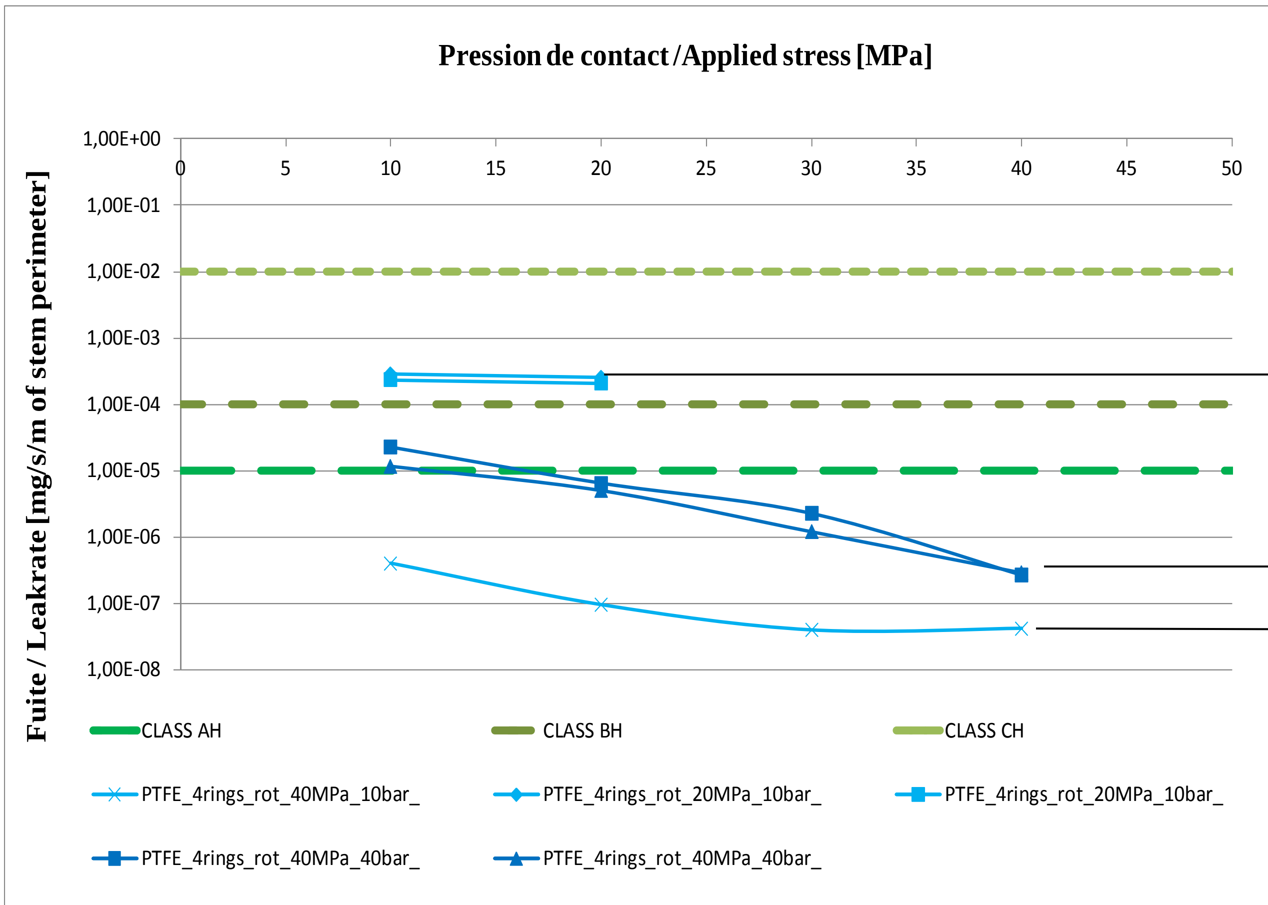


Contrainte initiale QA = 80 MPa		
Classe d'étanchéité	Flux de fuite [mg/s/m]	Contrainte résiduelle minimum [MPa]
CH	1.00E-02	26
BH	1.00E-04	35
AH	1.00E-05	40

Sealing test results

- Sealing test result example (braided PTFE)

He Pressure [bar]		10	10	40
Initial stress Q_{A1} [MPa]		20	40	40
Tightness class	Leak rate [mg/s/m]	Minimal required stress [MPa]		
CH	1.00E-02	<10	<10	<10
BH	1.00E-04		<10	<10
AH	1.00E-05		<10	17



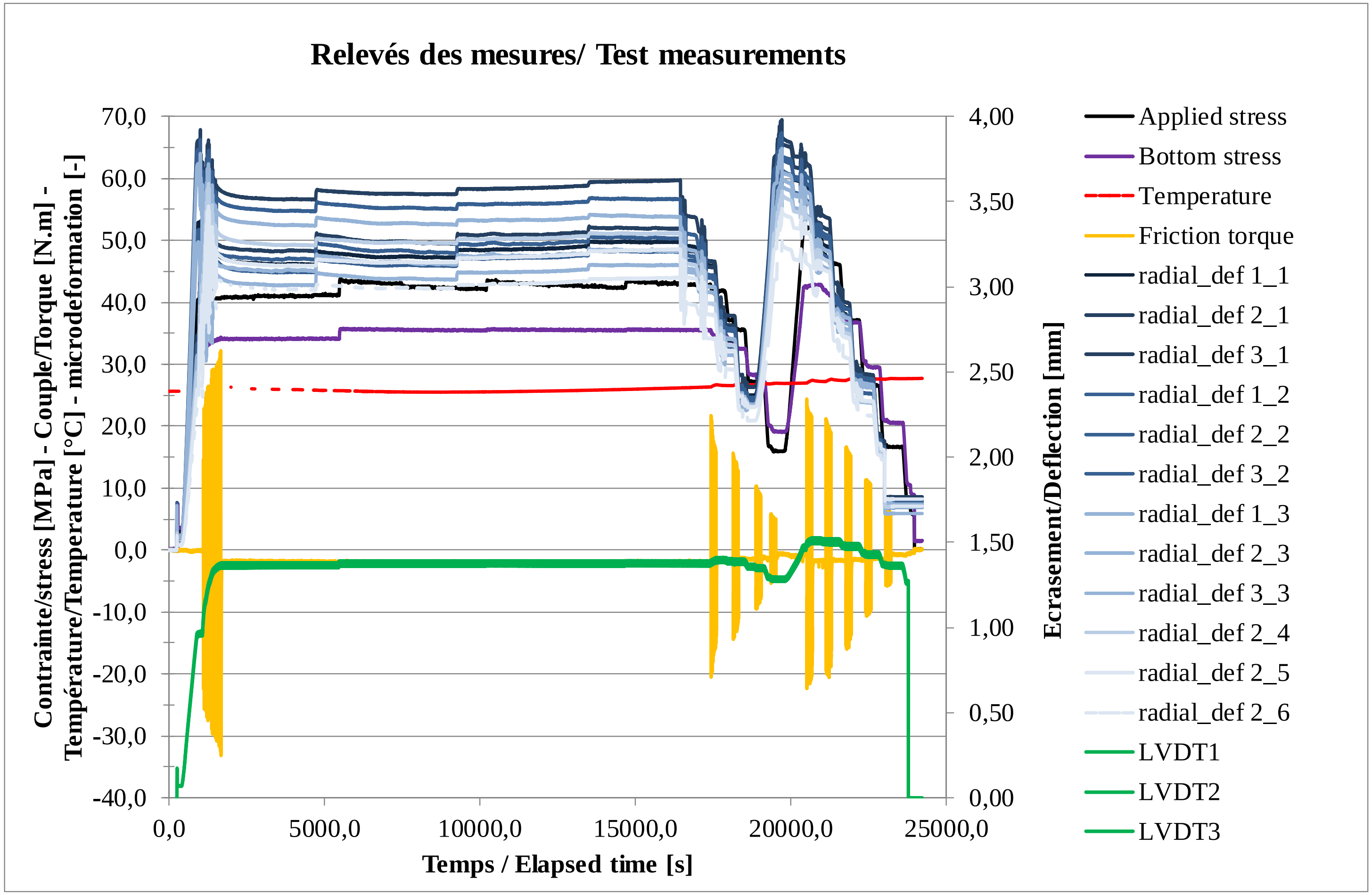
Mechanical test results

- Configurations testées

  12 tests performed with rotation stem movements with following parameters variation:

  - Packing type : graphite ring / braided PTFE
  - Packing initial loading
  - Number of packing rings: 1 to 3

Mechanical test results



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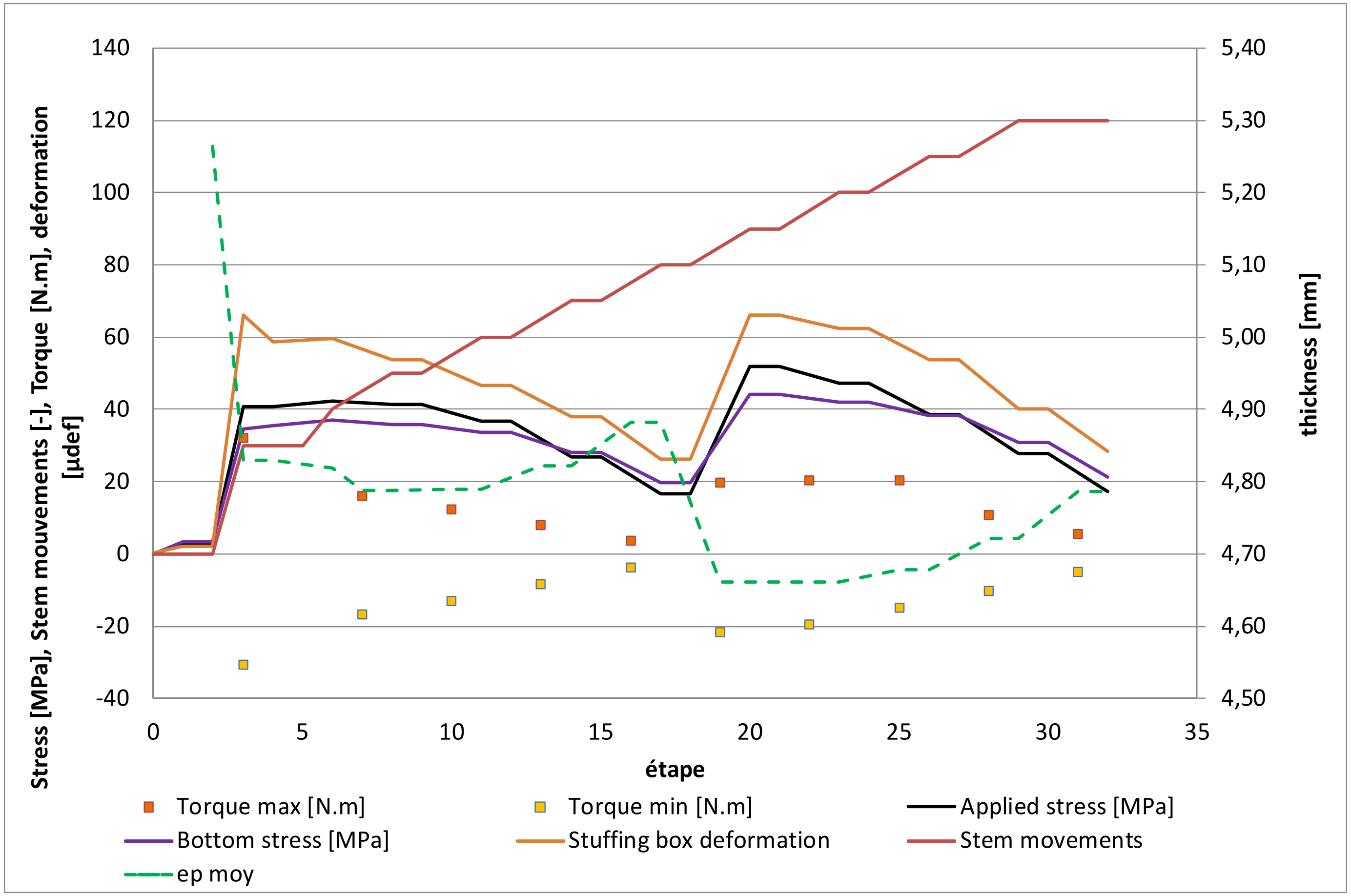
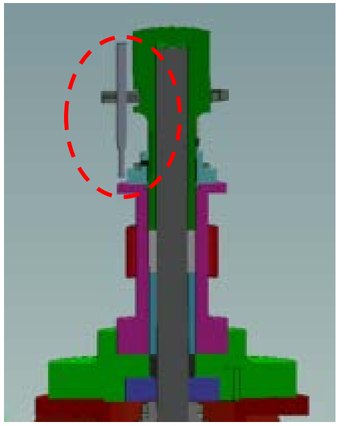
Mechanical test results

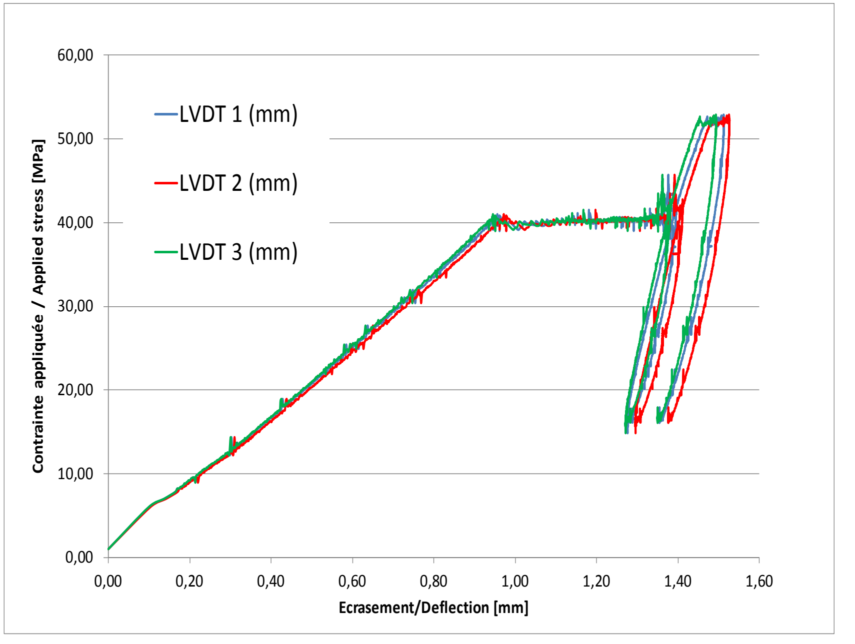
- Treated data example following test procedure1



Mechanical test results

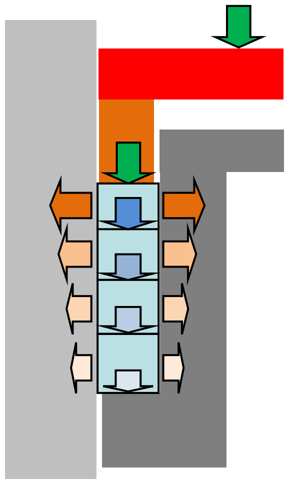


- Packing deflection measurement analysis
  - Good agreement between 3 sensors located at 120° (axisymmetric)
  - 1 graphite ring 6,35mm height: 1mm deflection (~16% strain) under 40 MPa (accordance with literature)
  - 3 rings 6,35mm height each: ~11% global strain under 40 MPa – interaction between rings involve slightly lower deflection (accordance with literature)
  - Braided PTFE: test on 1, 2 and 3 rings stacks – same trends as for the graphite rings

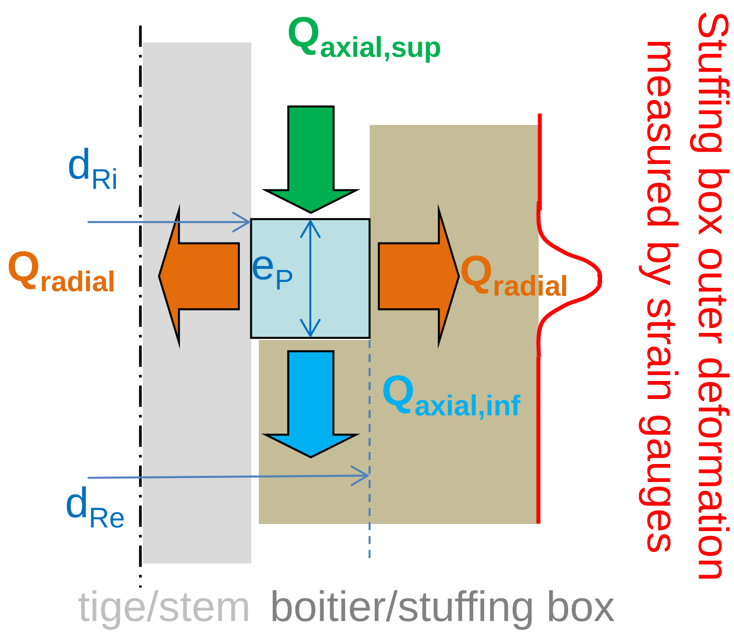


Deflection measurement example (1 graphite ring)

Mechanical test results



- Axial -> radial forces transmission (K)
  - Calculated from stuffing box outer diameter deformation measurement enabling to calculate the radial stress applied by the packing on the stuffing box inner diameter inner diameter = Q_{radial}



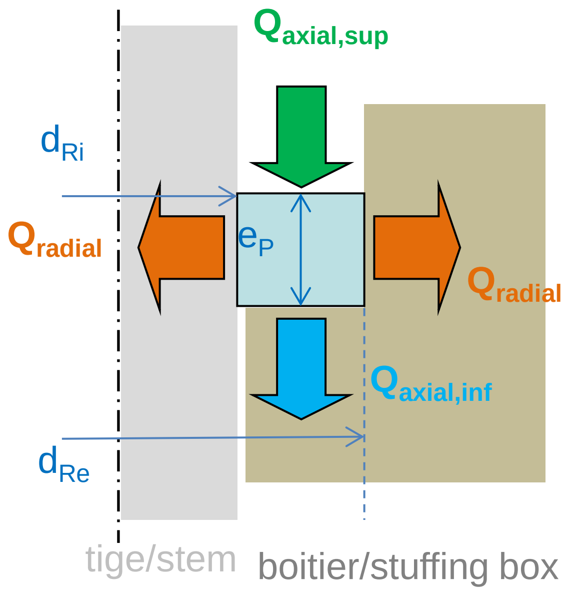
$$K = \frac{Q_{radial}}{Q_{axial,sup}}$$

Mechanical test results

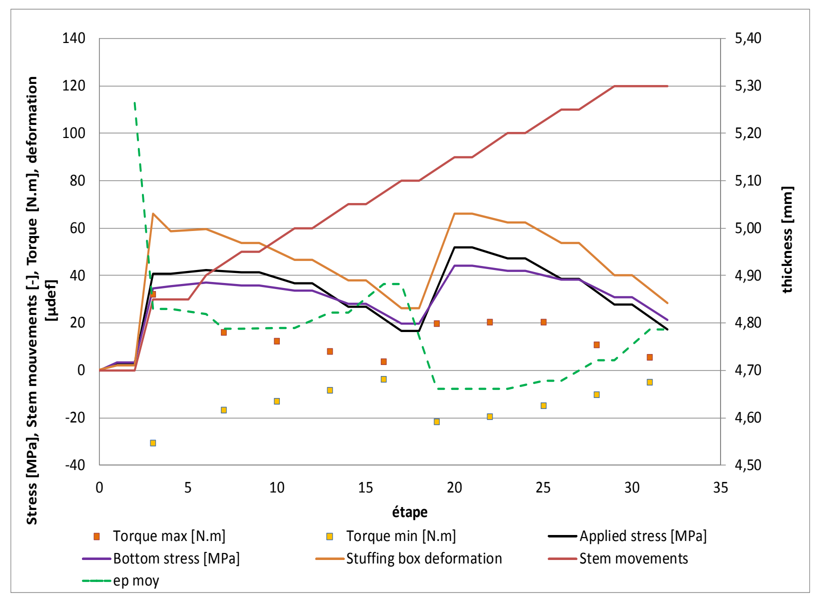
- Axial -> radial forces transmission (K)
  - Loading phase: Increase of K (graphite densification)
  - Unloading phase: increase of K with values >1 due to : $Q_{axial,sup} < Q_{axial,inf}$

		$K = Q_{rad}/Q_{axial,sup}$	
	Q_{A1} [MPa]	40	50
Q [MPa]	50		0,84
	40	0,80	0,88
	30	0,86	0,93
	20	0,95	1,01

Graphite ring example



$$K = \frac{Q_{radial}}{Q_{axial,sup}}$$

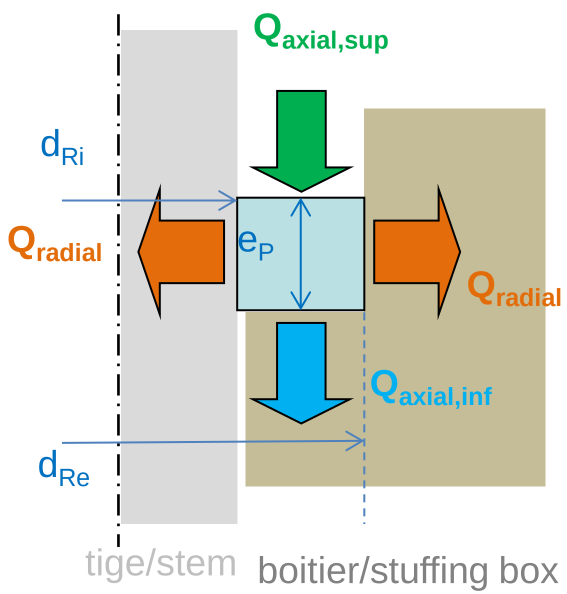


Mechanical test results

- Axial -> radial forces transmission (K)
  - Introduction of K' :

$$K' = \frac{Q_{radial}}{Q_{axial,sup} + Q_{axial,inf}}$$

=> K' leads to stables values at unloading: more suitable for modelling



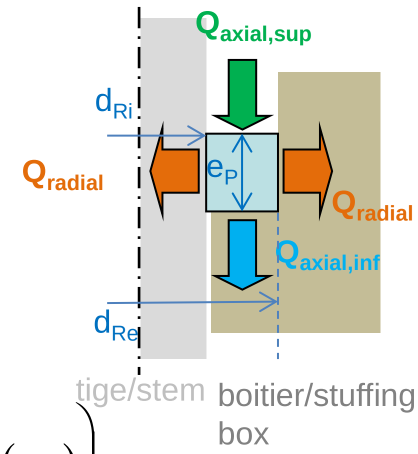
		K'= 2*Q_{rad}/($Q_{axial,sup}$+$Q_{axial,inf}$)	
	Q_{A1} [MPa]	40	50
Q [MPa]	50		0,90
	40	0,86	0,91
	30	0,86	0,90
	20	0,85	0,92

Graphite ring example

Mechanical test results

- <u>Static friction packing/stuffing box (μ_S and μ_{SB})</u>
  - Obtained through $Q_{axial,inf}$ et $Q_{axial,sup}$ measurements

$$Q_{\text{axial, inf}} = Q_{\text{axial, sup}} \times \exp\left(\left[-4 \times K \times \frac{\mu_S \times d_{Ri} + \mu_{SB} \times d_{Re}}{d_{Re}^2 - d_{Ri}^2}\right] \times (e_P)\right)$$



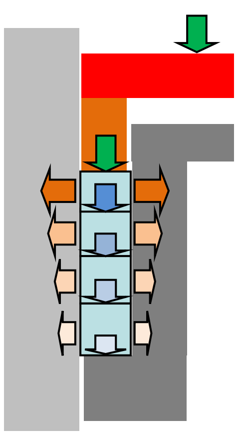
  - $\mu_S = \mu_{SB}$ as first approximation

Graphite ring

		μ_{SB} [-]	
	Q_{A1} [MPa]	40	50
Q [MPa]	50		0,13
	40	0,12	-0,02
	30	0,01	-0,06
	20	-0,09	-0,12

Braided PTFE

		μ_{SB} [-]	
	Q_{A1} [MPa]	20	30
Q [MPa]	30		0,09
	20	0,07	-0,06
	10	-0,11	-0,15



  - Loading phase: Increase ok μ_{SB} (graphite densification)
  - Unloading phase: decrease of μ_{SB} with negative values ($Q_{axial,inf} > Q_{axial,sup}$): *not representative of real friction but can be used in the calculation to determine axial load transmission through the packing → interest to define μ'_{SB} ?*

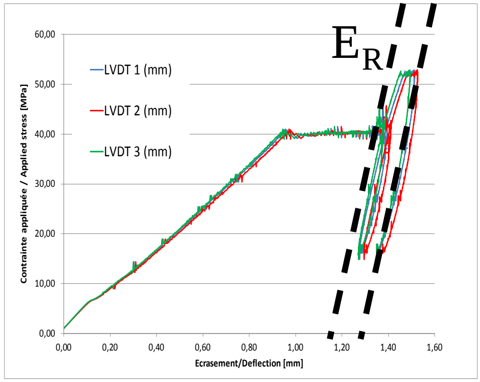
Mechanical test results

- Dynamic friction coefficient at stem/packing interface (μf_rot or μf_lin)
  - Obtained through measurement of friction torque (or force) for rotation (or linear) stem movement
  - Graphite ring
    - Loading: stable values for both tested initial load 40 & 50 MPa
    - Unloading: decrease of μf_rot
  - Braided PTFE
    - Stable values
    - μf_rot: stable values on investigated loading range

	Graphite ring		
		μ_{f_rot} [-]	
	Q_{A1} [MPa]	40	50
Q [MPa]	50		0,13
	40	0,13	0,12
	30	0,10	0,10
	20	0,08	0,07

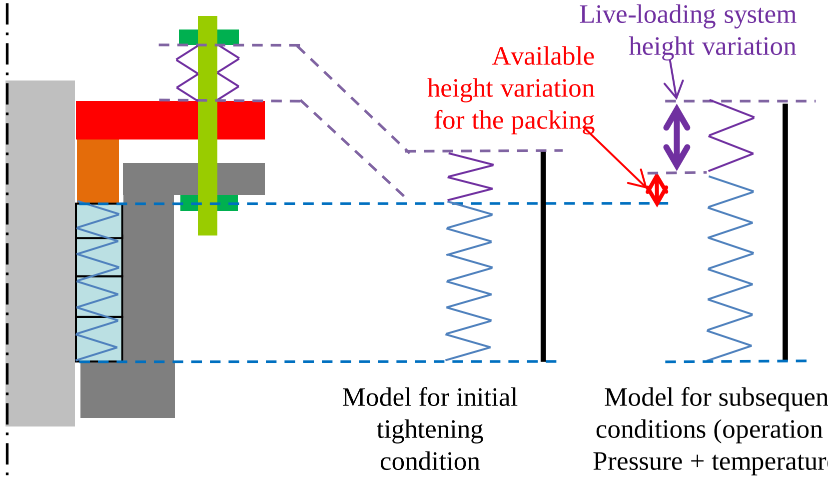
	Braided PTFE		
		μ_{f_rot} [-]	
	Q_{A1} [MPa]	20	30
Q [MPa]	30		0,10
	20	0,12	0,11
	10	0,12	0,11

Mechanical test results



- Unloading packing elastic modulus (E_R)
  - Used to calculate the packing load variation due to the variation of the available height between tightening and operation (impact of creep and thermal expansion)
  - Stable values in the investigated initial load ranges (linked with die forming load for graphite ring)
  - Braided PTFE: rigidification shown with initial load increase

type	movement	Initial stress [MPa]	E_R [MPa]
graphite	rotation	40	1190
graphite	rotation	40	1282
graphite	rotation	60	1128
graphite	rotation	60	1150
PTFE	rotation	20	1008
PTFE	rotation	40	1220



Conclusions

- A tool package has been developed for the optimization of valve packing. This package involves:
  - A calculation model (with an associated xls speadsheet)
  - Test procedures and rigs for packing sealing & mechanical behavior characterization
- The first test campaign performed on die formed graphite rings and braided PTFE show consistent results
- Other validations (not developed in this presentation) like comparison to FEA modeling (with simplified modeling of packing) and sensitivity analysis of the calculation method to the measured packing parameters variations have also been performed on a test case.

Looking forward

- On-going additional sealing test on 2 die-formed graphite packings with:
  - Test pressure up to 80 bar
  - Application of specific packing manufacturer installation procedure
  - Additional anti-extrusion rings for linear stem movement

- Proposal of a guidelines document based on the tool package (planned work) which could be used for standardization in the future