Fatigue assessment of scotch yoke for high cycles applications in heavy-duty valves actuators

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Limitorque Fluid Power System

Preliminar consideration

Actuator performance in high cycles applications: trust or verify?

I

- Actuator life-span is typically measured in cycles of operations – cycle life.

II

- Many flow-control processes require on-off valves and actuators to cycle with great frequency, meaning a reduced temporal lifespan and increased maintenance intervals.

III

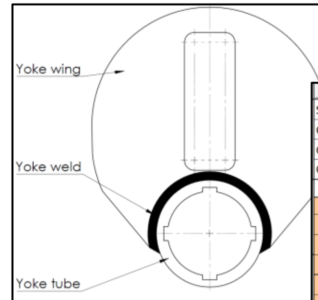
- Very often valves and actuators cycle life is based on estimation or field history and is not validated rigorous experimental evidence.

Challenge and applied methodologies

I
- Analytical analysis

II
- Numerical analysis

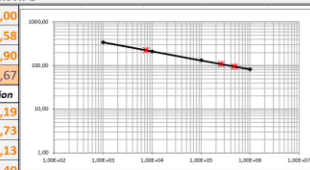
III
- Experimental test



Fatigue assessment HFC

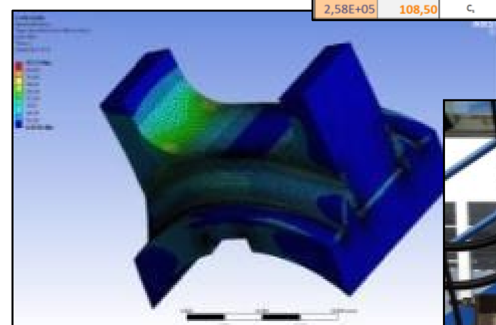
S'_n	235,00
C_l	0,58
C_g	0,90
C_s	0,67

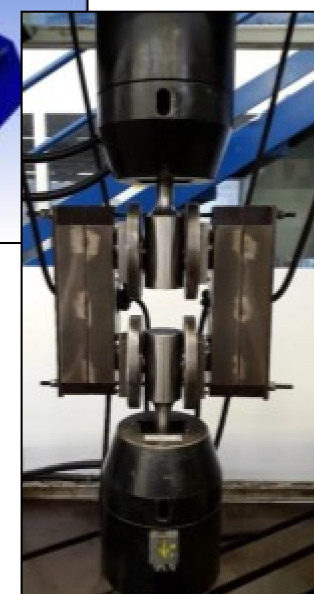
N.cycles	σ_{eq} torsion
1,00E+06	82,19
1,00E+05	131,73
1,00E+04	211,13
1,00E+03	338,40
7,51E+03	223,91
3,26E+07	40,25
4,76E+05	95,69
2,58E+05	108,50



$$S_n = S'_n \cdot C_L \cdot C_G \cdot C_S$$

C_l	fattore di carico
C_g	fattore per il gradiente di tensione
C_s	fattore di finitura superficiale





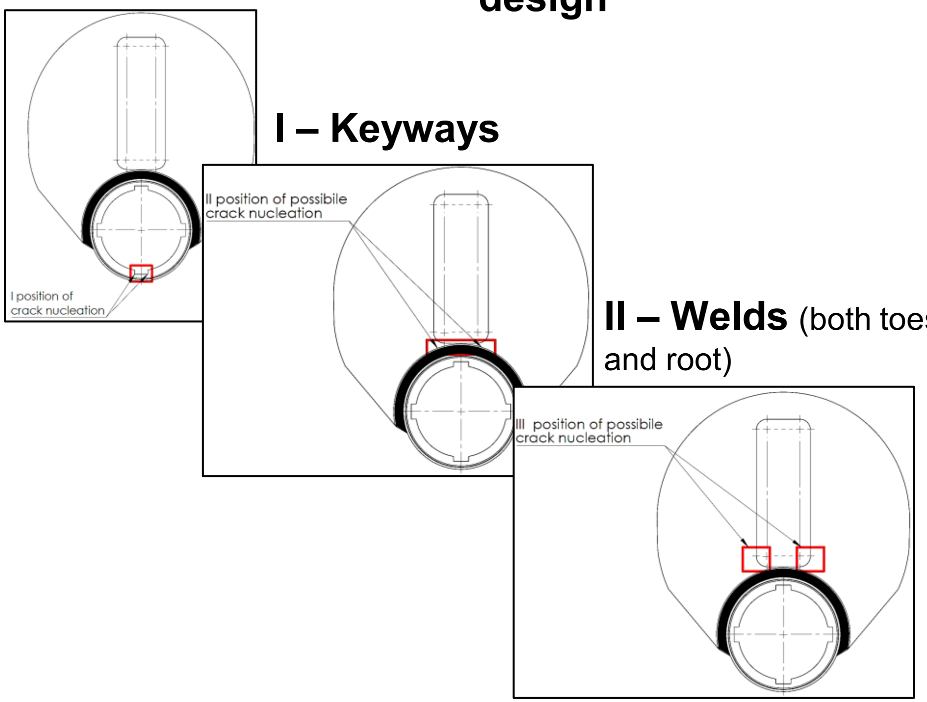
Analytical analysis

Load analysis

New scotch yoke design

Automatic spreadsheet

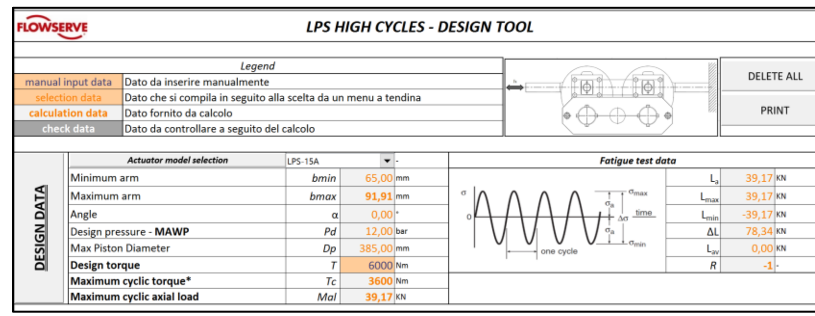
Link between spreadsheet and 3D template

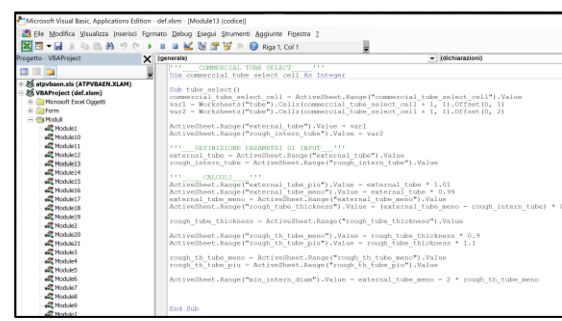


I – Keyways

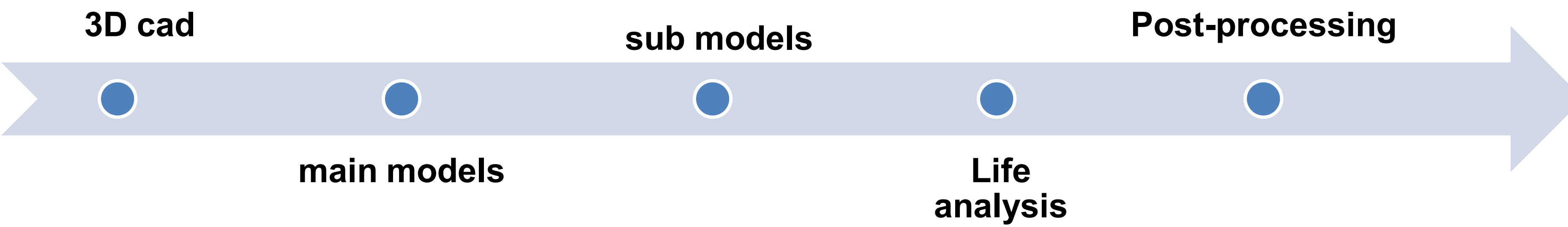
II – Welds (both toes and root)

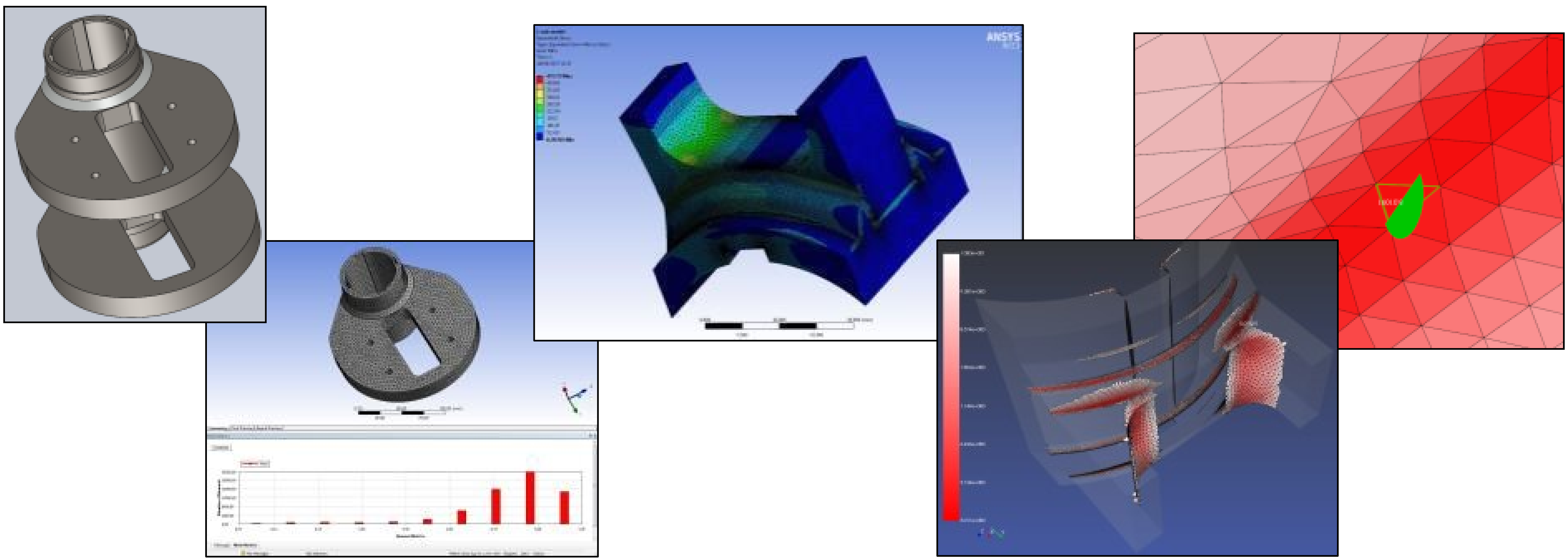
III- Slider Surface





Numerical analysis





Numerical analysis

3D cad

De-featuring operations

main models

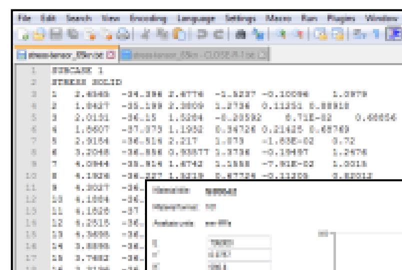
Two main models are required in order to evaluate both the loading conditions in the scotch yokes.

sub models

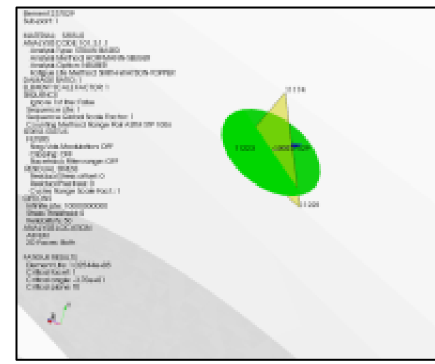
Mesh refinement around the hot spots.
Control in a cut zone
Results convergence is reached.
stress tensor results is exported.

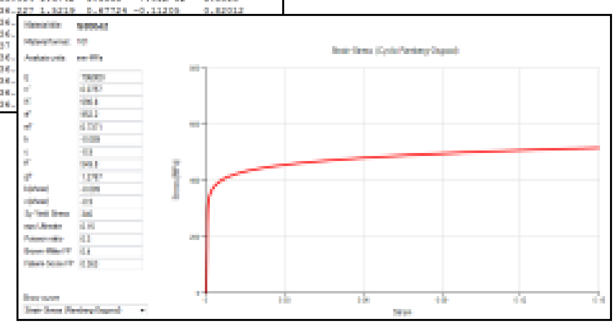
Life analysis

Stress tensor results.



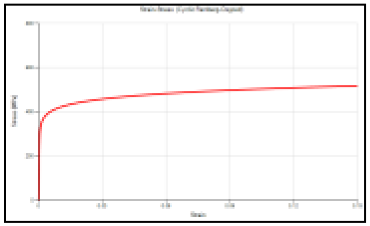
Post-processing





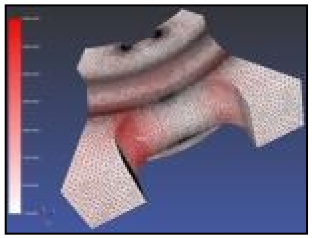
Numerical analysis

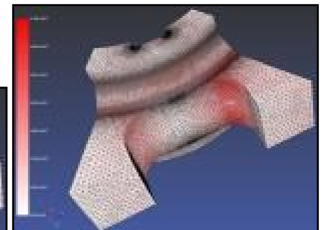
- Life Analysis



Fatigue properties of material from literature*

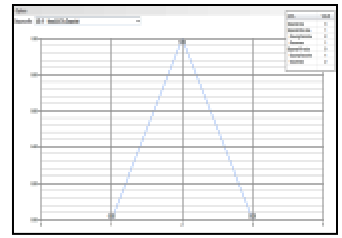
Loading condition 1

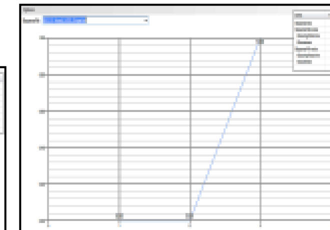




Loading condition 2

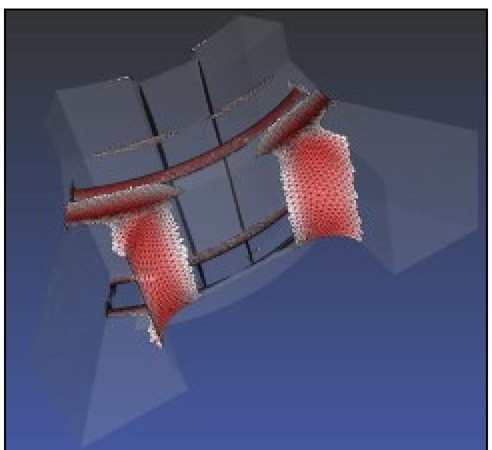
Load history 1





Load history 2

- Post-processing

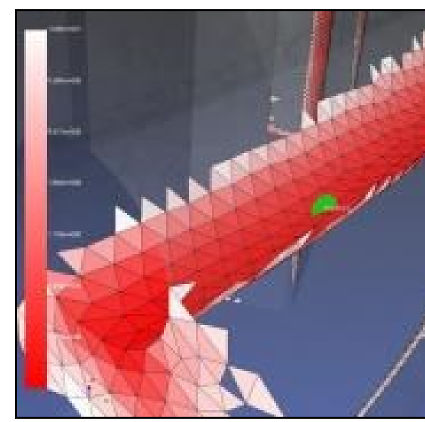


Hoffmann – Seeger approach.

The model highlight all the critical zone

1. **Weld root**;
2. **Weld toes**;
3. **Keyways**;
4. **Radious of slider surface**.

Severity



*A comparison of the fatigue behavior between S355 and S690 steel grades, de Jesus, Matos, Fontoura, Rebelo, da Silva, Veljkovic, Journal of Construcional steel research 79 (2012) 140-150

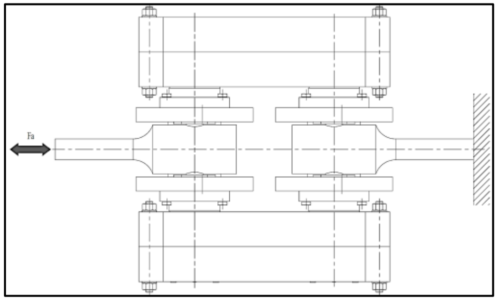
Experimental test

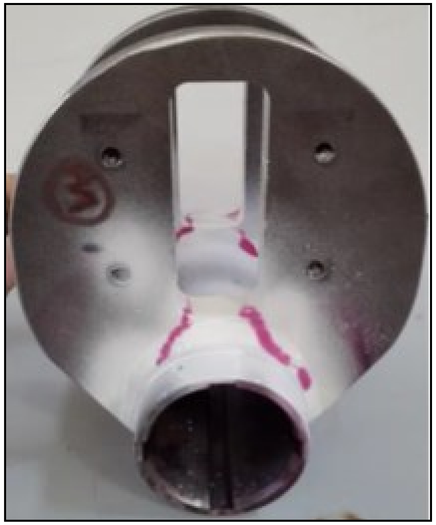
I
- Set-up definition

II
- Tool design

III
- Fatigue test

IV
- Output data analysis

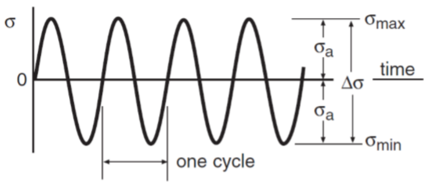




Experimental test

I

• Set-up definition



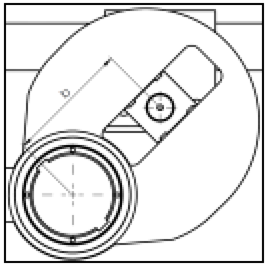
$$R = \frac{\sigma_{min}}{\sigma_{max}} = -1$$

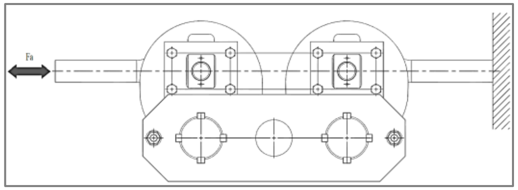
Frequencies to be define base on the noise in the laboratory.

II

• Tool design

Defining of b, position of the slider blocks





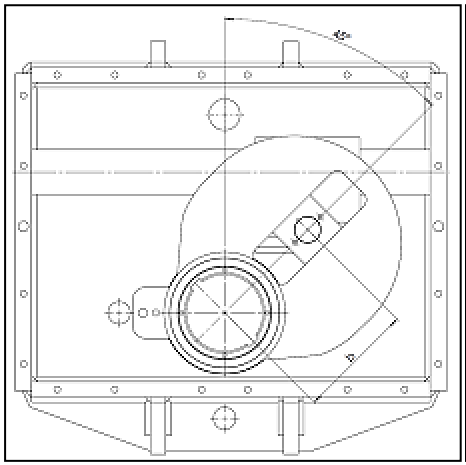
Tool design maintaining the same b

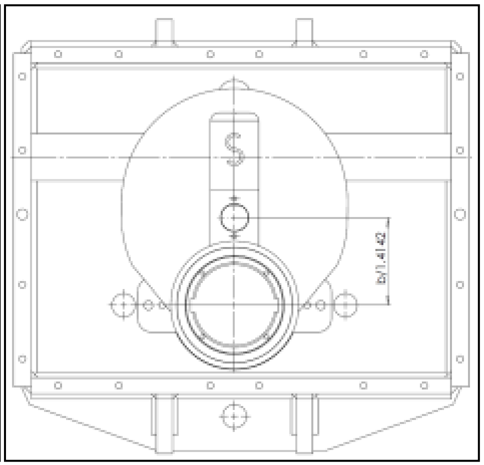
Tool realization, and pre-mounting

Experimental test – Added slide

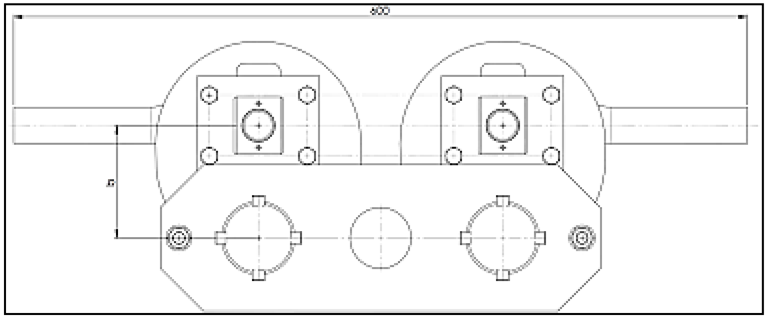
I

- Defining of b – Slider blocks position

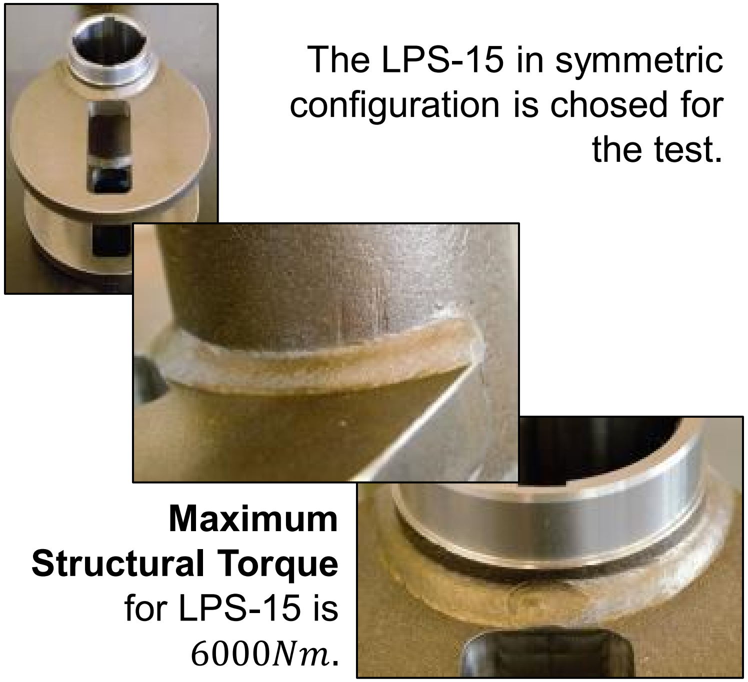




Full close position 0° Running position 45°



The max in-service arm for the scotch yoke is chosen.



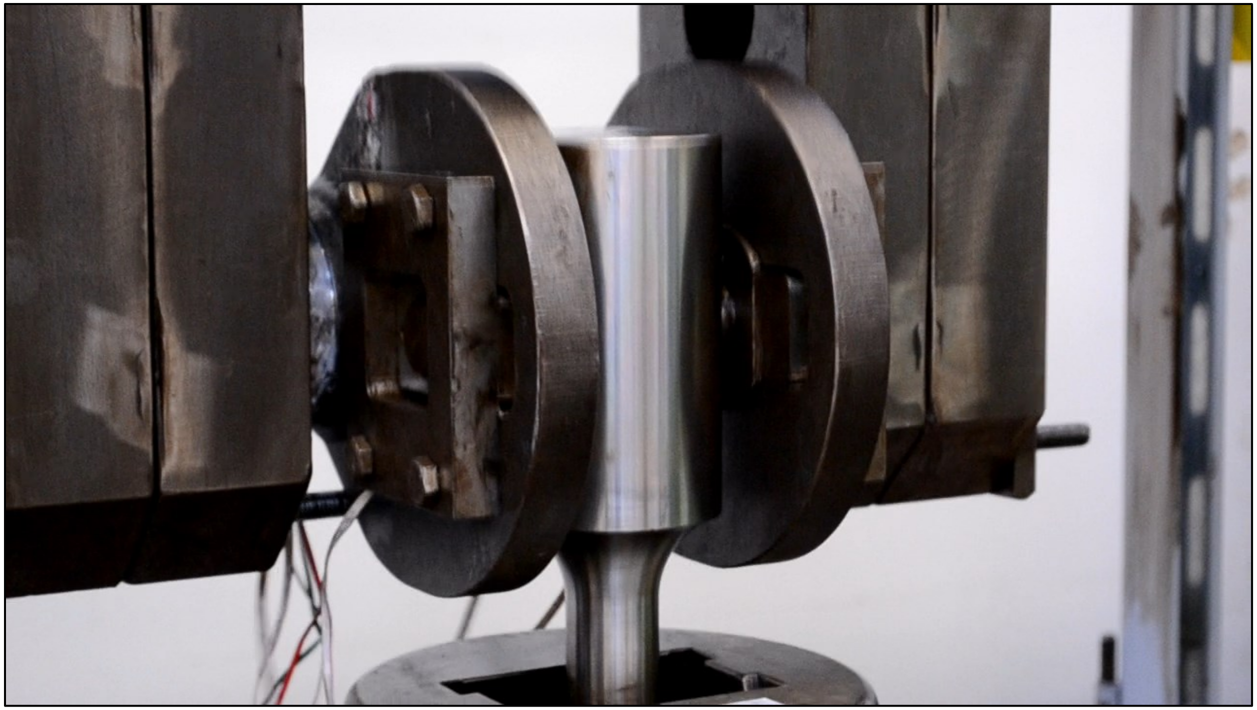
The LPS-15 in symmetric configuration is chosed for the test.

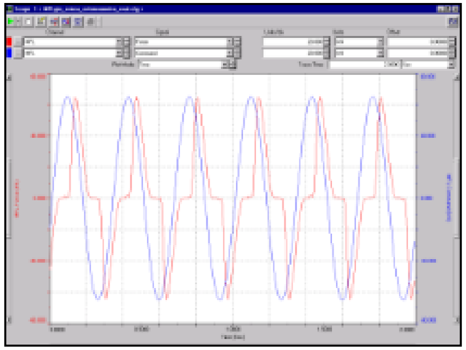
Maximum Structural Torque for LPS-15 is $6000Nm$.

Experimental test

III

- Fatigue test



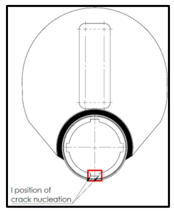


Finished the tool and samples assembly on the MTS, the fatigue test on two yokes per time is started. Room temperature and standard conditions are applied.

Experimental test

III

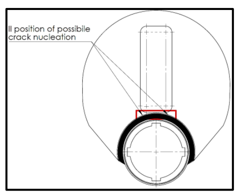
- Fatigue test



Zone I

$8{,}59 \cdot 10^5\ cycles$

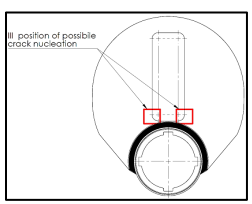
$MTT = 6000Nm$



Zone II

$6{,}61 \cdot 10^5\ cycles$

$MTT = 6000Nm$



Zone III

$6{,}03 \cdot 10^5\ cycles$

$MTT = 6900Nm$

ID	$MST\ [Nm]$	$MTT\ [Nm]$	cycles	Crack positions*	Note
1	10000	6000	53000	I	DISCARDED
2	10000	6000	859000	I	/
3	7000	4200	Run-out	/	/
4	7000	4200	Run-out	/	/
3	15400	9100	85000	II – III	/
4	15400	9100	85000	II – III	/
5	10000	6000	806000	III	/
6	11500	6900	287000	I – II – III	/
7	11500	6900	603000	II – III	/
8	11500	6900	316000	III	/
9	13800	8300	120000	I – II – III	/
10	13800	8300	120000	I – II – III	/
11	10000	6000	661000	II – III	/
12	10000	6000	661000	II – III	/

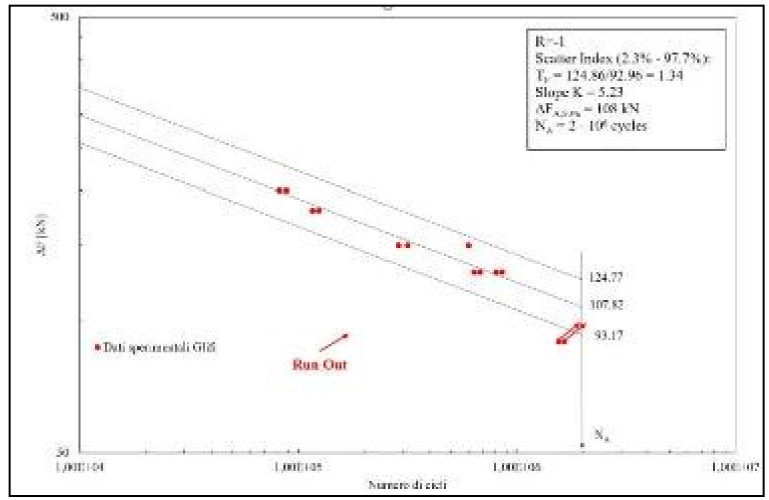
MST – Maximum structural torque;
MTT – Maximum test torque.

Experimental test

IV

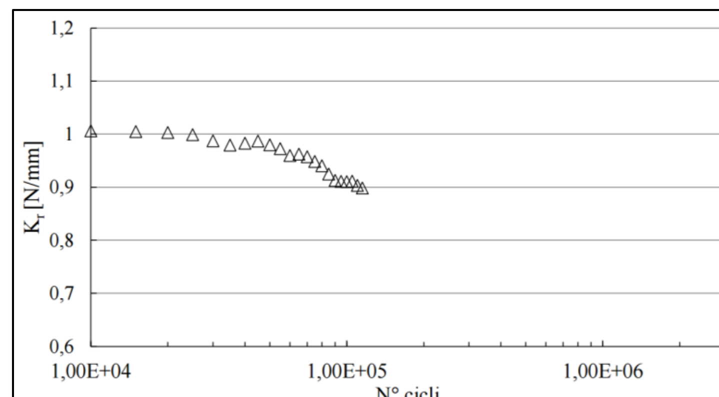
- Output data and results

Crack position highlighted by PT test.



S/N curve of the scotch yoke.
Picture obtained thanks the software "Diciotto", developed by Prof.Eng. Giovanni Meneghetti of the University of Padova.

The stiffness of the components has a small decrease (approximately 10%), despite the presence of cracks.



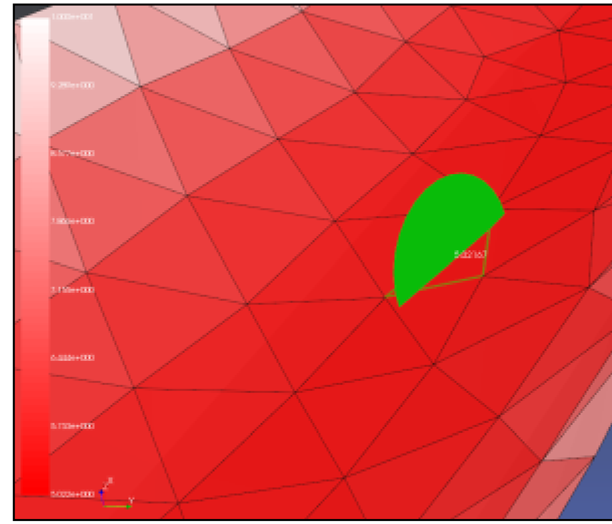
Results comparison

- Analytical analysis

MTT: $6000Nm$
MST: $10000Nm$
Load ratio: $R = -1$
More critical point: Yoke tube
Magnitude estimated life: 10^4

- Numerical analysis

MTT: $6000Nm$
MST: $10000Nm$
Load ratio: $R = -1$
More critical point: Weld root
Magnitude estimated life: $1{,}5 \cdot 10^5$ → ***Crack nucleation***



- Experimental analysis

MTT: $6000Nm$
MST: $10000Nm$
Load ratio: $R = -1$
More critical point: Not clearly identifiable
Magnitude estimated life: $6{,}6 \cdot 10^5$ → ***Eye-visible crack***

First considerations

I

- More frequent **crack nucleation** zone: **zone III**, also if in yoke 6, 9 and 10 are clearly recognizable a crack nucleation from the **zone II – weld root**

II

- **Difficult to know the number of cycles and the exact point where the crack nucleates with the currently test set-up;**

III

- **The material parameters are procured by the technical literature;**

IV

- **The analysis carryied out show a conservative behaviour if compared with the experimental evidence.**

Conclusions

I

- The new arrangement of LPS-15A scotch yoke permits to perform, without any problem not only the 1×10^5 cycles required by the EN 15714-3 but also the **2×10^6 required by the high cycles applications at the currently output torque, $6000\mathrm{Nm}$**;

II

- Despite the presence of some cracks in the sample yoke, the component's stiffness not decreases. **The yoke continues to work without problems despite the cracks.**

III

- **Analytical analysis is more conservative** compared with the real behaviour of the component.

IV

- **Numerical analysis is more accurate** despite che improvement points identified in the previous slide In the analysis set-up is very important the **choice of the analysis method**; a wrong decision could results in a overstimation of the real fatigue life of the component.

Future Developments

I

- Some other tests on the new design of scotch yokes are foreseen in order to optimize the design with some other adjustments and increase the case study.

II

- Verify the conformity between the real application and the laboratory test. In order to reach this target, a test campaign in the actuator is foreseen.

III

- Verify if the surface treatment applied at the scotch yoke influence or not the fatigue behavior highlighted in this first project step.

Acknowledgments

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- **Eng. Matteo Bergonzoni** – *Scholarship holder – University of Padova.*

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- **Mr. Gabriele Masiero;**

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Not last…

thanks to all for your attention!!!