LHC Collimation Project

CERN

MME Mechanical & Materials Engineering

EN ENGINEERING DEPARTMENT

CERN

Leadscrew taskforce report

L. Gentini

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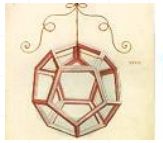
HiColDem

5th Septembre, 2017

EDMS: 1760258

Outline



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UMBRA screws

- First test campaign summary
  Dry screws: Ceramic / SS ø-20µm ball screw
- Second test campaign
  Dry screws: Ceramic / SS ø-40µm ; Full Ceramic ball screw
- **Lubricated screw:** Analysis post cycling

KSK screws

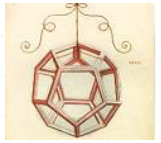
- **Dry screws:** Full Stainless steel ball screw

SKF

- **Dry screw:** Stainless Steel with Dicronite coating roller screw

Next steps

Dry UMBRA (old tests)



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Remind of first campaign of cycling tests

Test n°	Screw N°	Load [kN]	Last Cycle	Note
1	0006	1.4	1049	Motor lost step
	0002	2	1049	Noise
2	0004	1.4	1072	a lot of noise
	0005	2	1072	noise
3	0001	1.4	1072	motor lost step
	0010	2	1072	noise

- The screws of the first test bench have been dismantled and analysed at CERN (EDMS: 1761802)
- The screws of the third test bench have been sent to UMBRA for analysing.

FAILED UMBRA SCREW CHARATERIZATION

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Upper screw (0002): ø6.3 spring load– Jaw load = 1.4 kN max

Bottom screw (0006): ø6.3 spring load + Jaw load = 2 kN max

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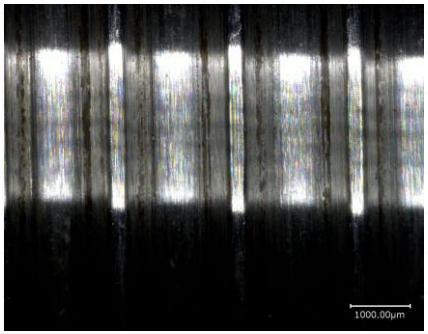
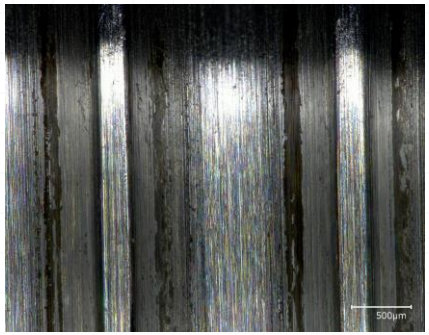
Screw 0002 (1.4 kN)

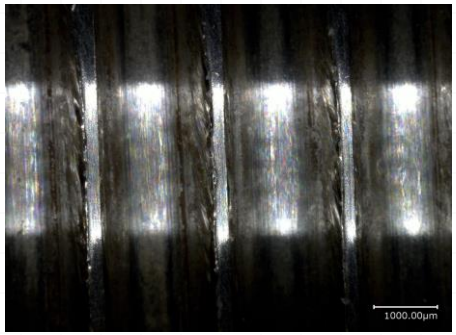


original magnification ×50



original magnification ×100

Screw 0006 (2 kN)



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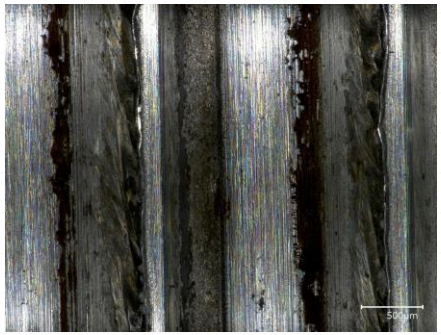

original magnification ×100

LOM: Thread of screw n°0006 appears to be clearly damaged whereas to thread of screw n°0002 which appears to be used but no really damaged.

From Mickael Denis Crouvizier EDMS: 1761802

FAILED UMBRA SCREW CHARATERIZATION

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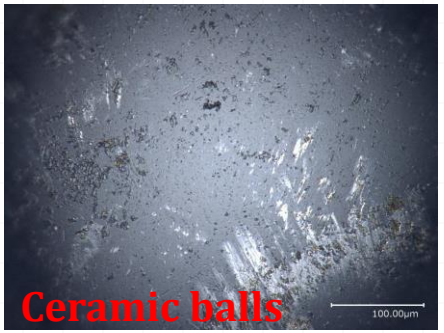
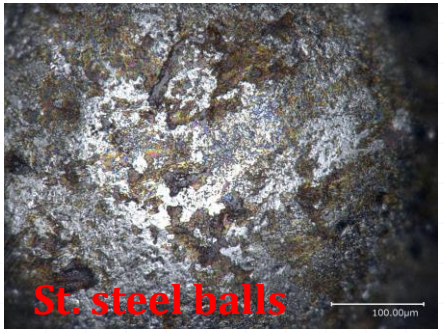
Screw 0002 (1.4 kN)

Screw 0006 (2 kN)



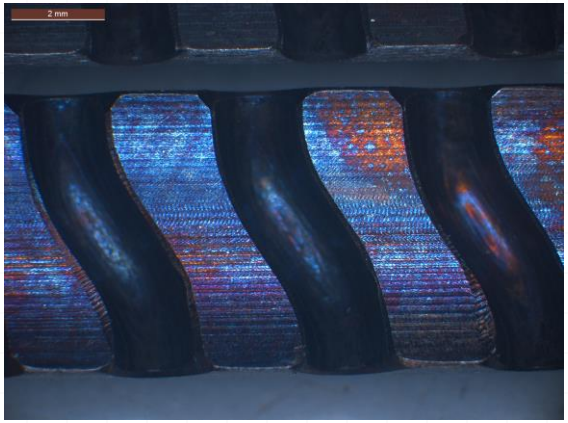


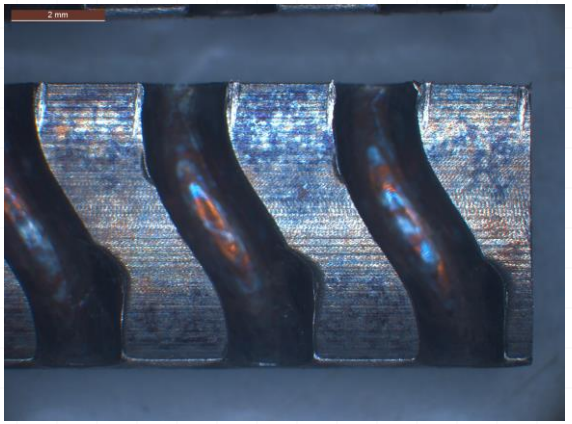
original magnification ×700

Ceramic Balls seam do not compromise the functionality of the screws, even if on the 0006 screws they are a bit damaged.

St. steel balls are very damaged on the bottom screw (much loaded)

Ball guide



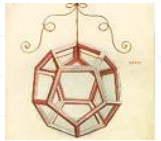


original magnification x12

The **ball guides** (17-4 PH) removed from the nut of the screw n°0006 revealed abnormal wear and are clearly deformed.

From Mickael Denis Crouvizier EDMS: 1761802

FROM UMBRA CUSCINETTI SPA



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The results of the **analysis done on the in UMRA's laboratory** on the failed screws of the third test bench **are very similar to CERN's results**.
The screws had same problems on the St. steel balls and the guiding pieces.

People from UMBRA are very surprised by these results.
They do not know a real cause, but they suppose the problem came by the friction between St. Steel balls and guiding pieces.

<u>They proposed 3 others kinds of screw to test:</u>

1. Full ceramic balls with same size
2. Half ceramic balls and half St. steel balls (ø-40µm)
3. Half ceramic balls and half St. steel balls (ø-80µm)

SECOND CAMPAIGN OF UMBRA SCREWS
- Ceramic balls/ St. Steel Ø-40µm
- Full ceramic balls

Test n°	Screw N°	Load [kN]	Last Cycle	Note
1	0028 C/C	1.4	460	Noise
	0035 C/C	2	460	Motor lost step
3	0032 C/SS - ø40µm	1.4	2740	Motor lost step
	0033 C/SS - ø40µm	2	2740	Noise

SECOND CAMPAIGN OF UMBRA SCREWS OPTICAL OBSERVATION

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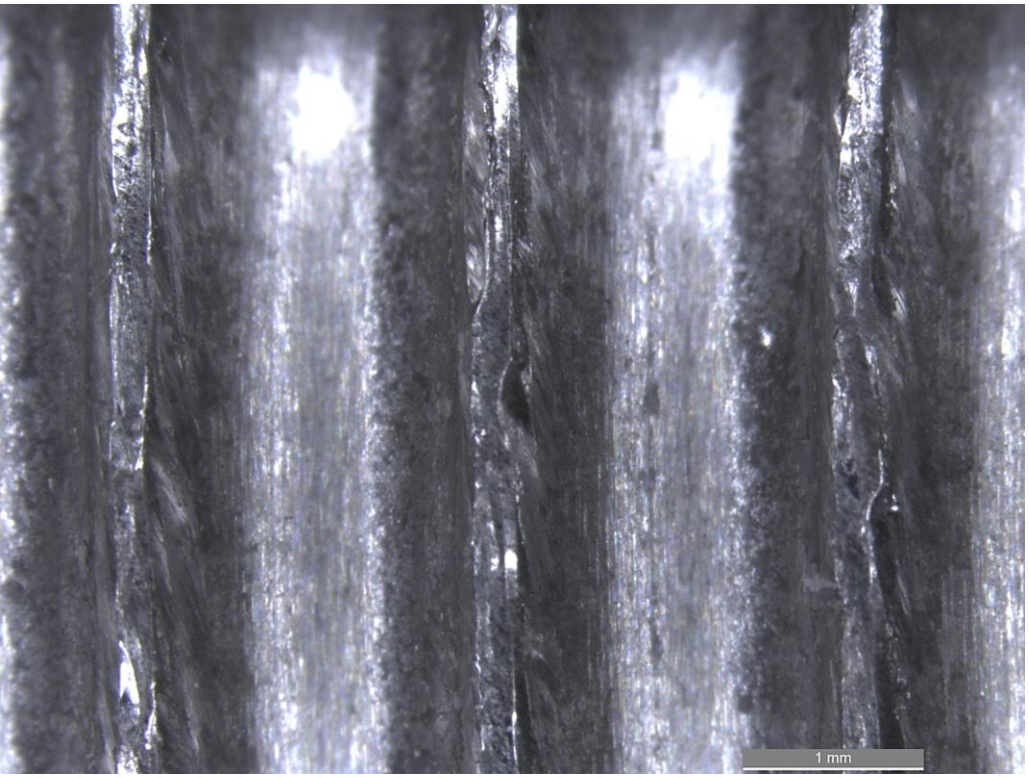
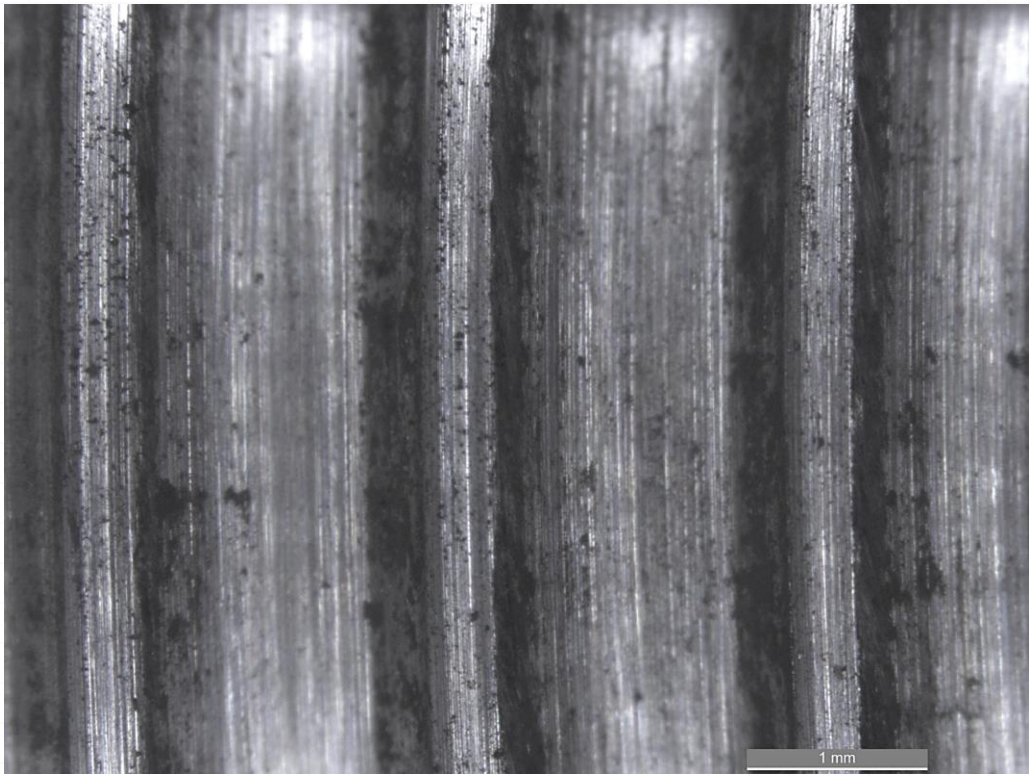
Screw 0032 : C/ SS Ø-40µm (1.4 kN)



original magnification ×16

Screw 0035 : C/C (2 kN)



original magnification ×16

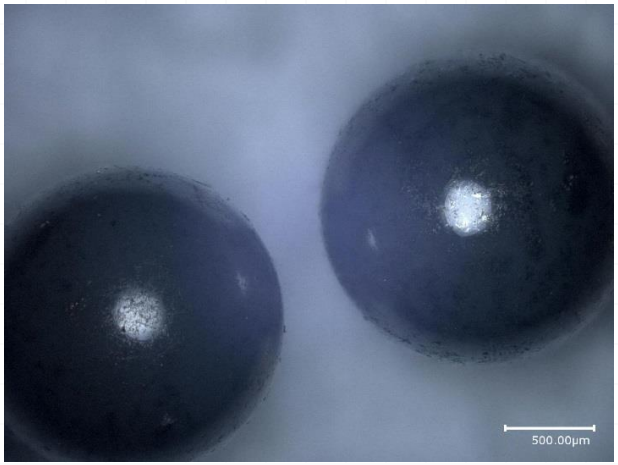
LOM: Thread of screw n°0032 appears to be clearly damaged whereas to thread of screw n°0035 which appears in good conditions.

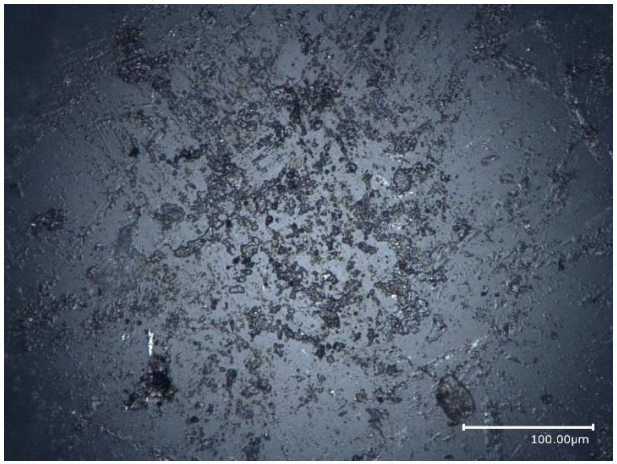
From Mickael Denis Crouvizier EDMS: 1762331

SECOND CAMPAIGN OF UMBRA SCREWS OPTICAL OBSERVATION

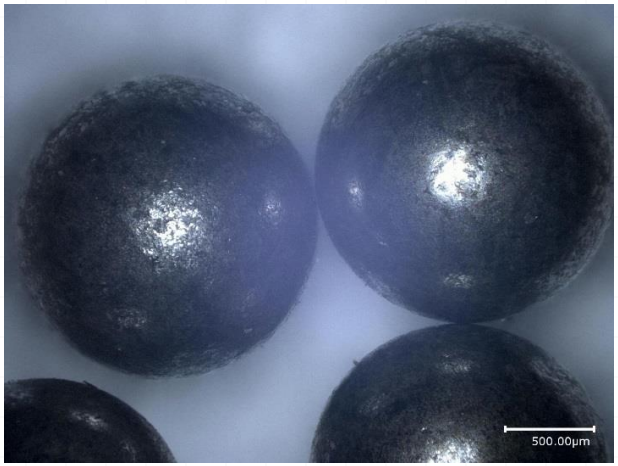
Screw 0032 : Ceramic balls/ St. Steel Ø-40µm (1.4 kN)

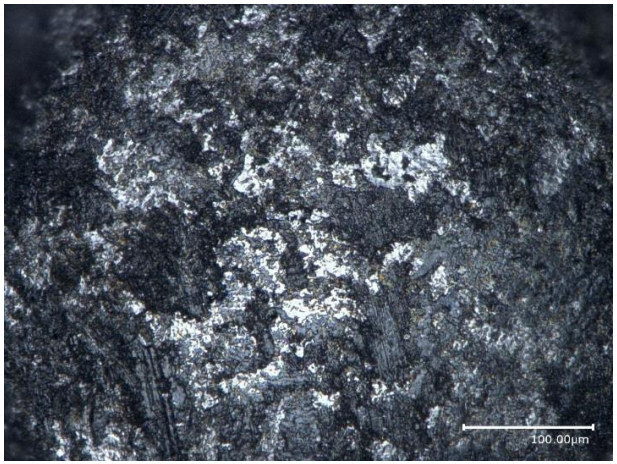
Ceramic balls





St. steel balls





original magnification ×100 and x700

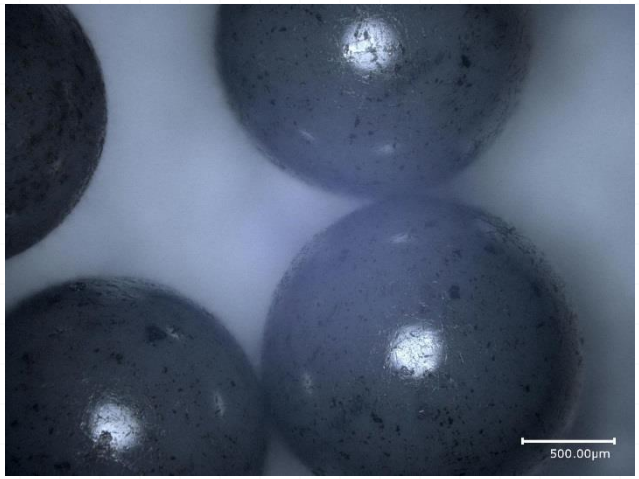
Ceramic Balls seam scratched but they do not compromise the functionality.
St. steel balls are very damaged.

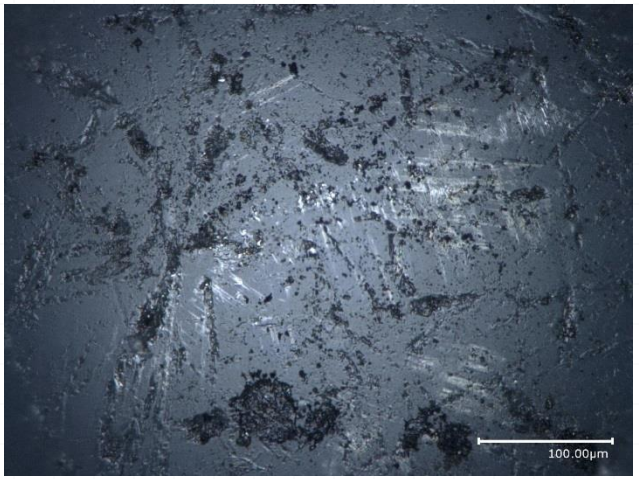
From Mickael Denis Crouvizier EDMS: 1762331

SECOND CAMPAIGN OF UMBRA SCREWS OPTICAL OBSERVATION

Screw 0035 : Full ceramic balls (2 kN)

Ceramic balls





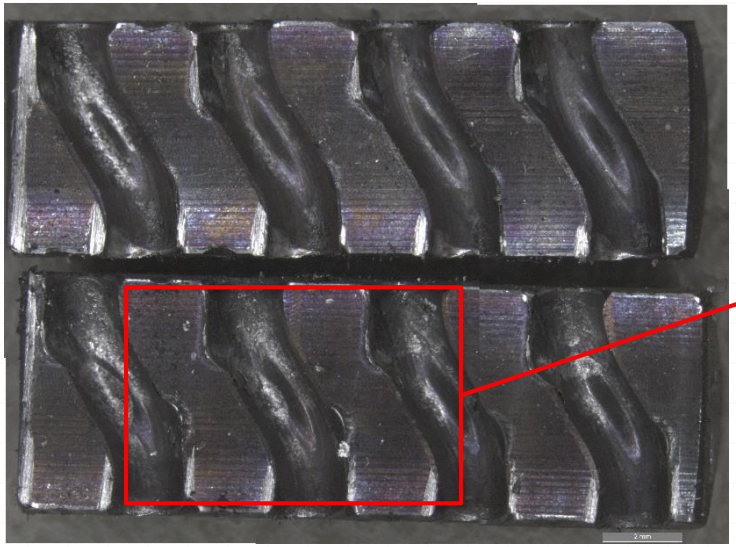
original magnification ×100 and x700

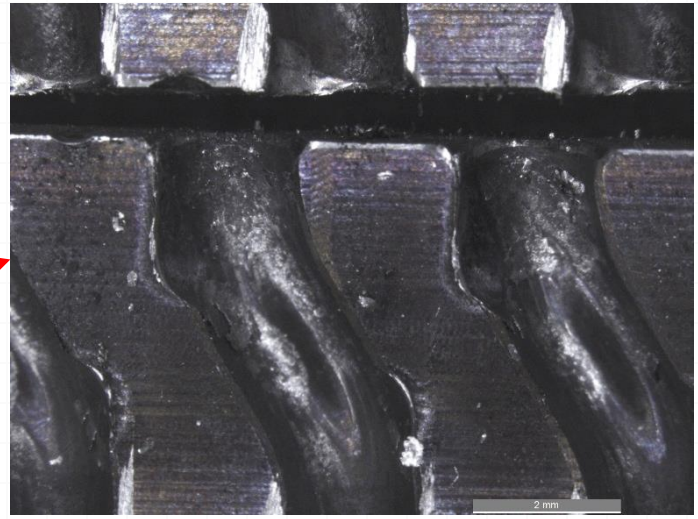
Ceramic Balls seam scratched but they do not compromise the functionality.

From Mickael Denis Crouvizier EDMS: 1762331

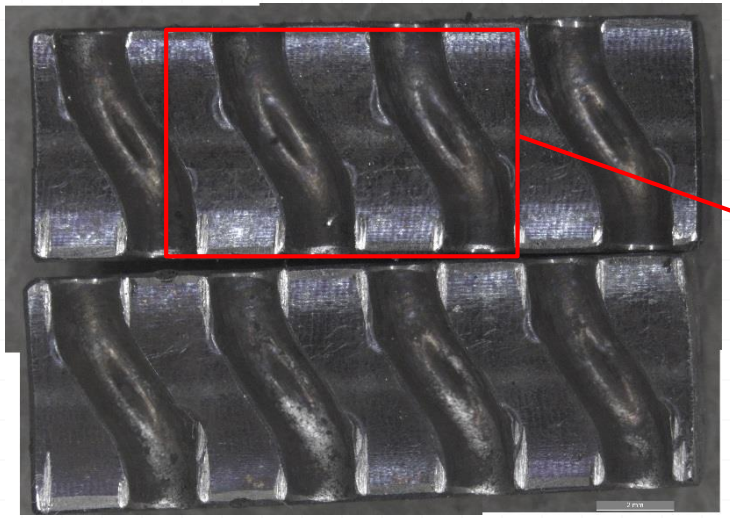
SECOND CAMPAIGN OF UMBRA SCREWS OPTICAL OBSERVATION

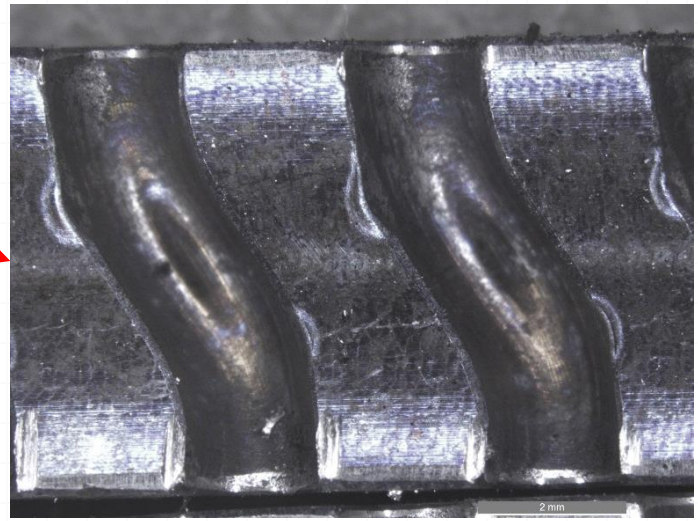
Screw 0032 : C/ SS Ø-40µm (1.4 kN)





Screw 0035 : Full ceramic balls (2 kN)

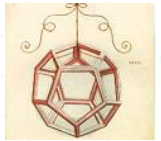




original magnification ×10

From Mickael Denis Crouvizier EDMS: 1762331

SECOND CAMPAIGN OF UMBRA SCREWS



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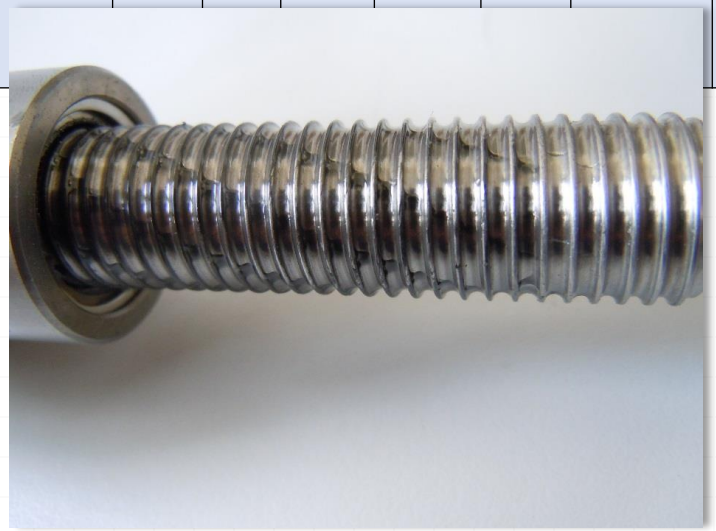
CONCLUSION:

- **Full ceramic balls:**
  - Thread in good condition
  - Balls scratched but not damaged
  - Ball guiding less damaged (more load, less cycles)
- **Ceramic / Stainless steel ø-40 µm balls:**
  - Thread clearly damaged
  - Balls clearly damaged
  - Ball guiding clearly damaged

CYCLING TEST ON LUBRICATE UMBRA SCREWS

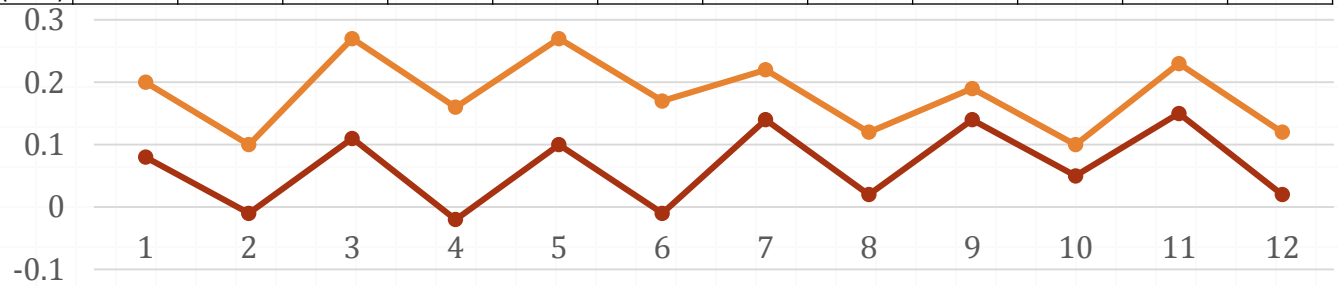
Type	Supplier	Ident. N°	reception	Lubricant	Visual test	Dimensional test	up / down	Starting test	Cycles end test	Status after test	Note	Cycles 1	Status after test3	Cycles 2	Status after test33
LHCTCS__0082	UMBRA	0015	01/10/2016	yes	100%	EDMS: 1753580	Up	13/03/2017	10000	Visual test: very good movement	test topped screw at CERN				
LHCTCS__0082	UMBRA	0016	01/10/2016	yes	100%	EDMS: 1753580	Down	13/03/2017	10000	Visual test: block at some points Elliptical lubricant distribution EDMS: 1797892	Test stopped screw sent back to umbra (26-03-2017)				
LHCTCS__0082	UMBRA	0017	01/10/2016	yes	100%	EDMS: 1753580	up	13/03/2017	10000	Visual test: very good movement		20000	(19-04-2017) Visual test: very good movement starting Elliptical lubricant distribution EDMS: 1797893	30000	(15-05-2017) Visual test: very good movement starting Elliptical lubricant distribution EDMS: 1797893
LHCTCS__0082	UMBRA	0018	01/10/2016	yes	100%	EDMS: 1753580	Down	13/03/2017	10000	Visual test: good movement starting Elliptical lubricant distribution EDMS: 1797892		20000	(19-04-2017) Visual test: very good movement starting Elliptical lubricant distribution EDMS: 1797893	30000	(15-05-2017) Visual test: very good movement starting Elliptical lubricant distribution EDMS: 1797893



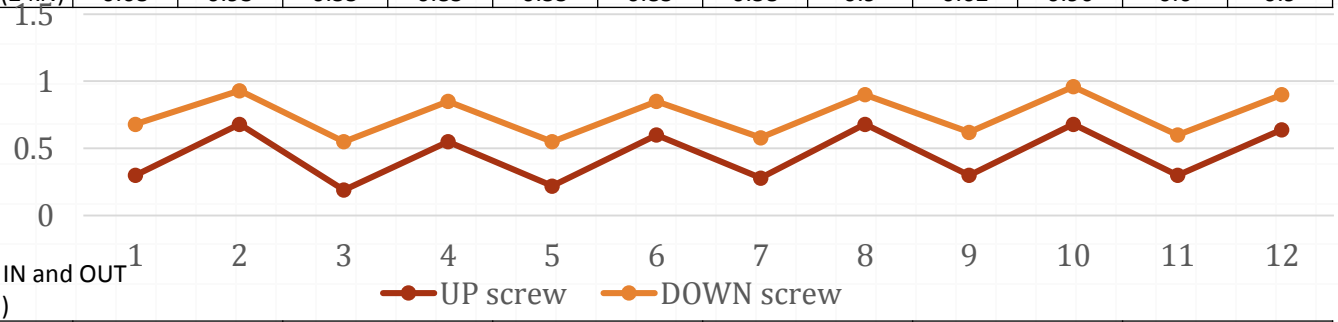
Both screws have been sent back to UMBRA.
They didn't disassemble the screws, but they suppose that screws work very well.
Could a internal adjustment happen?

TORQUE TEST ANALYSIS ON LUBRICATE UMBRA SCREWS

		0		5k		10k		15k		20k		25k	
		IN	OUT	IN	OUT	IN	OUT	IN	OUT	IN	OUT	IN	OUT
in to out	Screw 0017 UP (1.4 kN)	0.08	-0.01	0.11	-0.02	0.1	-0.01	0.14	0.02	0.14	0.05	0.15	0.02
	Screw 0018 DOWN (2 kN)	0.2	0.1	0.27	0.16	0.27	0.17	0.22	0.12	0.19	0.1	0.23	0.12



		OUT	IN	OUT	IN	OUT	IN	OUT	IN	OUT	IN	OUT	IN
out to in	Screw 0017 UP (1.4 kN)	0.3	0.68	0.19	0.55	0.22	0.6	0.28	0.68	0.3	0.68	0.3	0.64
	Screw 0018 DOWN (2 kN)	0.68	0.93	0.55	0.85	0.55	0.85	0.58	0.9	0.62	0.96	0.6	0.9



Difference between IN and OUT (Spring compression)

in to out	Screw 0017 UP	0.09	0.13	0.11	0.12	0.09	0.13
	Screw 0018 DOWN	0.1	0.11	0.1	0.1	0.09	0.11
out to in	Screw 0017 UP	0.38	0.36	0.38	0.4	0.38	0.34
	Screw 0018 DOWN	0.25	0.3	0.3	0.32	0.34	0.3

Difference between UP and DOWN (jaw load) theoretical 0.37 Nm

	IN	OUT	IN	OUT	IN	OUT	IN	OUT	IN	OUT	IN	OUT
in to out	-0.12	-0.11	-0.16	-0.18	-0.17	-0.18	-0.08	-0.1	-0.05	-0.05	-0.08	-0.1
out to in	-0.38	-0.25	-0.36	-0.3	-0.33	-0.25	-0.3	-0.22	-0.32	-0.28	-0.3	-0.26

SIMULATION ON LUBRICATE UMBRA SCREW

$$F_{screw} \cong F_{spring} - Q \sin\beta$$

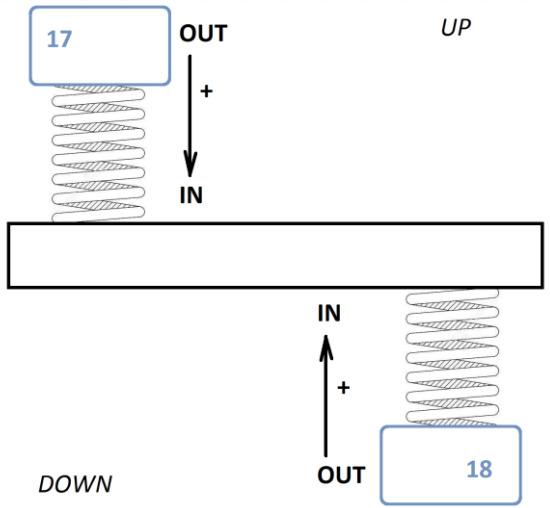
$$F_0 \cong F_{spring}(x = 0)$$

$$T_{direct} = \frac{p\,F_0}{2\,\pi\,\eta_p} + \mu\frac{d}{2}F_0 + \left(\frac{p\,K_{spring}}{2\,\pi\,\eta_p} + \mu\frac{d}{2}K_{spring}\right)\boldsymbol{x}$$

$$T_{inverse} = \frac{p\,\eta_i F_0}{2\,\pi} + \mu\frac{d}{2}F_0 + \left(\frac{p\,\eta_i K_{spring}}{2\,\pi} + \mu\frac{d}{2}K_{spring}\right)\boldsymbol{x}$$

With:

- p pass of the screw
- d diameter of the screw
- μ friction ball bearing
- η_p direct efficiency (0.6)
- η_i inverse efficiency (0.5)



From Carlo Zanoni

TORQUE TEST ANALYSIS ON LUBRICATE UMBRA SCREW

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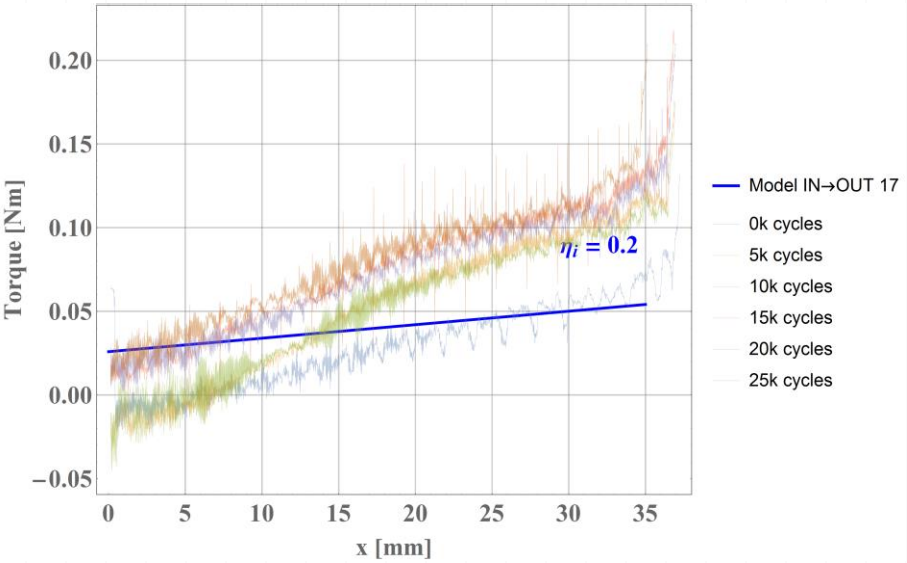
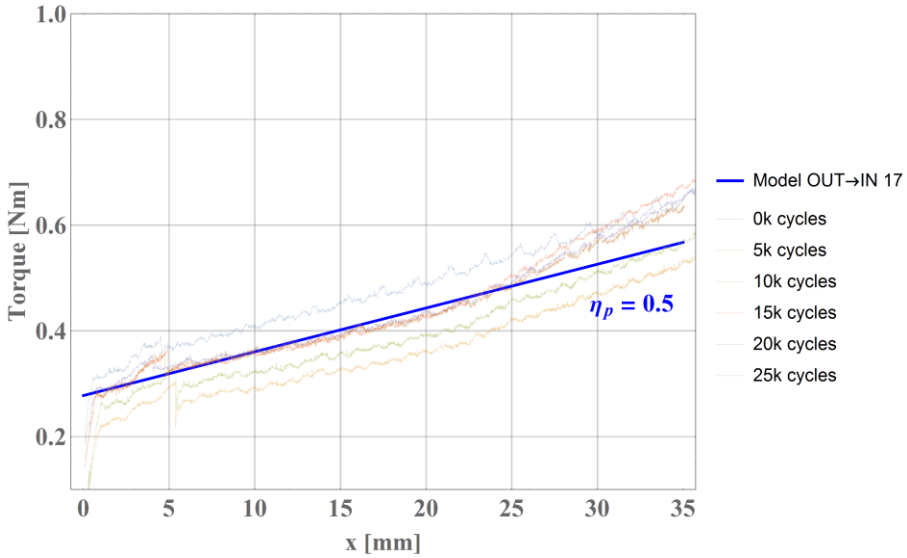
Screw 0017 IN to OUT



Screw 0017 OUT to IN



CONCLUSIONS

- There's an offset of ~0.1 Nm between curves of the same type but different cycles number
- There's no clear correlation between the number of cycles and the torque
- The measured efficiency is between 0.5 and 0.6, lower than what is expected by UMBRA (0.2)

From Carlo Zanoni

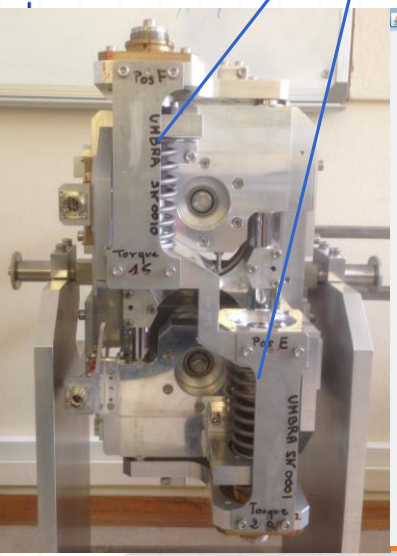
CYCLING TEST ON DRY KSK SCREWS

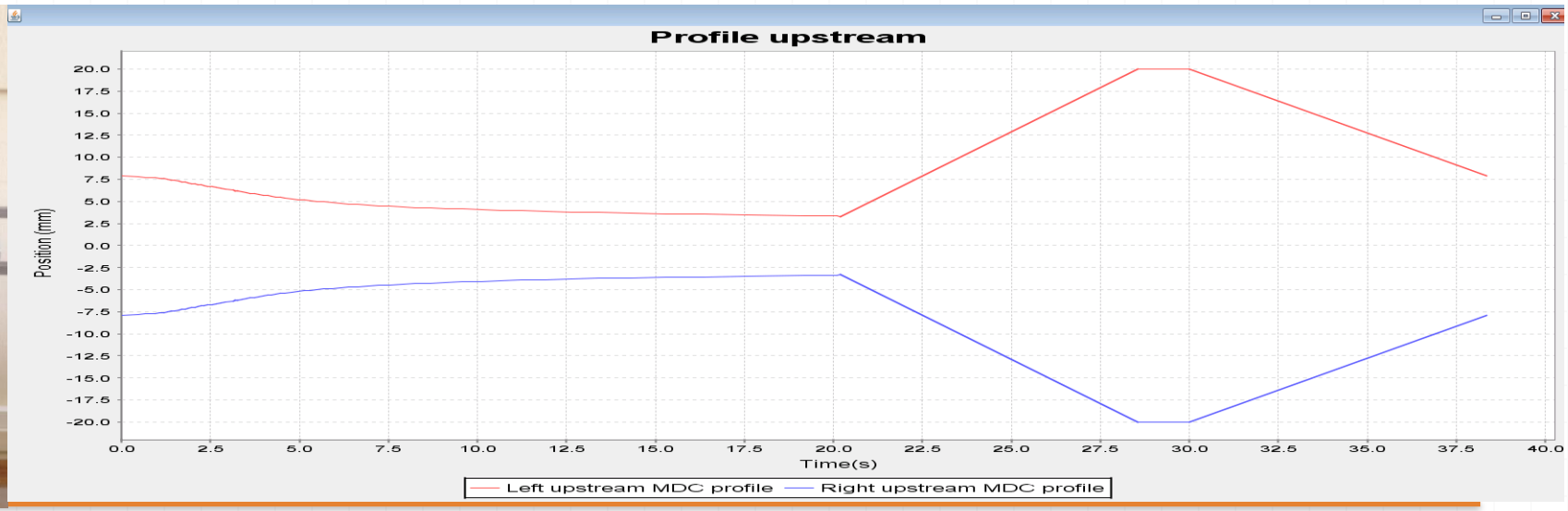
- *Phase II actuation system.*
- *All the screws must be submitted to 30.000 new cycle (same movement of a real collimator but accelerated).*
- *Torque measurements and screw visual inspection every 10.000 cycles.*

Test bench parameter	Value
Orientation	-90°
Mass	30 kg
Moment	74.3 Nm
Spring stiffness	12.97 N/mm
Spring free length	0.195 m
Spring length in x = 0	0.1195 m
Max spring force	1173.8 N
Min spring force	719.8 N
Vacuum force	713.4 N

Upper screw: ø6.3 spring load– Jaw load = 1.4 kN max

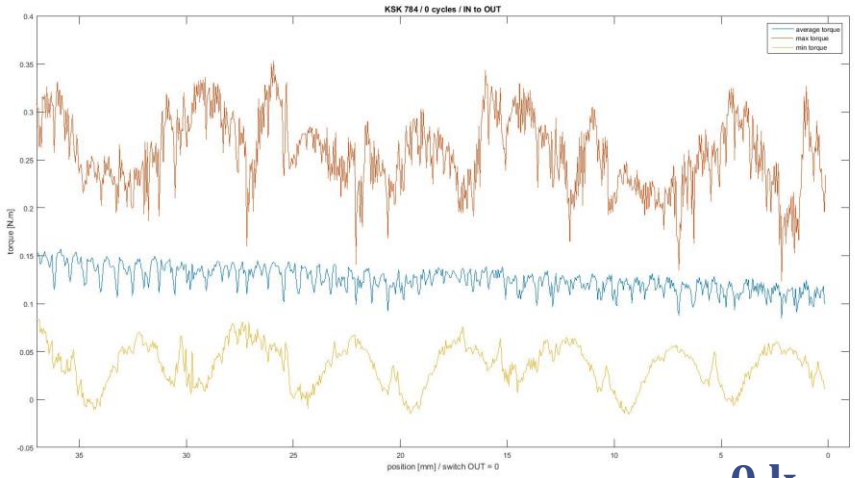
Bottom screw: ø6.3 spring load + Jaw load = 2 kN max



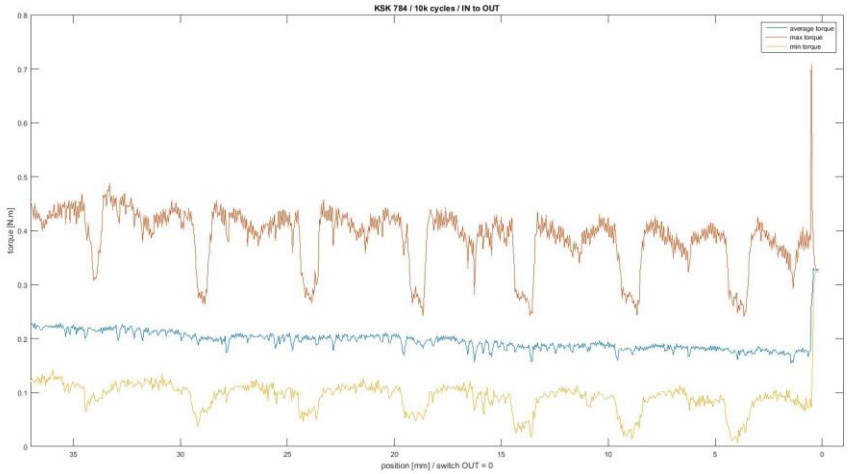


TORQUE TEST ANALYSIS ON DRY KSK SCREW

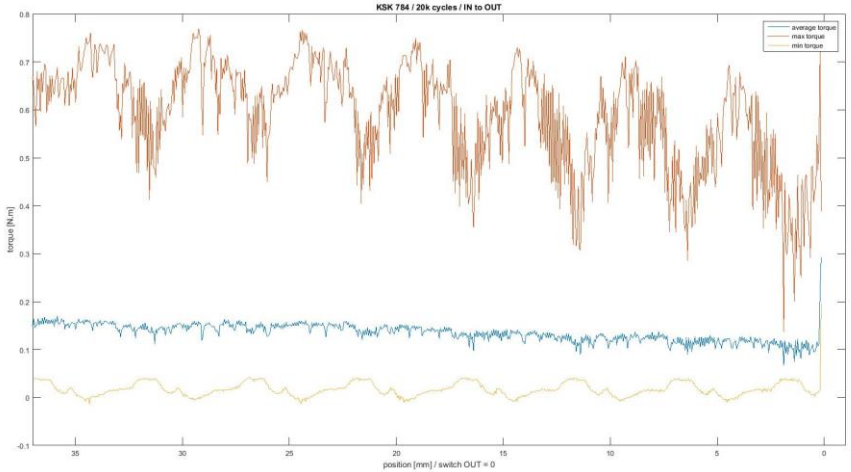
Screw 784 (down 2 kN) IN to OUT



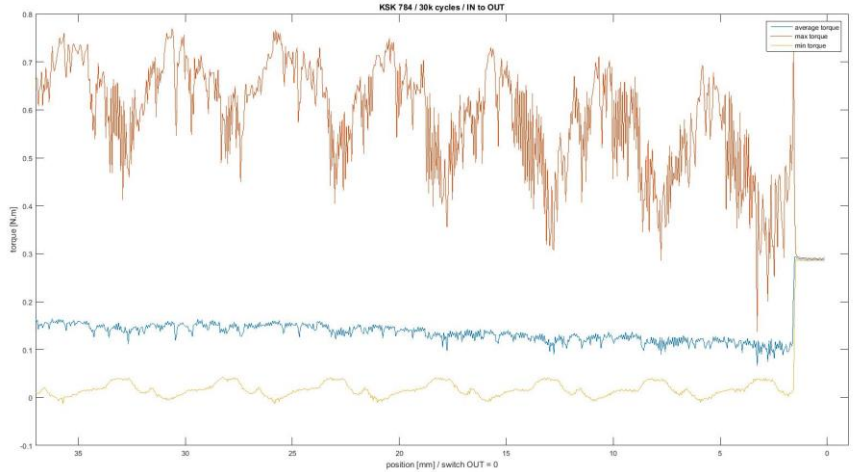
0 k



10 k



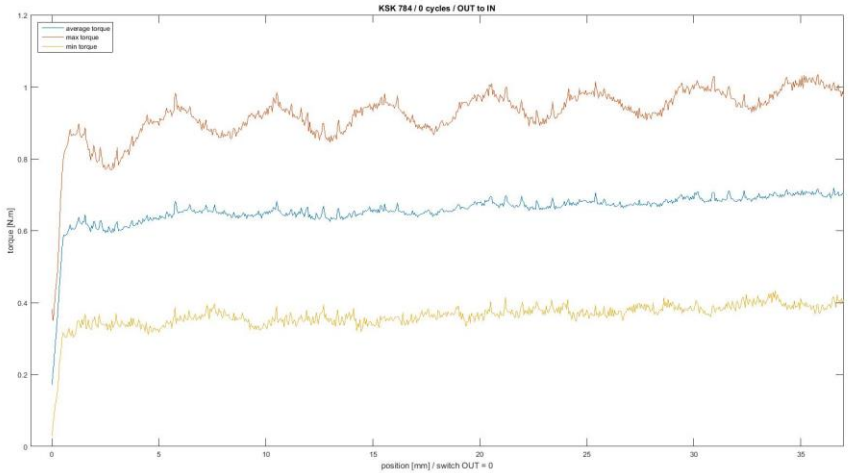
20 k



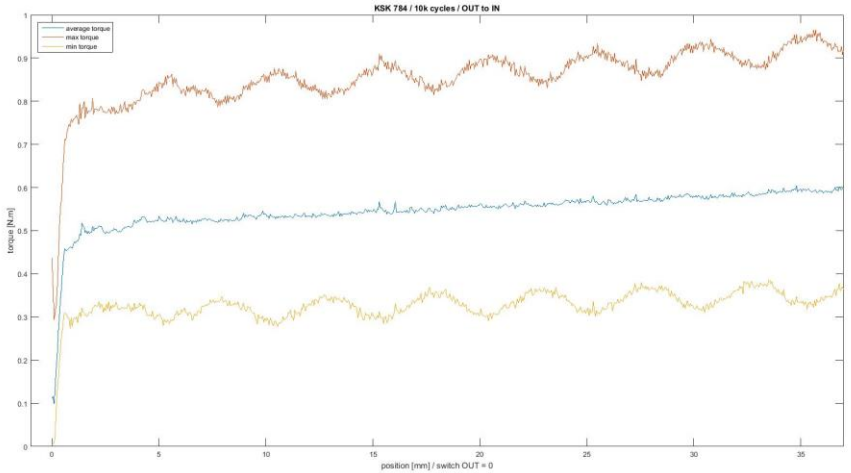
30 k

TORQUE TEST ANALYSIS ON DRY KSK SCREW

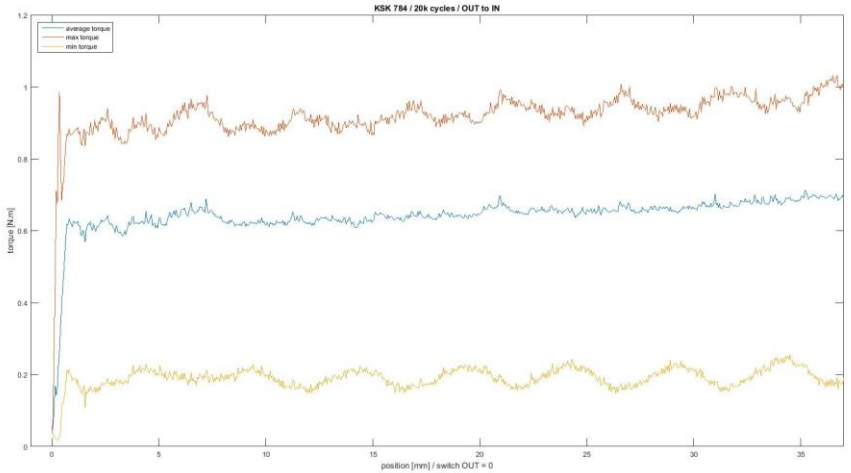
Screw 784 (down 2 kN) OUT to IN



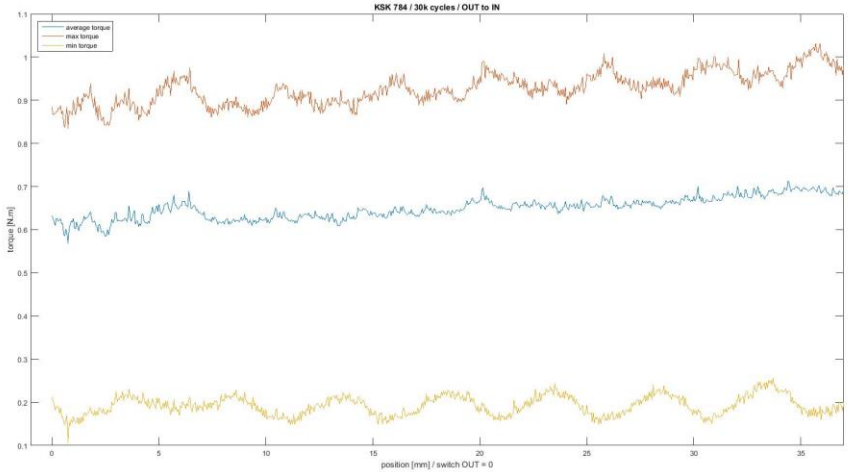
0 k



10 k



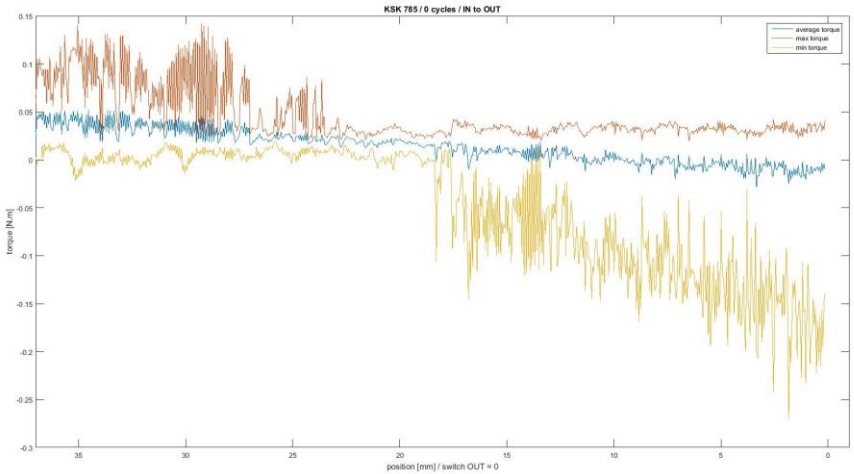
20 k



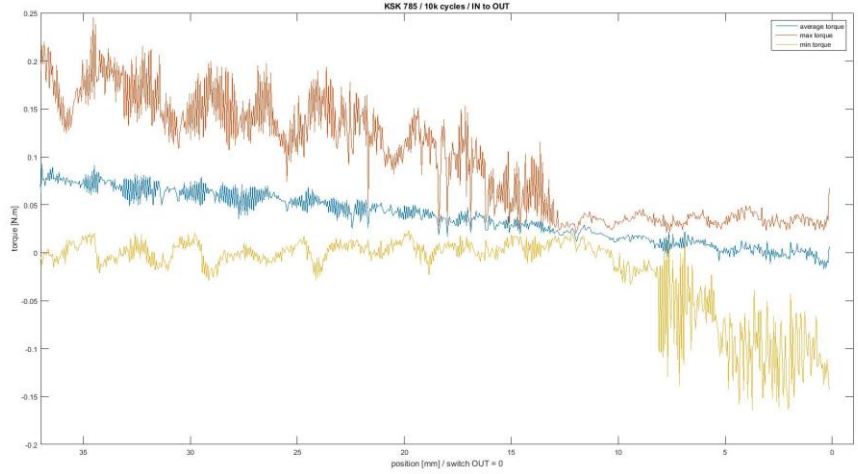
30 k

TORQUE TEST ANALYSIS ON DRY KSK SCREW

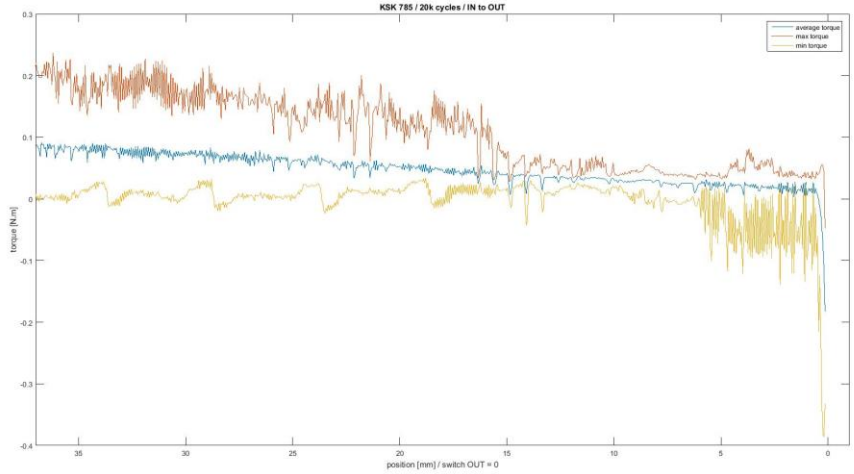
Screw 785 (up 1.4 kN) IN to OUT



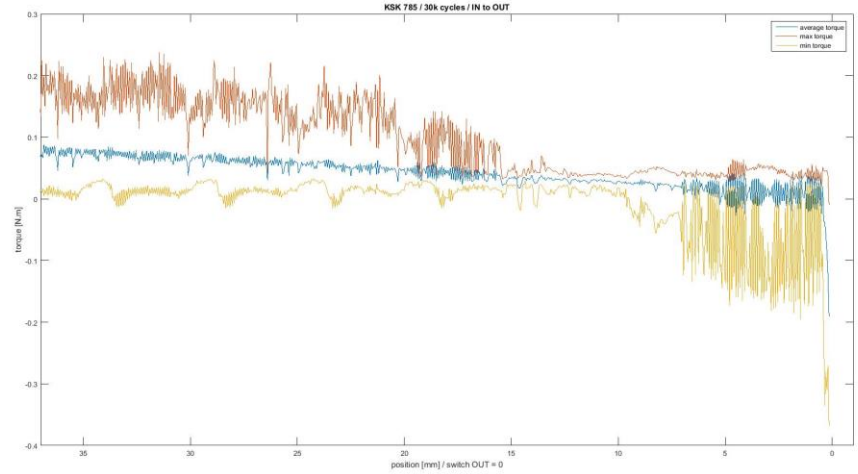
0 k



10 k



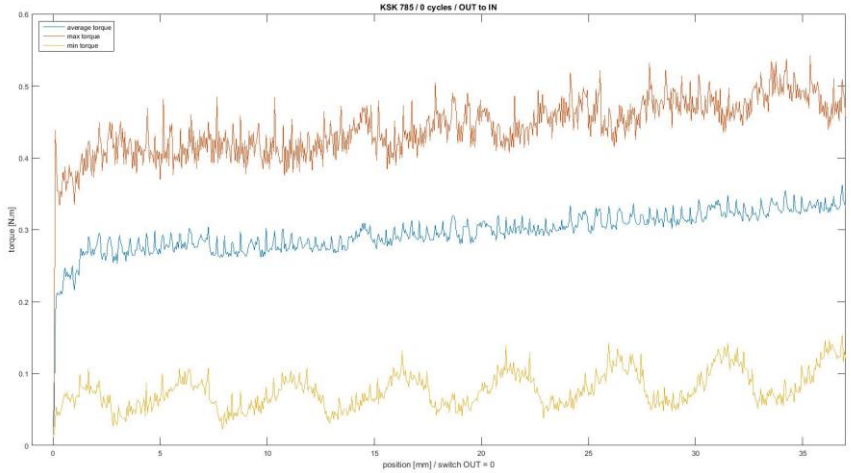
20 k



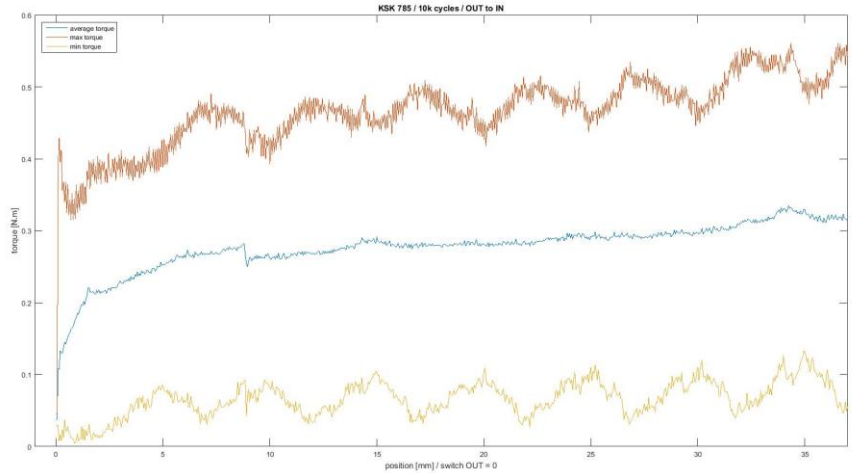
30 k

TORQUE TEST ANALYSIS ON DRY KSK SCREW

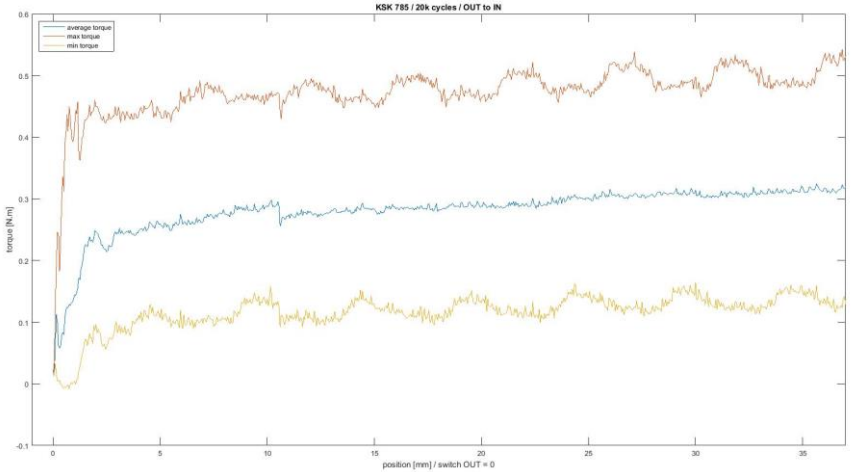
Screw 785 (up 1.4 kN) OUT to IN



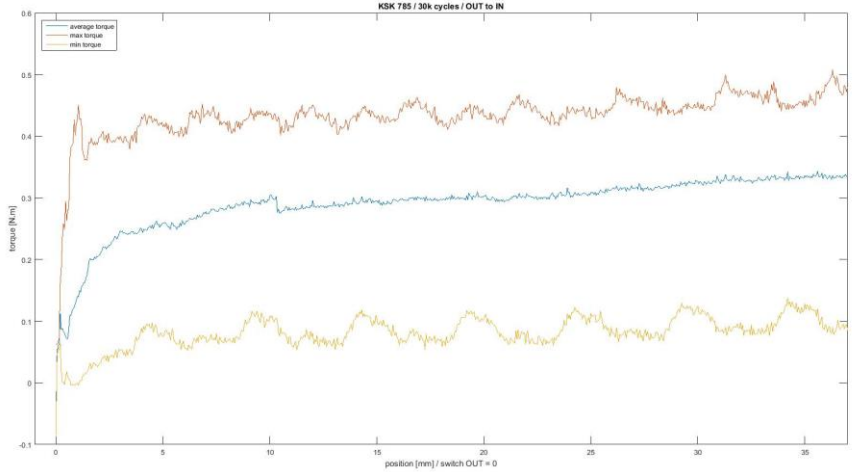
0 k



10 k

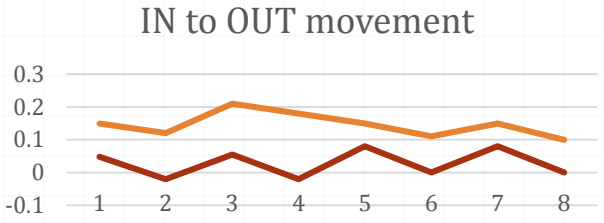


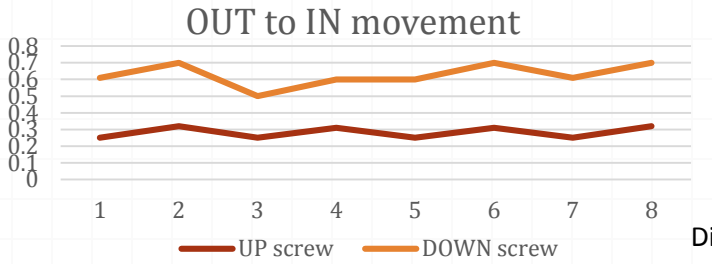
20 k



30 k

TORQUE TEST ANALYSIS ON DRY KSK SCREW





		0		10k		20k		30k	
		IN	OUT	IN	OUT	IN	OUT	IN	OUT
in to out	Screw 785 UP	0.048	-0.02	0.055	-0.02	0.08	0	0.08	0
	Screw 784 DOWN	0.15	0.12	0.21	0.18	0.15	0.11	0.15	0.1

		OUT	IN	OUT	IN	OUT	IN	OUT	IN
out to in	Screw 785 UP	0.25	0.32	0.25	0.31	0.25	0.31	0.25	0.32
	Screw 784 DOWN	0.61	0.7	0.5	0.6	0.6	0.7	0.61	0.7

Difference between IN and OUT (spring compression)

in to out	Screw 0017 UP	0.068	0.075	0.08	0.08
	Screw 0018 DOWN	0.03	0.03	0.04	0.05
out to in	Screw 0017 UP	0.07	0.06	0.06	0.07
	Screw 0018 DOWN	0.09	0.1	0.1	0.09

Difference between UP and DOWN (jaw load)

theorique 0.37 Nm

	IN	OUT	IN	OUT	IN	OUT	IN	OUT
in to out	-0.102	-0.14	-0.155	-0.2	-0.07	-0.11	-0.07	-0.1
out to in	-0.36	-0.38	-0.25	-0.29	-0.35	-0.39	-0.36	-0.38

Lubricated full Ceramic UMBRA screw **VS** dry KSK screws

- Torques in positions IN and OUT are constants during the cycling test on both screws in both directions.
- The torques of the KSK are slight smaller than UMBRA screw (**KSK Better efficiency**).
- Torque difference between IN and OUT position is constant during the cycling test on both screws but slight lower on the KSK screw (**KSK efficiency constant increasing the load**).
- Torque difference between UP and DOWN screws is the same for both screws and constant during the cycling test.

SKF dry screw

Test n°	Screw N°	Load [kN]	Last Cycle	Note
1	8183493-15	1.4	300	Motor lost step
	8183493-25	2	3300	A lot of Noise

Dry roller screw whit Dicronite coating

Cycling test summary

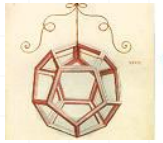
Supplier	Material	Lubricated	
UMBRA	5250-00032 Ceramic /SS -20µm	No	
UMBRA	5250-00032 Ceramic /SS -20µm	No	
UMBRA	5250-00032 Ceramic /SS -20µm	No	
UMBRA	5250-00032 Ceramic /SS -20µm	No	
UMBRA	5250-00032 Ceramic /SS -20µm	No	
UMBRA	5250-00032 Ceramic /SS -20µm	No	
UMBRA	5250-00032 Ceramic /SS -20µm	yes	
UMBRA	5250-00032 Ceramic /SS -20µm	yes	
UMBRA	5250-00032 Ceramic /SS -20µm	yes	
UMBRA	5250-00032 Ceramic /SS -20µm	yes	
UMBRA	5250-00028 Full Ceramic	No	
UMBRA	5250-00035 Full Ceramic	No	
UMBRA	5250-00032 Ceramic /SS -40µm	No	
UMBRA	5250-00033 Ceramic /SS -40µm	No	
SKF	Full Stainless Steel + Dicornite	No	
SKF	Full Stainless Steel + Dicornite	No	
KSK	Full Stainless Steel	No	
KSK	Full Stainless Steel	No	

Lubricated UMBRA screw
Possible replacement of SKF

Dry KSK screws

Validation after some others cycling test for statistic.

On-going Actions



MME Mechanical & Materials Engineering

- **KSK**
  - Metallographic investigations.
  - Comparison between analytical data and theoretical simulations.
  - Cycling test of others 2 screws for statistic.
- **SKF**
  - Metallographic investigations.
- **Kugel motion:** roller screws with WCC coating
  - Visual test. Done
  - Metrology test (EDMS: 1753580). Done
  - Cycling test of 4 screws.
  - Metallographic investigations.

Thanks for your attention