Master of Science

Part C: Hard Testing and Verification – Test report

Project: Wire Gear for Small Rotary Actuator

Contracting Authority: Kongsberg Space Systems

Rev:	Date:	Author:
6.0	070518	VOA

i. Abstract

Part A set the boundaries for the system to be developed, Part B developed the system. Both parts with the same goal of making a wire-geared small rotary actuator as close to the environment as possible. This Part C is now the hard and last verification post for the system development iteration. Is the system designed and produced correctly? Is the right system being build? Recall that the main goal for this thesis is to develop and produce a wire-geared small rotary actuator as close to the real environment as possible to find out how the wire behaves over time in vacuum.

As result, Part C concludes that the system was designed correctly, produced correctly, and build correctly. A feasible amount of the tests was executed, the pre-tensioning method before lifetime testing worked and the mechanism and wire preformed over 1M cycles and kept its integrity.

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vi. Abbreviations

EREQ	-	Environmental Requirement
HBM	-	Hottinger Baldwin Messtechnik GmbH
KH	-	Ketil Hansen
KSS	-	Kongsberg Space Systems
NORF	-	Norsk Fletteri AS
PDR	-	Preliminary design review
QDA	-	Quick Design Analysis
QDR	-	Quick Design Review
REQ	-	Requirement
SRA	-	Small Rotary Actuator
TBC	-	To Be Complied
TBD	-	To Be Determined
TREQ	-	Technical Requirement
VOA	-	Vebjørn Orre Aarud
WG-SRA	-	Wire Gear Small Rotary Actuator

1. Introduction

Part C is highly linked to Part A because of the boundaries set in Part A. Key features such as requirements and test methods was defined in Part A and now to be verified. Part B describes how the system is being build and provides a link to both Part A and C because of this input.

Part C builds on the verification structure as shown in Figure 1. First small and rapid verification on subsystem level is made, and slowly progress to system level verification, ending up with a life time test with the following global results:

- 59% of the planned test executed.
- Pre-life time test executed with success.
- Lifetime test executed with over 1.2M cycles with its integrity stable.

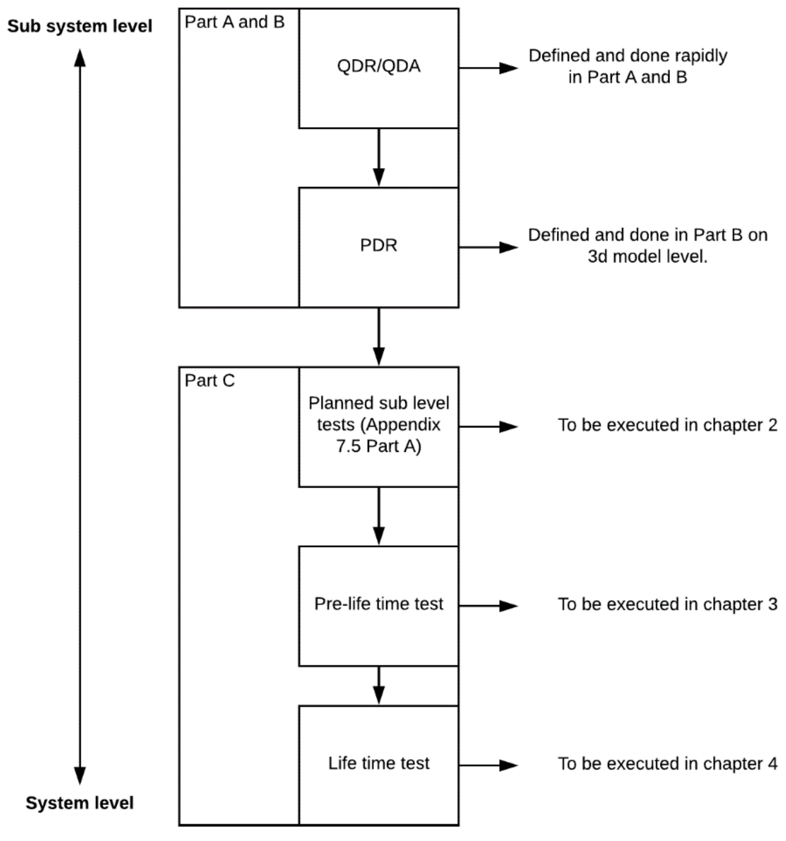

Figure 1: Verification structure.

2. Sub level tests and results

In Part A selection 7.5, several tests are defined and now to be executed and discussed. With the following status.

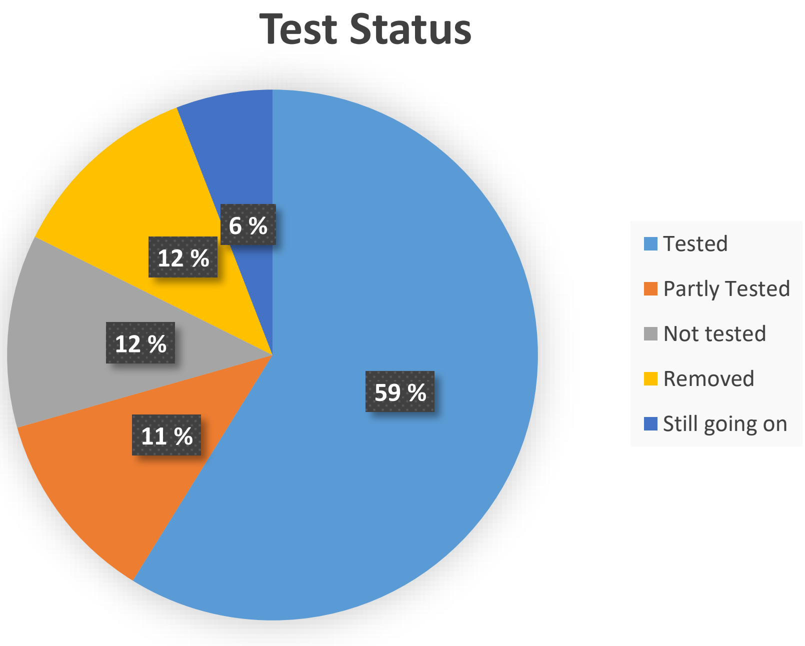

Figure 2: Test status.

59 % of the planned tests is tested and executed, 11% of the planned test is partly tested. 12% is not tested, 12% is removed and 6% is still going on. This result seems feasible for this first iteration, and all subsystems are considered stable.

Test: TST 1.

Test ID:	TST-1		**Requirements to be tested:**	EREQ-1, EREQ-2	
Pass criteria:	The system shall withstand operation in temperatures between [-25, +65] ºC both in function and not in function.				
Test method:	Analysis or review				
Execution:	Conduct a material analysis or review by engineering tool to select a suitable material.				
Result:	**Partly acceptable.**	**Date:**	070518	**Sign:**	
Comment:	The materials are selected accordingly to requirement EREQ-1 and EREQ-2 and can be found in Part B selection 3.6. The system has been tested in ambient temperature of 20-25 degrees Celsius. However, the system has not been tested for temperatures -25 or 65 degrees. No analysis is executed. Because of this TST-1 is partly verified but acceptable.				

Test: TST 2.

Test ID:	TST-2		**Requirements to be tested:**	EREQ-3	
Pass criteria:	The system shall not have an outgassing molecules/volume more than TBD.				
Test method:	Test				
Execution:	Conduct a test in vacuum chamber where the outgassing for the system is measured.				
Result:	**Removed**	**Date:**	070518	**Sign:**	
Comment:	By discussion with KSS, requirement EREQ-3 is removed and test is not executed.				

Test: TST 3.

Test ID:	TST-3		**Requirements to be tested:**	EREQ-4	
Pass criteria:	The system shall not degrade with the radiation levels in LEO				
Test method:	Review				
Execution:	Conduct a material analysis or review by engineering tool to select a suitable material.				
Result:	**Passed**	**Date:**	070518	**Sign:**	
Comment:	The system is designed accordingly to ECSS standards and materials selected with respect to EREQ-4. This can be found in Part B, selection 3.6. This test is verified and passes through review.				

Test: TST 4.

Test ID:	TST-4		**Requirements to be tested:**	EREQ-5	
Pass criteria:	The system shall not be affected by humidity levels of TBD				
Test method:	Review				
Execution:	Conduct a material analysis or review by engineering tool to select a suitable material.				
Result:	**Removed**	**Date:**	070518	**Sign:**	
Comment:	By discussion with KSS, requirement EREQ-3 is removed and test is not executed.				

Test: TST 5.

Test ID:	TST-6		**Requirements to be tested:**	EREQ-7,	
Pass criteria:	The system shall not be affected by the LEO environment.				
Test method:	Test				
Execution:	TBD				
Result:	**Not tested**	**Date:**	070518	**Sign:**	
Comment:	Not Tested.				

Test: TST 6.

Test ID:	TST-7		**Requirements to be tested:**	TREQ-1	
Pass criteria:	The SRA must have a center hole lager than 30.00mm				
Test method:	Analysis or review				
Execution:	Design review.				
Result:	**Passed**	**Date:**	070518	**Sign:**	
Comment:	Verified trough selection Part B selection 3. Note that the loadcell interfere with the hole, but not the system. This is acceptable because the load cell is not a part of the final product.				

Test: TST 7.

Test ID:	TST-8		**Requirements to be tested:**	TREQ-2	
Pass criteria:	The SRA cannot have large pointing error than 0.02 deg				
Test method:	Test, Analysis or review				
Execution:	Conduct a pointing budget.				
Result:	**Partly passed**	**Date:**	070518	**Sign:**	
Comment:	Verified trough selection Part B selection 5.5. This budget is highly estimated and must be verified by KSS before fully passed.				

Test: TST 8.

Test ID:	TST-9		**Requirements to be tested:**	TREQ-3	
Pass criteria:	The SRA must have a mass less than 1.0kg				
Test method:	Analysis or Review				
Execution:	Conduct a mass budget.				
Result:	**Passed**	**Date:**	070518	**Sign:**	
Comment:	Verified trough selection Part B selection 5.1.				

Test: TST 9.

Test ID:	TST-10		**Requirements to be tested:**	TREQ-4	
Pass criteria:	The life time of the SRA must be higher than 500000 cycles.				
Test method:	Test				
Execution:	Conduct a lifetime test				
Result:	**Still going on**	**Date:**	070518	**Sign:**	
Comment:	Still going on				

Test: TST 10.

Test ID:	TST-11	**Requirements to be tested:**	TREQ-5		
Pass criteria:	The motor uses less than 8W.				
Test method:	Analysis or Review				
Execution:	Conduct a power budget.				
Result:	**Passed**	**Date:**	070518	**Sign:**	
Comment:	Verified trough selection Part B selection 3.1. And with limiter on power supply.				

Test: TST 11.

Test ID:	TST-12	**Requirements to be tested:**	TREQ-6		
Pass criteria:	The total production cost less than 5,000 euro				
Test method:	Review				
Execution:	Cost budget				
Result:	**Passed**	**Date:**	070518	**Sign:**	
Comment:	Verified trough selection Part B selection 5.7.				

Test: TST 12.

Test ID:	TST-13	**Requirements to be tested:**	TREQ-7		
Pass criteria:	The SRA can move 380 deg from ends top.				
Test method:	Analysis or review				
Execution:	Design analysis				
Result:	**Passed**	**Date:**	070518	**Sign:**	
Comment:	Verified trough dynamical analysis, Proof of Concept and prototype.				

Test: TST 13.

Test ID:	TST-14	**Requirements to be tested:**	TREQ-8, TREQ-9		
Pass criteria:	The SRA can move with more than 90 deg/s and accelerate to 90 deg/s faster than 0.5 second				
Test method:	Analysis or review				
Execution:	Design analysis				
Result:	**Passed**	**Date:**	070518	**Sign:**	
Comment:	Verified trough selection Part B selection 5.4.				

Test: TST 14.

Test ID:	TST-15		**Requirements to be tested:**	TREQ-10	
Pass criteria:	The wire tension can be adjusted				
Test method:	Test				
Execution:	TBD				
Result:	**Passed**	**Date:**	070518	**Sign:**	
Comment:	Verified trough prototype.				

Test: TST 15.

Test ID:	TST-16		**Requirements to be tested:**	TREQ-12	
Pass criteria:	The driveline can overcome the friction in the SRA				
Test method:	Test or analysis				
Execution:	Design analysis				
Result:	**Passed**	**Date:**	070518	**Sign:**	
Comment:	Verified trough prototype.				

Test: TST 16.

Test ID:	TST-17		**Requirements to be tested:**	TREQ-14	
Pass criteria:	The preload in the ball bearing is 207 Newton				
Test method:	Analysis or review				
Execution:	Design Analysis				
Result:	**Passed**	**Date:**	070518	**Sign:**	
Comment:	Verified trough stiffener, cannot be preloaded with more than 207 Newton.				

Test: TST 17.

Test ID:	TST-18		**Requirements to be tested:**	TREQ-15	
Pass criteria:	The mass over SRA is less than 1.450 kg				
Test method:	Analysis or review				
Execution:	Design Analysis				
Result:	**Not tested.**	**Date:**	070518	**Sign:**	
Comment:	Not tested				

3. Pre-life time test

Based on experience during the thesis. Creep is an issue. The following process is applied to reduce the risk of creep. First the knots, are secured and glued. This to make sure it will hold its integrity and not "loosen". Second the wire is loaded with a given preload and set overnight. Third the wire is readjusted if needed and set in cycles overnight. Forth the system is set in the vacuum chamber, and set to run for 5 hrs., readjust if needed. And finally, a pre-test in vacuum. Hopefully all initial creep is now removed, and lifetime test can be executed. If the tension in the wire decrease below acceptable levels, the test must be stopped, wire adjusted, and test restarted. Figure 3 shows the results and process.

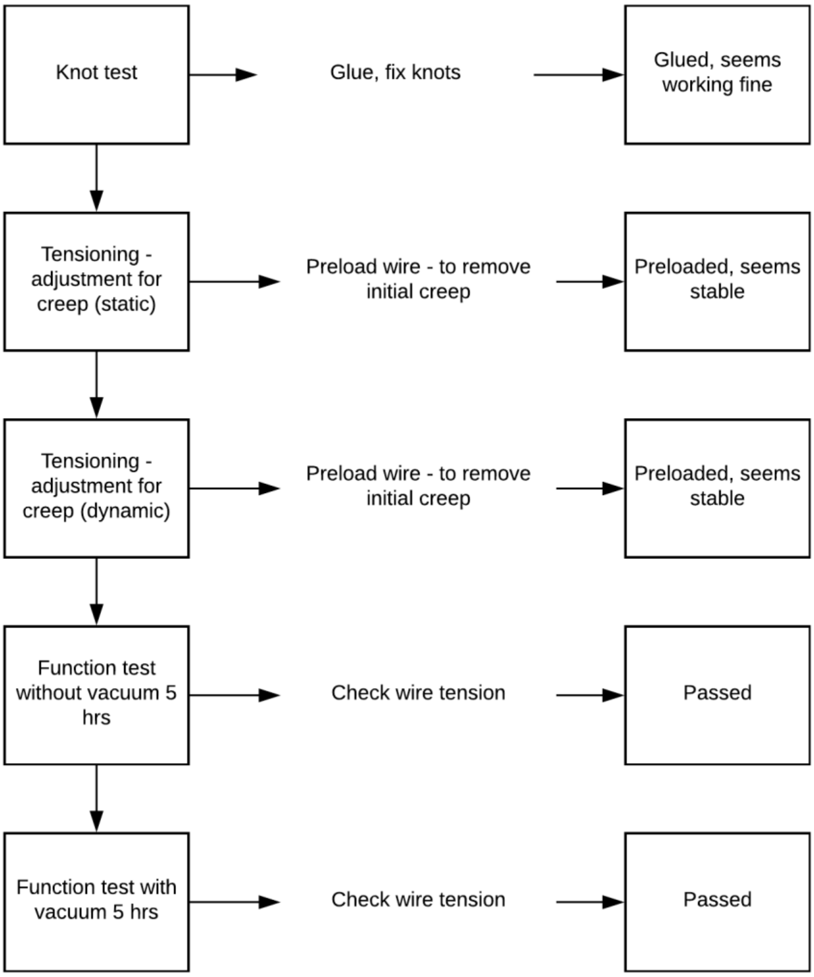

Figure 3: Pre-life time.

4. Life time test

4.1. Description on test rig.

The test rig is the developed SRA from Part B. Recall an output shaft of 140 mm in diameter, and an input shaft of 14 mm with a pitch of 1,75 mm, 12 turns. With a total angular friction of 345,6 mNm and surface roughness of N5. The test rig and equipment's are illustrated in Figure 4 to Figure 6

Figure 4: Tensioning monitor

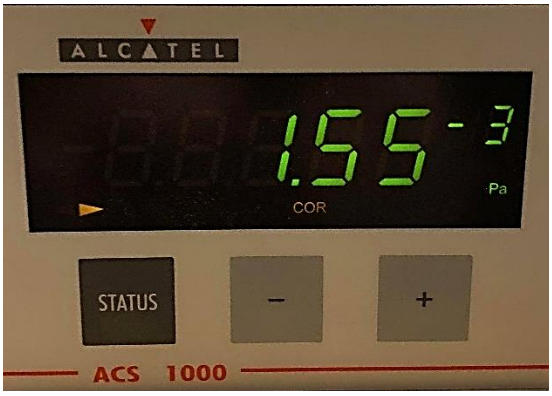

Figure 5: Pressure monitor

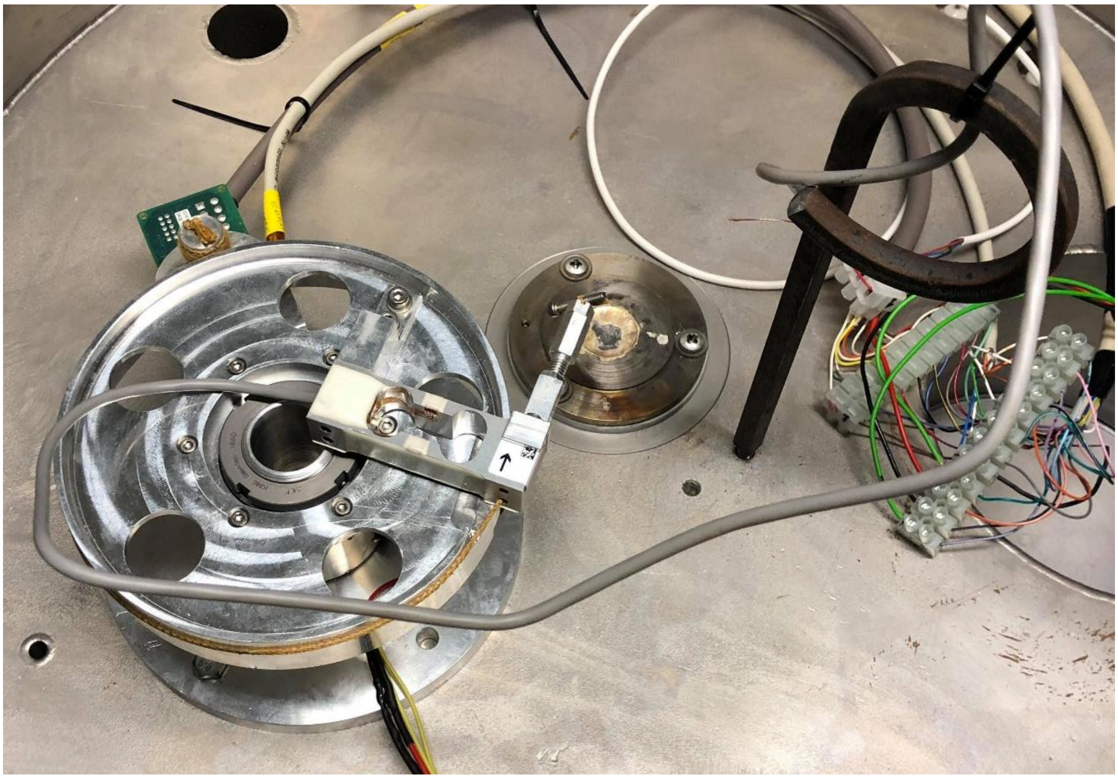

Figure 6: Test setup

4.2. Description of test wire.

The wire is the NORF-1, this was the only wire that executed friction test. The NORF-1 wire has the following specifications:

- Circular diameter of 1.0mm
- Fiber tensile modulus of 1650 cN/dtex
- Braided with 8 strands, in “flag line” braid
- Custom braided from Norsk Fletteri.
- Fibers directly from Toyobo.
- Wire tensile strength from test at Norut was estimated to 1250 N at approx. 43 mm elongation on a 385mm long wire.
- Completed over 1M cycles in adhesive friction test – no major remarks.
- NOT PROTECTED AGIANST UV BEAMS!

4.3. Procedure followed.

- Pre-lifetime procedure to reduce creep was executed.
- Test started without monitoring preload, an unspecified preload was given – no slack observed. Vacuum applied.
- Load cell manual calibrated by datasheet by HBM.
- Test running for approx. 350,000 cycles, loadcell now connected. Tension above suggested minimum.
- Wire tension and vacuum pressure monitored twice a day.

4.4. Test log.

Table 1: Test log

Cycles (10^3):	Wire tension (kgf):	Pressure (Pa):	Comment:	Engineer:
0			Started. Pre-running, not monitoring pressure or tension	VOA
357,30	2,3495	0,00158	No comment. Started monitoring pressure and tension	VOA
362,16	2,3483	0,00158	Possible knot failure ?	VOA
565,56	2,3433	0,00153	Squeaking noise.	VOA
576,54	2,3383	0,00153	Squeaking noise.	VOA
604,26	2,3345	0,00152	Squeaking noise.	KH
613,80	2,3339	0,00152	Squeaking noise.	VOA
646,02	2,3312	0,00156	Squeaking noise.	VOA
656,46	2,3302	0,00155	Squeaking noise.	VOA
667,26	2,3289	0,00155	Squeaking noise.	KH
690,3	2,328	0,0015	Squeaking noise.	KH
693,18	2,059	0,0015	Squeaking noise.	VOA
697,68	2,0566	0,00146	Squeaking noise.	VOA
709,74	2,0555	0,0015	Squeaking noise.	KH
733,86	2,0546	0,00143	Squeaking noise.	VOA
743,4	2,0543	0,00143	Squeaking noise.	VOA
753,3	2,0541	0,00144	Squeaking noise.	VOA
784,26	2,056	0,00165	Squeaking noise.	KH
862,92	2,054	0,00145	Squeaking noise.	VOA
876,06	2,0546	0,00148	Squeaking noise.	KH
904,86	2,0602	0,0015	Squeaking noise.	VOA
925,2	2,063	0,00165	Squeaking noise.	KH
948,24	2,0632	0,00134	Squeaking noise.	VOA
966,6	2,0624	0,00135	Squeaking noise.	KH
991,62	2,0629	0,00128	Squeaking noise.	VOA
1007,1	2,0627	0,00127	Squeaking noise.	KH
1034,46	2,0622	0,00141	Squeaking noise.	VOA
1051,2	2,0611	0,00173	Squeaking noise.	VOA
1164,24	2,0603	0,00133	Squeaking noise.	KH
1175,4	2,0598	0,00155	Squeaking noise.	KH
1181,34	2,0599	0,00139	Squeaking noise.	KH
1107,8	2,059	0,00142	Squeaking noise.	KH
1222,74	2,095	0,00155	Squeaking noise.	VOA
1228,5	2,0572	0,00156	Squeaking noise.	VOA
1250,64	2,0569	0,00126	Squeaking noise.	KH
1253,34	2,0585	0,00128	Squeaking noise.	KH
1254,06	2,051	1 ATM	Squeaking noise.	KH
1255,86	2,056	1 ATM	Stopped, finished	VOA

4.5. Test comment.

The test was supposed to start medio April 2018. However due to issues with the supplier related to the monitoring station for tension was delayed. The test started without monitoring 8 of May 2018. The equipment for monitoring was ordered medio Mars 2018. This causes issues with the desired amount of cycles needed, and I choose to start the test without monitoring the initial preload, tension.

This means that I have no data on how much the mechanism was preloaded initially, and how the tension was in the first 350,000 cycles. I did choose to start the test because 350,000 cycles represent only 7 % of the desired 5M cycles. I believe that my process for removing initial creep is good and the start is accepted. However, because of time slightly about 1M cycles was executed. Because of this, this test is incomplete, but give good initial information related to pressure, wear and tension.

Figure 7 shows the WG-SRA during test inside the vacuum chamber. Representative, electrical component and electrical guide are present. Note the steel beam to hold the electrical wire for the load cell to counter “flexing” fatigue.

Figure 7: WG-SRA during test

4.6. Test results.

By investigation of the WG-SRA the following results were observed:

- The glued knots with Loctite superglue, worked perfectly. No interference at all.
- The glued sensors and magnet, with Epoxy 2-component metal, worked perfectly. No interference at all.
- The guide for the loadcell electrical wire, no damage what so ever to the electrical wire.
- Small knot failure on the input shaft, see Figure 9.
- The squeaking noise is from the bearing package, assuming lubrication issues. Was lubricated at KSS by KSS.
- The wire itself, is slightly degraded, but stable, see Figure 10.
- Some metal dust around the input shaft is observed, see Figure 10.
- Metallic surface color on the wire, see Figure 9 and Figure 10.
- The wire seems and feels dry, some outgassing?
- Wire tension above 2.0kg during all cycles.
- Stable test rig, except the squeaking noise.

In collaboration with KSS, the following result is presented and shown in Figure 8 on the next page. The squeaking noise might come from poor lubrication or to high preload in the bearings. However, this did not affect the test results. The wire is slightly surface damaged and carved out some metal dust but still very stable. The drop in wire tension between 550000 and 750000 cycles has no explanation, however its feasible to believe that this is due to monitoring issues, grounding or electrical failure within the equipment. This because the graph is very stable before and after the drop. I also conclude that the system was designed correctly, and was build right, because of this result. It did what it was supposed to do.

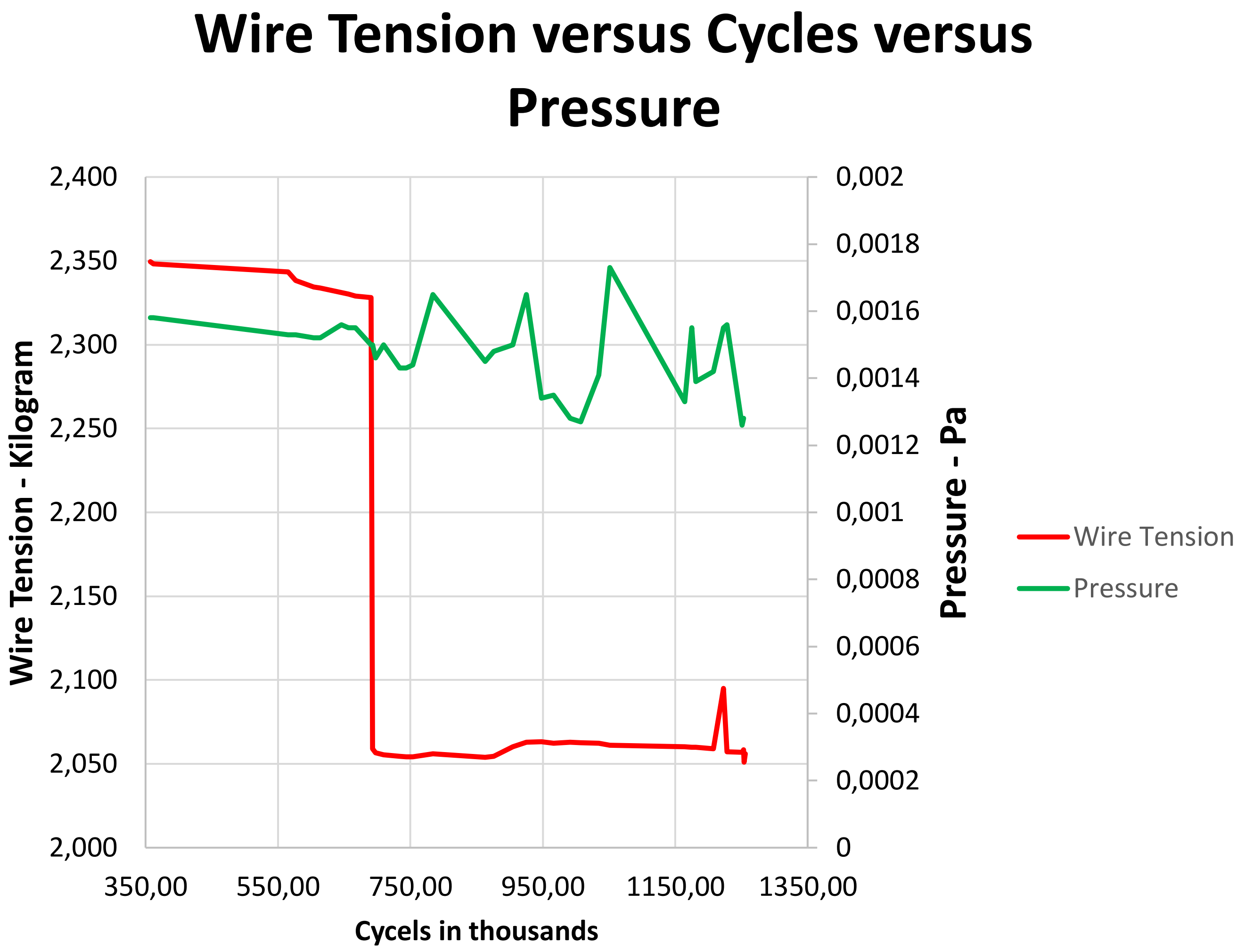

Figure 8: Wire Tension vs Cycles vs Pressure

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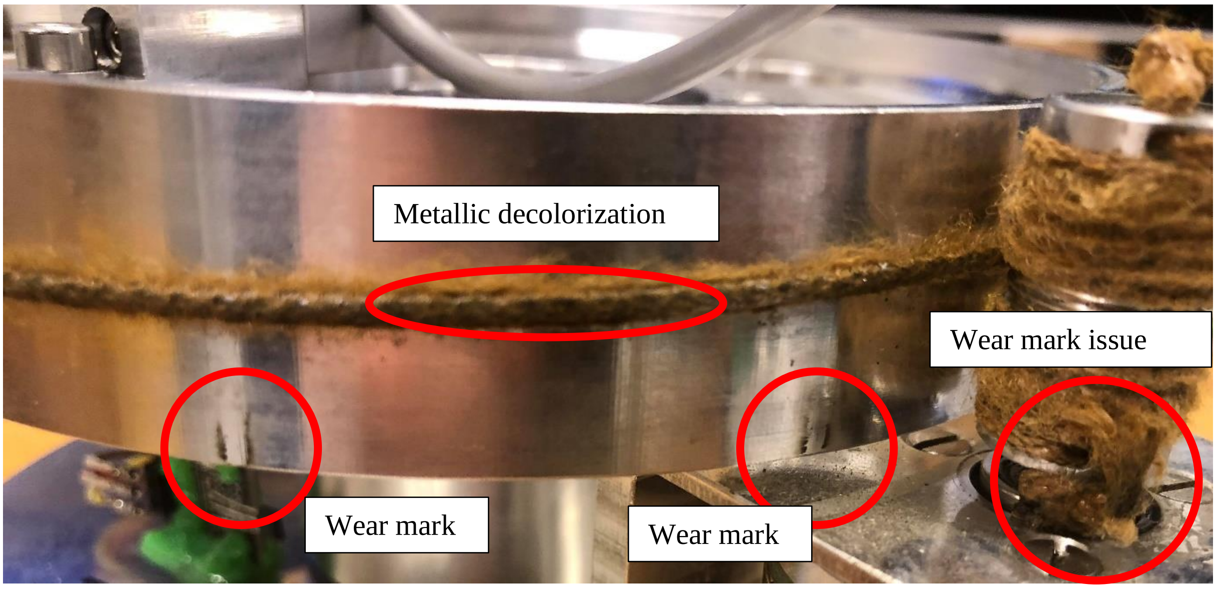

Figure 9: Minor knot failure.

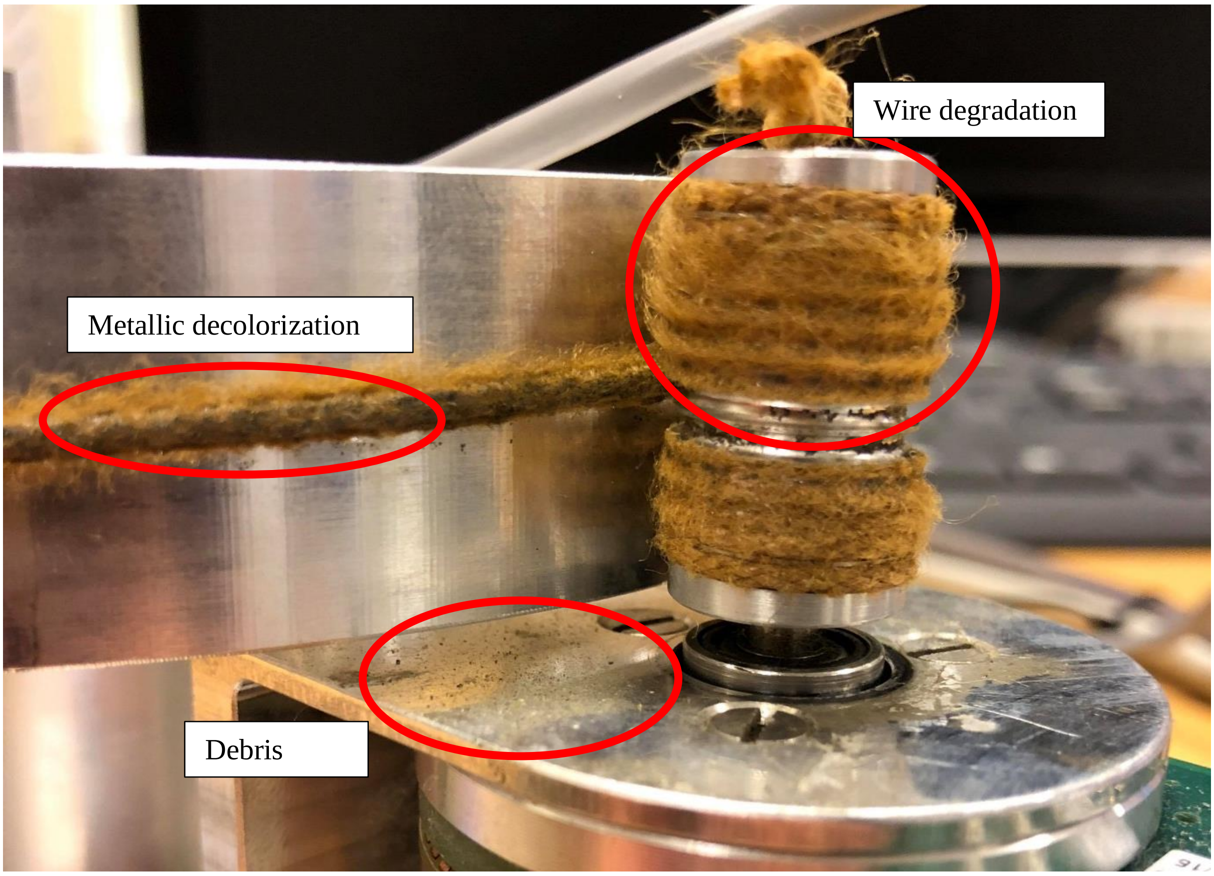

Figure 10: Wire degradation.

5. References

This document has no references.