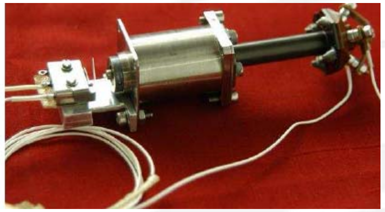
ARQUIMEA
Passion for Technology

DEVELOPMENT AND QUALIFICATION OF A EUROPEAN PIN PULLER

ESA ESTEC Contract No. 4000103964-11-NL-RA

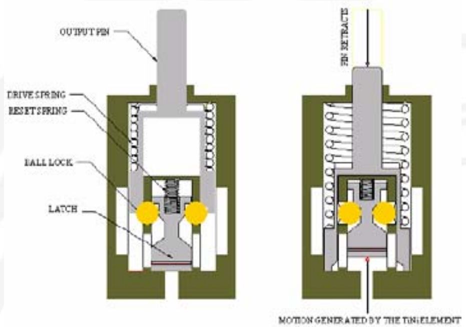
Mechanisms' Final Presentation Days 2014

12-13/06/2014



TECHNOLOGY SURVEY

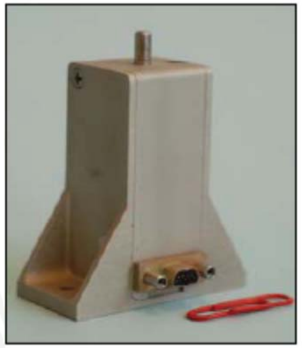
ISRO



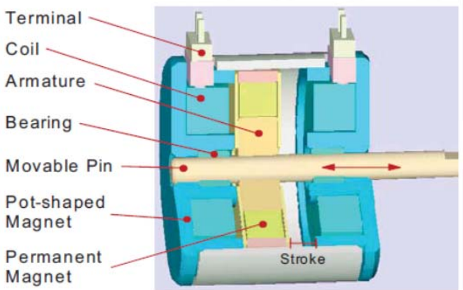
TiNi

Technology / Criteria	Paraffin	Burn wire	SMA	Electromagnetic	Piezoelectric
Stroke	High	-	Medium-High	Medium-High	Low
Load capability	High	Medium	Medium-High	Medium-High	High
Mass and volume	High	Medium	Low	Medium	Low
Actuation time	Slow response	Fast response	Moderate – Fast response	Moderate – Fast response	Fast response
Operating Temperature	Max. non actuation limited to 110ºC	Medium	Higher	Higher	Limited (Curie Temperature)
Type of release	Progressive	Shock	Progressive	Progressive	Progressive
Power consumption	High	High	Medium - High	High	Medium
Flight history	None (EM already developed)	None	PinPullers HDRM Rotary Actuators Frangibolt ...	None	None
Recurrent cost (ROM)	High	Low	Low	High	Low

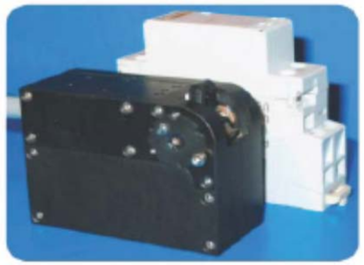
Paraffin



ASTRIUM Thermal Fuse



STARSYS HOP

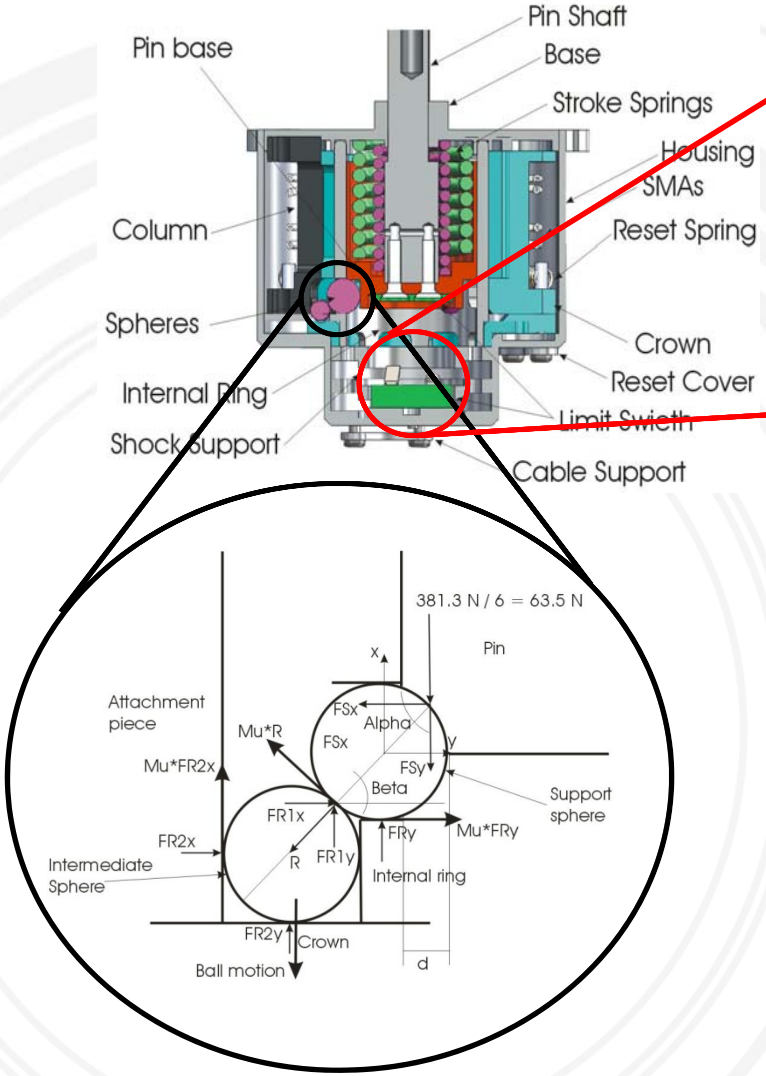


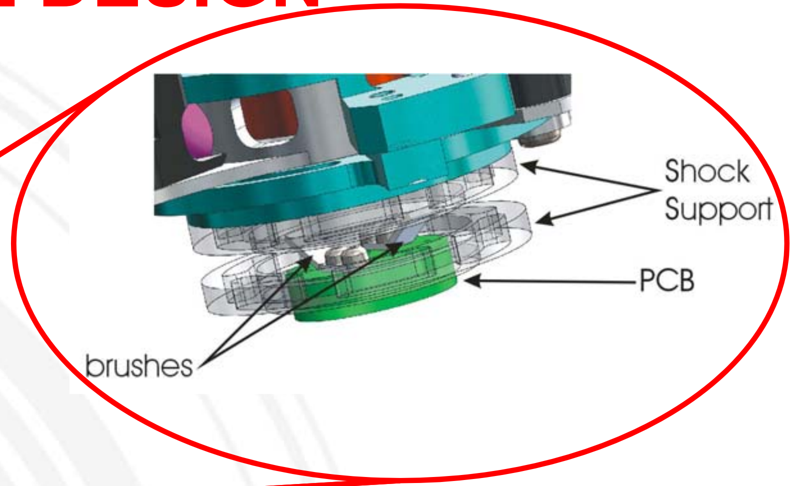
CEDRAT Piezoelectric

CRITICAL REVIEW OF ESA TECHNICAL REQUIREMENTS

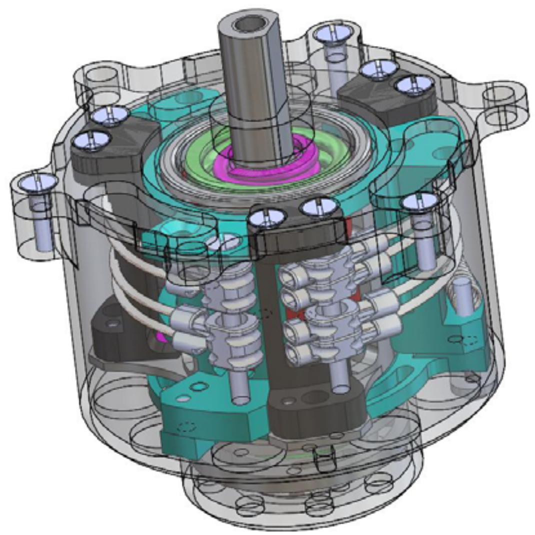
Parameter	Esa ITT	Achievable.	Comments
Recurring Price [k€]	< 7.0	Yes	– Preliminary analysis
Pin Stroke [mm]	10.0	Yes	– Ensured by preliminary design.
Min. Axial Pull Force [N]	100	Yes	– Ensured by preliminary design. – Motorization calculations according to ECSS-E-ST-33-01C.
Max. Shear Force (No-Actuation) [N]	1800	Yes	– Requirement change. (1) – Ensured by preliminary design. – Preliminary Analyses show the correct behaviour.
Max. Shear Force (Actuation) [N]	300	Yes	– Requirement change. (1) – Ensured by preliminary design. – Preliminary Analyses show the correct behaviour.
Mass [kg]	0.075	Yes	– Restrictive parameter. (2) – Ensured by preliminary design.
Operational Temperatures [°C]	-150 to +125	Yes	– Maximum Operational Temperature.(3) – Minimum Operational Temperature. (4) – Actuator design using SMARQ. (5)
Operational Cycles (min)	100 cycles	Yes	– Reliable Mechanical Design. – SMARQ lifetime > 100 cycles.
Redundancy	Redundant actuation	Yes	– Ensured by design. 2 independent trigger actuators will be included.
Electrical Interface	TBD after Market Research	Yes	– The most interesting option is Pyro interface(6)(7)
Actuation Time max [s]	< 0.5	Yes	– Restrictive requirement. (8)
Actuation Time Repeatability Error	10% of nominal actuation time.	Yes	– Error between actuations at the same environment temperature. (9)
No Shock	Yes	Yes	– Ensured by preliminary design. – Use of SMA technology.
Fully resettable	Yes	Yes	– Ensured by preliminary design. – A Reset Tool will be designed.
ITAR free	Yes	Yes	– ARQUIMEA technology.
Based on European components and processes	Fully	Yes	– Fully designed with European technologies and components. – SMARQ is an European product.
Pin Puller Technology	Non explosive	Yes	– Use of SMA technology.
Reusable	Yes. Without refurbishment	Yes	– Ensured by preliminary design.
Resettable	Yes, via manual operation.	Yes	– Reset Tool.
Pin Positions	Only 2 possible Pin positions (i) retracted (ii)deployed	Yes	– Ensured by preliminary design.
Position monitoring	Possible Position Sensor	Yes	– Position Sensor. – Possible problems with operating temperatures. (10)

MECHANICAL DESIGN



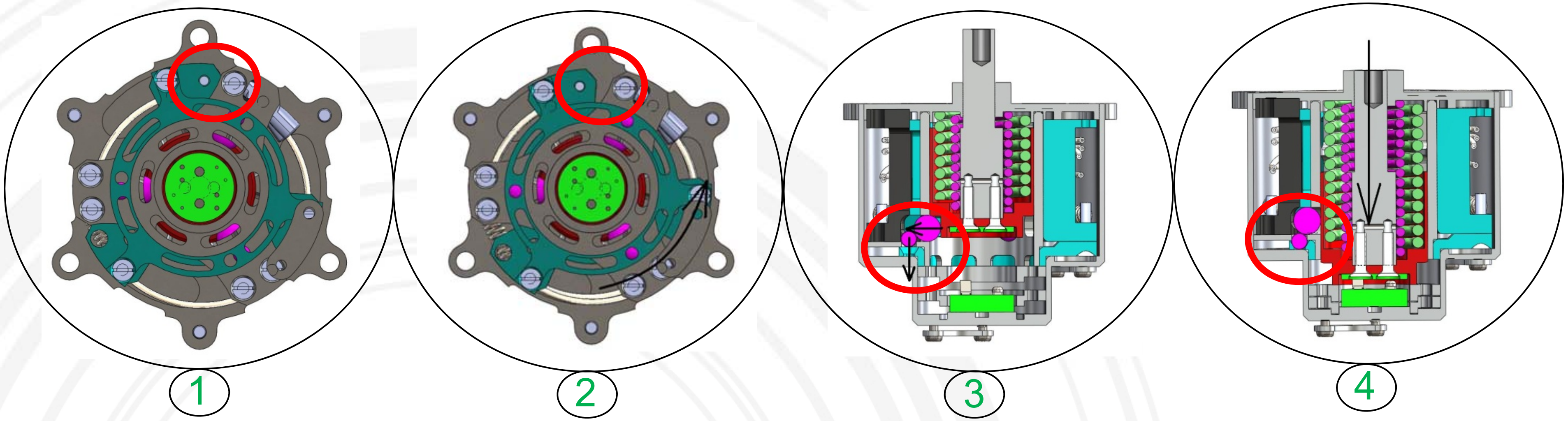


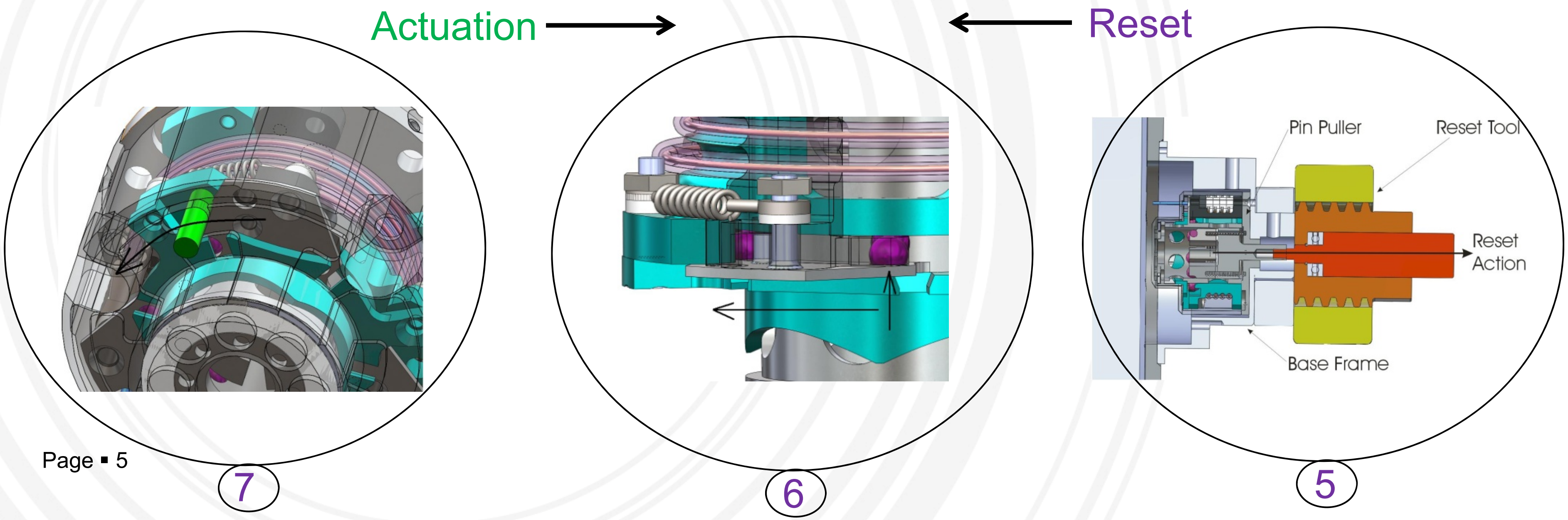
Monitoring System



3D-CAD Model of the Design

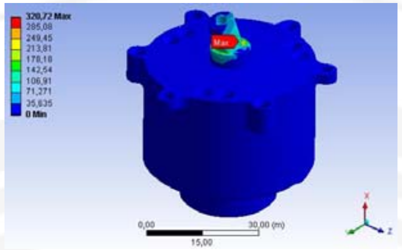
OPERATION PRINCIPLE



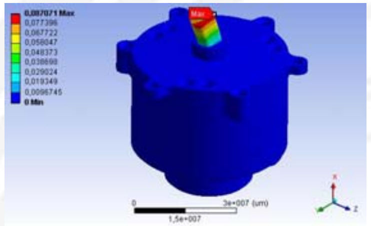


STRUCTURAL ANALYSES

Stress



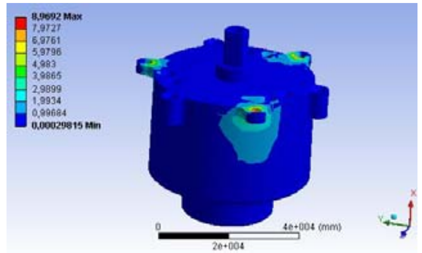
Stress



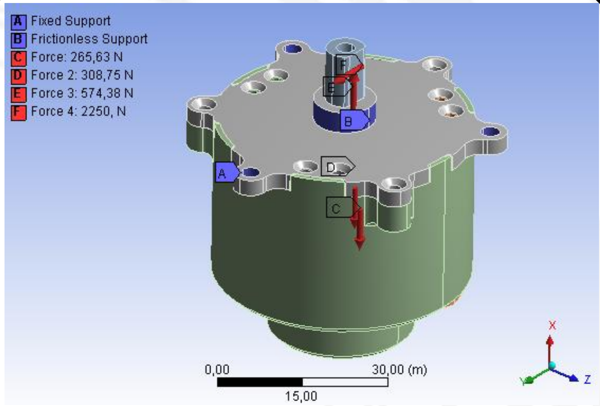
Deformation

Vibration

Modal

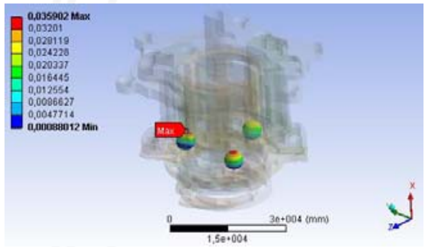


Stress Generated

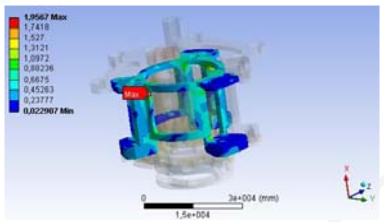


Finite Element Model

Self Actuation

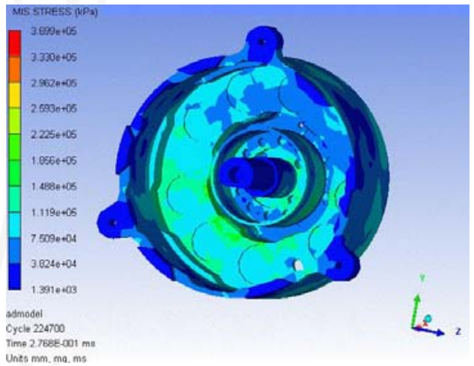


Spheres Failures



Self Crown Rotation

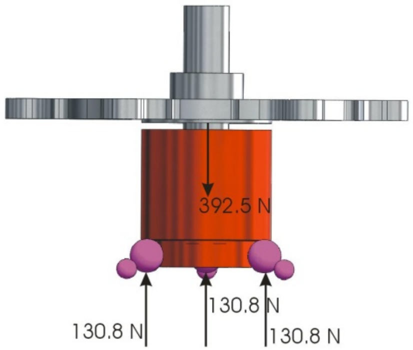
Shock



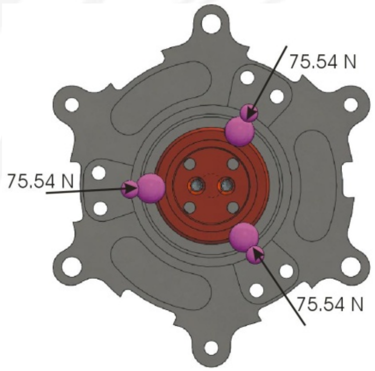
Equivalent Stress

MORE ANALYSES

Gapping

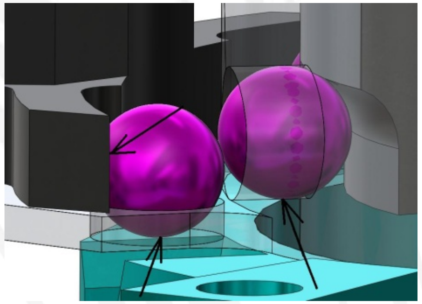


Axially

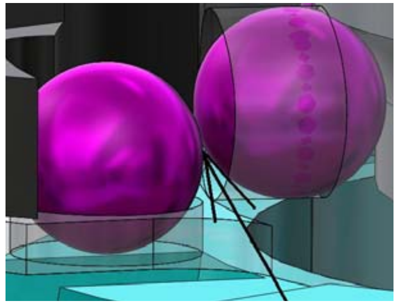


Radially

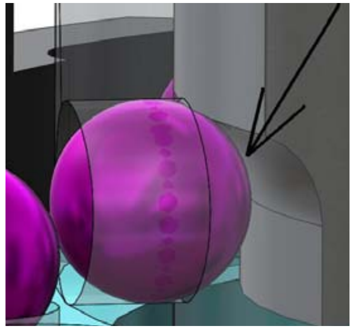
Hertzian



Sphere-Plane

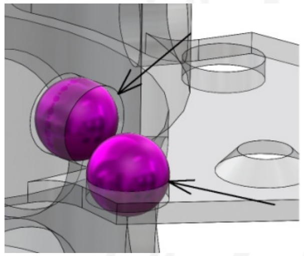


Sphere-Sphere

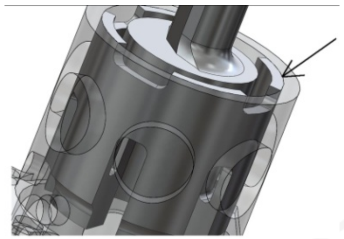


Sphere-Sphere

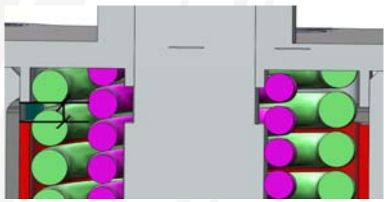
Thermal



Spheres

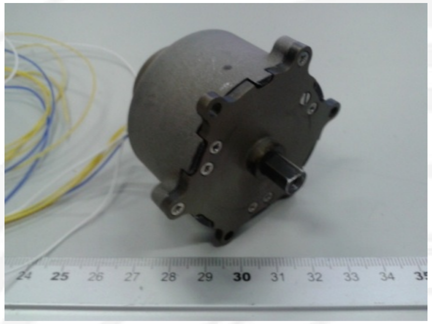


Diameters

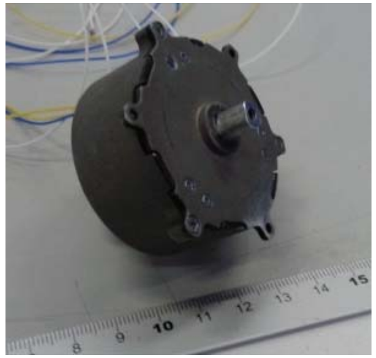


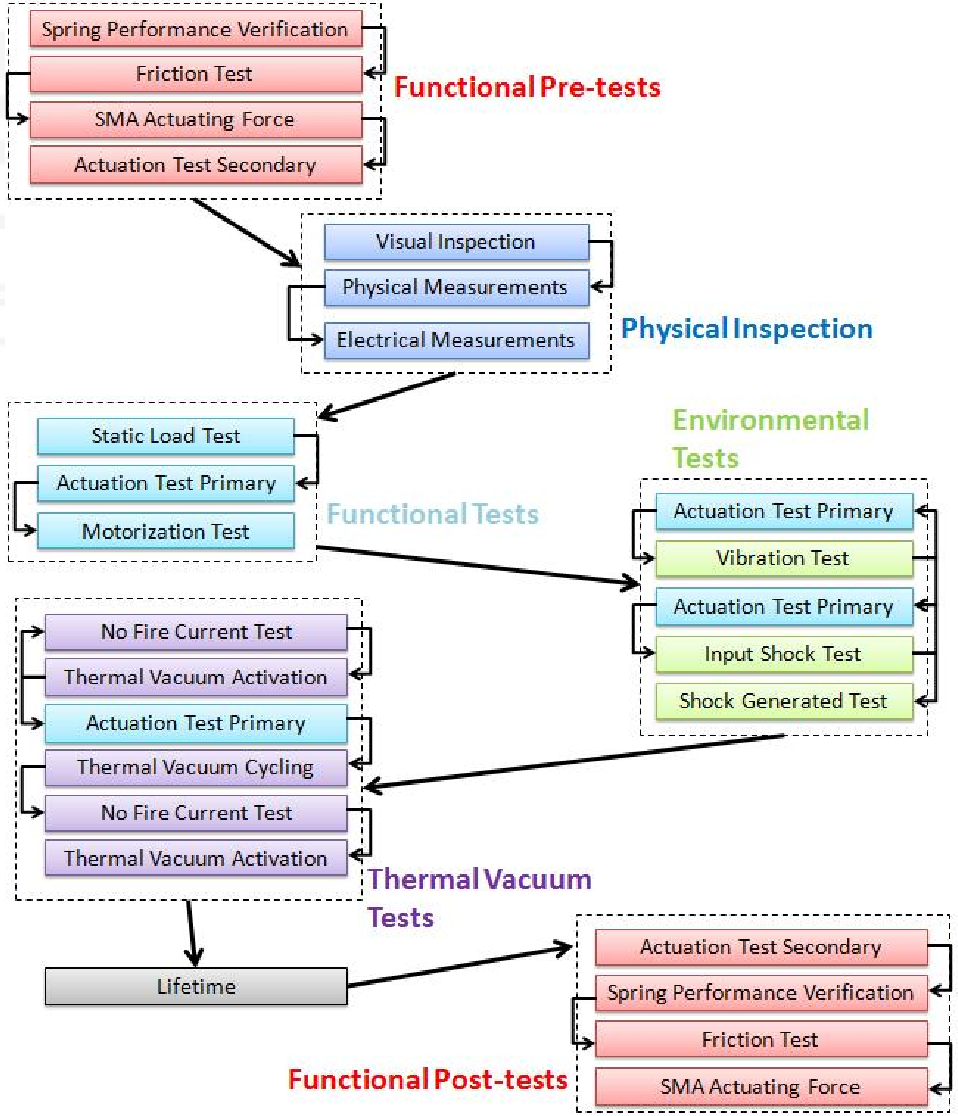
Height

TEST SEQUENCE FOR QM



100-N-Pin Puller



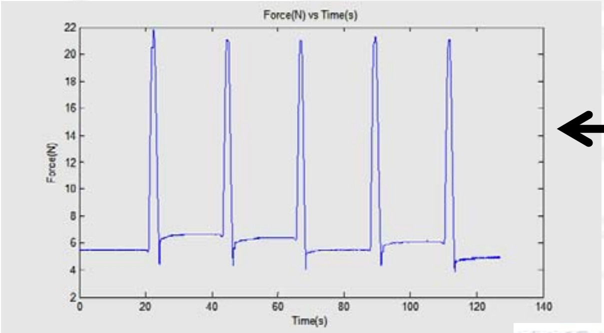


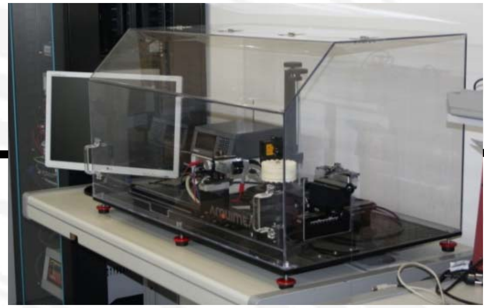
50-N-Pin Puller

FUNCTIONAL PRE-TEST

(SMA actuating force)

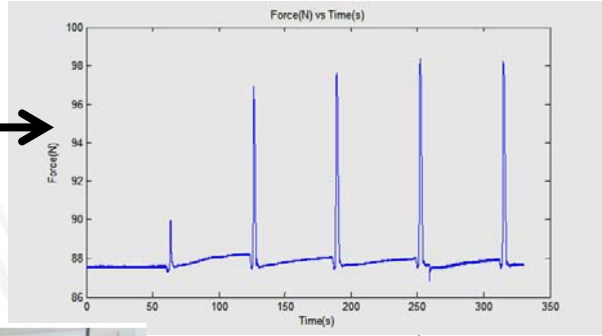
Small SMA Pull Force Straight

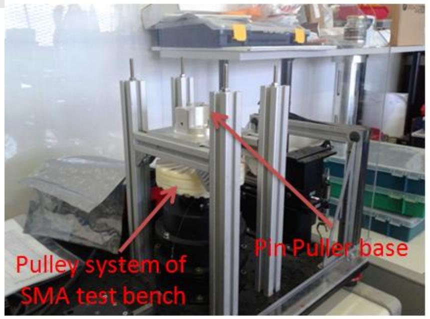


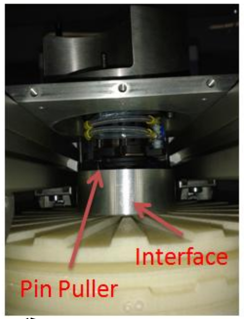


SMA Characterization Test Bench

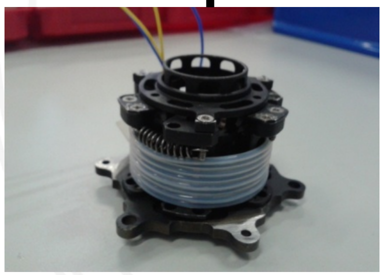
Big SMA Pull Force Straight



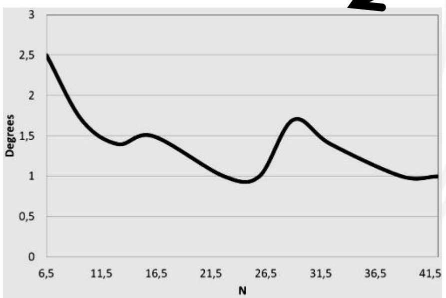




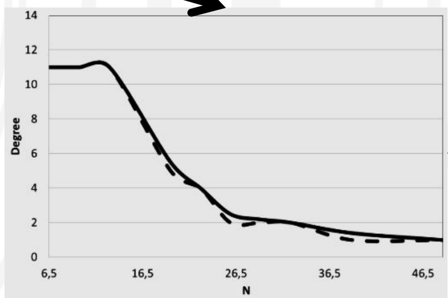
Pull Force Measurement in Curve



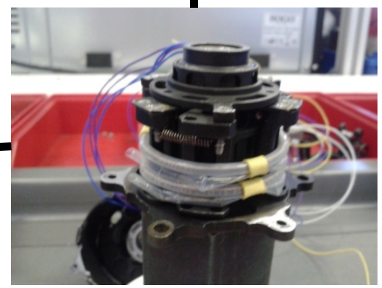
Small SMA Actuator
(Unfeasible)



Nitinol Pull Force in Curve



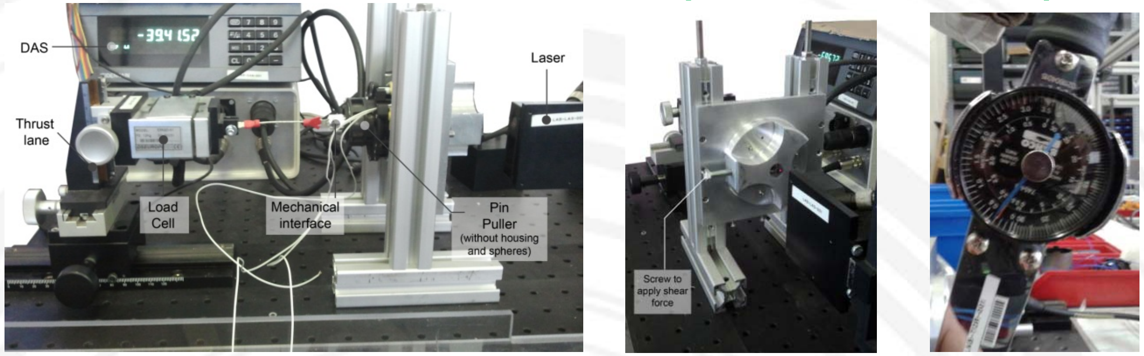
SMARQ Pull Force in Curve



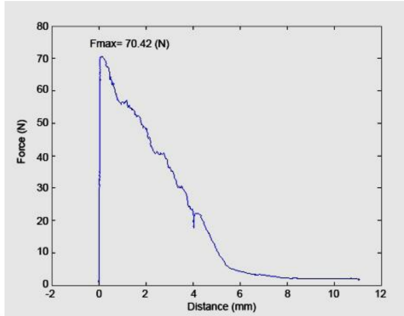
Big SMA Actuator

FUNCTIONAL PRE-TEST

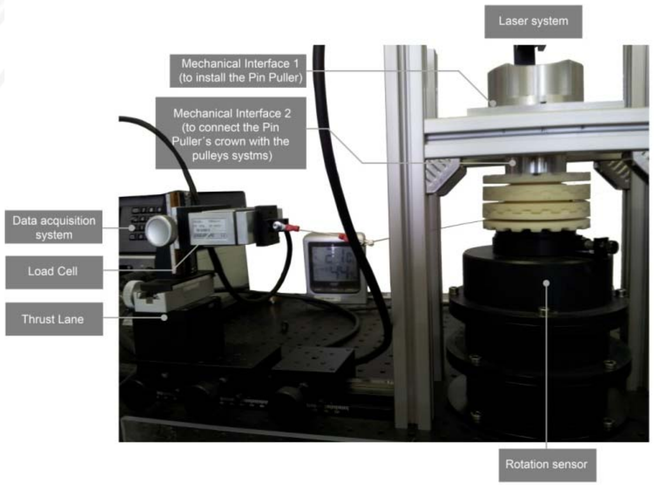
(Friction Tests)



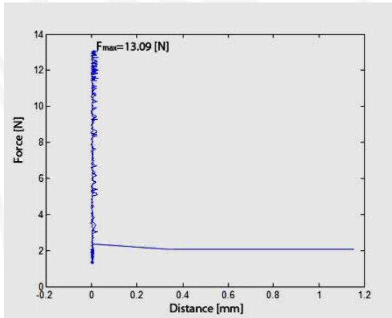
Setup for Friction Test on Pin



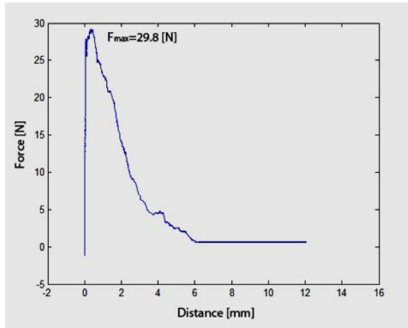
Friction on Pin for 100-N-Pin Puller



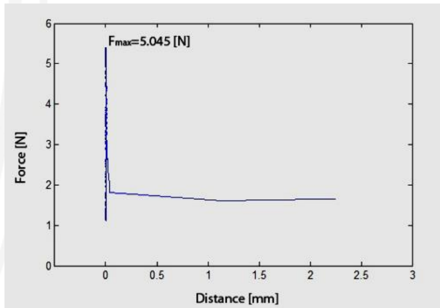
Setup for Friction Test on Crown



Friction on Crown for 100-N-Pin Puller



Friction on Pin for 50-N-Pin Puller



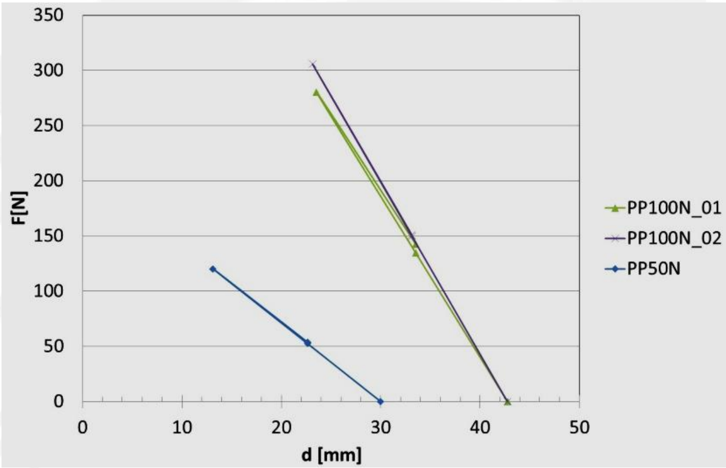
Friction on Crown for 50-N-Pin Puller

48.6 N ≥ 2*(1.5*(13.1N) + 1.2*(2.89)) ≥ 48.39 N => 100-N-Pin Puller

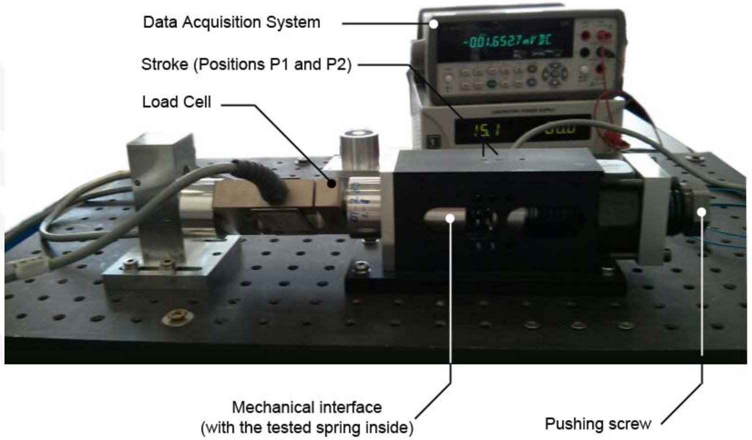
42.2 N ≥ 2*(1.5*(5.05N) + 1.2*(8.04)) ≥ 34.45 N => 50-N-Pin Puller

FUNCTIONAL PRE-TEST

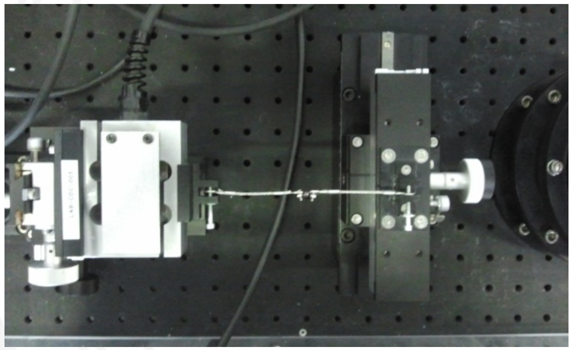
(Springs Performance Verification)

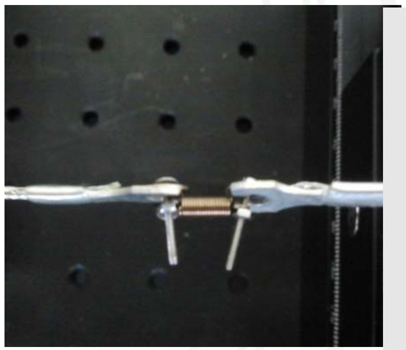


Stroke Spring Performances

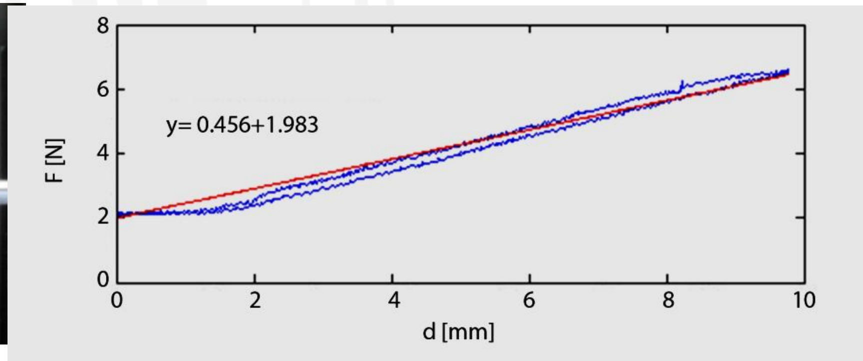


Setup for Stroke Spring Verification





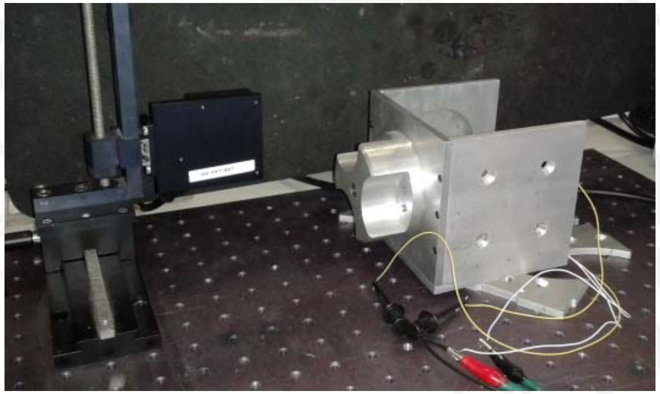
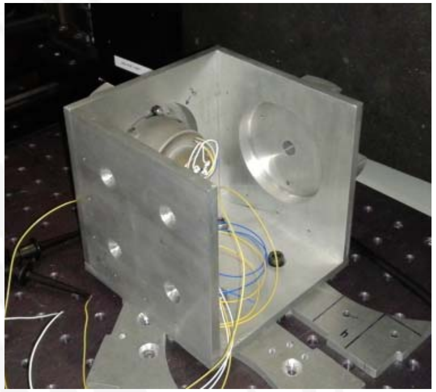
Setup for Reset Spring Verification



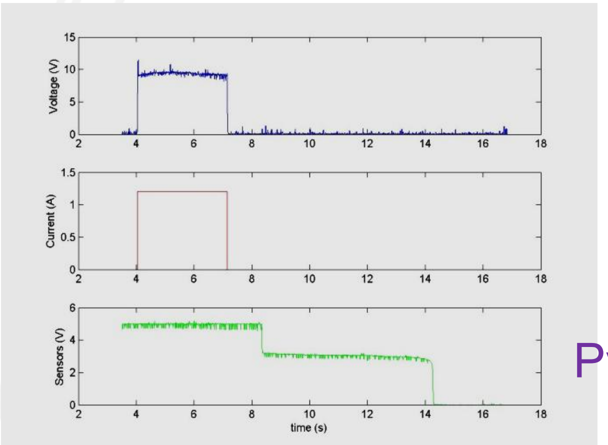
Reset Spring Performances

FUNCTIONAL PRE-TEST

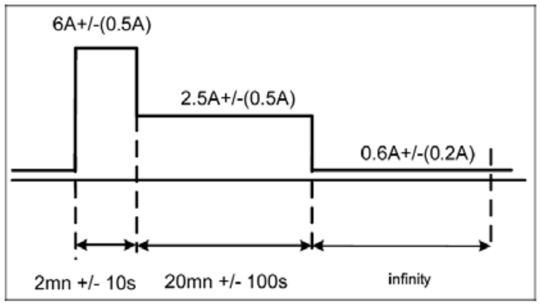
(Actuation Test with Secondary SMA)

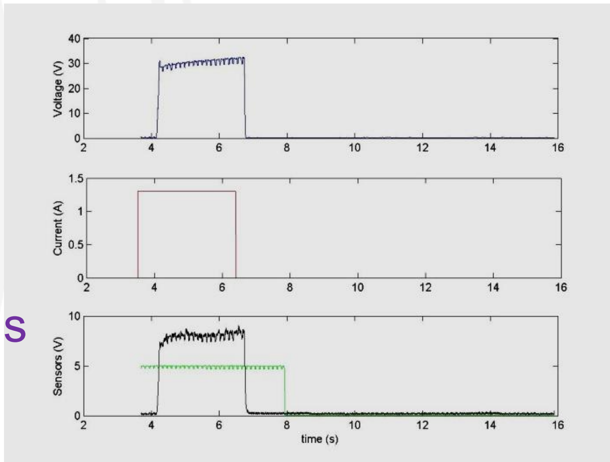
Setup for Actuation Test



Result Plots for 50-N-Pin Puller



Pyro Interface Amp Limitations
Output 28 – 40 V
(Pin Puller is Compatible)



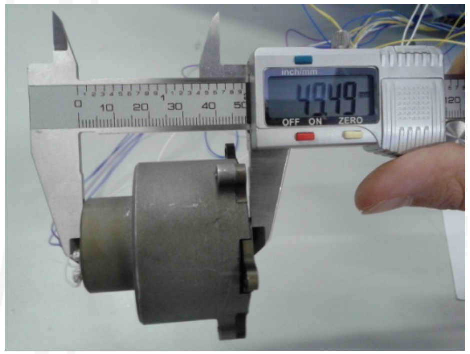
Result Plots for 100-N-Pin Puller

PHYSICAL INSPECTION
(Physical Measurement)

Reference	Iteration	Required result (gr)	Current result (gr)
Pin Puller of 100 N # 1			
10116_PP100_01_Weight_001	1	75	98.7
		Average	97.5
Pin Puller of 100 N # 2			
10116_PP100_02_Weight_001	1	75	97.2
		Average	95.5
Pin Puller of 50 N			
10503_ PP50_Weight_003	3	57	74.4
		Average	75.2

Mass

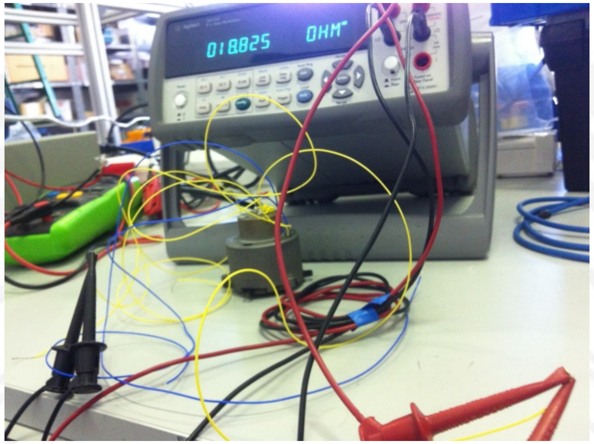
Reference	Iteration	Required result (mm)	Current result (mm)
Pin Puller of 100 N # 1			
10116_PP100_01_Diameter_001	1	≤ 60	53.15
	Diameter average		53.14
10116_PP100_01_Length_001	1	≤ 60	49.58
	Length average		49.52
Pin Puller of 100 N # 2			
10116_PP100_02_Diameter_001	1	≤ 60	53.07
	Diameter average		53.10
10116_PP100_02_Length_001	1	≤ 60	49.45
	Length average		49.49
Pin Puller of 50 N			
10503_PP50_Diameter_001	1	≤ 60	51.40
	Diameter average		51.40
10503_PP50_Length_001	1	≤ 60	38.82
	Length average		38.82



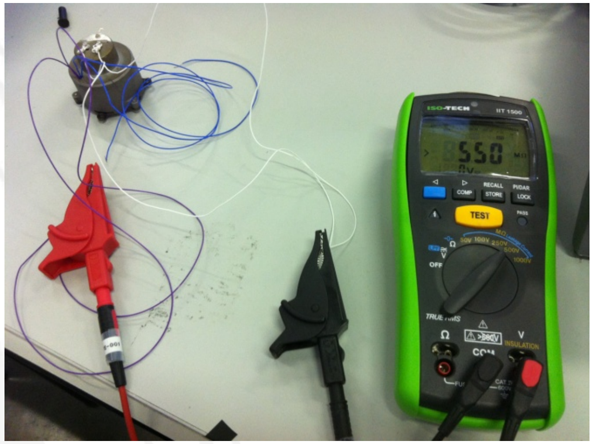
Envelope

PHYSICAL INSPECTION

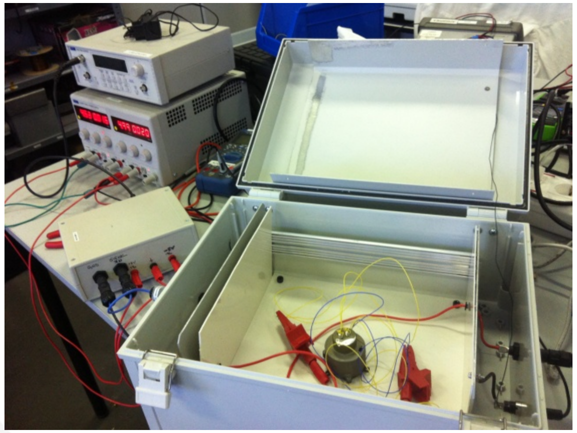
(Electrical Measurement)



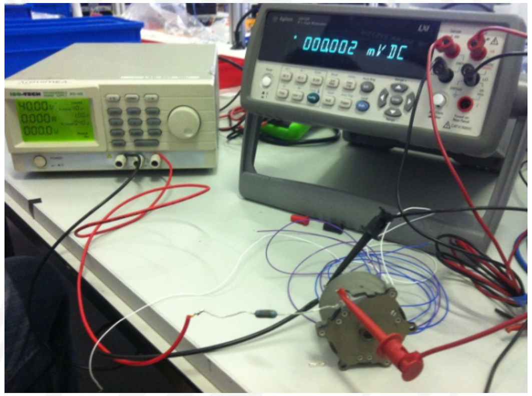
Electrical Resistance: 20 Ω for 100-N-Pin Puller
8 Ω for 50-N-Pin Puller

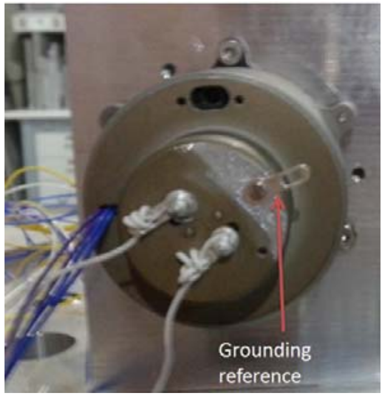


Insulation: results > 10 MΩ



Dielectric: results < 50E-12 C

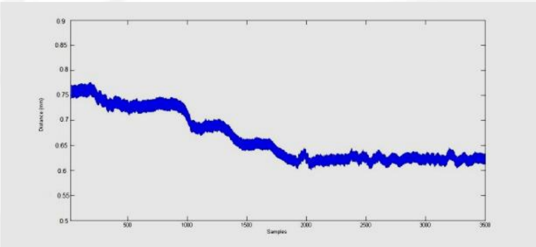




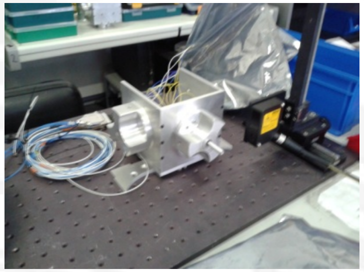
Grounding: results < 10 mΩ

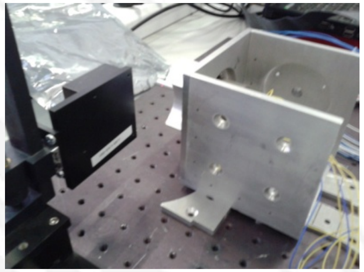
FUNCTIONAL TESTS

Static Load

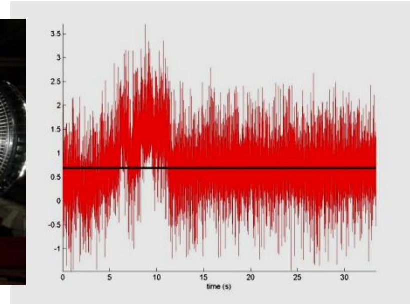


100–N-Pin Displacement



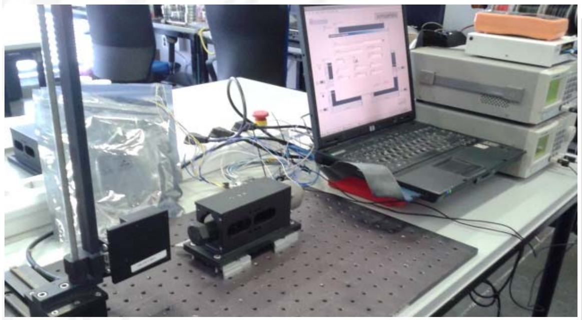


Test Setup for Static Load

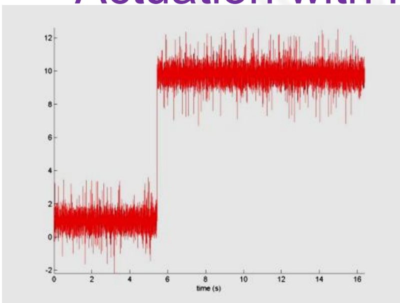


50–N-Pin Displacement

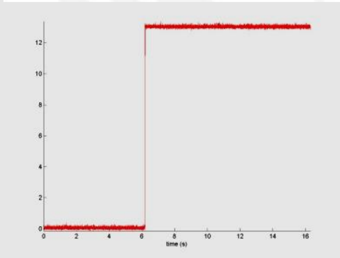
Actuation with Primary SMA



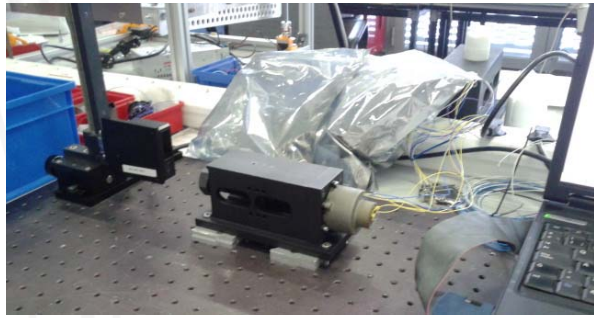
Test Setup for Actuation



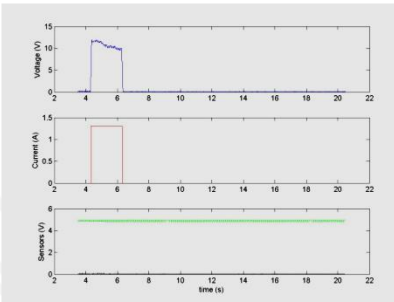
50-N-Pin Stroke



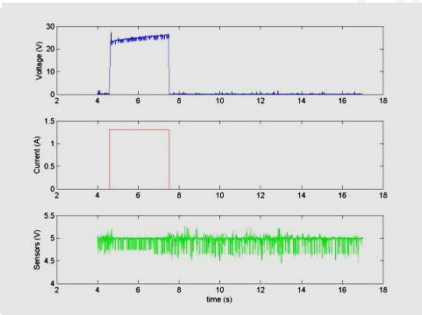
100-N-Pin Stroke



Test Setup for Actuation

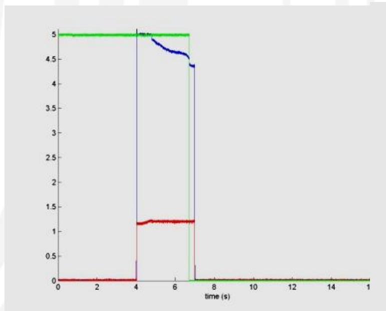


50-N-Pin Puller Results

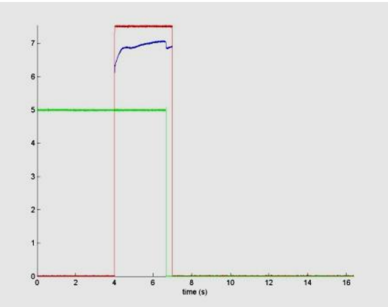


100-N-Pin Puller Results

Motorization



50-N-Pin Puller Results

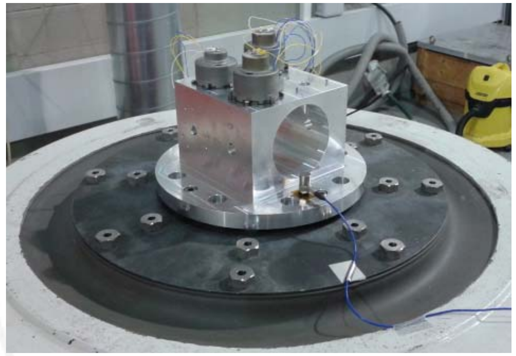


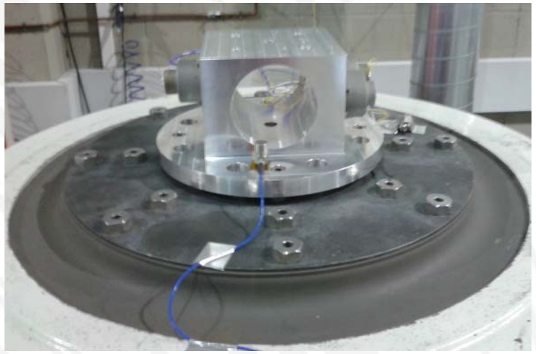
100-N-Pin Puller Results

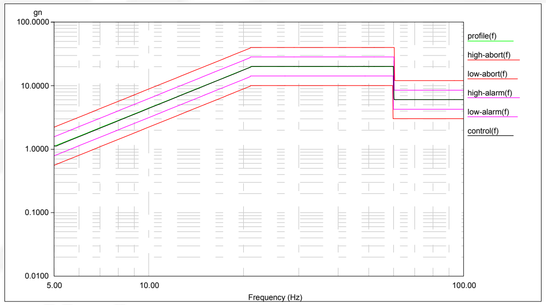
ENVIRONMENTAL TESTS

(vibration)

Test Setup for Axial Axis

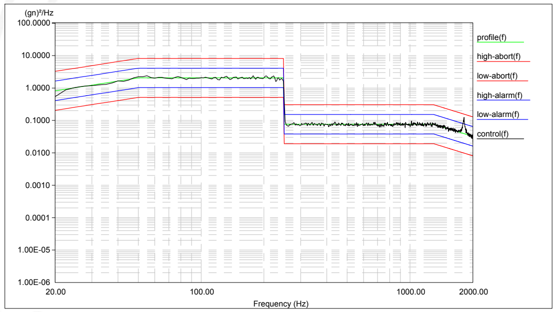




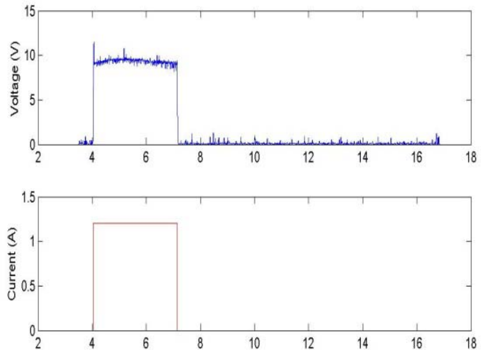


Profile of Sine Vibrations

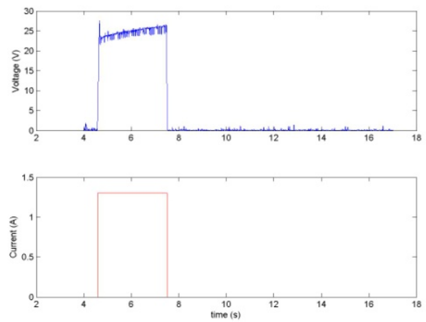
Test Setup for Radial Axes



Profile of Random Vibrations



Actuation of 50-N-Pin Puller Before and After Vibrations



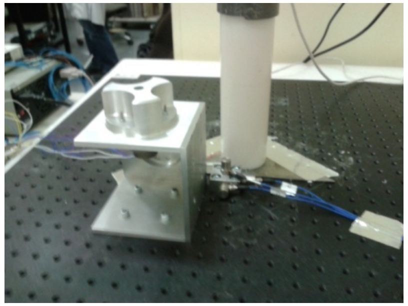
Actuation of 100-N-Pin Puller Before and After Vibrations

ENVIRONMENTAL TESTS

(Shock)

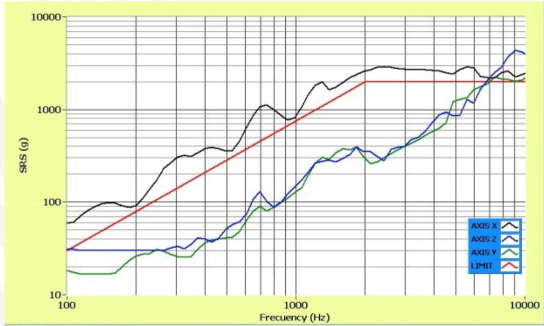
Shock Setup

Radial Axes



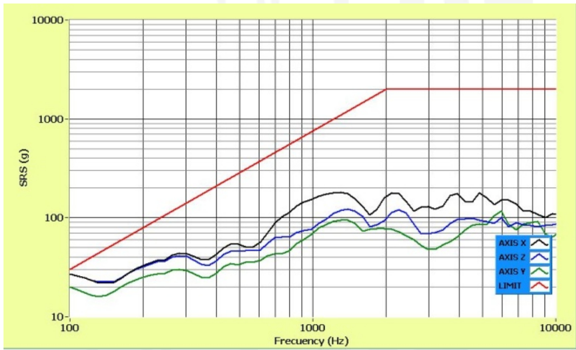
Axial Axes

Inputted Shock SRS

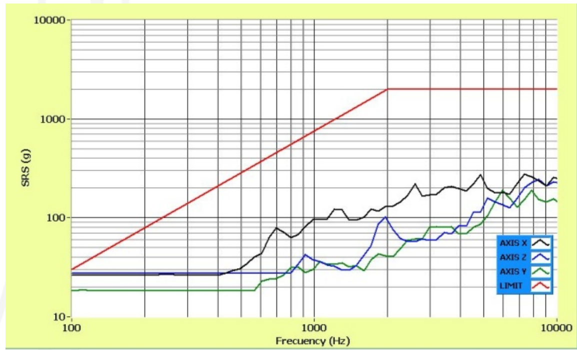


Shock Profile for All Axes

Shock Generated



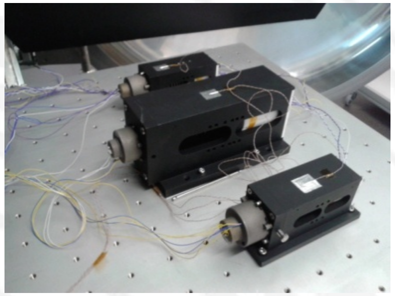
Shock Generated for 50-N-Pin Puller



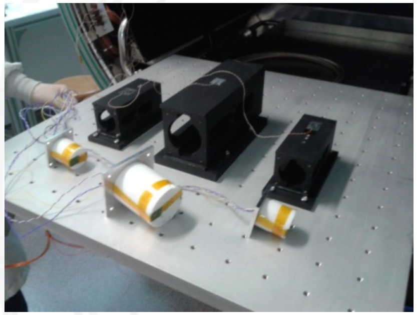
Shock Generated for 100-N-Pin Puller

THERMAL VACUUM TESTS

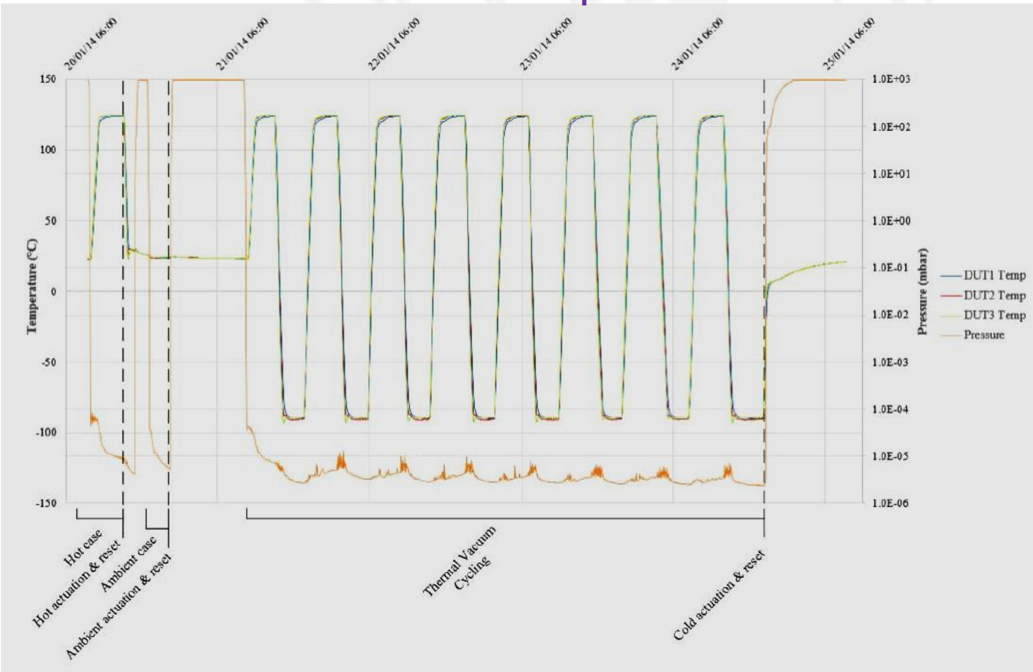
(Setup, Pressure, Temperature and Cycling)



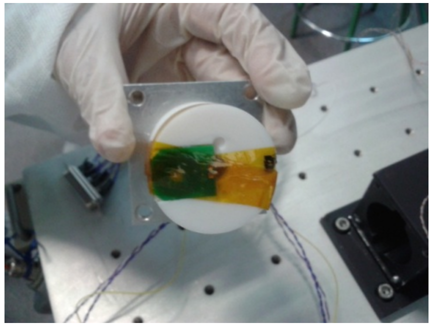
Test Setup



Stroke Measurement



Time Evolution of Temperature and Pressure

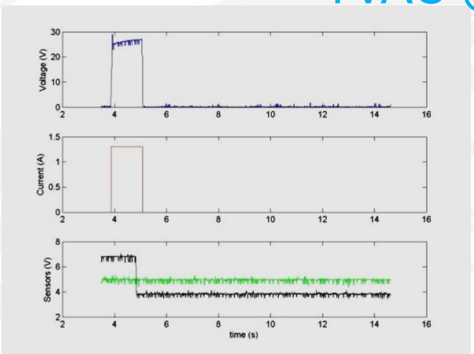


External Sensors

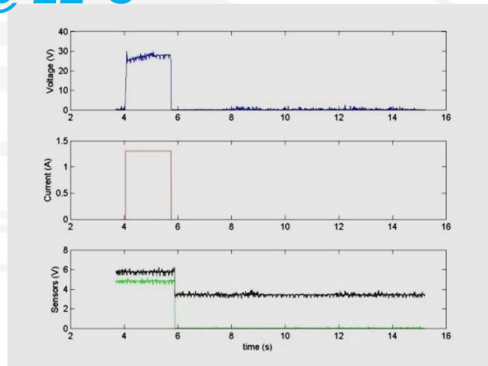
THERMAL VACUUM TESTS

(TVAC at Ambient and Maximum Temperatures)

TVAC @ 22ºC

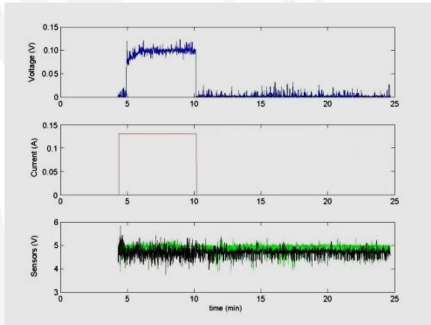


50-N-Pin Puller

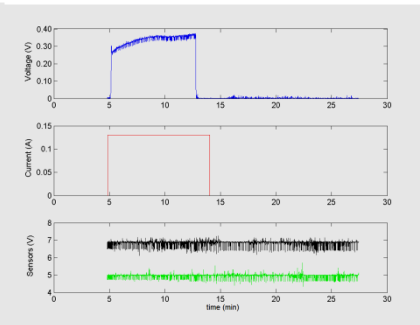


100-N-Pin Puller

No Fire TVAC @ 125ºC

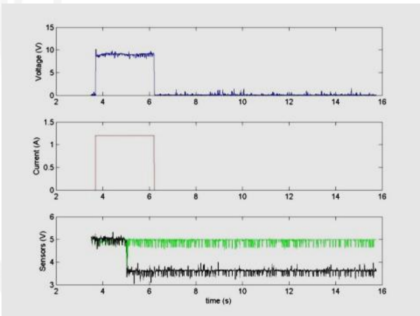


50-N-Pin Puller

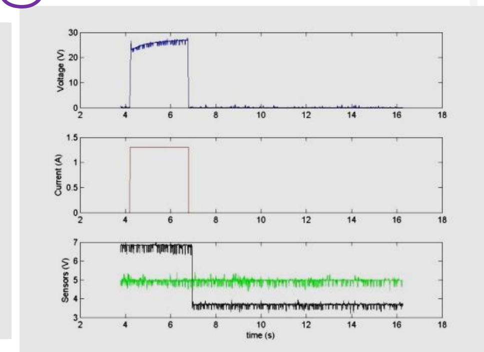


100-N-Pin Puller

TVAC @ 125ºC



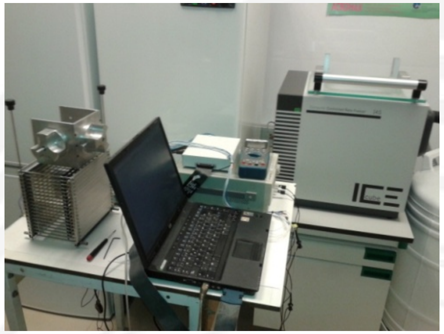
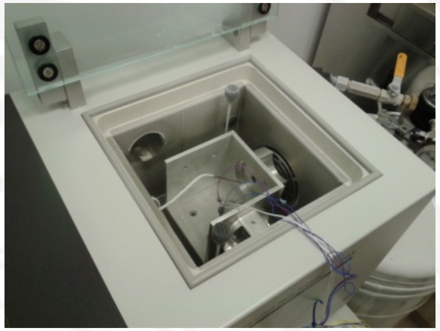
50-N-Pin Puller



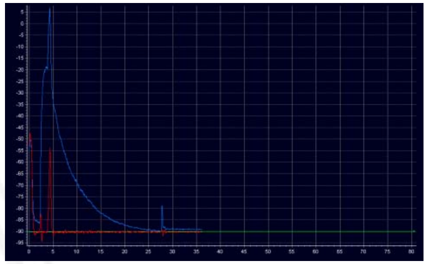
100-N-Pin Puller

THERMAL VACUUM TESTS

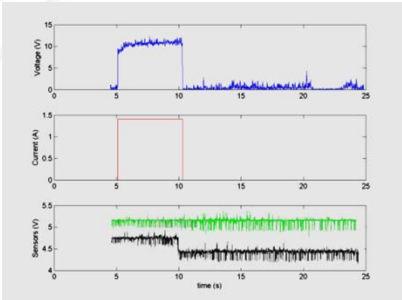
(TVAC at Minimum Temperature)

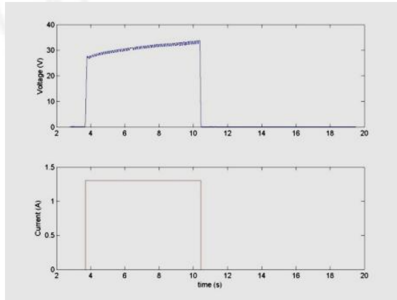
Cold Actuation in Inert Atmosphere



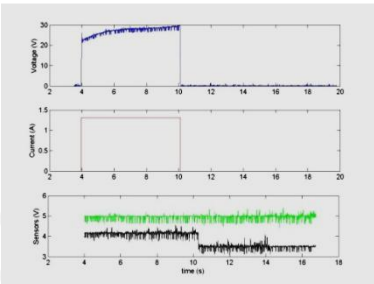
Temperature Evolution



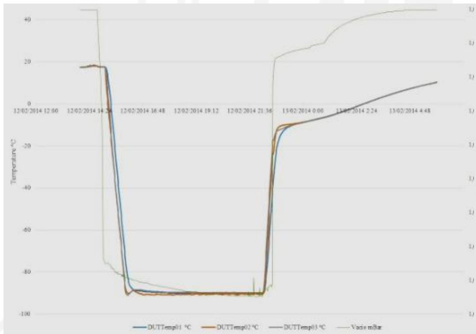
Cold TVAC of 50-N-Pin Puller



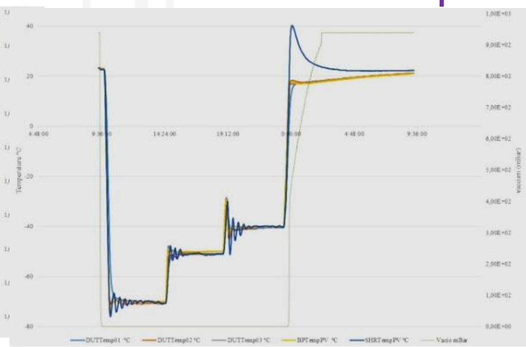
Result Plots in Inert Atmosphere



Cold TVAC of 100-N-Pin Puller



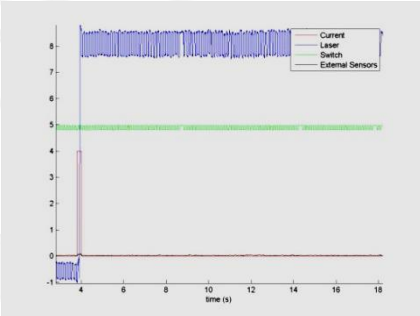
TVAC @ -90ºC

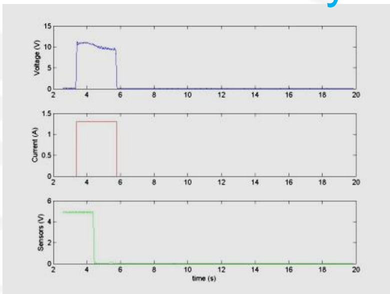


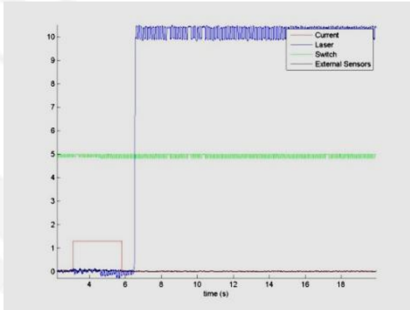
Stepped Cold TVAC

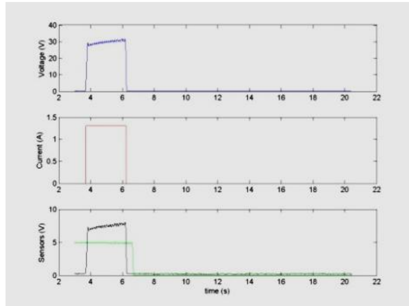
LIFETIME TEST

Cycle 1

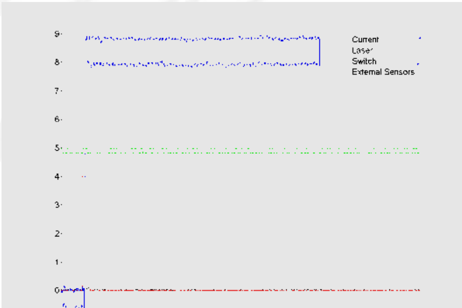

Stroke of 50-N-Pin Puller

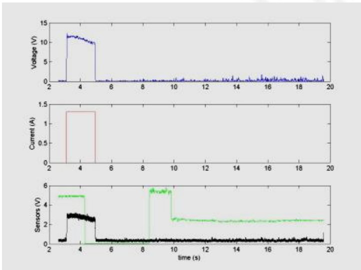

Results of 50-N-Pin Puller

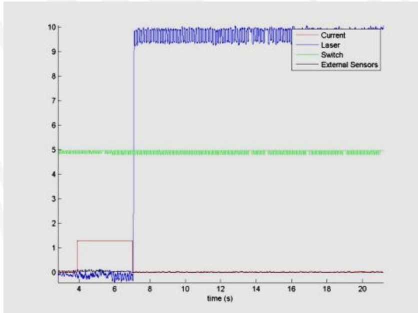

Stroke of 100-N-Pin Puller

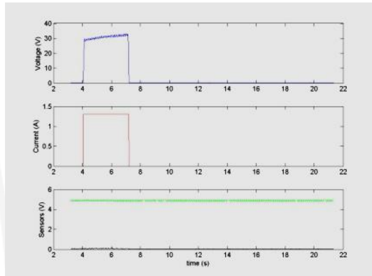

Results of 100-N-Pin Puller

Cycle 60

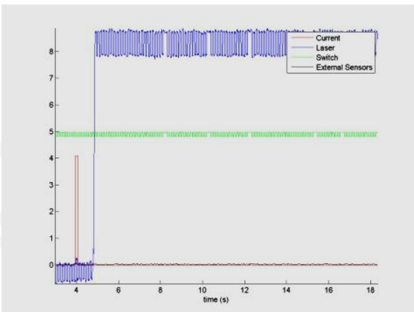

Stroke of 50-N-Pin Puller

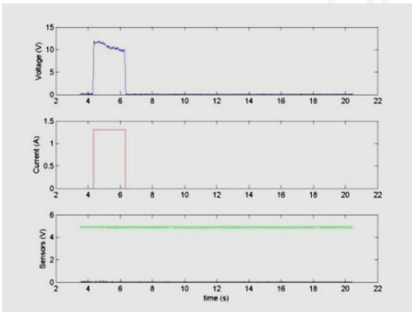

Results of 50-N-Pin Puller

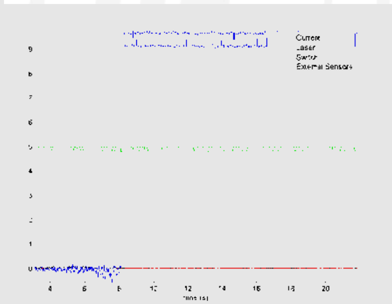

Stroke of 100-N-Pin Puller

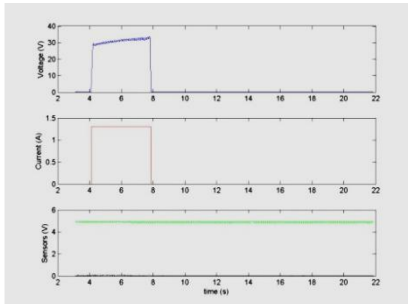

Results of 100-N-Pin Puller

Cycle 110


Stroke of 50-N-Pin Puller

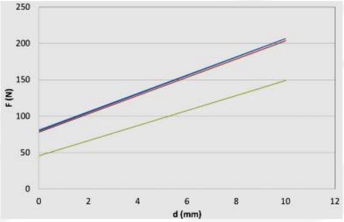

Results of 50-N-Pin Puller


Stroke of 100-N-Pin Puller

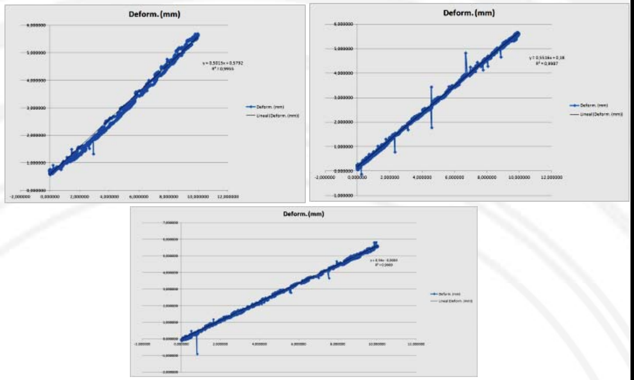

Results of 100-N-Pin Puller

FUNCTIONA POST-TEST

Spring Performance Verifications

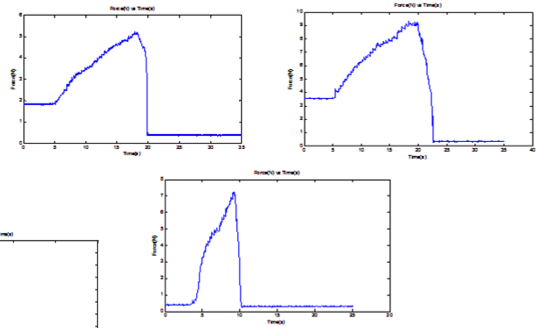


Stroke Springs (Degradation)

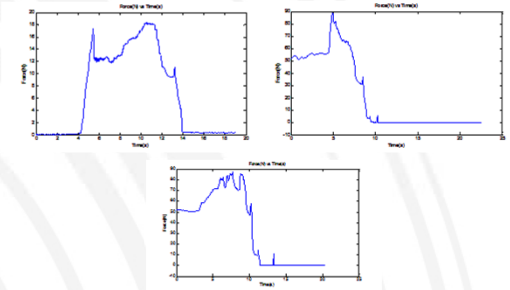


Reset Springs

Friction Test

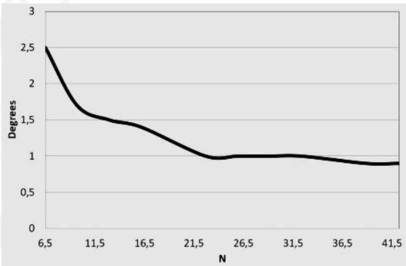


Crown (Less Friction)

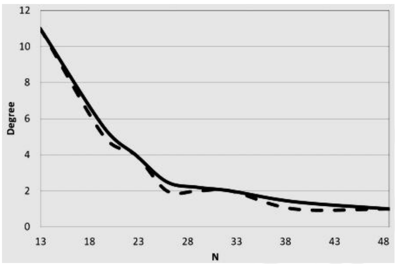


Pin (More Friction)

SMA Actuating Force

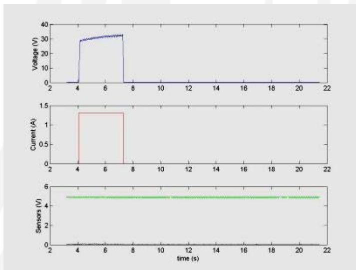


50-N-Pin Puller

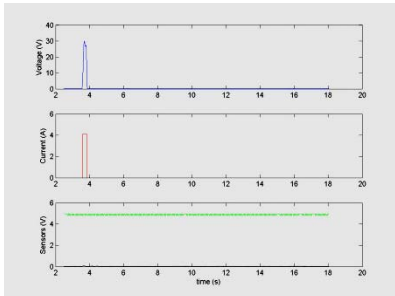


100-N-Pin Puller

Actuation Test Secondary



100-N-Pin Puller



50-N-Pin Puller

VERIFICATION OF CONFORMITY OF QM AGAINST REQUIREMENTS

Parameter	ESA ITT		ARQ Pin Puller		Achieved?	
	PP100N	PP50N	PP100N	PP50N	PP100N	PP50N
Recurring Price [k€]	< 7.0		< 7.0		Yes	
Pin Stroke [mm]	10.0	90	10.0	90	Yes	
Min. Axial Pull Force [N]	100	50	100	50	Yes	
Max. Shear Force (No-Actuation) [N]	1800	450	1800	450	Yes	
Max. Shear Force (Actuation) [N]	300	90	300	90	Yes	
Mass [kg]	0.075	0.057	0.0965	0.0752	No	
Envelope [mm]	60 x 60	60 x 60	53.1 x 49.5	51.4 x 38.8	Yes	
Operational Temperatures [°C]	-150 to +125	-90 to 70	- 50 to +125	- 50 to +70	No	
Redundancy	Redundant actuation		Redundant actuation		Yes	
Electrical Interface	Pyro		Pyro adaptable		Yes	
Voltage [V]	26 - 40		28		Yes	
Power [W]	< 40W		36.4	13	Yes	
Current [A]	3.5 to 5.2		1.3	4	Yes	
No fire current [A]	1		0.130 @ 5 min		No	
Resistance [Ω]	1 ± 0.2		20	8.2	No	
Actuation Time max [s]	< 1		< 6	< 5	No	
Insulation [MΩ]	< 10		< 10		Yes	
Dielectric [C]	$< 50x10^{-12}$		$< 50x10^{-12}$		Yes	
Grounding [mΩ]	> 10		> 10		Yes	
Actuation Time Repeatability Error [%]	< 10		25	< 10	No	
Low-Shock [g]	< 1000		< 300	< 200	Yes	
Lifetime (Cycles)	> 100		> 25 (tested for > 110 cycles)		No	
ITAR free	Yes		Yes		Yes	
Based on European components and processes	Fully		Fully		Yes	
Pin Puller Technology	Non explosive		Non Explosive		Yes	
Reusable	Yes, without refurbishment		Yes, without refurbishment		Yes	
Resettable	Yes, via manual operation		Yes, via manual operation.		Yes	
Pin Positions	Only 2 possible Pin positions (i) retracted (ii)deployed		Only 2 possible Pin positions (i) retracted (ii)deployed		Yes	
Position monitoring	Possible Position Sensor		Limit Switch		No	

CONCLUSIONS AND LESIONS LEARNED

- Using a one single SMA fibre with enough output force is more feasible than using several fibres.
- Small SMARQ fibres do not increase the electrical resistance enough, so indirect heating is the best solution.
- Reduction of SMA output force has been measured with the fibres in curve respect to the fibres in straight.
- The stroke springs of 100-N-Pin Pullers have presented degradation after test campaign.
- The frictions measured in the crowns was reduced after test campaign.
- The frictions on pins have been increased in 23% because wear have been recognized in the 100-N-Pin after test campaign
- The mechanical parts have been mechanized and good external appearances have been presented.
- The total weight of the assembly exceeds the required mass of the device.
- The measured values of enveloped, dielectric, grounding and insulation fulfil the project requirements.
- The measured value of the SMARQ actuator resistance is compatible with Pyro interface.
- The Pin Puller structure has presented a successful resistance to the application of these external forces.
- The QM has presented more than 9 mm of pull stroke.
- Successful actuations have been performed with half SMA actuator.
- No self actuations and degradation have been recognized after the environmental test and thermal vacuum cycling.
- The shock generated by the Pin Puller actuation has been measured obtaining values below 1000g.
- Thermal vacuum actuations have been obtained at 125 and 22ºC.
- The influence of just cold temperature has been checked by testing the devices at -90ºC in inert atmosphere with successful actuations.
- The combination of cold and vacuum is a worst condition that has not been overcame below -50ºC.
- Two factors have been recognized, which directly affect the actuations at cold temperature:
  - The pull forces measured with the SMA actuators in curve is less than the forces measured in straight.
  - The pull force of SMA in curve fulfils the motorization equation considering 1.5 as friction factor of uncertainty, but not considering 3.
- Lifetime has been validated since the Pin Puller has actuated for a total of 110 cycles.

ARQUIMEA
Passion for Technology

Many thanks!!

Questions?

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Mechanisms' Final Presentation Days 2014

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