EUROPEAN SYNCHROTRON RADIATION FACILITY
INSTALLATION EUROPEENNE DE RAYONNEMENT SYNCHROTRON

NASS test bench Test procedure

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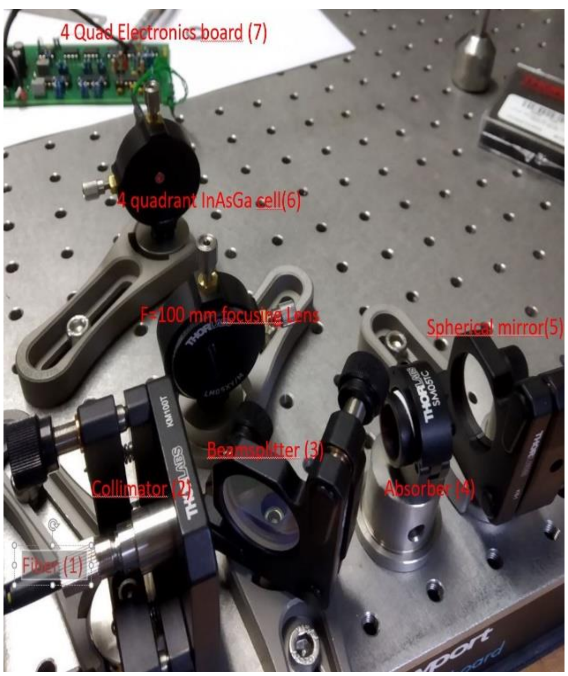
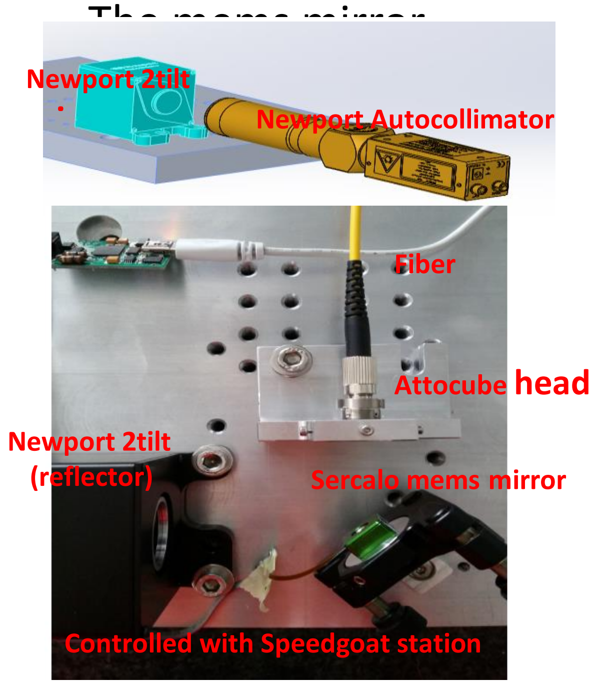
This paper is dedicated to the test procedure relative to the test bench proposed during the ISDD talk meeting called "ID31 NASS INTERMEDIATE TDR REVIEW" dated 29th March 2019 (file in annexe: NASS-talk-V2.pdf). The aim of this test bench is to prove that the system using a Mems mirror tilting device (Sercalo), in close loop with a 4Q diode and illuminated by an Attocube beam is able to work and more important that the information given by the interferometric beam delivered by the Attocube is repeatable. This means that the rotating point of the Secalo is repeatable. Theoretical model have proven that this is the weak point of the measuring principle if any.

This test bench It is the combination of the two preliminary test benches: the one from OH used to define the optics of the NASS metrology principal and the one from MM to check the performance of the Sercalo Mems mirror and the Newport 2tilts mirror foreseen as a reference.



The 4Q diode optical bench



The Mems mirror, Newport Attocube test bench
(report in annex: TestBenchSercalo-V2.pdf)

MAIN SPECIFICATION OF THE TIP/TILT SYSTEM

Specification for the tip/tilt mirror								
FixPoint of tip/tilt mirror: X=-187 ,Y=0 ,Z=-209							Distance from fix point galva to surface	
ConfigSolid	Motions					Angle AxisBeam/RefVert [degrees]	Lateral Miror XY [mm]	Vertical Mirror Z[mm]
	X	Y	Z	tiltX	tiltY			
Y-Z-tiltX	0	-15	-10	-3	0	45.39	36.69	31.24
YZ-tiltX	0	-15	10	-3	0	42.51	50.34	11.22
YZTiltX	0	10	10	3	0	38.95	30.68	39.33
-YZtiltX	0	-15	10	3	0	38.15	30.68	39.33
test2	-10	-15	-10	0	0	41.62	15.48	16
MAX [degrees or mm]						45.39	50.34	39.33
MIN[degrees or mm]						38.15	15.48	11.22
Max-Min angle for the refelctor with additionnal TY=5mm [degrees]						**7.24**		
Mirror angular mechanical stroke for X and Y [degrees]						**3.62**		
Max-Min(mm)with additionnal Y stroke							34.86	28.11
distance variation mirror/reflector [mm]							**34.86**	**28.11**
Max mirror angular stroke for Z [degrees]								**3**

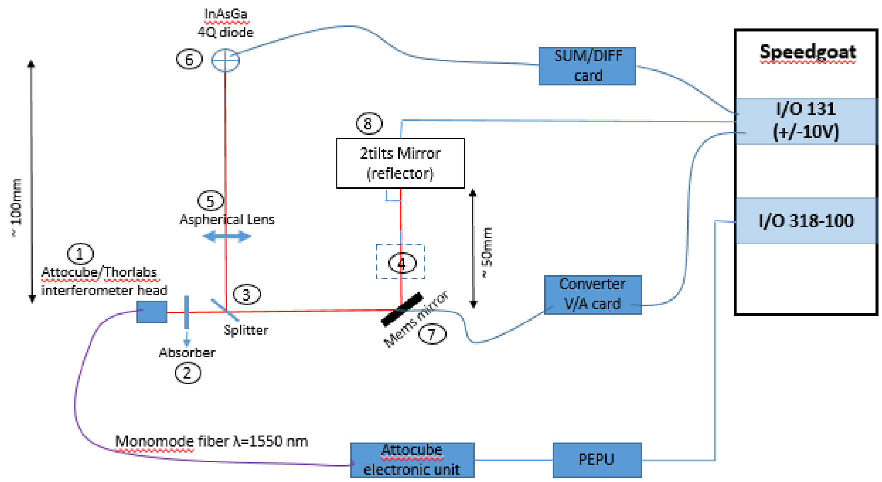
**Galva is the other name of tip/tilt mirror*

ERROR BUDGET

Error induced by	X(nm)	Y(nm)	Z(nm)	TiltX(µrad)	TiltY(µrad)	Comments
Specification (acceptable)	**20 (50)**	**20 (50)**	**10 (50)**	**1.7**	**1.7**	
Mems mirror (variation of center of rotation)	29	29	20	1.0E-01	1.0E-01	**Test bench1**
4Q diode precision (MEMS angular error)	1.5	1.5	1	9.3E-05	9.3E-05	**Test bench1**
Laser fluctuations	12	12	8	8.0E-01	8.0E-01	**Test bench2**
Residual error from calibration	14	14	5	1.0E+00	1.0E+00	**No experience for spherical**
Thermal variations	5	5	5	2.0E-01	2.0E-01	**Bibliographie**
Dynamical error	7	7	7	6.7E-02	6.7E-02	**Control model**
Global error = $\sqrt{\sum e^2}$	**35**	**35**	**24**	**1**	**1**	**Test bench3**

DESCRIPTION OF THE TEST BENCH

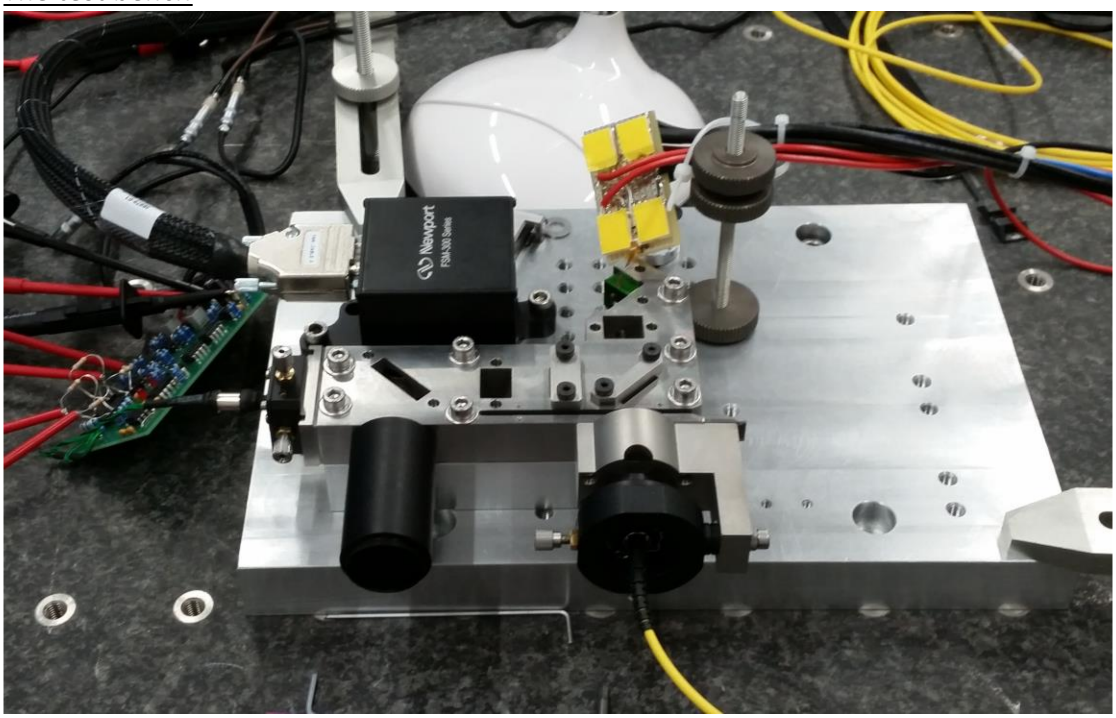
Principle



Reference of the devices:

1. Interferometric head Thorlabs ref: F230FC-1550
2. Absorber filter Thorlabs ref: NDL-10C-2
3. Beam splitter Thorlabs ref: BSS05
4. Corner cube Thorlabs ref: PS977-C (just for alignment)
5. Plano-convex lens Thorlabs ref:LA1207-C
6. InAsGa 4Q diode GPD electronics Corp ref: GAP 1000 Q
7. Mems mirror Sercalo ref: MM2536-2
8. Reference 2tilts mirror(lens) Newport ref: FSM300-01

The test bench



PROCEDURE

The following values will be registered systematically:

- The set point voltage of the Newport and the value of its position given by the Newport itself (out)
- The set point voltage of the Sercalo
- The values of each 4Q signal
- The value of distance given by the attocube
- Permanently check the contrast on the attocube
- Register each time when possible the absolute value of the path given by the attocube.
- Temperature measurement (Pt100) to be put at the back of the Sercalo

1. *First test*

1-1 The first test consists in evaluating the stability of the system without any active control. The Sercalo and the Newport have fixed tension so that the beam hits the 4Q diodes in its center.
Register the quantities during 5mn. Determine the "noise" of the signal given by the attocube and of the 4Q diodes on 5seconds. Analyse the stability of the Attocube beam and the 4Q signals over the 5mn.

1-2 Make the feedback control of the Sercalo active and redo exactly the same measurements and analysis.

2. *Second test*

2-1 Redo the procedure used in the MM test bench (see enclosed report) in Quasi-static mode.
Steps of 10microrad with the Newport for a stroke of 100micro-rad, with the feedback control of the Sercalo. Analyse the "noise" for each step.

Do the same cycle at least 10 times. Analyse the repeatability of the attcube beam, the position of the Newport and the control value of the Sercalo.

2-2 Do the second test with a dynamic motion of the Newport (0.1 Hz, 0.5Hz, 1Hz) with a sinusoidal control of the Newport. Analyse the same parameters.

3- Third test

The aim of the third test is to check that the surface of the sercalo is not too much deformed when tilting at large angle.

3-1 If the previous tests are consistent, redo the procedure "second test" with the largest stroke as possible of the Newport. (1.5degres)

3-2 Manually pre adjust the Newport in angle to explore the full needed range given in the specification above.

4-Next steps

Evaluate the limit of the system in term of speed.

Add a translation under the Newport.

TEST BENCH SERCALO + NEWPORT WITH ATTOCUBE

Warning: the following tests are really the first one and therefore should be optimized**.**

Description of the test benches. Both test benches are controlled via a speedgoat station equipped with two cards: an IO131 (analog input/output) and a IO 318-100.

1- Test bench for the Newport double tilt mirror

The first test bench consists in measuring the angles of the Newport double tilt mirror and the MIM of the Newport (ref: FSM300-01) with the autocollimator (Conex-LDS). The Newport mirror has an internal close loop which guaranty a quality of repeatability.

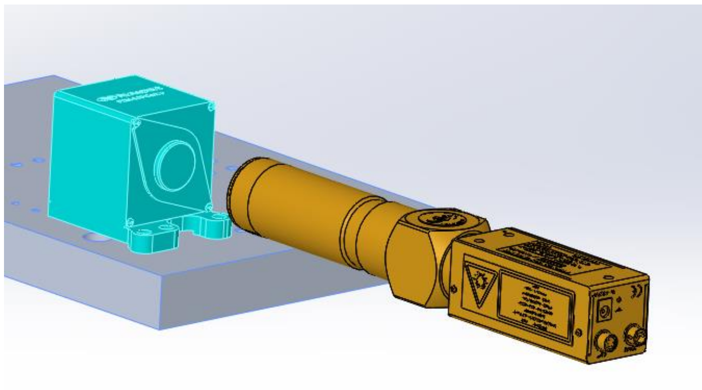


Figure 1: Solidworks of the Newport tilt mirror and the autocollimator

Data1.mat

Newport: Axe Y: stair control with steps of ~ 10µrad (3.817.10^{-3}V / step)

Axe Z: stair control with steps of ~ 10µrad (3.817.10^{-3}V / step)

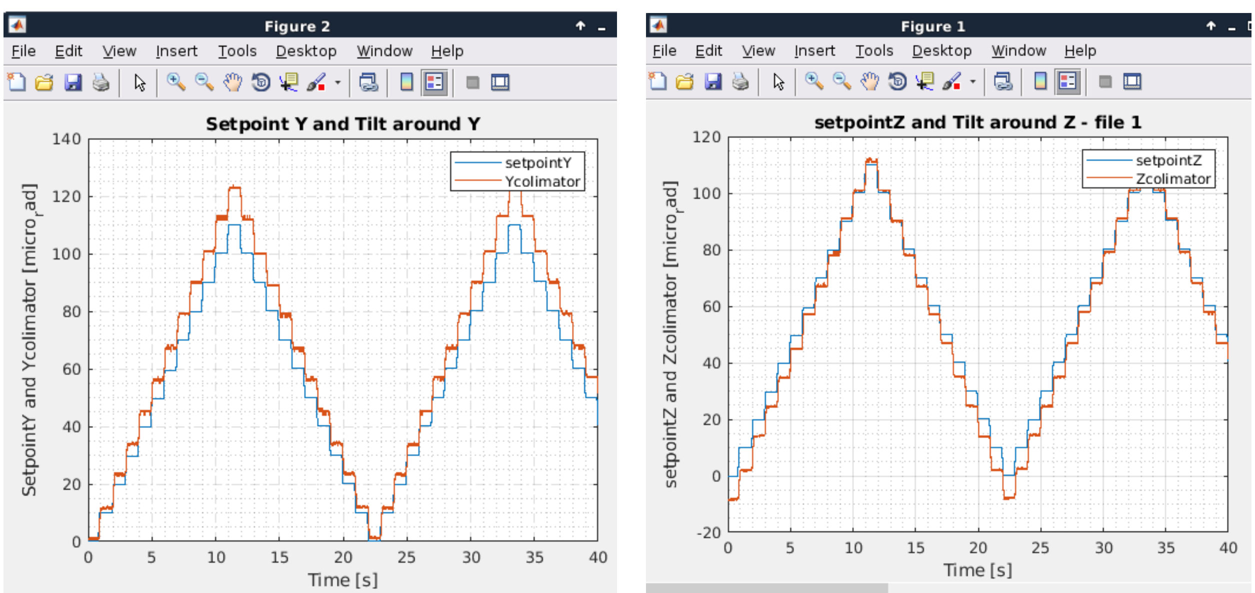
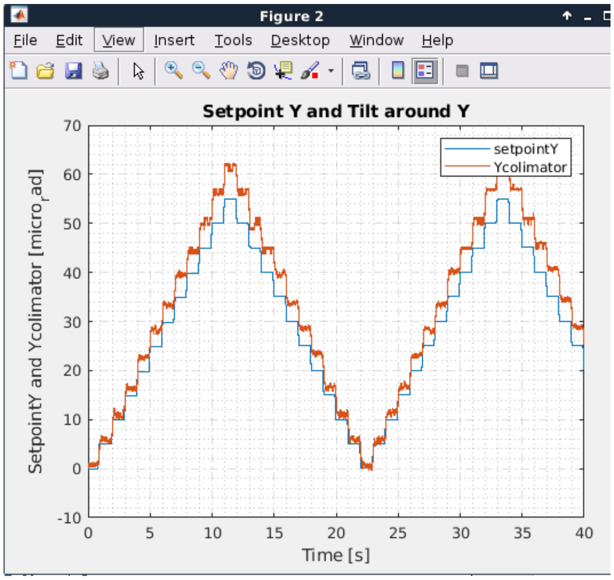


Figure 2: The Newport is control with a stair function (blue) by the speedgoat in both axis(left and right) and the value of the angle read by the collimator is registered (red) – Steps of 10 micro-rad

Data2.mat

Newport: Axe Y: stair control with steps of ~ 5µrad (1.908.10^{-3}V / step)

Axe Z: stair control with steps of ~ 5µrad (1.908.10^{-3}V /step)



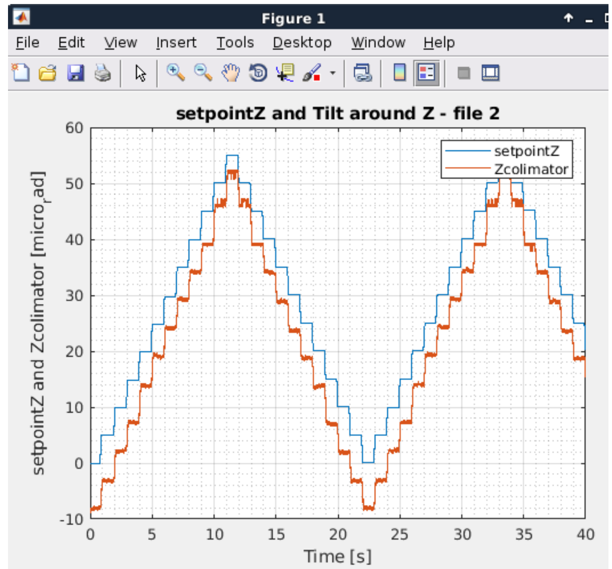


Figure 3: same procedure than above but with steps of 5micro-rad.

Conclusion: The MIM for the Newport is 5micro-rad and even a little better. We can notice a difference between the values of the displacement given by the set points and the real values. It is just a question of calibration.

2- Test bench for the Sercalo Mems mirror

From the previous test, we assume that the Newport mirror can be taken as a reference for the second test bench. On the other hand the Sercalo mems mirror has no internal close loop system.

The first check was to see the reflectivity of the Sercalo mirror (ref: MM2536) with an Au coating. 100% of reflectivity was obtained (even saturation), with the Attocube head ref: IDSH/M12/C1.6/RT (without filter).

The aim of this second test bench consists in getting an idea of the repeatability of the center of rotation of the Sercalo device (angle and center of rotation). With previous tests it seems that the repeatability of the Newport is very high, therefore we take this device as a reference. The Attocube interferometer beam hits the Sercalo Mems mirror with an incidence angle of 45degrees. The beam is reflected and goes normal to the Newport mirror surface and then comes back to the attocube interferometer. The attocube path signal is registered while the Sercalo mems mirror and the Newport mirror are exited synchronously with a sinus wave signal.

The following results are obtained in the PAMU lab (The integration lab. was not available at that time.

This means that the environmental conditions are far to be not optimum).

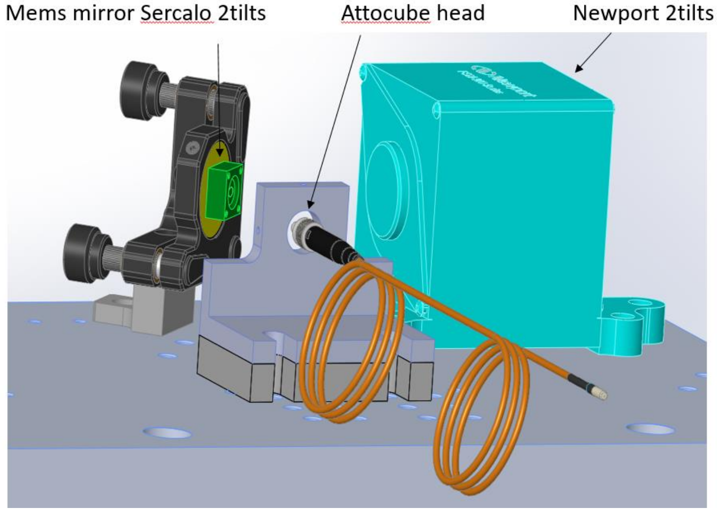


Figure 4: Solidworks model of the test bench

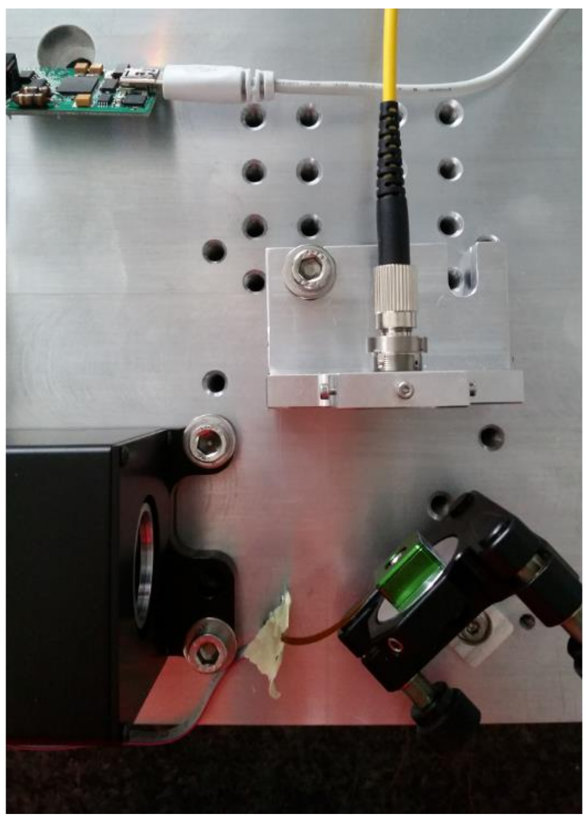


Figure 5: Top view of the test bench

The control of the Sercalo and of the Newport are both in openloop.
The Newport is controlled with a tension (+/-10V for full stroke) coming from the Speedgoat/AO directly, the Sercalo is controlled directly from the PC via an USB connection. It is possible to control the Sercalo with tension (information on the electronic card have been given by the company).

Data22:
Newport: Axe Y: 0V; Axe Z: 0V
Sercalo: Axis 1: 0V then at 25 s : sinus wave with an amplitude of 0.01degree (174microrad) in open loop at 20Hz; Axis 2: 0V

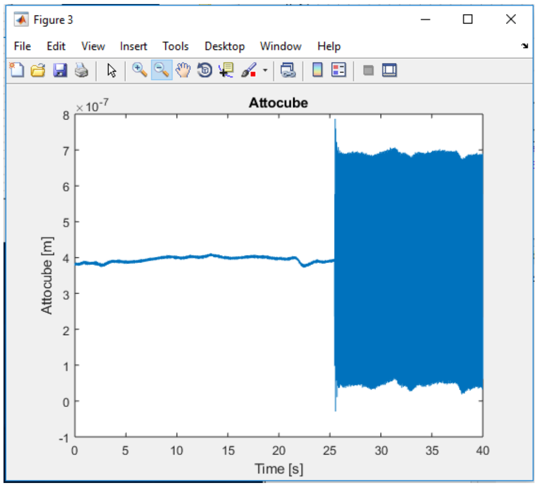


Figure 6: Path measured by the interferometer

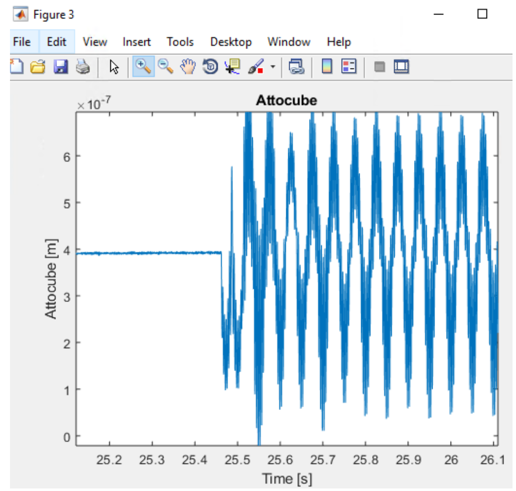


Figure 7: Zoom on the path measured by the interferometer

Data 17: Both mirror are now controlled at the same time both in open loop, but the synchronistation is not yet guaranty
Newport: Axe Y: sin wave with A = 0.664V (~ 174µrad) ; Axe Z: 0V
Sercalo: Axis 1: sinus wave with an amplitude of 0.01degree (174micro-rad); Axis 2: 0V

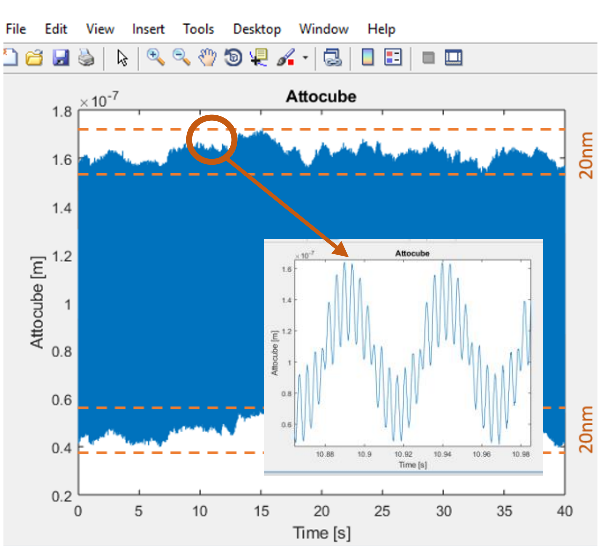


Figure 8: Path measured by the interferometer

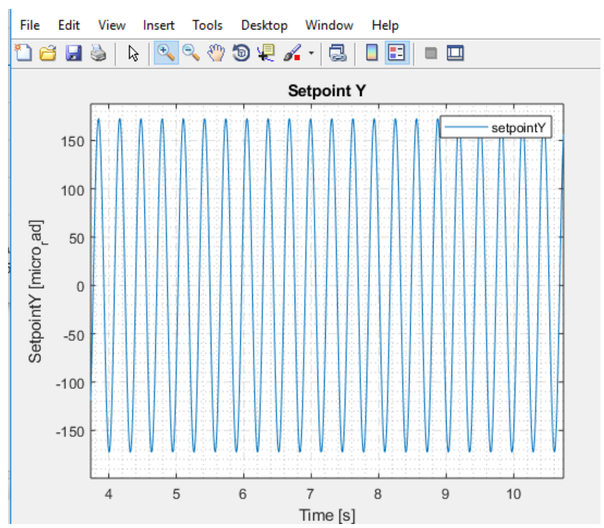


Figure 9: Setpoint in microrad sent to Newport

Conclusion: Despite of the fact that the two mirrors are not synchronised, we can notice two points:

- The total fluctuation of the attocube is less than when we do not move the Newport at the same time.
- The extreme position of the mesurements of the path of the mirrors is about 20nm. This gives an idea of the repeatability of the assembly.We may be should consider that the fluctuations we see concern as well the resolution of positionning of the Sercalo? In that case we should rather consider 40nm (see detail in figure 8). We have to keep in mind that this values are obtained in openloop. These results are extremly promissing for the future. The next step is now to redoo the same test but with the Sercal in close loop with the 4Q diode.
- These results are obtained on a very small period of time (40secondes), this means that the thermal effects are not taken into account. In any case it is obvious that the support of all the components for the metrology will have to be thermalised.

ID31 NASS INTERMEDIATE TDR REVIEW

Muriel Magnin-Mattenet 29th of March 2019

A Light for Science

ESRF

Co-writer of the TDR: *Jose-Maria Clement, Christophe Collette, Thomas Dehaeze, Ludovic Ducotte, Olivier Hignette, Veijo Honkimaki, Marc Lesourd, Muriel Magnin-Mattenet, Jens Meyer, Hans-Peter Van Der Kleij, Francois Villar*

THE THREE OBJECTIVES OF THIS MEETING

- ❑ Clarify the questions you have
- ❑ Agree on the next steps
- ❑ Allocate manpower resources and priorities

OUTLINE

- ❑ Specification
- ❑ The metrology and test benches
- ❑ Calibration
- ❑ Control
- ❑ Implementation at the Beamline
- ❑ Next steps, Manpower resources and priorities
- ❑ “B” Plan

SPECIFICATION

The NASS

The stroke of the actuators of the NASS need still to be confirmed with the final measurements of the performance of the micro-station

	Stroke	MIM	Repeatability
X translation	±15µm	3nm	20nm
Y translation	±15µm	3nm	20nm
Z translation	±15µm	3nm	10nm
X rotation	±30µrad	0.5 µrad	1.7 µrad
Y rotation	±30µrad	0.5 µrad	1.7 µrad
Z rotation	NA	NA	NA

Table 2: Specification of the NASS. These values have been revised taking into account the results of the characterisation of the micro-station.

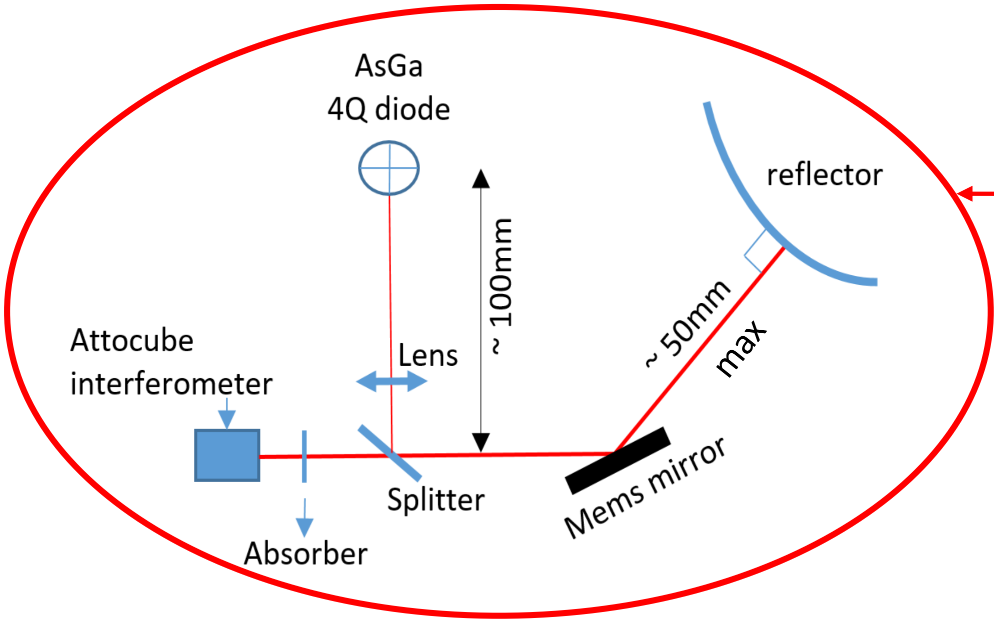
These values lead to a stroke for each actuator of +/-30microns. The aim is to optimize the micro-station to be able to reduce these strokes.

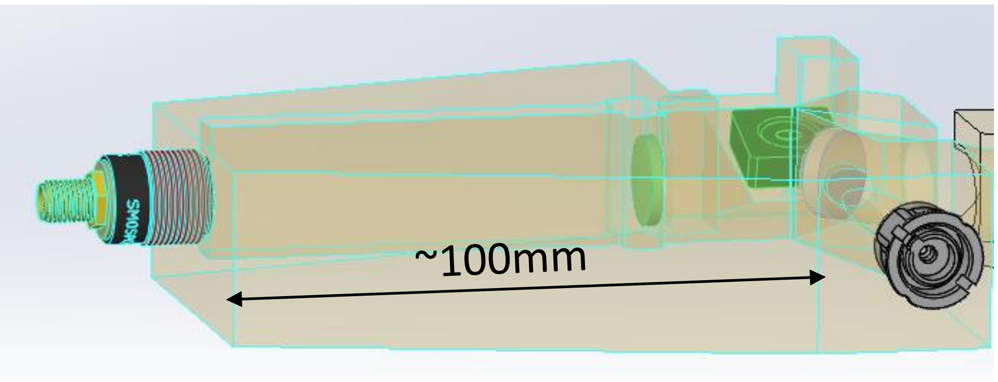
THE METROLOGY

PRINCIPLE

- ***4 branches for X and Y***
- ***3 (to 4) branches for Z and tilts***

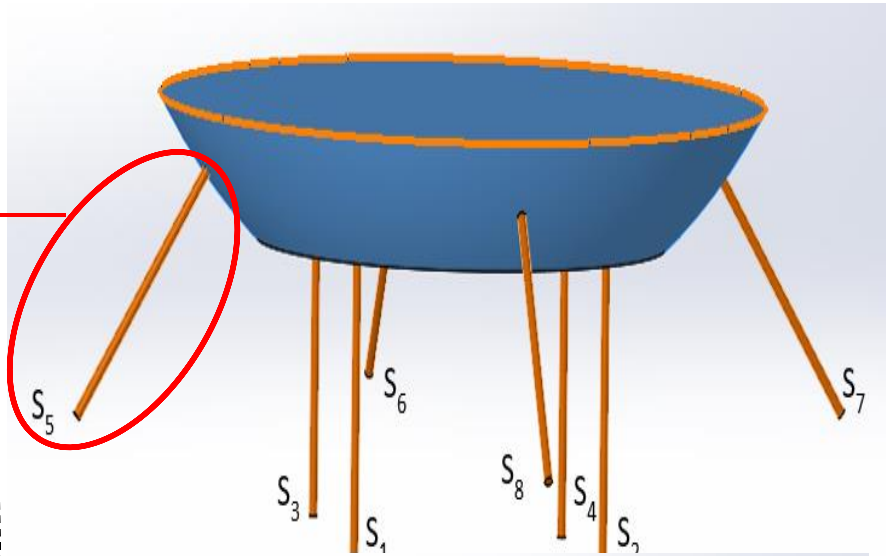
Detail of one interferometric branch

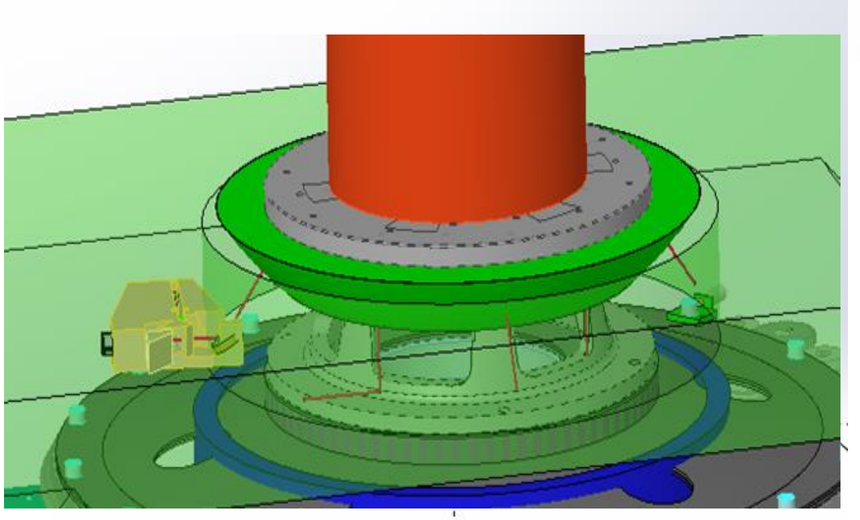




Mechanical implementation: piece in zerodur or equivalent (components will be glued after adjustment)

The reflector





THEORETICAL APPROACH AND ERROR BUDGETING

The sample positions are given in the fix laboratory frame and are deduced from the interferometric measurements in two complementary steps:

- 1st step: with an analytical data treatment done on speedgoat and integrating the various correction (see metrology paper MM)

Error induced by	X(nm)	Y(nm)	Z(nm)	TiltX(µrad)	TiltY(µrad)
Specification (acceptable)	20 (50)	20 (50)	10 (50)	1.7	1.7
Mems mirror (variation of center of rotation)	29	29	20	1.0E-01	1.0E-01
4Q diode precision (MEMS angular error)	1.5	1.5	1	9.3E-05	9.3E-05
Laser fluctuations	12	12	8	8.0E-01	8.0E-01
Residual error from calibration	14	14	5	1.0E+00	1.0E+00
Thermal variations	5 ★	5 ★	5 ★	2.0E-01	2.0E-01
Dynamical error	7	7	7	6.7E-02	6.7E-02
Global error = $\sqrt{\sum e^2}$	**35**	**35**	**24**	**1**	**1**

Error budget synthesis

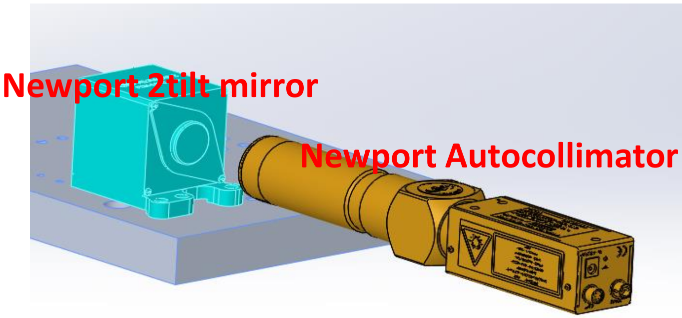
★ These values are expected after integration in the model (analytical or/and with transfert function extracted from Comsol FEA thermo-mechanical model)

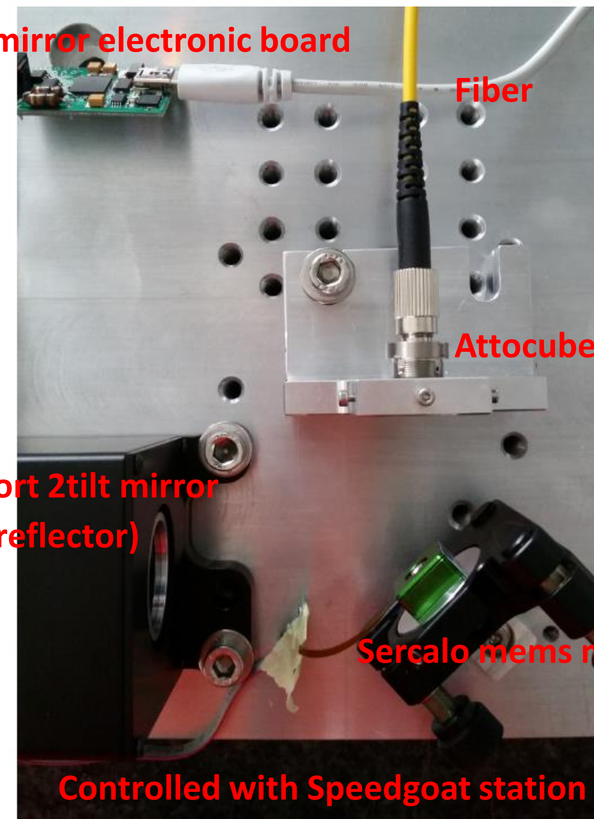
- 2nd step: we expect to reduce these errors with the LUT (look up table) technique (see metrology paper OH)

TEST BENCHES

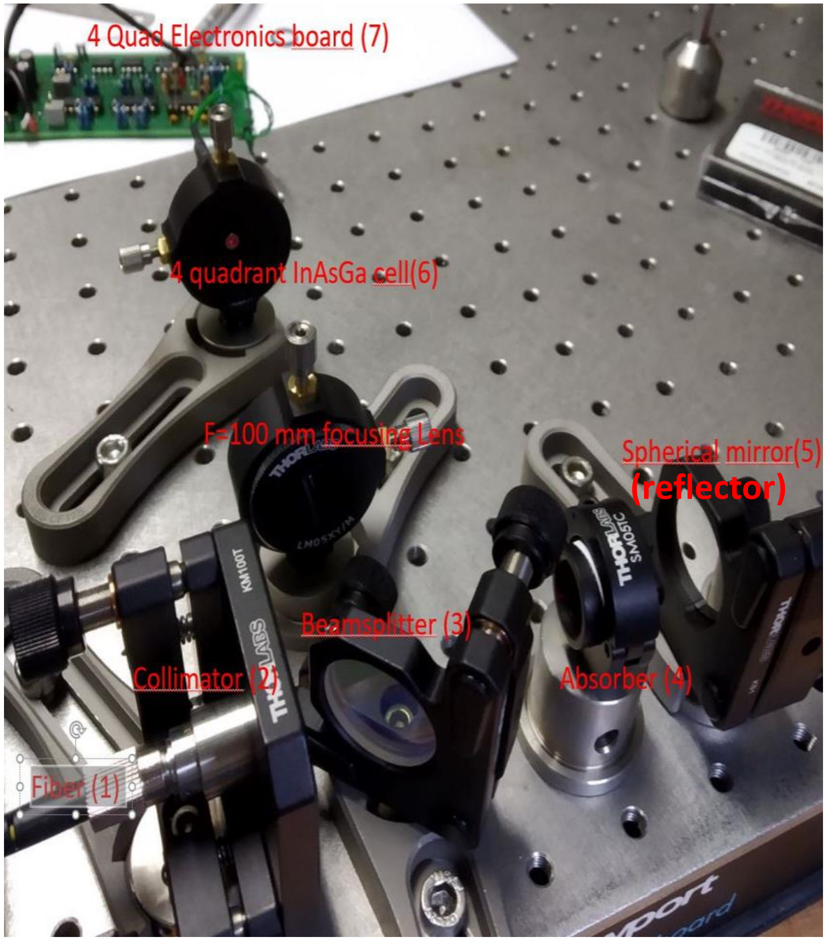
Two test benches have been produced: The 4Q diode test bench and the mems mirror test bench

The mems mirror test bench





The 4Q diode test bench



CALIBRATION OF THE REFLECTOR AND OF THE GLOBAL METROLOGIC SYSTEM

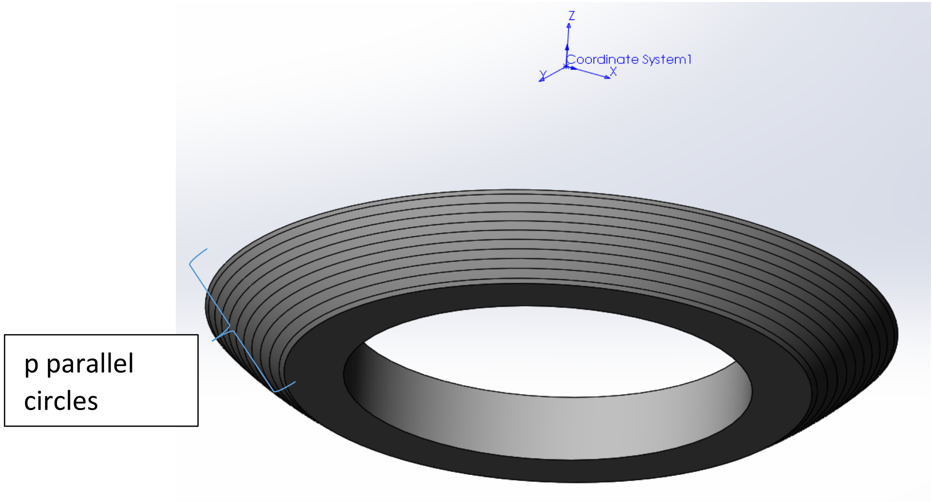
(Ludovic's paper)

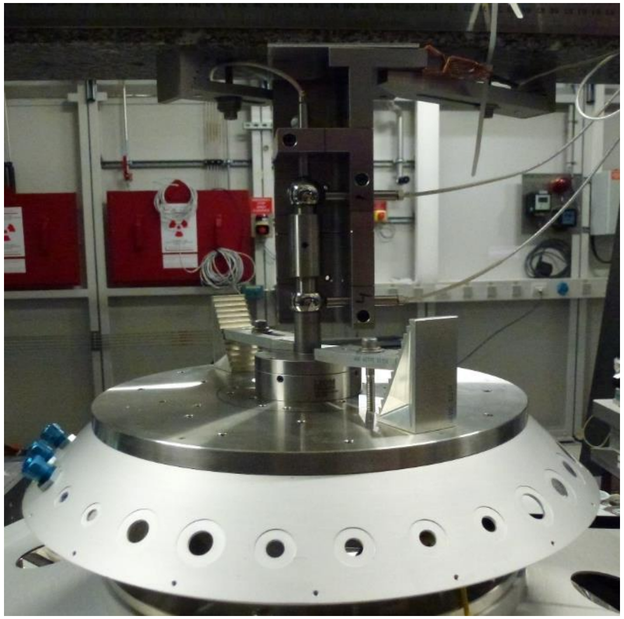
- *Calibration of the reflector alone*

. calibrate parallel circles as designed underneath with Attocube interferometers pointing on to the reflector and reference sphere with capacitive sensors

. Link the parallel circles either with a Fizeau measurement or with an external "metrologic reference"

. Will be done at PDM-Labs or at ID31





Spindle Error Analyzer system installed on the ID31 µ-end-station (Feb-2019)

- *Calibration of the global system with the final metrologic system*

. It will be done directly on the ID31 microstation. This LUT will be used for fine adjustment

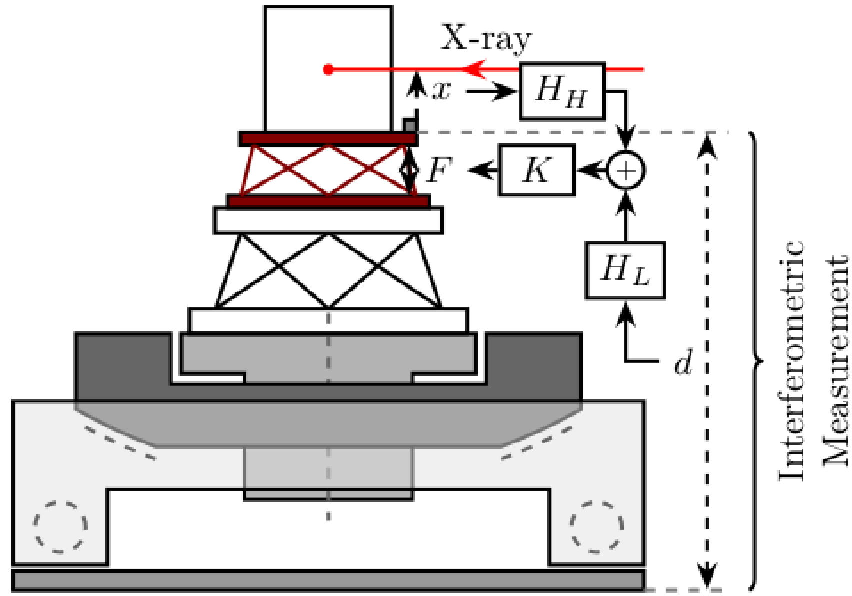
CONTROL STRATEGY

(from Thomas' paper)

Sensor Fusion Techniques

- Combination of multiple sensors in different frequency bands:
  - interferometric measurement used at low frequency to obtain high performance
  - Additional sensor located close to the used at high frequencies to ensure the stability of the system.

- Improves the performance and robustness of the system



Results obtained with an active damping techniques coupled with PID feedback control

Impact of floor perturbation: results obtained with the uniaxial model (Simulink) of the micro-station (based on measured vibrations behavior in static of the micro-station) + NASS model .

Open Loop versus Close Loop	Light Sample	Heavy Sample
Voice coil	45nm to 7nm	131nm to 7nm
Piezoelectric	10nm to 8nm	55nm to 8nm

MECHATRONIC ASPECT

Use of piezoelectric actuators

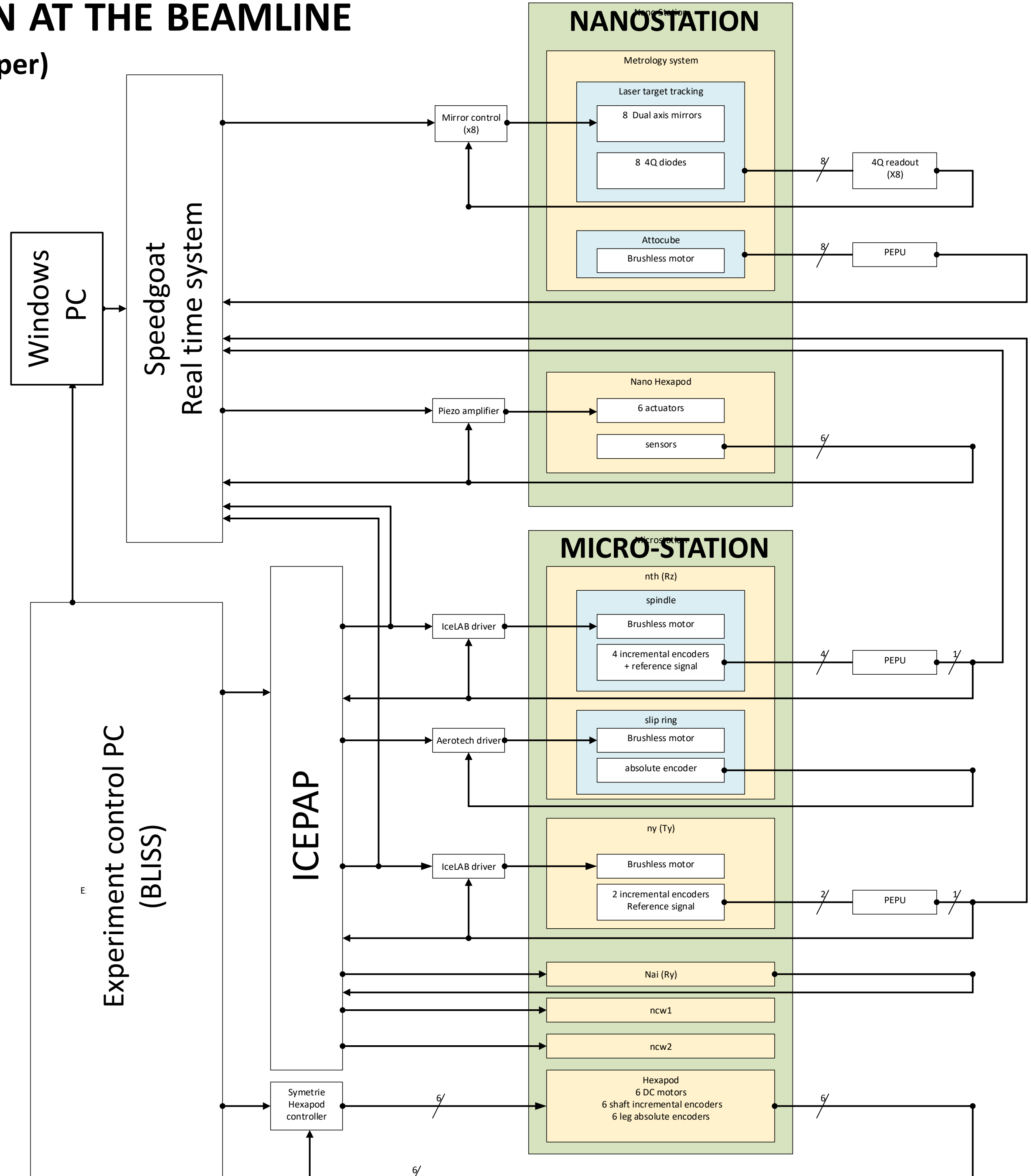
Advantages	Disadvantages
High Stiffness	Small stroke (should be enough)
Acceptable performances in open loop	More sensitive to vibrations induced by the other stages
Less sensitive to ground motion	
No heating problems	
No gravity compensation needed	

Use of Voice coil actuators

Advantages	Disadvantages
Large Stroke (not needed)	Risk of damage when control failure
Decoupled dynamics => high control bandwidth	Gravity Compensation Issues
Less sensitive to vibrations due to other stages	Integration Problems
	More sensitive to ground motion
	Bad compliance => Problem if cables connected to the sample
	Heating problems (due to centrifugal forces)
	Cannot work in open loop
	Very sensitive to rotation speed

IMPLEMENTATION AT THE BEAMLINE

(Jens and Jose-Maria paper)



NEXT STEPS, MANPOWER RESOURCES AND PRIORITIES

- Combine both test benches described above to build a complete branch of the metrology. The reflector is simulated by the 2 tilt Newport mirror (lens)
  - Setup and optical modelisation: Olivier
  - 4Q diode/mems mirror hardware close-loop: Jose-Maria
  - Data treatment: Marc Diot?
  - Setup and coordination: Muriel

- Qualify the deformation of the surface of the mems mirror with a Fizeau technique
  - Optical measurements: Optics lab.

- Measure the dynamical behaviour of the micro-station, complete the model for control and prepare the implement in the beamline of the NASS
  - AAUP/Thomas/Maxim/Jose/Jens/Muriel

- Design the all system with Comsol FEA (thermo-meca and optics – Space time model)
  - Thomas, Sylvie?, Muriel

- Manufacture two reflectors: one in Aluminium with diamond machining technique and one in ceramic or similar with lapping technique
  - Olivier, Muriel

- Calibration of the reflectors
  - AAPU, Optics lab, Thomas and Muriel

- Design and model with Comsol FEA the nano-hexapod (if not a commercial device)
  - Thomas, Muriel + BE

- Manufacture a nano-hexapod prototype.
  - Thomas, Muriel and procurement group

<u>In parallel</u>

- Design and build the capacitive sensors module for the lenses placed before the nano-station
  - Muriel + BE

- Work in collaboration with Symetry to try and reach expected positions with the hexapod in close loop with the capacitive sensors
  - Muriel, Thomas?

"B" PLAN

We are not able to get satisfactory results for the metrology:

- Alternative proposed solution do not fit the motion specifications
- We subcontract the metrology part
- We voluntarily slow down the project to be in phase with the European project that is being launched by the ESRF ;)

Manufacture of the piezo nano-hexapode:

- We find a commercial product which fits (PI?)
- We work with Symetrie to approach the specification with the exiting hexapod

Thank you for your attention and your collaboration