Appendix G

Thermal analysis of a piezo-actuated pointing mechanism

Paul Lardet
(Sodern, France)

Abstract

For the pointing of the Earthcare satellite lidar, Sodern designed a piezo-actuator tip-tilt mechanism. Each four piezo-actuator of this mechanism are equipped with two strain gages mounted in a Wheatstone bridge to precisely regulate pointing.
The behaviour of this regulation strongly depends on the thermal state of the actuators: temperature differences between actuators or gages lead to angular deviation of the mirror, and must be controlled. In particular, thermal studies were realised on two life stages of the mechanism.
During electronic system start-up, the thermal variation leads to temporary gradients delaying the availability of mirror pointing, and therefore must be minimized. Studies showed that the main factor influencing these gradients is the conduction in the system structure. The difficulty of this identification consisted in separating the influences of various parts, as the mechanism is very intricate and the required precision very fine (5mK gradients).
During operating mode, thermal variations at base plate induce gradients between the actuators. The time response of the system has been indentified in order to evaluate the spectral range of variation that must be taken into account. After that, the coefficient of influence of the base-plate temperature on the pointing performances has been determined. For that purpose, a new approach using a comparison between step response and frequency response has been developed, in order to consider small amplitude spectral thermal solicitations.

Thermal study of a piezo-actuated mechanism

P. LARDET – European Space Thermal Analysis Workshop – Nov. 20th 2012

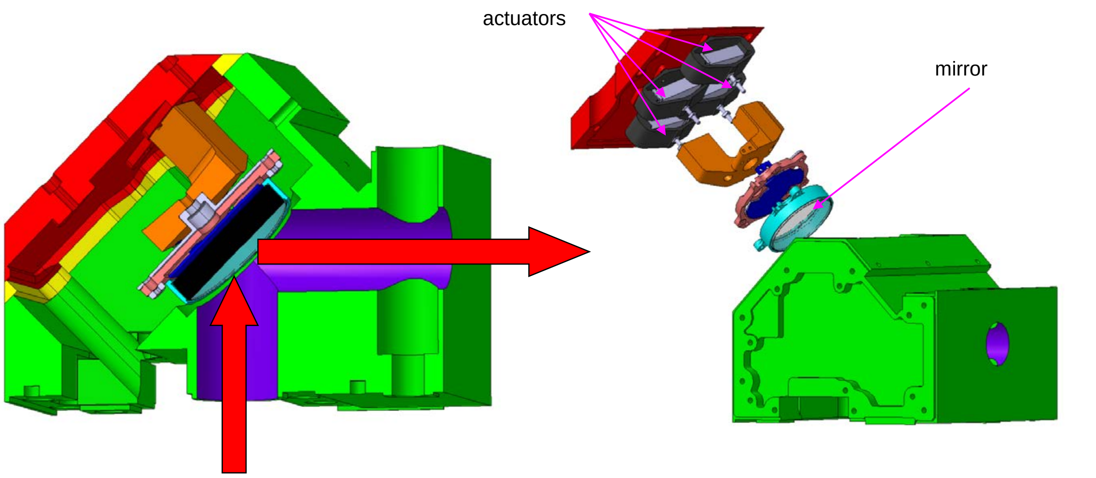
SODERN

Innovation based on Experience

SODERN

Mechanism presentation

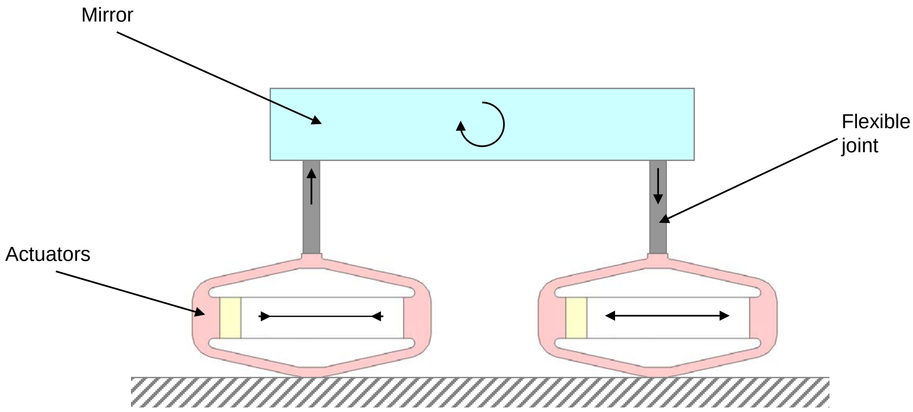
- **Equipment: pointing mechanism of the EarthCARE LIDAR**
- **A mirror points the LIDAR laser beam**
- **The mirror is actuated by four piezo-actuators, each equipped with two strain gages mounted in a Wheatstone bridge**



SODERN – 2012/11/20 European Space Thermal Analysis Workshop SODERN P. 2

Actuators schematic

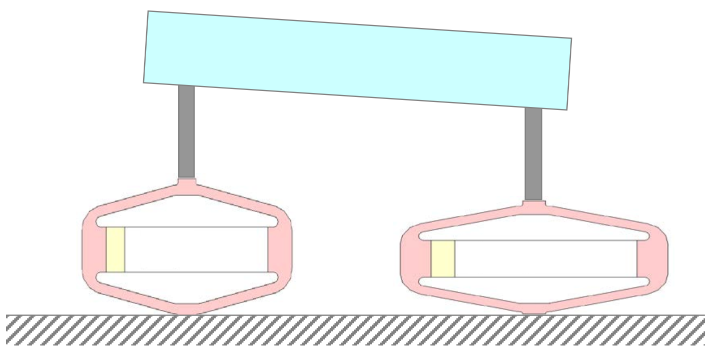
- **For each axe, 2 actuators working in push-pull**



SODERN – 2012/11/20 European Space Thermal Analysis Workshop SODERN P. 3

Actuators schematic

- **For each axe, 2 actuators working in push-pull**



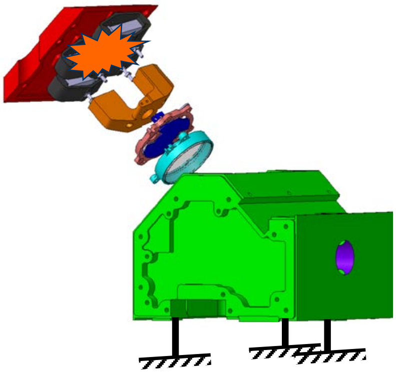
SODERN – 2012/11/20 European Space Thermal Analysis Workshop SODERN P. 4

SODERN

Thermal issues

- High pointing precision is required (~0.1% of 3mrad)
- Pointing precision strongly depends on thermal state of actuators: Temperature differences between actuators disturbs pointing

- Two lifecycle phases are studied



Electronic activation

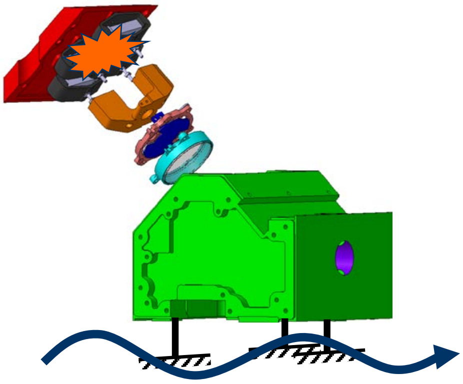
SODERN – 2012/11/20 European Space Thermal Analysis Workshop SODERN P. 5

SODERN

Thermal issues

- High pointing precision is required (~0.1% of 3mrad)
- Pointing precision strongly depends on thermal state of actuators: Temperature differences between actuators disturbs pointing

- Two lifecycle phases are studied

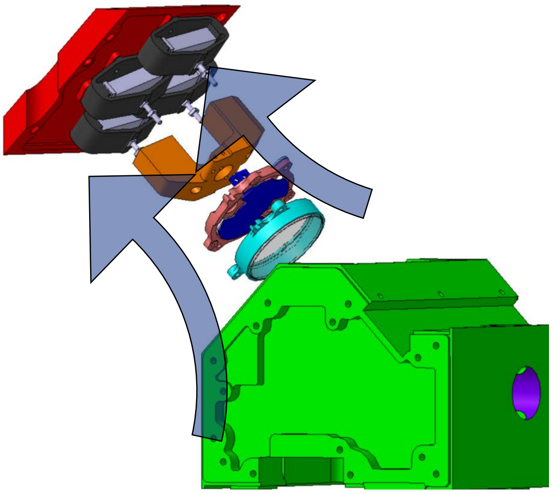


Thermal perturbation at base plate

SODERN – 2012/11/20 European Space Thermal Analysis Workshop SODERN P. 6

Main Thermal influencing factors

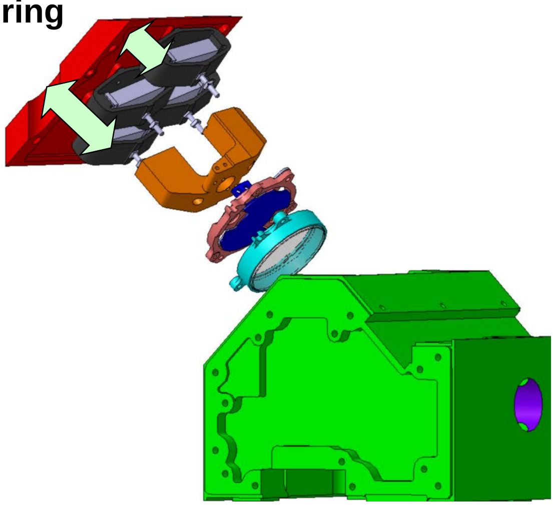
- Potential items influencing the actuators thermal state
- Geometrical dissymmetry of thermal diffusion



SODERN – 2012/11/20 European Space Thermal Analysis Workshop SODERN P. 7

Main Thermal influencing factors

- Potential items influencing the actuators thermal state
- Geometrical dissymmetry of thermal diffusion
- Contact thermal resistance scattering

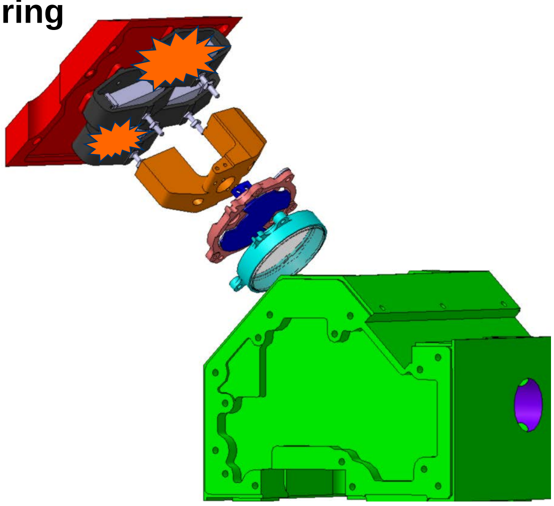


SODERN – 2012/11/20 European Space Thermal Analysis Workshop SODERN P. 8

Main Thermal influencing factors

- **Potential items influencing the actuators thermal state**

- **Geometrical dissymmetry of thermal diffusion**
- **Contact thermal resistance scattering**
- **Gage thermal power scattering**



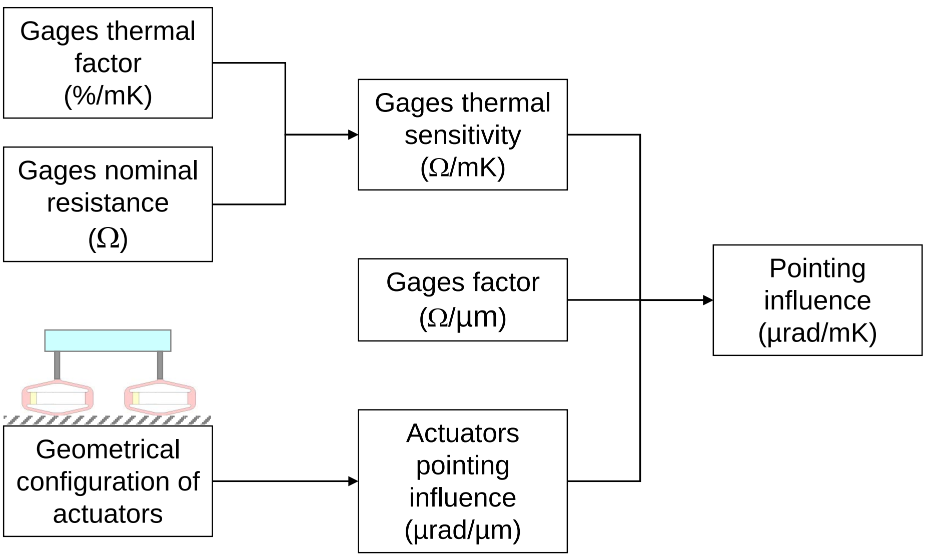
- **Because a compensing system is present, only temperature difference *variation* is important**

→Scattering is not an issue in this study, because it is constant over time. The problem is purely diffusive

SODERN – 2012/11/20 European Space Thermal Analysis Workshop SODERN P. 9

Influence factor of temperature on pointing

- **On each axis:**



SODERN – 2012/11/20 European Space Thermal Analysis Workshop SODERN P. 10

SODERN

Technical challenges

- **Main difficulties of the studies:**

- **Electronic start:**
  - **Quick stabilization of *temperature difference* between actuators is needed to get early equipment availability**

  → **Actuator stabilization is not important, but *symmetry between them* is !**

- **Thermal perturbation at base plate**
  - **Thermal specification includes random variation (0.05mHz-10mHz) and drift (above 90min up to lifetime) of base plate temperature**
  - **Phase B do not allow to dig further detailed random calculations**
  - **And long term transitory calculations are not achievable**

  → **Time constant calculation is the key**

- **For both cases**
  - **Small temperature differences (~5mK per push-pull) are expected**

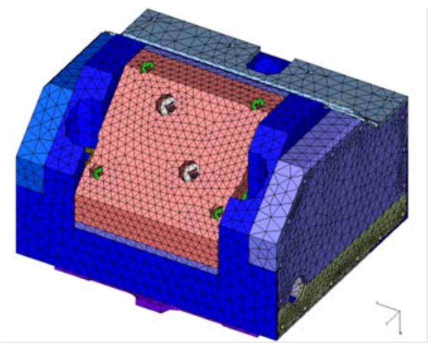
  → **High precision results are needed**

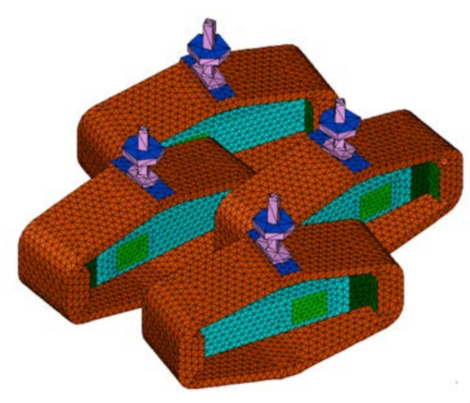
SODERN – 2012/11/20 European Space Thermal Analysis Workshop SODERN P. 11

SODERN

Model used for calculations

- **NX I-DEAS/TMG 6 modelling**
- **Special attention on actuators**

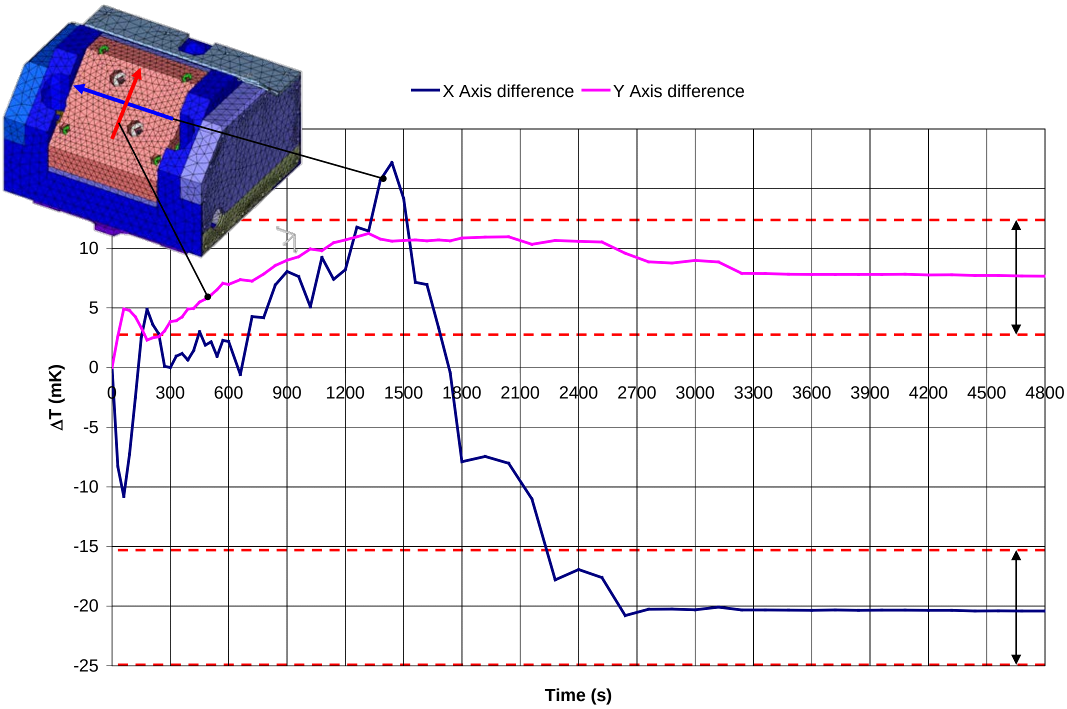




SODERN – 2012/11/20 European Space Thermal Analysis Workshop SODERN P. 12

SODERN

Transient evolution after electronic starts

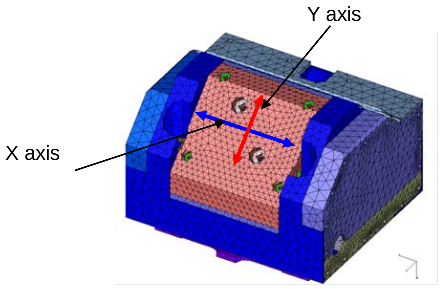


SODERN – 2012/11/20 European Space Thermal Analysis Workshop SODERN P. 13

SODERN

Analysis of transient results

- **The big differences between X and Y Axis asks for temperature field analysis**

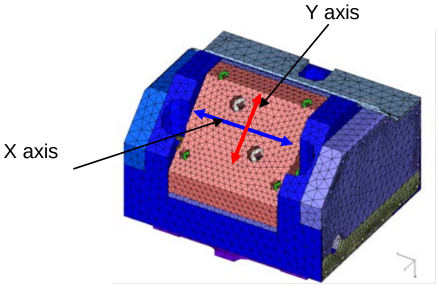


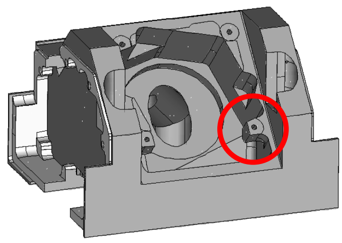
- **Late stabilization is not caused by global dissymmetry**

SODERN – 2012/11/20 European Space Thermal Analysis Workshop SODERN P. 14

Analysis of transient results

- **The big differences between X and Y Axis asks for temperature field analysis**



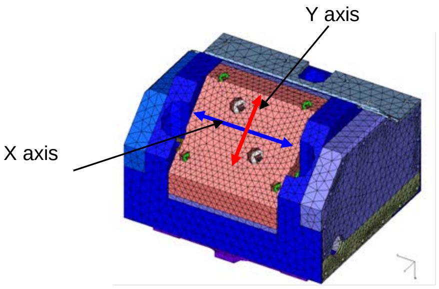


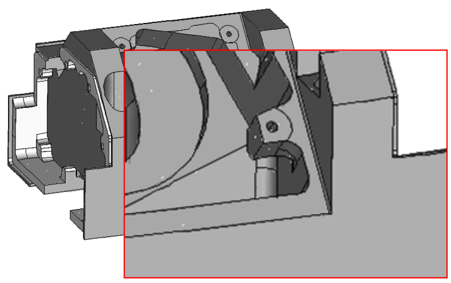
- **Late stabilization is not caused by global dissymmetry**
- **Late stabilization is caused by very local dissymmetry**

SODERN – 2012/11/20 European Space Thermal Analysis Workshop SODERN P. 15

Analysis of transient results

- **The big differences between X and Y Axis asks for temperature field analysis**





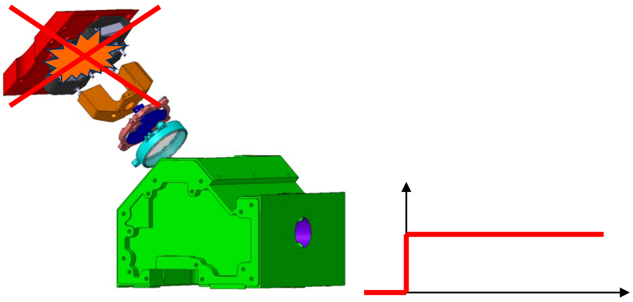
- **Late stabilization is not caused by global dissymmetry**
- **Late stabilization is caused by very local dissymmetry**

- **Design recommendations for phase C: As low as possible geometrical dissymmetry on equipment casing**

SODERN – 2012/11/20 European Space Thermal Analysis Workshop SODERN P. 16

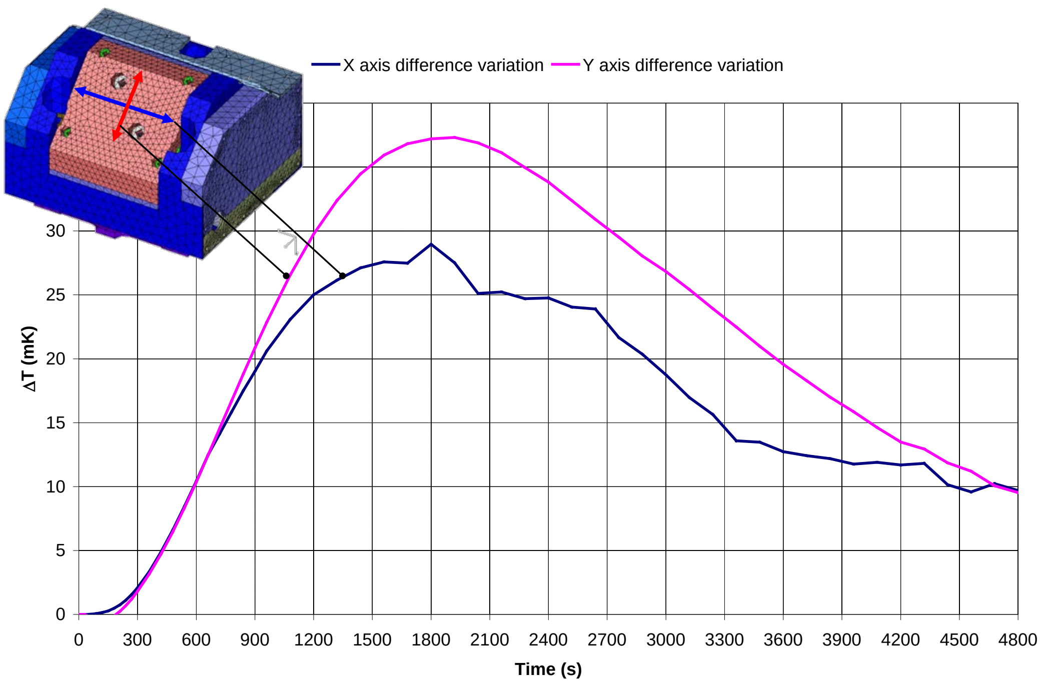
Thermal perturbation study

- Influence of radiation proved to be positive on gradients
  → Calculation w/o radiation, system is linear
- As system is linear, BC influences can be separated
  → Calculation w/o any electronic dissipation
- Response to a step is greater than to a sine
  → Calculation: 10°C temperature step at base plate, output of variation of temperature differences between actuators



SODERN – 2012/11/20 European Space Thermal Analysis Workshop SODERN P. 17

Time response to a step perturbation



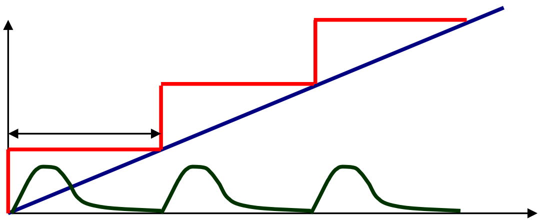
SODERN – 2012/11/20 European Space Thermal Analysis Workshop SODERN P. 18

Analysis of stability results

- Time constant τ of actuators response is about 1800s
- Response coefficient of actuators temperature difference is less than 35/10=3.5mK/°C

- For random perturbations, RMS values of pointing thermal stability (µrad²) can be calculated with this upper bound value

- For drift perturbation, base-plate variation is over-estimated by steps of length 10τ
- Drift on this period is used to calculate the corresponding maximum pointing deviation



SODERN – 2012/11/20 European Space Thermal Analysis Workshop SODERN P. 19

Synthesis and coming next

- Answer to various issues with very few calculations

- Use of simple step response to estimate response to random perturbation
- Use of middle term time constant to estimate response to very long term perturbations

- For Phase C, frequency analysis could be performed:
  - calculation of harmonic response for different frequencies
  - With this transfer function, calculation of the RMS thermal pointing stability

  → Increase of calculation precision

SODERN – 2012/11/20 European Space Thermal Analysis Workshop SODERN P. 20

The end

- **Thank you for your attention**
- **Any questions ?**

SODERN – 2012/11/20 European Space Thermal Analysis Workshop SODERN P. 21