Hexapod Control Upgrade at Synchrotron Soleil

Method and Results

Presentation

Christer Engblom, on behalf of:

Louis Amelineau (worked at SOLEIL: 2017-2021)

ECA (Electronique de Contrôle et Acquisition) Group in Synchrotron SOLEIL

- Electronics & Motion Control

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  - What is a Stewart Platform?
  - Objective
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Introduction

What is a Stewart Platform?

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Mechanical Configuration:

Introduction

What is a Stewart Platform?

Mechanical Configuration:
Positional Plate + Base Plate

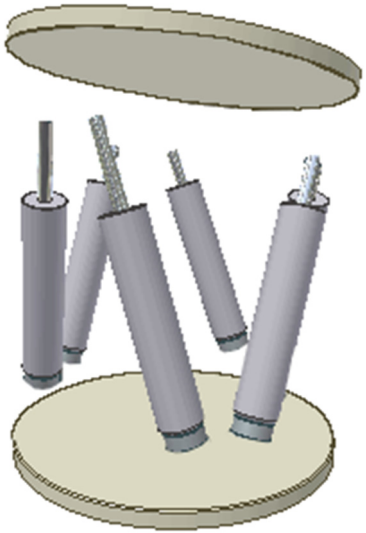
Introduction

What is a Stewart Platform?

Mechanical Configuration:

Positional Plate + Base Plate

6 x Linear Actuators



Introduction

What is a Stewart Platform?

Mechanical Configuration:

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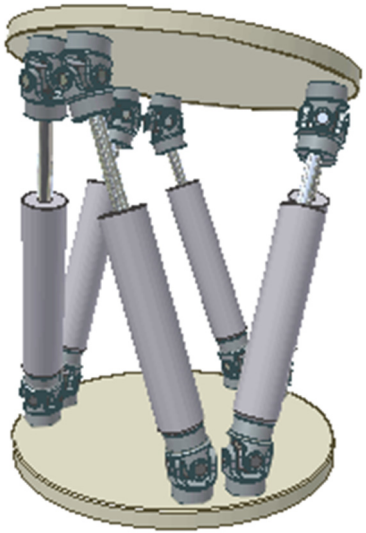
6 x Linear Actuators

12 x Universal Joints



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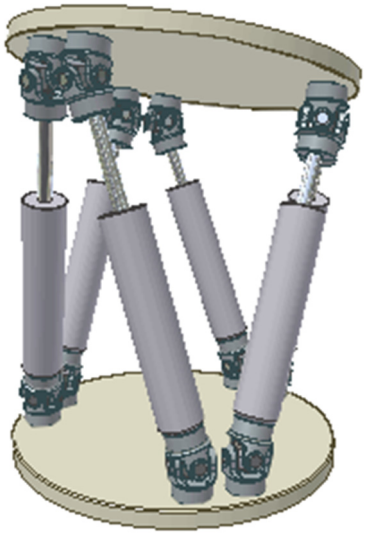

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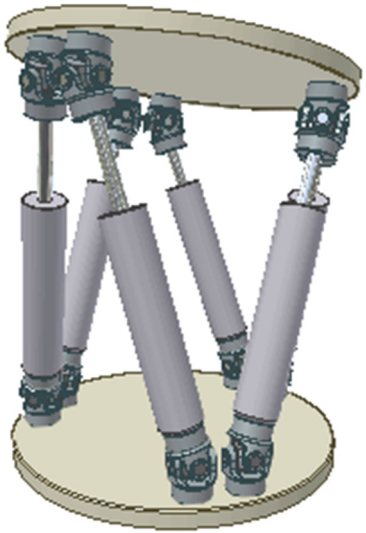
Multi-axial control using
a kinematic model



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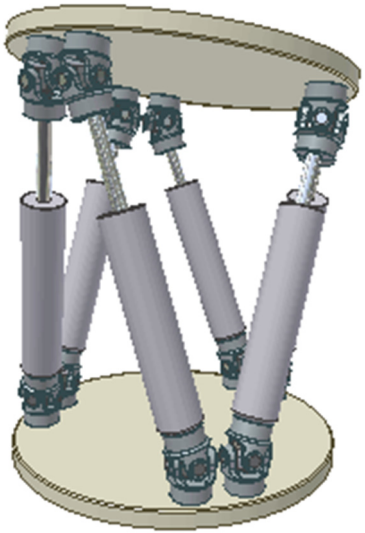
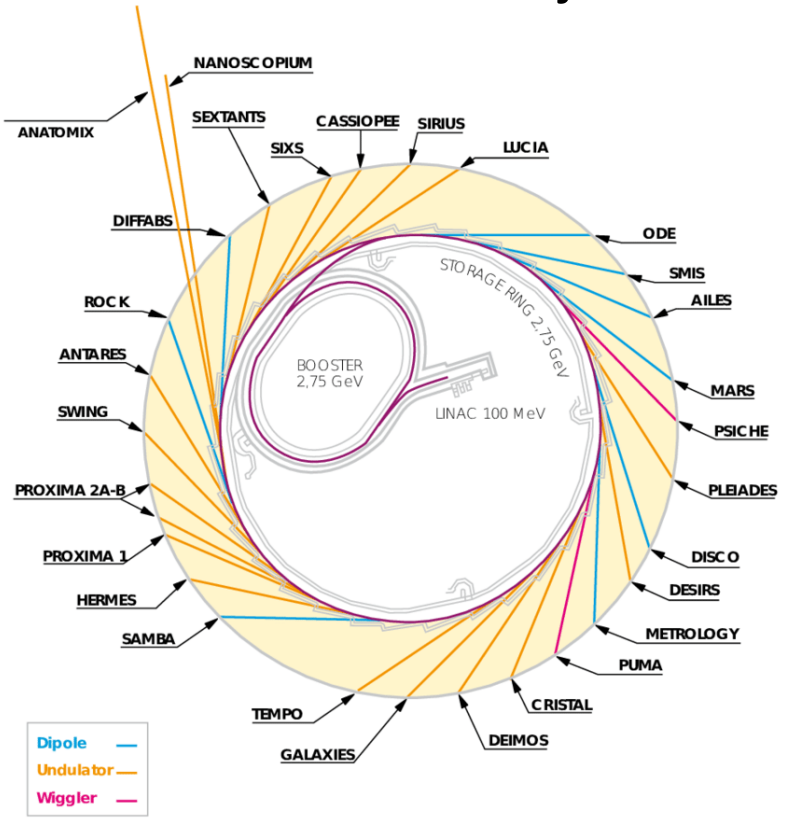
Positional Plate in 6 DOF
(X, Y, Z, R_x, R_y, R_z)



Stewart Platform Systems at SOLEIL



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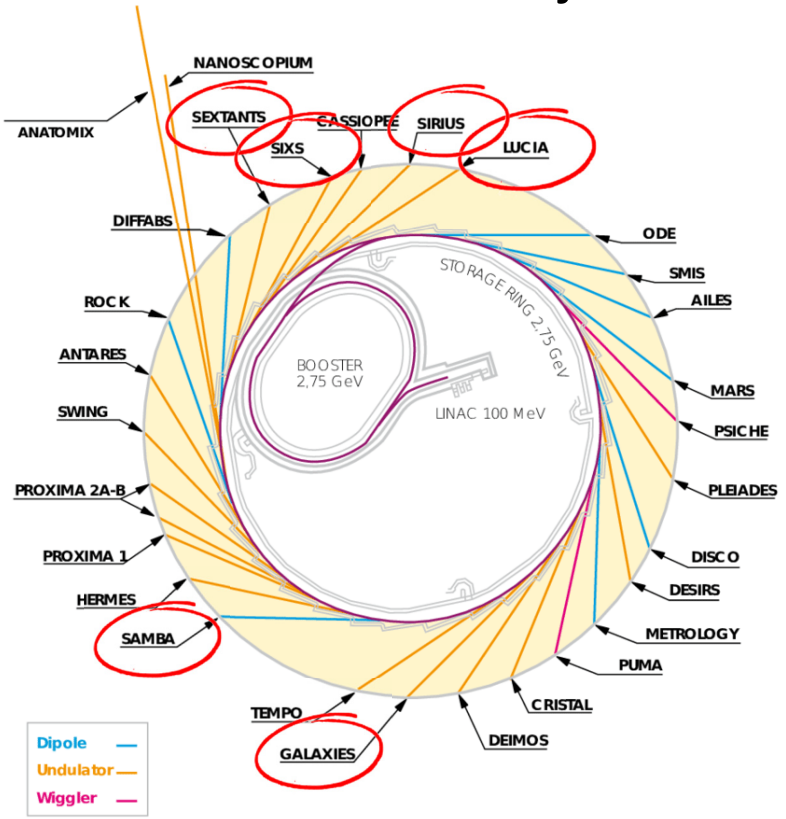
Objective

Stewart Platform Systems at SOLEIL

At least 12 systems covering
6 different beamlines



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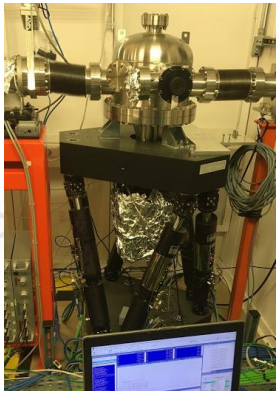
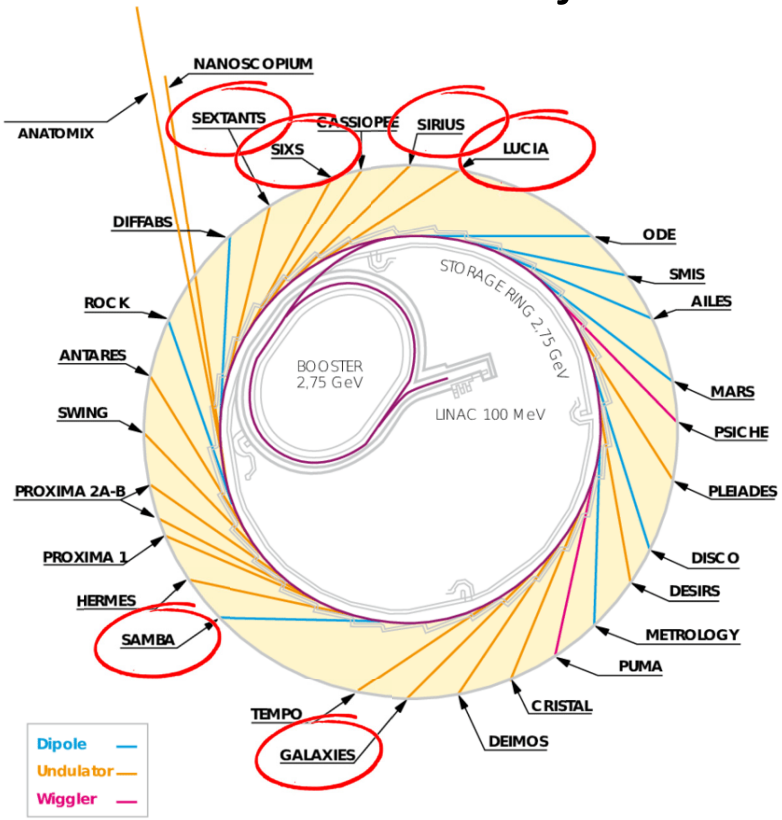
Stewart Platform Systems at SOLEIL

At least 12 systems covering
6 different beamlines

Most common use-case

Displace mirror systems
(often with micron-precision
& repeatability)





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Stewart Platform Systems at SOLEIL

At least 12 systems covering
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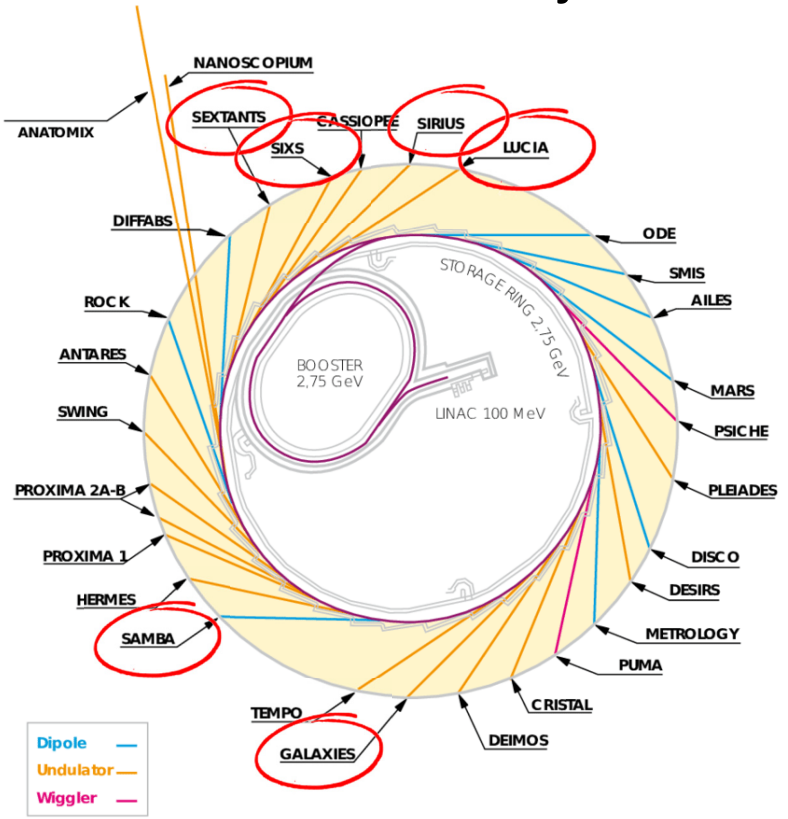
Most Control Systems:
Proprietary & Black-Box

Kinematic Models:
Proprietary & Black-Box



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Objective

Stewart Platform Systems at SOLEIL

Most Control Systems:
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Kinematic Models:
Proprietary & Black-Box

Key drawbacks:

- Risk of product discontinuity
- Limited maintenance & support
- Limited System evolution

Introduction

Objective

Stewart Platform Systems at SOLEIL

Control Systems:
SOLEIL Standard (Delta Tau Powerbrick)

Kinematic Models:
In-house

Most Control Systems:
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Hexapod Project

Main Objective:

Apply SOLEIL-standard controller (Delta Tau Powerbrick LV*) solution to generic Stewart Platform beamline applications using in-house kinematic models

*Revolution Project (https://accelconf.web.cern.ch/ICALEPCS2015/papers/mopgf047.pdf)

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Hexapod Project

Context

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2017 – 2021: Louis Amelineau
(Apprenticeship, 1-year contract)

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Apply SOLEIL-standard controller solution to a Stewart Platform application in beamline

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Hexapod Project:

Apply SOLEIL-standard controller solution to a Stewart Platform application in beamline

Hexapod Project

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2017 – 2021: Louis Amelineau (Apprenticeship, 1-year contract)

$$\mathbf{L} = \mathbf{L}(x, y, z, \theta, \phi, \psi) = (l_1 \quad l_2 \quad l_3 \quad l_4 \quad l_5 \quad l_6)^T = \\ = (|\mathbf{P}_1| \quad |\mathbf{P}_2| \quad |\mathbf{P}_3| \quad |\mathbf{P}_4| \quad |\mathbf{P}_5| \quad |\mathbf{P}_6|)^T$$

$$\text{where: } \mathbf{P}_i = \mathbf{T} + \mathbf{R} \cdot \mathbf{p}_i - \mathbf{b}_i = \begin{pmatrix} x \\ y \\ z + h \end{pmatrix} + \mathbf{R} \cdot \begin{pmatrix} x_{pi} \\ y_{pi} \\ z_{pi} \end{pmatrix} - \begin{pmatrix} x_{bi} \\ y_{bi} \\ z_{bi} \end{pmatrix}$$

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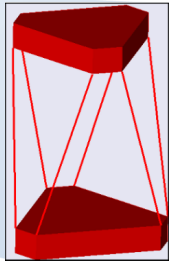

Hexapod Project:

Stewart Platform kinematics validation (simulations)

Apply SOLEIL-standard controller solution to a Stewart Platform application in beamline

Hexapod Project

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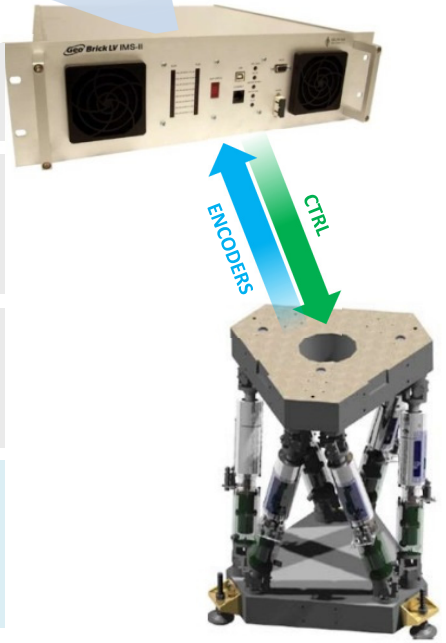
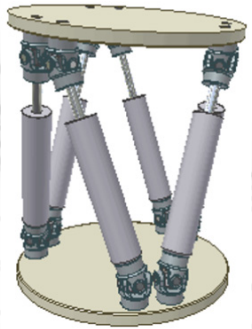
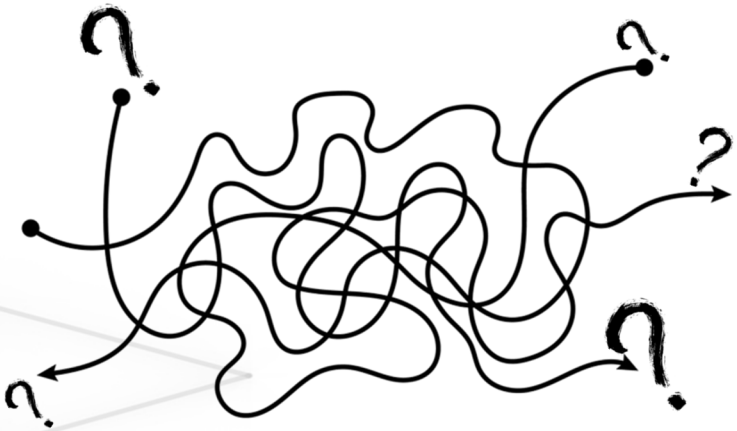


Hexapod Project

Kinematics & Control

Virtual Axes:
(X, Y, Z, R_x, R_y, R_z)





Leg Lengths:
($L_1, L_2, L_3, L_4, L_5, L_6$)

Hexapod Project

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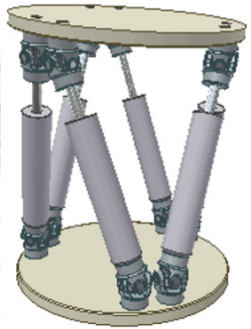

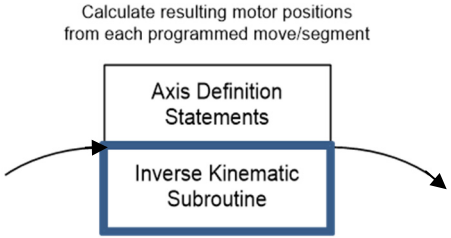

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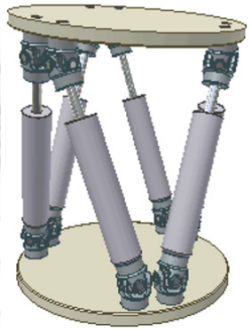

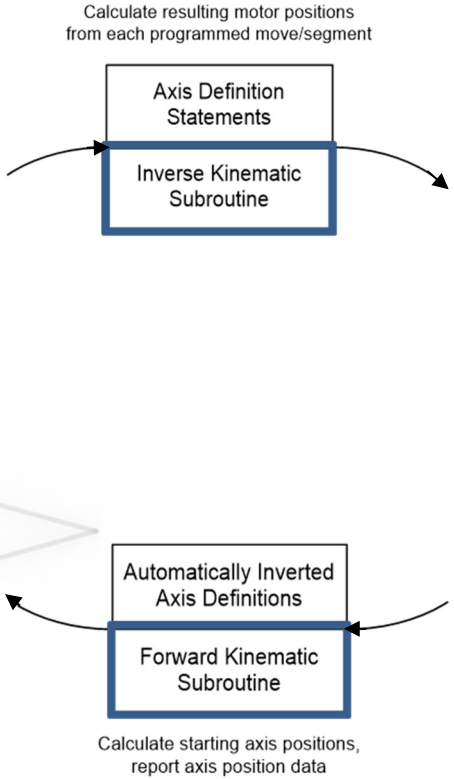

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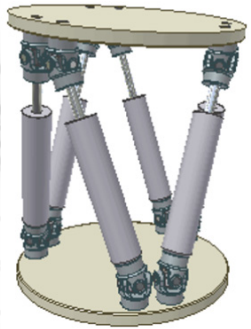
Hexapod Project

Kinematics & Control

- Kinematics
  - Inverse
  - Forward



Hexapod Project

Kinematics & Control

- Kinematics
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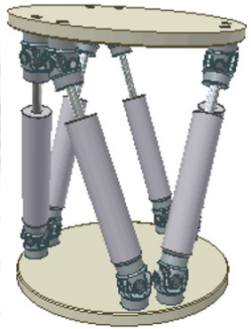
  - Forward
- Workspace Definition



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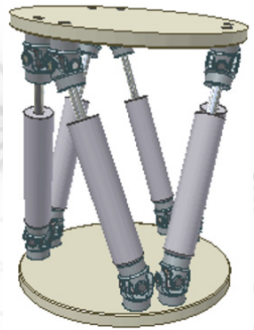
Kinematics & Control



- Kinematics
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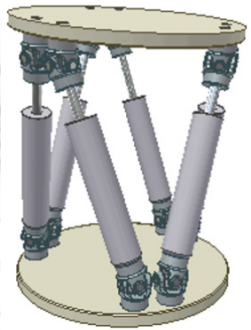
  - Mechanical limits and security (in part limited by mechanical constraints, such as leg-lengths)

Hexapod Project

Kinematics & Control



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  - Lack singularity points (kinematics)

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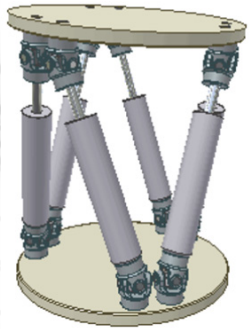
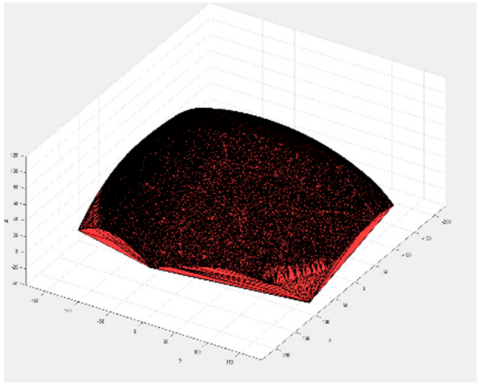
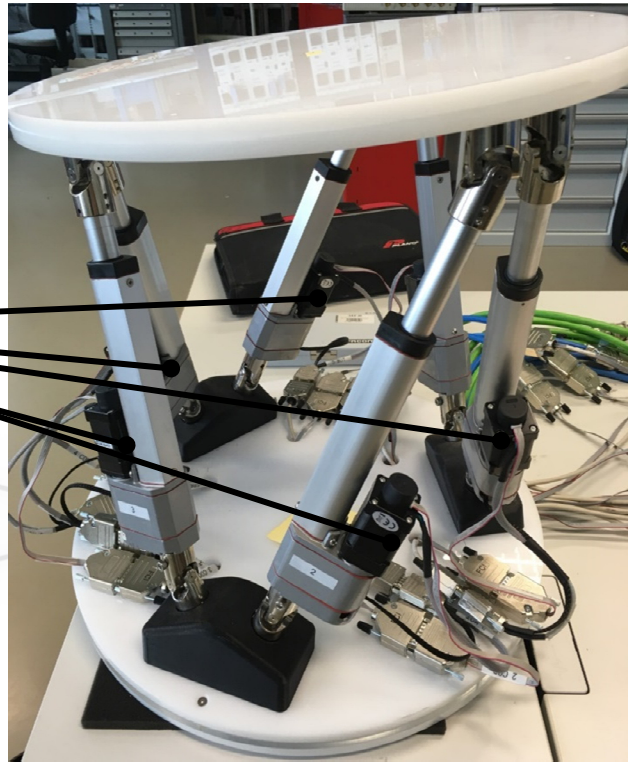


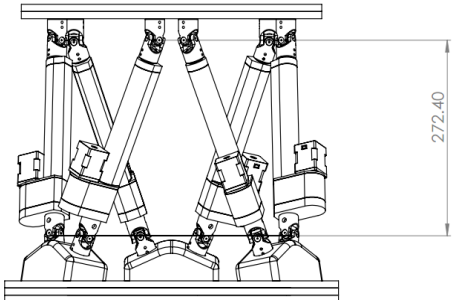


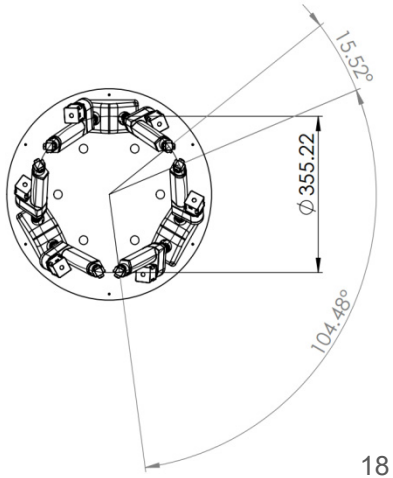
Hexapod Project

Test-Bench

Stepper Motors
(Low resolution encoders)

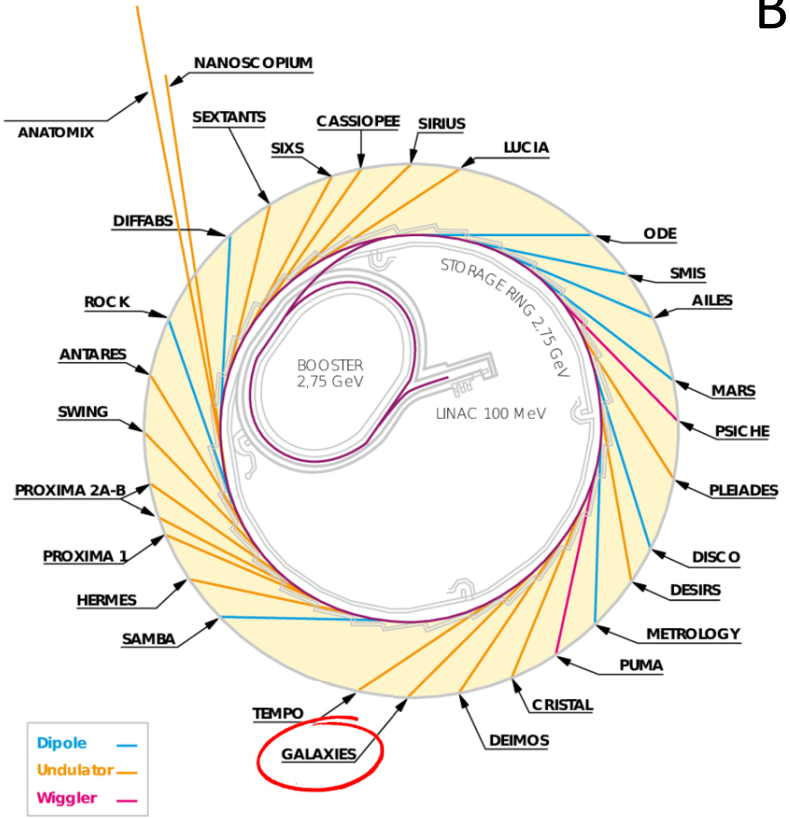






Hexapod Project

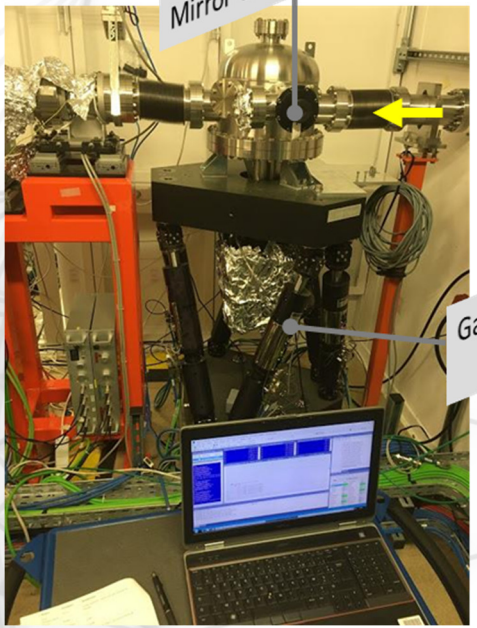
Beamline Application



Hexapod Project

Beamline Application

GALAXIES Hexapod Mirror setup (M2B)



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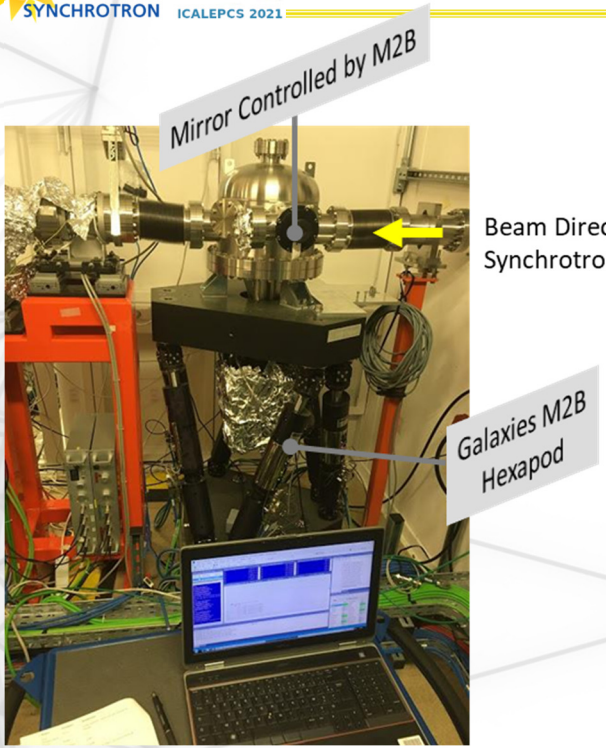
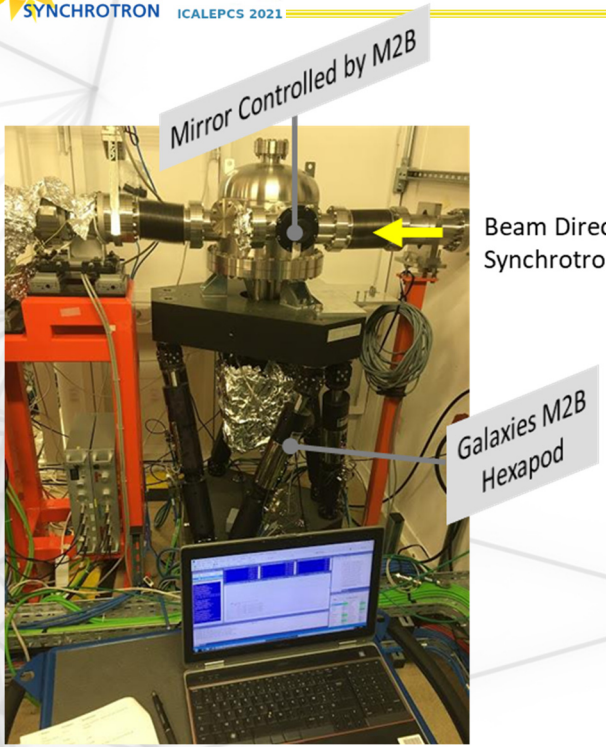


GALAXIES Hexapod Mirror setup (M2B)

- **Use**: Insertion/Extraction of mirrors to/from synchrotron beam

Hexapod Project

Beamline Application



GALAXIES Hexapod Mirror setup (M2B)

- **Use**: Insertion/Extraction of mirrors to/from synchrotron beam
  - High precision (repeatability): a few µm

- Hexapod specifications
  - Stepper motors
  - Encoded (100nm resolution)

MOTION	RANGE SOFT LIMIT
PITCH	± 2.0 DEGREES
ROLL	± 2.0 DEGREES
YAW	± 2.0 DEGREES
VERTICAL	± 10.00 mm
LATERAL	± 30.00 mm
LONGITUDINAL	± 25.00 mm

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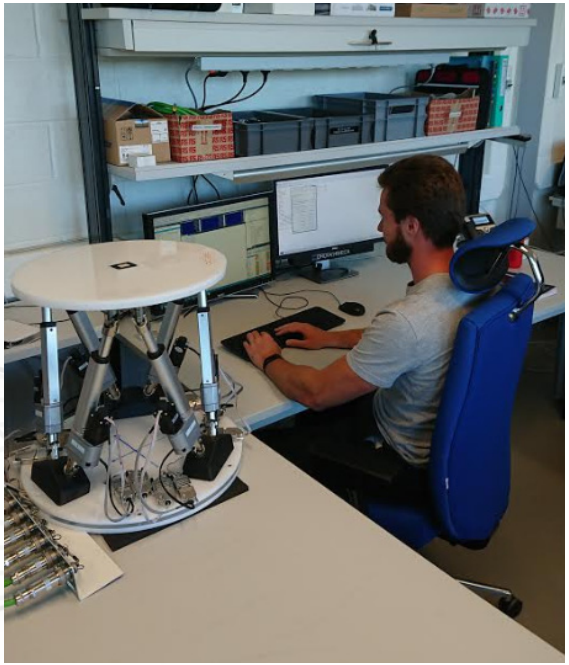
Results

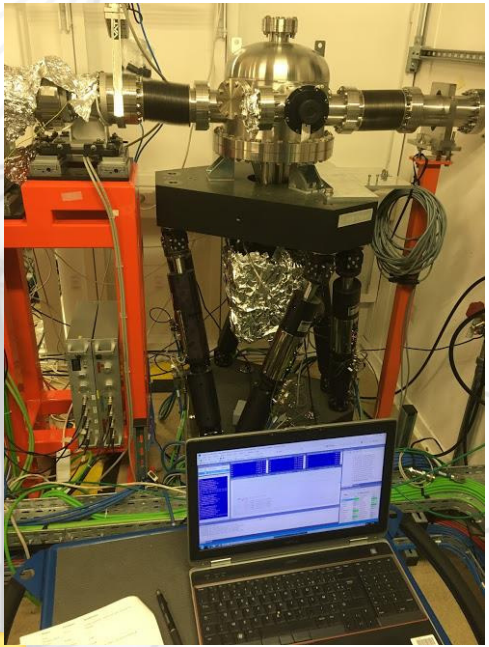
Proof of Concept validated in 2019: Test-bench implementation successful



Results

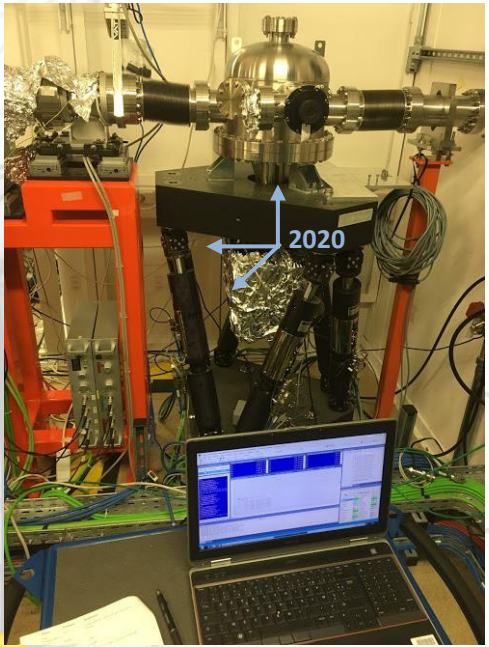
GALAXIES Hexapod Implementation

2020



Results

GALAXIES Hexapod Implementation

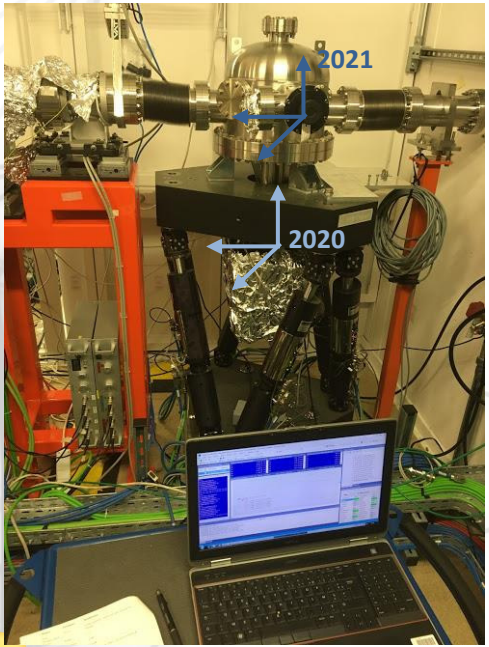


2020

- New control solution successful & in production since 2020 (with coordinate system centered **below** mirror system).
- Controlled via SOLEIL standardised TANGO-devices

Results

GALAXIES Hexapod Implementation



2020

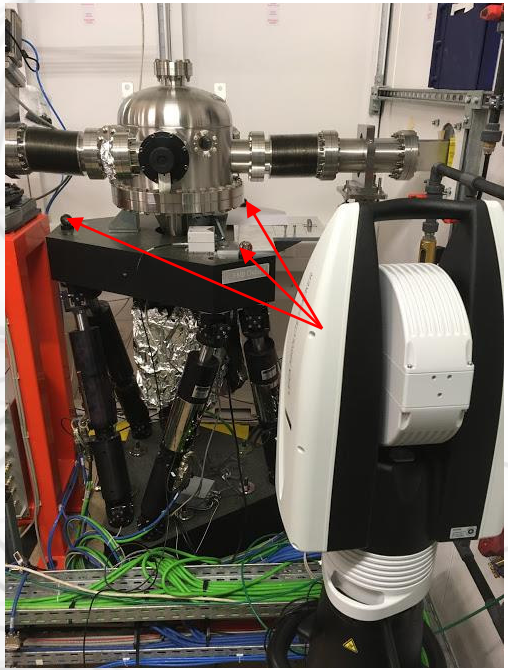
- New control solution successful & in production since 2020 (with coordinate system centered **below** mirror system).
- Controlled via SOLEIL standardised TANGO-devices

2021

- Improved kinematics (with coordinate system centered **on** mirror system.
- Metrology measurements (old control system vs new)

Results

GALAXIES Hexapod Implementation

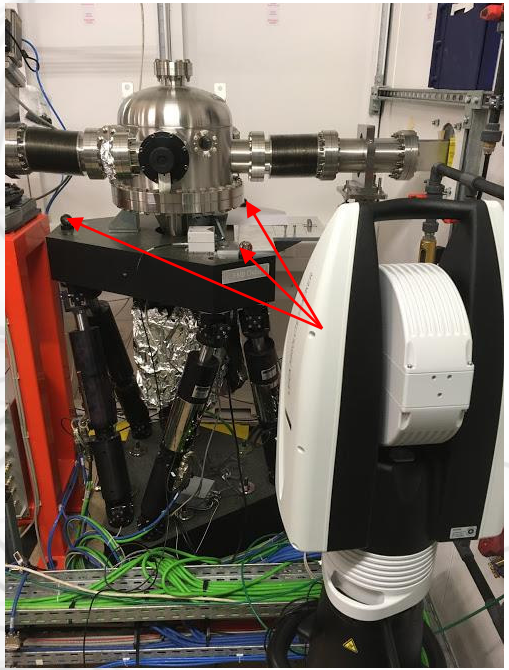


Metrology measurements (using laser trackers + retroreflectors)

- Hexapod positioning precision performance:
  original control-solution **vs** new control-solution

Results

GALAXIES Hexapod Implementation



Metrology measurements (using laser trackers + retroreflectors)

- Hexapod positioning precision performance :
  original control-solution **vs** new control-solution

	Old CTRL System	New CTRL system
Lateral errors during linear moves	< 10 µm (peak-to-peak)	**< 10 µm (peak-to-peak)**
Rotational errors during linear moves	< 20 µrad (peak-to-peak)	**< 20 µrad (peak-to-peak)**

Conclusion

Hexapod Project:

Stewart Platform kinematics validation (simulations)

Stewart Platform kinematics implementation into SOLEIL standard controller (Powerbrick LV)

Control implementation: Test-bench platform

Apply SOLEIL-standard controller solution to a Stewart Platform application in beamline

Conclusion

Hexapod Project:

- Stewart Platform kinematics validation (simulations) ✓
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Conclusion

Hexapod Project:

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Hexapod Project:

- Proven in-house solution (using SOLEIL standardised controller + kinematics)
- Solution is shown to be generic to Stewart Platform builds, and would therefore be applicable to other SOLEIL applications
- New open-controller access is already proving useful ➔ system developments already done and new ones underway

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Future Outlook

Conclusion

Hexapod Project:

- Proven in-house solution (using SOLEIL standardised controller + kinematics)
- Solution is shown to be generic to Stewart Platform builds, and would therefore be applicable to other SOLEIL applications
- New open-controller access is already proving useful ➔ system developments already done and new ones underway

Future Outlook

- Kinematic improvements (using metrology data) already underway to improve system models
- Stewart Platform kinematics ready for additional system implementations in SOLEIL

We would also like to thank the GALAXIES beamline and the SOLEIL Metrology group.