New Opportunities for Better User Group Software, 23-27 September 2024
ILL & ESRF, Grenoble, France

# Motor device interfaces and a multi-axis motor framework at the European XFEL

**D. Hickin, A. Silenzi, A. Garcia-Tabares Valdivieso, A. Parenti, A. Klimovskaia, A. Samadli, B. Baranasic, D. Göries, F. Sohn, G. Giovanetti, G. Flucke, I. Karpics, L. Zanellato, M. Smith, N. Jardon, P. Geßler, R. Costa, R. Fabbri, S. Esenov, S. Hauf, S. Huynh, T. Freyermuth, V. Bondar, W. Ehsan**

**European XFEL GmbH, Holzkoppel 4, 22869 Schenefeld, Germany**

## Introduction

The European X-Ray Free-Electron Laser (the European XFEL) is an X-ray research laser facility which generates ultrashort (<100 fs) X-ray pulses up to 27,000 times per second at a brilliance that is a billion times higher than that of the best conventional synchrotron X-ray radiation sources.

A control system toolkit, Karabo, developed in-house, is used to implement the control and data acquisition systems of the European XFEL.

Motion systems play an essential role in research at the European XFEL. More than 3000 motors move components within the various tunnels and instrument hutches.

Standard interfaces to motion systems allow interoperable client software to be written.

A Karabo framework (Virtual Motor Base) facilitates the creation of software for controlling systems of motors which implement these standard interfaces.

## Overview of Karabo

**Karabo** is an open source device-based distributed control system toolkit[1]. It provides software infrastructure for use in building distributed SCADA (supervisory control and data acquisition) systems and is used to implement the control and data acquisition systems of the 3 tunnels and 7 instruments of the European XFEL[2].

Karabo is device-based: Clients interface named objects called **Karabo devices** which are hosted by server processes (device servers).

Hardware is interfaced through Karabo devices. Some Karabo devices represent hardware devices such as pumps, pressure gauges, cameras and motors. Other Karabo devices may not be directly associated with hardware, but may carry out other roles, such as coordination or composition of multiple other devices.

Devices are instantiated via pluggable software components (**device classes**).

Currently there are 21000+ such devices of 570+ classes in the control and data acquisition systems of the tunnels and instruments of the European XFEL.

## Karabo Motor Devices and Motor Interfaces

Motor hardware is interfaced through Karabo devices and typically one Karabo device (**Karabo motor device**) represents one motor axis.

The majority of motors are controlled through programmable logic controllers (PLCs). Karabo motor devices interface the PLC to control the hardware device.

A smaller number of motors are controlled more directly by the Karabo motor device, for example though an ASCII command set or vendor library over a USB, Ethernet or serial connection to a motor controller.

Karabo motor devices provide a standardised interface and behaviour allowing Karabo client software to be written which is interoperable with different motor devices.

The Karabo **interfaces** property advertises a device's conformance to the standard. This aids the implementation of interoperable Karabo clients for motor devices. An important example is the scan tool, Karabacon.

## Combined Motion and Multi-axis Motor Interfaces

Combined movements of motors are often required. These are sometimes performed without real-time coordination of the motion of the motors, but coordination at the PLC level is sometimes required for equipment protection or to obtain the necessary precision for experiments.

This is often carried out by devices implemented using Karabo's Python **middlelayer API**.

One approach to combined motion is provided through devices implementing the **multi-axis motor interface**. Such devices are presented as a number of **virtual axes**, each with a single-axis-like interface. These provide a standardised interface and behaviour and also advertise conformance through the interface property.

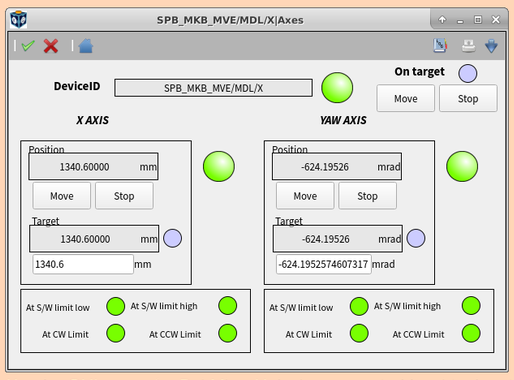
Examples include:

- Centre position and gap size of two blades of an exit slit system or synchrotron radiation aperture (SRA)
- Position (X/Y/Z) and orientation (pitch/roll/yaw) of equipment such as mirrors or experiment chambers
- Hexapod systems (X/Y/Z & U/V/W coordinates)

## Virtual Motor Base

**Virtual Motor Base** is a framework using the Karabo middlelayer API which enables the creation of multi-axis motor devices to control multiple motor axes through a number of single-axis Karabo motor devices with relatively little new code.

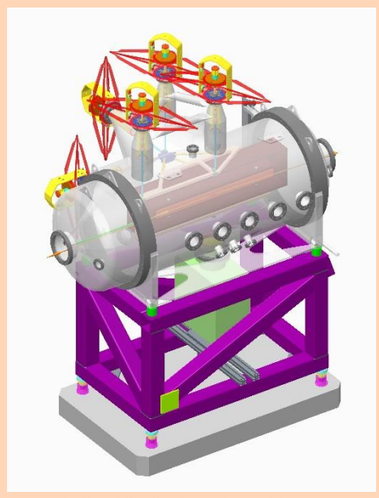
This reduces overall effort, implements the expected interface and behaviour, and ensures compatibility with clients using motor interfaces including the scan tool.

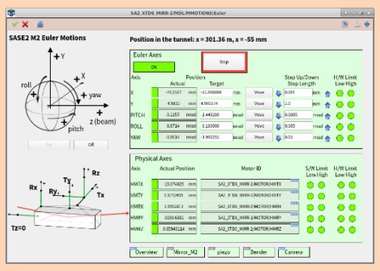


Karabo GUI scene for PairMirrorX device generated by virtual motor base

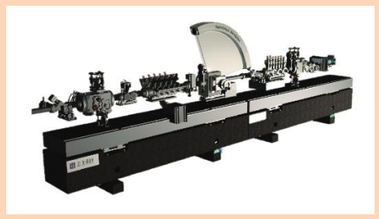
- Features:
  - Axes can be moved and stopped independently
  - Support for motion coordinated at the PLC level
  - Linear and angular units supported (e.g. mm or mrad), other units also possible
  - Hardware and software limits for virtual axes
  - Support for runtime changes to parameters such as position offsets or scaling
  - Karabo GUI scene (operator interface) generation
  - Unit testing framework

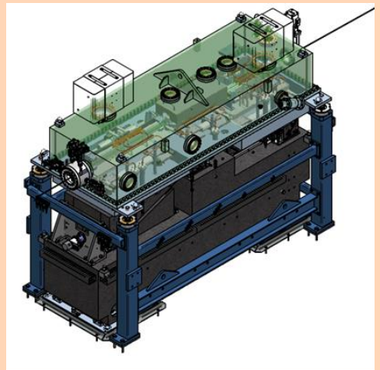
## Multi-axis motor devices at European XFEL


Tunnel offset/distribution mirror with 5 motors



Karabo GUI scene for MirrorMotions on SASE 2


Optical granite table at FXE (© European XFEL)


Kirkpatrick-Báez X-ray mirror system at SCS

- MirrorMotions
  - 5-axis device controlling the offset and distribution mirrors of the 3 tunnels
  - Pitch, roll and yaw, and X-Y motion transverse to beam
  - Motion synchronised by setting motor velocity
- OgtMotion
  - 5-axis motion of optical granite tables at Femtosecond X-ray Experiments (FXE) instrument [3]
- KbsMirrors
  - Kirkpatrick-Báez X-ray mirror system at Spectroscopy & Coherent Scattering (SCS) instrument designed by FMB Oxford
  - 5-axis motion of vertical focusing and deflecting mirrors
  - 3-axis motion of horizontal focusing mirrors
  - Motion coordinated at the PLC level
- Pair and triplet mirror systems
  - In use at Single Particles, Clusters, and Biomolecules & Serial Femtosecond Crystallography (SPB/SFX) and Small Quantum Systems (SQS) instruments
  - 2-axis motion: transverse position (X) and yaw
  - 3-axis motion: height (Y), pitch and roll
  - Motion coordinated motion at the PLC level
- AqsChamberMotion
  - 5-axis motion of Atomic Quantum Systems chamber (SQS)
- CssCoordMotion
  - 4-axis coordinated motion at SPB instrument
- PumaMotion
  - 5-axis motion of pulsed magnet (PUMA) at Materials Imaging & Dynamics (MID) instrument
- HRIXS spectrometer motion at SCS instrument
- Hexapod systems
  - Device class using Virtual Motor Base in use at MID, HED & Soft X-ray Port (SXP) instruments
  - Multi-axis motor device interfacing a hexapod through a motor controller used at SPB, MID & HED instruments
- Numerous others deployed or in development: including:
  - Experiment platform of FFT endstation at SCS
  - 2-axis and 4-axis blade/slit systems

## References

[1] Hauf, Steffen, et al. "The Karabo distributed control system." Journal of synchrotron radiation 26.5 (2019): 1448-1461.
[2] Tschentscher, Thomas, et al. "Photon beam transport and scientific instruments at the European XFEL." Applied Sciences7.6 (2017): 592.
[3] Bressler, Christian, et al. "Technical Design Report Scientific Instrument FXE" XFEL.EU TR-2012-008 European XFEL, Germany (2012) .

European XFEL GmbH, David Hickin, Holzkoppel 4, 22869 Schenefeld, Germany, Phone +49 40 8998-6931, david.hickin@xfel.eu
**www.xfel.eu**

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