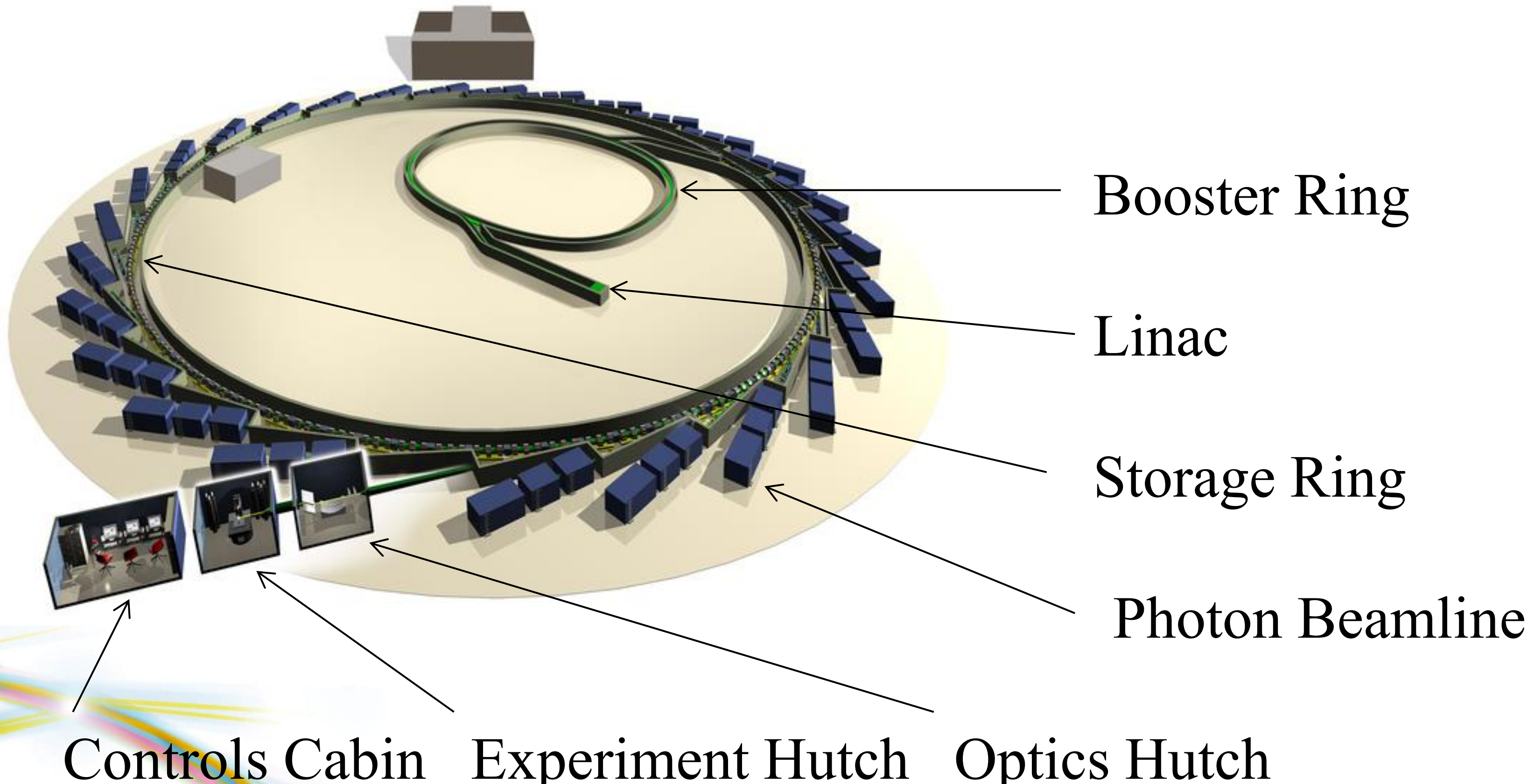
Overview of Motion Control at a Synchrotron Light Source Facility

Brian Nutter

Diamond Light Source, Oxfordshire, UK

A Synchrotron Light Source



Key Motion Devices

- Storage Ring
  - Insertion Device - creates the photon beam
  - Front End - selects the optimum area of the photon beam
- Optics Hutch
  - White Beam Slits - select the required amount of white beam
  - Monochromator - select the photon energy(ies) for the experiment
  - Focussing Mirrors - create optimum profile for the experiment
- Experiments Hutch
  - Beam conditioning - further optimise beam delivery to the sample
  - Sample stages - position and move the sample in the beam
  - Detector stages - position and move the detector to collect images

Other Motion devices

- Diagnostics - in / out devices to monitor photon beam
- Beam Stops - protection to prevent direct beam onto camera
- Cryo Devices - sample cooling and perhaps humidity control
- Backlights - to assist with on axis sample alignment
- Robots - from sample changing to detector positioning.

Motion Requirements

- Repeatability / Accuracy / Resolution
- Static Stability
- Open / Closed Loop
- Step Scan / Fly Scan
- Synchronised / Co-ordinated
- Triggering to / from External Events

Motion Requirements

- Repeatability / Accuracy / Resolution
  - Typically a beamlines requires highly repeatable motion. The accuracy is determined externally by the interaction with the beam. Often a table of positions is recorded against specific energies, and this makes repeatability more relevant than absolute accuracy.
  - Resolution is often mixed up with Minimum Incremental Motion. It is unrealistic to assume that the system can move by 1 encoder count. It is impractical to obtain repeatable motion of less than 10% full step.
  - At Diamond diagnostic sticks can have a repeatability spec of +/- 1mm. Slit blades to +/- 1 micron. Mirror jacks to better than 0.1 micron. The goal is typically better than 10% of beam diameter, and Diamond is heading towards a 0.3 micron beam.

Motion Requirements

- Static Stability
  - Many beamline components must maintain the same static position for indefinite periods of time. When step scanning the detectors measure at fixed static positions. Mirrors and slits will typically be static for the duration of an entire experiment, or allocation period.
  - As the beam becomes smaller so the demands on the long term stability increase, and often thermal effects will have the biggest influence. Again beam size drives the numbers
  - Static stability is also affected by how we handle the static stepper motor. Do we turn it off and risk creep? Do we leave it on and risk thermal effects or electrical noise? Do we fold back the current?Do we run it permanently in closed loop?

diamond

Motion Requirements

- Open / Closed Loop
  - At Diamond the motion controller can run stepper motors in open or closed position loop. If closed loop the encoder is typically mounted on the mechanics.
  - Open loop stepper systems run faster than closed loop stepper systems. Depending upon the mechanics this can be up to a factor of 2.
  - An open loop stepper is potentially more stable.
  - Closed loop steppers maintain encoded position at standstill, and can be used to accurately trigger external event depending upon measured position.
  - A hybrid state exists whereby EPICS closes the position loop at the end of moves by commanding small correction moves to take place. This feature is only available on phase 2 and phase 3 beamlines.

Motion Requirements

- Step Scan /Fly Scan
- Step Scan
  - A series of Point To Point moves. When each axis involved reaches its desired position the detector is triggered. When the detector signals it is complete, then the next move is initiated on the desired axes.
  - Easiest moves to programme, but can be time consuming.
- Fly Scan
  - The motion is started and the detectors take readings whilst the axis (axes) is in motion. May involve one or more motors. Will involve multiple data readings per move.

Motion Requirements

- Synchronised / Co-ordinated Motion
  - A synchronised move simply requires motors to start and perhaps stop at the same time.
  - A coordinated move requires a group of motors to follow a pre-defined path.
  - Synchronised moves are often used to speed up step scanning, or to ensure that axes that need to remain close to each other do so. In the EPICS motor record this is sometimes known as ‘deferred moves’.
  - Coordinated moves might be as simple as XYZ cartesian type plotting, or may be the basis of more complex kinematic transforms. Detector scanning of diffractometer requires complex trajectories to be pre-calculated. Energy scanning of monochromators requires the path of the 3 axes of the second crystal mount to accurately track the Bragg rotation.

Motion Requirements

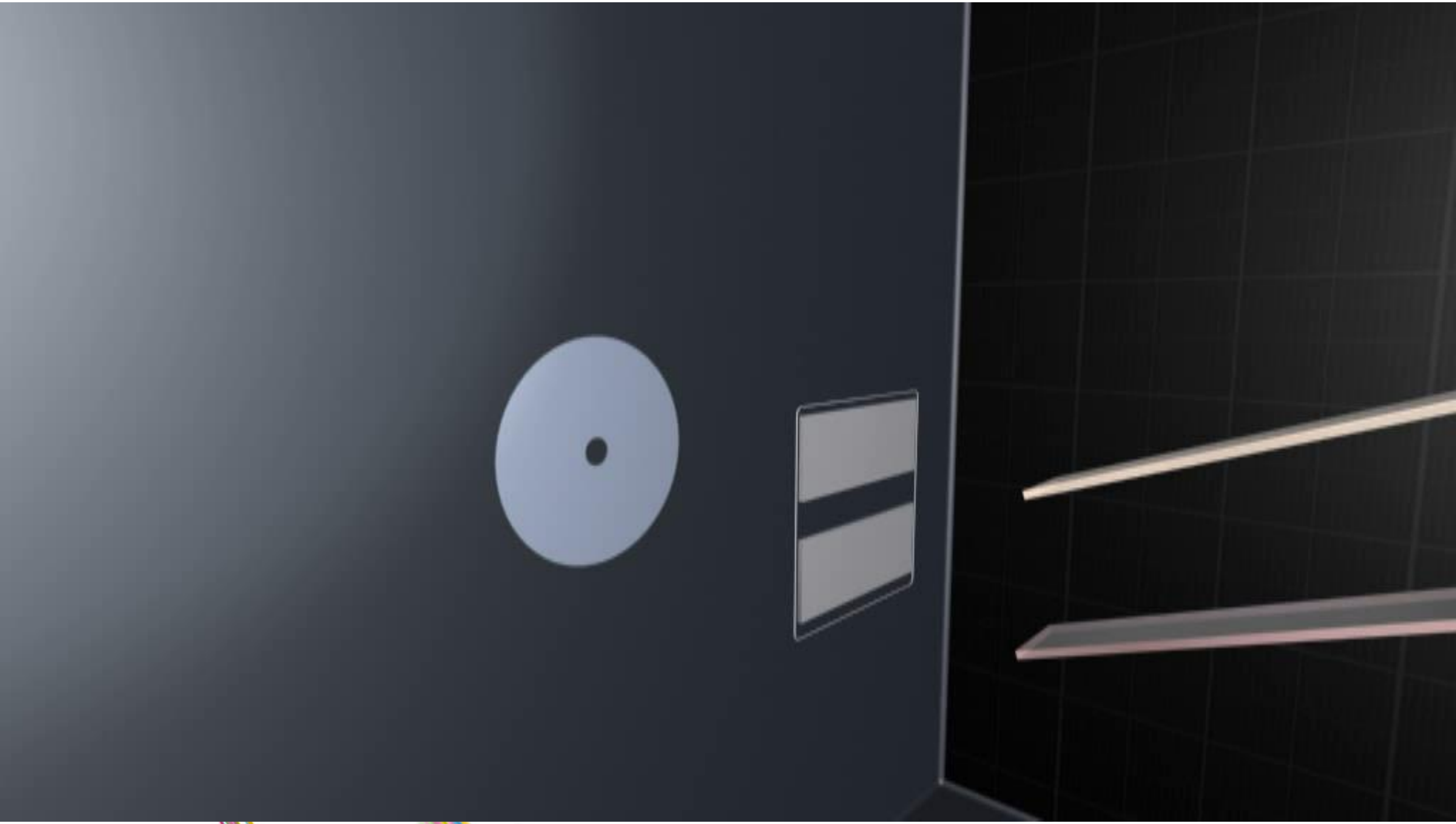
- Coordinated Moves -Kinematic transforms.
  - By defining a mathematical relationship between a group of motors other ‘soft axes’ can be created. For example the motors driving the upper and lower blade of a slit can be combined to create a soft ‘GAP’ motor and soft ‘CENTRE’ motor.
  - If Soft Motor Records are created in EPICS, then the motor record sends synchronised move commands to the two blade motors. This is only good for step scanning
  - If the soft motors are combined on the motion controller with a Kinematic Transform, then the motions of the two blades are coordinated and can be used for fly scanning. An EPICS coordinate system motor record is required. Coordinate system motor records are now being used more commonly at diamond than Soft Motor Records.

diamond

Motion Requirements

- Triggering to/from External Events
  - Typically we need to synchronise the detector or camera to the motion so that we can relate the recorded image to the underlying structure.
  - Software triggering waits for all the motors to signal that they have finished. The experimental software (GDA at Diamond) then sends a signal to the camera to take the next picture.
  - Position Trigger. The encoder position uses a hardware comparator to generate a logic signal to trigger the detector. Images are now at exact locations.
  - Time based triggering. The detector takes images at a fixed rate. Either we 'trust' that the motors are in the correct position or take a signal from the detector and store the exact position at that point in time. Real positions and images are analysed together.

A Typical Beamline



Typical Phase 1 Beamline Motion Hardware

- Turbo PMAC2 VME Ultralight
  - A 32 axis VME based controller from Delta Tau is chosen. It requires a 19” 6U subcrate to split out the controls and 3U crates for the amplifiers, which have 8 or 16 stepper amplifiers.
  - A fibre optic network is used to communicate between the VME controller and the two 16 axis MACRO sub controllers.
  - Accessory cards take the commands from the MACRO sub controller and provide the control signal to the amplifier and read the encoder feedback signals. Each card controls up to 4 amplifiers.
  - A single VME crate contains the EPICS IOC controller and up to 3 PMAC cards providing 96 axes of control from a single IOC. A single rack typically houses 32, but occasionally 48 axes.

Typical Phase 2 Beamline Motion Hardware

- GeoBrick LV IMS
  - 8 axis amplifier , configurable as stepper, servo or DC motor with integral Turbo PMAC 2 controller.
  - 5 amps continuous current rating 15amps peak. Stepper motor running current is set by configuration software, as is motor resolution.
  - Internal DC supply configured to 48Vdc or 24Vdc motor rail.
  - Optional add on card for MACRO link, serial / analogue encoders and resolvers.
  - Ethernet link to VME IOC or Linux soft IOC. Same connections as Phase 1. Still provides 32 axes per rack.

Typical Phase 3 Beamline Motion Hardware

- GeoBrick LV IMS II
  - 2 years ongoing product development to improve suitability for synchrotron use. Now suitable for in vacuum motors. Has 3 current ranges from 0.25 amps up to 5 amps. Improved over travel limit protection and Safe Torque Off.
  - 240MHz processor enables better processing of complex kinematic transforms .
  - Extended memory enables random path tables to be stored. A table of 4000 target positions for each of six axes for coordinated motion.
  - FAT can now be performed easily as the controller can be free issued to machinery suppliers. Delta Tau harware is complex however, so this can place extra burdens on the motion support team.

diamond

One Novel Application

- A 200 kHz in Vacuum infra red beam chopper
  - A specially balanced 3 phase 2 pole brushless servo motor is required to spin at up to 30,000 rpm with a 445 slot disc. There is only hall effect feedback and an open collector optical switch detecting the slots. Speed demand is the pulses from a function generator
  - A GeoBrick LV IMS axis is configured as a 3 phase stepper motor to overcome the lack of encoder feedback. The stepper resolution is set to 500 micro-step per full step giving an equivalent resolution of 2000 microsteps per rev.
  - The slotted switch is fed into one encoder channel and used in the velocity loop to maintain accurate speed control. The demand pulses are fed into a second encoder channel.

One Novel Application

- A 200kHz in vacuum infrared beam chopper
  - Velocity ripple was significant until motor resolution was changed to be an integer of the disc slot number. With 2225 microsteps per rev at 100kHz the measured frequency error at the motion controller was less than 100Hz.
  - Motor speeds of 30,000 rpm were achieved in vacuum, but the optical switch failed at 150kHz.
  - A ZEBRA box is used to convert the single pulses from both the function generator and the optical switch into quadrature encoder signals to improve noise immunity. Schmidt triggers were implemented on the Opto switch signal
  - More on this in poster TUPPC069 Zebra: a flexible solution for controlling scanning experiments .T. Cobb, Y. Chernousko, I. Uzun.

diamond

THANK YOU FOR LISTENING.

Questions should follow the round table presentations.