PERMANENT MAGNET INSERTION DEVICE CONTROL SYSTEMS ON DIAMOND

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Abstract

Diamond Light Source has designed and constructed twelve permanent magnet insertion devices over the past five years. These are ten In-vacuum undulators and two Ex-vacuum Apple II undulators. For all of these a common control system has been used. This uses a VME based motor controller, and a separate PLC subsystem for protection. The VME system runs EPICS to integrate in with overall control system. Two new designs of Insertion Device are currently in progress, which will require variants of this control system. The design for these control systems, issues experienced, and operational performance will be presented.

INTRODUCTION

The Diamond Light Source is a new medium energy third generation synchrotron light source located at Harwell Science and Innovation Campus in the UK. The primary purpose of the Diamond Light Source is the production of high intensity x-rays from insertion devices. An insertion device is a periodic array of magnets (often referred to as an undulator or wiggler) which is designed to controllably produce x-rays by varying the trajectory of electrons as they pass through the magnetic field of the device. Phase 1 of Diamond's construction involved the building and commissioning of seven pure permanent magnet insertion devices as well as the installation of a superconducting wiggler. Eventually, there will be at least twenty-five insertion devices installed at Diamond [1] [2] [3].

Figure 1: Photograph of a 'four-axis' Insertion Device.

INSERTION DEVICE CONTROL SYSTEM

Overview

An in-vacuum insertion device typically consists of two arrays of permanent magnets positioned symmetrically above and below the electron beam. The magnetic forces are considerable; forces between the in-vacuum device arrays produce an added load of approximately 1 tonne. Each magnet array is supported by a large and stiff beam outside of the vacuum vessel, via eight columns passing through the vacuum wall using bellows. The supporting beams are mounted to the main structure on linear bearings. Each beam is controlled by two actuators, one at each end of the beam. This configuration ensures that the parallelism of the magnet arrays can be set and maintained irrespective of the precision of the ball-screw assemblies and also allows the beams to be intentionally tapered relative to each other. However, this configuration also causes considerable added complexity, as an over-taper of one or both beams can mechanically damage the linear bearings, the overall structure or in the worst case allow the magnet arrays to come in to contact with each other. The motion control system consists of the following hardware:

- EPICS IOC [4]
- Prodex motion controller card [5].
- Hannifin Compax servo drives, motors, brakes and resolvers [6].
- TR Electronics linear absolute 0.1um resolution encoders and interfaces [7].
- Omron protection PLC [8].
- Applied Geomechanics tilt sensors [9].

An ex-vacuum Apple II undulator has two arrays of magnets mounted on each supporting beam, external to the vacuum vessel. One set of these magnet arrays on each beam can also be driven from their centre position by a servo control system. These are referred to as the phase axes. However, this paper will primarily concentrate on the four-axis vertical control that is common to both types of insertion device.

Protection System

A PLC based protection system has been developed to protect the structure from failures in the motion control system. A key feature of this protection mechanism is that it operates independently of the motion control system. The PLC has the following inputs:

- Encoder position sensors for all four vertical axes
- Maximum and minimum limit switches for all four axes.
- Tilt sensors mounted to the upper and lower support beams.

The PLC can halt the motion of any axis by disabling the given motor drive. The PLC can also trip the whole system into a Motion Stop State. This is done by tripping a PILZ safety relay. The PILZ relay can only be re-energized if all of the errors are cleared or overridden.

The protection PLC generates a set of composite limit switch signals for the motion control system. The physical limit switch inputs are passed directly through to the motion system, and the appropriate drive is disabled. The encoders are used to provide a second level of limit thresholds. The encoder values are also used to generate a beam tilt figure. The tilt sensors are also processed to give an independent tilt figure. The tilt values are then compared against thresholds to produce limits, as shown in Table 1.

Table 1: Tilt threshold definitions

Safe window	> +/- 0.100 mRad	Disable associated motor drives
Absolute window	> +/- 0.175 mRad	Enter Motion Stop State, but can be overridden
Extreme window	> +/- 0.250 mRad	Enter Motion Stop State, but requires manual intervention

Encoder Processing

Due to the mechanical requirement for beam parallelism and the required control accuracy of 1µm, it is necessary to use absolute linear encoders on the vertical axes. The absolute measurement of the beam position allows the parallelism to be maintained over power cycles and control system re-starts. These encoders are mounted such that the feedback is an accurate representation of the position of the supporting beam. The encoders use a synchronous serial interface (SSI) to communicate with the control system. It is necessary to distribute this encoder value to the motion control system and also to the protection PLC. Neither the OMS motion controller card nor the Omron protection PLC support the SSI interface. There is therefore an extra interface PLC that implements an absolute SSI value to a quadrature incremental signal conversion. During the transition from the Motion Stop State to the Motion Enabled State the protection PLC synchronizes the loading of the absolute value and the clocking of the quadrature signals to the protection PLC and the motion control card.

Motion Control

The motion control system consists of an EPICS IOC (MVME 5500 processor running VxWorks) and a Prodex MAXv 4000 motion control card (The earlier OMS VME58 type is also in use) mounted in a VME crate. The EPICS IOC provides the user interface mechanism and higher level controls. The MAXv card provides a 4 axis PID based control system with a 122 µs control loop time. The PLC derived limit switches, quadrature encoder signals and home switch signals are connected via a breakout board to the MAXv card. The servo velocity demand signal is connected via the breakout board to the Compax 3 servo drive unit.

The EPICS IOC provides the interface process variables (PVs) to allow the user to enable the system and to enter position demand values. There are a number of motion control modes available:

- Single axis demand control
- Dual axis demand control
- Gap control
- Offset control
- Taper control

Each of these control modes are handled by an EPICS genSub routine that ensures that the drives are enabled and that the demand values are with in the allowable range of travel before calculating the individual axis demand positions and triggering the move. The EPICS motor support module is used to interface between the higher level control structure and the MAXv VME card.

Velocity and Position Control

The design maximum motion velocity of the structure is 2mm/s, gap. However, the system is limited to a maximum 1mm/s gap as this was considered to be a safe velocity given that the dynamic response of the tilt sensors is about 200ms. The minimum target velocity is 5µm/s, gap. This is quite a challenge, as it requires 2.5µm/s, per axis. By reducing the per axis acceleration period from 2 seconds to 0.02 seconds, it was found that the velocity could be controlled to 2.6µm/s. No attempt has yet been made to compensate for the error, as it was felt that this was acceptable for the time being.

The other design consideration was the requirement to be able to do 1µm step scans. By tuning the EPICS retry mechanism we found that this was achievable. However, at these tight tolerances, the control system does occasionally fail to achieve the per axis target position to within 0.5µm, and given that there are 4 axes, the tolerances can build up and give an actual position outside of the requirements. However, the overriding requirement for this type of motion control is that the scan sequence remains monotonic.

Beamline Communication

It is necessary to allow the beamline to set a gap demand position to allow automated beamline scanning. The Diamond network is configured so that the storage ring control PVs can only be written to by devices on the machine control network. Each beamline has its own network and only devices on that network can write to the beamline PVs. However, an EPICS gateway has been implemented to allow beamline PVs to be read from a machine device, and visa-versa for the machine control network. Thus the control of an insertion device from a beamline is implemented by ’pulling’ the demand values across the gateway, and similarly, the beamline can also ‘pull’ the insertion device status PVs across. This also allows the machine side control system to implement an enable/disable control on the beamline based demands.

Trim Coil Control

Each insertion device is fitted with two correction coils per end, for vertical and horizontal corrections. Each pair of coils is driven from a 5 Amp bipolar high accuracy DSP based power supply [10]. These power supply units are directly controllable from EPICS. The required correction field applied to the electron beam is a function of insertion device gap. An EPICS genSub linear interpolation routine has been implemented to generate a current demand as a function of insertion device gap. For the Ex-Vacuum Apple II type Undulators the current demand has to be a function of gap and phase position, thus a three dimensional table has been implemented that can also handle parallel and anti-parallel phase conditions. The trim tables were obtained during the insertion device commissioning procedure [2].

EXPERIENCES

The reliability and performance of the insertion devices has been good [2]. The complexity of the protection system requires a reasonable amount of knowledge to recover from the day-to-day problems. The one major problem has been the failure of the encoders during an electron beam dump. The complexity of the electronics in the encoder read head to implement a 0.1µm absolute measuring system is considerable. It appears that electron beam dumps and the associated shower of particles can interfere with the embedded electronics. This was a significant issue during the early days of the storage ring commissioning. Better beam control and correct setting of the collimators have alleviated this problem to a large extent. Lead shielding was also installed around the encoders, but the effectiveness of this is debatable. Investigations of other feedback technologies and systems, and the option of placing the encoders further way from the electron beam are on-going. It is clear that locating the encoders away from the plane of the electron beam is desirable.

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