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ALS-U ACCELERATOR MOTION DESIGN AND REALIZATION*

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Abstract

Transitioning from the aging ALS Geo MACRO motor controller, this paper details the selection process for a new, cost-effective standard to fulfill the diverse motion requirements of the upcoming ALS-U project. Targeting primarily simple stepper motors with varying current demands, the chosen solution seamlessly integrates into the existing ALS-U EPICS environment while preserving the established ALS motion architecture and EPICS IOC support. Notably, the solution maintains independence from Delta-Tau technology while accommodating the project's required range of servo/stepper motor types and offering dedicated support for critical subsystems like Beam Scraper and Cold Finger motion. This document delves into the exhaustive selection process, from summarizing the current architecture and ALS-U requirements to analyzing the results of a year-long evaluation of diverse vendor offerings.

INTRODUCTION

The existing Advanced Light Source (ALS) Geo Macro motor controller used as a standard for ALS is being deprecated by the manufacturer and a new standard is necessary to support the Advanced Light Source Upgrade (ALS-U) [1] motion requirements. The ALS-U project will be using and extending the existing infrastructure, where a significant part of the ALS equipment, cables, and racks will remain in place, limiting the available rack space for new equipment. The goal of this study was to create a smooth transition plan between legacy and new motion equipment that would take into consideration inventory availability, hardware reliability, and minimum maintainability efforts.

It was important to find a feasible solution to meet the ALS-U motion requirements and to keep the ALS architecture as close as possible to market-available protocol, which is reliable and sustainable for the next two decades. Moreover, it would be beneficial to make a modularized solution for each axis, so it can be scaled up to cover potential multi-axis requirements without losing design strategy.

ALS ARCHITECTURE

The ALS has many Geo MACRO controllers and relies on the Delta Tau MACRO ring for communication with a central Delta Tau controller. The advantage of this architecture is that amplifiers (Drives) can sit closer to the device being controlled (in the tunnel of an accelerator ring). An optical fiber connection needs to be pulled between an amplifier (Drive) and a controller to reduce cable management regarding labor-intense resources and reduction of limited cable tray space requirement.

The motion controllers are in a centralized location in the pit, where they can be accessed even if the accelerator is in an operational state. However, the most important fact is their communication protocol, the Delta Tau MACRO ring protocol, is now end-of-life. Thus, the architecture that ALS uses, shown in Fig.1, is not suitable for the ALS-U accelerator, which will be the future generation of the ALS and stay for the next two decades serving scientific research at Berkeley Lab.

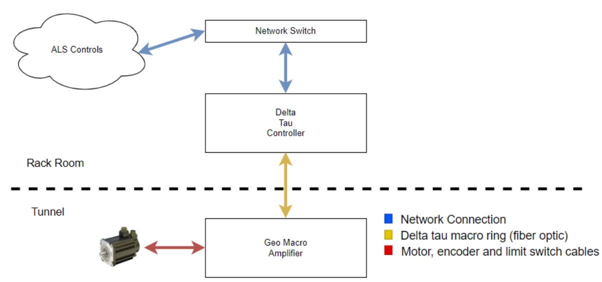

Figure 1: Current ALS motion architecture.

ALS-U MOTION REQUIREMENTS

ALS-U will have in total new 56 axes installed for only the ALS-U accelerator, thirty-two of these devices will be operated with a stepper motor with an encoder for the control loop. Most actuators will require currents smaller than 3A, with a few motors requiring higher up to 5A current. Figure 2 shows a summary of the requirements grouped by device type.

QTY	Motion Drive Type	Device	Motor Type	Motor Model	Current	Encoder Type
2	MOT1B	Beam Scraper / Collimator	Stepper	23HS-108 E	3.8A per phase	5V TTL differential 500 ppr
2	MOT2B	Beam Scraper / Collimator	Stepper	23HS-108 E	3.8A per phase	5V TTL differential 500 ppr
2		Beam Scraper / Collimator	Stepper	23HS-108 E	3.8A per phase	5V TTL differential 500 ppr
2	MOT1B	Cold Finger	Stepper	23HS-108 E	3.8A per phase	5V TTL differential 500 ppr
2	MOT4B	Diag BL M1 Mirror Chamber	Stepper	PKP268MD28A	2.8A per phase	5V TTL differential
2		Diag BL M2 Mirror Chamber	Stepper	PKP268MD28A	2.8A per phase	5V TTL differential
2		Diag BL Lens Adjustment	Stepper	PKP268MD28A	2.8A per phase	5V TTL differential
2		Diag BL Obstacle Plate Adjustment	Stepper	PKP268MD28A	2.8A per phase	5V Incremental R2FL
2	MOT4B	Diag BL Baffle Plate Adjustment	Stepper	PKP268MD28A	2.8A per phase	5V TTL differential
2		Diag BL Baffle Plate Adjustment	Stepper	PKP268MD28A	2.8A per phase	5V TTL differential
2		Diag BL Baffle Plate Adjustment	Stepper	PKP268MD28A	2.8A per phase	5V TTL differential
2		Diag BL Baffle Plate Adjustment	Stepper	PKP268MD28A	2.8A per phase	5V TTL differential
6	MOT4C	H-Bend	Servo	AKM23E-ACCNI	6A continuous	Resolver and Encoder Dual Feedback
6		H-Bend	Servo	AKM23E-ACCNI	6A continuous	Resolver and Encoder Dual Feedback
6		H-Bend	Servo	AKM23E-ACCNI	6A continuous	Resolver and Encoder Dual Feedback
6		H-Bend	Servo	AKM23E-ACCNI	6A continuous	Resolver and Encoder Dual Feedback
2	MOT3B	SRM	Stepper	ZFS25B	0.25A	N/A
2		SRM	Stepper	ZFS25B	0.25A	N/A
2		SRM	Stepper	ZFS25B	0.25A	N/A

Figure 2: ALS-U motion requirements.

While not strictly necessary, closed-loop control of the devices is desired. Due to the current load of the ALS cable trays and with retro-compatibility in mind, the motion solution will have to accommodate having the amplifier and

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controller at different locations, preferably with an optical fiber-based communication link between them. To save development time, all the controllers and drivers evaluated have active Experimental Physics and Industrial Control System (EPICS) [2] driver support from the community.

HARDWARE ASSESSMENT AND SELECTION PROCESS

We created a standardized hardware testing procedure that covered basic hardware checks, long-term stability testing, and fault recovery steps in order to test motion products suggested by local vendors and our own searches. For hardware validation, we conducted connectivity checks to ensure the EtherCAT link between the motion controller and a drive was functioning correctly. This was followed by verifying wiring integrity and motion accuracy through various jog commands and end-stop tests. Additionally, we confirmed resolution and closed-loop functionality by comparing encoder counts with actual travel distances and checked acceleration and speed parameters by comparing reported positions with timestamps.

We proceeded to assess the setup's robustness by adding the reported position to the EPICS archiver appliance [3]. A script was then employed to command 10,000 movements spanning from +15 to +15 mm, with brief pauses at each endpoint and at the 0 mm position. Subsequently, we cross-referenced the recorded readback positions with the archiver history to evaluate repeatability and accuracy during the extended and repetitive movements. This analysis included verifying whether the reported positions and timestamps aligned with the expected values for the experiment. Moreover, for axes requiring coordinated motion in a gantry system, we repeated the extended repetitive movements using a coordinated axis system and verified the synchronized movement of both motors.

In the final step, we assessed the controller's ability to recover and clear faults in the event of a power loss. With the EPICS Input Output Controller (IOC) [4] running, we deliberately turned off the motor controller to simulate a potential field failure. After a brief pause, the controller was restarted, and we confirmed that the IOC could automatically recover without manual intervention.

Hardware

EtherCAT was chosen for communication between controllers and drives due to its large industrial usage, which helps increase the number of possible suppliers and availability. Adopting this technology also adds a lot of flexibility to the motion system which helps keep it relevant and maintainable for the foreseeable future.

For the EtherCAT motor controller, to minimize labor efforts and facilitate the transitioning, the Omron CK3M-CPU111 was the unit of choice. This multi-axis controller has an EtherCAT communication cycle of 250 µs and can command up to 4 EtherCAT drives (i.e., 4 axes) using Cyclic Synchronous Position, Velocity, or Torque modes.

When selecting hardware to test potential EtherCAT drives, we took several factors into account including maximum current, closed loop, EtherCAT capability, and lead time. We took recommendations from the ALS controls group, the motor actuator vendor, and Omron to compile a list of hardware to test. This list consists of Kollmorgen `AKD2G`, Galil `EDD-37017`, and Nanotec `C5-E-1-21`.

Assessment and Selection

- The Kollmorgen `AKD2G` amplifier was tested as a dual-axis servo controller with closed-loop and coordinated motion capabilities. The controller accuracy, repeatability, and fault recovery met the current ALS-U requirements, with its simple configuration for servos being a good advantage over the more flexible motion controller solutions. Combining it with a standard motor record using the Omron `CK3M` master controller extends its capabilities and allows for a more flexible distributed solution similar to what ALS uses today. This was ultimately chosen as the servo solution.

- The Galil `EDD-37017` was tested as a single-axis stepper controller. After weeks of testing different configurations, we concluded that this stepper driver is not compatible with the Omron `CK3M` master controller and removed this as a possible solution. Some of the issues we ran into included the inability to close the loop at the drive, IDE configuration and it does not follow the `CiA402` standard EtherCAT protocol.

- The Nanotec `C5-E-1-21` was tested as a single-axis stepper controller with closed-loop capabilities. The controller accuracy, repeatability, and fault recovery met the current ALS-U requirements, with its closed-loop configuration for steppers being a good advantage over the more flexible motion controller solutions. While the PID tuning was a little more cumbersome than expected, the manufacturer support provided decent guidelines on properly setting up the system in a closed-loop fashion. This was ultimately chosen as the stepper solution.

MODULARIZED MOTION CHASSIS DESIGN

With the controller being in the pit and the drivers being in the ring, two chassis designs were needed. Figure 3 shows the controller chassis design which supports 4 daisy-chain drives and it houses a 24V DC power supply, circuit breaker switches, a Moxa media converter, and an Omron `CK3M`.

Figure 4 shows a single axis drive chassis, such as MOT1B and it contains a 20A 24V DC power supply, breakout terminal blocks, circuit breakers, a Moxa media converter, and a Nanotec `C5-E-1-21` stepper drive. If there is a motion requirement up to n, where $n = 1 \cdots 4$, the MOTnB chassis will be designed to accommodate to maximum 4 Nanotec `C5-E-1-21` stepper drives as well as the maximum 2 power supplies. Our current Omoron CPU was selected due to the

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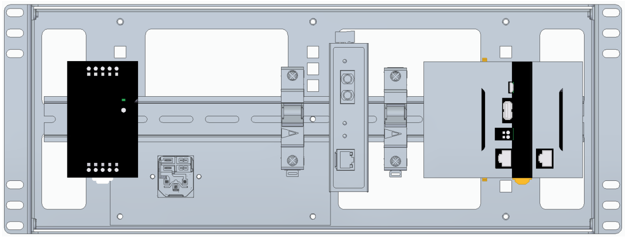

Figure 3: MOT1A chassis design.

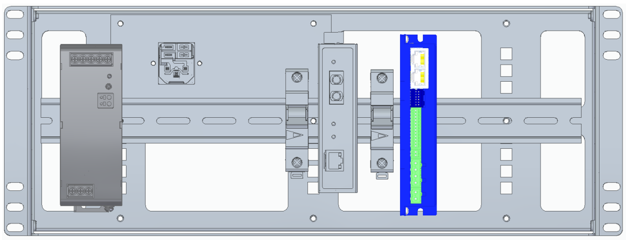

Figure 4: MOT1B chassis design.

chassis space limitation where we can maximize 4 stepper drives to be installed.

SUMMARY AND OUTLOOK

All controllers besides the Galil `EDD-37017` were successfully tested utilizing a PMAC driver following the ALS-U EPICS environment [5]. The ALS-U controls group decided to move forward with the Kollmorgen `AKD2G` as the servo solution and the Nanotec `C5-E-1-21` as the stepper solution. These drives meet the performance requirements needed for servo and stepper configurations as well as the space requirements. Figure 5 shows an example of the single axis stepper motion architecture.

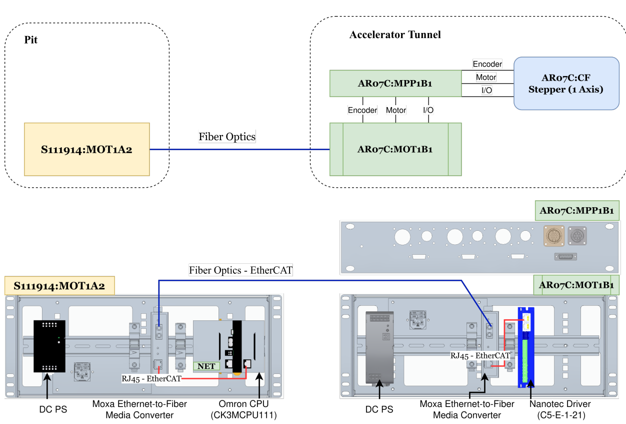

Figure 5: ALS-U single axis stepper motion architecture.

We are currently building out the first article, shown in Fig. 6 and will be ordering production hardware during this year. We need to build the 18 MOT1As for the motion controller, four MOT1Bs for a single axis stepper support, one MOT2Bs for 2-axes stepper support, two MOT3Bs for 3-axes stepper support, five MOT4Bs for 4-axes stepper support, and 6 MOT4Cs for 4-axes servo support for the ALS-U project to meet its accelerator motion requirements.

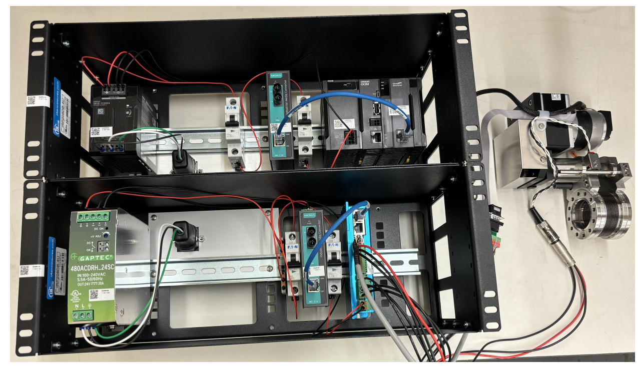

Figure 6: First articles for MOT1A and MOT1B with a single axis stepper motor.

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