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OVERCOMING CHALLENGES DURING THE INSERTION DEVICE STRAIGHT SECTION COMPONENT PRODUCTION AND TUNING PHASE OF THE ADVANCED PHOTON SOURCE UPGRADE*

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Abstract

The Advanced Photon Source Upgrade (APS-U) scope for insertion devices (IDs) and ID vacuum systems is extensive. Thirty-five of the 40 straight sections in the storage ring will be retrofitted with new 4.8-meter-long Superconducting Undulators (SCUs) or a mix of new and reused Hybrid-Permanent Magnet Undulators (HPMUs). All 35 ID straight sections will require new vacuum systems and new HPMU control systems. Production is well underway at multiple manufacturing sites around the world for these components. Simultaneously, ID assembly and HPMU tuning is occurring onsite at Argonne National Laboratory (ANL). In addition to component production and assembly/tuning activities, our team also started the ID swap out program at the Advanced Photon Source (APS) in late 2020. This program allows us to remove HPMUs intended for reuse from the APS storage ring and retune them to meet the APS-U magnetic specifications to reduce the tuning workload during the dark year. These activities have presented technical and logistical challenges that are as unique as the components themselves. Additionally, the ongoing Covid-19 pandemic presented unforeseen challenges that required new work processes to be created to sustain pace and quality of work while maintaining the high workplace safety standards required at Argonne. This paper will summarize the many challenges encountered during the project and how they were overcome.

INTRODUCTION

The APS-Upgrade (APS-U) project plan calls for the current APS 40-sector storage ring (SR) to be retrofitted with a new 6 GeV, 200 mA storage ring optimized for brightness above 4 keV. 35 of the 40 sector straight sections will be dedicated to insertion devices (ID) which will produce photons at various energies to ID beamline users based on their needs. The APS-U ID group is responsible for upgrading equipment within the straight sections for the upgrade. The group's extensive scope can be broken up into three main technical areas: Hybrid Permanent Magnet Undulators (HPMUs), Superconducting Undulators (SCUs), and ID Vacuum systems (IDVS). The following sections will detail each areas scope, major challenges encountered during production, and solutions to those challenges.

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HPMU

Scope

HPMUs are the main type of ID utilized in the APS-U. 30 out of 35 straight sections will be equipped with at least one HPMU. This requires our group to deliver 55 HPMUs for which 12 are the revolving type. Of the 55 HPMUs required for the APS-U, 32 will be new period devices and 23 will be made from existing period magnet structures harvested from devices currently in use. The harvested devices will require retuning to meet APS-U magnetic specifications. All HPMUs require new motors and control system due to the obsolescence of the current motors and controls currently in use at the APS.

Challenges and Solutions

There have been many major challenges associated with the HPMU scope. Our group is required to deliver 55 HPMUs for installation to the Removal and Installation group (R&I) prior to the start of commissioning. We have also encountered issues during assembly of the HPMUs that occurred prior to sending the devices for tuning. Finally, our tuning facility has limited space for device tuning given the aggressive timetable required to meet our delivery schedule.

Schedule The APS-U ID group project schedule is one of our largest challenges. We are required to deliver all 55 HPMUs, canting and phase shifter magnets, and ID control system to the R&I group prior to the start of commissioning. We implemented two strategies to meet our schedule: pre-tune new period devices and swap out reused periods during maintenance periods.

Pre-tuning new period devices will allow our team to tune all new period magnet structure sets to the APS-U magnet requirements. New period devices represent the largest subset of HPMUs that need to be delivered. To accomplish this, our group has procured 6 additional gap separation mechanisms (GSM) from our central shops. After the magnetic structure set (MSS) is assembled onto one of the spare GSM, our tuning group tunes the MSS to meet APS-U magnetic requirements. The MSS is then removed from the GSM and stored until the start of dark time when it can be assembled onto the GSM that will be installed into the storage ring. The MSS cannot be considered "final tuned" until it has been installed onto the GSM it will be installed with due to minor variations in deflection that occur between different GSM. The exception to this is the revolver HPMUs, which our group redesigned the GSM as part of the design phase of the APS-U. This allows us to assemble the MSS onto the unique revolver GSM, which

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in turn can be final tuned and then stored until R&I is ready to take possession for installation in the storage ring. The only additional tuning that will need to occur with this device, and this is true for non-revolving HPMUs as well, is to account for the center phase shifter for revolver HPMUs that will be installed in the inline configuration.

The strategy for the reused period devices is slightly different. Reused period devices represent a smaller subset of the overall quantity of HPMUs to be delivered prior to the start of commissioning. Our group is utilizing the remaining maintenance periods leading up to the dark year to swap out devices that are intended for reuse. Swap out is a logistically challenging exercise, as it requires coordination between APS operations (OPS) and the APS-U. The process begins with APS-U delivering a completed device to APS OPS prior to the start of a maintenance period. The device is an exact match to the device that will be swapped (i.e., same type of GSM and same MSS). APS OPS then remove the device that is installed in the storage ring and replaces the device with the exact match delivered by APS-U. The removed device has it is MSS retuned to meet both APS and APS-U magnetic specifications. The retuned device is then delivered back to APS OPS for swap with a device in a different sector. This process is repeatable for most devices; however, a subset of swapped devices requires swapping of the MSS and GSM which can complicate the process. This challenge will be further described in the next section.

Assembly Assembly activities mainly involve assembling new period devices or reassembling reused devices removed during a maintenance period as part of the swap out program. Additionally, activities can require quality checks (QA) of manufactured assemblies upon delivery from the vendor as a pre-determined amount of time in the procurement contract. Challenges we have encountered during assembly activities are typically logistical or technical in nature.

Logistical issues arise due to late deliveries from manufacturers and sudden manpower needs by APS OPS. To try and mitigate this issue we require vendors to meet with the responsible technical team weekly. While this does not eliminate delays, we have found that it helps uncover delays sooner so that we can update our high-level schedule to accommodate the delays and reprioritize work accordingly. Unfortunately, this strategy does not work when sharing manpower with APS OPS. OPS require matrixed staff to support operations whenever an emergency arises that threatens the facilities ability to provide usable synchrotron radiation to users. Due to the nature of the need, notice is often extremely short or non-existent. To deal with this challenge, technicians and engineers were hired to specifically support the upgrade. These staff support OPS only during maintenance ID swaps. They maintain productivity when emergency situations occur that require OPS staff to support the current APS operations.

Technical issues arise when assembling multiple magnetic periods simultaneously. These issues can be in the assembly of the MSS or the GSM. For the MSS, the challenge of assembling different periods simultaneously arises from the use of different fasteners and components for each MSS. For example, if the wrong fastener or torque is used, then the magnetic pole could be irreversibly damaged. To minimize the risk of error each MSS is documented in our Component Database (CDB) [1]. This allows our technicians and engineers the ability to identify what components, drawings, and specifications are required to assemble the MSS. We also prepare and stage components for each magnetic period near where the specific MSS is being assembled to avoid the risk that components for another magnetic period will be mixed in. For the GSM, the challenge is in identifying mechanical issues occurring within the GSM that are difficult to identify by eye or with conventional gauges. One example would be a gas spring that isn't providing the correct spring force. This can lead to an issue referred to as "clunk" where the MSS suddenly jolts during operation when the magnetic attractive force is overtaken by gravity while opening the magnetic gap. This leads to unreliable reads from the linear encoders which complicates user operation. To deal with this issue, the technical lead for APS-U ID controls has written a script that allows an engineer the ability to compare the rotary encoder output to the linear encoder output [2]. Although determining the specific mechanical cause (i.e., gas spring, lead screw misalignment, etc.) discovered by this script is still being developed, allows us to identify mechanical problems in the GSM before the device is tuned or installed in the storage ring.

Tuning Tuning represents a large challenge for the APS-U. For the APS-U, large volume of different period devices needs to be tuned in a short period of time. Most of these devices are new period devices which our team have little or no experience tuning. Additionally, our facility only has one 6- and 3-meter bench for tuning activities, limiting capacity for multiple measurements to occur at a single time. Our tuning team has implemented automatic tuning algorithms and phase error based tuning methods to overcome these issues. These techniques have been used on 24 devices thus far for APS-U with great success. More detailed information on these techniques can be found in the following [3-6].

SCUS

Scope

Eight SCUs are required to be delivered to R&I for installation, however, they must be delivered prior to the start of the dark year. Six of the eight SCUs have a magnetic period of 16.5 mm while the remaining two have a magnetic period length of 18.5 mm. Four of the SCUs are arranged in a colinear arrangement. The other four SCUs are canted devices. More information on details of the new design can be found in [7].

Challenges and Solutions

Although the SCUs represent a smaller part of the overall project scope, significant challenges are still present as we progress with production. Specifically, there are large

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challenges in manufacturing the magnet cores to specification and challenges associated with assembling the device.

The new magnet cores in the colinear devices are each approximately 1.9 meters long. The flatness tolerance across the length of the cores is difficult for most vendors to hold. Additionally, footed poles are periodically required across the length of the core to help ensure pole contact with the impregnation mold guide plate. This is to give added confidence that epoxy will not build on the pole face, which could allow for contact conduction between the vacuum chamber operating at 20K and the 4K magnet cores.

The first attempt to solve these issues was to pursue two different magnet core designs with two different vendors. Both vendors had great difficulty is meeting the project schedule, and the cores ended up being delivered behind schedule. Additionally, once the cores were delivered, our team discovered that the areas near the footed poles on both designs were prone to shorts during winding. This had not been experienced on previous SCUs. The team quickly worked to solve both issues by coming up with a design that did not require footed poles. This required an alteration to the potting mold as well. This new design was used for canted SCU core periods. After award, the vendor for both sets of cores noted that the new design will be simpler to machine and that the simplicity of the design opened additional machines the vendor could use to manufacture the cores. More detailed information on the magnet core manufacturing can be found in [8].

ID VACUUM SYSTEM

Scope

35 IDVS require re-design and replacement. Separate vacuum systems are required for the HPMUs and SCUs due to the extreme difference in operating temperature. The small magnetic gap of the undulator and the minimum aperture allowed in the storage ring require extremely thin walls in both IDVS. The HPMU IDVS has a minimum wall thickness of 0.6 mm while the SCU IDVS has a minimum wall thickness of 0.4 mm. All IDVS are required to be fabricated and delivered before the start of the dark year.

Challenges and Solutions

One challenge both IDVS have in common is in performing the welding of aluminum joints to the labs strict weld standards. We require the welds meet spec AWS D17.1 class B or better standards. Given the thin wall of the joint being welded, this necessitates little to no porosity in the weld. The vendors awarded the contracts had great difficulty achieving these standards initially. The solution to this issue was to have our weld engineer become involved in our weekly vendor meetings. Our weld engineer was able to identify small details in the vendors weld process that was causing issues with minimizing porosity in the welds. We also worked with the vendor to provide additional resources so that they could produce additional weld samples and incorporate additional x-ray scans into their process. Both first article IDVS were delivered within specification. The following will now describe challenges that were specific to each IDVS for the HPMUs and SCUs.

HPMU IDVS The main challenges that were present during the design and production of the new HPMU IDVS were mainly based around the manufacturing of the main vacuum chamber. Our physics requirements for the APS-U storage ring necessitated the minimization of welded joints. This required the design to be fabricated from a single extrusion. This included the aperture transitions that needed to occur at the ends of the chamber. To accomplish this, we worked with two vendors to develop multiple methods to machine and plunge electrical discharge machining (EDM) the cone into the ends of the extrusion. We then worked with our physics group to identify which solution presented the best environment for the stored beam. Our physics group selected the machined cone, and the group that produced the feature ended up being awarded the total manufacturing contract for the chamber. More information on the HPMU IDVS first article can be found in [9].

SCU IDVS The main challenge with the SCU IDVS was handling and integrating the chamber into the cold mass. The chamber arrives on a support structure due to its small cross section and thin wall. There is also a bimetal joint on each end that is very delicate. During assembly, our team discovered that the chamber would need to be removed from the support to assemble onto the cold mass. To solve this issue, a support beam was constructed to support the entirety of the chamber and end flanges during assembly. More information on the SCU IDVS first article can be found in [9].

COVID-19

Covid-19 shut down the laboratory at the end of March 2020. This time coincided with our ramp up in assembly and production. All work onsite was paused for a period of three weeks while procedures could be put in place so that work could be performed safely and minimize risk of transmission of the virus. We worked closely with our safety team to implement safety controls and were able to restart work a few weeks after work was halted. We updated procedures so that workers maximized social distancing. HPMU and SCU assembly work require workers to regularly be within 6 feet of one another. If social distancing was not possible, then we implemented moveable shields to separate workers. Using these controls, we were able to safely resume work and minimize the transmission of the virus within our group. No one in the APS-U ID group to date has contracted the virus from a coworker onsite.

SUMMARY

The APS-U ID group has an extensive scope that can be broken into three main technical areas: HPMUs, SCUs, and IDVS. Each area presented many challenges during production and ongoing assembly activities. The solutions we implemented were as unique as the challenges themself.

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