REMOTE HANDLING IN HIGH-POWER PROTON FACILITIES*

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Abstract

Design for remote handling of highly activated accelerator components is becoming more prevalent as proton facilities are designed and constructed to provide ever-increasing beam powers. During operation of these facilities it is expected that many components will become activated, consequently mechanical engineering design work must address this issue if components are to be maintained by traditional hands-on methods. These design issues are not new and operating proton facilities around the world have gone through the same process to varying degrees. In this paper we discuss the design and design philosophy of remote handling of active accelerator components, using as examples designs which have been proven at operating facilities, as well as new approaches which are being incorporated into accelerator facilities under construction, such as the Spallation Neutron Source (SNS) and J-PARC.

INTRODUCTION

Many complex activated machines around the world rely solely on remote handling to carry out maintenance and repair tasks, most notably fusion energy machines such as JET [1], ITER (proposed) [2] and the many nuclear reactors. These machines have no personnel access due to very high residual radiation levels, contamination issues or a combination of both. The term remote handling truly means remote in that complex devices such as manipulators are operated from a remote location, typically a dedicated control room, utilizing camera systems to monitor the activities. Equipment is removed via posting ports into casks that can be sealed to prevent contamination leakage. Once removed from the activated machine and safely inside a sealed cask the equipment can be transported to a hot cell where the posting port operation is reversed to place the activated component inside the cell, it can then be worked on or replaced. Remote handling equipment of this complexity must be reliable and durable because failure during a remote operation can result in schedule delays or more importantly potential risk to maintenance personnel. The capital cost of this type of set-up is high therefore considerable project justification is required prior to its implementation.

PROTON ACCELERATORS

Remote Handling

Remote handling on high power proton accelerators has evolved over ~30 years but the remote aspect has been limited to the handling of targets and similarly activated components where it was known from the onset that hands-on maintenance could not be carried out. Typically these components would be withdrawn either vertically or horizontally into a remote handling cell (RHC) that is equipped with through the wall (TTW) manipulators and a camera system. The cells are designed to allow maintenance and replacement work to be carried out from the other side of a shielded wall with the operator viewing through a lead glass window or similar, aided by a camera system.

The SNS facility will provide a 1 GeV, 1.44 MW proton beam to a liquid mercury target. The facility hot cell has four sets of TTW manipulators all mounted on the same side and access to equipment out of reach of the manipulators is achieved by a high performance telescopic servo-manipulator that is attached to the remotely operated crane.

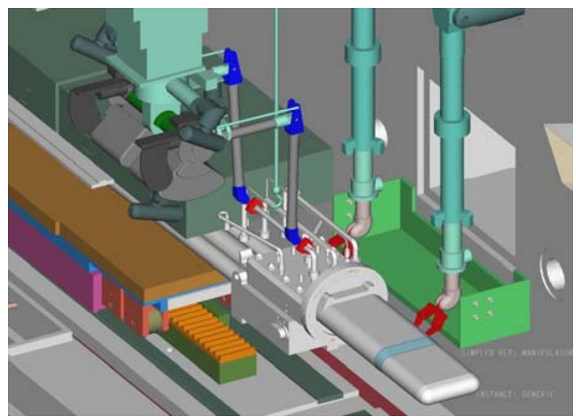

Figure 1: 3-D Model of SNS hot Cell.

Figure 1 shows a 3-D view of the SNS cell that is currently under construction [3]. Utilization of a servo-manipulator differs from many of the older hot cell designs e.g. the ISIS facility in the UK.

The ISIS facility provides an 800 MeV, 160kW proton beam to a tantalum clad tungsten target. The RHC has two pairs of TTW manipulators each pair being positioned on opposite sides of the handling cell and mounted above a dedicated viewing window. This allows maintenance work to be carried out simultaneously on both sides of the cell. The cell is also equipped with a crane, camera system and posting ports for tooling etc. The proposed second ISIS target station which is also under construction at present has adopted the same RHC design as the first [4]. The SNS cell however is much larger and TTW manipulators did not have enough reach to fully service the equipment therefore an alternative solution was sought. The telescopic servo-manipulator of course should make target changes much more efficient as well as being more adaptable to cope with any unforeseen problems that arise.

From an equipment standpoint the Japan Proton Accelerator Complex (J-PARC) hot cell is essentially a combination of the SNS and ISIS cells. J-PARC is a joint project between JAERI and KEK. The accelerator complex will comprise a 400 MeV normal conducting linac, a 600 MeV superconducting linac and a 3 GeV (1MW beam power) & 50 GeV (0.75 MW beam power) synchrotron rings [5]. The hot cell will have TTW manipulators on either side of the cell and a six-axis power manipulator overhead supported by full camera coverage. Figure 2 shows the SNS manipulator during testing and highlights the size of the mass that will be suspended from the crane.

Figure 2: SNS Telescopic Servo Manipulator.

The Los Alamos Neutron Science Centre (LANSCE) operates a pulsed neutron source that comprises an 800MeV linear accelerator, proton storage ring and production targets. Maintenance and repair of the accelerator equipment is carried out using remotely operated manipulator arms that are attached to a remote handling machine called "Monitor II" [6]. The monitor capabilities are impressive and include:

- 28' plus reach from the top of the shielding to the highly activated components.
- Ability to mount and operate two manipulator arms simultaneously.
- 300' maximum distance from control centre to manipulator (100' nominal).
- Force feedback to operators.

Figure 3 shows the remote handling machine with one manipulator arm mounted.

Figure 3: LANSCE Remote Handling Machine.

The manipulator arm can perform most maintenance operations including operation of hand powered, pneumatic, electric tooling as well as torch/stud welding and soldering.

Another example of remote handling can be found at the ISOLDE facility where a robot is used to change radioactive ion beam targets. The ISOLDE facility is dedicated to the production of a large variety of radioactive ion beams. Targets are required to be exchanged ~every ten days and have in the region of 200mSv residual radiation dose on contact. A six-axis industrial robot with an adapted grip is controlled remotely to remove, transport and place the target into a shielded flask. The target assembly is designed to allow easy disconnection and re-connection of services [7]. Figure 4 shows the robot head during a change-out procedure.

Figure 4: ISOLDE Target Exchange Robot.

To ensure safe and correct working conditions for personnel and comply with Swiss regulations for the handling of high levels of radioactivity ISOLDE are in the process of building a new Class A radioactive laboratory. This will have an improved and more versatile hot cell and will allow a more streamlined disposal of target material.

Active Handling

Maintaining active components on the linac and ring has generally been done hands-on with upper limits of accumulated dose set for personnel. Wide use of overhead cranes, long handled tooling, portable shielding, novel engineering designs and good work planning have helped limit the dose rates to accepted levels. This form of maintenance is more commonly known as active handling as opposed to remote. However with most facilities now adopting the as low as reasonably achievable (ALARA) principle for working in activated areas maintaining components on the higher powered proton facilities will become increasingly difficult and will certainly maintain a high profile with the various funding agencies.

ALARA essentially mandates that dose rates to personnel should be kept to a minimum. This can be

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achieved by many means e.g. shielding, sound machine design (low loss physics and/or high quality engineering), careful tuning and thorough planning of maintenance work. In older machines this is quite often difficult due to component geometry, available space etc. Designs are often retro-actively improved and upgrades to existing equipment generally give the best opportunity to improve the handling characteristics of the equipment.

A good example of this philosophy can be seen at the Paul Scherrer Institute (PSI). PSI operates a cyclotron facility for the production of a high intensity proton beam at 590 MeV. The accelerator was designed in the late sixties and had achieved a current of 100μA by 1980. After several years of operation an upgrade to 2mA was started and this in turn led to a review of the handling concepts for the beam line components due to the expected increase in activation. All beam line elements, the carbon targets, monitors and collimators etc. are mounted on support stands that are precisely positioned with the elements themselves and fit snugly into the bulk shielding as a module. This allows the elements to be positioned accurately without fastenings which is important from a removal/installation point of view because it eliminates the need for mechanical work on the active components.

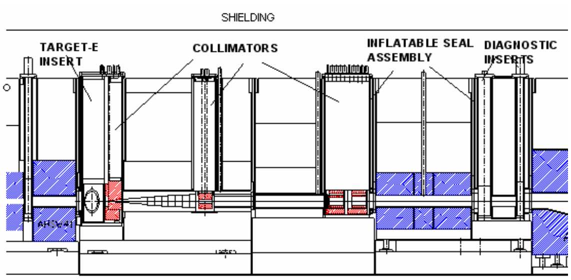

Figure 5: Vertical Cross-Section of PSI Beam Line.

Figure 5 shows a vertical cross-section with the individual elements inserted. The shielding above the elements can be removed allowing access to a working platform on top of the element modules themselves this platform is used during maintenance. All utility connections e.g. power, water and signal are routed through the shielding to the working platform area.

Once the modules are inserted vertically there is no access to beam line vacuum therefore a radiation resistant inflatable seal was designed. These can be inflated between modules to make vacuum with no clamping required and exhibit a leak rate of ~10^{-5} mbarl/s.

Removal of active modules is achieved by extracting them vertically from the beam-line into a remotely controlled shielded flask shown in Figure 6. This flask is then transported by crane to a hot cell facility where it is docked and the active components lowered into the cell. The cell is equipped with tooling, ventilation and a crane with a power manipulator. The flask concept is now being used on the cyclotron components making full use of the hot cell capabilities [8].

Figure 6: PSI Shielded Flask.

The Neutrinos at Main Injector (NuMI) project at FERMI Laboratory produces an intense beam of neutrinos after interaction of a 120 GeV proton beam with a production target. A work cell has been designed and built to provide a well shielded facility for repairing or replacing the target and horn assemblies. During beam-line operation these components become intensely radioactive. The work cell is situated adjacent to the target pile provides the ability to carry out maintenance/repair work with minimal radiation dose to personnel. Failed components and their utility modules can be placed into the work cell using the overhead bridge crane. The upstream steel door of the cell can be opened and closed remotely to gain access. While in the work cell components and modules can be separated, mechanical connections can be made and utility lines and connections (water, vacuum, and instrumentation) can be tested [9]. Figure 7 shows the NuMI work cell during testing.

Figure 7: NuMI Work Cell.

FACILITIES UNDER CONSTRUCTION

At present there are three high power proton facilities under construction that will require remote or active handling: one neutrino experiment and two spallation neutron source projects.

The CERN Neutrino to Gran Sasso (CNGS) project will transport a proton beam to a graphite target which will in turn produce muon-type neutrinos. The target interactions will make the target station assembly highly radioactive therefore much work has concentrated on designing the assembly to be remotely installed, serviced and dismantled by the crane. Automatic lifting and kinematic mount systems will aid the remote handling operations. A remotely-controlled radiation-hard crane will be utilized with a camera attached. The few operations that require manual tooling are well shielded and can be performed through access ports in the shield wall [10]. Figure 8 shows the remote crane installation in the target station hall.

Figure 8: CNGS Tunnel Target Area .

In areas of such high prompt radiation dose it is important to select materials carefully. Some examples of materials selected by the engineers are given below. In the highest dose regions up to 10^9 Gy pure carbon in several forms is used for the target and its supports, 316LN stainless steel is used where rigidity and mechanical resistance is an issue e.g. transmission shafts & couplings and no grease of any kind is used.

The J-PARC accelerator has been designed to exhibit low beam loss but expected hot zones do exist due to inherent beam loss on the components. These are in the collimation, injection and extraction areas. To reduce the dose to personnel during maintenance several areas have been addressed from an active maintenance point of view. Design work and testing has been carried out for quick release vacuum, water and current connections. Components will be mounted on linear motion guide rails and an overhead crane supplemented with air pallets will be used to transport equipment. Hot spots will be shielded using movable local shielding similar to that used on the ISIS facility. A J-PARC conceptual vacuum clamp and bellows retraction mechanism is shown in Figure 9.

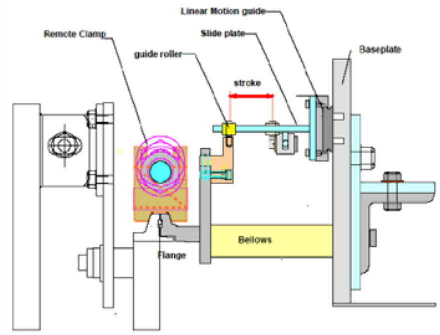

Figure 9: J-PARC Remote Clamp/Bellows Concept.

The SNS project has similar accelerator handling issues to J-PARC with many components expected to become highly radioactive. A concerted effort has been made over the last three years to improve the active handling characteristics of the components in the expected hot spots around the accelerator [11]. When accelerator handling was addressed many of the components were already well down the design path therefore attention was focused on the interface areas such as water couplings, lifting, vacuum clamps and vacuum bellows retraction. Based on a proven ISIS idea a quick release water coupling was designed for use on the collimators but has since been adapted for the target interface region.

Specialized or integrated lifting fixtures have been used wherever possible to eliminate the need for hands-on attachment of lifting equipment. Remote vacuum clamps have been designed for the linac dump region to allow removal/replacement of the dump window. This design is now being used in various areas around the ring.

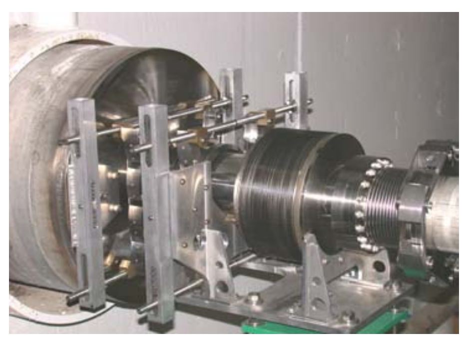

Figure 10: SNS Linac Dump Assembly.

Two concepts have been designed and developed to axially move vacuum bellows one is a retro-fit for the collimators and the other is a custom co-axial arrangement. Figure 10 shows the linac dump window installed with two remote vacuum clamps and the co-axial vacuum bellows and Figure 11 shows the bellows and remote clamp arrangement fitted to a collimator.

Another area of concern is the accelerator/target interface region where residual dose levels are expected to be high due to back-streaming from the target. Consequently the last four quadrupoles (25 Tons each) are designed to be radiation hard and have mineral insulated coils. A cross-section of this area is shown in Figure 12.

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Figure 11: SNS Bellows Retraction Mechanism.

The magnets have integrated shielding and are designed to be removed vertically, similar to the PSI model. The support structure will rest on a pseudo kinematic mount and rail system. All utility connections will be terminated above the integrated shielding and are designed to be quick release. To maintain vacuum integrity a Ø17" inconel 718 co-axial bellows and remote clamp design will be utilized [12].

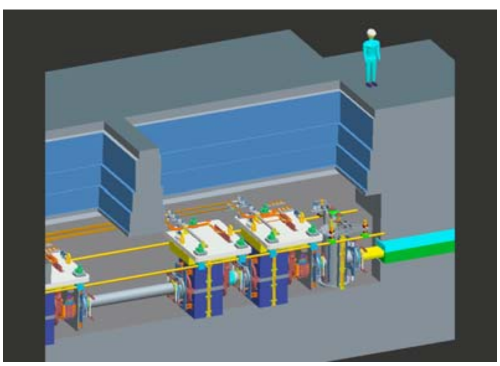

Figure 12: SNS Accelerator/Target Interface.

SUMMARY

There is no doubt that remote/active handling is becoming more prevalent as facilities increase in power and deal with the issues associated in ALARA. It will become increasingly difficult to design and built high power facilities without a thorough look at the consequences of ignoring the need for remote or active handling. To what extent one would take this in the accelerator itself is debatable. When considering high power targets there is no argument that a large amount of time and money should be spent on hot cells, manual and servo manipulators, sophisticated camera systems etc. because the expected levels are generally so high that there is essentially no choice. This can be seen in the target stations at ISIS, J-PARC and the SNS. CNGS and NuMI both identified in the early stages that the target and horn handling would be an issue and addressed it in a similar manner.

As can be seen from many of the stated examples this philosophy is not so clear when considering accelerator components. The sophisticated handling equipment used at LANSCE, ISOLDE and PSI has evolved through the life of the facilities either due to upgrades or operational experience dictating where the trouble spots are and consequently a need for remote handling identified. J-PARC and SNS have gone some way to address the accelerator handling issues but could this be used as a model for future generation machines with potentially worse problems?

Machine conceptual engineering designs need to be an integrated effort between physics and engineering with a sound experienced staff available early in the life of the project. It is imperative to identify potential hot spots at the outset and distribute design effort accordingly. Make full use of existing proven designs e.g. remote vacuum clamps, utility connections, kinematic mounting systems etc. Identifying early that these are issues will save money due to economies of scale and it is certainly more expensive and problematic to retro-fit equipment at a later date. One must balance the initial engineering cost against not only ALARA issues but also machine downtime which on a large facility is extremely expensive. Project cost and schedule pressures typically push what are seen as the less important issues to a lower priority but over the life of a facility the quality of the engineering design work instigated in the early stages will pay off immensely.

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REFERENCES

[1] http://www.jet.efda.org/
[2] http://www.iter.org/RemoteH.htm
[3] Rennich M., Private Communication, ORNL, SNS Project, USA.
[4] Jenkins D., Private Communication, RAL, ISIS, UK.
[5] Yoshioka M. et al, Private Communication, J-PARC, Japan
[6] Eddleman J. & Borden M., Private Communication, LANL, USA.
[7] Catherall R. & Lettry J., Private Communication, ISOLDE, CERN, Switzerland
[8] Heidenreich G. & Schmelzbach P., Private Communication, PSI, Switzerland.
[9] Hylen J., Private Communication, FERMI National Laboratory, USA.
[10] Bruno L. & Sievers P., Private Communication, CNGS, CERN, Switzerland.
[11] Murdoch G. et al, Design & Handling High Activity Collimators & Ring components on the SNS, EPAC'04'.
[12] Holding M. et al, Engineering the SNS RTBT/Target Interface for Remote Handling, These Proceedings.

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