REMOTE HANDLING AND ACCELERATORS*

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Summary

The high-current levels of contemporary and proposed accelerator facilities induce radiation levels into components, requiring consideration be given to maintenance techniques that reduce personnel exposure. Typical components involved include beamstops, targets, collimators, windows, and instrumentation that intercepts the direct beam. Also included are beam extraction, injection, splitting, and kicking regions, as well as purposeful spill areas where beam tails are trimmed and neutral particles are deposited. Scattered beam and secondary particles activate components all along a beamline such as vacuum pipes, magnets, and shielding. Maintenance techniques vary from "hands-on" to TV-viewed operation using state-of-the-art servomanipulators. Bottom- or side-entry casks are used with thimble-type target and diagnostic assemblies. Long-handled tools are operated from behind shadow shields. Swinging shield doors, unstacking block, and horizontally rolling shield roofs are all used to provide access. Common to all techniques is the need to make operations simple and to provide a means of seeing and reaching the area.

Introduction

A survey paper was presented at this conference in 1975 that discussed radiation levels, shielding, radiation damage, and remote handling at the then new high-power accelerator facilities of LAMPF, SIN, TRIUMF, and FERMILAB.[1] The facility descriptions given have remained fairly constant over the intervening 8 years; however, operational experience has been gained, and some changes in remote-handling equipment have occurred. This paper will discuss the additional information.

LAMPF

Design of the LAMPF Line-A equipment and facilities was based on a philosophy of providing ready removal of equipment expected to require routine maintenance (position monitors and targets), while providing general access to all other components.[2] The position monitors and targets are mounted on shielding stalks that are inserted into vacuum-tight enclosures that penetrate to the surface of the bulk shielding from the beamline. The drives, utilities, and vacuum seals are, therefore, in an accessible location for hands-on-connection and service.[3,4] Access to the beamline components is provided by horizontally opening shield doors that weigh hundreds of tons. This is accomplished by inserting roller trucks under the doors and transferring the weight of the door onto the trucks by hydraulically expanding the trucks, which are then pushed or pulled with a pair of horizontal cylinders.[5] The original requirements that the radiation emanating from the beamline components be shielded and that all components removed from the beamline be transported in a cask resulted in the construction of a portable hot cell dubbed MERRIMAC. The shield doors, shielding configuration, and hot cells of Area A were all designed to be compatible with the MERRIMAC concept, which put rather tight constraints on the configuration of the shield doors.

LAMPF operated for over a year (1974) at reduced intensities to permit hands-on maintenance because some of the main beamline components and much of the shielding had not yet been installed. Another year (1975) was required to complete equipment and shielding installation. During that time, a second manipulative system was proposed that was more versatile for use in areas not requiring the complete shielded handling MERRIMAC provided. This system, named MONITOR,[6,7] and its offspring have become the prime manipulative systems; MERRIMAC has been scrapped, and the complete shielding requirement has been waived.

MONITOR began in 1976 as a hydraulic-powered truck self-loader to which a switch-operated electric manipulator (PaR 150) was attached. The boom of the self-loader is capable of placing the small, human-arm sized, manipulator near the beamline components located as far as 8 m below the top of the shielding. Viewing is with television. A prototype hydraulic master/slave manipulator was obtained from the Navy, modified slightly, and mounted alongside the PaR. This arm was manufactured by the Remotion Company, weighs 8 kg, and responds to the position of the master arm very rapidly.[8] The PaR 150 manipulator later was replaced by the PaR 3000 salvaged from MERRIMAC. This equipment was used on several occasions including working with a beam exit window and collimator in a 10^4 R/h environment. Great increase in manipulative speed was achieved through the acquisition of two TOS Model 229 bilateral servomanipulators of 10-kg capacity. These manipulators have been used as a pair of arms or singly, paired with either the Remotion arm or one of the PaR manipulators.[9,10]

LAMPF today has experienced the most remote handling and the highest radiation levels of any accelerator. The main proton line has radiation levels of 1000 R/h in the first target cell, 2000 R/h in the second, 800 R/h at the biomed target cell and 10^5 R/h in the beamstop area. All operations are performed remotely using TV viewing. There is absolutely no direct viewing because radiation levels from 10 to 25 R/h exist at the edge of the open shield doors. Shadow shields and distance are used to keep radiation levels within limits where people must work on top of the shielding.

The remote-handling crew consists of 3 engineers, 4 draftsmen, and approximately 15 technicians, under the direction of Donald L. Grisham. They can field three crews for continuous operation. A fourth crew builds tooling, and components to support the manipulating crews. When not operating, they are continually maintaining and upgrading the manipulative systems and building new systems. They are assembling a third MONITOR to utilize the third TOS Model 229 manipulator that they have acquired. They have a good operating history because of their preventative maintenance program. An example being a 5-month stint of operating 24 h/day, 7 days/week (minus 3 days to rest people) with only 24 h of downtime to repair manipulator problems. The first two TOS arms have clocked ~10 000 h each in practice, tune-up, and operation with about 6000 of this being actual working hours.

The LAMPF main beamline has been plagued with water and vacuum leaks resulting in an awesome assortment of tasks that range from the replacement of five of the 17-ton target-cell triplets, through welding,

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soldering, polishing flanges, to making up electrical connectors. A time-consuming task has been the removal of the close-in shielding that is fitted around the beamline components within the target cells. They have been reducing the number of pieces by welding them together into larger sections.

SIN

The main proton beamline, two target assemblies, and the beam dump are located within a vault that is approximately 40 m long, 5 m wide, and 3 m high. The roof slabs are removable to provide access from above. Convenient personnel access is provided. The target assemblies are surrounded by close-in shielding and a side-entry cask is used to transport the target assemblies to hot cells for maintenance. Maintenance was intended to be accomplished by hand or with the use of shadow shields and long tongs. A manipulator system called MINIMAC[11] was assembled to handle unforeseen events that involve radiation levels high enough to preclude the use of people.

MINIMAC consists of one PaR Model 3000 switch-controlled manipulator mounted on a trolly system that runs on a 4- by 6-m frame. Suspended from the frame are television cameras and a tool board. A 3-D television camera is mounted on the manipulator. This camera also may be used as a 2-D camera to reduce operator eye fatigue when the nature of the manipulation does not require depth preception. A bent Quasar telescope allows an observer to peer over a shadow shield for additional viewing capability.

Although MINIMAC was conceived for emergency use only, experience showed it could be used for many operations that originally were planned to be accomplished with shadow shields and long tongs. MINIMAC has had approximately a month's usage each year since 1979, doing modifications or repairs to the main beamline production-target enclosures. Radiation levels in the 1000- to 2000-R/h level were measured on components removed by MINIMAC.

SIN has two engineers and four technicians, under the direction of Eyke Wagner, that are responsible for the remote-handling effort. Five individuals are capable of operating the manipulator.

Wagner has developed a clever method of disposing of activated components. He has designed concrete blocks whose outside dimensions are the same as SIN standard shielding blocks but contain a large void into which an activated component is lowered remotely. A lid covers the component, and the remaining void may be filled with grout, completing the encapsulation. The activated component and its surrounding concrete thus serve as a shield block for the remainder of the life of SIN, by which time the component will have decayed to manageable levels.

Future plans include changing the thin target system in 1984 and the thick target and beamstop in 1988. The beamline vault will be filled with shielding. Vertical shield plugs will provide access to the beamline components. The electrical and water services for the components will rise through the shielding for manual maintenance. The beamline vacuum connections will consist of inflated bellows attached between pairs of flanges similar to the system used on their cyclotron vacuum chamber. A shielded area will be assembled from standard blocks and equipped with lead-glass windows and master/slave manipulators to allow performance of more on-site work on activated equipment.[12]

TRIUMF

TRIUMF routinely produces a 450-MeV proton beam with a 100-μA intensity. Cyclotron maintenance is based upon the ability to gain access into the 18-m diameter, 45-cm-high vacuum chamber by jacking the top half of the cyclotron upward by 1.2 m. A service bridge is inserted into the opened vacuum chamber, with the inner end supported on the cyclotron center post and the outer end supported on wheels that ride on the cyclotron periphery. A drive system positions the bridge at any radial location desired. Various specialized trolleys can be mounted on the service bridge to accomplish inspection and maintenance functions.

Personnel access into the vacuum chamber requires the remote placement of ∿10 tons of 5-cm-thick lead shields over the vacuum chamber walls where neutralized beam particles have impinged at the beam plane level. It requires ∿20 h to install or remove these lead shields remotely with the service bridgetrolley system. Four copper blocks located at places of known high beam spill also are removed. This shielding and removing procedure reduces the general background within the chamber to the 10- to 15-mR/h level.

A goal of 300 μA by 1986 will require replacing the 80 resonator panels whose drooping has been a continuous problem. The present resonator panels are ∿0.8 m wide by 3 m long and weigh 275 kg each. There are specialized trolleys for remotely replacing both upper and lower resonator panels of the current design.

Beamline-component maintenance requires unstacking the covering concrete blocks to expose the component. A platform, having a 5-cm-thick lead floor, is placed over the opening and an operator on the platform performs manipulations 3 to 5 m below, using long-handled tools. Television is used to provide viewing. Radiation levels of 10 to 15 R/h at the beamline are attenuated to the 10-mR/h range at the operator by this system. The beamline vacuum connections use double indium seals, which on occasion develop leaks. Repair requires four to six hours to unstack shielding, one hour to set up the platform and actually change out the seals, and another four to six hours to replace the shielding. All beamline components other than the target chambers are maintained in this fashion.

The target systems consist of shielding thimbles, below which are suspended ladder targets that can consist of Be, Cu, H_2O, and C. Typically, these are run until a water leak develops somewhere in the ladder, which is attached to the thimble with Swagelock fittings. Routine replacement of a target ladder requires about a half day. The thimble is withdrawn vertically into a bottom-entry cask that is hoisted into a hot cell for replacement using master/slave manipulators. A bellows associated with the vertical-motion portion of the target system has a lifetime of about a year. A full day is required to change this bellows remotely.

TRIUMF has acquired a Unimate programmable robot in cooperation with the University of British Columbia Engineering Department. The robot will be used for welding operations within the vacuum chamber.

The remote-handling section at TRIUMF consists of one engineer, four designers, two electronic technicians, two mechanical technicians, and one hot-cell technician, under the direction of William Cameron. Of this group, two are familiar with hot cell operations, three with beamline remote handling, and five with service bridge-trolley handling.[13,14]

CERN

For over a dozen years, Roger A. Horne at CERN has been promoting the use of remote handling using servomanipulators to reduce personnel dosage. At that time he acquired a pair of Mascot servomanipulators that were manufactured by Selenia in Italy.[15] The various CERN groups historically preferred to do hands-on maintenance; however, because of growing radiation levels and a stable work force, the dosages of the maintenance workers is approaching the CERN limit of 1.5 R/yr. The decision to build LEP with no increase in personnel or relaxation of the dosage limit has increased interest considerably in doing more work remotely.

Horne has assembled a remote-handling vehicle, named MANTIS after the insect it resembles, that has become so in demand to handle modifications and repairs that management has provided funds to build additional upgraded systems and new manipulators.

MANTIS consists of a self-propelled hydraulic truck loader that carries the Mascot manipulator arms.[16] In the traveling modes, it folds up into a compact package 1 m wide, 2.2 m high and 4.5 m long, weighing 6 tons. The compact configuration is required to enable it to thread among the equipment in the accelerator tunnels. A quarter-ton of spooled cable mounted on a trailer allows MANTIS to maneuver 80 m in its manipulations; another 250 m of cable connect the trailer to the master control station. Before beginning work, either MANTIS or an operator runs into the work area, unrolling a black rubber mat upon which a white line is drawn. MANTIS then automatically follows the white line in and out of the area. This is a clever and quick way to deliver components and pick up tools without the risk of colliding with shield blocks or accelerator apparatus. It was observed that a white line painted on the floor was quickly eroded away because people tended to follow it when walking, and equipment configurations changed so frequently that no path remained the same for any length of time.

Upon arriving at the work area MANTIS unfolds itself and an operator can position the MASCOT manipulators anywhere within an 8-m radius, including over shielding walls.

The 13-yr-old Mascot servomanipulators have operated over 2500 h. They use glass-tube electronics, and as only a half-dozen arms were manufactured, parts must be custom constructed. Prototype work has been completed at CERN on a new generation of compact servomanipulators using some of the concepts advanced by Kentner Wilson's hydraulic arm.[8] A complete arm will weigh 20 kg and can handle 25 kg. It is intended to build six of these force-reflecting hydraulic servomanipulators within the next year. The remote-handling community is watching this development with interest because the power, speed, and simplicity of hydraulic manipulators is appreciated; however, the risk of spraying oil around a hot cell and the traditional use of electrical motor power manipulators have restricted use within the reactor fuel community.

Under the direction of Roger Horne, the permanent remote-handling team consists of an engineer, a technician, and a mechanic. Operations require two people, one of which concentrates on the manipulations while the other observes, plans, and helps make decisions. After a half-day of work, the operator leaves because of fatigue, the observer becomes the operator, and the third person becomes the new observer.

The remote-handling group prides themselves on being able to go anywhere and do any job quickly. To do this may require a few months preparation to do a few weeks of work, especially if special tooling is required or access is particularly difficult. Most of the areas of CERN were built without regard for ease of remote maintenance. The remote-handling group insists that a senior technician who really knows the nuts and bolts be their only interface with the group controlling the area where work is to be done, and that he be with them for guidance when they are doing the remote work. As the necessity of remote operations increases, more groups are asking for guidance in equipment design to facilitate remote maintenance.

FERMILAB

The final beam-transport magnets and the production targets for the neutrino area at FERMILAB are mounted on bedplates, which are picked up and carried by a railroad system.[17] Various train assemblies, which are dozens of meters long, exist to provide an assortment of target and beam geometries. Trains may be driven between locations in an evacuatable target tube for producing mesons, in shielded storage tunnels, and in a service building for maintenance or equipment change out. The service building contains bridge-mounted servomanipulators.[18] One pair of servomanipulators are the prototype Mark IV units developed by the Remote Control Division of the Argonne National Laboratory. The second pair are slightly modified CRL Model M manipulators, which look somewhat like the prototypes but with one arm having a higher capacity. All viewing uses television. The control room for remote operations is 130 m outside the shielded area. Hot items requiring remote maintenance are moved to the service building.

The train system provides a very fast way to change out a large number of complicated and heavy components. The just-removed train may be stored for future use or modified. Since 1975, three trains have been scrapped, requiring $\sim$500 h of remote-handling operations. The average hottest item is 30-50 R/h at 30 cm and remote-handling crews have worked on items as hot as 200 R/h. They prefer to do as much disassembly and reassembly remotely, as time allows, to reduce dosage, using local shielding of hot areas to permit some hands-on work. Early trains that were hastily assembled proved to be difficult to work on remotely. The later trains had more attention given to remote maintainability, which has permitted more to be done at lower dosages. Jack Lindberg directs the remote-handling effort at FERMILAB.

SLAC

The SLAC switchyard was provided with long tool-maintenance capability. However, equipment reliability has been very good, and the activation is more a nuisance than a problem. SLAC beam powers of 200 to 300 kW are only half of those of a few years ago because of changing experimental emphasis. Targets and beam dumps are activated to the 15 R/h range on contact after a day of cooling. Additional cooling is allowed to permit maintenance work to be done by hand. Dieter Walz, having been responsible for the design of the components that absorb power, is the most knowledgeable at SLAC about radiation levels and how they design to accommodate them.

Manipulators

Manipulative equipment originated within the National Laboratories in support of the needs of fission reactor fuel development. These original designs were developed into commercial products by private industry, and for the past generation PaR and CRL have been household acronyms within the remote-handling community. Essentially, every established hot-cell Laboratory in the country has through or over-the-wall master/slave manipulators manufactured by Central Research Laboratories (now a division of Sargent Industries).[19] The heavier manipulations are handled by rate-controlled (switch-operated motors with no feedback) Programmed and Remote Systems (now GCA/PaR Systems)[20] manipulators that are mounted on telescoping tubes supported by trolleys riding on bridges within the hot cell. A few other companies have been involved intermittently with the production of manipulators, but the market is declining and development costs are so high that new-equipment introductions are infrequent and usually are either funded by the first customer or are an entrepreneural spin-off of a device developed at a Laboratory. An example is the creation of TOS, TeleOperator Systems Corp.,[21] by Carl Flatau whose first product was produced on an order by LAMPF and is a descendent of servomanipulators he developed at Brookhaven National Laboratory as a proposed solution to the maintenance problems associated with increasing the intensity of the AGS in the midsixties.[22]

A very expensive and slowly acquired legacy of experience within the remote-handling machining industry could well wither away from lack of adequate markets to support the skilled teams necessary to produce these items. The sale of one or two servomanipulators a year by CRL or TOS is inadequate to keep these products alive.

"Why not send a robot in to do the work?" is an often asked question. There are $\sim$3000 industrial robots at work in the United States today. Most are quite primitive, with no capacity to see or feel or respond to their environment in any significant way. Poor mechanical accuracy and repeatability, along with inadequate control and cumbersome teaching, will delay robot entry into the delicate and often unpredictable realm of accelerator remote handling. The most likely scenario would be the adding of intelligence to a specific operation, like Roger Horne has done with MANTIS in having it follow a white line.

Approximately 500 people involved in all aspects of remote handling constitute the membership of the Remote Systems Technology Division of the American Nuclear Society. The yearly publication, "Proceedings of the Conference on Remote Systems Technology," is a compilation of the complete papers presented at their conferences during the year. The dozen senior people involved with the accelerator remote handling described in this paper are regular participants in the activities of this Division. A buyer's guide is published annually by the America Nuclear Society that lists suppliers that cater to the nuclear industry.

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