Shield Plug-Mounted Hot Cell Manipulator System

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INTRODUCTION

PaR Systems has been providing remotely-controlled manipulator systems for use in hot cells since 1961. These systems have traditionally consisted of a bridge, which traverses on crane rails mounted to the inside of the cell walls; a carriage that travels on bridge-mounted rails; a telescoping mast that provides vertical travel; and an electro-mechanical manipulator. Manipulators usually have 5-7 individually controlled axes. Most are supplied with remotely interchangeable grippers.

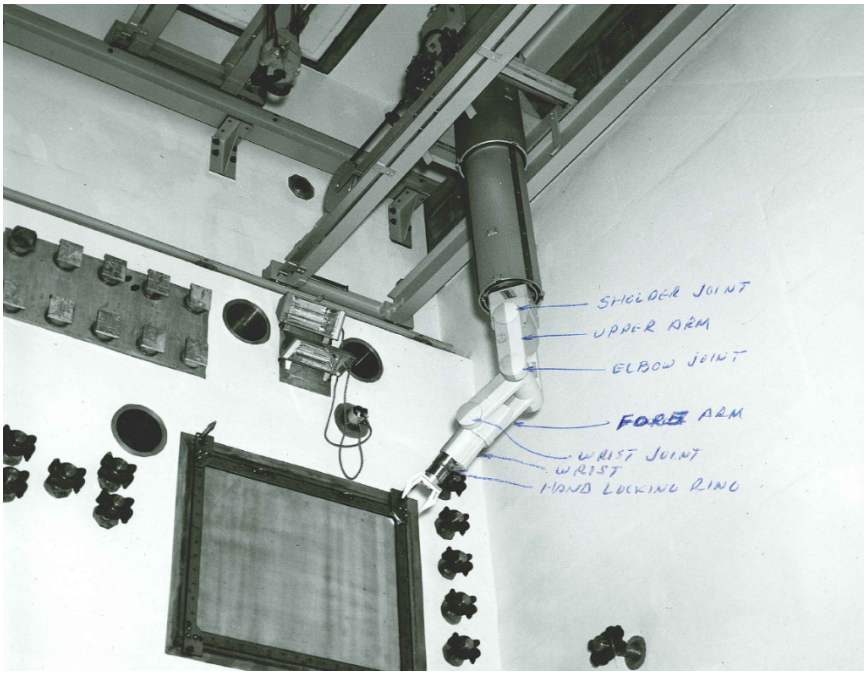
PaR supplied an M3000 bridge and trolley-based manipulator system to Oak Ridge National Laboratory (ORNL) Radiochemical Engineering Development Center (REDC) in 1964. The ORNL facility is located in Oak Ridge Tennessee in the USA. REDC produces radioisotopes for use in industry and research and produces more than 70% of the world's supply of ^{252}Cf. The manipulator system used in this hot cell was designed for hands-on maintenance and operator training and was not intended for use in a hot cell, however it installed in a REDC hot cell and suffered a bridge drive chain failure in 2008. Since no human access is possible in the cell, replacement of the system presented an enormous challenge for ORNL and PaR. Numerous repair, removal and replacement scenarios did not identify a solution that was workable in terms of cost and the potential exposure and contamination to personnel and facilities.

The engineers from ORNL and PaR Systems worked together to develop a manipulator system that allowed installation of a new system with little or no exposure to personnel. The new system is mounted from a new shield plug with provision for manipulator mounting and electrical cable passageways. Access ports were also designed into the new shield plug that attached to features on the drives with long-handled tools so disabled joints can be recovered from outside the hot cell.

ORIGINAL SYSTEM

Typical bridge and trolley-based manipulator systems are installed as the cell is being commissioned prior to the cell "going hot". They undergo a full range of testing and maintenance demonstrations to ensure the machinery is fully functional and maintenance/repair operations are understood by personnel. Some of these systems that were installed and commissioned in the 1960's and 1970's are reaching the end of their useful life and need to be partially or fully replaced. Hundreds of these M3000 systems are installed in hot cells worldwide. Photographs of the original system taken during commissioning of the ORNL REDC hot cell are shown below in Figure 1 and Figure 2.

Many of these systems can be replaced with like systems when they reach the end of their service life provided limited cell access is possible by personnel. However in some cases the radiation levels are too



high to make replacement possible. The biggest challenge is in installing the equipment and making the necessary electrical connections. This was the case for the ORNL manipulator system. There were no existing cell wall penetrations that could be used for routing the electrical cabling where it would enter the cell where the connection points could be reached with the existing MSM's.

Figure 1: Original M3000 Manipulator System during Installation

Figure 2: Original System Looking Down Through Shield Plug Opening

NEW SHIELD PLUG-MOUNTED SYSTEM

After months of attempting to come up with a solution for installing a new system and making the in-cell power connections, ORNL asked PaR if they could design a ceiling-mounted system. They proposed a unique shield plug-mounted system that would not require removal of the failed system, rather it would be pushed to one end of the cell and left there until cell decommissioning. The hot cell was designed with a large (1830mm x 3050mm x 1520mm thick) ceiling plug as shown in Figure 2 above. The proposed design would have to provide equivalent functionality, capacity and the same cell coverage as the original system. In its retracted position the plug-mounted system would fit through the shield plug opening. All of the electrical cables would be routed through passageways in the plug and final connections would be made outside the cell on a bulkhead connector panel on the top of the plug.

ORNL provided PaR with the design specifications, hot cell CAD models and a rough concept model in SolidWorks format. The concept and requirements were refined by PaR in the detailed design stage. Throughout the design process CAD models were exchanged and reviewed by both engineering teams. The mounting interface between the manipulator and shield plug, cabling passageways and ports for long-handled recovery tools. Figure 3 below shows the ORNL-designed shield plug with mounting studs on the bottom and electrical connections on the top.

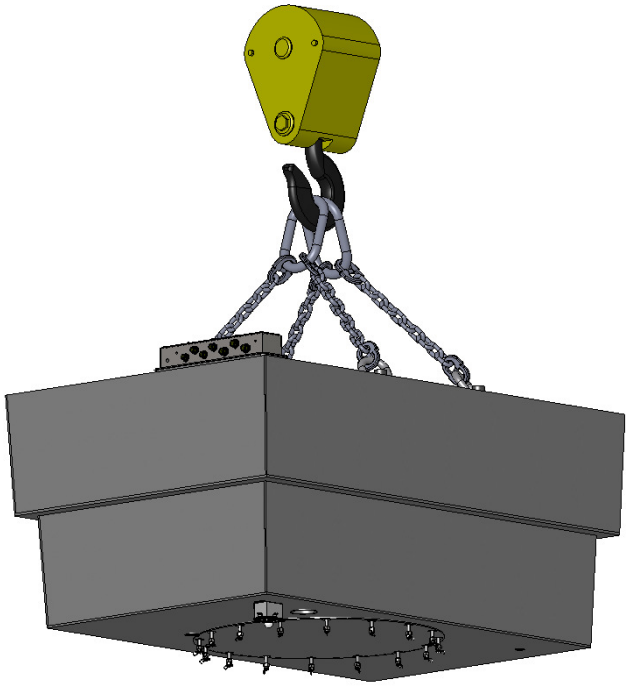


Figure 3: New Shield Plug with Manipulator Mounting Features

The new manipulator system design consists of a plug-mounted 360 degree rotating turret and a two-stage horizontally extending boom with 2590mm of reach from the plug centerline. The turret is powered by a motorized pinion that meshes with a large ring gear mounted to the boom structure.

The horizontal boom extension is driven by two capstan drives, where a motor/reducer combination drives a grooved drum and cable mechanism providing independent motion for each stage of the boom. Stage one provides gross positioning and stage two, which has a lower maximum speed, provides fine positioning. The boom is shown in its fully extended position in Figure 4 below.

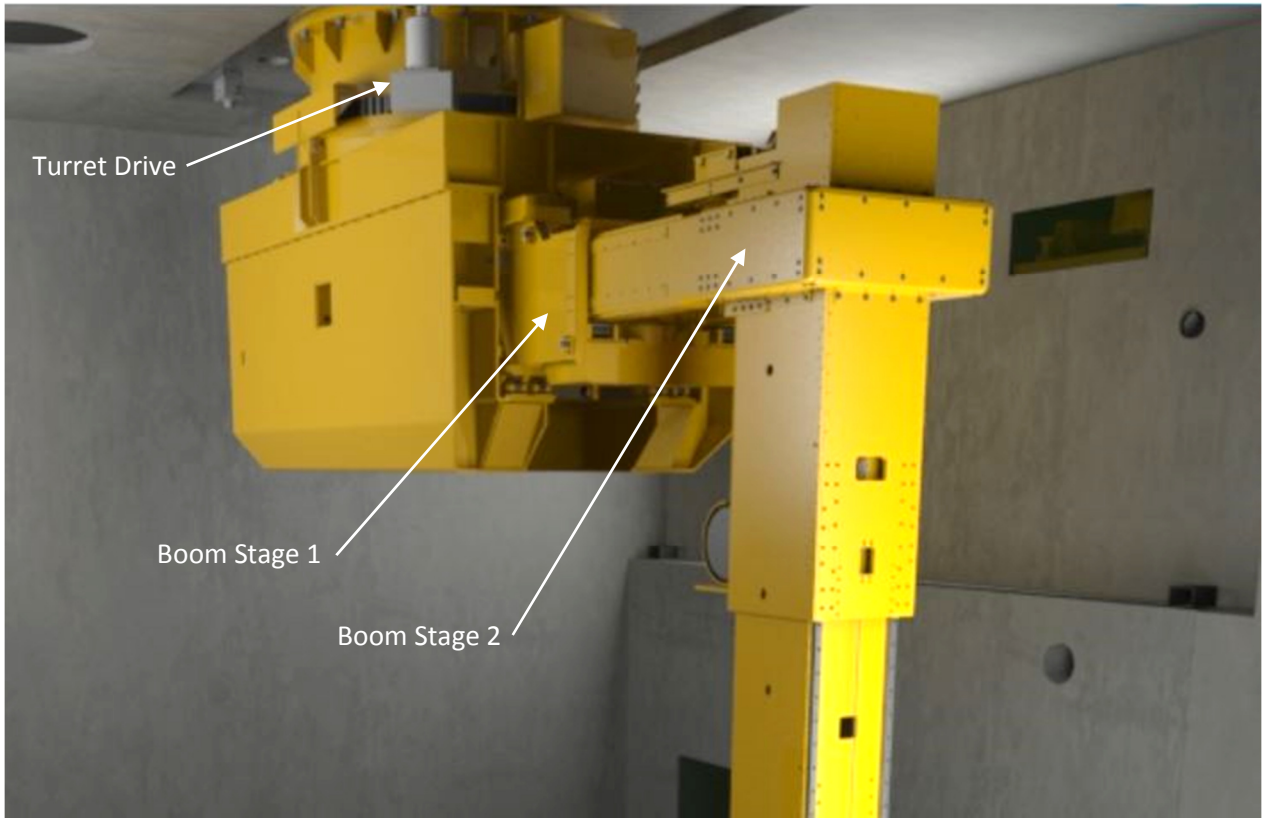


Figure 4: Two-Stage Horizontal Boom

At the end of the boom a telescoping mast is attached with a vertical travel of 4268mm. The mast is driven by a wire rope hoisting mechanism. Each of the four telescoping tube sections are sequenced via cables and pulleys between adjacent sections, so each section extends and retracts simultaneously. This provides maximum horizontal stiffness throughout the range of vertical travel.

Each mast section consists of a thick aluminum back plate on which linear bearing rails are mounted. The mating bearing slides are mounted to the adjacent smaller sections inside the larger sections for each tube. Three-sided formed aluminum shapes are then fastened to each of the back plates to form rigid box sections, which gives the mast its torsional rigidity. Figure 5 shows the CAD model of the complete manipulator system in the hot cell with the mast fully extended.

Figure 5: Complete System Shown with Mast Fully Extended

A PaR M3000 manipulator arm with seven degrees of freedom is attached to the bottom of the mast. M3000's have been used in hot cells since 1961 and the same arm (with very few design changes) is still being produced by PaR today. A complete listing of all of the manipulator system axes is shown in Table 1 below.

Table 1: Ranges of Motion and Axis Speeds

Axis	Range of Motion	Speed
Turret Rotate	370º	0-0.5 rpm
Boom Stage 1	2100 mm (82.5 in.)	1830 mm/min (6 ft/min)
Boom Stage 2	500 mm (19.7 in.)	915 mm/min (3 ft/min)
Telescoping Mast	4270 mm (14 ft)	4570 mm/min (15 ft/min)
Shoulder Rotate	Continuous	0-1 rpm
Shoulder Pivot	250º	0-1 rpm
Elbow Pivot	260º	0-1 rpm
Wrist Pivot	260º	0-1 rpm
Wrist Rotate	Continuous	0-7 rpm
Wrist Extend	100 mm (4 in.)	0-380 mm/min (0-15 in/min)
Gripper	100 mm (4 in.)	0-50 cm/min (0-1.6 ft/min)

The turret rotate, boom extension, mast and manipulator pivot joints all contain recovery features to allow for remote positioning of the axes using long handing tools through plug or cell wall penetrations.

SYSTEM FABRICATION, TESTING AND INSTALLATION

Following fabrication and assembly of the manipulator system, ORNL sent their new shield plug to PaR's factory for fit-up and testing. PaR constructed a temporary structure to support the plug and manipulator. The mating flange on the manipulator turret was fastened to threaded studs on the bottom of the plug. All cabling was routed through the passageways in the plug and were connected to the control system. A complete Factory Acceptance Test was performed, which included full range of motion for all axes, joint capacity tests, control system functionality and joint recovery demonstrations. Figure 6 below shows the test setup in PaR's factory.

Figure 6: Test Setup in PaR's Factory

ORNL designed and fabricated a maintenance and test stand that support both the manipulator system and the shield plug. This stand is also used in installation of the system. Installation into the hot cell is as follows:

1. Hoist rings are attached to the upper flange of the turret rotate. A building crane is used to lift the manipulator system onto the maintenance stand.

2. The shield plug is then lowered onto the fixture where it comes to rest above the manipulator mounting flange as shown in Figure 7. The flange is attached to the bottom of the shield plug and electrical cables are fed through the conduit in the plug.

3. The old shield plug is removed from the cell ceiling and the new plug/manipulator assembly is lowered into the plug opening. External electrical connections are made at the top of the shield plug.

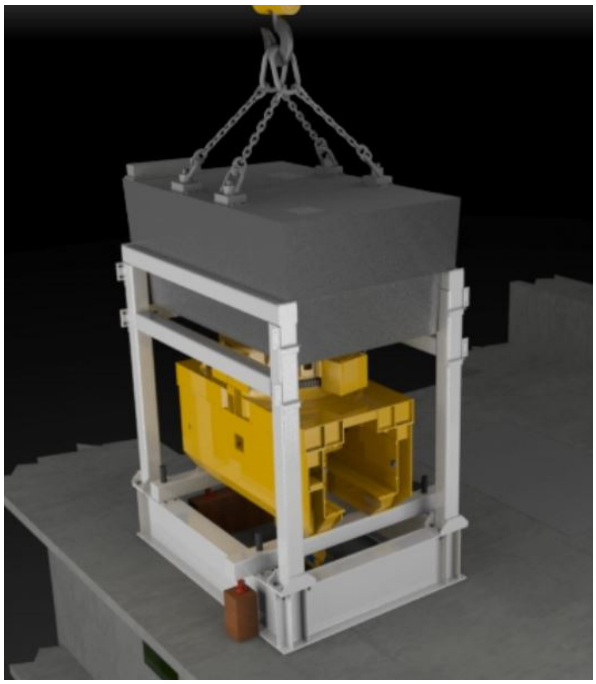


Figure 7: Installation using Maintenance Stand

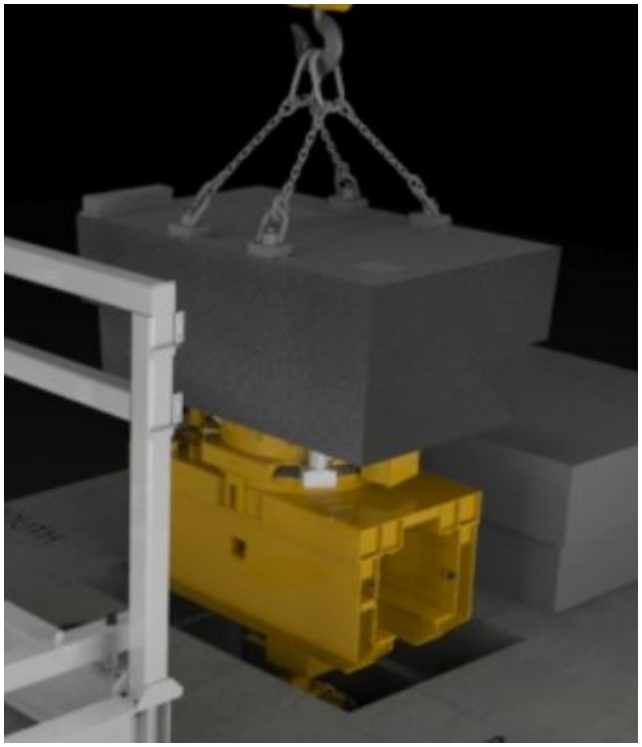


Figure 8: Installation into Hot Cell

Factory acceptance testing was completed in fall 2013. The system was shipped to ORNL at year's end. It is currently awaiting installation at a time convenient to REDC operations and production scheduling.

CONCLUSION

The ability to install a complete manipulator system in an existing active hot cell presents an opportunity for other similar cells where similar roof plugs exist and new or replacement remote handling systems are required. With this type of system configuration, installation and maintenance activities can be performed with minimal radiological exposure to personnel.

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