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Consolidated Fuel Reprocessing Program

HEAD-END REPROCESSING EQUIPMENT REMOTE MAINTENANCE DEMONSTRATION

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ABSTRACT

Prototype equipment for reprocessing breeder reactor nuclear fuel was installed in the Remote Operation and Maintenance Demonstration (ROMD) area of the Consolidated Fuel Reprocessing Program (CFRP) facility at the Oak Ridge National Laboratory (ORNL) in order to evaluate the design of this equipment in a cold mock-up of a remotely maintained hot cell. This equipment included the Remote Disassembly System (RDS) and the Remote Shear System (RSS). These systems were disassembled and reassembled remotely by using the extensive remote handling systems that are installed in this simulated hot-cell environment.

INTRODUCTION

The RDS and shear are products of major developmental activities of CFRP at ORNL. These activities are intended to advance the state of the art of breeder reactor nuclear fuel reprocessing. With the recent initiation of a joint collaboration between the U.S. Department of Energy and the Power Reactor and Nuclear Fuel Development Corporation of Japan in the field of nuclear fuel reprocessing, these efforts are being continued and will incorporate the results of the present tests. One goal of these activities is to reduce personnel exposure to ionizing radiation in future nuclear fuel reprocessing facilities. There will be no human access in a hot cell where this type of equipment will be located since high radiation and contamination levels will exist. Therefore, the concept of remote operation and maintenance applied to such a hot cell will accomplish this goal. This concept requires that all operations, modifications, maintenance, and decommissioning be performed using remotely operated equipment.

This paper covers a demonstration of remote maintenance using the ROMD maintenance system[1] to disassemble and reassemble RDS[2] and the shear. The objectives of these demonstrations were to (1) determine if the in-cell components are remotely maintainable as designed, (2) identify and document where improvements in design, procedures, or facility interfaces are desirable to enhance the maintenance operation, (3) establish the times required to perform the specified removals and replacements, and (4) establish and document tool requirements. The test of RDS was performed in the spring of 1987, and the test of the shear was performed during the summer of 1986.

REMOTE MAINTENANCE FACILITY AND SYSTEM DESCRIPTION

The ROMD facility, shown in Fig. 1, has been developed by CFRP and consists of a large high bay area with a 15-m (48-ft) working height and a 400-m^2 (4,312-ft^2) ground level floor. Assembled in the ROMD area is a complete state-of-the-art

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Fig. 1. The ROMD facility (1) gantry bridge crane, (2) manipulator transporter bridge, (3) force-reflecting servomanipulator, (4) fuel disassembly system, and (5) fuel shear system.

remote handling system that includes a two-armed, force-reflecting servomanipulator system, two power manipulators, a manipulator transport bridge, an overhead gantry bridge crane with two 9-metric-ton (10-ton) hoists, a closed circuit television (CCTV) viewing system, and a remote operator control station. The ROMD remote maintenance system allows comprehensive development and demonstration of key remote maintenance concepts and techniques.

Under a joint development effort, Sargent Industries' Central Research Laboratories and ORNL developed the model M-2 servomanipulator, which is the key component of the maintenance system. The model M-2 is a state-of-the-art, bilateral, force-reflecting servomanipulator and is the first totally digitally controlled servomanipulator in existence.[3] This system, shown in Fig. 2, essentially duplicates the dexterous handling capabilities of through-the-wall mechanical master/slave systems, but with the added advantage of being able to perform operations over a large facility volume. The model M-2 was installed in the ROMD facility in 1983 and has been extensively used in all of the following test programs. It has proven to be a very effective remote handling device.

Operator interface with the remote maintenance system, shown in Fig. 3, is based on a centralized control room that is located adjacent to the facility and houses the model M-2 control

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Fig. 2. The model M-2 teleoperator slave (1) transporter interface, (2) movable overhead cameras, (3) auxiliary hoist, (4) slave arms, (5) fixed lower camera, (6) servomotor housing, and (7) control electronics rack.

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Fig. 3. The ROMD control room (1) model M-2 master control station, (2) teleoperator transporter and facility camera control console.

station, a viewing system console of eight 17-in. CCTV monitors, and an operating panel containing the CCTV system controls and control for the balance of the maintenance system (i.e., hoists and transports). Visual information for control of remote operations in the ROMD facility is based on the strategic placement of television cameras within the facility to provide comprehensive coverage of anticipated remote handling operations. Cameras are mounted on the secondary bridge, which also carry the M-2. Two of these cameras are mounted to a boom on the center telescoping tube trolley to provide flexible, close-up viewing of manipulator operations. There are also cameras mounted on the primary bridge, which carry the two 9-metric-ton (10-ton) hoists, cameras mounted on the facility walls, one camera on RDS, and one on the shear. Each camera is equipped with a fully motorized telephoto lens and pan-and-tilt base. There are also three cameras mounted on the M-2 slave; two of them are boom mounted and fully motorized to provide orthogonal views of the work, and the third is fixed and mounted between the slave arms with only a motorized lens.

REMOTE MAINTENANCE DESIGN CONSIDERATIONS

The designs of RDS and RSS were intended to demonstrate essential features that could be considered critical in an actual hot-cell application. The design is based on remotely removable modules with the intent of remote replacement of the module(s) containing the failed component(s) with the prime objective of returning the in-cell system to operation with a minimum of downtime. Repair in a maintenance area or disposal of the failed module is then considered. The in-cell portions of these systems are subdivided into modules based on perceived failure frequencies and the availability of simple mechanical interfaces that can be remotely made. Module interfaces that require complex adjustments, alignments, or calibrations are avoided where possible.

Incorporated into the design of the module are special handling features to simplify and facilitate remote handling. These features are standardized to the highest degree possible in all process equipment designs to simplify in-cell maintenance and reduce the number of special tools required.

Remote maintenance and other operations that were deemed to be routine, or "tried-and-proven" hot-cell technology, were not demonstrated remotely. However, the components and features of the systems that had questionable or unknown reliability or functional capability were remotely demonstrated and were designed to be as prototypic as possible. A number of components were excluded from the maintenance demonstration because they were in one of the following categories: (1) nonprotypytic of final design, (2) facility specific and not appropriate for future application, (3) equipment items primarily having a structural or passive function, or (4) similar in design to an item already demonstrated.

DESIGN REQUIREMENTS FOR RDS AND RSS

The designs of RDS and RSS were based on the throughput necessary for operation of a proposed nuclear fuel reprocessing facility called the Hot Experimental Facility (HEF). The HEF flow sheet called for a throughput of 0.5 metric tons/d of heavy metal with the capability to scale up to 5 metric tons/d. The criteria also called for the ability to handle any U.S. commercial reactor oxide-type fuel such as light water reactor (LWR) fuel, fuel from the Fast Flux Test Facility, the proposed Clinch River Breeder Reactor, and the proposed Prototype Large Breeder Reactor.

THE REMOTE DISASSEMBLY SYSTEM

The RDS was designed to meet ORNL's system design requirements by Westinghouse Advanced Reactors Division of Madison, Pennsylvania, and built by Pennsylvania Tool and Gage of Erie, Pennsylvania. It was installed in the ROMD facility in 1984 and subsequently tested for remote operation.

The function of RDS, shown in Fig. 4, in a nuclear fuel reprocessing facility is to remove the nonreprocessible hardware from the fuel assembly before the fuel bearing portion is sheared into segments and sent to the dissolver. The RDS accomplishes this through the use of a high power (9 kW) continuous wave CO_2 laser and laser beam transport system as a metal cutting device. The operation of RDS, using a ducted Liquid Metal Fast Breeder Reactor (LMFBR) fuel assembly as an example, would be as follows: (1) receive the assembly in a vertical orientation, (2) rotate the assembly to a horizontal position, (3) capture the ends of the fuel assembly, (4) remove the flow duct from the fuel bearing portion of the assembly by making circumferential and longitudinal slitting laser cuts, (5) remove the coolant inlet nozzle from the assembly by making a laser cropping cut through the fuel rod end caps at the attachment rails, (6) discard the removed parts in appropriate waste receivers, (7) deliver the disassembled bundle of fuel rods to the shear feeder, and (8) feed the fuel to the shear in small increments. As shown by the previous discussion, RDS is a mechanically intensive system that consists of many devices which have a limited life and which must be remotely replaced. The RDS is divided into ten subsystems: (1) fuel upender, (2) inlet disposal module, (3) fuel rotator, (4) laser beam transport, (5) laser focusing head, (6) debris collection, (7) shroud disposal hopper, (8) fuel transfer table, (9) shear feed enclosure, and (10) shear feed pusher. All of the subsystems except (6) and (7) were either completely or partially disassembled and reassembled remotely.

THE REMOTE SHEAR SYSTEM

The RSS was designed at ORNL and built by Hunt Valve Company of Salem, Ohio. It was installed in the ROMD facility in 1984 and subsequently tested for remote operations. As previously mentioned in the design requirements section, the shear was designed to be a very versatile device capable of segmenting many types of LWR and LMFBR fuels. This versatility drove five parameters in the design: (1) the necessity for three independent tools, a compactor, a gag, and a shear; (2) a large force capacity, a 1.8-MN (200-ton) compactor, a 0.9-MN (100-ton) gag, and a 2.7-MN (300-ton) shear actuator; (3) fast operation, 3 cycles/min; (4) long actuator strokes, 15 cm (6 in.) for the gag and compactor and 61 cm (24 in.) for the shear actuator; and (5) rapid tool change capability to accommodate the different fuels.

Fig. 4. Remote disassembly system.

In order to achieve total remote maintainability of the in-cell mechanical system, the traditional method of through-the-wall push rods was abandoned in favor of a "works-in-a-box" approach. This "box" is shown in Fig. 5 along with the removable modules of the shear. The advantage of this architecture is the elimination of a dynamic cell wall penetration that reduces seismic constraints, eliminates contact maintenance of through-the-wall shaft, its bearings and seals, and allows freedom of shear placement within the cell. The disadvantage of in-cell actuators is the relatively low resistance of hydraulic oil to ionizing radiation. This was overcome through the use of High Water Base Fluid (HWBF), which is made up of 95% water with 5% synthetic additive in the in-cell actuators. Although the degradation of HWBF due to ionizing radiation is about the same as petroleum-based hydraulic fluid (10^8 rad), its volume can be significantly reduced for disposal after a fluid change. Also, the mechanism of degradation is markedly different for HWBF as compared to hydraulic oil. Where the petroleum-base hydraulic fluid forms a gummy residue, which tends to clog valves and control mechanisms, the HWBF additives break down the high molecular weight molecules and lose some of their lubricating properties,[4] but it does not gum up the works. All of the remotely removable modules are vertically accessible with the hinged covers open. This is necessary because most of the components of the shear are quite heavy and cannot be handled by a manipulator without the aid of a hoist.

MAINTENANCE TOOLS

The tools required for these tests were general purpose tools which are commonly used for maintenance of other in-cell equipment. Fastener operations were performed using impact wrenches. Impact wrench operations were primarily performed using the M-2, but in a few cases on the shear they were performed using an impact wrench suspended from a primary bridge hook where M-2 access was limited. Lead screw operations on the shear were performed with a 3/4-in.-drive ratchet

Fig. 5. The removable modules of RSS.

wrench. Torquing operations on the shear were performed with a 3/4-in.- or 1/2-in.-drive torque wrench. Fastener torque requirements on the shear ranged from 68 to 340 Nm (50 to 250 lb ft). The following tools were used for fasteners on RDS:

1. 1/2-in.-drive electric impact wrench, M-2 operable
2. 1/2-in.-drive 8-in. long extension
3. 1/2-in.-drive by 3/4- and 13/16-in. sockets

The following tools were used for fasteners on the shear:

<u>Wrenches</u>:

1. 1/2-in.-drive electric impact wrench, M-2 operable
2. 1/2-in.-drive manual torque wrench, 0 to 175 lb ft
3. 3/4-in.-drive electric impact wrench, M-2 operable
4. 3/4-in.-drive electric impact wrench, hoist operable
5. 3/4-in.-drive ratchet wrench
6. 3/4-in.-drive manual torque wrench, 0 to 600 lb ft

<u>Sockets and extensions</u>:

1. 3/4-in.-drive 15-in. long extension
2. 3/4-in.-drive by 3/4-in. hex key
3. 3/4-in.-drive assorted sockets from 1 1/8 to 2 1/2 in.
4. 1/2-in.-drive 6-in. long extension
5. 1/2-in.-drive by 5/8- and 3/4-in. hex keys
6. 1/2-in.-drive by 3/4-in. socket
7. 1/2-in.-drive by 3/4-in. drive adaptor

Most of the modules of RDS were lifted and transported using the M-2's 227-kg (500-lb) capacity auxiliary hoist, or simply by the slave arms themselves, which have a capacity of 23 kg (50 lb) each. Some of the modules of RDS were large enough to require the use of the overhead trolley hoist. Conversely, most of the modules of the shear were lifted using the 9-metric-ton (10-ton) lifting fixture attached to one of the overhead trolley hoists. The shear slide required the use of a 4.5-metric-ton (5-ton) self-leveling beam. Modules exceeding the lifting capacity of the M-2 auxiliary hoist, but weighing less than 454 kg (1000 lb), were lifted using a 1-m (3-ft) extension hook mounted to the load block of one of the overhead trolley hoists.

REMOTE MAINTENANCE PROCEDURES

The remote maintenance tests of RDS and RSS were performed under simulated remote conditions. These tests were exclusively performed from the ROMD control room by a two operator team using the M-2 manipulator, its auxiliary hoist, the gantry bridge crane, and the CCTV system. An observer was stationed at the work site during operations with an open channel of communication to the control room for safety purposes only and was not allowed to "coach" or assist operations. Test data and video recordings were collected by the two control room operators in addition to their performing maintenance operations. Data collected fc: these operations included the total time required, to complete removal and replacement of a module, video recordings of all test operations, the tools required to complete the operations, and general comments and observations of the test operators and engineer observers. For removal, timing began with the maintenance system located in the general vicinity of the work equipped with the necessary tools and lift fixtures and ended once the component had been transported and released in the set-down area. For replacement, timing began with the maintenance system located in the general vicinity of the set-down area equipped with tools and lift fixtures and ended once the module had been released from all rigging and completely installed. Timing of operations that did not require a module removal or replacement, such as an adjustment operation, began with the maintenance system located in the general vicinity of the operations, equipped with tools, and ended once the operations had been completed.

The RDS was disassembled and reassembled by subsystem with all modules of a subsystem being removed then replaced to complete the remote maintenance testing of a subsystem. The shear was completely disassembled, module by module, down to the bare housing and then completely reassembled.

RESULTS

The remote maintenance testing demonstrated that RDS and RSS were well designed for remote maintenance. All of the remote maintenance operations that were planned were performed with the exception of one operation on each piece of equipment. The one on RDS was the installation of the debris hood actuator, which required an extra hand to complete. In this case, the alignment of the linkage with the actuator required one arm of the M-2 on each part, which left no remaining method of insertion of the locking pin. The one on the shear was the installation of the lower roller modules. These are located in the bottom of the shear housing between the stiffener ribs. This presented accessibility and viewing problems for the M-2. The problem was that the locating pins could not be engaged. This could have been solved by better gross alignment guides, which would have guided the module to its locating pins upon lowering it into place. The inability to complete these two required operations represents only 1.6% of the operations performed during these tests. A listing of the remote maintenance operations and their completion times along with an assessment of the remote accessibility and view-ability and the general difficulty of each operation is available from the authors upon request.

CONCLUSIONS AND RECOMMENDATIONS

The following recommendations are documented so that they might benefit similar projects in the future. Some of the recommendations are specific and may require further background knowledge. It should be acknowledged that some of these recommendations are maintenance system related (i.e., different comments may have resulted if the remote maintenance operations had been performed with a different type of manipulator). First and foremost, as was the case with both RDS and RSS, the design of any piece of equipment to be remotely maintained should be in compliance with the guidelines presented in the Design Guidelines for Remotely Maintained Equipment.[5] The following recommendations, specific to RDS, should be considered in the design of future systems:

1. Electrical Connectors: Wiggins quick-disconnect connectors were utilized because they were the best available at the time of design. Better remote connectors are available and should be considered.
2. Connector Spacing: In a number of cases in the RDS design, where several connectors were located in the same vicinity, a connector plate was utilized. The spacing on the plate was inadequate to conveniently access the individual connectors.
3. "T" Handling Devices: When the RDS was designed, it was thought that maintenance would be done with a PaR-type power manipulator and that the "T" handling devices were appropriate. However, using a force-reflecting servomanipulator that employs an auxiliary hoist with a hook requires difficult rigging to lift the "T" handles. They should be replaced with lifting bails aligned with the center of gravity of the modules.
4. Cabling Systems: Two different cabling systems were utilized in the RDS design; a festoon system and a cable wire-way system. The festoon system, supplied with the fuel rotator, required more space and in some cases restricted the movement of the M-2 and made it difficult to handle. The cable wire-way system supplied with the shear feeder is a superior system.
5. Alignment Devices: Alignment of components is an important point when performing remote maintenance. The RDS design provided locating pins for most operations; however, these pins were small and difficult to see. When using locating or alignment pins for proper assembly of mating parts, an evaluation of each application should be completed to determine spacing, number, diameter, length, viewing, and location of gross alignment guides to assist in engaging the pins. This will facilitate easy engagement and prevent ratcheting or misalignment locking.
6. Spring-Loaded Captive Fasteners: Almost all remote fasteners employed in RDS were spring-loaded and captive with a minimum number of standardized bolt head sizes. Maintenance experience of systems with these fasteners was extremely good; therefore, a similar design should be adopted as a standard in future systems.

The following recommendations are specific to RSS but should be considered when designing similar hot-cell equipment:

1. Captured Fasteners: The floating nut technique of capturing fasteners used throughout the shear performed poorly. The floating nut seldom engaged with the bolt, and galling was experienced in one case when the nut did engage. Future designs should employ the spring-loaded captured fasteners.
2. Gross Alignment Guides: These guides should be used whenever possible, particularly for modules that are not easily accessed, positioned, or viewed under remote conditions. Installation of the lower roller modules would have been successful with the application of simple gross aligning guides. Recognizing that such guides are not always possible, visual cues to proper alignment should be utilized. Incorporation of more alignment guides and/or marks would have greatly increased the efficiency of shear maintenance operations. Also, modules that do not utilize fasteners to achieve positive positioning and that do not have easily identifiable features to check for proper positioning should include some form of alignment and positioning verification identifier. Examples of such components specific to the shear include the side rollers, upper vent barrier, and hydraulic actuators. Clearly visible visual indicators should be considered here. Good self-alignment features are doubly important for these types of modules and should be stringently reviewed.
3. Remote Torquing: Development or adaptation of a power tool for remote nut-running and torquing operations is necessary for applications where an impact wrench cannot be used. Many shear maintenance operations would be speeded significantly with the elimination of manual wrench operations. Such a tool would have a broad application to in-cell maintenance, in general, provided that torque and speed could be varied and precisely controlled.
4. Fastener Tools: Remotely operable, positive locking sockets and drive extensions are needed and should be adapted from commercially available tools, or developed if necessary. The

ball-detent type of engagement used during these tests frequently disengaged during maintenance operations. This can result in the loss of a tool into an area that could cause equipment damage if not retrieved.

5. Lifting Load Information: Sharp edges between adjacent tight fitting modules should be avoided or beveled where possible to prevent interference during removal and replacement operations. This is particularly important when no form of force feedback is available and the lifting device capacity is substantial. Visible control of crane capacity or loading information feedback to operators would be very useful during maintenance operations and could reduce the risk of accidental equipment damage.
6. Clearance: The potential for binding at module interfaces should be minimized by maintaining clearances as large as reasonably possible. Interference fits must be avoided.
7. Remote Viewing: Although CCTV viewing is seldom optimal, a more flexible choice of camera viewing positions could significantly improve the maintenance system capabilities and efficiency. Use of small portable cameras that can be positioned independent of the maintenance system would be very useful.

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