Use of Tank Retrieval Manipulator Systems in Nuclear Decommissioning – 11353

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ABSTRACT

Over the past 2 years S.A. Technology (SAT) has designed and built two long reach manipulators called the Rotary Deployment Arm (RDA1 and RDA2). Led by a design and manufacturing team of SAT resources, the project has been a challenging yet exciting one for SAT. The RDA offers many benefits to the nuclear industry by providing a highly capable and versatile solution for incredibly difficult tank retrieval dilemmas. With a surplus of tank cleaning opportunities around the world, the RDA will help SAT come closer to its goal of becoming a world leader in advanced tank cleaning technologies.

The main purpose of the RDA will be to retrieve a variety of tank waste at Magnox's Trawsfynydd Decommissioning Site in Wales, UK. The RDA is designed to complete a variety of clean up tasks within four main areas on site including the Resin Vaults (RV2 and RV3), Main Sludge Vault (MSV), and Pond North Void (PNV). All of these tanks have different size and technical constraints making it difficult to design a single solution that could meet each areas requirements.

The purpose of this paper is to provide a description of the RDA, its current application and explain how its versatility is applicable throughout the nuclear industry.

INTRODUCTION

The use of advanced technologies such as remote manipulators for operational and decommissioning purposes is becoming more common throughout the nuclear industry. As it stands today, the methods and processes used to remove bulk nuclear waste are relatively straightforward at most nuclear facilities around the world; however a significant amount of waste remains in underground storage tanks with limited access and safety provisions making it difficult to be removed. One tool that has seen increased interest for these types of situations is remote manipulators. However, most commonly used off the shelf remote manipulators are built for a specific need and are limited in capabilities and versatility. Therefore, a need was identified within the nuclear industry for an all-in-one manipulator with increased capability, versatility and reliability for decommissioning purposes.

S.A. Technology is an engineering company which specializes in the design, fabrication and deployment of remote manipulators. The RDA system is one of the most recently developed manipulators at S.A. Technology that meets the industry's capability, versatility and reliability needs. This arm is compact, durable capable of multiple uses and will continue to be highly instrumental in the nuclear decommissioning industry while decreasing operational risk and increased safety.

Figure 1 - RDA during factory acceptance testing, using a bulk suction tool to remove simulated tank effluent

TECHNICAL APPROACH OF THE RDA SYSTEM

The RDA is designed to be easily moved from tank to tank, through existing plant rooms and doors. The size and configuration of the RDA had to consider a multitude of plant room constraints including limited head room, access in and out of doorways, existing plant room equipment, and penetration locations. During deployment and retrieval, the RDA follows a specific cam path allowing the manipulator to travel vertically down a penetration.

The RDA, its ancillary equipment and all equipment associated with its control system, are easily transportable allowing the RDA to operate and deploy a range of tools in the following voids and tanks: PNV, MSV, RV2 and RV3 (see Table I for a summary of each tank/void). The purpose of the RDA is to facilitate those operations necessary to remove all remaining waste inventory and clean the internals of the tanks to a suitable level to permit the tanks to be dismantled and removed from the site. All the tanks are located inside shielded vaults with penetrations accessible through corresponding ports in the shielded floor of plant rooms situated directly above. The vaults and plant rooms are designated as radiation controlled areas. The tanks / voids variously contain ion exchange resin, sludge, effluent and other products.

TABLE I: SUMMARY OF TANK PARAMETERS

	RV2 and RV3	MSV	PNV
Construction	Cylindrical, stainless steel tank	Rectangular, carbon steel tank	Rectangular, concrete tank
Inner Dimensions	15.4ft diameter x 15.7ft deep	20.3ft long x 7.87ft wide x 17.4ft deep	25ft long x 9.84ft wide x 20.3ft deep
Access	Top Access, 250mm diameter central penetration	Top Access, 700mm x 600mm central penetration	Top Access, 300mm diameter off-center penetration
Tank Contents	Effluent (filled to 4m depth), ion exchange resin and sand	Effluent (partially filled), sludge, and concrete cores	Effluent (partially filled) and sludge

To accomplish this, the RDA allows the attachment of a number of customized tools that are maneuvered within the tank to carry out several operations. One example is the RDA's capability of removing bulk ion exchange material and sand using a suction tool while being fully submerged up to 13 ft in effluent. This has made the RDA a valuable system for deployment into the vaults and tanks which commonly are filled with sludge and liquids.

SYSTEM OVERVIEW

The RDA is capable of being deployed through penetrations of 10 in and larger in diameter; has a vertical reach of 32 feet and a horizontal reach of 15 feet when fully extended. The RDA consists of mast and forearm assemblies, which are constructed from carbon fiber and stainless steel components, as well as electromechanical and hydraulic components to provide actuation. These mast and forearm assemblies reside inside the tanks during operations. At the plant room floor level, the RDA is mounted to a carriage, which allows the RDA to be deployed into and retrieved from the various tanks and provides cable management for the variety of required services. The RDA and its carriage are mounted to a stationary support frame, which provides containment for operation, wash down, and transportation. The frame itself is mounted to each of the plant room floors during operations. In its retrieved state, the RDA fits completely within the support frame. The RDA system includes a hydraulic skid, electrical enclosure and control system to provide motive power and control. Figure 2 below demonstrates the RDA removing simulated waste for a tank floor.


Figure 2 – RDA simulated waste removal test

Mast

The mast consists of four telescoping carbon fiber tubes, with a single stationary tube attached to the carriage of the support frame. The telescoping mast extends by gravity and is retracted using dual electrically driven wire rope hoists. These wire rope hoists position the mast along its stroke, as desired by the operator. The distance of the mast extension is measured by a string encoder mounted to the carriage. The mast rotate is operated by an electric geared motor attached to a turntable bearing, and uses a resolver for position feedback. The mast rotate is capable of 360º non-continuous motion.

All cables and hoses for the actuations of the RDA are run internally to the mast. The cable management for the mast is accomplished using an external tensioned reel system that is attached to the carriage. The mast includes a redundant wire rope hoist for failure recovery. Each of the two hoists is capable of retracting the mast on its own in the case the other one fails. The mast tubes are equipped with dual keys and matching key slots in the bushings to keep the sections from rotating independently. Polymer bushings between the carbon fiber sections provide a low friction surface for extension/retraction, and are designed with slots to allow wash down water to flow through them and remove contaminated material during retrieval.

Elbow

The elbow is a two stage actuation allowing for a total of -10 to +180º of motion from vertically down. The mast side stage of the elbow allows for 90º of motion, to allow the elbow linkage to be oriented down or horizontal. The forearm side stage of the elbow allows -10 º to +90º of actuation. The combination of these actuations allows the RDA to reach vertically to the tank ceiling, horizontally to the tank extents, and over-center downwards to achieve full cleaning. Each stage is actuated using a single hydraulic cylinder, and each pivot pin incorporates a resolver for position feedback.

Forearm

The forearm consists of two telescoping carbon fiber tubes, and a stationary stainless steel tube. The telescoping forearm extends and retracts using two hydraulic cylinders internal to the tubes, which are ported together to allow them to actuate at the same time. The cylinder rods themselves are hollow to minimize the number of hydraulic lines required to run through the forearm.

The extension of the forearm is measured using a string resolver mounted inside the forearm itself. Cable management is accomplished using an internal cable chain. The telescoping tubes themselves are equipped with dual keys and matching keyways in their polymer bushings to keep them from rotating relative to one another. The bushings have slots machined into them like the mast bushings to allow wash down water to flow through them.

Inside the forearm, at the interface between the forearm and the wrist, a load sensor is included to detect any contact that the arm may encounter with the tank internals. This load sensor is a six axis sensor capable of relaying the direction and magnitude of the impact back to the operator at the control station.

Wrist

The wrist consists of two separate actuations; a wrist pitch and a wrist roll. A camera and LED lights are mounted on the wrist. The camera and lights are stationary with relation to the Gripper, and rotate with the wrist roll. The wrist pitch is actuated using a hydraulic rotary actuator for $\pm 90^{o}$ of motion in the vertical plane. The wrist roll utilizes a hydraulic rotary actuator, and is capable of 180^{o} non-continuous rotation. In the event the wrist roll actuator failed it would not cause any issues with recovery of the manipulator.

Gripper

The main purposes of the gripper are to hold the tools imported into the tanks/voids, and to perform various tasks associated with picking and placing small items in the tanks. The maximum gripper jaw opening is 4.72in and the jaws are attached to a linkage to ensure they remain parallel during opening and closing. The gripper is hydraulically actuated and has a gripping force sufficient to hold the maximum 132.3lb payload. To accommodate attaching the tooling in different orientations, there is a matching interface between the jaws and tool attachments. In the event of a hydraulic failure, the gripper will fail in its “as-is” position. If pressure is lost the jaws will become compliant and able to move if a load is applied to the jaws. A reduced stroke piston is used in the smaller penetrations of RV2 and RV3, keeping the gripper from opening to a size greater than 9.02in. All RDA components intended to fit through the penetration have been designed to fit within a 9.02in diameter passage. This is an internal SAT constraint to ensure passage through the 9.45in RV penetrations. When the gripper is operated with the reduced stroke piston, the jaws are limited to ~2.36in opening.

Wash-down

The RDA design includes an integrated wash-down system that is designed to remove contaminants from the manipulator during retrieval from the tanks/voids. The wash-down system consists of three separate wash rings located within the RDA which allow pressurized water to be sprayed onto the RDA surfaces. During retrieval, each of the three wash rings (one at the top of the mast, one at the bottom of the mast and one inside the forearm) are pressurized in a series of steps to insure full cleaning of all components. A water supply of approximately 94.27 psi is required to run the wash-down system. The electrical components attached to the manipulator that will be going into the tanks/voids will be IP 68 or higher to protect against the liquids in the tanks/voids. All electrical components mounted in the frame are rated to IP 64 or higher to protect them from overspray. All overspray and over flow water is caught by the frame containment covers and drains out the bottom of the wash pan and into the penetration. In the event of a drain blockage a float will automatically shut off the wash water.

Hydraulic Power Unit

The RDA hydraulic power unit provides motive power for all hydraulic actuators associated with the RDA manipulator including: both elbow pivots, the forearm extend, the wrist pitch, the wrist roll and the gripper open/close. The hydraulic power unit supplies hydraulic oil to all the hydraulic actuators at a maximum pressure of 2.9 ksi and a maximum flow rate of 3.96 gallons per minute. A graduated hydraulic tank provides leak detection by monitoring its hydraulic fluid level. This design is capable of detecting very small changes in fluid level and prevents a hydraulic leakage of more than 1.06 gallons to any vault.

Controls

The RDA is provided with a local and remote Human Machine Interface (HMI) which provides the operator control of the RDA. The remote HMI will be used for normal operations, and will include joint-by-joint actuation as well as inverse kinematic actuation. Inverse kinematics allows the operator to control the gripper/tool position, and the control system will determine the joint movements to achieve that position. The local HMI is used for deployment, retrieval, tool change and maintenance activities. Figure 3 below shows the remote HMI controls for the RDA system.

Figure 3 - Remote Human Machine Interface

Cameras/Viewing

Two cameras are provided with the system for viewing of the RDA during operations. A fixed camera is mounted to the Gripper to allow a close up view of the gripper, and a pan-tilt-zoom camera is mounted at the top of the tank/void to allow for an overview of the tank. The pan-tilt-zoom camera is attached to the tank separately from the RDA. In addition to the cameras, lighting is provided at each camera position. The operator is able to view the output from these camera systems at the remote HMI.

Payload Capabilities

As seen in Figure 4, the integration of carbon fiber technology minimizes the overall weight of the RDA while retaining a high payload capacity. The payload capacity of the RDA is from 100 lbs at full reach to 132 lbs in specific orientations.

Figure 4 - RDA system in testing and its payload capabilities.

Deployment Overview

The RDA utilizes a frame installation cart to assist with transporting into the plant rooms. The installation cart allows the frame and manipulator to be laid down on its side, and also includes a manually-actuated four bar linkage which allows the manipulator to be moved from a horizontal to a vertical orientation. When in the horizontal orientation, the reduced height allows the RDA to be pushed through standard door openings as required for installation. Once in the plant room, the installation cart four bar linkage can be actuated using a hand pump to power the two onboard hydraulic cylinders. When the frame is in the upright position and located over the penetration, the installation cart can be removed and the frame anchored to the plant room floor.

For deployment, the manipulator uses an overhead A-frame gantry beam and chain falls provided with the system. Alternatively, existing plant room lifting equipment can be used if available. During deployment and retrieval, the RDA carriage will follow a specific cam path allowing the manipulator to travel vertically down the penetration as it is lifted with the chain falls. Figure 5 below shows the small footprint of the RDA equipment as well as the unique deployment method that will be used on each of the tanks.

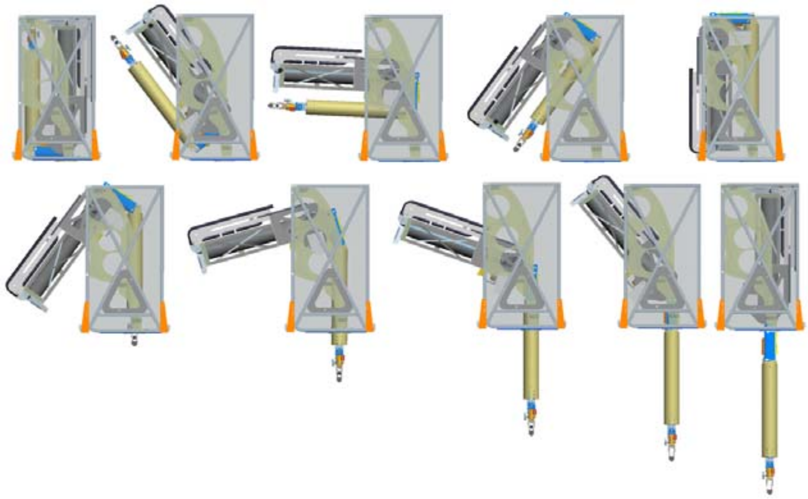

Figure 5 - RDA carriage will follow a specific cam path

Tooling

The RDA provides a means of deploying tooling and tooling cable management. The tooling is deployed in each tank/void through penetrations offset from the manipulator penetration. The tools and umbilical lines are carried to the tank room by hand, and transported in commercial storage containers. The tools are attached to a wire rope, which is used to lower the tool into the tank, and subsequently retrieve it. This wire rope is kept on a spring tensioned spool, which can also be driven in and out by hand crank. The umbilical is attached to the wire rope at one or more places, providing management of the umbilical line. The wire rope spring reel is provided in several tension ranges, to adapt to various tool and umbilical weights. The wire rope reel assembly is placed into the penetration enclosure for RV tanks, and onto an adapter plate for MSV and PNV tanks.

The tooling is attached to the manipulator using the gripper. Each tool has a mounting interface that allows it to be attached to the gripper in several orientations. For each tank the tool will be lowered into the tank through the specified penetration using the wire rope. Once the tool is attached to the gripper the wire rope will be spring tensioned, and pulled out by the RDA as needed. A CAD model of the deployed RDA and tool rack can be seen below in Figure 6.

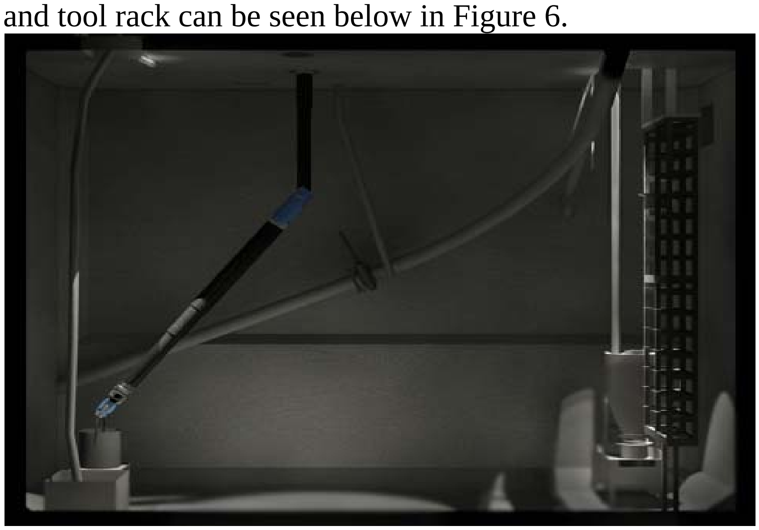

Figure 6 - RDA deployment into PNV

MAJOR BENNEFITS TO THE NUCLEAR INDUSTRY

The nuclear industry has begun to fully embrace remote manipulators as a viable solution to seemingly impossible decommissioning projects. The technology has proven itself through development and testing in increasingly more complex applications. The RDA system meets the requirements for an established, reliable, and effective solution while maintaining the overriding principles of safety necessary in the nuclear industry.

No Impact on Surrounding Infrastructure

The small carriage and installation cart allows the RDA system to be installed and deployed in extremely tight quarters without impacting the infrastructure. Most manipulator deployments require heavy machinery and open areas to operate and install the equipment. However, the installation cart allows for the RDA to be pushed through small doorways and around obstructions that would otherwise prevent a remote manipulator installation or deployment. Doorways do not need to be modified and walls do not need to be removed to install the RDA system. After the arm has performed its function, it is washed down, retrieved from the tank and removed from the site on the installation cart the same way it was installed. These capabilities make a seemingly impossible and very expensive project into a cost effective success.

Ease of Deployment

The RDA system is relatively straightforward to deploy and does not require expensive or specialized tooling. During deployment and retrieval, the RDA carriage will follow a specific cam path allowing the manipulator to travel vertically down the penetration as it is lifted with the chain falls. The deployment requires little physical exertion and can be done in a safe and controlled manner.

Improved Working Environment

The nuclear decommissioning environment is risky and thus a safe working environment is always paramount. In an attempt to mitigate risk and maintain safety, new and custom equipment is cautiously used in nuclear decommissioning. Tank cleaning operations further compound safety risks because of the obstructions leading to and surrounding the tanks penetration points. The RDA system addresses these concerns and improves the working environment. The system is small and mobile, making it easy to transport and install on the work site without making costly modifications to the building structure. Deployment is done manually and reduces the likelihood of damaging building structures or surrounding equipment. The RDA can be controlled by both a local HMI and remote HMI. After completing the tank cleaning, the versatile RDA is retrieved from the tank then relocated to another site to clean another tank. The RDA system improves the work environment through its safe and easy installation, deployment and operation while successfully cleaning and decommissioning previously unattainable sites.

CONCLUSION

While reactor decommissioning remains challenging, new technologies and techniques continue to simplify the decommissioning process, and worker safety continues to be improved by the use of remote deployment methods. Using remote manipulator technologies will make future decommissioning safer, quicker, and economical.

The RDA system developed by S.A. Technology offers many benefits to the nuclear industry, providing a highly capable and versatile solution for very difficult tank retrieval problems in our industry. In the end, the RDA has proven to be an amazing product that has become a staple in SAT's robotic arm repertoire.

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