

Remote Water Lance Technology for Cleaning Waste Tanks

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ABSTRACT

This paper describes the use of remote water lances for cleaning sludge or solidified heel materials from waste tanks. S.A.Robotics has developed a long arm retrieval system to deploy ultra-high pressure water lances and vacuum recovery systems for tank cleanup operations. This system uses remote-operated telescoping long arms with light weight, high strength materials, innovative high capacity joint designs, and multiple degrees of freedom to deploy tank cleaning heads to all areas within the tanks. Arm designs can be scaled and adjusted to suit even the largest tanks.

INTRODUCTION

Many waste tank cleanup projects require the removal and processing of stored liquids and years of accumulated sludges, crusty hardened salts, and tightly adherent residues of various consistencies. Water lances deliver controlled jets of water at various pressures and are now considered part of a mature technology for cleaning everything from driveways to boiler tubes. Ultra high pressure water lances and hydromilling heads with nozzles delivering 240 to 480 MPa (30,000 to 60,000 psi) have demonstrated the ability to blast through hardened concrete, without affecting embedded steel materials as illustrated in Figure 1. These properties make this a practical technology for breaking up and removing residual waste materials without damaging tank structures.

S.A.Robotics' tank cleaning system uses long robotic arms to deploy ultra high pressure water lance nozzles to break up tank waste forms and high capacity vacuum removal equipment to remove the resulting debris. This remote cleaning system allows waste tanks to be prepared for future use or permanent closure, without exposing workers to the hazardous environments inside the tank.



Fig. 1. Remote hydrolasing to remove concrete surfaces

DESCRIPTION

The S.A.Robotics system to remotely deploy and operate water lance technologies is based on long robotic arms, powerful hydraulic joints, ultra high pressure (34,000 psi) water lance or hydromilling heads, and easy to use controls. Waste debris is recovered with a vacuum retrieval system that can be connected to a shroud around the water lance heads, or the vacuum system can also be deployed separately.

Deployment System -- Arms

The long arm tank cleaning system uses a telescoping mast with one or more movable arm sections as shown in Figure 2. The arm sections are manufactured from lightweight, high strength wound carbon fiber structural tubing.

The use of composite structural materials allows the development of long robotic arms that are simply not practical with traditional metal structural beams. The most critical factor in designing effective long reach manipulators is minimizing distributed weight along the arm's length. However, this must be accomplished while maximizing torque density of the arm's joints and structural stiffness and load capacity. Manipulators created from metal are fundamentally limited in capacity by the nature of metals. In nearly all structural metals the stiffness-to-density ratio is nearly identical. This basic material property limits the optimization that can be accomplished when designing alloy manipulators.

Composite materials are not governed by this limitation. S.A.Robotics uses wound carbon fiber beams as the structural members in our manipulators. The use of composites allows two main gains. The first is an exponential gain in load bearing capacity per unit weight of beam. Carbon fiber structural beams have approximately 1/5 the weight density of steel and can exhibit only 1/16 the deflection as steel beams. The second advantage is that carbon fiber does not have the same material properties in all directions. The way in which the material is created can dramatically change how the material behaves. This allows engineers to design the material properties they desire into the manufactured part and offers an additional potential weight reduction. These material properties allow high loads with lightweight arms.

The robotic arm shown in Figure 2 includes a telescoping mast, movable bicep, movable forearm, and powerful hydraulic joints that provide six degrees of freedom. The tank cleaning arm can also include telescoping bicep and forearm sections to deploy water lance equipment into all areas of the tanks.

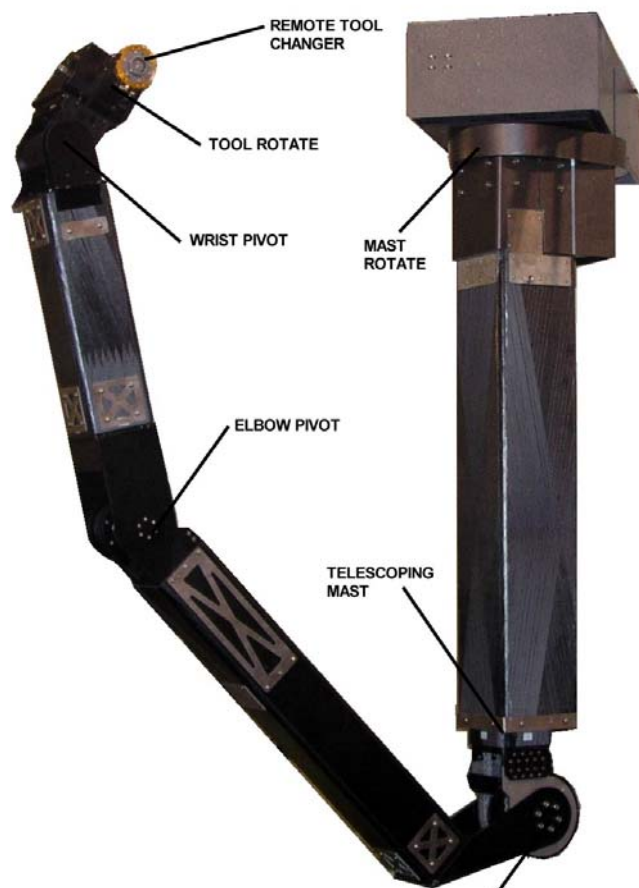


Fig. 2. Long arm with multiple degrees of freedom

Carbon fiber structural tubing sections are hollow and this provides a pathway so that all service lines and cables can be routed inside the arms. Electrical power cables, signal wires, and hydraulic tubing are controlled inside the arms as part of a complete services management system. This avoids kinking, twisting, and excessive bending of these lines and cables and enhances system reliability.

Deployment System – Joints

Another important technology in the long arm tank cleaning system is the proprietary hydraulic joints. When designing manipulators the torque that must be created to drive the joints can quickly become very high as longer and longer arms are contemplated. Typically this problem is solved by actuating arms with external cylinders that allow a mechanical advantage to be gained by driving the joint away from the center of rotation. This is typical of almost all large equipment such as backhoes. The approach has two basic problems.

- The first is that it makes the joints cumbersome because the cylinder is external to the joint and creates a triangular support. This is fine for operations in open spaces but when arms must be deployed through small spaces this becomes a major space problem.
- The second reason this design is problematic is that the rotation of this type of joint is limited. Typical external cylinder joints don't work well outside of 90° actuation. With clever use of additional lever arms, this value can be increased but with rapidly decreasing mechanical advantage.

To solve these problems S.A.Robotics designed hydraulic joints that are integrated inside the structural beams of the arms. These joints streamline the arm for work in tight spaces. These joints also allow unlimited rotation with no change in rotational force. The design is scalable and is used in joints as small as 75 mm (3 inches) square. It is also easily scaled up and versions with drive torque capacities as high as 11,000 kg-m (1,000,000 in-lbs) have been designed. The torque density (torque per unit weight) of these joints is more than double that of existing rotary hydraulic actuators.

The flexibility of robotic arms is determined by the number and type of joints and the amount of extension provided in telescoping sections. For example, the hydrolasing arm shown in Figure 2 was built to access all interior surfaces of the Hanford K-Basins and has six degrees-of-freedom, as follows:

- 360° mast rotate joint
- Vertical telescoping extension
- 180° shoulder pivot joint
- 180° elbow pivot joint
- 180° wrist pivot joint
- 360° tool rotate joint

For smooth extension actions, ultra-high molecular weight (UHMW) polyurethane guide blocks are used in telescoping sliding sections. UHMW demonstrates excellent radiation resistance and frictional wear characteristics.

Deployment System – Controls

The operator can control the long arm tank cleaning system using programmable logic controllers (PLCs) and easy-to-use joystick controls as shown in Figure 3. The operator can observe waste removal operations by using video images from digital cameras located inside the hot cell and displayed on monitors at the control station. Several cameras are typically used with pan-tilt-zoom functions, work

area lights, and independent joystick camera controls. Visibility at the work surface can be enhanced by powerful vacuum recovery equipment which can be connected to a shroud around the blast nozzles or can also be introduced separately.



Fig. 3. Typical control panel

Water Nozzle Heads

Ultra high pressure water lances and nozzles are commercially available. These are mounted to tool changer connections at the end of the arm, as shown in Figure 2. In addition to water lances, ultra high pressure hydromilling heads are also deployed from long robotic arms and are used to break up residual wastes and clean tank surfaces.

Hydromilling heads include an array of nozzles on a rotating bar or disc as shown in Figure 4, and cover a wider surface area than water lances and could provide faster cleanup, depending on the consistency of the waste form. The nozzles rotate at approximately 1000 rpm and are positioned approximately 25 mm (1 inch) from the waste surface. The head shown in Figure 4 is similar to the head used to remove the surface layer of a concrete pad as shown in Figure 1.



Fig. 4. Hydromilling nozzles mounted inside vacuum recovery shroud

Debris Recovery

High powered vacuum systems are effective for removing waste debris in addition to the water added by water lance or hydromilling operations. Vacuum systems can be deployed in several ways depending on the tank configuration. They can be managed independently of the water lance to remove waste and water in a sluice arrangement, typically from a low point in the tank. As shown in Figure 4, vacuum recovery equipment can also remove water and debris from a shroud mounted around the blast heads. The shroud has the advantage of removing materials before they get dispersed throughout the tank, thereby enhancing visibility within the tank. Vacuum recovery shrouds around hydromilling heads have been demonstrated effective in both underwater and air environments. In underwater applications, concrete removal was performed without clouding the water around the shroud. Also, in a typical air environment, hydromilling was performed within a shroud with no surrounding cloud or escaping water.

Processing

After removal from the tank through the vacuum recovery system, the waste stream passes through a processing and packaging system. The waste stream is remotely characterized to determine its radioactive or hazardous constituents. Characterization will determine whether the waste will be processed as low level or high level radioactive waste and will also determine shielding requirements for the equipment and resulting waste containers. The waste stream will pass through a knock out pot and a liquid separator such as a decanter centrifuge, so that the solid debris may be directed to a dryer or other conditioning equipment to support packaging with minimal handling. Depending on the size of the cleanup effort and the amount of water expected to be used, a water filtration and processing system may be included to allow re-use of the water in the water lance or hydromilling heads.

DEPLOYMENT

Long arm retrieval equipment can be introduced into waste tanks, hot cells and fuels basins through various configurations based on the physical and/or safety basis restrictions. A long arm deployment system with a hydromilling head and vacuum recovery shroud can be installed through a standard 24-inch diameter access hatchway, if one is available. For example, smaller tank access penetrations can use an unshrouded water lance deployed with a long arm system, with a vacuum recovery system installed separately, preferably through another penetration if one is available to support simultaneous blasting and recovery operations. If no suitable access pathway is available, a new tank penetration can be installed, consistent with the facility's design modification process. For underground tanks, an auger and casing system can be used to create a new tank penetration and the equipment required for boring and for installing the long arm cleaning system can be operated from work platforms that minimize loading on the tank dome. Examples of where this type of technology has been deployed and some of the performance data are highlighted below.

Hanford K Basin Hydrolasing: Up to a one inch depth of concrete was removed at a rate of 150 ft²/hr. The hydrolasing head delivered an ultra high pressure steam fully contained in the vacuum shroud. The head was deployed using a telescoping arm having a 3-axis carbon fiber arm that was deployed underneath the existing fuel pool decking. This gantry mounted system was hung through the one and a half inch floor grating slots without any modification to the existing infrastructure thereby maintaining the facility Authorization Basis. Dose rates were immediately reduced by a factor of ten from a single pass of the hydrolasing head.

West Valley Vitrification Cell D&D: lessons learned on this project began upon installation when the local labor force dropped gantry mounted dual arm system. The system had to be repaired and reinstalled under S.A.Robotics oversight. The Remote Manipulator System included Two identical telescoping masts were fabricated from carbon fiber, the arms had 5 degrees of freedom; Shoulder Rotate - 340 degrees, Shoulder Tilt - 180 degrees, Forearm Rotate – 180 degrees, Wrist Tilt - 180 degrees, and Wrist Rotate - 340 degrees. Each mast telescoped to a length of 40 feet with an additional 10 feet of reach with the carbon fiber forearm assembly. Additionally, a 5 degree of freedom high-capacity (1000 pounds at the gripper) forearm assembly was provided to work in tandem with the long arm.

UKAEA Windscale Hydromilling Demonstration: Figure 1 depicts the actual hydromilling demonstration where an ultra high pressure head and shroud were mounted on a Cartesian track managing the x and y axis. The depth of cut was managed effectively by adjusting flow rates. Benefits of the system included the ease of managing the depth of concrete penetration while leaving the rebar intact for purpose of maintaining structural integrity. The amount of slurry waste generated and subsequent waste minimization steps also need to be considered when selecting this technology.

Savannah River F Canyon Tank Sludge Removal: a gantry mounted arm with an ultra high pressure heated (200 Degrees F) water (HPHW) lance was used to breakup and remove a hardened contaminated tank heel. The HPHW was combined with a Vortex Vacuum Recovery system which combines the head rotation, nozzle blast direction, and vacuum air flow in the same rotational direction. This creates a powerful vortex which holds the material inside the shroud and keeps solid material entrained in the air flow. A Submerged Trash Pump Sluicing System was also used to move the tank waste into storage containers.

Degussa Tank Residue Removal: a handheld water lance was used to remove residual adhesives from the interior walls of commercial tank. The 35,000 psi jet stream provided adequate cutting force to remove the dried adhesive to allow reuse of the containment vessel.

CONCLUSION

The long arm remote water lance or hydromilling tank cleanup system, along with a remote vacuum recovery system, allows workers to safely and remotely remove hazardous materials from solidified tank heels, salts, and sediments. The system described in this paper uses proven components and demonstrated technologies to provide a reliable, robust, and versatile robotic system for cleaning waste tanks and preparing them for closeout or reuse. This remote system allows operators to remove the most dangerous materials from the most hazardous environments from the safety of a protected control station.