Powered Remote Manipulators Perform Hazardous Retrieval, Handling, and Size Reduction Operations

M.D. Cole, J.R. Owen, S.R. Adams
S.A.Robotics, Inc.
3985 S. Lincoln Avenue, Suite 100, Loveland, Colorado 80241
USA

ABSTRACT

This paper describes a new lightweight, powered remote manipulator (PRM) that S.A.Robotics has developed for remote material handling and size reduction in hazardous environments such as reactor decommissioning projects. PRMs can be mounted to various deployment platforms such as remote controlled track-driven vehicles, commercial All Terrain Vehicles, or crane-mounted arms. They can also be installed as replacements for traditional Master-Slave Manipulators (MSMs) in hot cells. The PRM is a six degree of freedom manipulator with carbon fiber structural components that can provide up to a 3 meter (10 foot) reach. Either electric or hydraulic power options can be used and a variety of hydraulic fluids are available to meet combustible material limitations. The PRM is operated with easy-to-use joystick controls that allow operators to sit in a comfortable work station and handle 90 kg (200 pound) loads with a hydraulic power pack or 45 kg (100 pounds) with electric servo-motor driven equipment. With a quick disconnect tool changer, the manipulator can operate grippers, drills, shears, saws, sampling and survey instruments, and the arm can also deploy cameras and lights to support a wide range of remote applications.

INTRODUCTION

S.A.Robotics engineers developed a small, light weight PRM that can be easily deployed into hazardous environments to perform retrieval, handling, and size reduction operations. The PRM can be attached to a gantry crane system and operated over a specific work location or it can be mounted to a mobile platform. In addition, PRMs can be installed in hot cells to take the place of manually operated Master Slave Manipulators (MSMs). MSMs have traditionally been used to remotely handle hazardous materials in hot cells and other inaccessible environments, however, their complexity has led to maintenance problems and their capabilities are limited by an operator's strength and dexterity.

The PRM uses high strength arms and a combination of powerful, flexible joints to allow operators to remotely perform tasks such as picking up objects, cutting-up large items, placing items in waste containers, obtaining samples for characterization, performing monitoring, and performing a myriad of operations in hot cell laboratories and other hazardous locations. The use of proven components and straightforward controls combine to make this a versatile and reliable tool for remotely lifting and moving loads in environments that are unsuitable for workers.

DESCRIPTION

The essential features of the PRM are the composite arms, hydraulic or electric powered joints, general use gripper as shown in Fig. 1, an additional set of quickly changed end effectors, power pack, and operator control station, as described below.

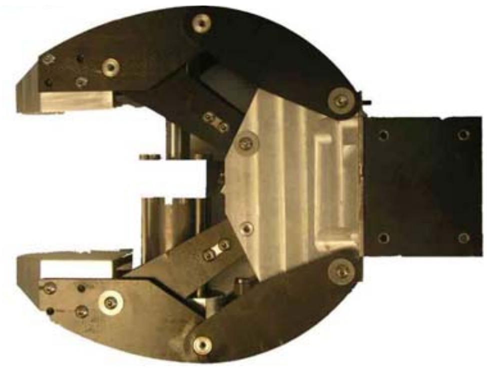

Fig. 1. General use PRM gripper

Arms

As shown in Fig. 2, the PRM includes one telescoping arm section and one fixed length arm section. The PRM can also be provided in various capacities, configurations and lengths from 1.2 meters (4 feet) to 3 meters (10 feet). The telescoping arm section can include up to a 750 mm (30 inch) extension and may be mounted in either arm position. When mounted directly to the shoulder joint as shown in Fig. 2, the telescoping bicep provides extension capability in the vertical direction and would be preferred for most hot cell applications. For mobile mounted arms, the telescoping section could be mounted directly to the wrist joint to provide more forearm extension capabilities when reaching for items.

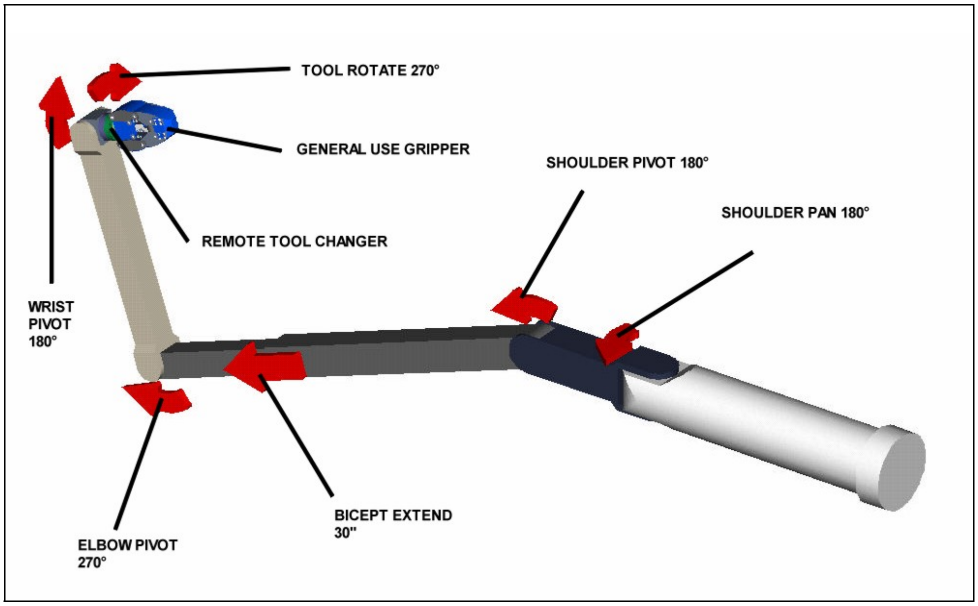

Fig. 2. PRM with six degrees of freedom

The arm sections are manufactured from lightweight, high strength wound carbon fiber structural tubing. Unlike most structural metals, the stiffness of composite materials is not directly proportional to the density of the material. Carbon fiber structural beams have approximately 1/5 the weight density of steel and exhibit only 1/16 the deflection as steel beams. These material properties allow high loads with lightweight arms.

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.

In addition to enhancing service life, routing service connections through the long hollow arms of the PRM also keeps the exterior surfaces clear and easy to keep clean. For hot cell applications, the entire length of the arm and joints are encased in a smooth flexible sheath that provides a barrier to keep contamination out of the arm. This sheath also contains hydraulic fluid leaks and can be easily removed for maintenance access.

Joints

The PRM includes proprietary joint designs to provide strength and flexibility. Joint actuators fit inside the structural tube sections of the arms so that they are not in the way of any moving parts and do not restrict arm motions. This is a significant advantage over external operators such as hydraulic cylinders that are commonly used to operate backhoe-type devices.

For the hydraulic powered PRMs, unique joint drives and rotary actuators have been custom built to provide torques required to handle loads at full extension. The torque density or available torque per actuator weight is more than double that of standard actuators.

Electric powered PRMs use lightweight, powerful 460 volt servo motors to control joint movements. Electric motors do not achieve the same torque density as hydraulic actuators but the use of encoders allows accurate positioning and precision control over arm movements.

For smooth extension actions, ultra-high molecular weight (UHMW) polyurethane guide blocks are used in telescoping sliding sections. UHMW demonstrates excellent radiation resistance. As shown in Fig. 2, the PRM joints provide the following flexibility:

- Shoulder pan 180º (this joint can use a 360º pivot if mounted vertically on a mobile platform)
- Shoulder pivot 180º
- Bicep extend 750 mm (30 inches)
- Elbow pivot 270º
- Wrist pivot 180º
- Tool rotate 270º

These six degrees of freedom and up to 3 meter (10 foot) extension capability provide a full range of motion that allows a wide range of motion. In hot cell applications as shown in Fig. 3, the PRM can access containers, laboratory equipment, and other objects on the floor, work bench, back wall, and most areas in the hot cell.

End Effectors

The PRM includes a quick disconnect tool changer at the end of the wrist joint. A general use gripper as shown in Fig. 1 is the standard PRM tool. The gripper has the capacity to lift up to 90 kg (200 pounds) for the hydraulic powered unit with a weight of only 23 kg (50 lbs) or 45 kg (100 pounds) for the electric driven PRM with a weight of only 34 kg (75 lbs), and also has the flexibility to lift laboratory beakers, cans, or stirring rods. With its modern control system, the power, speed, acceleration, and gripping strength of the grippers or other end effectors can be adjusted instantly to suit the item being handled, independently of the operator or type of PRM or end effector.

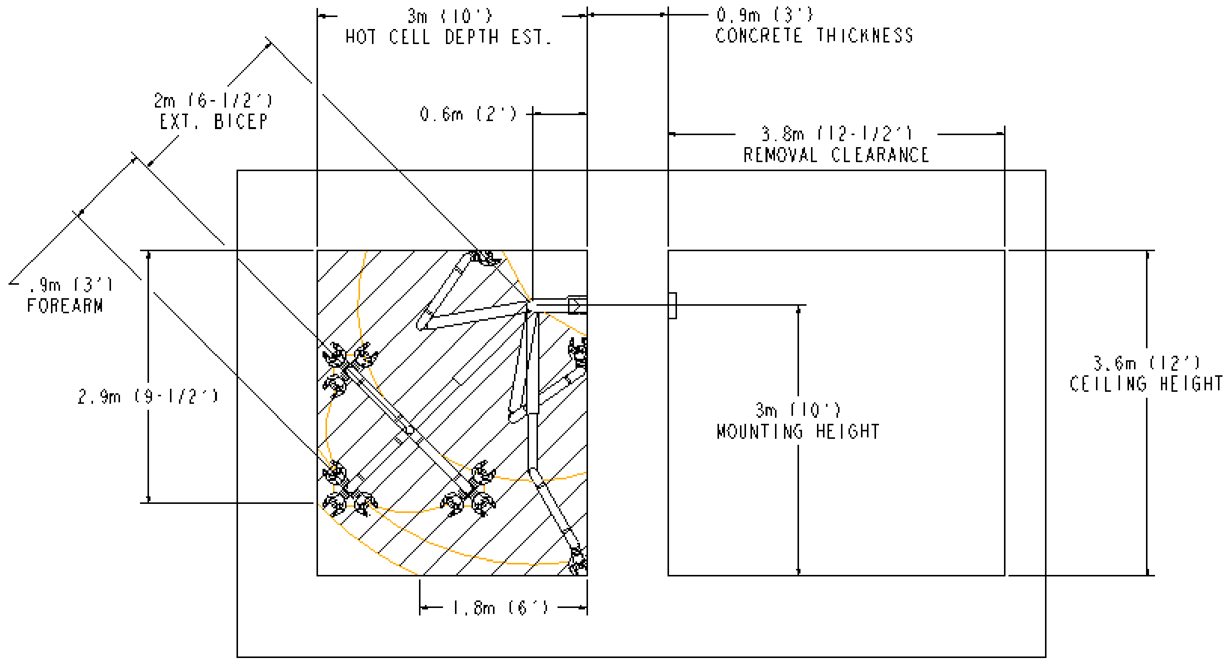

Fig. 3. Range of motion for PRM in hot cell (side view)

Other end effectors can be remotely attached to the PRM. These tools include power drills, shears, saws, pumps, scoops, hammers, chisels, screwdrivers, and a variety of wrenches. Custom tools for specialized applications can also be provided.

The PRM includes a quick disconnect tool changer at the end of the wrist joint. This quick disconnect fitting is a two-part assembly with electrical connectors and fluid couplings in a pre-established configuration. One part of the assembly is mounted to the wrist joint and mating fittings are provided with each tool. The two halves are keyed so that they only fit together one way, and are tightly sealed to prevent leaks. This ensures that once the quick disconnect fitting halves are mated, all required electrical, pneumatic, and/or fluid connections will be properly made. Tool heads and their connecting fittings are typically mounted in a tool rack where they can be readily accessed by the PRM. For mobile applications, a tool rack can be provided in a cart that can be towed behind the powered vehicle.

Power

The PRM is powered by either a distributed hydraulic system or by electric servo-motors. The hydraulic PRM is capable of higher load capacities but there are some applications, e.g., in laboratory hot cells, where electric PRMs are preferred.

Hydraulic PRMs require a 20 MPa (3000 psi) hydraulic power supply, either from a centralized system in the facility or from a small power supply located somewhere nearby and outside the hot cell. The PRMs use a distributed hydraulic system that supplies all joint actuators from a single set of supply and return lines within the arm. Hydraulic fluids are nonflammable and nontoxic. Typically a water based glycol fluid is specified for areas with strict controls against the use of flammable or combustible materials. A miniature hydraulic power supply has been developed for mobile uses.

For hot cell applications, a flexible outer sheath that is provided for contamination control around the PRM arms also prevents hydraulic fluids from leaking into the hot cell environment. Minor leaks are confined within the sheath and high pressure leaks of hoses or fittings are also mitigated within the flexible but tough sheath. The sheath also prevents high pressure leaks from atomizing in the hot cell and minimizes the likelihood of potentially explosive mixtures of vaporized fluid.

Electric PRMs use powerful servo motors and power is distributed from cabling routed along the inside of the structural tubing. Power lines are separated from shielded signal wires so that power spikes do not interfere with control signals in the arm. Electric motors and position sensing instrumentation are spark resistant and use explosion proof connectors so that they do not produce an ignition source during normal operations.

The PRM can also be CE certified for European use.

Operator Controls

The operator can control the PRM using programmable logic controllers (PLCs) and easy-to-use joystick controls as shown in Fig. 4. The operator can observe PRM operations where a direct line of sight is available, e.g., through a hot cell window, or 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. The modern control station is set up to suit the ergonomics of the operator, who can sit in a comfortable chair throughout manipulator operations.

Fig. 4. Typical control panel

Depending on the delicacy of operations and on the consequences of inadvertent dropped or broken loads, the PRM can be supplied with advanced features such as position feedback, force feedback, and load cells.

PERFORMANCE

The PRM uses a fundamentally simple, straightforward design and is assembled from components that have a history of high reliability. There are few parts to fail and the manipulator requires minimal maintenance.

Other manipulators such as the traditional MSMs are complex mechanical systems that have to simultaneously transmit many forces and movements through relatively small penetrations. This requires many belts or cables packed into tight spaces with numerous connections, bearings, pulleys and fixtures. The only power transmission systems required for the PRM are either electrical power cables or hydraulic tubing, and these result in an extremely reliable manipulator system.

DEPLOYMENT

S.A.Robotics has deployed several versions of the PRM as listed below. Each PRM application is custom built to the owner specifications. The determination of the type of controls, joint configuration, and material selections are determined by S.A.Robotics. The new light weight version described in this document is a next generation item that was derived from the lessons learned from the deployments listed below.

Bechtel High Level Waste Swab and Monitoring System: For the Hanford Waste Treatment Plant, an 8 axis robotic arm was provided to perform removable contamination wipe samples from high level waste canister surface areas. The swab and monitoring system integrated a canister turntable with a robotic arm capable of reaching any point on the surface of the canister. The controller stores the contact position data used to produce an accurate measurement of the straightness and ovality of the canister and provides the resulting cylindricity geometry in digital form to the customer’s Integrated Control Network (ICN). The control system manages axis motion, data input/output, and communication with the customer ICN. Inverse kinematic calculations provide accurate, coordinated motion for the servo driven joints to produce easily controlled global frame of reference position and orientation for the end effector. Thirty-four separate specialized components are included in this system. This robotic arm was made of stainless steel for ease of decontamination and accuracy in end effector movements.

West Valley Remote Manipulator System: In support of the Vitrification cell decontamination and dismantling activities, two identical telescoping masts were fabricated from carbon fiber and the arms are designed with 5 degrees of freedom as follows: Shoulder Rotate - 340 degrees, Shoulder Tilt - 180 degrees, Forearm Rotate – 180 degrees, Wrist Tilt - 180 degrees, and Wrist Rotate - 340 degrees. One mast telescopes 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) short forearm assembly was provided for lifting heavier objects. The lessons learned with this project include close supervision of site personnel during installation activities, the unit was dropped during installation requiring significant repairs prior to startup.

CONCLUSION

The S.A.Robotics lightweight PRM is a reliable, strong, versatile robotic manipulator that allows workers to safely and remotely perform various size reduction and material handling tasks in hazardous environments. The PRM can be readily deployed into a reactor D&D site or it can also be used in hot cell applications where master-slave manipulators have traditionally been used.

The basic PRM is a 6 degree-of-freedom manipulator with carbon fiber arms, high strength joint actuators, and joystick controls. It is available with explosion proof electric motor driven positioning joints and end effectors, or with more powerful hydraulically powered joints and end effectors. The selection of power mode depends on the project’s risk tolerance with regards to hydraulic fluid leaks, vaporized hydraulic fluids due to high pressure line leaks, and explosion initiators. The hydraulic version has a lift capacity of approximately 90 kg (200 pounds) and the electric version can lift approximately 45 kg (100 pounds). The PRM operator can operate the manipulator while observing actions directly through a shielded window, or it can be operated remotely from a comfortable work station by viewing actions on a video monitor.

The PRM is a reliable tool for remotely handling hazardous materials. The manipulator design can be scaled or otherwise adapted for a variety of applications and the PRM can be deployed from fixed or mobile work platforms to perform an endless variety of tasks to keep workers out of hazardous environments.

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