Camera Inspection Arm for Boiling Water Reactors – 13330

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ABSTRACT

Boiling Water Reactor (BWR) outage maintenance tasks can be time-consuming and hazardous. Reactor facilities are continuously looking for quicker, safer, and more effective methods of performing routine inspection during these outages. In 2011, S.A. Technology (SAT) was approached by Energy Northwest to provide a remote system capable of increasing efficiencies related to Reactor Pressure Vessel (RPV) internal inspection activities. The specific intent of the system discussed was to inspect recirculation jet pumps in a manner that did not require manual tooling, and could be performed independently of other ongoing inspection activities.
In 2012, SAT developed a compact, remote, camera inspection arm to create a safer, more efficient outage environment. This arm incorporates a compact and lightweight design along with the innovative use of bi-stable composite tubes to provide a six-degree of freedom inspection tool capable of reducing dose uptake, reducing crew size, and reducing the overall critical path for jet pump inspections. The prototype camera inspection arm unit is scheduled for final testing in early 2013 in preparation for the Columbia Generating Station refueling outage in the spring of 2013.

INTRODUCTION

During outages at Energy Northwest's Columbia Generation Station, operators currently use long-handled tools to perform inspections on the recirculation jet pumps. This inspection method has proven to be inefficient and problematic. Obtaining accurate inspection results is difficult due to the tool instability, and the inspection tool is not easily maneuvered by personnel required to stand on the refueling floor (up to 18 meters above the inspection region). In a review of reactor outage activities, it was noted that an increase in efficiency of the jet pump inspections would result in a significant reduction in overall outage schedule, crew size and dose uptake to outage personnel. Existing remote reactor inspection technologies were considered, but were found to either be not cost effective, or incapable of viewing the areas required.

With the goal of realizing more efficient outage activities, Energy Northwest and SAT worked together to develop a low cost solution for the remote inspection of BWR jet pumps. This Camera Inspection Arm is a durable and innovative tool that will increase the accuracy and speed of the inspection activities while removing inspection personnel from high dose locations and allowing for a level of precision and repeatability that is not afforded by the current manual inspection method.

INSPECTION REQUIREMENTS

BWR Jet Pumps, like those present at the Columbia Generating Station provide water flow to control the reactor's power output. The pumps are located between the core shroud and the reactor vessel wall in a vertical orientation. The Columbia Generating Station utilizes a second generation General Electric BWR/5 which contains ten (10) jet pump pairs located evenly around the diameter of the vessel interior in pairs.

During reactor outages, these pumps and their attachment brackets must be visually inspected for weld integrity and general condition. This inspection process requires a camera to be lowered between and around the jet pump pairs to allow viewing and documentation of the specific areas. The majority of the inspections are completed on each jet pump from the "Ram's Head", at the top of the jet pump assembly, to the restrainer bracket, a vertical distance of approximately 4.6 meters. The surrounding outage activities and reactor geometry limit the room available for the installation of inspection tooling.

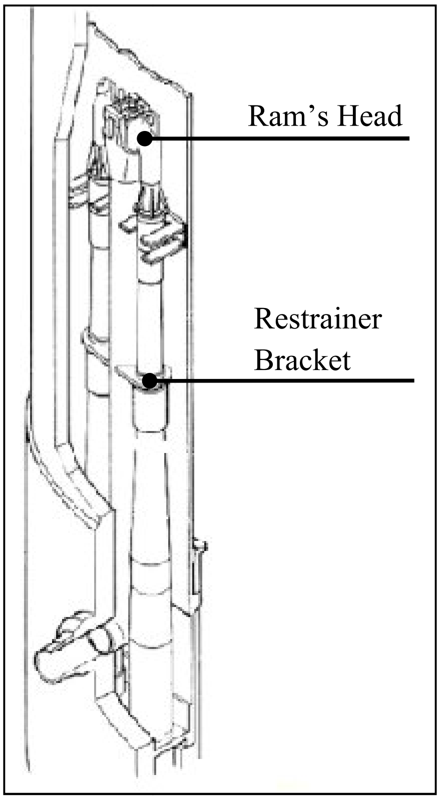

Figure 1: Jet Pump Cutaway Diagram

DEGREES OF FREEDOM

The newly developed Camera Inspection Arm system is a dual camera, six (6) degree of freedom in vessel visual inspection tool. Prior to commencing the inspection, the tool is lowered into the RPV using the existing overhead monorail and installed directly on the jet pump Ram's Head. Then the tool can be "locked" into place between the steam dam and vessel wall using a pneumatic cylinder located at the top of the tool to apply force to both surfaces.

Once in place above the jet pump Ram's Head, each of the Pan-Tilt-Zoom cameras can be positioned around the jet pump through the use of three (3) independent actuations; a vertical axis rotate, a radial extension and a vertical deployment.

- The vertical axis rotate provides rotational range of motion about the vertical axis of the jet pump. This axis allows the camera to be located anywhere within a 255 degree arc around the jet pump. To increase the strength of this rotational joint, the central pivot bar is rigidly mounted to the tool body at both ends.
- The radial extension allows the cameras to articulate horizontally in and out with respect to the jet pump. The radial extension maintains the orientation of the camera by

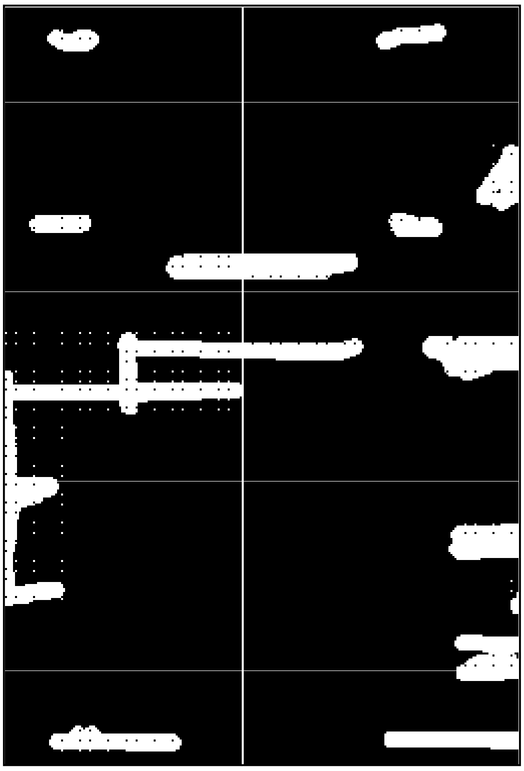

Figure 2: Camera Inspection Arm Range of Motion

implementing a four-bar linkage design. In addition to maintaining the camera orientation, the four-bar linkage design ensures a durable and reliable operation.

- The vertical deployment actuator allows deployment of the cameras up and down the annulus between the jet pumps. Utilizing an advance bi-stable composite material for the vertical deployment, the Camera Inspection Arm system has the ability to remain very compact when in the fully retracted state.

These degrees of freedom allow the operator to place the camera in nearly any location surrounding the jet pump assembly, and then use the versatility of the Pan-Tilt-Zoom camera to inspect the specific area of interest. Additionally, due to the design of the tool, the motion of each camera is independent so the two cameras can be operated simultaneously to inspect two separate jet pumps at the same time. Each degree of freedom is powered by a pneumatic piston motor, driving the motion of each axis through custom gear boxes.

All degrees of freedom on the Camera Inspection Arm are designed to be fail-safe. Allowing the tool maintain its position and subsequently be retrieved in the event of a joint failure.

COMPACT & LIGHTWEIGHT DESIGN

The overall size restrictions faced by the Camera Inspection Arm design are substantial when compared to the overall reach required for the inspection. Early on in the design process the decision was made to place the Arm directly on the Ram's Head, instead of attaching to the RPV steam dam, as is the case in a number of other inspection tools. This innovative placement of the Inspection Arm produced a number of benefits:

- Allows for unobtrusive access to the core components on the inside diameter of the core shroud.
- Provides the shortest possible "pole length" from the tool to the camera, increasing camera stability and image quality
- Allows for simultaneous inspection of multiple jet pump annuluses with the tool installed in a single location

However, in order to fit the Inspection Arm into the desired area, a number of size and weight restrictions had to be met. For installation, the tool must be no taller than 1.7 meters, and must be capable

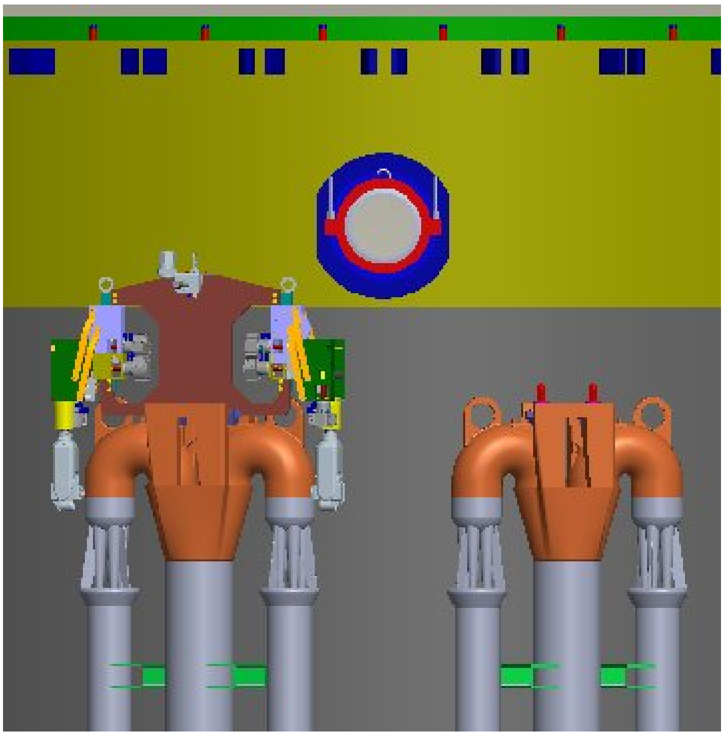

Figure 3: Inspection Arm Shown on Jet Pump Assembly

of working around the LPCI coupling which exits the reactor core shroud directly above the jet pumps in three separate locations around the reactor. Additionally, the core shroud lip must be avoided during operations; this lip extends horizontally above the jet pump.

The Camera Inspection Arm was designed considering all the space restrictions, using the compact geometry of the four-bar radial extension and the innovative use of the bi-stable composite tube. Additionally, the tool is lightweight, less than 91 kg in air, to allow it to be placed directly on the top of the Ram's Head to deploy the cameras.

INNOVATIVE TECHNOLOGY

A major challenge in the design of the Camera Inspection Arm system was the requirement to inspect areas up to 4.6 meters below the Ram's Head, without interfering with other operations occurring above the inspection equipment. An innovative extension tube technology was integrated into the design of the Inspection Arm design to meet these objectives. The Camera Inspection Arm utilizes a bi-stable composite tube to provide a rigid camera platform without the need for available overhead space. The bi-stable composite is stable in two distinctly separate physical forms. In the first form, the tube is rolled around itself in a helical form. In the second form, the tube is rolled on its shorter dimension to form a structural shape similar to a pipe or tube. This property allows the 4.6 meter extension tube to roll up into a coiled diameter of only 125 mm.

Figure 4: Bi-Stable Composite Tube

This type of composite tube has been previously used for in-air inspection tasks of graphite core reactors, but the Camera Inspection Arm represents the first use of this technology to perform underwater tasks using a fully motorized tool Considering the simplicity, ease of operation and minimal parts required for these tubes, the technology is ideal for RPV inspection tasks.

CONCLUSION

With the ever increasing desire by nuclear utilities to reduce outage durations and meet strict ALARA radiation exposure goals, the need has arisen for low-cost remote solutions to replace manual inspection activities. The Camera Inspection Arm is a standalone inspection tool capable of providing safer and more efficient inspection of BWR jet pumps. The system's small size, light weight and use of innovative technologies represent a step forward in the ability to deploy inspection tools for in-vessel visual inspection. Currently, the first article is scheduled for testing in January 2013 with a planned initial deployment in the Columbia Generating Station spring outage.