HYDRO-QUÉBEC INSPECTION ROBOT RIT-LRG

Dominique Champagne[1], François Rinfret[2], Yves G. Bourgault[2]

ABSTRACT

ABSTRACT — Hydro Québec's Research Centre (IREQ), has developed a variety of inspection tools over the years. The Métar bracelet for the feeder tubes, the REC robot for the heat exchanger and the RIT robot for the Delayed Neutron system just to name a few.

This paper discusses with the successful deployment of the Camera Probe Positioning robot for Visual Inspection of the sample lines of the delayed neutron system of CANDU power plants. This RIT robot has three possible configurations (Face, Cabinet and LRG configurations) and has remained a prototype version although it has been used over the years in many outage inspection campaigns since 1997. The main advantages of using this robot are: the significant reduction in radiation exposure, the high quality of the data collected and the archiving of inspection data for further analysis and reports.

In 2007, Gentilly-2 (G-2), decided to industrialize the LRG configuration of the RIT robot and to designate it the standard tool for the inspection of the Delayed Neutron System. An improved RIT-LRG robot, along with its control box and command station was developed. The software had to be rewritten requiring an ergonomics analysis of user tasks, work station and interface display. These issues included both physical and cognitive requirements aspects. The two principal topics of this paper will be on the Inspection Robot Technology developed and highlights of the 2008 outage inspection campaign.

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INTRODUCTION

The robot **RIT-LRG,** which stands for "**R**obot d'**I**nspection **T**élévisuelle – **L**ocalisation de **R**upture de **G**aine " or "Camera Probe Positioning robot for Visual Inspection of the Delayed Neutron (DN) sample lines", belongs to a family of specialized robots designed to verify the state of piping, supports and collars and to detect anomalies. The **RIT-FACE** is used to inspect the feeder supports at the face of the reactor and the **RIT-CABINET** to inspect seismic supports and dampers and chafing sleeves located in the cabinet region.

The inspection robot RIT-LRG serves to inspect the DN sample lines that become worn down due to fretting. This fretting is due to the pipes rubbing against themselves. The wear on the sample lines could lead to unwanted coolant leakage.

The DN system is designed to detect breaches in the cladded fuel used in a nuclear reactor. There are neutrons emitted long after the fission process (sometimes several minutes later), these are called *delayed neutrons*. The DN system has the ability to sample the coolant from individual fuel channels. There are as many sample lines as fuel channels. These sample lines transport the coolant sample away from the high radiation fields surrounding the feeders array to a low-background radiation counting area. The counting is performed by a boron trifluoride (BF3) neutron detector, and the scan method is hydraulic, activated by solenoid valves. The sample line lengths are identical, as required by the sampling method (i.e. count value comparison). Half the sample lines reach a first DN system where six probes alternatively screen the samples. A second DN system is responsible for the other half of the sample lines. The sample lines are connected to the outlet feeders above the reactor and below the steam generator (SG). They are arranged in an orderly fashion, so that all lines are parallel to the face of the reactor and form approximately 15 vertical planes of seven different heights, each 3/4" apart. The sample lines travel from reactor face to the DN system rooms where they are tested for the presence of delayed neutrons. The coolant is returned to the low pressure side of the pumps via collectors.

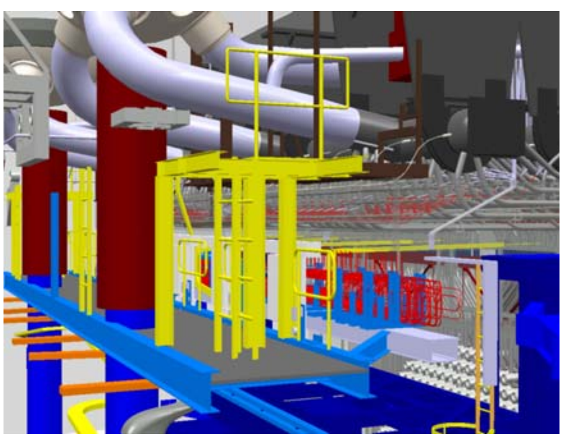


Figure 1 A) Upper reactor – Sample lines (in red)

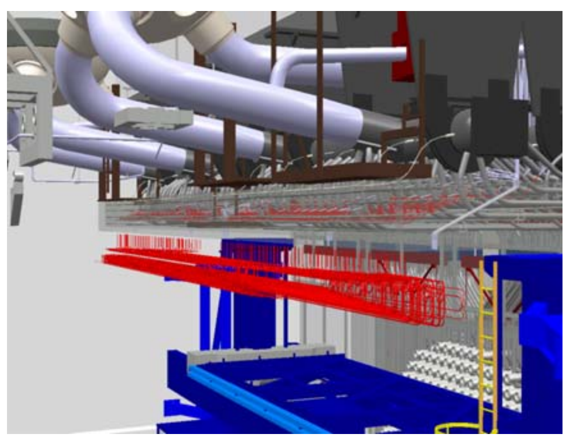


Figure 1 B) Upper reactor – Without the catwalk

Table 1 shows the use of the different RIT robots over the last decade.

Table 1 Robot utilization over the years

Module	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008
Face												
Cabinet												
LRG												

In 2007, Gentilly-2 (G-2) decided that further inspection of the DN’s sample lines would be performed with the RIT-LRG robot. This tool would become the standard tool for visual inspection. The project began shortly thereafter and the improved RIT-LRG robot was delivered to G-2 in March 2008 for their periodic inspection.

SYSTEM INDUSTRIALIZATION

System industrialization was necessary in order to proceed with the transfer of the RIT-LRG robot technology to G2. The objectives of the industrialization were to:

- Finalize the mechanical design of the prototype and of the upgrade required for certain components
- Provide the robot with a software application designed for its control and for the generation of reports
- Ensure the durability of the RIT-LRG system components
- Ensure proper training, on use and maintenance of the robot, of G2 plant personnel
- Provide spare parts
- Provide all pertinent documentation
- Provide technical support during inspection

The following sections present the different components of the robot with a brief description and an explication of the modifications made to each.

HUMAN FACTORS

Before beginning the re-design, it was important to review the physical and cognitive requirements associated with RIT operation to identify current design issues which could lead to a decrease in effectiveness and efficiency, to equipment damage and to human error.

The operators work 12hours shifts, under time constraints, to complete the inspection as planned. Fatigue, either mental or visual, could lead to errors, and those errors could result in failing to detect a defect, neglecting to inspect an area, or experiencing orientation difficulty and inadvertently damaging the equipment.

Our approach was to address the user’s requirement and to carry out a task analysis. The task analysis consisted of:

- Defining the roles and responsibilities of the inspection team members (small field of vision, medium-sized field of vision, overall view),
- Providing a means for the co-pilot to assist the pilot (activate the PTZ , select camera view, write comments on pictures),
- Allowing the progress of the inspection to be tracked along its plan (maintain progress reports (interruption), use of color-coded tags),
- Ensuring continued awareness of the robot orientation (correspondence between the movement command (joysticks) and the actual movement of the robot, video mirror to invert camera view),
- Considering equipment constraints (unplugged-manual options indicators on user interface, software representation of the probe) and
- Facilitating the utilisation of software-integrated inspection reports (organize inspection data, generate reports for repair groups).

ROBOT RIT-LRG

The RIT-LRG inspection robot includes a probe installed at the end of a positioning arm with five degrees of freedom (d.o.f.), see Figure 2, operating at a distance of up to 400 feet from the command station. The probe provides five different camera views (front, side, top and bottom, plus a PTZ Camera) and strong lighting. It also has an “ergot”, a tool used to pull or push on a pipe and a paint marker.

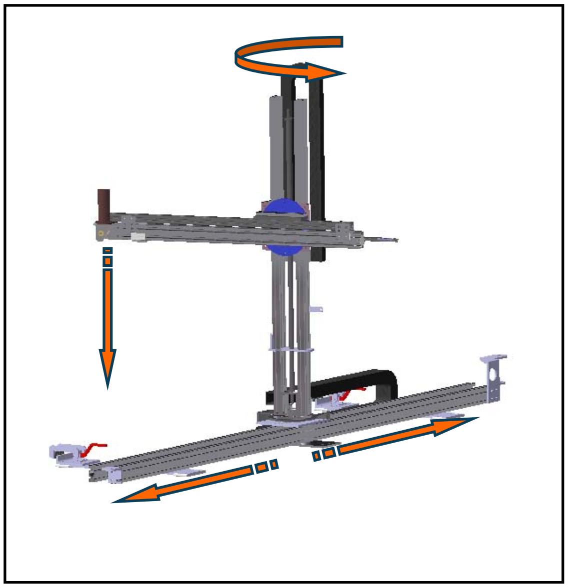


Figure 2A) Robot RIT-LRG Base – 3 d.o.f.

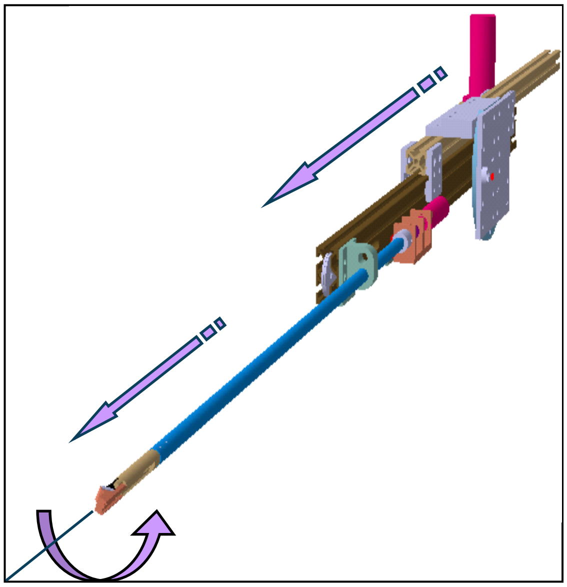


Figure 2B) Robot RIT-LRG Probe - 2 d.o.f.

The robot’s modular design allows the positioning arm to be reconfigured to adapt to the spatial constraints of the different insertion zones of the sample lines grid. The base of the robot is anchored to the catwalk and the probe is positioned facing the grid. A control box is located near the robot on the catwalk floor. A fibre optic link provides communication with the command station.

As part of the process of industrialization, all of the robot's plastic parts were exchanged for parts made of steel or another metal alloy. The obsolete motor controllers were updated and the wiring was replaced. The paint marker mechanism was revised to prevent the dry paint from being able to clog the orifice.

Figure 4 Robot RIT-LRG on catwalk

Transportation constraints were considered and orientation markers were added. Step-by-step procedures were also written to insure proper installation and removal of the robot and equipment.

CONTROL BOX

The control box is located near the robot. It houses the communication system, the fibre optic link system, the motor and video controllers and various other components. It is the link between the robot and the command station. A real-time embedded controller has been added, improving the performance and reliability of the control. All of the components are commercially available, which means that they can be easily replaced if needed.

COMMAND STATION

The command station provides the robot's operators with different camera viewpoints. It includes four monitors: three for camera viewpoints and one monitor for the software control application. The computer provides the operator with position feedback from the robotic arm, data archiving of snap-shot images and video recording. All inspection reports are generated with the software application.

The command station underwent a series of changes, including the removal of all CRT monitors and the VHS video recorder and its writing device. The old wheeled casings were removed, thereby creating a much smaller command station with more available working area for the operators. The computer, electronics and components are now located in a stand-alone casing beside the command station table. Certain functions of the old electronic equipment were integrated into the software control application.

Figure 5 Robot RIT-LRG Command Station

Three joysticks are included in the console each one controlling the movement of the robot along a different axis. The console is connected to the computer via a USB link. The auxiliary console was completely removed and its functions integrated into the software user interface.

All connecting wires pass through the panel connectors, either at the front or at the back of the casing. A team of two operators are positioned at the command station while the inspector is behind them.

CONTROL APPLICATION SOFTWARE AND USER INTERFACE

The control application software was rewritten in LabVIEW (National Instrument). The old application was written in MICROB V1.0 and required an additional application to maintain the Ethernet link with the control box. The new control application software is of a distributed architecture with part of the logic directly implemented into the two CompactRIOs. A first CompactRIO incorporates all the motor controllers, whereas the second holds the logic for all the instruments and I/O. The user interface displayed on the main computer sends the commands to the CompactRIOs and provides access to the system configuration and indicators of the robot's activity.

The left side of the user interface shows a static view of the PTZ camera image and control, indicators of the robot's state and the probe orientation. The image displayed on the right side of the user interface can be change dynamically in response to the operator's selection. The display choices are: camera images, state indicators for the robot, 3D representation of the robot or inspection data images. Many tools are now available to facilitate report generation.

Figure 6 User interface

TRAINING

Personnel were trained on the mechanical assembly of the robot, the control box and command station.

The training in a simulated environment, using the control software was more difficult than expected mainly due to the various levels of computer literacy among the personnel, and the difficulty in grasping the notion of spatial orientation and in mastering the use of the joysticks. Operators tended to rely on a written procedure to facilitate their task and instinctively looked at the robot itself to obtain its position. These reflexes are expected to disappear as their confidence builds.

During field training, operators repeatedly requested visual confirmation of the robot's spatial orientation. The proposed solution was to use a second PTZ camera in addition to the one already located on the robot itself, to provide a view of the robot on the catwalk from an outside viewpoint. Consequently, the 3D view available on the user interface was used infrequently, if at all. Familiarization with the annotation and report-generation tools was, and still is, a long process, requiring further investigation.

2008 INSPECTION RESULTS

The RIT-LRG robot was used for the 2008 inspection of the sample lines of the DN system.

Insertion zones 4, 5 and 6 of both the north and south faces were inspected with the RIT-LRG robot. Figure 7 shows the insertion zones of the north face. Insertion zones 3 and 7 were inspected manually and the inspection pictures where combined with the RIT-LRG inspection results to create a report.

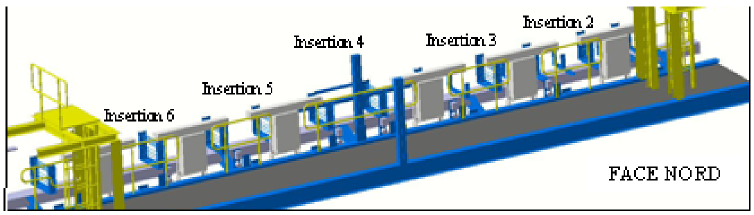


Figure 7 North face: insertions zones

Certain areas of the sample lines are more susceptible to being worn by fretting. Defects were most frequently detected at the locations where the pipes enter the grid and primarily in the last curvatures before heading towards the wall penetration. In almost all of the cases, defects were caused by the fretting of adjacent pipe-planes, Figure 8 illustrates the configuration.

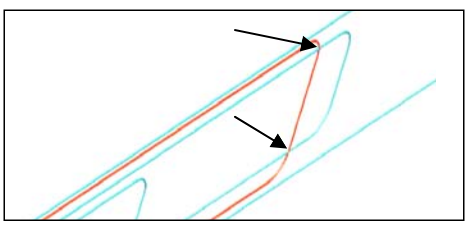
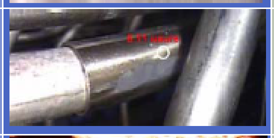
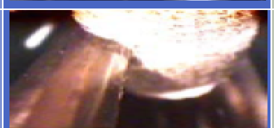
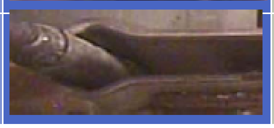


Figure 8 Sample lines in the same vertical plan

Defects are identified from the camera images and pictures are taken. The defect pictures are labelled and later physically verified by the operator in the actual grid. The defects are measured and marked for other maintenance group.

Table 2 shows the 2008 inspection results. The majority of the defects detected fall in the “25-50%”category. Only those defects in the “50% and greater” category of defect along with the used bushing and protective wrapping will require a corrective action.

Table 2 2008 Inspection result DN Sample lines

			North Face	South Face
Pipe Defect: wear due to fretting	25 to 50 %		14	13
	50 % and greater		4	1
Used bushing			2	-
Protective wrapping replaced			4	5
Pipes (2) repositioned on mechanical support			2	-

Technical support was provided for the duration of the inspection. This daily collaboration motivated various specialized additions to be made to the software and user-interface.

CONCLUSION

The RIT-Face and the RIT-Cabinet robots allowed for the success of the RIT-LRG robot. They provided evidence to suggest advantages in using a robot for the inspection of the DN sample lines, a long and difficult task in hard to reach areas. In addition, the RIT-LRG robot benefited from the knowledge and experience acquired with the RTI-Face and RIT-cabinet robots.

The RIT-LRG prototype performed very well during the five consecutive periodic inspections in which it was employed before entering the industrialisation step. The goal of industrialisation was to preserve the advantages of the prototype system, while making the necessary adjustments. The adjustments included: implementing the software feature required to perform the inspection, redesigning the software architecture and selecting new component parts given the maintenance issues.
The industrialization also aimed to reduce the operator task load and improved the durability of the robot at a time when refurbishment of the plant was being considered.
The RIT-LRG robot shows improved reliability, and consistency thus allowing a more efficient improved inspection. Finally, remote-controlled inspection using the LRG-RIT robot greatly reduces radiation exposure.

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