Tight Fitting Garter Springs-MODAR

Dennis Kazimer, P.Eng

Bruce Power

Tiverton, Ontario

Acknowledgements

The author of this paper would like to acknowledge Mitch King, Paul Feenstra, Andrew Kittmer, Greg Hersak and those at AECL-Chalk River and Sheridan Park dr. offices who worked many long hours in the development, design, testing and demonstration of the MODAR tooling system. It is without these dedicated people that this project would not be possible.

Abstract

Annulus spacers are used in CANDU™ reactors to maintain the annular gap between two tubes - an inner pressure tube (PT) and the outer calandria tube (CT). Typically four annulus spacers are used in one fuel channel assembly, each at a specified axial position.

Bruce Unit 8 and many other CANDU units were constructed with tight-fitting garter springs (TFGS). The TFGS were not designed to be detected or relocated by the conventional tool, Spacer Location And Repositioning (SLAR) processes.

Due to non-optimal 'As Left' construction locations for the Bruce Unit 8 TFGS, PT/CT contact has been predicted to occur well prior to its End of Life (EOL). Bruce Power entered a Project with AECL-CRL to design, manufacture & test and implement a new tooling system that would detect and reposition tight fitting annulus spacers.

Table of Contents

Introduction

Annulus spacers are used in CANDU™ reactors to maintain the annular gap between two tubes - an inner pressure tube (PT) and the outer calandria tube (CT). Typically four annulus spacers are used in one fuel channel assembly, each at a specified axial position. It is important that the spacers are in the correct position, as incorrect positioning may lead to contact between the hot PT and cooler CT. Such contact is unacceptable in the long term. Note that there is no direct access to the annular space between the PTs and CTs that would facilitate direct detection or repositioning of the spacers. These operations must be performed remotely either from the inside of the PT or from the outside of the CT.

Two types of spacers (i.e. loose fitting and tight fitting) are used in CANDU™ reactor fuel channels. The tight fitting spacer is the newer design replacing the loose fitting spacer. The new design was introduced because of issues related to the inability of the loose fitting spacers to maintain their axial position along the fuel channel due to inadequate pinching loads. The tight fitting spacer design uses an overlapping girdle wire, which causes them to be only detectable very early in life using eddy current techniques. This detection method is used by the existing Spacer Locating and Repositioning (SLAR) tool, which relies on the welded girdle wire inside the spacer to form a continuous electrical circuit.

Project-MODAR™

Modal Detection and Repositioning (MODAR) is based on the effects of controlled vibrations of a short length of pressure tube (PT). There are two basic functions of the MODAR™ tool, detection and repositioning.

Detection

The detection technique compares the acceleration of points at the top and bottom of the PT in the vicinity of a loaded spacer. When the tube is vibrating, the stiffness and mass added locally by the annulus spacer pinched between the PT and calandria tube (CT) will alter the local acceleration of the PT wall. The quantity of interest is the ratio of bottom surface Root Mean Square (RMS) acceleration to top surface RMS acceleration over a selected frequency band. This ratio can be obtained at a number of locations near the spacer and it will diverge from 1:1 as the spacer is approached from either side. The spacer location is identified as the point where the acceleration ratio is farthest from 1:1[1].

[1] King. J. M., and Stevenson, M., Design Description: MODAR Dry Demonstration System, AECL Report 29-30160-DD-001, 2009 June.

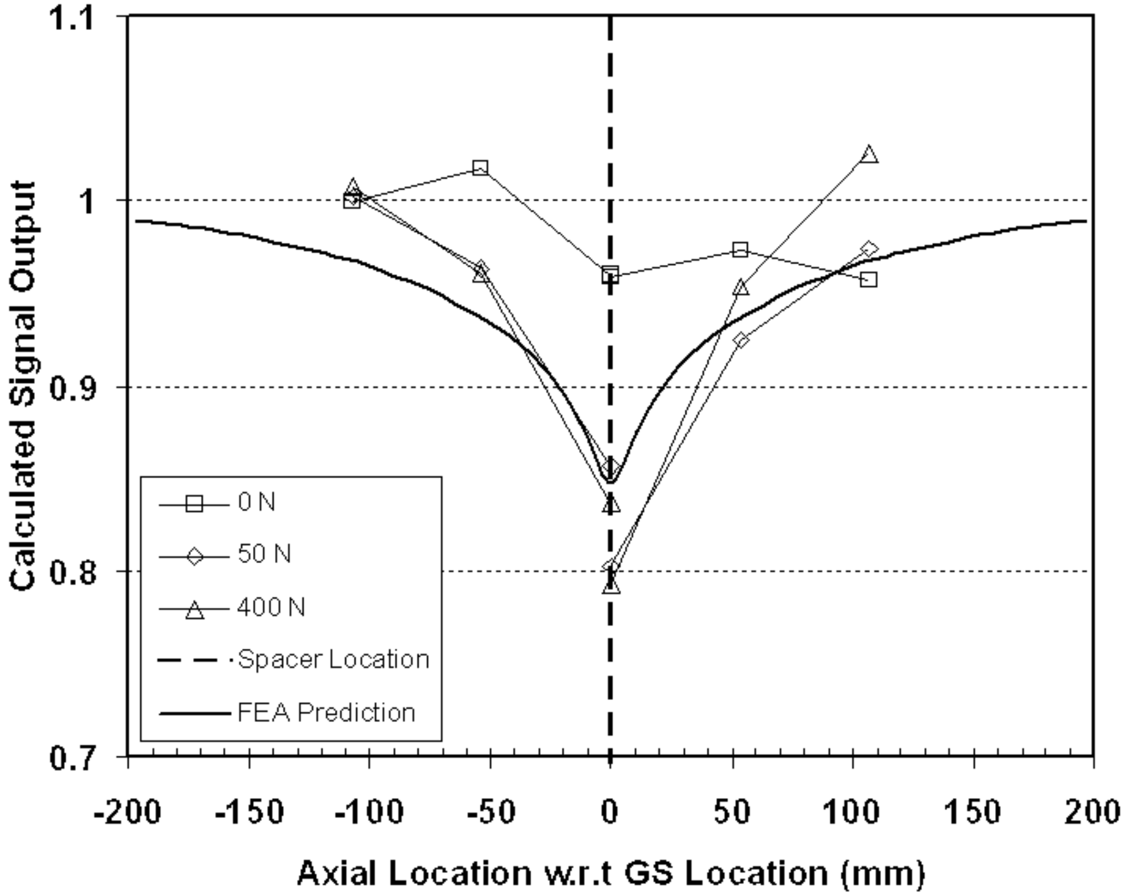

Figure 1: TFGS MODAR Response

Repositioning

Repositioning of an annulus spacer is achieved by vibrating a section of the PT in a controlled manner. To move the spacer, the isolated length of PT is excited to vibrate at one of its modal frequencies. If the spacer is between a node and an antinode, it will move away from the antinode and towards the node. The figure below shows the (2,1), (2,2) and (2,3) mode shapes of the isolated length of PT. The mode shape designations (2,1), (2,2) and (2,3) refer to the (i,j) indices, where “i” is the circumferential mode number and “j” is the axial mode number[2].

[2] Tarbiat, Raoof & Xu, Feng (2010). Analysis and Assessments in Support of In-Reactor use of MODAR. AECL Assessment document 153-30160-ASD-001.

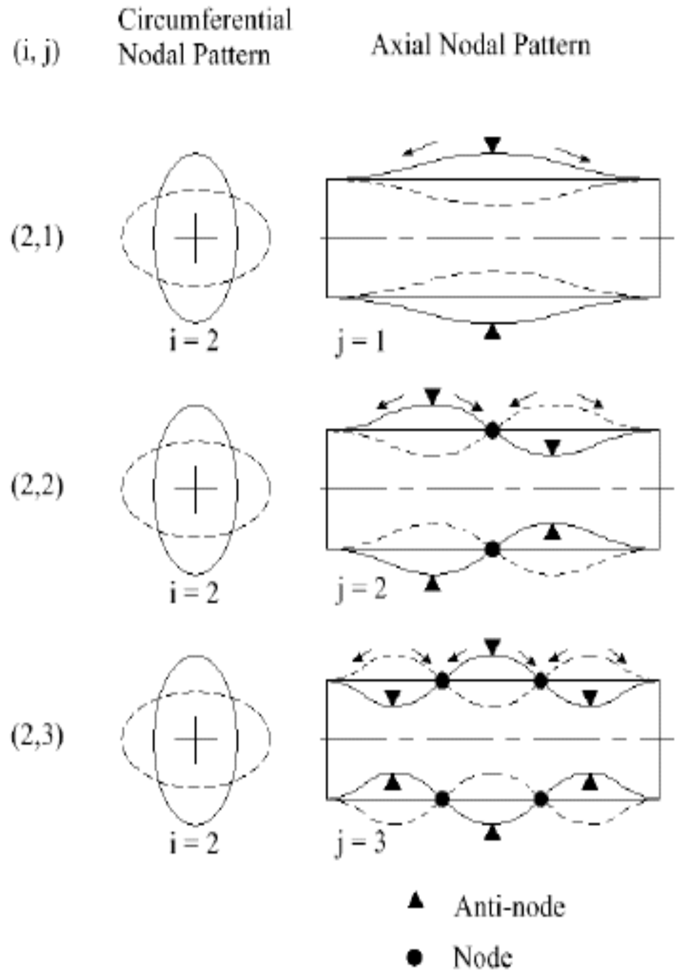

Figure 2: PT Nodes and Antinodes showing (2,1), (2,2) and (2,3) shell modes[3]

The arrows indicate the direction of spacer movement for a spacer located between an anti-node and node

[3] Tarbiat, Raoof & Xu, Feng (2010). Analysis and Assessments in Support of In-Reactor use of MODAR. AECL Assessment document 153-30160-ASD-001.

MODAR™ Tool Head

The MODAR tool head comprises of Piezo-Actuators, Accelerometers, and Isolation Clamps / Jacking modules.

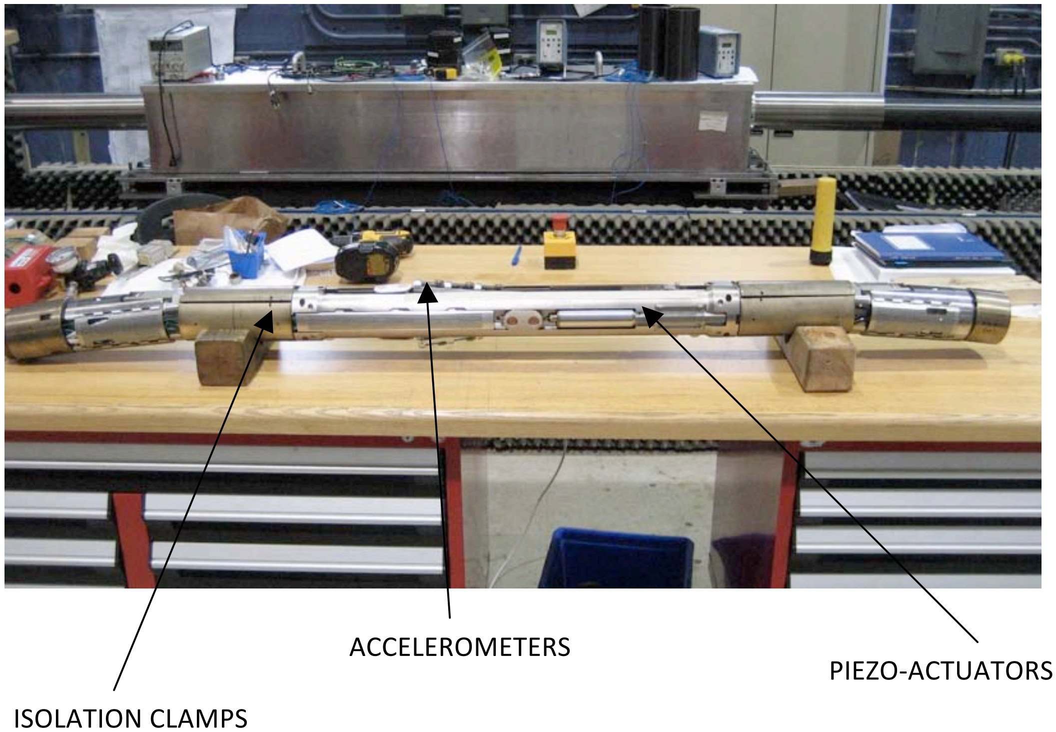

Figure 3: MODAR Tool Head

Isolation Modules and Jacking Mechanisms

Isolation modules and jacking mechanisms are present at both the ram end and the free end of the tool. The isolation modules clamp onto the inside surface of the PT to perform two important functions. First, they create a fixed length of PT that is allowed to vibrate between the two modules, making the MODAR process consistent and independent of the tool's axial position within the fuel channel. Second, they minimize the transfer of MODAR vibrations to other parts of the fuel channel and reactor. The isolation modules are attached to each end of the Detection-Repositioning Section with a bolted joint.

Accelerometers & Piezo-Actuators

Three pairs of accelerometers are used to detect the presence of an annulus spacer. A pair consists of two accelerometers mounted at the same axial location, with one at the top (12 o'clock) and the other at the bottom (6 o'clock). The accelerometers are mounted on a carriage that can travel 300 mm axially within the Detection-Repositioning Section of the tool.

The piezo actuator assembly is used to vibrate the PT in a controlled manner. The assembly includes two identical piezo actuators mounted inside housings and a drive mechanism that extends and retracts the housings. Each piezo actuator is a stack of multiple piezo electric disks enclosed in a cylindrical metal casing. The actuators are installed horizontally between the structural beams. Force and displacement output from the actuator is transferred to the surface of the PT through a lever that is mounted in the housing with a pin joint.

On Reactor Results

Bruce Power and AECL-CRL Project team demonstrated first time use of MODAR^{TM} during the recent B1181 Planned outage. Two fuel channels were visited with MODAR (N04 & Q10). As the first time use of MODAR^{TM} was a 'Dry Demonstration' each fuel channel was defuelled, isolated, drained and manually opened. The MODAR^{TM} tool head was then positioned to the predicted 'As Found' spacer location and operated to detect the annulus spacer. MODAR^{TM} detection process was executed for each spacer location within the channel. The spacers were found within the predicted 'As Found' locations within 5-20mm tolerance. A typical Detection screenshot is shown below.

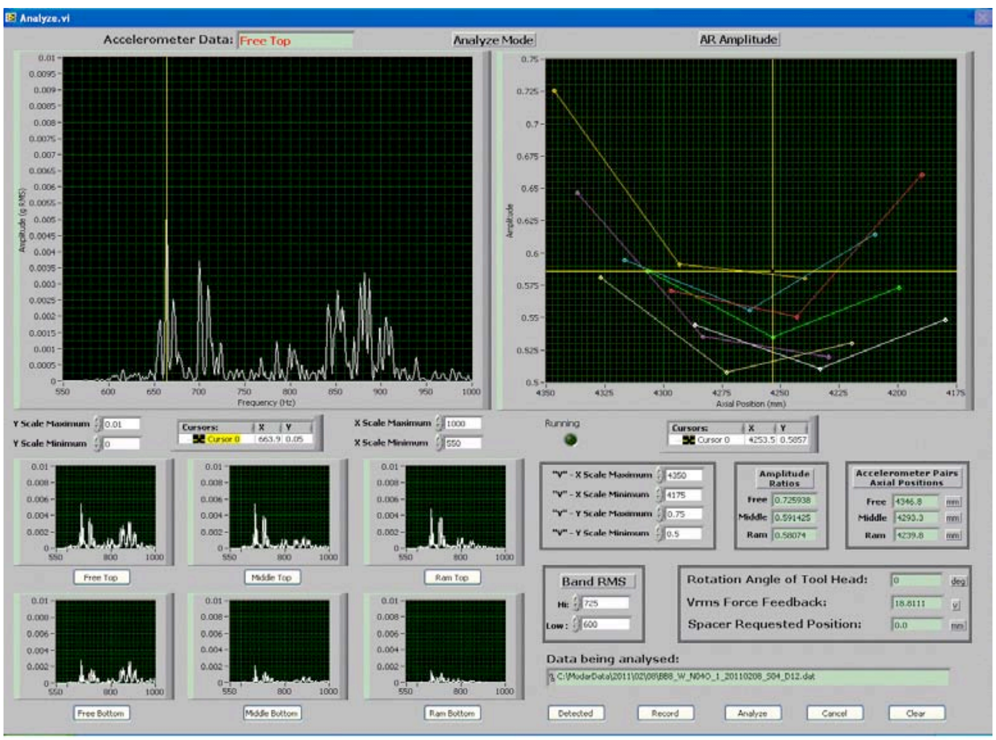

Figure 4: Detection Response - MODAR

In Figure 4 each Accelerometer head is shown in the lower left. The right side shows the typical response with a local minimum indicating the spacer location.

Conclusion

MODAR™ has the ability to detect and reposition TFGS. Even though MODAR™ has only visited two fuel channels to date the results are cautiously promising. There is still much work to be completed to have the MODAR tool delivered by a delivery machine in much the same way as other fuel channel inspection tools are being delivered.

References

[1] King. J. M., and Stevenson, M., Design Description: MODAR Dry Demonstration System, AECL Report 29-30160-DD-001, 2009 June.

[2] Tarbiat, Raoof & Xu, Feng (2010). Analysis and Assessments in Support of In-Reactor use of MODAR. AECL Assessment document 153-30160-ASD-001.