DEVELOPMENT OF METHODS FOR DETECTING AND REPOSITIONING OF SNUG-FITTING ANNULUS SPACERS

P.A. Feenstra, B.A.W. Smith and J.M. King
Atomic Energy of Canada Ltd.
Chalk River Laboratories
Chalk River, ON
Canada, K0J 1J0
Email: feenstrp@aecl.ca

ABSTRACT

Annulus spacers are used in the fuel channels of the CANDU® power reactor to maintain the gap, or annulus space, between the pressure tube and surrounding calandria tube. It is important that the spacers remain close to their installed locations to prevent pressure tube to calandria tube contact and subsequent hydride blister formation. There is currently no means of in-service repositioning for snug-fitting annulus spacers. In addition, it is desirable to have a means to directly detect the location of a snug-fit spacer that does not rely on secondary effects of spacer location.

AECL has been working to develop the capability to directly detect and reposition snug-fitting spacers. To date, means to detect and reposition snug-fitting spacers using vibration have been successfully demonstrated in the laboratory and work is continuing towards implementing this technology for field use. This paper presents an overview of the detection and repositioning techniques.

INTRODUCTION

Annulus spacers are used in the fuel channels of the CANDU power reactor to maintain the gap, or annulus space, between the pressure tube (PT) and surrounding calandria tube (CT). As shown in Figure 1, two types of annulus spacers have been used, the “loose-fit” type and the newer “snug-fit” type [1]. The snug-fit design was introduced because of issues related to the ability of the loose-fit spacers to maintain their axial position along the fuel channel. It is important that the spacers remain close to their installed locations to prevent PT-CT contact and subsequent hydride blister formation in the PT.

Tooling exists to detect and reposition loose-fitting annulus spacers. The process is known by the acronym SLAR (Spacer Locating And Repositioning). The technique relies on the welded girdle wire inside the spacer to form a continuous electrical circuit around the PT. Unlike the loose-fitting spacer, however, the ends of the girdle wire of the snug-fitting spacer are not welded, but simply overlap by about ½ of the circumference. This prevents the snug-fitting spacer from being repositioned by the existing SLAR method. The lack of a welded girdle wire also limits the means of detecting the spacer position. As a result, there is currently no means of in-service repositioning for snug-fitting annulus spacers. Present detection methods do not make a direct measurement of snug-fit spacer location and are reliable only after the fuel channel has reached about 100,000 hours of service.

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This paper introduces a new method to detect and reposition snug-fitting spacers using controlled vibration and analysis. Laboratory tests have demonstrated the feasibility of the method for field use and a patent is pending. The new process is identified by the acronym “MODAR” for MOdal Detection And Repositioning.

PRACTICAL CONSIDERATIONS

The reactor conditions for annulus spacer detection can be divided into two cases, when the annulus spacer is loaded (i.e., pinched between the PT and CT) and when it is unloaded. It is assumed that after some years of operation all of the annulus spacers would be pinched between the PT and CT even when the channel is de-fuelled.

In a campaign to detect the locations of spacers, it is most desirable to quickly scan a de-fuelled PT filled with heavy water. If an annulus spacer needs to be repositioned, the tool would be positioned over the targeted spacer and a jacking mechanism, similar to that used in the current SLAR tool, would be used to unload the spacer. The jacking mechanism applies a bending moment to the PT to effectively unload the spacer from contact with the CT. An actuator would then be used to excite a short section of PT to resonate in a particular mode and thereby cause the targeted spacer to move in the desired direction. The jacking device incorporates a feature that effectively isolates the PT section being excited from the remainder of the PT. This limits the vibrations applied to the rest of the reactor components including non-targeted spacers in the same fuel channel. This process may be performed in a wet or dry fuel channel (de-fuelled).

LABORATORY TESTING

Testing of the MODAR method was performed using actual samples of PT and CT set up to be typical of a CANDU fuel channel. The PT was mounted concentrically within the CT and equipped with an adjustable support that allowed for altering and measuring the load on the spacer from zero up to 800 N (about 180 lbs). A spacer was positioned at midspan of the PT and the CT was immersed in a water tank to simulate the water in the calandria.

A vibration-inducing actuator mounted in a specially designed holster is used to excite the natural shell modes of the PT. The actuator can be driven with sinusoidal or random excitation. A force transducer measures peak excitation forces and vibration probes are used to measure the acceleration of the PT wall at prescribed axial locations in the vicinity of the loaded spacer.

The mode shapes of a clamped-clamped tube are shown in Figure 2 [2]. The “i,j” indices refer to the circumferential and axial modal patterns, respectively. Hence, the (1,1) mode is the fundamental beam mode while the (2,1) mode is the lowest shell mode. The (2,2) and (2,3) modes are the 2nd and 3rd shell modes, respectively.

A digital data acquisition system is used to collect the necessary measurements at a prescribed sample rate and duration (up to 100 kHz). A LABVIEW® Virtual Instrument was developed to post-process the acquired data for analysis.

SPACER DETECTION

Numerical Analysis

Finite element analysis (FEA) of the vibratory behaviour of the PT indicates that distortions to one or more of the pressure, tube mode shapes will occur in the vicinity of a loaded spacer. These distortions are not present, however, if the spacer is unloaded. Figure 3 shows FEA results for a particular shell mode of the pressure tube. These results demonstrate that the axial location of a loaded spacer in a de-fuelled fuel channel may be determined by axially scanning the natural modes of the pressure tube using specially designed in-reactor tooling.

Laboratory Detection Tests

For these tests, a prototype of a detection and repositioning tool was inserted in the PT to obtain the necessary measurements. This tool was equipped with end clamps to isolate a short section of the PT for vibration. Special vibration sensors measured the relative vibration amplitudes of the PT wall in the 12 and 6 o'clock positions at several axial locations.

The results of a series of tests are shown in Figure 4, where the calculated signal output of the vibration sensors is plotted as a function of axial distance from a loaded spacer. Three sets of results are plotted corresponding to three different spacer loads. FEA predictions are also cross-plotted on this figure for comparison. The measurement results indicate that a local minima in the analysed signals exists at the location of the spacer (i.e., at 0 mm). These particular tests demonstrated that the signal strength was relatively insensitive to spacer loads above about 50 N (about 11 lb).

SPACER REPOSITIONING

Pressure Tube Constrictions

As the name implies, the snug-fit annulus spacer is designed to fit snugly around the PT when initially installed. Hence, the repositioning method must be able to overcome the residual tension force of the spacer around the PT. However, the repositioning method must also be capable of moving the spacer axially past a constriction without becoming stuck in the trough. Constrictions in the PT are a result of diametral creep of the PT arising from non-uniform neutron irradiation of the PT in the region between fuel bundles. The constrictions are deepest in the portion of the channel closest to the outboard end (i.e., where the coolant exits the fuel channel). Figure 5 shows the prediction of the axial profile of the PT between the 9^{th} and 10^{th} fuel bundles at 170,000 effective full power hours (EFPH) in a selected CANDU power reactor. This prediction was extrapolated from gauging data provided by the Deformation Technology Branch of AECL [3]. Based upon these data, a constriction was machined into the laboratory PT sample used in the repositioning tests. As shown in Figure 5, the slopes on the left and right hand side of the simulated constriction are designed to represent the maximum axial slopes in the profile of a constriction after 240,000 and 170,000 EFPH, respectively.

Spacer Creep

Radiation induced creep of the spacer material also has a bearing on the repositioning method since it alters the circumferential spacer tension. Calculations have been performed to predict spacer tension for a given rate of neutron irradiation over a specified time [4].

Repositioning Tests

A comprehensive series of tests was performed to measure spacer repositioning using controlled vibrations of the PT. These tests revealed the variables that had the greatest influence on a successful repositioning effort, including those that resulted in the successful repositioning past the simulated constriction. In Figure 6, a sequence of video stills shows the results of a successful repositioning effort. Roughly ½ of the total span of the sample PT is shown in these photos, from roughly midspan on the left to the clamped end on the right. Vertical lines drawn on the PT are spaced at 50 mm intervals.

The starting position of the spacer is about 150 mm from midspan (t = 0 seconds). The second photo, taken after about 8 seconds shows that the spacer has moved about 75 mm in the right-hand direction. The final photo, taken after about 16 seconds, shows that the spacer has moved a total distance of 175 mm. The small white indicator mark on the spacer (at roughly the 3 o'clock position) shows that rotation of the spacer during repositioning was negligible in this test.

CONCLUSIONS

A new process to detect and reposition the snug-fit type of annulus spacer has been introduced. Several technological hurdles have been overcome in laboratory testing. Recent results indicate that the method is suitable for field use and work continues towards developing a reactor-ready tool. A patent on the technology is pending.

ACKNOWLEDGMENTS

The funding for this project was provided by AECL under Nuclear Platform Work Package FC-040738. Special thanks are extended to the Deformation Technology Branch of AECL for providing the PT gauging data.

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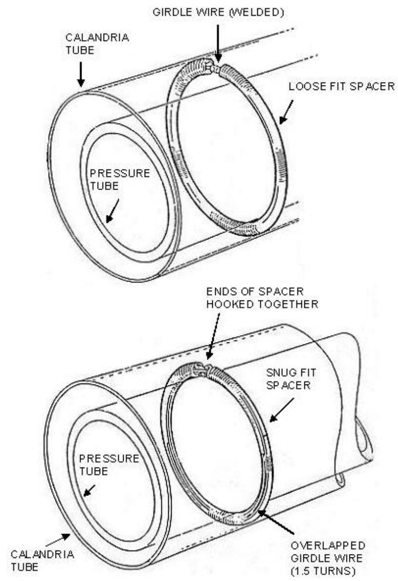

Figure 1 Comparison of a loose-fit and snug-fit annulus spacer in the annular space of a fuel channel [1].

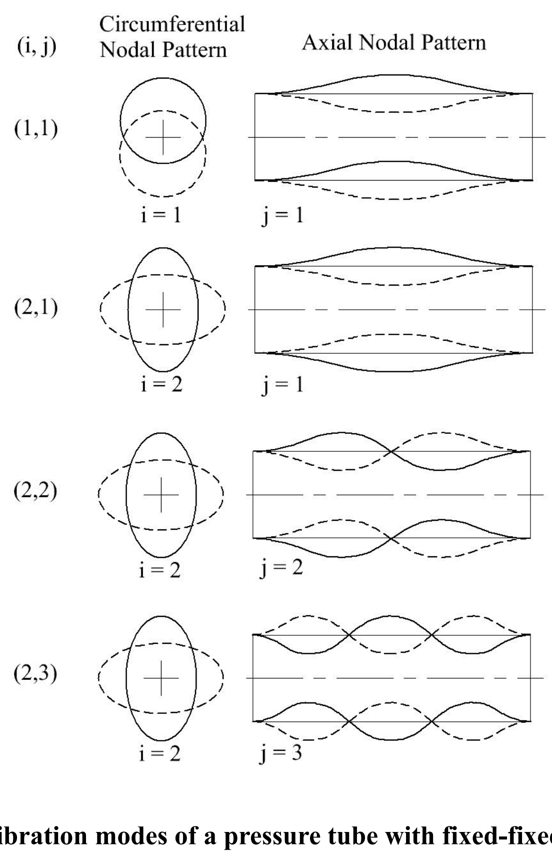

Figure 2 Natural vibration modes of a pressure tube with fixed-fixed end conditions [2].

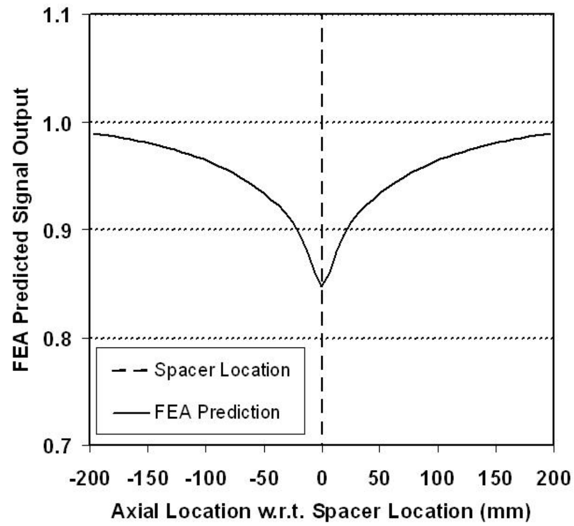

Figure 3 Finite element analysis prediction of mode shape distortion in the vicinity of a loaded spacer.

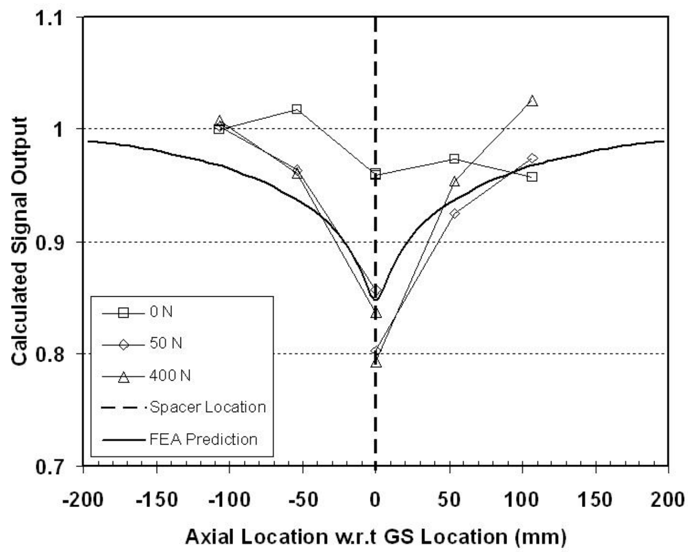

Figure 4 Experimental measurements of mode shape distortion in the vicinity of a loaded spacer with FEA prediction superimposed.

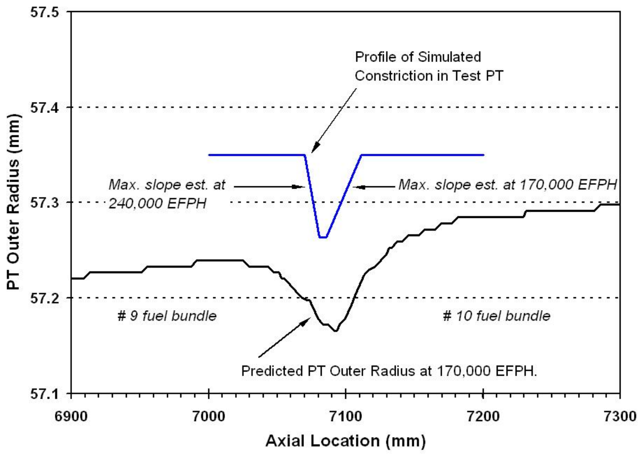

Figure 5 Prediction of constriction profile in a pressure tube in a CANDU power reactor with simulated constriction profile superimposed [3].

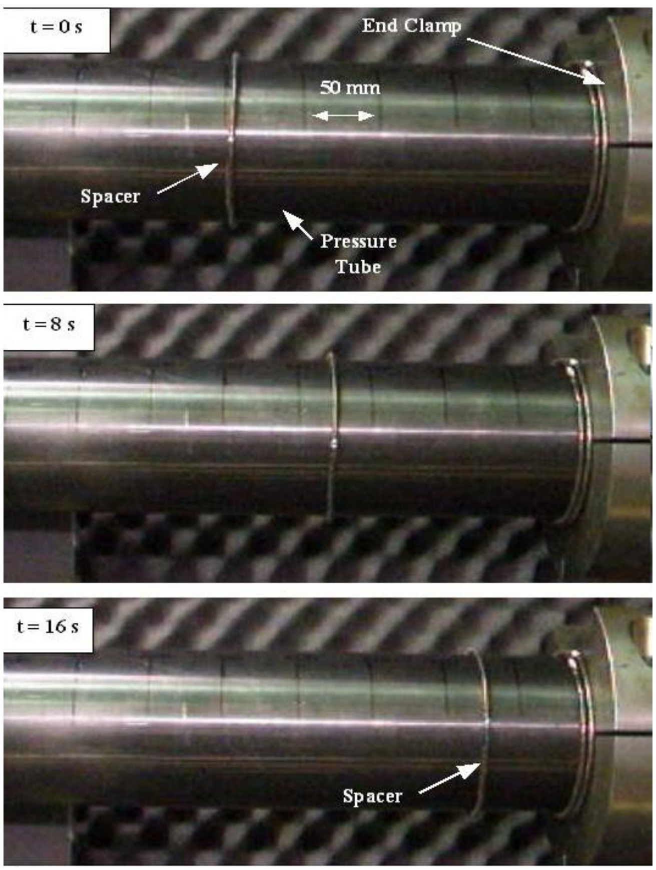

Figure 6 Photo sequence of spacer repositioning.