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Diagnostics of direct CT–PT contact of the coolant channels of PHWRs

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Abstract

It has now been realised that the garter springs which maintain the gap between the pressure tube (PT) and calandria tube (CT) of a PHWR can get displaced significantly from their design position in many channels. It has also been recognised that the large unsupported span of the PT restricts the life of the channel due to premature contact of the PT with the CT making it susceptible to delayed hydrogen cracking. This paper reports the details of a non-intrusive diagnostic technique based on vibration measurement for detecting the contacting channels.

1. Introduction

The basic building block of the pressurised heavy water reactors (PHWRs) is the pressurised coolant channel. As shown in Fig. 1, each coolant channel consists of a pressure tube (PT) which contains the fuel and hot pressurised coolant. The pressure tube passes through another tube called the calandria tube (CT) with the garter spring spacers maintaining the annular insulation gap. A number of such pressure tube–calandria tube assemblies immersed in a tank of low pressure, low temperature moderator form the reactor. There are 306 such channel assemblies in a 235 MWe reactor.

It has now been realised that the garter springs which maintain the gap between the PT and the CT of a PHWR can get displaced significantly from their design position in many channels. It has also been recognised that the large unsupported span of the PT restricts the life of the channel due to premature contact of the PT with the CT making it susceptible to delayed hydrogen cracking.

The conventional techniques for channel inspection call for extended shut down of the reactor and complete unloading of the channels. The total time and effort involved in such measurements preclude the inspection of all the 306 channels of a 235 MWe reactor in a single shut down.

To circumvent the unacceptable downtime and cost of inspection, a non-intrusive technique has been developed and implemented for identifying the channels with direct CT–PT contact. The technique uses the dynamic response, as measured at the two ends of the channel for identification. This paper brings out the definition of the discriminating criteria, the actual measurement and feature extraction for the identification.

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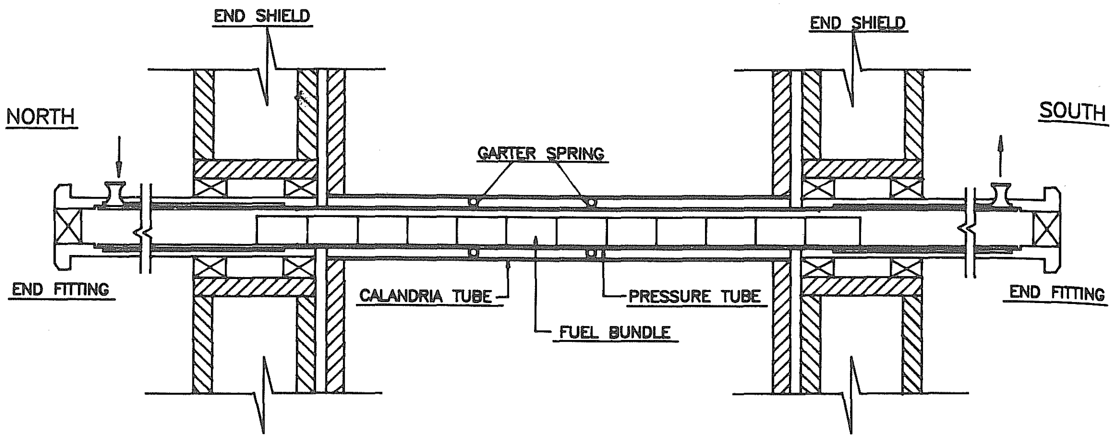

Fig. 1. Coolant channel of PHWR.

2. Discriminating feature of a contacting channel

The response of a contacting channel to a broad band excitation is limited to fewer modes than a non-contacting channel. This feature of response in a narrower band has been used to identify the contacting channel. A small excitation due to the shut down flow is sufficient to bring out this feature. Fig. 2 shows this difference for two channels on which in-service inspection (ISI) has been done to confirm the status.

Because the excitation level due to shut down flow is small, feature extraction calls for additional processing which is described separately.

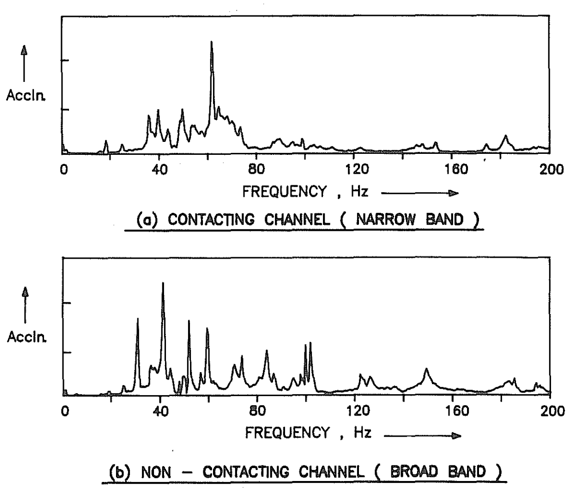

Fig. 2. Dynamic response of coolant channel.

3. Theoretical basis for the discriminating criteria

To understand the dynamics of the contacting channel, a finite element analysis of the channel was carried out. Fig. 3 shows the model which has been analysed. The PT and end fittings were modelled using beam elements. The CT was modelled with single mass and spring corresponding to its first mode. Since the contact generally takes place around the centre of the span, and the first mode of the fixed–fixed CT is the most significant contributor to the response, such a simplification would approximate the interaction between the PT and the CT adequately enough to bring out the discriminating feature. The response of the model to an impulse given at one end was computed. The response was computed using the Newmark-β method (Bathe, 1978; Belytschko, 1976; Cook, 1981). When the PT does not contact the CT, it responds to the impulse based on its own dynamic characteristics. When the CT and the PT cross each other, an elastic impact is simulated (Ma, 1976)—that is, there is a momentum transfer from the PT to the CT wherein there is a conservation of momentum and kinetic energy. For these conservation equations, the participating mass of the first mode has been used for both PT and CT. Since the interaction occurs at anti-nodes of the first mode, such an approximation could still represent the dynamics adequately as may be seen from the experimental results referred to subsequently. The solution was carried

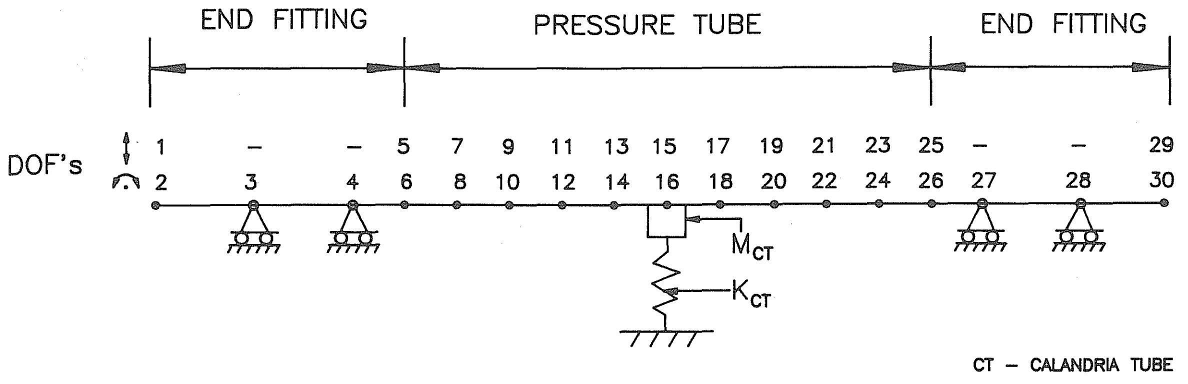

Fig. 3. Finite element model of contacting channel.

out with a time step of 1.0×10^{-5} s. To ascertain the accuracy of solution, the time step was reduced progressively to 1.0×10^{-6} s. On a visual comparison of the power spectrum of the solutions, no change in the pattern could be noticed.

It may be noted that the actual energy exchange between the PT and the CT could occur in more than one beam mode. Moreover, since the CT is thin, the contact at a localised point could excite shell modes as well. These have not been considered in the model and their effects are explained subsequently.

Fig. 4 shows the response of the centre of the channel to the impulse at one end. The figure shows the interaction between the PT and CT.

In the actual reactor, the measurement can only be taken at the ends of end fittings. Fig. 5 shows the spectrum (Digital Signal Processing Committee, 1979) of the response of the end of the channel opposite the one where the impulse was given. The figure also shows the spectrum when such a non-linear CT–PT interaction is absent. It can be seen that some of the modes are attenuated.

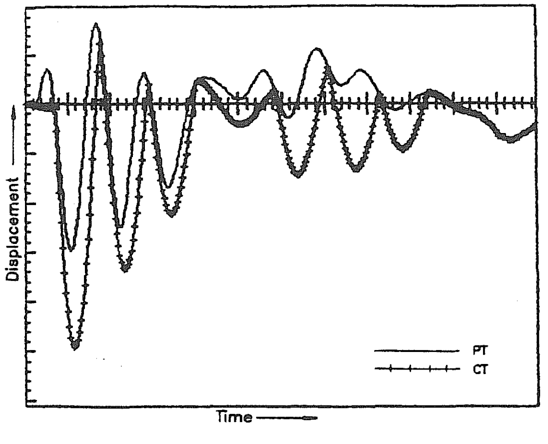

Fig. 4. Impulse response of the centre of the contacting channel.

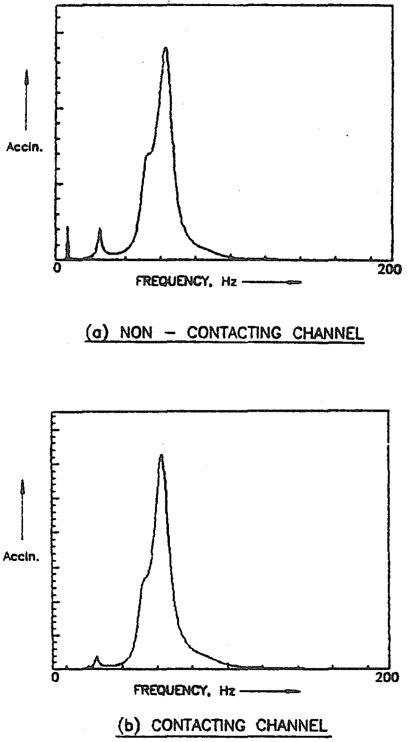

Fig. 5. Spectrum of analytical response of coolant channel.

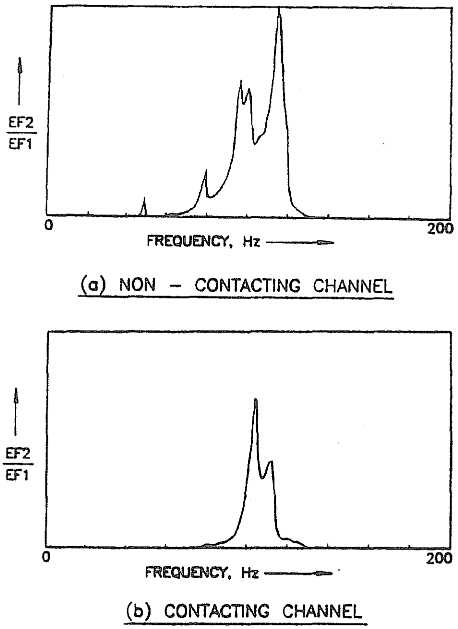

Fig. 6. Transfer function reported from Embalse (de Paz, 1991).

3.1. Experimental validation of the theoretical basis

De Paz et al. (1991) have reported experimental transfer functions of the contacting and non-contacting channels. These are shown in Fig. 6 where again the attenuation of the modes could be clearly seen; in fact, this is slightly more evident than the analytical results of Fig. 5. This is understandable as the present analytical model does not account for the transfer of energy in higher beam modes and the shell modes.

4. Feature extraction

As brought out in Sections 2 and 3, the non-intrusive technique to detect CT–PT contact makes use of the phenomenon of narrow band response of the contacting channels when subjected to broad band excitation due to flow through the channels. It has been observed that the small excitation due to shut down flow is sufficient to bring out the difference between a contacting and a non-contacting channel. Even though the phenomenon could be observed consistently in all the contacting channels, a discriminating criterion to identify all the contacting channels without missing any and to identify the non-contacting ones with high confidence could not be defined from the power spectrum of the signals. This was observed to be due to higher instrumentation and structural noise during the measurement of very low level vibration due to small shut down flow. Figs. 7(a) and 7(b) show the power spectrum from two ends of the end fitting of a non-contacting channel. While the response at the north could be termed narrow band, the south side shows many frequency components.

To overcome this handicap, the vibration from both the ends of the coolant channels were measured with multiple high sensitive modal accelerometers with different design and electronics.

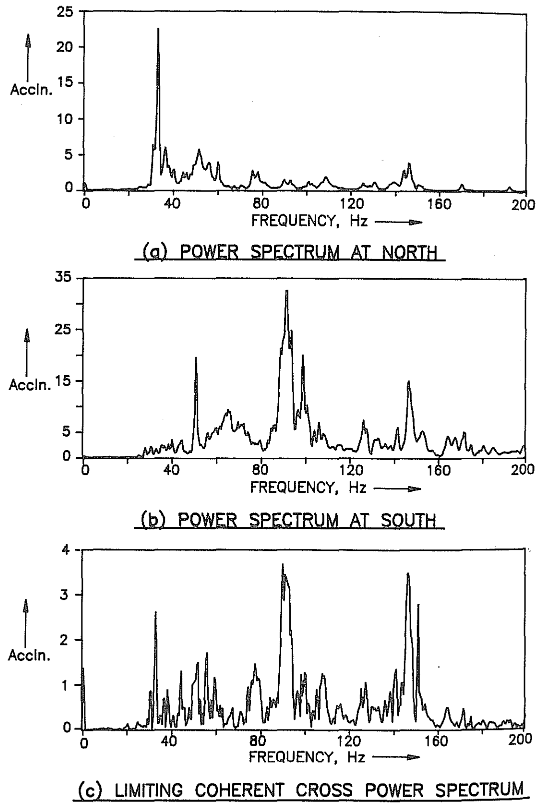

Fig. 7. Feature extraction non-contacting coolant channel.

These were processed to attenuate the extraneous noise. The processing is explained heuristically as follows.

The vibration spectra due to the coolant channel modes have to be identical on both the sides. However, we found in Figs. 7(a) and 7(b) that there are some peaks which are not common in the two figures. They could come either from components outside the channel or from the instruments. One way of getting over these problems is to compute a coherent power spectrum—that is, the power spectrum of one side which is coherent with the other. If we were to take the cross power spectrum of the coherent power spectrum of either side we would get a reliable spectral pattern for the channels where the influence of the external components would be minimal. Using accelerometers of different designs and electronics, the noise characteristics could be different, thus minimising the instrument noise as well. If we have multiple accelerometers, it would be possible to obtain the limiting value of these cross spectra by taking the geometric mean of the coherent spectra. The vibration signal pattern so derived is termed limiting coherent cross-power spectrum. Fig. 7(c) shows such a limiting coherent cross-power spectrum which brings out the feature clearly.

The bandedness of such a spectrum is estimated by the fraction of the total power concentrated in a defined band. The higher the concentration of the power in the defined band, the higher the possibility of contact. This concentration is defined by the contact index (CI) parameter. In other words, CI indicates the fraction of the total power contained in a specified band and is an indicator of the probability of contact.

5. Qualification of the discriminating parameter

To qualify the discriminating parameter, vibration measurements were conducted on a total of 30 channels from different reactors on which ISI was also carried out. It has been observed that all the contacting channels have a high value of CI. For the purpose of predicting the contacting channels, the cut off value for CI has been so defined that none of the contacting ones would be missed and any error would be only to identify the non-contacting ones as contacting. This ensures adequate conservatism as far as the safety of the reactor is concerned.

6. Application of the technique and feedback

The technique has now been applied to survey the entire core of two power reactors. Of the two, the ISI has been carried out on one of them. Here, five out of the top six channels in the order of CI have been found to be in contact. In the other reactor one channel with a high value of CI was inspected and was also found to be contacting.

7. Discussion and conclusions

Presently we have 51 channels from different reactors for which the ISI data and vibration measurements are available. Of these, about 20 are found to be in contact, and in all of them the CI values are high. The results of these 51 channels can be grouped into three categories.

(1) *Channels with* $CI > 85$—out of 14 such channels, 11 are contacting.

(2) *Channels with* $CI < 70$—out of 14 such channels, none is contacting.

(3) *Channels with* $70 < CI < 85$—out of 23 such channels, nine are contacting.

This shows that CI is a reliable parameter for identification of contacting channels.

Presently the cut off value of CI is deliberately kept low ($CI = 70\%$) so that none of the contacting channels is missed. Even then, the inspection load has come down to really small numbers. With feedback from more channels available it would be possible to refine the criteria further so that the inspection effort is still reduced and it is concentrated on channels with suspected contact.

Acknowledgements

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