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Review Article

Dynamic Analysis of Coolant Channel an Internals of Indian 540 MWe PHWR Re

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Abstract

The horizontal coolant channel is one of the important parts of
reactors. There are in all 392 channels in the core of Indian 54
uranium fuel bundles and shielding and sealing plugs one each on
flows through the coolant channel and carries the nuclear heat tc
production in the turbo-generator. India has commissioned one
another similar unit will be going into operation very shortly. For
internals under the influence of high coolant flow, experimental ai
correlation has been achieved between the results of experimen
typical coolant channel typically ranges from 10 to 15 full-powe
health monitoring becomes an important activity. Vibration dia
management of coolant. Through the study of dynamic characteris
condition, an attempt has been made to develop a diagnostics to
operating life. A study has been also carried out to characterize the

1. Introduction

In the first phase of the Indian nuclear power programme, the f
water reactors (PHWRs) of 235 MWe and 500 MWe ratings in d

PHWRs of 235 MWe in operation and additional four units o construction. Backed with excellent experience of design, constru India has stepped onto indigenous design of 540 MWe reactor operation successful in September 2005. There are many innovati almost all the systems so as to enhance safety in operation, to e operation more users friendly. One such component with new d important part of primary heat transport system. There are 392 through the calandria and end shield. Each channel carries 13 shielding plug, and one sealing plug on the either ends. The fuel 13.22 mm diameter and 495 mm in length. These are held b welded. The pressurized heavy water coolant flows through the co generators.

The coolant channel and its internals are under constant vibrat moderator circulation. In order to qualify the design of the coolant the core, it is important to carry out dynamic characterization Experimental and finite-element modal analyses have been carri element fuel bundles and the fuel locators under simulated nor results and its potential use as diagnostic tool to monitor the hea core.

2. Schematic of Coolant Channel and the Internals

Figure 1 shows the schematic of the coolant channel and its inter m. The outer calandria tube and the internal pressure tube are made of stainless steel. To keep the hot pressure tube and the w springs in the annular space. Important dimensions of the channel

(i) Fuel bundle: 37 element, 496 mm long, weighing 26 k
(ii) Pressure tube: 112 mm OD, 6.425 m long.
(iii) Calandria tube: 132 mm OD, 5.944 m long.
(iv) Fuel locator: 990 mm long and weight 42 Kg (two per
(v) Shielding plug: 990 mm long and weight 56 Kg (two p
(vi) Garter Springs: 4 tight fit on the pressure tube.

On a full-length high temperature and pressure test set up, v measurement was carried out with rated coolant flow conditions the pressure tube, circular holes were drilled on the calandria tu positions of these holes were so chosen that they do not foul wit enough to pick up the response corresponding to higher modes c the pressure tube through the holes in the calandria tube and si analysis.

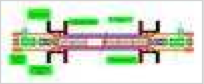

Figure 1: Coolant channel and its internals.

3. Modal Analysis

The pressure tube, the calandria tube, and the end fittings were in mvolt/g and excited with portable reaction type electromagnet sh was given to the shaker mounted on one end fitting. Figure 2 sho up to 50 Hz. The shape of the spectrum is typical to the end fitti [1]. Figure 3 shows the frequency response function of the two e The first mode natural frequency of the two end fittings are 10.2(end fittings are identical, the difference is basically because of th fittings. One is horizontally connected and the other is vertically co

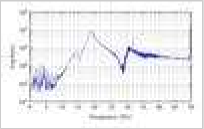

Figure 2: Shaker excitation to the coolant cha

Figure 3: Frequency response function of pres

Figure 3 also shows frequency response function of the pressure tube. The first two modes are at 6.5 Hz and 16.70 Hz. The pr response function of the end fitting. That is to say that without dir possible to monitor the dynamics of the pressure tube by monitor experimental mode shape of the pressure tube. The unsymmetrica condition on the two ends of the channel. Such unsymmetrical sh well.

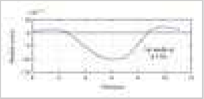

Figure 4: Experimental mode shapes of coolar

4. Finite-Element Model of Coolant Channel

A finite-element model of the coolant channel was developed on s loading and boundary conditions. Figure 5 shows the FE Model. discretized using 2-node axisymmetric-harmonic structural shell (bundles and the water in the channel is uniformly distributed on shielding plug(s), and sealing plug(s) are lumped at the respec springs between the pressure tube and calandria tube were mode out for the design as well as for other boundary conditions of conditions are explained in Table 1. These conditions are selecte inspection in some channels of different operating reactors. Sor channel during its lifetime in the reactor. Others, like shifting of ga and bunching of garter springs, are considered only for academic not feasible in the current generation PHWRs under normal circum channel is irradiation-induced creep. The effect of creep is to ir discussed in para 6.1. The first three natural frequencies for differ 2.

Table 1: Channel cases considered in the anal

Table 2: Natural frequencies of coolant channe

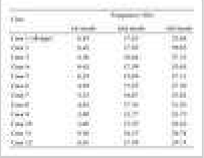

Table 3

Figure 5: Finite element model of the coolant

Figure 6: Coolant channel different garter
Bearings shown in green.

Figure 7: Coolant channel with different beari

4.1. Channel Dynamics in Design Condition

The first two natural frequencies of the coolant channel model are
match with the experimental values shown in Figure 4 under si
experimental channel is a full-scale setup, the close match of FE
the FE results are directly applicable to the reactor. Having tune
under simulating loading condition such as fluid structure interacti

The important boundary conditions of direct relevance and that
significantly are cases number 7 and 8, which pertain to effective
quite likely that one or more bearing (out of four) may become pa
or when the irradiation-induced sag in the channel is large. The los
the channel frequencies significantly. Such a change is measurable
of coolant channels.

5. Response of the Channel due to Coolant Flow

The channel response was measured during the rated coolant flow
shows the response of the pressure tube due to the flow excitati
and 16.7 Hz, respectively, can be clearly seen. It has been seen
lower than rated flow due to lower flow excitation [3]. The amplitu
coolant flow then was 6.3 microns. Figure 9 shows the response
two spectra correspond to the first mode natural frequencies of th
two end-fitting modes as explained in para 3.0 and shown in Figur
seen in the response spectrum of one of the end fitting at 6.25
ratio of 6.25 Hz peak at center of the pressure and on the end fi

analysis capabilities, it is possible to identify the first mode of the p

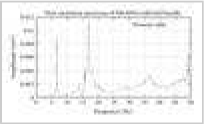

Figure 8: Flow excitation spectrum of pressur

Figure 9: Flow excitation spectrum of end fitti

6. Channel Response Characteristics as a Tool for D

Having been able to measure the pressure tube vibration from th diagnosing the health of the pressure tube during plant operatio online process carried out by the special purpose machine, which The same machine can be made use of for measuring the end fitt campaign may be undertaken. The only requirement would be observed that the shut down flow is not sufficient to excite the cha can be detected on the end fittings.

As can be seen from the results of FE model of the coolant chan condition of the channel results in change in its modal frequenci changes in the channel-bearing conditions and number of effe developed on the basis of channel vibration to detect changed reactor is explained in next section.

6.1. Nonintrusive Diagnostic of Coolant Channels in Earlier

In the earlier generation Indian PHWRs, the concept coolant c channels except that the sizes are different. Accordingly, the mo were two loose garter springs in the annulus of the coolant cha channel to keep the hot pressure tube and the cold calandria t reactors was 19 element bundles weighing about 16 Kg, which ar

During the commissioning activity, when the channels are subje channel. In such a condition, the loose garter springs are free to s fluid flows in the pressure tubes and hence induces vibration in th the garter springs got shifted in number of channels. This displac mm between the two tubes when the fuel is loaded. This and irra contact between the tubes in loaded condition. Such a contact i reactor.

To identify the contacting channels in the core, a nonintrusive change in natural frequency of the channel. In this technique, o portable shaker and response is measured from the other end of t the first mode of the channel. With this technique, the entire core frequency. As low-level excitation is given to the channel, the nei influence the channel under excitation. Such screening campaig repeating two to three times on the same channel over the period channels with high creep, the first natural frequency of the cha shows the trend of the natural frequencies with high and low creep

The first mode natural frequency of the coolant channel of 235 540 MWe channels. Due to irradiation-enhanced creep and due had sagged (elastic and plastic) by more than 14 mm in the c channels into a permanently sagged condition. Such channels sho of increase was found to be very slow in a healthy channel wher found to be relatively fast.

Some of the typical channel frequencies and its changes over the channels shown in the table below were removed from the core ir of suspected contact based on analytical estimation of time of cont flux channels. Except for channel D15 and N10 other four channe table that all the four contacting channels had first-mode freque which was an increase of 0.175 Hz from normal. Since the sma was 0.03 Hz, it was possible to trend the change in the frequen natural frequency was reliably used as a diagnostic tool to identify

7. Fuel Bundle Vibration

The fuel bundle in the 540 MWe reactors is made of 37 elements, fuel. In Indian PHWR channels, there are some changes with resp fuel bundles per channel instead of 12 and there is fuel locator or which is free in the channel and so is in contact with the first and come as a requirement for the fueling machine design.

In view of the new in-core components in the channel, a study vibration performance. Such a study was carried out in a specially fuel locator vibration by optical vibration transducer through a Per conditions were simulated and the dynamic head of the coolant being the main source of excitation to the in-core components, th different flow rate through the channel.

Figure 10 shows the picture of optical probe measuring the fuel v spectrum of the first bundle measured at the front, middle, and peak in the spectrum corresponds to the first bending mode of t mode of the element is excited at about 70% of the rated flow. excitation reduces with increase in flow rate [5]. At 100% flow, rocking mode [5] of the bundle at 2.62 Hz can be seen in the t vibration of the element at 36 Hz was about 10 micron.

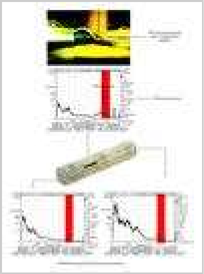

Figure 10: Experimental results of 37 element

8. Conclusions

The coolant channel is the heart of PHWR type of reactors. In PH
years. Besides the wear and tear in the channel due to continuou
induced damages to the material of the channel and associated s
changes happening in the channel from the reactor safety point o
the dynamics of the channel. The experimental and modeling stud
aim to understand the dynamics of the channel. The measured r
and from the response analysis of the channel during flow excita
channel.

Changes in the support conditions (garter springs), large sag
mechanistic changes also influence the dynamics of the channel.
observed in Indian PHWR channel over its operating life. These ch
less than 15 years. The study carried out in this paper aims to de
that happen in the channel. As an example, detecting contact betw
illustrated based on actual measurement and inspection.

The fuel bundles in the channel are also subjected to flow-induce
that under simulated test conditions, it is possible to detect fuel v
during the design phase of the fuel. There are number of reporte
flow-induced vibration. Detection of the bending mode of the fu
through this paper. Such fuel vibration overextended period of tim
in the channel that support the fuel.

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