Innovative Tool for ID Measurement of Coolant Channels of PHWRs

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Abstract

In PHWRs, fuel bundles are contained in Pressure Tube, these tubes guide coolant to pass through fuel bundles for heat removal. The gap between fuel and Pressure Tube is kept minimum, to allow movement of fuel in anticipated sagged channel. ID of the tubes increases over the time due to neutron flux and temperature, resulting in lesser heat removal from fuel, which increases chances of fuel clad failure. It is important to monitor increase in diameter to avoid fuel clad failure. The ID is conventionally measured by Ultrasonic Techniques, which requires special machine to be installed on the Fuelling Machine bridge. Increased ID is one of the principal aging mechanism in PHWRs, hence it is advised to measure as many channels as possible. An innovative tool is developed for mass scale measurement of Pressure Tube, this tool can be deployed without much preparation and uses existing setup. Since the tool is Fuelling Machine operated it saves time and man-rem consumption over other methods. The uncertainty in measurement is found to be ±100μm. The tool was successfully used in reactor for ID measurement, with some abnormal readings in high sagged channels. The reengineered version of the tool is developed to get readings in high sagged channel up to 5% enlargement in diameter. The tool is tested in full length sagged channel successfully. This paper describes details of the tool with experimental results.

Keyword: Inside Diameter Measurement, Pressure Tube, PHWR.

1. Introduction

220 MWe Indian Pressurized Heavy Water Reactor (PHWR) consist of 306 numbers of horizontal coolant channels. Coolant channel consists of Pressure Tube (PT) with End-Fittings (EF) at both ends. The reactor vault contains Fuelling Machines (FM), one on each side of coolant channel, which move in horizontal and verticaldirection(on fuelling machine bridge) to approach channels. These machines are used for replacement of spent fuel from the channel with fresh fuel. The fresh fuel is inserted by one FM and spent fuel is received by other side FM. The FMs are capable to house fuel and other channel components in the 12 channel rotatable magazine. FMs have telescopic rams named Ram-B & Ram-C to push the fuel bundles, gripping of various components and operation of shield plug & seal plugs. The approach of rams in channel is extended by use of extensions stored in magazine.

Heavy water at high temperature and pressure flows inside the coolant channels. Periodic monitoring of ID is one of the important inspection requirements, as increase in ID beyond some limit causes problem of flow bypass across the fuel bundle, squeeze of garter spring and its structural integrity.

Conventionally, ID of pressure tubes is determined by non-contact type method (Ultrasonic sensor based). This technique requires special delivery machine to be installed on the Fuelling Machinebridge for delivery of Inspection Head (IH). This system has dis-advantages like, installation of the delivery machine on top of Fuelling Machine (FM) bridge, laying cables, setting up control room, special procedure, defueling of channel, manual joining/disjoining of drive tubes in the FM vault.

To overcome above limitations, anFM operated ID Measurement Tool (IDMT) has been developed at Refuelling Technology Division, BARC [I]. The tool has many advantages over presently available ID measurement tools. IDMT is FM operated and can be used for large scale measurement quickly in reactor shutdown condition. It does not require cable/hose connection. Once the tool and Extensions are loaded in to the magazine of FM, ID measurement of large number of channels can be carried out remotely from control room. IDMT can be loaded in FM magazine from FM service area and afterwards no human intervention is required in the active area, hence man-rem consumption in entire operation is negligible. IDMT is simple mechanical tool with only one moving part to actuate balls. The tool can be deployed without defueling.

IDMT was designed and deployed [II] in one of the PHWR in September 2010 (26 channels) [III], August 2012 (16 channels) [IV,V] and recently in April 2014 (41 channels). The IDMT readings were found to be useful for estimating peak diameter in the channel and werecomparable with other technique within accuracy margin, with some shortcomings in IDMT readings. The tool is re-engineered into a compact IDMT to overcome short comings. This paper describes details of development of compact IDMT and its trials at shop floor.

2. Overall Scheme

IDMT is simple mechanical tool which does not house any sensor and instrumentation. The scheme uses locating IDMT against fuel column with the help of extensions and fuelling machine rams at required axial position in channel. After locating tool, it is actuated by ram- C and movement of Ram-C measured by its potentiometer which in-turn indicates the inside diameter at that location. Figure-1 shows pictorial representation of the scheme.

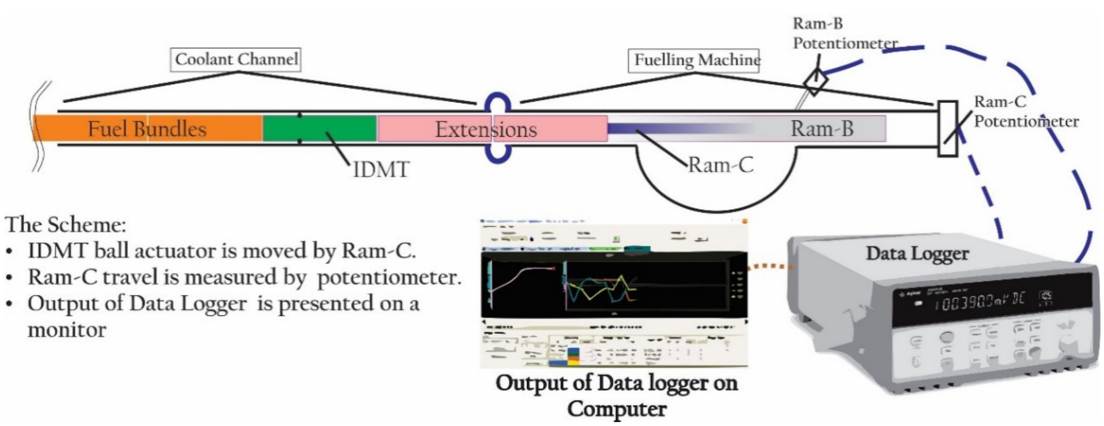

Fig. 1: IDMT schematic

3. Working Principle

IDMT (fig. 2) is assembled with 3 balls (5) supported on a ball actuator (4) and retained in the specific grooves. The balls get radially outer movement due to axial motion of a taper ball actuator. The ball actuator is moved in axial direction by Ram-C of FM. The ball actuator is normally held backwards by spring (6) force. In this condition balls are in collapsed condition. Due to Ram-C advancement, ball actuator & stem (1) move inwards (spring getting compressed) causing balls to move radially outward towards PT walls. The balls radial movement is a linear function of ball actuator travel. Ball actuator has one degree half cone angle, this results in 0.035 mm diametral travel of balls for each 1 mm travel of ball actuator. Ram-C travel is calibrated in terms of PT inside diameter.

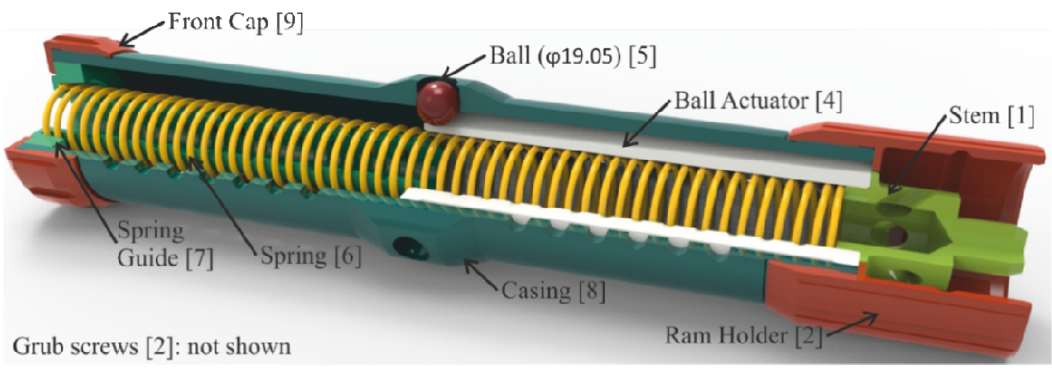

Fig. 2: IDMT 3D visualization, component number in square bracket

IDMT is loaded in the measurement side FM. Fuel column is located such that tool is able to reach the desired location. During measurement tool front face gets supported against the fuel column. The tool is located at the required position in the channel by Ram-B of measurement side FM. To reach up to center of the channel, extensions(4 nos) are used. Other half of the channel can be approached from the opposite side FM. Subsequently Ram-C (measurement side FM) is advanced, to moveball actuator and balls in the tool expand radially out till they come in contact with PT. The travel of Ram-C is recorded to calculate inside diameter of PT. following formula used to estimate ID of pressure tube, eq. [1]:

$$ID = ID\_min + K\,(X - E) \quad \text{.......} [1]$$

ID_min: Ball over diameter, ball actuator fully retracted condition
K: 2*$tan(\theta)$, θ: half angle of ball actuator cone
X: Ram-C travel
E: Extra travel of Ram-C, due to gaps between extensions rods and IDMT stem

4. Motivation for Compact tool development

The main concern of earlier IDMT was its measurement profile shows prominent dips. Figure 3 shows typical plot with dip in ID profile, the dip is about 1.3 mm.

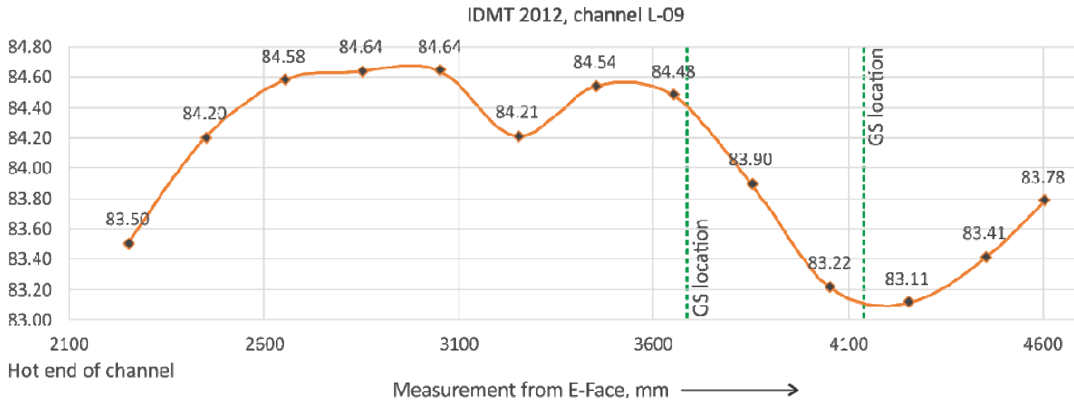

Fig 3: Typical plot showing dip in ID profile

This problem was analysed for all possible factors viz. potentiometer resolution, lifting force inadequacy and geometric constraints due to high sag and curvatures.

Figure 5: Recently manufactured compact IDMT components

The most prominent reason for dip is, in case of sagged channel tool becomes incapacitated and it's all balls donot touch the coolant channel ID.Thisresults in reading lesser diameter. Fig. 4 shows exaggerated PT curvature and case where one ball and IDMT body aretouching inside surface of the PT. In this case, the IDMT reading willbe less than actual Inside Diameter.This problem is overcome by shortening of length of the tool. In view of above the IDMT is designed and the length of tool is shortened to as minimum as possible to eliminate the dip problem, fig. 5.

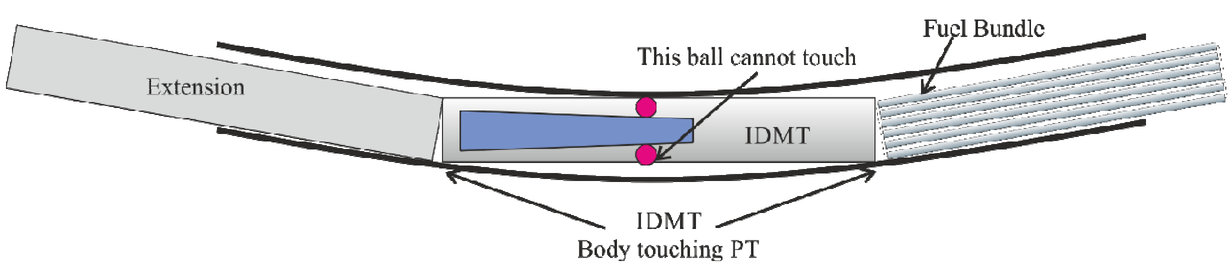

Fig. 4: Explanation of reading lesser diameter than actual

Calculations were performed for effect of actual sag and ID at the end of reactor life to find numerical error in ID.

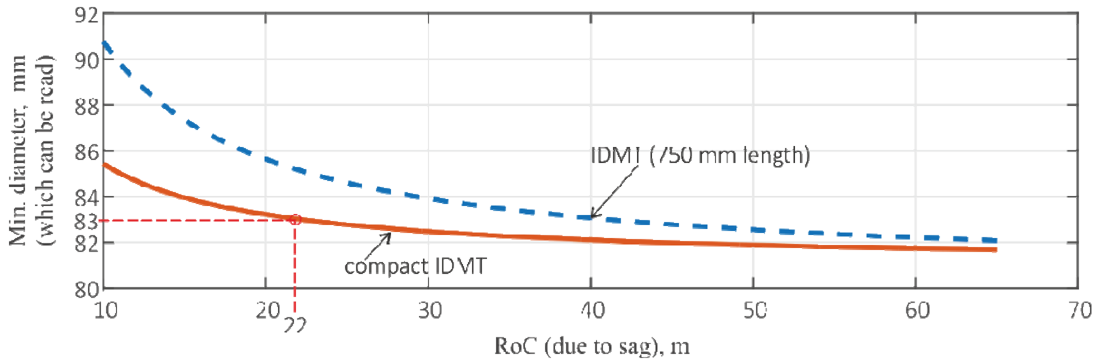

Figure 6: Relation between Radius of Curvature (RoC) and min. diameter required for reading

From above curve, fig. 6, it is seen that, compact IDMT can be used upto 22m RoC, as PT min. diameter is 82.55 mm. From available sag data, it was found that there are cases where curvature reduces beyond 22 m, at some locations at the end of life of channel.

5. Shop Testing

A setup is fabricated for sagged channel ID measurement, refer fig 7. IDMT is tested with and without sag in high diameter (86.67 mm) pressure tube. A pneumatic cylinder is used to simulate Ram-C force of fueling machine. Cylinder force is controlled using a Pressure Reducing Valve. IDMT with maximum 2 extensions were used to take readings at various locations.

Fig. 7: Sagged pressure tube test setup

Figure 8: Pneumatic cylinder, for Ram-C force simulation

The IDMT performance was satisfactory in the trials. Force required to take reading is 45 to 60 kgf (only IDMT) and 75 kgf (with one dummy extension). Tool was lifting and reading was within ± 60 µm.

Table 1: ID readings in simulated sag pressure tube						
S. No.	PT location, from ‘A’ side, (mm)	Travel (mm)	Pressure Tube ID, mm			Remarks
			Measured	Actual	Error	
1	210 (no extn.)	155	86.62	86.67	0.05	Straight Tube
2	220 (no extn.)	156	86.65	86.67	0.02	Straight Tube
3	1210 (1 extn.)	157	86.69	86.67	-0.02	Straight Tube
4	3210 (3 extn.)	157	86.69	86.67	-0.02	Straight Tube
5	3210 (3 extn.)	158	86.73	86.67	-0.06	Straight Tube
6	3410 (3 extn.)	159	86.76	86.67	-0.09	With sag 40 mm
7	3450 (3 extn.)	159	86.75	86.67	-0.08	With sag 40 mm
8	3450 (3 extn.)	159	86.76	86.67	-0.09	With sag 40 mm
9	3450 (3 extn.)	159	86.77	86.67	-0.10	With sag 40 mm

Diameter of sagged pressure tube was 86.67 mm. the Table-1 results are within 100µm of actual diameter. There is no detrimental effect observed due to sag in the readings of IDMT. It is observed that smaller IDMT is capable of taking correct readings in 40 mm sagged tube.

6. Conclusion

For fuel bundles safety,it is important to monitor Inside Diameter of pressure tubes at regular intervals.A tool has been designed and developed to monitor ID of channel, which has many advantages like, mass scale wet-condition measurements using existing Fuelling Machines,remotely operable, quick deployment, no cable connection, negligible man-rem consumption, easy operation and maintenance.

TheIDMT is capable of capturing correct ID even in case of 40 mm sag. The accuracy achieved is about ±100µm. IDMT has solved problem of dips in the ID measurement based on trials taken at sagged channel set-up.

7. References

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