IMPROVEMENTS IN THERMAL AND VIBRATION RESPONSE OF MODERATOR HEAT EXCHANGES AT MADRAS ATOMIC POWER STATION

M.R.K. Rao and L.G.K. Murthy

Nuclear Power Corporation of India Limited

ABSTRACT

Vibration and thermal hydraulic analysis in addition to alteration in geometry have been studied to improve the thermal and vibration response of moderator heat exchangers at Madras Atomic Power Station. Mock up studies for in-situ experimental verification of theoretical predictions to ensure structural stability at enhanced flow have also been completed. The feasibility of modifying the heat exchangers to improve thermal capacity has been established so as to increase the reactor power by meeting technical specification requirement of moderator temp. This paper presents the summary of various investigations and analyses conducted.

1.0 INTRODUCTION

Madras Atomic Power Station consists of twin units pressurised heavy water reactors of 220 MWe capacity each. The inlet manifolds in both the units have partially got damaged due to structural defects and the reactors are being operated in the reverse moderator flow mode with reduced flow rate and at reduced power. The flow reduction had to be done due to the modification in moderator circuit for reverse flow. The moderator has to be kept below 70°C at the outlet of calandria as a requirement of technical specifications since this temperature limits the NPSH of the moderator pumps. The main moderator heat exchangers which are of shell and tube type have the moderator on tube side as shown in (Fig.1). The design flow of process water on the shell side was found to excite vibration and failure of tubes at an earlier site. This is due to the fact that the area of admittance for the flow at the central belt portion is about 0.3 sq.metre per pass while the outlet nozzle area is only about 0.1 sq.metre. Hence the heat exchangers have been operating at 50% design flow of process water since commissioning.

For increasing the power of reactors, attempts to reduce the inlet temperature of moderator to the calandria by improving the performance of the heat exchangers has been studied and the feasibility
of modifying the heat exchangers has been established. This paper presents the summary of various investigations and analyses conducted.

2.0 FLOW INDUCED VIBRATION STUDIES

2.1 Theoretical
Firstly, studies investigating the safe cut off point for process water flow from flow induced vibration consideration and the effect of increasing process water flow as a means of enhancing heat transfer were undertaken.

Initial study of cross flow velocities, based on TEMA standards was found to be inadequate. Hence a detailed three dimensional flow analysis for velocity mapping on shell side was carried out using a computer code TMYC-3D (2). Results showed that the cross flow velocities calculated were slightly greater than the values calculated from TEMA standards. An initial study revealed that the flow velocity at the exit nozzles was about 6m/sec. and it was suspected that the tubes nearest to the nozzle were the most susceptible to vibration failure. However, Flow Induced Vibration analysis (FIV) based on fluid elastic instability modelling shows that the limiting velocity is at the edge of the segmented baffles and not near the exit nozzles. The analytical prediction based on FIV consideration indicates a maximum safe flow of 72% for the tubes near the baffle cut and 70% for the tubes near the exit nozzles.

2.2 Thermal hydraulic studies
Thermal response studies indicate that it is possible to reduce the outlet temperature of the moderator by about 4°C by increasing the cooling water flow to the safe limit of 72% as predicted in the FIV studies. It was also observed that there is some reverse heat transfer taking place in the heat exchanger i.e., the temperature cross over is found to occur near the moderator outlet zone as seen in the temperature profiles of heavy water and process water (Fig.2).

2.3 Validation of computer code
Validation of thermal hydraulic code developed for this purpose (THYC-3D) was done by comparing the actual data on the moderator heat exchangers with the theoretical prediction. The measured and calculated overall temperature responses were found to match well.

2.4 Experiments
The safe cut off flow obtained from theoretical prediction from FIV analysis, will be subjected to verification by in-situ vibration measurements. Also vibration amplitudes measured from in-situ experiments will be used as input data to the analysis programme
to confirm whether structural stability is ensured for continuous operation of heat exchangers at enhanced flow.

Miniature piezoelectric accelerometers (ENDEVCO-2222C) have been calibrated and will be installed inside the tubes, after necessary draining and drying of heavy water from the tubes. Feasibility of installing such probes with proper type of mounting inside the tubes has been confirmed in a full scale mock up of the heat exchanger tubes. It has been established that the accelerometers respond adequately in the frequency range of interest with accuracy. The probe can be pulled along with the mounting through the entire tube including the U-bend portion.

3.0 ALTERATION IN GEOMETRY OF HEAT EXCHANGER TO ENHANCE CAPACITY

A mismatch in the inlet and outlet areas of the heat exchanger for secondary flow has been mentioned. To correct this situation, studies have also been made to alter the geometry of the heat exchangers. The present outlet nozzles which are at either end of heat exchanger can be converted to inlets through which 25% of process water flow can be admitted in each nozzle and together with the present 50% of flow through the central inlet, 100% flow can be achieved. This entails creation of new outlets for the flow as shown in (Fig.3). This option was also examined for flow induced vibration point of view and thermal response. The results indicate that with this modification in geometry, there is neither a vibration problem nor any reduction in thermal performance. The same reduction in outlet temperature of the moderator can be achieved as in the earlier case with augmented flow. However, this modification would involve cutting of slots/openings in the shell of the heat exchanger to provide for the outlets, through annular distributors.

3.1 Mock up and other studies
An experimental mock-up has been used to study the feasibility of cutting slots with spark erosion technique. It has been fully established that smooth and clean slots can be cut without any damage to the tubes nearest to the shell.

Stress analysis of the shell indicates that it is feasible to cut the slots without compromising the adequacy in strength.

Further thermal hydraulic and vibration studies were performed to assess the effect of these modifications. It was observed that even while passing 100% flow, vibration of the tubes is not excited any more. Also the thermal transfer pinch point indicating reversal of heat gets eliminated which results in improved heat transfer efficiency.(Fig.4).

4.0 CONCLUSIONS

Both the options studied do not involve any modifications work
on the heavy water circuit of the moderator system and hence does not call for any additional changes in operating parameters. The feasibility of implementing these modifications in-situ has also been examined from the point of view of accessibility and it is proposed to effect the changes in the next available shut down in Unit-II. It may be mentioned that reduction of moderator temperature in Unit-I has been achieved by incorporating a third heat exchanger, which has been found to be quite expensive.

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REFERENCES


Fig. 1: Existing moderator heat exchanger of MAPS

Fig. 2: Verification of temperature along the length of the tube at location shown above.

Fig. 3: Proposed alteration in geometry of heat exchanger.

Fig. 4: Verification of temperature along the length of a tube at location shown above.