Fretting Failures in Early Canadian Nuclear Steam Generators

by

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Abstract:

Fretting failures in early Canadian nuclear steam generators are reviewed. In all three designs considered, high single phase liquid velocities appear to have led to excessive vibrations and fretting failures. It is suggested that single phase liquid fretting was more damaging than two phase flow induced fretting because of the absence of the cushioning effect of the second phase and because of the existence of vortex shedding in single phase liquid flow which does not exist in two phase flows. These two effects (cushioning and no vortex shedding) need to be considered in steam generator design.

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1 Introduction / Preamble

Serious fretting failures occurred in the first three CANDU steam generators built in Canada: Nuclear Demonstration Plant (NPD), Douglas Point and Pickering A. As this fretting became rampant in both Canada and the USA, research facilities in both countries were quick to respond. CRNL, AECL, McMaster U, EPRI and Combustion Engineering all built test rigs to study boiling heat transfer. However, the first two Canadian plants failed from vibrations caused by single phase liquid cross flow. This paper reviews these early designs to determine the cause or causes of the fretting induced by single phase liquid cross flow.

2 Nuclear Demonstration Plant (NPD)

The NDP steam generator (figure 1) was a 20MW version of the full scale 50MW steam generator for the propulsion plant for the USA Navy submarine. Babcock Wilcox Canada (BWC) received the engineering design information as payment for the nuclear research work that AECL had done for the Allies during World War II. Because of the military origins, the full design history was and is not available. BWC did receive a set of US Navy controlled drawings from BW (the US mother company of BWC) with observers from the USA stationed at BWC's plant at Galt, Ontario (now Cambridge) to restrict distribution of information contained in the USA Navy drawings.

Thus we conclude that the design of the boiler was done by a group of engineers in the USA. These engineers asked BWC to calculate the heat transfer surface area using heavy water steam tables values (which BW did not use or support) and asked BWC to guarantee the result. Thus the responsibility for the design rested with BWC.

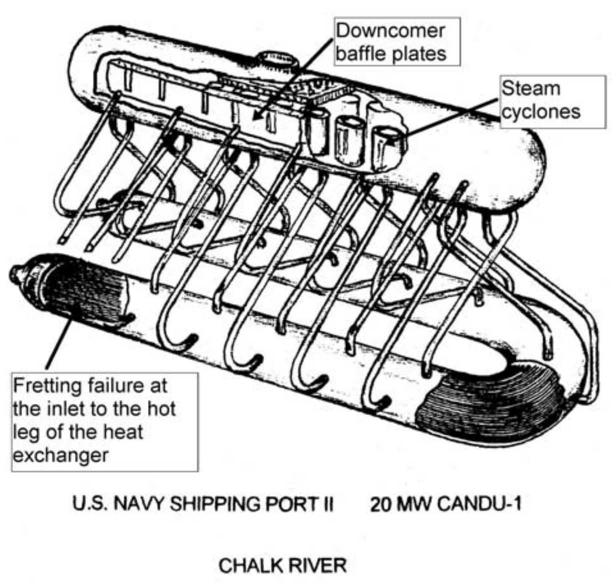

Figure 1 Nuclear Power Demonstration (NPD) illustration

It appears that the number of downcomer tubes blocked off in the steam drum were too few, leading to exit velocities that were too high. Consequently, fretting occurred in the area indicated in figure 1 (estimated 630 tubes with fretting failures in 9 years – J. Dyke) There were no guarantees set for this parameter.

In a follow up with the USA, BW responded that there was no evidence of similar failures in any of the USA Boilers and indicated that if there were any failures, it was classified Navy information.

3 Douglas Point

The next steam generator under consideration was for the Douglas Point 200MW station, the first commercial nuclear power station in Canada. While the details of the steam generator are different, the fretting occurred in single phase flow like in the NPD boiler. The design of this steam generator came from AECL's Nuclear Boiler Competition (1958-59). AECL chose a modified Combusting Engineering design. This revised design was included in the specifications for Douglas Point. It was specified as the only acceptable design until the rules were changed at the insistence of BWC.

This boiler directed the downcomer flow from the steam drum to the bottom section of one leg of the hair pin U bent tube heat exchangers. Normal design rules would have dictated entrance velocities which would not induce single phase fretting. However, cross tube velocities were too high and fretting occurred (see figure 2).

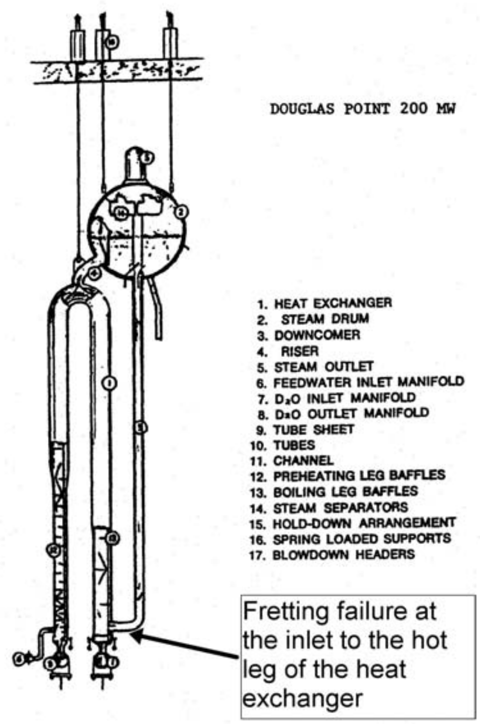

Figure 2 Douglas Point

At this point, fretting was also occurring in nuclear steam generators in the USA. Whereas Canada was experiencing single phase flow fretting as noted above, steam generators in the USA were experiencing two phase flow fretting at the top end of the tube bundles. In response, Combustion Engineering, for example, believed that it would probably be a good thing to design a bundle to have the exit flow over horizontal tubes rather than over semi-circular tubes exiting upwards. Thus the needs of each country were different. The USA technical bodies were interested in two phase flow fretting and most, if not all, of the experimental test rigs were set-up to study this problem. Very few people believed that it was necessary to use water only for the test medium to reach the real two phase conditions found in a pool boiling heat exchanger. Most labs thought that one could use a mixture of liquid water and Freon vapour or water and compressed air to replicate a two phase condition in the test rigs. Test results were spotty and unreliable, and most labs did not publish the results. In retrospect, it is now generally accepted that it is essential to use a single fluid (preferably water) with representative geometries, heat fluxes and velocities if one is to properly capture the phase change effects of bubble formation and collapse (boiling, flashing, local re-pressurization, condensation) and of phase change effects on flow regimes. The lack of single phase flow tests was also a concern to J. Dyke.

While looking for a solution for the best means of supporting the tubes, J. Dyke came across the fact that single phase fretting was more damaging than two phase flow induced fretting because of the absence of the cushioning effect of the second phase. In addition, vortex shedding, a source of vibration inducing forces, does not happen in two phase flows because the second phase separates from the main stream as it passes over the round tube surfaces, breaks the bond of the vortex shedding flows and stops the forces that cause the shedding action of tail streams. These are two important effects (cushioning and no vortex shedding) to know about when studying causes of fretting in boiling water heat transfer.

4 Pickering A 500MW Station

The third boiler under discussion is Pickering A. During the design phase of Pickering A the steam generator designers were gave priority to the design of tube supports. As it turned out, insufficient priority was given to the problems of single phase flow accelerated erosion / corrosion.

Up to this point the nuclear group at BWC had never dealt with setting the recirculation ratio in the steam generators. Hence, assistance was sought from the fossil group (1964/65). It seems that there must have been a misunderstanding or an error because, when Pickering A was under refit many years later, serious flow assisted corrosion was discovered to have taken place in the downcomer channel near the inlet nozzle of the internal economizer (see figure 3). This was disturbing news to say the least. It did show, however, that the design was correct in all respects other than the recirculation ratio, and the steam generator had preformed well over the years.

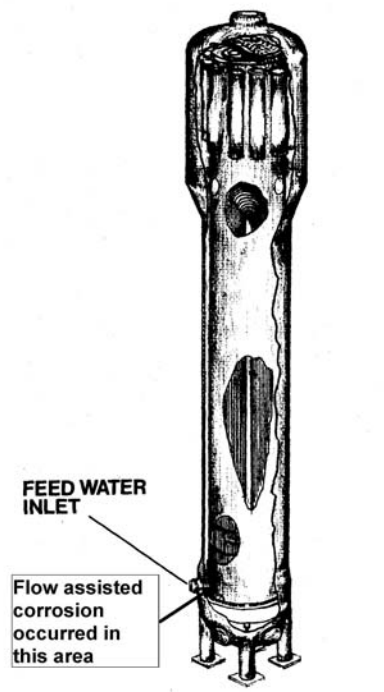

Figure 3 Pickering A Steam Generator.

The second generation steam generators should have been better. However, AECL and BW changed the tube support system for the Pickering B station from the lattice bar design used in Pickering A to broached hole plates and the U bent tubes to a ridge system. The steam generator tubes consequently did not stand up to their environment. For more information on the tube support aspects and steam generator design evolution, see [DYKE 2006].

5 Conclusion

The otherwise good performance of early Canadian nuclear steam generators was marred by excessively high shell side velocities in the inlet area of the hot leg of the tube bundles. The flow in this area is single phase liquid. As such, compared to the more benign two phase flow (from the vibration point of view), the mitigating factor of two phase flow cushioning is absent and the fretting enhancing factor of vortex shedding is present. This should be noted in future designs.

6 Acknowledgements

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7 References

DYKE 2006 "Evolution of CANDU Steam Generators, Babcock Wilcox Canada 1958-1980", by J.M. Dyke and Wm. J. Garland, CANTEACH March 2006, http://canteach.candu.org.