GENTILLY 2 DIVIDER PLATE REPLACEMENT

J. Forest
Hydro Quebec

E. Kiisel/G. McClellan/W. Schneider
Babcock & Wilcox, Cambridge, Ontario

CA9800486

ABSTRACT

The steam generators at the Gentilly 2 Nuclear Plant in operation since 1983 were built with primary divider plates of a bolted panel configuration. During a routine outage inspection, it was noted that two bolts had dislodged from the divider and were located lying in the primary head. Subsequent inspections revealed erosion damage to a substantial number of divider plate bolts and to a lesser extent, to the divider plate itself. After further inspection and repair the units were returned to operation, however, it was determined that a permanent replacement of the primary divider plates was going to be necessary.

After evaluation of various options, it was decided that the panel type dividers would be replaced with a single piece floating design. The divider itself was to be of a one piece all-welded arrangement to be constructed from individual panels to be brought in through the manways. In view of the strength limitations of the bolted attachment of the upper seat bar to the tubesheet, a new welded seat bar was provided. To counteract erosion concerns, the new divider is fitted with erosion resistant inserts or weld buildup and with improved sealing features in order to minimize leakage and erosion.

At an advanced stage in the design and manufacture of the components, the issue of divider strength during LOCA conditions came into focus. Analysis was performed to determine the strength and/or failure characteristics of the divider to a variety of small and large LOCA conditions. The paper describes the diagnosis of the original divider plates and the design, manufacture, field mobilization, installation and subsequent operation of the replacement divider plates.

INTRODUCTION

In September 1993, it was discovered that the original primary side divider plates in operation in the steam generators since 1983 had experienced a degree of degradation. The units were inspected, the damage stabilized and returned to service. Over a period of months, the problem and various repair alternatives were evaluated and replacement dividers were designed, developed and installed so that the units could be returned to service with new dividers plates in June 1995 as described in this paper.

SEGMENTED DIVIDER PLATES

The original divider plate construction for the Gentilly 2 steam generators incorporated a number of 1½ inch thick vertical panels supported by peripheral seat bars as shown in Figure 1. The divider assembly was of a floating configuration in which the segmented panels rested on the seat bars at their periphery in such a way that the dilation of the pressure vessel during changes in operating temperature and pressure were accommodated by sliding of the floating divider relative to the seat bars. The divider panels were attached to each other by a lap joint secured by a number of bolts. The lower edge of the floating divider was supported by a seat bar which was partial penetration welded to the primary head. The lap joint between the divider panels and the primary head seat bar was clamped by clamping blocks. The upper edges of the divider panels were bolted to a seat bar which was bolted to the tubesheet. At the outer corners of the divider in the space bounded by the end of the tubesheet seat bar, the head seat bar and the divider panels, a space exists which is filled with filler blocks which are called "ears" because of their shape. The ears were affixed to the outer-most divider panels. The divider plates were designed as segmented panels in order to meet the specified requirement that they be removable. Their design function was to partition the steam generator primary head so that the primary flow was directed from the inlet side of the head, through the tubes to the outlet side – a process involving a pressure drop of approximately 35 psi.

During a routine inspection in September 1993, it was discovered that two of the divider panel joint bolts were missing. One was discovered lying in the head and the second some distance down the primary piping. It appeared that the bolts which tend to be held in place by the flow had simply popped out at some time during the shutdown or during the subsequent waterjet decontamination process. Further examination showed that a number of the divider panel joint bolts had experienced erosion to the underside of the bolt head, to the shank of the bolt and even to engaged threads. The divider plate components of all four steam generators experienced this type of damage to some degree. The divider panel to tubesheet seat bar bolts experienced a similar type of damage. The clamping block and tubesheet seat bar bolts were relatively unaffected. After further inspection, it was determined that 9, 12, 20, and 7 bolts had to be replaced on SG's #1, 2, 3 and 4 respectively. On return to operation, it was noted that surprisingly the performance of the steam generators improved by a small but significant amount and that the amount of improvement happened to be consistent with the number of bolts which had been replaced in the respective steam generators – reinforcing the feeling that divider leakage may have been more significant than previously assumed.

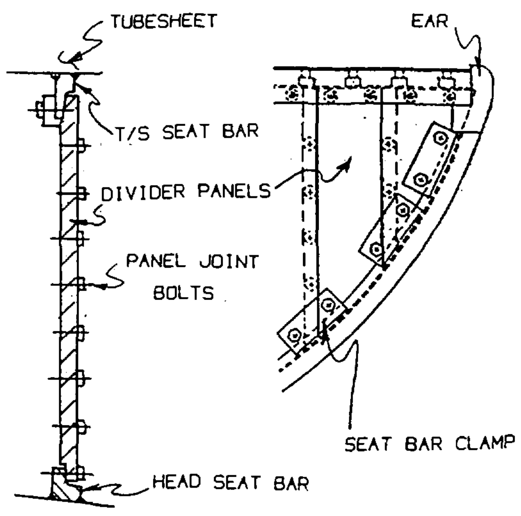

FIGURE 1
SEGMENTED DIVIDER PLATE

REPAIR & REPLACEMENT CONCEPT

On return to operation, work began immediately at B&W to develop a more permanent repair or replacement for the existing temporarily repaired divider. An initial concept for a flat floating divider somewhat like that used on the later Candu 6 steam generators was quickly conceived. It was realized that it should be possible to install the very large divider plate into the primary head in only 4 pieces – a very important consideration in minimizing the amount of in-head fitup and welding. In response to questions, suggestions and feedback from Hydro Quebec and NB Power, numerous variations and fixes were evaluated. At some point the variations included – replacement of the existing divider plate bolts only, doubling the number of bolts, replacement of the existing divider plate bolts and seating clamps, seal welding of the divider plate panels and replacement of bolts, replacement of the entire divider plate with a similar assembly, replacement of the divider plate with a one piece floating design with bolted joints, installation of the divider replacement components robotically, application of a seal panel over the face of the divider plate to preclude leakage, adding a seal panel and repairing bolts as well – and other variations too numerous to mention. Many of the alternatives were developed to the point of having a worked-out design concept, feasibility and cost.

Assessment of the individual options indicated that many of the quick and cheap options were in fact not quick and not particularly cheap – often costing a large fraction of the full fix cost and taking as long. It was also determined that the divider plates had to satisfy a wide range of requirements which were not met by any of the "quick" options. The selected option had to – correct the loose parts problem, sustain normal operating pressure differentials, accommodate vessel thermal motions, reduce divider plate leakage to an absolute minimum, preclude on-going erosion damage, accommodate various forward and reverse loss of coolant accident (LOCA) loads in an acceptable manner, be installable in a short period of time with a minimum radiation uptake, minimize in-head work including welding and be of a reliability consistent with this critical application.

After evaluation of many concepts and performing many cost and feasibility assessments, it was determined that a replacement divider of a dish shaped, welded, floating configuration was the only concept which adequately addressed all of the requirements.

WELDED FLOATING DIVIDER

The dish shaped welded floating one piece divider concept evolved from the prior flat one piece concept. The concept incorporated a 3/4 inch dish shaped central portion supported by a heavy peripheral rim. The dish shaped section allowed for a higher load bearing capability with greatly reduced weight and field welding requirements. The features of the floating divider shown in Figure 2 include:

- A one piece floating welded divider incorporating a thin dished central section within a heavy peripheral rim.
- 3/4 inch thickness to minimize weight and welding.
- The divider is fabricated in four segments which are manipulated into the primary head for final assembly.
- The divider incorporates a continuous peripheral tongue and groove support and seal configuration.
- A new tubesheet seat bar welded to the tubesheet weld overlay.
- Ears integral with the new tubesheet seat bar which fill the corner spaces and create an essentially continuous seat bar for the entire periphery of the divider.
- Erosion resistant material for the new tubesheet seat bar, for weld buildup on the sealing faces of the divider, and for a head seat bar liner to preclude further erosion.
- Tight fitup tolerances at seal locations to minimize leakage.

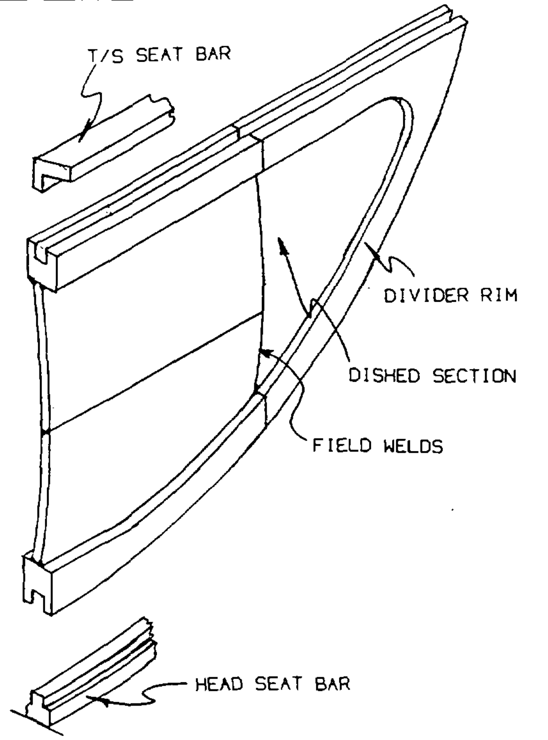

FIGURE 2
WELDED FLOATING DIVIDER PLATE

DESIGN & NORMAL OPERATION

The design configuration for the welded floating dividers was established based on a number of requirements established in a special design specification. The design considerations included;

- As a normal design condition, the divider must sustain a forward pressure differential of 61 psi. To demonstrate this capability the divider was subjected to finite element elastic/plastic plate model analysis. The divider is dished in the upstream direction and therefore tends to flatten as load is applied in the flow direction. At normal loads the deflections and stresses are small. During overload conditions the divider flattens and gets somewhat softer but does not "snap" as the dish shape flattens and eventually assumes the reverse curvature.
- The divider is required to sustain a static load of 130 psi as a means of demonstrating strength during small LOCA conditions. At this loading condition, the divider has deflected substantially and has assumed a degree of reverse curvature however it remains fully engaged at the peripheral seat bar.
- The divider needs to accommodate the dilation of the head and tubesheet during the thermal and pressure effects experienced in operation. This is accommodated by the sliding feature of the tongue and groove seat bar configuration.
- Divider plate leakage was required to be less than 1%. By tolerance control at the seat bars and the corner ear fillers, the calculated divider leakage during normal operation was reduced to 0.6%.
- The replacement tubesheet seat bar was classified as an ASME Section III, Class 1 pressure boundary attachment. This was accommodated by providing the seat bar material, the seat bar to tubesheet overlay weld and the seat bar analysis all to Class 1 requirements.
- No loose parts may be released from the steam generator during a large LOCA. The divider plate and seat bar configuration was designed to allow large inelastic distortion but to disengage in a graceful fashion so as to release the divider plate from the seat bars in a single piece.

LOCA LOADS

In December 1994, at a point where the divider plate concept and design had been fully detailed and where materials procurement and manufacture of components were underway, the need to design for LOCA loads suddenly changed from a consideration to a major requirement. LOCA load requirements were developed by Hydro Quebec in conjunction with NB Power who were simultaneously considering the need for divider plate replacement. It became necessary to incorporate the dividers into LOCA modelling i.e. to show that the dividers would sustain a range of small LOCA loads without rupture or disengagement, to show that during very large LOCA loads the dividers would be released without generating any loose parts outside the steam generator and that for certain intermediate loads the partially disengaged divider be considered in the modelling.

To address the LOCA loads, a large number of pipe break/divider plate condition cases were identified and modelled by Hydro Quebec. Response of the dividers to these various load cases was evaluated for B&W by Ontario Hydro using a dynamic, elastic/plastic finite element analysis. The results of the analysis have shown that the divider is able to sustain small breaks (5% and 7½% break sizes) with significant distortion but without any disengagement of the divider from the seat bar. For the purpose of modelling LOCA flow conditions, this allows the divider to be considered totally intact. The response of the divider to a small break LOCA is shown in Figure 3.

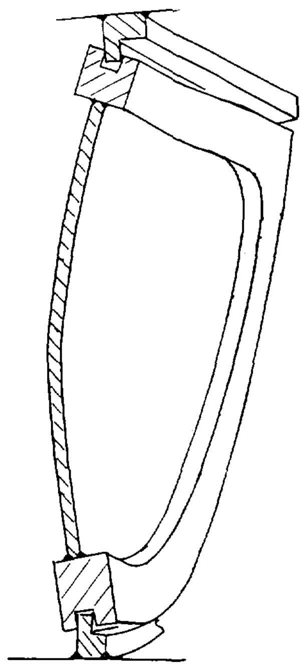

FIGURE 3
DIVIDER PLATE UNDER
SMALL BREAK LOCA LOADS

For the very large LOCA loads, the dynamic elastic/plastic analysis shows the divider to fully disengage from the seat bars. The central portion of the divider first pops through and dishes in the downstream direction, next the upper rim pulls downward and begins to disengage from the tubesheet seat bar and finally the entire peripheral rim pulls away and disengages from the seat bar so that the divider is fully disengaged from the seat bar and is moving toward the outlet nozzle. In this condition, the divider is fully open for purposes of LOCA flow modelling. For various intermediate LOCA loads, the divider may partially disengage and offer a partial flow area for consideration in further LOCA analysis.

In the large LOCA case, analysis has shown that the divider plate is totally intact though severely distorted, that the new tubesheet seat bar remains totally intact and welded to the tubesheet but with some seat bar distortion and that the head seat bar is distorted but remains welded to the head. The new U-shaped liner which is applied over the primary head seat bar by double strength welds does experience severe distortion during the disengagement of the divider plate. It may shear through at a corner but the remaining pieces would remain attached to the seat bar because of the strength welds. On verifying this point and that the disengaged divider cannot in any way block the outlet nozzle, the response of the divider-to-LOCA conditions will have been confirmed.

COMPONENT MANUFACTURE

The replacement divider plate components are a unique and novel design and therefore required the development of unique and novel manufacturing procedures. The divider was manufactured by a vessel fabricator as a heavy peripheral "window frame" into which was welded the curved central portion. Subsequently the 4 segments were prepared for field assembly by breaking the divider assembly into 4 pieces and adding the edge weld preparations. The complex shape of the tubesheet seat bar was machined from solid by an air craft component manufacturer using sophisticated NC machines to deal with the complexities of the 7° divider slope and the ear profile.

INSTALLATION

Field installation of the replacement divider plates - shown in Figure 4 – was a major operation involving installation of this first-of-a-kind design in a retrofit situation in a difficult access, high radiation environment. A major consideration in determining the feasibility of field installation was the radiation level to be anticipated during the changeout. The radiation levels were high enough to require very large field crews for the installation of the dividers if done manually. The initially assumed radiation levels (1R/hr in the head) meant that the fields were so high that robotic techniques would have been required – an option requiring a large upfront cost and a long lead time. A planning value of 0.5R/hr was established which allowed for large but feasible crews. The values ultimately experienced in the field were above the planning value.

Installation procedures were developed in Cambridge by a combination of procedure development, special tools design, mockup trials, weld procedure qualification, inspection development and personnel training. Mockup trials were of great importance. Cardboard and then wood mockups of divider segments showed that the dividers could be installed into an existing head mockup in only four pieces – a factor which was key to setting the design configuration.

To establish the installation procedures, a full scale mockup was constructed including the SG primary head, existing divider, seat bars, manways, vessel support and the external floor and walls. A full scale Lexan replacement divider assembly was built to provide an early confirmation of the configuration and for use in developing procedures. When the full complement of metal parts became available, they were used to further verify procedures and for fitup and welding trials. In parallel, a large field force was recruited. Field personnel under B&W supervision were trained for execution of the work segments as feasible within individual radiation exposure limitations.

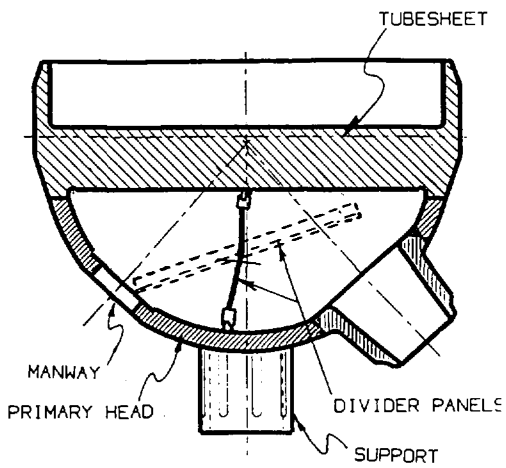

FIGURE 4
DIVIDER PLATE REPLACEMENT

In the field, installation of the replacement dividers would first require removal of the existing divider plates. As anticipated, the removal of the existing divider plates and tubesheet seat bars was an operation that went relatively quickly because of the nature of the existing design and the condition of the bolting.

Refurbishment proved more of a problem. On removal of existing dividers, it was observed that the existing primary head seat bars had experienced a significant amount of erosion. While the erosion observed at G2 did not affect the strength of the seat bar it had to be repaired in order to allow it to properly receive the seat bar liner. The repair required weld buildup and grinding to re-establish the head seat bar profile.

The observation that the old primary head seat bar had in fact experienced a significant amount of erosion was a vindication of the earlier design decision to include an erosion resistant seat bar liner, erosion resistant divider groove faces and an erosion resistant tubesheet seat bar as part of the design.

On completion of seat bar refurbishment, the seat bar liner could now be installed. The liner was a machined profile sized to slide into the periphery of the divider plate after installation. Between the machining operation and divider installation, the liner was rolled to the curvature of the primary head, pressed over the seat bar and strength welded on two edges. After all of this manipulation, the liner required a degree of adjustment to allow for the subsequent installation of the divider.

The next step was the installation of the two seat bar/ear components. The two seat bar/ear components which join at the centre of the tubesheet were each positioned and secured to the tubesheet. Once this was complete, the tubesheet and head seat bars created a continuous tongue across the tubesheet and around the head.

The divider itself consists of four very heavy components. These components, the largest of which is 16.6" by 56" and weighs 300 pounds had to be maneuvered into the head through the 14 x 18 inch cold leg manway. Once inside the head the components were manoeuvred into final position using various guide channels and rope and pulley devices. In the installation, the two corner portions are installed first followed by the lower central portion and finally by the very heavy upper central portion.

At this point the divider panels are in their final position with their weld preparations aligned. The welding process incorporated completion of the root passes from each side of the 3/4 inch full penetration double groove weld profile, a root pass inspection and then progressive welding simultaneously on both sides. Double sided welding was done so as to better control and balance weld distortion. After cleanup, the welds are subjected to surface examination and partial volumetric examination. Execution of the tubesheet seat bar to tubesheet overlay welds completed the welding program.

Completion of the divider plate installation represented the culmination of a complex manufacturing and installation of a unique first-of-a-kind configuration which was executed in a highly satisfactory manner notwithstanding the vagaries of the unexpected seat bar condition and a few inevitable first-of-a-kind considerations. The resultant divider plate was a highly satisfactory installation.

The replacements of the divider was completed at G2 in 15 days and 9 days on the first two and second two SG's respectively by a total of 220 personnel.

RETURN TO OPERATION

Upon completion of the installation and the plant outage, the plant was returned to operation. In operation the divider plate has been performing very well. After the outage the steam generators, which had been experiencing a continuous degradation of performance in the form of an increase of the reactor inlet header (RIH) temperature, where observed to have a very large improvement in the RIH temperature. The divider replacement was the only relevant change (other than ID cleaning of a very small number of tubes on one generator). On re-start the plant was observed to have a very large RIH temperature reduction of 5.2°C average. This correction restored the steam generator operation to very nearly the original startup condition. This type of RIH temperature improvement will indefinitely avoid the need for the plant derating which had been anticipated prior to the outage.

CONCLUSION

The replacement of the segmented original divider plates at the G2 plant with a welded floating one-piece design has been completed as a unique first-of-a-kind operation. The result has been a very satisfactory installation of a design which is better able to meet the various loading requirements and which has had the effect of substantially improving the plant performance.

ACKNOWLEDGEMENTS

The authors wish to acknowledge the contributions to this successful project of P. Lafreniere,

H. Hyung and S. Michaud of Hydro Quebec,

K. Verma of NB Power, W. Teper of Ontario Hydro, D. Pink, J. Bowman, R. Horvath,

C. Holmes, R. Lecsek, J. Morton, D. Muth,

A. Mockler, P. Gowthorpe and M. Schneider of B&W and the numerous other people who contributed to this project.