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INFLUENCE OF BOTTOMED OUT SPRING HANGER SUPPORT ON STEAM GENERATOR NOZZLE WELD

Khalid Chaudhry¹

¹ Technical Specialist, Canadian Nuclear Safety Commission, Ottawa, Ontario, Canada
(khalid.chaudhry@canada.ca)

ABSTRACT

Variable spring hangers are widely used in nuclear industry as piping supports. The design of variable spring hangers allows the support to be flexible and accommodate thermal expansion and contraction of pipes when they move from cold to hot position and vice versa.

One such variable spring hanger in the primary heat transport system piping was found to be bottomed out in a CANDU nuclear plant. In its bottomed out state, the spring hanger was not able to accommodate the pipe thermal expansion and thus it acted as a rigid restraint. By acting as a rigid pipe restraint, not only the variable spring support sees an increased load itself, also the resistance to pipe thermal expansion will exert extra loads to the neighbouring pipe supports and equipment. In the affected CANDU nuclear power plant, the bottomed out support lies in a close proximity to the steam generator nozzle and hence the nozzle weld will also experience the increased loads that were not considered for nozzle and its weld during design phase.

It is proposed that the steam generator nozzle weld to the primary heat transport system piping shall be analyzed for as 'designed' and hanger bottomed out conditions to estimate the magnitude of the increased loads seen by the nozzle and its weld. The effect on fatigue usage factor shall also be investigated.

The results indicate that due to bottomed out variable hanger, an up to 8% load increase on the steam generator nozzle is possible. The fatigue evaluation results, by relative comparison, showed an increase in usage factor from 0.09 to 0.4 for a single transient. A revision of the cumulative fatigue usage factor of an in-service steam generator nozzle weld location discontinuity is recommended.

BACKGROUND INFORMATION

The Canadian designed 900 MW(e) Pressurized Heavy Water Reactor typically consists of a cylindrical, horizontal, single-walled stainless steel vessel called the calandria. It provides containment for the heavy water moderator and reflector. 480 calandria tubes axially penetrate the vessel. These tubes contain the pressure tubes, which contain the fuel and heavy water coolant and hence are called the fuel channels. The calandria, the two end shields, and the shield tank form an integral, multi-compartment structure.

The Primary Heat Transport (PHT) system is designed to meet the requirements of ASME Section III for Class 1 components [1]. This system circulates pressurized heavy water through the fuel channels and thus removes the heat produced in the fuel, which is then transferred to light water in the steam generators. The PHT system consists of two loops, each containing two circulating pumps, two steam generators, four headers, feeder pipes to and from each fuel channel, and other piping. A simplified heat

transport system flowsheet is shown in Figure 1 below. Each loop removes the heat from half of the 480 channels in the reactor core.

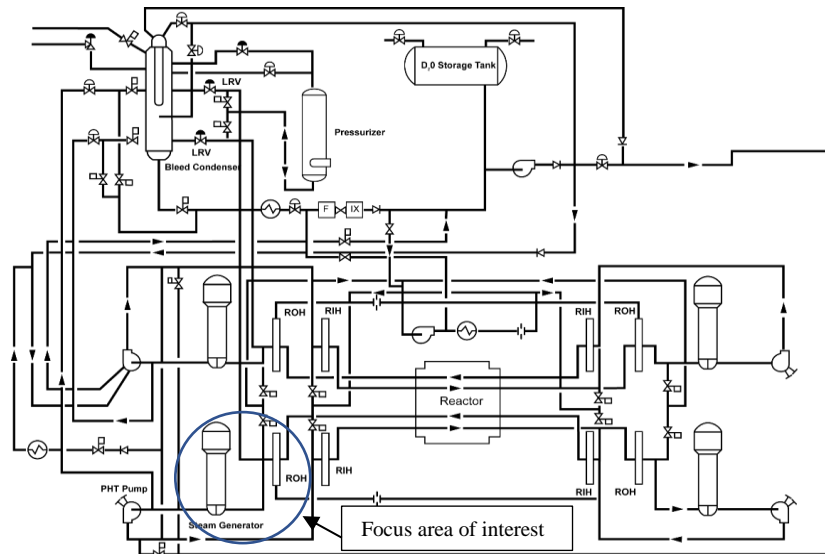


Figure 1. Simplified flow sheet of a 900Mw CANDU reactor heat transport system

There are four inlet and four outlet headers, two at each end of the reactor. Each of the outlet headers receives the flow from 120 outlet feeders and conducts the flow to two steam generator inlet lines (NPS 22") which lead to a single steam generator. In each loop, the outlet headers are interconnected by balance lines circumventing the reactor. On the west side of the reactor, the outlet headers of the two loops are also interconnected by a line from one of the steam generator inlet lines from each loop. They join a common line running to the pressurizer. There are four inlet headers, two at each end of the reactor. Each of the inlet headers receives the flow from the two discharge lines from a single Heat Transport pump and conducts the flow to 120 inlet feeders. The inlet headers have an inside diameter of 451 mm and the outlet headers have an inside diameter of 495 mm. The material is seamless carbon steel, ASME SA 106 Grade B pipe. The nominal pressure set point is 10.0 MPa(a) and the corresponding saturation temperature is 310°C. The temperature of the coolant in the reactor inlet header is 266.8°C.

During normal operation, the feed and bleed circuit controls the PHT system inventory by controlling the level in the pressurizer. The system is also used for PHT system pressure control when the pressurizer is isolated during shutdown. The system handles the shrinkage and swells during cooldown and heatup of the PHT system. Bleed flow from the PHT system pump suction is passed through two control valves and flashes into the bleed condenser. The bleed condenser pressure is normally controlled at 1.72 MPa(a). The bleed condenser is a receiver for all relief from the PHT system and has two, 100% relief valves per loop for overpressure protection.

PROBLEM DEFINITION

Process piping employing rigid simple supports, will either generate a potentially huge upward force when the pipe expands downward or leave the support inactive when the pipe moves upward. One solution, to maintain the pipe properly supported, is to replace the rigid support with a spring support. With spring support present, the pipe will always be supported with an appropriate amount of force, regardless of its vertical movement. The magnitude of the supporting force, however, changes as the pipe moves vertically. Because of this change in support force as the pipe moves up and down, spring supports are called variable spring support.

The CANDU PHT piping systems employs a large number of variable spring supports. During the design process, the springs are properly selected so that the load variation is within the acceptable limit that will not compromise the integrity of the piping system. However, because of reasons unknown, a variable spring hanger support, which lies near the main header and the steam generator inlet piping, was found to be bottomed out. In this manner, the bottomed out variable spring support acts as a rigid restraint. The continuous heat up and cool down operation will exert large thermally induced loads on the nearby piping sections, equipment and piping support. The increased loads can jeopardize the structural integrity of the PHT system piping. This paper investigates the impact (in terms of increased load and fatigue life) caused by such a rigid support on the steam generator inlet piping nozzle and nearby piping supports.

METHOD OF ANALYSIS

Finite element modelling technique is employed to investigate the impact caused by bottomed out variable spring hanger support. A global piping model is created to calculate the increased nozzle loads. The PHT piping is analyzed for two situations separately where the variable spring support is acting either normally as designed or in as found bottomed out state. Both support condition scenarios were analyzed for dead weight plus internal pressure loading and thermal loading individually. The cause of variable spring hanger support is not investigated.

The ASME code section III, subsection NB-3200 fatigue calculation rules are used to assess the fatigue usage factor for a typical start-up/shutdown transient. The fatigue evaluation was based on a relative comparison of usage factor obtained from as designed spring hanger support versus a bottomed out spring hanger support. The cyclic load stress range was calculated from a full thermal & pressure load case and the zero stress load case. The impact on nozzle weld fatigue is investigated by classical calculations as opposed to detailed FE (finite element) stress analysis.

Analysis Assumptions & Simplification

To simplify the overall analytical process, following assumptions and simplifications are made:

- (a) The PHT piping system is a very large and complex system. Because of this fact, only a quadrant of the PHT piping system is modelled.
- (b) To further simplify the model, the one quadrant model piping was further truncated where it is judged that loads from the truncated piping will not influence the affected nozzle of the steam generator.
- (c) ASME code evaluations were not performed. Only loads at steam generator nozzle were calculated and compared for the as designed spring hanger support and the as bottomed out spring hanger support condition.
- (d) Only one thermal transient (start-up/shutdown with 600 cycles) was considered for fatigue usage factor comparison between the as designed spring hanger support and the as bottomed out spring hanger support condition.
- (e) The stress intensity ranges is based on full thermal and pressure load case and the zero stress load case.
- (f) For fatigue evaluation, a fatigue strength reduction factor of 5 is used along with a factor of 1.1 for Young's modulus correction.
- (g) The start-up/shutdown transient pressure is assumed as 10.0 MPa and the temperature is assumed as 265 °C.

ANALYSIS MODEL

The global piping model is prepared, solved and results post processed using “ANSYS®” commercial finite element software package [2]. Straight piping element type PIPE288 and piping elbow element type ELBOW290 are used to model the piping sections. Variable spring hangers, guide supports, sliding supports are all modelled with spring elements type COMBIN14. The PHT piping model is composed of a single

header, two steam generator inlet lines coming from the header. Portions of steam generator balance line, PHT over pressure relief line and header to header interconnect lines are also included in the piping model. A total of 261 elements were used in the piping FE model. Out of these 261 elements, 237 elements formed the piping sections and the other 24 elements represented supports of various kind. The COMBIN14 spring element consists of two coincident nodes. The spring element node J is allowed to stretch or compress while node I has its displacement restrained in the direction the spring is active. The node J is connected to the piping and it moves along with it. The total nodes created for the FE model were 359. The global piping finite element model is shown in Figure 2 below. The model dimensions are extracted from licensee submissions. The variable hanger support spring stiffness were also obtained from licensee reports. The piping material densities are calculated from metal and water weights per meter length of the pipe and then dividing the result by pipe cross section area. Consistent units such as N, mm, MPa and tonne/mm³ are used in the analysis. Anchors are placed at the piping model terminal points. Because of the anticipation of large deflections, the ANSYS program's non-linear large deflection analysis option was turned on.

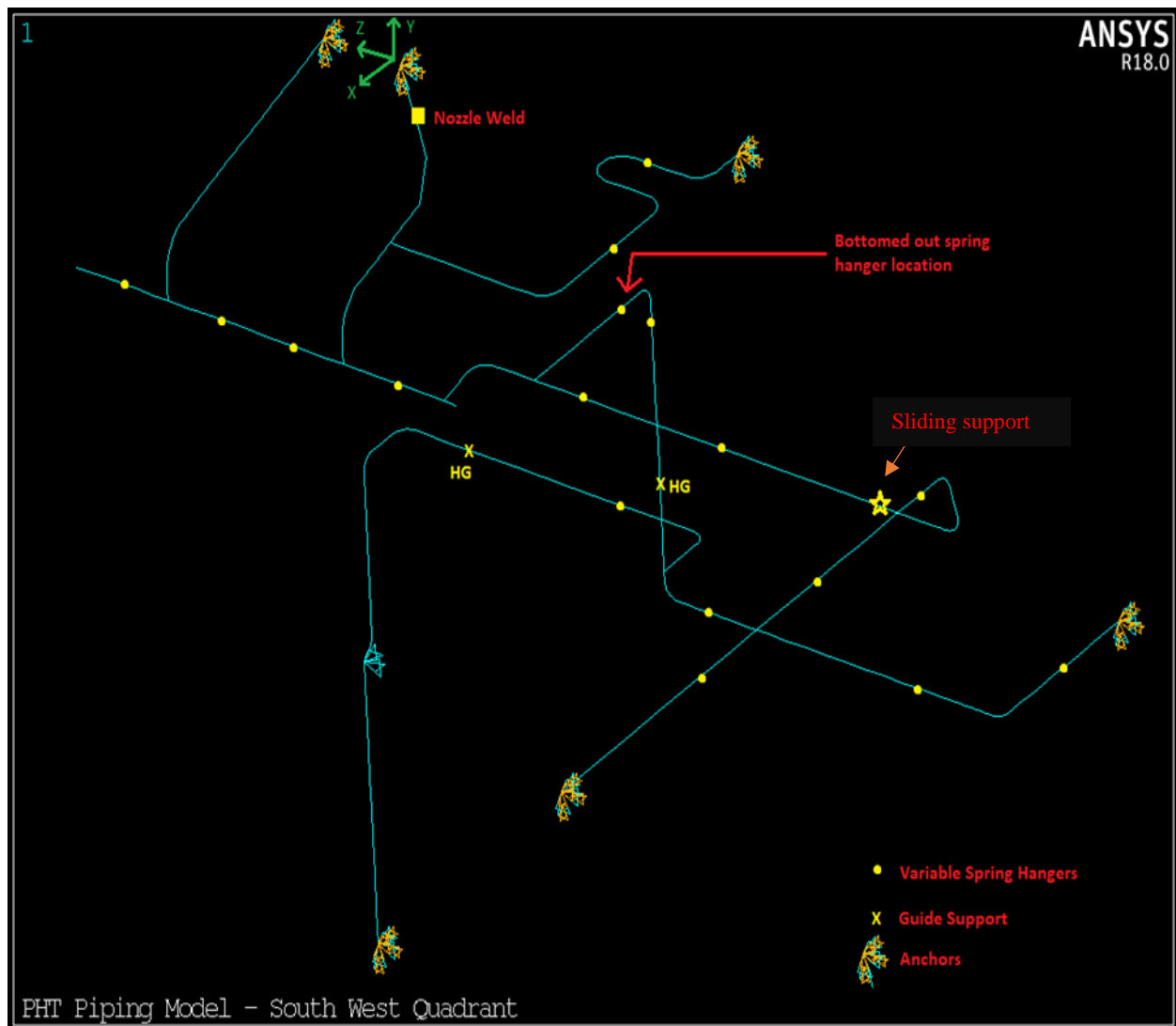


Figure 2. Global FE model of the heat transport system piping

The model co-ordinate system is also shown in Figure 2. The model overall dimension are such that center of mass is located at global (X, Y, Z) = 2317.1, 112.37E+3, -2007.2 millimetres.

LOADS AND BOUNDARY CONDITIONS

The loads and boundary conditions used for various analyses are described below:

Loads

The loads used in the analyses are:

- (a) Internal pressure = 10.0 MPa
- (b) Temperature = 265 °C with 27 °C taken as reference temperature for thermal stress calculation.
- (c) Deadweight (metal plus contained liquid) = 29,832 Kgs.
- (d) The piping end cap effect load is applied by the solver program.

Boundary Conditions

The boundary conditions used for static analyses are given as follows:

- (a) The nodal displacements at the terminal end points of the PHT piping system model are fully fixed in all degrees of freedom. This represents anchor boundary condition.
- (b) For the piping guide supports, the two in-plane degrees of freedom directions, in either horizontal or vertical plane, are restrained by springs with proper spring stiffness. The spring stiffness represents the actual support capacity in that direction.
- (c) Variable spring supports are modelled with vertical springs. The spring stiffness are obtained from support data sheets. As stated before, the node I of the spring elements are restrained in the direction the spring is active.
- (d) For thermal loading, steam generator thermal movements are applied to both inlet piping nozzle location nodes. The applied displacements are 2.68 mm in X direction, -20.8 mm in Y direction and -4.82 mm in Z direction.

DISCUSSION OF ANALYSIS RESULTS

Both the as designed active variable spring support and the as found bottomed out (rigid) support scenarios are solved first for pressure and dead weight loading and then for thermal load individually. By comparing the results from two different support conditions, it will be possible to quantify the load impact on the steam generator inlet nozzle which is near to the malfunction support. The results are presented and discussed below:

Analysis Results From Pressure & Weight Loading

Pressure and dead weight combined loads for two support conditions are presented in Table 1.

Table 1: Comparison of nozzle loads for pressure + weight loading

Support condition	Direct Load (N)	Shear Load (N)	Bending Moment (N-m)	Torsional Moment (N-m)	Maximum Spring Hanger Stretch (mm)	Maximum Load in Spring Hanger (N)	Maximum Vertical Displacement in the PHT Piping System (mm)
Variable spring support <u>Active</u>	19,809	118,480	303,634	122,800	-4.35	-16,978	-5.03

Bottomed out Variable spring support	15,689	115,250	297,494	118,380	-4.27	-16,351	-4.96
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Because of the nozzle weld geometric location being at different angles to three axes of the applied co-ordinate system, it is difficult to calculate the direct force, shear force, the torsional and bending moments acting on the weld location. The direct load is thus, conservatively calculated as the resultant of the two in-plane individual components, i.e.; X & Z direction forces. The shear load is calculated from the Y component force. With a similar logic, the resulting bending moment is obtained as vector sum of all three individual direction moments and the torsional moment is based on the X direction moment. By observing the results from Table 1, it can be seen that the nozzle loads, from active spring hanger support condition to the rigid bottomed out support condition, change very little.

Analysis Results From Thermal Loading

Thermal load from start-up/shutdown transient (temperature = 265°C) is analyzed for two support conditions. The summary of results is presented in Table 2.

Table 2: Comparison of nozzle loads for thermal loading

Support condition	Direct Load (N)	Shear Load (N)	Bending Moment (N-m)	Torsional Moment (N-m)	Maximum Spring Hanger Stretch (mm)	Maximum Load in Spring Hanger (N)	Maximum Vertical Displacement in the PHT Piping System (mm)
Variable spring support active	46,266	66,124	313,086	230,480	-30.48	-1.52E+5	-30.82
Bottomed out Variable spring support	42,150	78,752	338,490	247,870	-30.69	-1.52E+5	-31.13

As stated before, the nozzle weld geometric location is at different angles to three axes of the applied co-ordinate system which makes it difficult to calculate the direct force, shear force, the torsional and bending moments acting on the weld location. The results given in Table 2 are calculated using a similar rationale as is done for Table 1 results.

It can be seen from Table 2 that, compared to Table 1 results, direct load has increased while the shear load on the nozzle has decreased. This can be attributed to the expansion of the piping under the thermal load. The bending and torsional moments have increased due to thermal load between variable spring being active and the spring support acting as a bottomed out support. The maximum spring hanger stretch has also increased due to thermal load, but the stretch results are similar between active spring support and bottomed out spring support conditions. The vertical support load for the spring hanger support adjacent to bottomed

out support, increased from 18,582 Newton to 44,869 Newton between the two support conditions. The maximum vertical displacement anywhere in the PHT piping is 31.13 mm (acting downward) for the bottomed support condition.

Assessment of Impact on Nozzle Weld Fatigue

The fatigue evaluation for the steam generator weld is a comparative evaluation. It is carried out by calculating alternating stress for a single start-up/shutdown transient for the two support conditions, namely, the spring support being active and working as designed and the malfunctioning state where the spring support has bottomed out. The stress range is based on the difference between full load and the zero load cases. The maximum pressure during the transient is 10 MPa and the maximum temperature is 265 °C. The number of transient cycles are 600.

The nozzle loads are established from the piping analysis for the full pressure and thermal loads. From the direct force, shear force, bending moment and torsional moment loads, stresses are calculated at the junction of steam generator inlet piping and its nozzle using the smallest pipe diameter and the pipe thickness (pipe OD = 559.0 mm and wall thickness = 34.9 mm). Table 3 provides the stress calculation results.

Table 3: Comparative fatigue evaluation – stress analysis results

Support condition	Direct Load (N)	Shear Load (N)	Bending Moment (N-m)	Torsional Moment (N-m)	Direct Stress (MPa)	Shear Stress (MPa)	Principal Stresses (MPa)
Variable spring support <u>Active</u>	49,850	67,313	323,706	235,150	232.61	17.75	S1 = 233.96 S2 = -1.35
<u>Bottomed</u> out Variable spring support	45,480	80,051	349,326	252,670	275.33	21.13	S1 = 276.94 S2 = -1.61

From the individual component stresses, principal stresses are established. After this the stress difference and the alternating stress are calculated. Based on the alternating stress, number of allowed cycles are established from ASME code fatigue curve. Fatigue usage factor is calculated and compared between the two support conditions. Table 4 presents the results of this comparative fatigue evaluation for the steam generator weld.

Table 4: Comparative fatigue evaluation – Usage factor results

Support condition	Stress Difference S1 – S2 (MPa)	S _{alt} (MPa)	Transient , Number of Cycles ‘n’	Code Allowed Cycles ‘N’	Fatigue Usage Factor
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Variable spring support <u>Active</u>	235.31	129.42	600	7000	0.09
<u>Bottomed out</u> Variable spring support	278.55	153.2	600	1500	0.4

The alternating stress has been multiplied by a factor of 1.1 to account for Yong's modulus correction. It can be seen that fatigue usage factor, for an individual transient, can increase from 0.09 to 0.4 for a variable spring support that has bottomed out in the vicinity of the steam generator nozzle.

CONCLUSIONS

Based on the results presented in this paper, it can be concluded that:

1. A failure of a variable spring support in the heat transport system, in the vicinity of a steam generator nozzle, will increase the reaction loads acting on the nozzle weld. Although the torsional and bending moments decreased marginally for pressure and dead weight loading, however, for thermal loading the increase is close to 8%.
2. For a bottomed out variable hanger support, in the vicinity of steam generator nozzle, the comparative fatigue usage factor increased from 0.09 to 0.4. Based on this, rather simple assessment, this appears to be a considerable increase.
3. The variable spring support, adjacent to the bottomed out spring support, had its support load increased from 18.5 KN to 44.8 KN. This has the potential to cause failure of the adjacent support.

REFERENCES

- [1] American Society of Mechanical Engineers boiler and pressure vessel code, 2007 edition.
[2] ANSYS® [Mechanical/APDL and Workbench], release 18.0, ANSYS, Inc.

DISCLAIMER & ACKNOWLEDGEMENT

The opinions expressed and the conclusions derived in this paper are those of the author and do not reflect the opinions of the Canadian Nuclear Safety Commission.

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