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EVALUATION TECHNIQUE OF THE REACTING FORCE ON JET AT SPRAY COLLECTOR NOZZLE

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The analysis of the possible cause generating the collector pipe failure of the Degasser-Condenser equipment at CANDU 6 NPP implies checking its mechanical resistance. During execution of the degassing function, the normal jet force which act direct on collector pipe in each nozzle area, bends it. The characterization of the minimum cross section geometry (shape and size determination) of the fluid passage through the nozzle, together with the analytical and numerical models for the reacting force evaluation of the jet is presented in this paper.

The paper has original contributions in the domain and is dedicated to specialists working in the research and technological engineering.

Keywords: collector pipe, nozzle, minimum flow section, reacting force on jet

1. Introduction

At CANDU 6 NPP the Degasser – Condenser equipment is a component part of a safety system from primary heat transport system. The Degasser-Condenser behaves cyclic for a settled time as degasser, and as condenser for the rest. The pressure is controlled by heat supply brought by electric heaters and by cooling primary agent injection. To behave like a degasser, the sample of cooling primary agent has to indicate a limit concentration of the solution gases. Increasing of the pressure level in Degasser-Condenser over a threshold value releases the injection of cooling primary agent in spray tank, injection that stops when the steam pressure from the vessel decreases under the maximum value. The gases are removed from cooling agent by their part pressure drop, above liquid surface [1]. This is thermally made in a steam environment when the partial gases pressure towards the steam pressure became practically zero [1]. To remove the gases from the primary agent a necessary condition is a large contact area of the

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agent with the steam environment and a great difference between the partial pressures of the gases in the liquid/ steam environment [2]. The complete removing of the gases from the liquid environment requires a long time, during the finite available time for degassing the gases could be removed up to a cut fraction from their initial concentration [1]. In our case, the increase of the contact area between water and steam is carried out through spraying the cooling primary agent in particles reduced at "fog" stage [2] by special nozzles.

Apparently, the cooling agent jet at nozzle outlet can be considered harmless. Loosing the collector pipe integrity, well in advance of reaching its design lifetime, imposed paying a proper attention to evaluation of the reacting force of the jet that came out from nozzle.

The paper describes the determination method of the components for calculating the forced flow section of the cooling agent through nozzle and the evaluation technique of the normal jet value. The elements on view are part of own analysis of a case study completed with proposal of resizing solution of spray collector pipe [2].

2. Geometrical adapted description. Nozzle details

The spray collector is a subassembly made of a thick wall pipe ($d_e/d_i = 1.2 > 1.1$) [3], along it are N nozzles thread fitted (2) whereby the cooling primary agent injection is made, as fine drops, in the steam environment of the Degasser-Condenser, injection required for execution of degassing function, see Fig. 1.

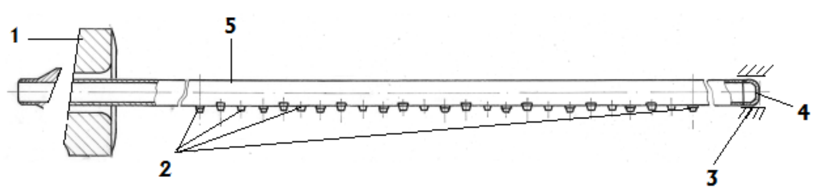

Fig.1. The spray collector pipe – adapted chart

At one end, the spray collector pipe (5) is assembled by a special sleeve (1) to the pressure vessel wall and, the other pipe end, plugged by a cover (4) is simply supported (3) being locked for both loading generated by the reacting force of the water jet, injected through nozzles during the short time executing degassing function and thermal elongation. The nozzles (2) are assembled alternative on the collector pipe, at equiangular and equally spaced, obtaining a symmetry around those placed as „six hour" (Fig. 1), to provide the greater contact area between water and steam. The cooling primary agent is passing from the collector through the adapted nozzle, as it can be seen in the Fig. 2.

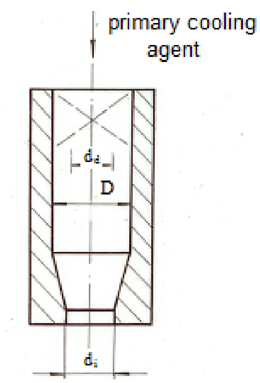

Fig.2. Nozzle – adapted chart

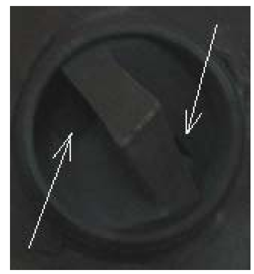

Fig.3. Detail (inlet of the cooling primary agent in the nozzle)

The geometrical layout of the primary agent inlet from the collector pipe into nozzle is utmost complex, see Fig. 3.

The precise settlement of the slits and their sizing (even when the nozzle is in disassembled condition) was for a while an issue because, without these information the flow section couldn't be calculated.

3. The complete characterization of the real flow section

In the first step, the characterization of the flow section assumes to perform the two slits projection in the cross section on the flowing alignment. Performing of these projections is difficult due to complexity of the slit geometry. Thereby, it has been adopted as a possible solution, the replacement of the cooling primary agent with a light beam produced by a spot [4]. Two spot lights have been obtained on the plane surface, see Fig. 4.

The light beam was replaced with the light generated by a LED [4]. Looking into the nozzle, from the outlet, one can observe in series the presence of two light slits antipodal placed, having the shape showed in the Fig. 5.

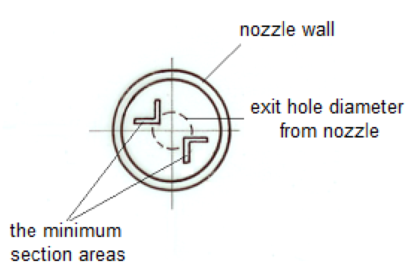

Fig.4. The projection of the light beam on the plane surface

Fig.5. The projection of the real flow section on the plane surface

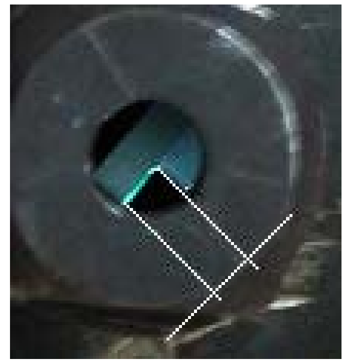

Fig.6. Viewing the light slit wing sizes

Sizing of the width “a” and of the thickness “g” of the light slit projection in plane has no problem [4]. Two identical slits can’t be seeing together because the exit hole diameter from nozzle doesn’t allow it. It has been attempted shooting a light slit as control sample [4]. No more than one of light slit wing has been obtained, see Fig. 6.

4. The evaluation technique of the normal jet force

At nozzle outlet, the jet has the shape shown in Fig. 7. The characteristic of this shape is the vena contracta diameter [5].

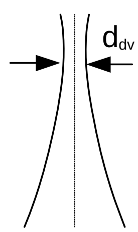

Fig.7. The jet shape at nozzle outlet

From the beneficiary’s data the primary cooling agent parameters are the average flow per hour through nozzle Q_h and the average flow per hour through the collector pipe, Q_{hc} [2].

Using this data one can calculate:

- the rate of cooling primary agent through collector:

$$v_1 = \frac{Q_{hc}}{3600 S_c} \tag{1}$$

where: S_c is the flow section through collector:

$$S_c = \frac{\pi d_c^2}{4} \tag{2}$$

and d_c is the inner pipe diameter of the collector pipe [2];

- the rate of primary cooling agent through nozzle depends on the area of the minimum flow section:

$$v_2 = \frac{Q_{hc}}{3600 S_{de}} \tag{3}$$

where: S_{de} represents the minimum flow section area:

$$S_{de} = 2ag + 2g(a - g) \tag{4}$$

where: a is the slit wing width and g is the slit wing thickness;

- the vena contracta diameter is [5]:

$$d_{dv} = 0.65 d_i \tag{5}$$

- the vena contracta cross section area can be calculated as:

$$S_{dv} = \frac{\pi d_{dv}^2}{4} \tag{6}$$

- the rate of primary cooling agent at nozzle outlet:

$$v_3 = \frac{Q_{hc}}{3600 S_{dv}} \tag{7}$$

- the hole area at nozzle outlet:

$$S = \frac{\pi d_i^2}{4} \tag{8}$$

where: d_i is the hole diameter at nozzle outlet [2], see Fig. 2.

the fluid mass blowing out as jet through nozzle during time period Δt_2 ($\Delta t_2 = \Delta t_3$) is finding during period time Δt_1 into collector pipe:

$$\rho S v_1 \Delta t_1 = \rho S v_3 \Delta t_3 \tag{9}$$

$$\frac{\Delta t_1}{\Delta t_3} = \frac{v_3}{v_1} \tag{10}$$

where: ρ is the primary cooling agent density (from thermo-dynamic nomograms [6] at pressure and temperature at which degassing is made);

- variation rate of the cooling primary agent impulse along entire line passed through the nozzle outlet is equal to force acting on the fluid [5]:

$$F = \rho S v_2^2 \frac{\Delta t_1}{\Delta t_3} \tag{11}$$

- according to the third Newton's law, on the rest of the system (the collector pipe) acts an equal and opposed force [5]. The reacting jet force through the nozzle central placed:

$$N_1 = \rho S v_2^2 \frac{\Delta t_1}{\Delta t_3} \tag{12}$$

- the reacting jet force for the nozzles placed under an angle „α”, referring to the nozzle placed at „six hour”:

$$N_2 = \rho S v_2^2 \frac{\Delta t_1}{\Delta t_3} \cos\alpha \tag{13}$$

5. The finite element analysis

A finite element (FE) analysis has been performed for the collector pipe assembly and the maximum von Misses stresses and the maximum deflection of the pipe nozzle have been obtained. The FE analysis includes several steps [7]:

- creation of the geometric model
- meshing;
- elaboration of the physical model, i.e. material data, loads and boundary conditions inclusion;
- solving of the FE model;
- determination of the fatigue usage factor according to the ASME requirements.

A FE model was prepared to represent the nozzle pipe (Fig. 9). Solid 187 element has been used to idealize the geometry. The mesh characteristics are:

- number of nodes: 372307
- number of elements: 230344
- minimum element quality: 0.295

The cinematic conditions and the applied loads of the model are shown in Fig. 9. The Degasser-Condenser vessel nozzle has zero imposed displacements and the pipe end cover is represented by cylindrical type support. The nozzle loads are applied to the FEM in the correspondent pipe orifices. Some graphical results are presented below (Figs. 9 and 10) denoting the pipe deformations and stresses pattern for the loads shown in Fig. 8.

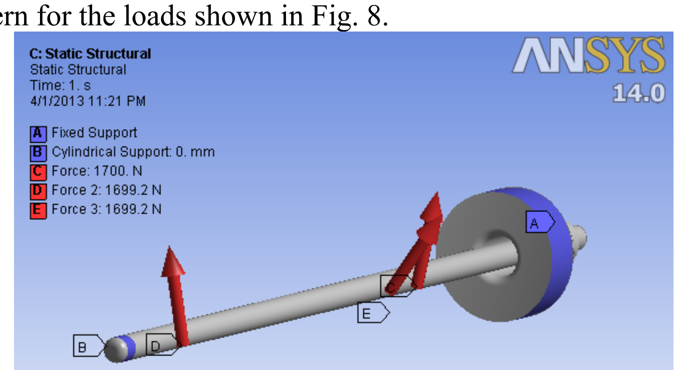

Fig.8. The boundary conditions and the loads imposed on the FE model

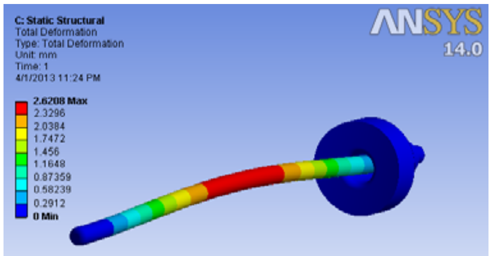

Fig.9. Example of nozzle pipe deflections

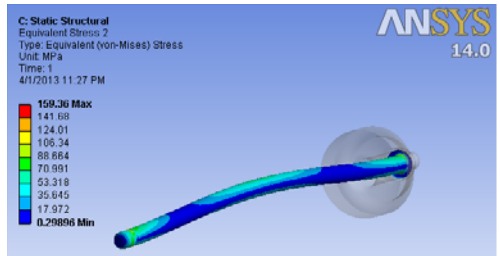

Fig.10. Equivalent stresses pattern on pipe nozzle

The main objective of the FE analysis was to calculate the maximum pipe deflections and the maximum von-Misses stress for various velocities of the jet passing through the pipe orifices. To account for different jet conditions the reaction force for each orifice was varied from 10 to 200 N. The numerical results are given in Table 1.

Table 1

Numerical FE analysis results

Reaction force [N]	Maximum von -Misses stress[MPa]	Maximum deflection [mm]
10	5.50	0.123
50	27.47	0.617
100	54.90	1.236
150	82.40	1.850
200	109.88	2.469

6. Conclusion

The analysis of the event root cause of the Degasser-Condenser nozzle pipe failure leads to the need of mechanical resistance checking. Corresponding to the assembling positions, the nozzle – collector pipe section is of least resistance. To come out the cracking in this area and even the pipe breaking a mechanical bending load has to exist, that have to be considered. The bending load is generated by a combined action of the jet reacting and collector pipe weight forces distributed between the bearings. The reacting forces value could be the direct cause of the event. To evaluate the jet reacting force value it was required to build a calculus model. Further, to evaluate the maximum stresses and deflections of the pipe a finite element model has been developed.

The calculus model was based on the impulse setting given by the fluid mass blowing out as jet through the nozzle and the maximum flow rate value. The maximum primary flow rate is given by its passage through the minimum cross section area of the nozzle.

The complex shape of the nozzle makes the complete characterization of its internal geometry to be problematic. At the nozzle inlet we do not have two bands half-coil but one single piece that splits the fluid valve in two parts, leading to two antipodal slits. The jet exit from the nozzle full tapered shaped with an angle γ carrying out the "fog" spray required by the degassing function. The minimum flow section into the nozzle is not circular, it is resulting from projections of the flow section surfaces on the plane normal to the flow direction. A dismantling or cutting of the nozzle on the generatrix wouldn't solve the issue of the minimum flow section value determination. An experimental reproduction of the process would require conformation to geometrical and physical conditions and also afferent instrumentation. Neglecting the execution costs of such experiment, we can affirm that, the experiment and its results wouldn't lead to reacting forces determination in due time. The approach presented in this paper is original. Therefore, for a direct data results about the shape and sizes of the flow hole, we proceeded to the replacement of the cooling agent, at the nozzle inlet, with monochromatic light generated by a led. The results obtained allowed a quick setting of the minimum flow section area. The calculus model proposed allowed obtaining the force acting on the fluid when it passes through spray collector nozzle and implicitly the reacting force evaluation on the absolute jet need for checking of the collector pipe mechanical resistance.

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