RESPONSE TO REQUEST FOR ADDITIONAL INFORMATION

APR1400 Design Certification

Korea Electric Power Corporation / Korea Hydro & Nuclear Power Co., LTD

Docket No. 52-046

RAI No.:	**549-8856**
SRP Section:	**03.12 – ASME Code Class 1, 2, and 3 Piping Systems and Piping Components and Their Associated Supports**
Application Section:	**3.12**
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Question No. 03.12-19

ASME BPV Section III, mandated by 10 CFR 50.55a, requires that the structural evaluation of systems, structures, and components important to safety consider combinations of various loadings, including dead weight (DWT), pressure, seismic, thermal expansion and transient loads from system operating transients. Topical Report APR1400-Z-M-TR-12003-P-A (ML17129A596), “Fluidic Device Design for the APR1400” and technical report APR1400-K-ANR-14005-P Rev.0 (ML14164A170), “CFD Analysis of Fluidic Device” both discuss the operation and the performance of the safety injection tank fluidic device (SIT-FD). The computational fluid dynamics (CFD) modeling, using full scale experimental data, showed that vaporous cavitation can occur in the center of the exit nozzle and the discharge tube for both large and small flow modes.

a) The staff would like to understand whether and how cavitation effects and vibration originating from the operation of the SIT and its FD have been taken in to account in the structural design evaluation of the SIT, its discharge piping and pipe supports.

b) Also please discuss whether the operation of the SIT with its FD can result in other phenomena, such as water hammer, and how their effects have been accounted for in the structural design of SIT, FD, piping and supports.

c) In addition, please discuss whether the structural evaluation model of the SIT is coupled with the FD. If decoupled, please discuss how consideration for protection against resonance has been accounted for.

Response

a) -1. Resonance due to Cavitation

As discussed in the technical report “CFD Analysis of Fluidic Device,” APR1400-K-A-NR-14005 [1], cavitation was apparent at the discharge tube of the fluidic device.

Cavitation bubbles are created when the static pressure of a liquid locally drops to the vapor pressure of the liquid. The bubbles collapse suddenly in the downstream region where the static pressure exceeds the vapor pressure. When the bubble collapses, non-periodic high frequency noises are generated. Data from numerous experiments show the implosion bubble noises are of about 5 kHz and above [2], [3].

Generally, the possibility of resonance caused by flow induced vibration is investigated by comparing the flow characteristic frequency and the natural frequencies of the components. The natural frequencies of the safety injection tank (SIT) and safety injection (SI) line, including supports, were calculated by using commercial software such as ANSYS and PIPESTRESS. Table 1 shows the natural frequencies of the SIT and safety injection line. Schematics of these structures are displayed in Figures 1-1 and 1-2. The table reveals that the first five modal frequencies of the SIT and discharge piping are less than [ ]TS. Since the cavitation noises are non-periodic and their frequencies are much higher than the modal frequencies of the SIT and the SI line, there exists no possibility of resonance due to the cavitation implosion.

Table 1 - Modal Frequencies of the SIT and SI line (units: Hz)

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Figure 1-1. Schematic of the SIT and Fluidic Device

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Figure 1-2. Schematic of the SI line

a) -2. Resonance due to Vortex Breakdown

The solid surface in the cavitation zone can be impaired by cavitation erosion if it is exposed for a long enough time under severe cavitation conditions. The SIT with the fluidic device is designed to mitigate the hypothetical large break loss of cooling accident. Since the loss of coolant accident is assumed to occur once during the 60 year operation [4], it is not necessary to take cavitation erosion into account in the design of the fluidic device and discharge tube.

Swirling flow is observed in the flow through draft tubes of hydraulic turbines [5]. If the flux of angular momentum entering the discharge tube is large enough as compared to the flux of axial momentum, a recirculation flow known as vortex breakdown occurs along the centerline of the tube. It has long been recognized that the formation of a vortex breakdown can create flow oscillation in the tube.

Swirling flows inside the fluidic device vortex chamber and vortex breakdown in the discharge tube were observed [1] in the CFD analysis results. Swirling flow increases flow resistance due to the rotational motion. Vortex breakdown also increases flow resistance caused by the flow blockage effect. The fluidic device uses these mechanisms to control the flow rate of safety injection water. Due to the formation of vortex breakdown, flow oscillation is expected to occur in the discharge tube of the SIT. This oscillation can increase the risk of excessive structural vibration when the flow characteristic frequency coincides with the structural frequencies.

Systematic experimental study on the pressure oscillation in draft tubes of hydraulic turbines was conducted by Palde [6]. Those experiments were conducted for the model with wicket gates and various tube shapes. The structure of the test rig to create swirl is similar to the vortex chamber and discharge tube of the fluidic device.

Palde obtained the correlation between draft tube shape and the characteristic frequencies. He used the frequency parameter $(fD^3)/Q$, the momentum parameter $\Omega \mathrm{D}/(\varrho Q^2)$, and dimensional parameter L/D to compare experimental results from various tubes. In defining the parameters, $f =$ frequency; $D =$ throat diameter of tube;

Q =volumetric flow rate; Ω =angular momentum flux entering the tube; ρ = density; L =length of tube, respectively.

In order to assess the possibility of resonance caused by vortex breakdown, the CFD analysis results were compared with Palde's draft tube experiments [6]. Palde tested 75 distinct tube shapes. Most of them were simple geometrical shapes or combinations of straight circular cylinders, truncated diverging cones, and circular cross-sectional elbows. However, it is determined that there is not an identical shape corresponding to the fluidic device discharge nozzle in Palde's tests. Therefore, the most approximate shape in the Palde's tests is used to estimate the frequency parameter. Figures 2-1 to 2-3 show the dimensions of the fluidic device compared to Palde's discharge tubes.

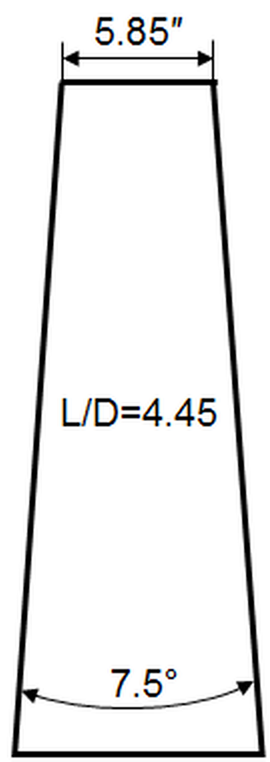

Figure 2-1. Dimensions of Discharge Tube Used in Palde's Experiment

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Figure 2-2. Dimensions of SIT Exit Nozzle

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Figure 2-3. Dimensions of SIT Discharge Tube Connected to the Exit Nozzle

Figures 3-1 to 3-5 display the tangential velocity distributions obtained from the CFD analyses.

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Figure 3-1. Tangential Velocity Distributions for L-CASE1

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Figure 3-2. Tangential Velocity Distributions for L-CASE2

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Figure 3-3. Tangential Velocity Distributions for S-CASE1

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Figure 3-4. Tangential Velocity Distributions for S-CASE2

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Figure 3-5. Tangential Velocity Distributions for S-CASE5

Table 2 - Flow Variables and Momentum Parameters Obtained from the CFD Analyses

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Table 2 shows the variables and momentum parameters obtained from the CFD analyses for the various flow cases specified in the technical report [1]. Among the variables, Ω is approximated by [ ]TS. V_θ is the tangential velocity at the discharge tube throat.

The frequency parameter is predicted from Palde's experiments for the truncated cone type discharge tube. The momentum parameters are not exactly the same as Palde's data and at smaller flows, (i.e., S-CASE1, S-CASE2, and S-CASE 5 – Figure 3-3, Figure 3-4, and Figure 3-5) the parameters exceed the experimental range. Accordingly, a linear fit based on Palde's data is utilize to estimate frequency parameters.

Figure 4 shows the predicted frequency parameters for the large and small flow cases. The characteristic frequencies associated with the predicted frequency parameters are summarized in Table 3.

As seen in Tables 1 and 3, the frequencies from vortex breakdown are much higher than the structural frequencies of the SIT and SI line. From this fact, it can be concluded that the probability of structural resonance due to vortex breakdown is very low in the SI system.

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Figure 4. Frequency Parameter Predicted from Palde's Experimental Data [6]

Table 3. Frequency Parameters and Predicted Frequencies

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The fluidic device was tested over 100 times by KAERI (Korea Atomic Energy Research Institute). In spite of the large series of tests, no damage was found. This further ensures that flow oscillation does not cause serious structural problems in the SI system.

Reference

[1] APR1400-K-A-NR-14005, CFD Analysis of Fluidic Device

[2] C. E. Brennen, "An Introduction to Cavitation Fundamentals," Turbo-machinery & Medical Applications WIMRC FORUM (2011)

[3] J. F. Gulich, Centrifugal Pumps, Springer Verlag (2007)

[4] APR1400 DCD Tier 2

[5] E. Naudascher and D. Rockwell, Flow-induced Vibration: An Engineering Guide

[6] U. J. Palde, "Influence of Draft Tube Shape of Surging Characteristics of Reaction Turbines," REC-ERC-72-24 (1972)

b) Generally, water hammer occurs in piping systems which experience rapid changes in water velocity. Quick isolation valve opening or the gas accumulation in the SIT discharge line may be potential reasons for water hammer.

During pre-operational testing (SIT discharge line isolation valve operation test [DCD Tier 2 14.2.12.1.22]) and SIT blowdown testing (DCD Tier 1 Safety Injection System ITAAC Table 2.4.3-4 9.a), the water inside the SIT is discharged into the reactor vessel. The isolation valve is initially closed to keep the water inside the SIT. The discharge will then be started by opening the isolation valve. The valve, designed with a stroke time of approximately 30 seconds, opens so slowly that water hammer is not expected to occur during the pre-operational testing.

During pre-operational testing, water stored in the SIT is discharged into the reactor vessel. The flow is not compressed on the downstream of the piping because the vessel is empty and open to the containment atmosphere. In a LBLOCA event during a plant normal condition, the SIT discharge line isolation valve is already open. Therefore, a rapid decrease in the RCS pressure induces the quick injection of the water inside the SIT into the reactor vessel. However, the break in the RCS should be so large as to decrease the RCS pressure rapidly. Therefore, the reactor vessel condition could be also regarded as a vessel opened to the atmosphere. Therefore, water hammer is not expected to occur during the pre-operational testing or Large Break LOCA event.

The SIT discharge line is filled with water by gravity from the Safety Injection Filling Tank (SIFT) during the plant overhaul period. With the filling procedure, the air which may be accumulated in the piping is removed through the vent valve. In addition, the SIT discharge line is usually in the pressurized condition. Therefore, there is no possibility of air intrusion from the outside of the piping during normal plant conditions.

c) A structural evaluation model of the SIT for seismic analysis is coupled with the fluidic device because it is installed inside of SIT with support welding. Therefore, a resonance of fluidic device is considered in the seismic analysis for the SIT. Figure 5 shows the structural evaluation model for the SIT, including the FD.

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Figure 5. Seismic Analysis Model for the SIT

Impact on DCD

There is no impact on the DCD.

Impact on PRA

There is no impact on the PRA.

Impact on Technical Specifications

There is no impact on the Technical Specifications.

Impact on Technical/Topical/Environmental Reports

There is no impact on any Technical, Topical, or Environmental Report.