Attachment 4

White Paper Prepared in Response to a Question Raised During the Audit (Nonproprietary)

This Report Does Not Contain CDI Proprietary Information

CDI White Paper: 16-05NP

Significance of Steam Dryer Fluid-Structural Interaction – CDI Perspective
In Response to Nine Mile Point Unit 2 Audit

Revision 0

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April 21, 2016

Significance of Fluid Structure Interaction in Steam Dryers – CDI Perspective

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Fluid-Structure Interaction in Steam Dryer Analysis

The general phenomenon of fluid-structural interaction refers to the mutual coupling between the fluid (here, acoustic) and structural response. In the general case: (A) the fluid pressure impresses a load on the structure thus causing it to dynamically deform; and (B) simultaneously, the fluid response induces an acoustic contribution that modifies the surrounding pressure field. Prior stress evaluations have generally accounted for the [[

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In the CDI 14-08 stress report, [[

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In 3D, the acoustic field is more complicated and additional inertial and stiffness contributions also arise. However, as with perforated plate damping, these complicating effects were conservatively accounted for [[

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Figure 1. Pressure measurements on the Quad Cities steam dryer at the co-located pressure transducers PT20 (outside) and PT14 (inside) at 790 and 930 MWe operating conditions.

Model Problems by the NRC Consultant

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However, during the NRC technical review held at the CDI office on 02-18-2016, this value was challenged on the basis of two 'model' problems which would indicate that the FSI load is considerably smaller. The first model problem considers a loudspeaker in a large volume and the other examines the propagation of waves on infinite structures. Both examples are described in the

Structural Acoustics Tutorial published in Acoustics Today April 2007, particularly Part 2 of this tutorial. While the solutions and physics of these examples have long been understood, they are not representative of steam dryer geometries since they omit the effects of confinement in a closed 3D geometry.

In the first example, formula (5) in [2] provides the in-phase component of pressure P induced on the piston due to its own velocity u (i.e., the real part of the impedance) as

$$\frac{P}{u} = \rho c\left(1 - \frac{J_1(2\omega a / c)}{(\omega a / c)}\right) = \rho c K$$

where ρ is the fluid density, c is the fluid acoustic speed, ω is the circular forcing frequency, and a is the piston radius. K equates to the adjustment factor used to correct 1D VIL. For the piston in an infinite domain, K depends on the Bessel function J_1 and is plotted in the upper diagram of Figure 4 in [2]. Note that when $\omega a/c=\pi/2$, then K=0.82. [[

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The other model problem considers the effects of a plate (finite or infinite) that is again adjacent to an infinite space. The physics of waves radiating or decaying and the manner in which these effects are characterized in terms of sub- or super-sonic bending waves are also well understood and not in dispute. The phenomenon explains, for example, why sonic booms generated by supersonic aircraft produce a loud effect on the surface (and thus are banned for over land transport) while subsonic aircraft do not. However, the acoustics of infinite plates next to infinite steam volumes do not correspond to those of steam dryers except for higher order (and high frequency) modes.

The Effects of Confinement

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The high frequency case also reveals other nuances that arise in full 3D analysis. [[

(3)]] This is explained by noting that the acoustic field supports different vertical modes at each frequency, resulting in different pressure distributions. Note too that the plots here show the real part of the complex pressure (i.e., in phase with the velocity); an imaginary component (not shown) also is present which, for this particular geometry, generally corresponds to a spring force (but in general could also include contributions from acceleration, jerk and other higher order rate terms).

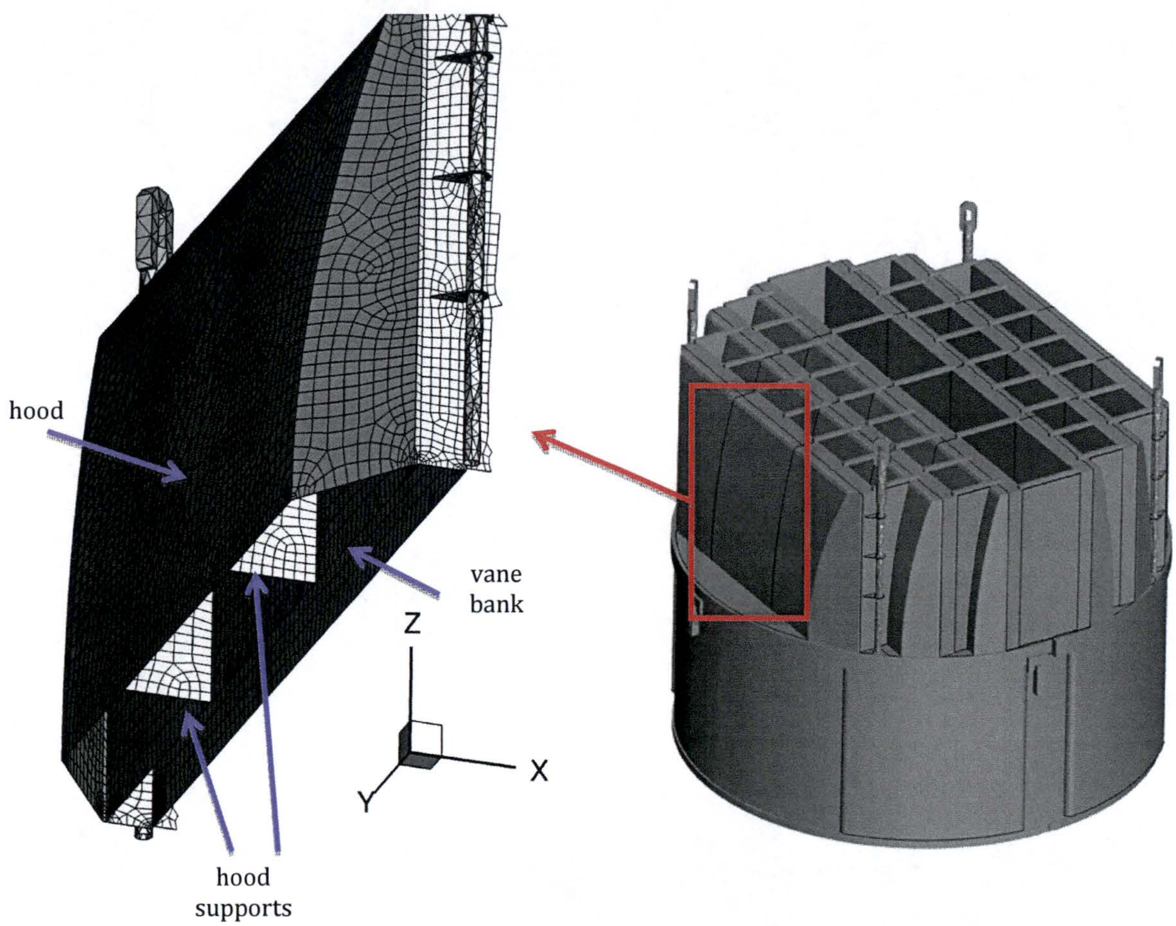

Figure 2. Steam dryer section associated with hood section, hood supports and vane bank.

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Figure 3. Geometry and boundary conditions for vibration-induced pressure example.
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Figure 4. Pressure field produced by moving surface. Left to right corresponds to forcing frequencies of 30 Hz, 60 Hz and 120 Hz respectively. Pressures are normalized by ρuc where ρ is the density of steam, c is the acoustic speed and u is the velocity amplitude. [[
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Summary

The basis for [[

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References

1. Continuum Dynamics, Inc. (2014) Stress Re-Evaluation of Nine Mile Point Unit 2 Steam Dryer at 115% CLTP. C.D.I. Report No. 14-08P (Proprietary), July.
2. Hambric, Stephen A. and John B. Fahnline, *Structural acoustics tutorial, Part 2: Sound - Structure Interaction.* Acoustics Today, 2007. **3**(2): p. 9-27.