ENCLOSURE 2

ATTACHMENT 3

"Dryer Instrumentation on New Steam Dryer for Quad Cities Unit 2, Summary of the Effects of the Sensor Cover Plates on Dynamic Pressure Measurements," GE-NE-0000-0038-2076-01-NP, Non-Proprietary, Revision 0, dated April 2005

GE Nuclear Energy

GE-NE-0000-0038-2076-01-NP
Revision 0
Class I
April 2005

Dryer Instrumentation on New Steam Dryer for Quad Cities Unit 2

SUMMARY OF THE EFFECTS OF THE SENSOR COVER PLATES ON DYNAMIC PRESSURE MEASUREMENTS

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GE-NE-0000-0038-2076-01-NP
DRF 0000-0038-2076
Class I
April 2005

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ABSTRACT

This report summarizes the effects of the pressure sensor cover plate on the dynamic pressure measurements to be taken on the replacement dryer. The effect of the cover plate on the dryer external flow is insignificant except that the increased hydraulic resistance due to the cover plates weakens the vortex in front of the main steam nozzle. It is recommended to further evaluate the effect of the weakened vortex after the in-plant dynamic pressure measurement data become available. The dynamic pressures measured with the cover plate do not require significant correction. This was predicted by a one-dimensional analysis, and supported by wind tunnel tests. The amplitude of the dynamic pressure measured on the cover plate may be [[ ]] than measured by a flush mounted pressure sensor. The frequency of the pressure wave is not affected by the presence of the cover plate.

1. INTRODUCTION

The cause of the steam dryer cracking/failure is believed to be due to high level of pressure oscillation load on the steam dryer hoods at EPU power level. It is believed that the high level of dynamic pressure (meaning pressure oscillation or fluctuation compared to static pressure) is a result of potential resonance between the acoustic excitations and the flow induced pressure waves. Therefore, it is important to measure the dynamic pressures on the steam dryer hood to help define the dynamic loads on the dryer structure. Ideally, it is best to install the pressure sensors mounted flush on the surface. However, it is highly invasive and undesirable to make many holes on the dryer hood. Even after the pressure sensors are removed, inspection may be required during outage on the repaired holes where the pressure sensors used to be located. For this reason, a sensor cover plate was designed to install the pressure sensors with minimum perturbation to the flow and with minimum error for dynamic pressure measurements, and to allow easy removal after the in-plant measurements without affecting the structural integrity of the dryer. The pressure sensors that measure dynamic pressures are of piezoelectric type and do not sense the static pressure but only senses dynamic or time dependent pressure variations in the frequency range of 3 to 1000 Hz. The final cover plate design is shown in Figure 1.

The effects of the cover plate on dynamic pressure measurements may be summarized by the answers to the following two questions:

1. Would the presence of cover plates change the dryer external flow pattern? If the flow pattern change is significant, it could invalidate the measurement because it could change the phenomenon itself.

2. How much modulation or modification of the pressure wave signals would occur locally due to the cover plate? The effects of the cover plate on pressure wave amplitude and frequency should be evaluated as a function of pressure wave frequency, incoming flow velocity, and the amplitude of the incoming pressure wave. The results of this evaluation are summarized as a correction factor to the measured dynamic pressures.

In order to answer the first question, a three-dimensional steady state Computational Fluid Dynamics (CFD) study was performed with and without a cover plate. This study is summarized in Section 2. The dryer external flow pattern is not significantly affected by cover plates, and a recommendation is made regarding a small change in the flow pattern observed. Also this study provides the flow conditions for cover plates.

The second question was addressed by a one-dimensional analysis, and the results of the one-dimensional analysis were confirmed by wind tunnel testing. This study is summarized in Section 3. The correction needed for the cover plate is small.

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Figure 1 Pressure Sensor Cover Plate Design

2. The Effect of Cover Plates on Dryer External Flow Pattern

A three-dimensional CFD model of the steam dryer external flow was developed to evaluate the effects of the cover plates on the dryer external flow pattern, and the detailed flow patterns were studied with and without a cover plate. In this section, only the relevant results are presented and discussed.

The following assumptions were used for this evaluation:

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Figure 2 compares the dryer external flow patterns with and without cover plates. It is seen that there is no significant change in the dryer external flow pattern as a result of adding seven cover plates on the one half section of the dryer hood exterior surface. [[

]] This may be similar to the trip wires used on air plane wings that prevent stall, or flow separation behind the wing. This effect is manifested in pressure distribution also, which is discussed next.

Figure 3 compares the pressure distributions with and without cover plates. The maximum pressure depression is [[

]]. The area occupied by the maximum pressure depression is very small in size. The fact that the pressure depression is higher without a cover plate reveals that the vortex near the main steam nozzle is stronger without a cover plate. The flow that feeds the vortex slows down for the case with cover plates, and weakens the vortex. However, these pressure depressions are quite small in magnitude compared to the pressure depression with the current dryer. The current dryer has a pressure depression of [[

]]. The current dryer has a square shaped hood, and has much smaller flow area between the RPV wall and the dryer, and the secondary circulation pattern is greatly amplified. With the proposed new dryer, the dryer hood has a triangular shape instead of the current rectangular shape, and allows much wider flow area in this region. The wider flow area lowers the velocity, and the flow in front of the main steam nozzle behaves closer to the sink flow with the new dryer design.

Figure 4 shows further details of the pressure distributions over the dryer hood. Two numbers shown at the corner of the different regions represent the coordinates of the corners, and the average pressure difference across the dryer hood is shown inside each region using the unit of psi. [[

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Figure 5 shows the local velocity, at approximately one inch over the center of the cover plate. The approach velocity to the cover plates vary from [[ ]].

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Figure 2 A Comparison of the Dryer External Flow Patterns With and Without Cover Plates

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Figure 3 Comparison of Pressure Distribution on the External Dryer Hood With and Without Cover Plates

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Figure 4 Comparison of Detailed Pressure Distributions on the External Dryer Hood With and Without Cover Plates

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Figure 5 Local Velocities Near Cover Plates

3. Cover Plate Correction Factor for Dynamic Pressure Measurements

In this section, the correction factor for the presence of the cover plate was evaluated analytically as well as experimentally by wind tunnel testing. The results of this evaluation are summarized in this section.

3.1 Correction Factor by One-Dimensional Analysis

The pressure wave modulation along the flow path over the sensor cover plate is complicated, and is of three-dimensional nature. However, if we select a stream tube that passes over the sensor area on the cover plate, it can be considered like a pipe because within the stream tube the mass flow is conserved and the overall direction is along the main flow direction. Therefore, the stream tube can be considered as a pipe that has its flow area varied as the flow velocity varies, and one-dimensional analysis can be applied to the stream tube. The detailed derivation of the governing equation and the solution for one-dimensional analysis is provided in Appendix A. A steady state CFD analysis of the flow field around the cover plate was performed to obtain a more accurate velocity ratio, the maximum velocity over the sensor on the cover plate divided by the incoming velocity. The velocity ratio was calculated to be [[ ]]. Also from Figure 5 of Section 2, the approach velocity to the cover plate may vary from [[ ]]. These steady state CFD analysis results were incorporated for this evaluation.

Figure 6 shows the pressure wave amplitude ratio of the cover plate over the flush mounted sensors in the reactor steam environment with [[ ]] approach velocity, calculated according to the solution by the one-dimensional analysis. The pressure wave amplitude ratio varies between [[ ]]. [[ ]] Figure 7 shows the same result with the approach velocity changed from [[ ]]. Comparing Figures 6 and 7, it is clear that the effect of [[ ]]

Figure 8 shows the pressure wave amplitude of the cover plate over the flush sensors in the room temperature air environment, a typical condition for the wind tunnel testing, with [[ ]] approach velocity, calculated according to the solution of the one-dimensional analysis. [[ ]]

Separately Dr. F. J. Moody analyzed a three-dimensional potential flow problem for a sphere in an infinite flow medium with a constant velocity and a sinusoidal traveling pressure wave far away from the sphere. In his analysis, Dr. Moody assumed that a sphere can effectively model the cover plate assuming the shape of the cover plate is a hemisphere and ignoring the viscous effects near the wall. His analysis indicates that the pressure amplitude ratio is [[ ]]. This independent calculation validates the applicability of the one-dimensional analysis performed in this section.

The potential frequency shift by Doppler effect was considered, and was calculated to be [[ ]] of the frequency observed.

3.2 Correction Factor Confirmation by Wind Tunnel Testing

It was difficult to simulate the incoming two-dimensional pressure wave in the wind tunnel testing. The wind tunnel testing was performed in two sets of test series. The first series of testing was found out to be not applicable. Even for the second series of testing, only the last part of the testing is applicable. The following describes the sequence of trials for different methods of generating acoustic waves and why some of the methods were rejected.

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In this section, only the relevant results are summarized.

Figure 9 shows the pressure wave amplitude ratios for the cover plate over the flush mounted sensors as a function of frequency. The data in Figure 9 were generated by averaging the 3 sets of 10 second test data for amplitudes as well as frequencies. Several observations were made:

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It is concluded that the wind tunnel test data supports the results of the one-dimensional analysis with the detailed review of PSDs as described above.

Figure 11 shows the PSD difference [PSD with the cover plate – PSD without a cover plate] [[ ]], without an acoustical source. [[

]] In summary, the cover plate does not generate its own pressure wave in the frequency range of 5 to 200 Hz.

The peak frequencies at the acoustic source and the peak frequencies measured on the sensor with and without cover plate were carefully compared. This examination reveals that there is no Doppler effect and there is no frequency shift. Occasionally there were some frequency shifts, but they appeared to be caused by the superposition of the turbulence noises on the acoustic wave instead of the Doppler shift.

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Figure 6 **Predicted Pressure Amplitude Ratio of the Cover Plate over Flush Mounted Sensors in BWR Steam Environment with [[ ]] Approach Velocity**

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Figure 7 **Predicted Pressure Amplitude Ratio of the Cover Plate over Flush Mounted Sensors in BWR Steam Environment with [[ ]] Approach Velocity**

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Figure 8 **Predicted Pressure Amplitude Ratio of the Cover Plate over Flush Mounted Sensors in Room Temperature Air Environment with [[ ]] Approach Velocity**

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Figure 9 **The Measured Pressure Wave Amplitude Ratios of the Cover Plate over the Flush Mounted Sensors**

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Figure 10 Turbulence Noise PSD Difference with No Acoustic Source [PSD with Cover Plate – PSD without a Cover Plate] for Frequency Range of [[ ]]

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Figure 11 Turbulence Noise PSD Difference with No Acoustic Source [PSD with Cover Plate – PSD without a Cover Plate] for Frequency Range [[ ]]

4. CONCLUSIONS AND RECOMMENDATIONS

The following conclusions are made from this evaluation:

- The dryer external flow field is not significantly affected as a result of the presence of the cover plates.
- The presence of the cover plates adds hydraulic resistance, and weakens the vortex in front of the main steam nozzle.
- The vortex in the current dryer is stronger, and the new dryer reduces the vortex strength.

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The following recommendation is made:

- It is recommended to examine carefully the effects of weakened vortex on the dynamic pressure measurements due to cover plates. The presence of a vortex in front of the main steam nozzle would affect the sensors located closer to the main steam nozzle, and the vortex could produce an acoustic pressure wave at a certain frequency or frequencies. The examination of the dynamic pressure measurements would reveal the extent and magnitude of the effect of the cover plate on the dynamic pressure measurements by means of the weakened vortex.

Appendix A

Derivation of One-Dimensional Solution for the Pressure Wave Modulation Considering the Effects of Friction and Flow Area Changes

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REFERENCES

A.1 Moody, F. J., *Introduction to Unsteady Thermofluid Mechanics*, John Wiley & Sons, 1990, Chapter 7.