ENCLOSURE 3

"Dresden Strain Gage Uncertainty Evaluation," SIA File No.: EXLN-17Q-301, Revision 0, dated April 25, 2005

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PROJECT NAME: Strain Gage Uncertainty for Steam Dryer Load Definition

CLIENT: Exelon Generation Co., LLC	**Contract / P.O. No.:** 00083767
PLANT: Dresden Unit 3	

CALCULATION TITLE: Dresden Strain Gage Uncertainty Evaluation

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1 INTRODUCTION

This calculation determines the dynamic pressure resolution and uncertainty for the strain gage measurements taken at Dresden Unit 3.

2 DRESDEN STRAIN GAGE DATA ACQUISITION

During the Dresden EPU vibration testing, strain gage measurements were made on the Main Steam piping to determine the internal dynamic pressure. Strain gages were installed at several locations in the pipes' circumferential direction. The hoop strain was then converted to internal dynamic pressure utilizing general strain equations and thick-wall cylinder pressure equations for hoop and axial stress due to internal pressure.

This document reviews the calculations to determine the pressure from the strain measurements and provides the dynamic pressure resolution and uncertainty.

Figure 1 is a diagram of the strain gage circuit including the Wheatstone Bridge and data acquisition system (DAS). The weldable strain gages provided by Hitech Products, Inc. (HPI) for this task were installed in the circumferential direction and connected to the opposite arms of the Wheatstone bridge with completion resistors inserted in the other two arms. The gages and completion resistors were assembled and connected in the bridge configuration by HPI.

The four wires, bridge input excitation and output voltage, were then spliced to a 4 conductor, shielded wire leading to the DAS. The DAS consisted of the Yokogawa Bridge Head, Model 701958, Yokogawa Strain Gage signal conditioning module, Model 701271, and the Recorder, Model DL750.

The bridge head provides a location for termination of the strain gage wires, shunt calibration and connection to the signal conditioner. The signal conditioner provides the bridge excitation (10 V), bridge balance, input range (2.5 mV/V), low pass filter (1 kHz), calibration constant (0.000251 mV/V-psi) and analog-to-digital (A/D) conversion (16 bit). The recorder provides the capability to view the data and transfer to disk (2 ksps/ch).

2.1 Full Scale Range, Resolution Calculation and Scaling Factor

In this configuration the bridge will add the two arms according to the following equation.

$$V_o/V_i = \frac{1}{4}\left(\frac{\Delta R_1}{R_1} - \frac{\Delta R_2}{R_2} + \frac{\Delta R_3}{R_3} - \frac{\Delta R_4}{R_4}\right) \qquad \text{(A)}$$

where V_o = output voltage of the bridge

V_i = bridge excitation voltage

$\frac{\Delta R}{R}$ is the change in gage resistance, ΔR, divided by the gage resistance, R, due to an applied strain, ε, for each arm of the bridge.

For this case, R_2 and R_4 are completion resistors thus $\Delta R_2 = \Delta R_4 = 0$ (no resistance change due to strain) and $\frac{\Delta R_1}{R_1} \cong \frac{\Delta R_3}{R_3} \cong \frac{\Delta R}{R}$ for strain in the same plane along the pipe. Equation A is reduced to

$$V_o/V_i = \frac{1}{4}\left(\frac{\Delta R_1}{R_1} + \frac{\Delta R_3}{R_3}\right) \text{ or } V_o/V_i = \frac{1}{4}\left(2\frac{\Delta R}{R}\right) = \frac{1}{2}\left(\frac{\Delta R}{R}\right) \qquad \text{(B)}$$

The applied strain, ε, changes the gage resistance according to the formula

$$\frac{\Delta R}{R} = \text{GF}\varepsilon \qquad \text{(C)}$$

where GF is the dimensionless gage factor provided by the gage manufacturer that relates the strain to the change in resistance.

Equation C then becomes

$$V_o/V_i = \frac{1}{2}\text{GF}\,\varepsilon \quad \text{or} \quad \varepsilon = \frac{2\,V_o/V_i}{GF} \qquad \text{(D)}$$

The input range was set to ±2.5 mV/V (V_o/V_i), thus the full scale strain range calculated from Equation D using a GF of 2.0 (per HPI), is ±2500 με.

The analog-to-digital, A/D, converter is 16 bits or 2^{16} bits for the full input range of 5000 με, providing an A/D resolution of $(5000/2^{16}) = 0.0763$ με.

The relationship between the pipe's internal pressure to the hoop strain was calculated by Dresden (Reference 1) to be 0.251 με/psi from the hoop equations found in Section 2.2 Uncertainty Analysis below. Using this factor the

Full Scale Range = ±2500 με /0.251 με/psi = ± 9960psi

and the

A/D Resolution = 0.0763 με /0.251 με/psi = 0.304 psi.

The scaling factor used by Dresden was inserted in the Yokogawa recorder to provide the recorded data in psi. This value is based on the input range, V_o/V_i, and strain-to-pressure conversion factor, 0.251 με/psi through Equation D

$$V_o/V_i\,|_{FS} = 2.5 \text{ mV/V} = 2500\ \mu\varepsilon = 9960 \text{ psi}$$

Therefore, the system scaling factor is

9960 psi /2.5mV/V = 3984 psi/mV/V.

2.2 Uncertainty Analysis

The uncertainty analysis combines the uncertainty of the strain-to-pressure calculation and the measurement system. The strain as measured in the circumferential direction is the superposition of the strain in the circumferential and that due to the Poisson effect of the axial strain due to the internal pipe pressure.

The hoop and axial stress are calculated from the equations

$$\sigma_H = \frac{2Pd_i^2}{d_o^2 - d_i^2} \qquad \text{(E)}$$

and

$$\sigma_L = \frac{Pd_i^2}{d_o^2 - d_{i_i}^2}. \qquad \text{(F)}$$

The hoop strain is the strain in the circumferential direction minus v times the axial strain as shown in the following equation

$$\varepsilon_H = \frac{\sigma_H - \nu\sigma_L}{E} \qquad \text{(G)}$$

Substituting Equations E and F into Equation G yields

$$\varepsilon_H = \frac{Pd_i^2(2-\nu)}{E(d_o^2 - d_i^2)} \qquad \text{(H)}$$

where the strain per unit pressure is

$$\frac{\varepsilon_H}{p} = \frac{d_i^2(2-\nu)}{E(d_o^2 - d_i^2)} \qquad \text{(I)}$$

or

$$p = \frac{\varepsilon_H E(d_o^2 - d_i^2)}{d_i^2(2-\nu)} \qquad \text{(J)}$$

where
σ_H = Hoop stress due to internal pressure, psi
σ_L = Axial stress due to internal pressure, psi
ε_H = Hoop strain, µin/in
p = unit applied internal pressure, psi
d_i = pipe inside diameter, in
d_o = pipe outside diameter, in
E = Young's Modulus, psi
v = Poisson's ratio.

Substituting the strain from Equation D into Equation J results in

$$p = \frac{2\,{}^{V_o}\!/_{V_i} \cdot E(d_o^2 - d_i^2)}{GF * d_i^2(2-\nu)} \quad \text{(K)}$$

This equation relates the internal pipe pressure to the measured strain.

The overall uncertainty is determined by a SRSS method used for random errors. The nominal (no error) pressure is calculated first. Then the pressure is calculated again by changing each variable in the equation by the amount of the potential error, one variable at a time. The new pressure calculated for each variable with the error is then subtracted from the nominal pressure and squared. This is done for each case where there is an uncertainty in the parameter of the pressure equation. Each case's squared difference from the nominal is summed and the square root taken of the result.

The nominal values are as follows:

d_i=17.93 in
d_o= 20 in
E = 27.9x10^6 psi
ν = 0.3
GF= 2.0
${}^{V_o}\!/_{V_i}$ = 2.5 mV/V.

The accuracy values are as follows:

d_i = 2.8% (ASME Code worst case)
d_o= 0.625% (ASME Code worst case)
E = 5% (SI metallurgist, common practice)
$\nu \approx 0$ (SI, common practice)
GF= 2% per gage, for 2 gages (SRSS) = 2.8% (HPI, Reference 2)
${}^{V_o}\!/_{V_i}$ = 0.5% (Yokogawa specification)

The overall uncertainty on the pressure is calculated as described above to be 28.7% (see Attachment A). The uncertainty due to the measurement of the strain using Equation D and the SRSS method is 2.8%. Thus most of the uncertainty is due to the uncertainty on the pipe diameters and Elastic Modulus with the pipe diameter uncertainty contributing significantly.

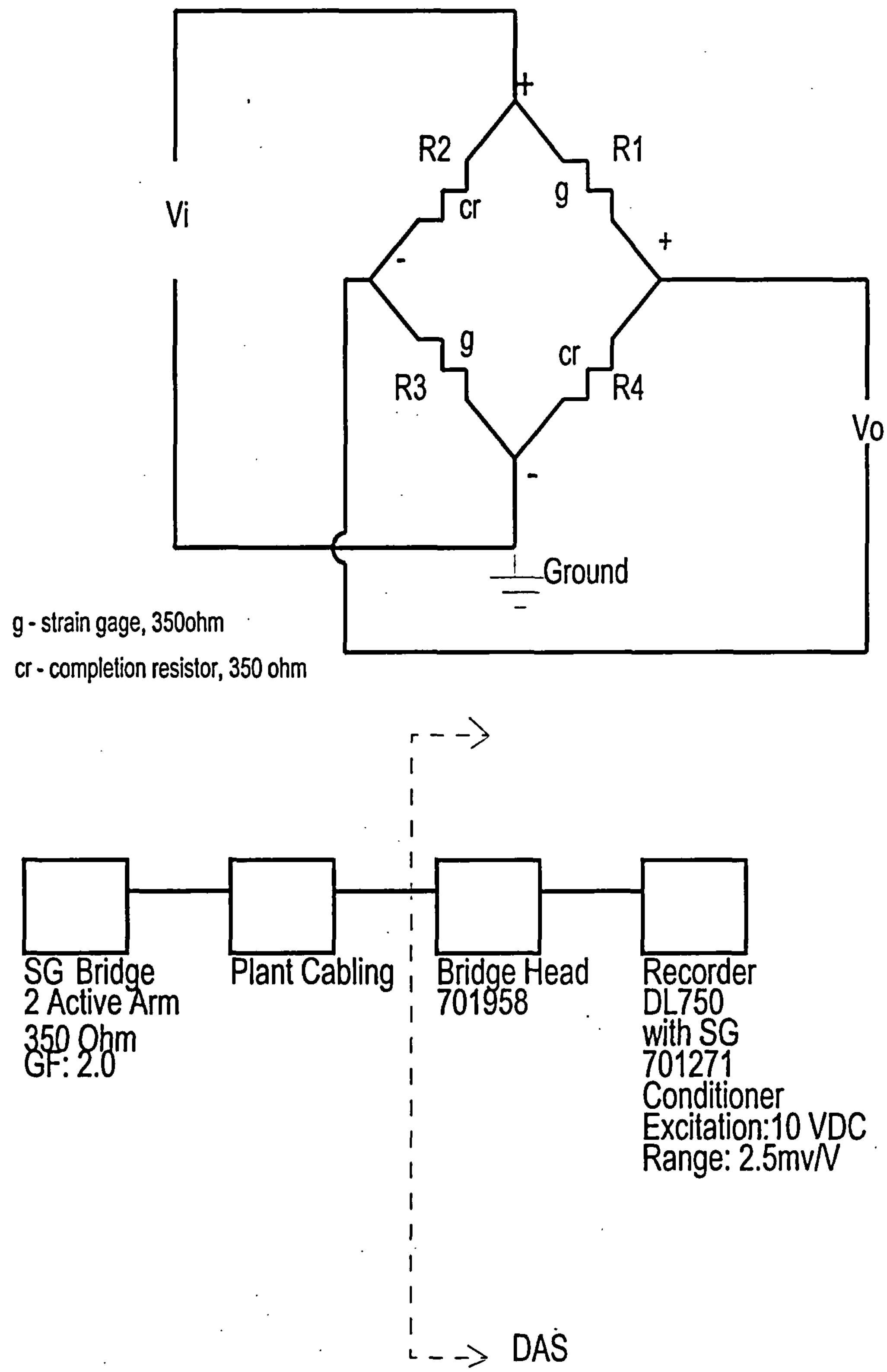

Figure 1: Wheatstone Bridge and Electrical Schematic

3 REFERENCES

1. E-mail from Guy DeBoo (Exelon) to K. Fujikawa (SI) and L. Dorfman (SI), dated 2/1/05, "Dresden MS Line Strain Gage Information," SI File No. EXLN-17Q-201.

2. Y. Dayal, "Exelon Corporation Quad Cities Unit 2 Nuclear Power Plant Dryer Instrumentation Uncertainty", GE-NE-0000-0037-1951-01 Rev 0, February 2005, SI File No. EXLN-17Q-202.

APPENDIX A

UNCERTAINTY ANALYSIS SPREADSHEET

Dresden Accuracy

	Nominal	Accuracy Values		Nominal Plus
di	17.93	2.80%		18.43204
do	20	0.63%		20.125
E	2.79E+07	5%		29295000
v	0.3	0		0.3
GF	2	2.8%		2.056
vo/vi	0.0025	0.50%		0.0025125

	Nominal	+ di	+ do	+ E	+ GF	+ vo/vi	SRSS
Pressure	10020.466	7277.4109	10660.583	10521.489	9747.5346	10070.568	
Theta		97966.236	-102418.82	-10020.466	9747.5346	-10020.466	
Uncert*Theta		2743.0546	-640.1176	-501.02328	272.93097	-50.102328	2874.3913

Pressure = 10020.466 **psi** ± 2874.3913 **psi**

% Error 28.7%