ENCLOSURE 4

"Quad Cities Strain Gage Uncertainty Evaluation," SIA File No.: EXLN-17Q-302, Revision 0, dated April 25, 2005

Structural Integrity Associates, Inc.	CALCULATION PACKAGE	File No.: EXLN-17Q-302 Project No.: EXLN-17Q

PROJECT NAME: Strain Gage Uncertainty for Steam Dryer Load Definition

CLIENT: Exelon Generation Co., LLC	Contract / P.O. No.: 00083767
PLANT: Quad Cities Unit 2	

CALCULATION TITLE: Quad Cities Strain Gage Uncertainty Evaluation

Document Revision	Affected Pages	Revision Description	Project Mgr. Approval Signature & Date	Preparer(s) & Checker(s) Signatures & Date
0	1-9 App A	Initial Issue	K. K. Fujikawa [signature] 4/25/05	L. S. Dorfman [signature] 4/25/05 K. K. Fujikawa [signature] 4/25/05

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1 INTRODUCTION

This calculation determines the dynamic pressure resolution and uncertainty for the strain gage measurements that will be taken at Quad Cities Unit 2 (QC2) during the upcoming 2005 outage.

2 QUAD CITIES STRAIN GAGE DATA ACQUISITION

Strain measurements will be made at Quad Cities Unit 2 (QC2). The data acquisition system including signal conditioning and DAS is entirely different than that used at Dresden; although the strain gages are the same. For Dresden the strain gages and completion resistors were assembled as a completed bridge, for QC2 the completion resistors will be installed near the DAS in the signal conditioner.

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 Wheatstone Bridge. 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.

Figure 2 provides a schematic for the QC2 DAS. The strain gages are spliced to shielded pair electrical cable, fed through the primary containment penetration to a strain gage cabinet that includes the strain gage signal conditioner and amplifier (Kyowa DPM-71A). The signal conditioner provides bridge balance and amplification. The DPM-71A will be shunt calibrated to provide a system sensitivity of 100με/V.

The amplified signal is then fed into a LMS SCADAS data acquisition system with a PQFA voltage amplifier. The amplifier provides amplification (±0.0625 – 10 V input range), anti-alias filtering, A/D conversion (24 bit) and storage to disk.

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

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

The DPM-71A provides full scale input ranges of ±100 to 10,000με providing ±1V out for the full scale input.

Assuming that the input range of the LMS PFQA amplifier is set to ±1V (±100με), the A/D resolution can be calculated as follows:

The A/D, converter is 24 bits or 2^{24} bits for the full input range of 2V (200με), providing an A/D resolution of $(200/2^{24}) = 0.000012$με.

Assuming the same relationship between the pipe's internal pressure to the hoop strain is the same as Dresden [1], 0.251με/psi will be used to determine the Full Scale range and A/D resolution in pressure

Full Scale Range = ±100με /0.251με/psi = ± 398psi

and the

A/D Resolution = 0.000012με /0.251με/psi = 0.000048psi.

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

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

The hoop strain is the strain in the circumferential direction minus ν 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
ν = Poisson's ratio.

Equation (J) 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 = 27.9×10^6 psi
ν = 0.3
GF = 2.0
ε = 100$\mu\varepsilon$, the full scale range.

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)

The uncertainty for ε, Absolute Strain Error (ASE) is found in Reference 2 for a quarter bridge as

$$ASE = (GF^2 + OEE^2)^{0.5} \text{ or for a half bridge as } (2(GF^2) + OEE^2)^{0.5}$$

where OEE = overall electronics error, 1.1% (Reference 2)
GF = Gage Factor of 2.0 (HPI).

The uncertainty for ε is calculated as ASE = 3.03%.

For QC2 the error will be minimized by making actual pipe thickness (ultrasonic) and outer diameter measurements. Assuming that d_o can be measured with an error of 10 mils and the thickness can be measured (ultrasonic) within 20 mils the error becomes

$$d_o = 0.05\%$$
$$d_i = 0.22\%.$$

The overall uncertainty on the measurement and conversion to pressure is 6.3% (see Attachment A).

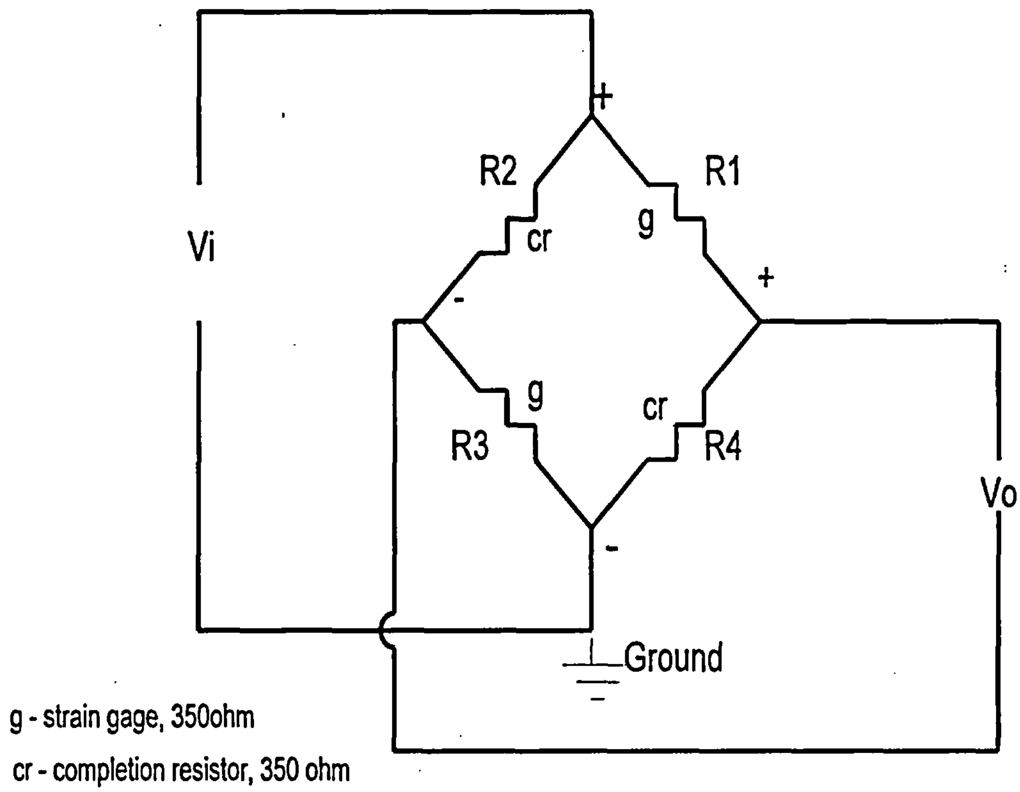

Figure 1: Wheatstone Bridge

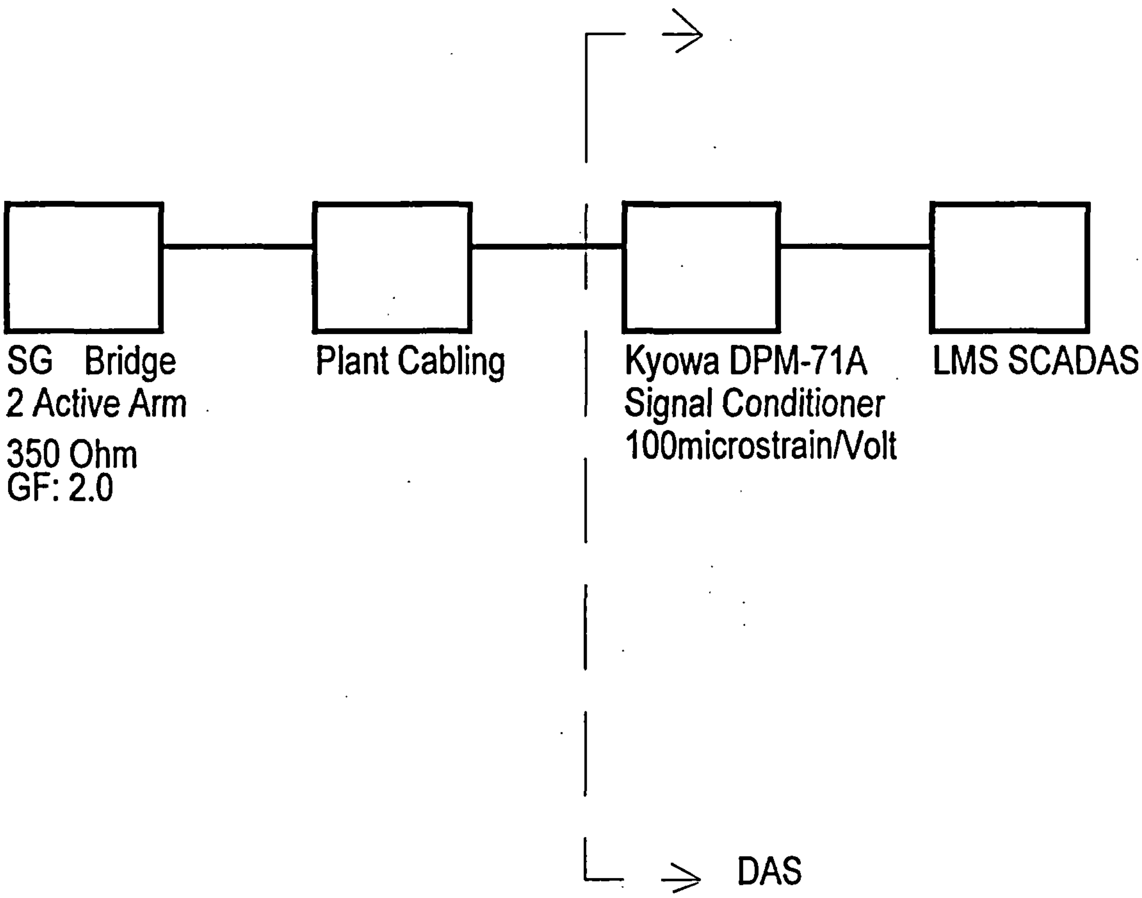

Figure 2: Electrical Schematic for Quad Cities Unit 2

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

Quad Cities 2 Accuracy with improved diameter measurements

	Nominal	Accuracy Values		Nominal Plus
di	17.93	0.22%		17.969446
do	20	0.05%		20.01
E	2.79E+07	5%		29295000
v	0.3	0		0.3
GF	2	2.8%		2.056
ε	0.0001	3.03%		0.000103

	Nominal	+ di	+ do	+ E	ε	SRSS
Pressure	400.81862	391.86341	402.86113	420.85955	412.96343	
Theta		4070.5524	-4085.0112	-400.81862	-400.81862	
Uncert*Theta		8.9552154	-2.0425056	-20.040931	-12.144804	25.169484

Pressure = 400.81862 **psi** ± 25.169484 **psi**

% Error 6.3%