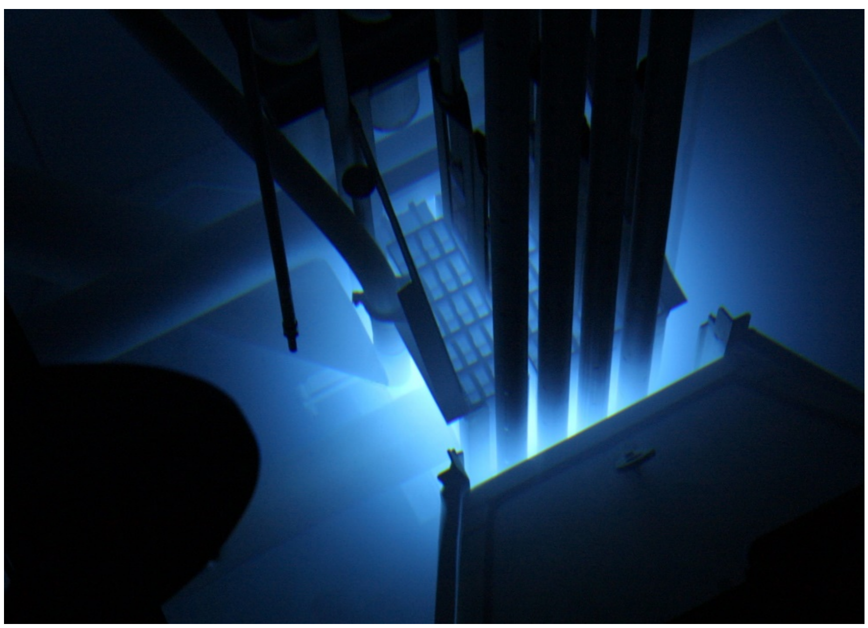
NC STATE UNIVERSITY

REACTOR THERMAL POWER
AND
SCRAM SETPOINT DETERMINATION

Nuclear Reactor Program

NORTH CAROLINA STATE UNIVERSITY

RALEIGH, NORTH CAROLINA 27695



LICENSE NO. R-120

DOCKET NO. 50-297

11-FEBRUARY-2020

1 INTRODUCTION

The following uncertainty and safety system setpoint calculations have been performed according to the general guidance and methodology provided in NRC Reg Guide 1.105[1]. Total one-sigma uncertainties calculated for the flow and temperature channels include terms for standard calibration uncertainty and all channel process module uncertainties. Uncertainty terms are summed in quadrature and result in total one-sigma uncertainties of 1.31% for the flow channel and 1.12% for the temperature channels. Flow and temperature values are then utilized to determine true reactor power as detailed below.

2 FLOW MEASURING SYSTEM UNCERTAINTIES

The nominal volumetric flow rate for the primary coolant system is 1000 gpm. Converting to a mass flow rate, assuming a temperature of 100°F, yields:

$$\dot{m} = 1000\, {}^{gpm}/_{min} \times 60\, {}^{min}/_{hr} \times 8.2877\, {}^{lbm}/_{gal} = 497262\, {}^{lbm}/_{hr} \quad \text{EQ 1}$$

The flow measuring system consists of an annubar sensor and transmitter, a panel meter, and a recorder. A precision manometer is used during the calibration procedure.

Annubar System (sensor and transmitter)

$\sigma_{\dot{m}1}$ = Uncertainty = ±0.8%[2]

Calibration Manometer

$\sigma_{\dot{m}2}$ = Uncertainty = ±0.025 in-H_2O (resolution of ruler scale)

Where 1000 gpm = 9.265 in-H_2O[3]

0.025 inH_2O/9.265 in-H_2O = 0.27%

Simpson Hawk 3 Panel Gauge (Model Number: H345-3-71-2-4-2)

$\sigma_{\dot{m}3}$ = Input Module Uncertainty = ±0.05% [4]

$\sigma_{\dot{m}4}$ = Output Module Uncertainty = ±0.05% [4]

Readings would be at 1000 gpm

Yokogawa Recorder

$\sigma_{\dot{m}5}$ = Input Module Uncertainty (0-10 volts) = ±0.05% [5]

Reading would be at 1000 gpm

Averaging Flow Measurement Uncertainty

$\sigma_{\dot{m}6}$ = 5-minute average – Standard Deviation = 1.0%

Total Flow Measuring System Uncertainty:

$$\sigma_{\dot{m}} = \sqrt{(\sigma_{\dot{m}1})^2 + (\sigma_{\dot{m}2})^2 + (\sigma_{\dot{m}3})^2 + (\sigma_{\dot{m}4})^2 + (\sigma_{\dot{m}5})^2 + (\sigma_{\dot{m}6})^2} \quad \text{EQ 2}$$

$$\sigma_{\dot{m}} = \sqrt{(.008)^2 + (.0027)^2 + (.0005)^2 + (.0005)^2 + (.0005)^2 + (.01)^2} \quad \text{EQ 3}$$

$$\sigma_{\dot{m}} = 1.31\% \quad \text{EQ 4}$$

Using the conversion from Equation 1, the total flow measuring system uncertainty in units of mass flow rate yields,

$$\sigma_{\dot{m}} = 1.31\% \times 497262 \, {}^{lbm}\!/_{hr} = 6514 \, {}^{lbm}\!/_{hr} \quad \text{EQ 5}$$

3 TEMPERATURE MEASURING SYSTEM UNCERTAINTIES

A primary coolant temperature of 37.8°C (100°F) is assumed.

The temperature measuring system consists of Pt-100 RTDs, transmitters, and a recorder. A precision Pt-100 calibration RTD is used during the calibration procedure.

Transmitter System Uncertainty [6]

Digital Accuracy - ± 0.10°C

D/A Conversion Accuracy (± 0.02% of 100°C span) - ± 0.02°C

Digital Accuracy Ambient Temperature Effect - ± 0.015°C

D/A Conversion Accuracy Ambient Temperature Effect - ± 0.01°C

σ_{t1} = Total System Uncertainty = ± 0.10°C = ± 0.18°F = 0.18%

Calibration RTD

σ_{t2} = Calibration RTD Uncertainty [7] = ± 0.5°F = 0.5%

Temperature Recorder

σ_{t3} = Input Module Uncertainty (4-20 volts) = ±0.3% of reading at 100°F [5]

Averaging Temperature Measurement Uncertainty

σ_{t4} = 5-minute average – Standard Deviation = ± 0.5%

Total Temperature Measuring System Uncertainty:

$$\sigma_t = \sqrt{(\sigma_{t1})^2 + (\sigma_{t2})^2 + (\sigma_{t3})^2 + (\sigma_{t4})^2} \quad \text{EQ 6}$$

$$\sigma_t = \sqrt{(0.0018)^2 + (.005)^2 + (.003)^2 + (.005)^2} \quad \text{EQ 7}$$

$$\sigma_{t\,hot} = 0.79\% \,, \sigma_{t\,cold} = 0.79\% \quad \text{EQ 8}$$

A differential temperature of 13.8°F across the core equates to 2 MW reactor core power. Therefore, the uncertainty in the differential temperature calculation is:

$$\sigma_{\Delta T}^2 = \sigma_{t\,hot}^2 + \sigma_{t\,cold}^2 \quad \text{EQ 9}$$

$$\sigma_{\Delta T}^2 = (0.0079)^2 + (0.0079)^2 \quad \text{EQ 10}$$

$$\sigma_{\Delta T} = 1.12\% \quad \text{EQ 11}$$

$$\sigma_{\Delta T} = 1.12\% \times 13.8°\text{F} = 0.15°\text{F} \quad \text{EQ 12}$$

4 REACTOR THERMAL POWER UNCERTAINTY

The reactor thermal power can be calculated using the following equation:

$$Q = \dot{m}C_p(\Delta T) \quad \text{EQ 13}$$

where,

$Q = reactor\ power$

$\dot{m} = mass\ flow\ rate\ of\ the\ primary\ water\ (from\ Eq\ 1) = 497262\ {}^{lbm}/_{hr}$

$C_p = specific\ heat\ of\ the\ water = 0.998\ {}^{BTU}/_{lb°\text{F}}$

$\Delta T = temperature\ difference\ across\ the\ core\ or\ heat\ exchanger = 13.8°\text{F}$

Reactor power can be calculated using the average data including their associated uncertainties. The error of the calculation can be expressed as:

$$\sigma_Q^2 = \sigma_{\dot{m}}^2 \left(\frac{\partial Q}{\partial \dot{m}}\right)^2 + \sigma_{\Delta T}^2 \left(\frac{\partial Q}{\partial \Delta T}\right)^2 \quad \text{EQ 14}$$

where,

$$\frac{\partial Q}{\partial \dot{m}} = C_p(\Delta T) \quad \text{EQ 15}$$

$$\frac{\partial Q}{\partial \Delta T} = \dot{m}C_p \quad \text{EQ 16}$$

$\sigma_Q = uncertainity\ in\ reactor\ power$

$\sigma_{\dot{m}} = uncertainity\ in\ mass\ flow\ rate\ (from\ Eq\ 5) = 6514\ {}^{lbm}/_{hr}$

$\sigma_{\Delta T} = uncertainity\ in\ differential\ temperature\ (from\ Eq\ 12) = 0.15°\text{F}$

Using Equation 14 and substituting to calculate the uncertainty in reactor power:

$$\sigma_Q^2 = \sigma_{\dot{m}}^2 \left(C_p(\Delta T)\right)^2 + \sigma_{\Delta T}^2 \left(\dot{m}C_p\right)^2 \quad \text{EQ 17}$$

$$\sigma_Q^2 = (6514^2)\left(0.998\,{}^{BTU}/_{lb°F}\,(13.8°F)\right)^2 + (0.15°F)^2\left((497262)\,{}^{lbm}/_{hr}\,0.998\,{}^{BTU}/_{lb°F}\right)^2 \qquad \text{EQ 18}$$

$$\sigma_Q = 1.18 \times 10^5\,{}^{BTU}/_{lbm} = 0.0345\,MW \qquad \text{EQ 19}$$

Therefore, at a thermal power of 2 MW the uncertainty is:

$$\sigma_Q = {}^{0.0345\,MW}/_{2\,MW} = 1.73\%$$

$$2\sigma_Q = {}^{0.069\,MW}/_{2\,MW} = 3.45\%$$

5 DETERMINATION OF OPERATING LIMITS AND SETPOINTS (2σ)

As shown above, the total 2σ uncertainty for true reactor power is 3.45%. This value is utilized to determine the Limiting Safety System Settings (LSSS) and maximum Safety System Setting (SSS_{max}) and is summarized in Table 1 below. The maximum setpoint for the scram channel also has to account for the 0.5% measurement uncertainty of that channel[8], therefore the maximum scram setpoint would be 1.92 MW. For operational purposes the actual scram setpoint will be 1.90 MW.

Table 1 – Setpoints for 2 MW Forced Convection Mode

Power Level	**Description**
$License\ Limit = 2.0\ MW$	Maximum power level allowed by license.
$LSSS = 2.0\ MW$	Maximum safety system setpoint for power level
$SSS_{max} = 2.0\ MW - (2.0\ MW * 3.45\%) = 1.93\ MW$	Maximum safety system setpoint for power level accounting for the total power calibration uncertainty at the 2-sigma level.
$SSS_{SCRAM-max} = 1.93\ MW - (2.0\ MW * 0.5\%) = 1.92\ MW$	Maximum safety system setpoint for power level accounting SCRAM channel uncertainty.
$SSS_{SCRAM-actual} = 2.0\ MW - (2.0\ MW * 5.0\%) = 1.90\ MW$	Actual safety system setpoint for SCRAM.
$SSS_{reverse} = 2.0\ MW - (2.0\ MW * 7.5\%) = 1.85\ MW$	Actual safety system setpoint for Reverse Drive.
$OPL = 2.0\ MW - (2.0\ MW * 10.0\%) = 1.80\ MW$	Nominal operating power level.

6 REFERENCES:

[1] Regulatory Guide 1.105 Setpoints for Safety-Related Instrumentation, Revision 3, US Nuclear Regulatory Commission, December 1999.

[2] Rosemount 3051 SF DP Flowmeters, Product Data Sheet, Part# 00813-0100-4485, Rev GA, Table 5, Page 36, June 2017, Emerson Process Management, Rosemount Inc., Chanhassen, MN.

[3] 3051 SFA – Annubar Flowmeter Calculation Data Sheet, Tag No. Enercon, 8/21/2012

[4] Simpson Hawk 3 Operator’s Manual Part# 06-117287, Edition 13, Table 1-2, Page 9, April 2016, Simpson Electric Company, Lac du Flambeau, MI.

[5] Yokogawa GX90XA I/O Module General Specifications, GS 04L53B01-01EN, 4th Edition, Page 2, October 27, 2014, Yokogawa Electric Corporation, Japan.

[6] Rosemount 3144P Temperature Transmitter, Reference Manual, Part# 00809-0100-4021, Rev GB, July 2012, Emerson Process Management, Rosemount Inc., Chanhassen, MN.

[7] NIST Traceable RTD Calibration Certificate.

[8] Wide Range Linear Signal Processor, Instruction Manual No.222B Rev2, Gamma-metrics, Feb 1995.

Reactor Thermal Power and SCRAM Setpoint Determination

Appendix A - References

North Carolina State University

PULSTAR Reactor

11-FEB-2020

Specifications

Performance specifications

Performance assumptions include: measured pipe I.D, transmitter is trimmed for optimum flow accuracy, and performance is dependent on application parameters.

Table 4. Multivariable Flow Performance - Flow Reference Accuracy (Measurement Type 1)[1][2]

Rosemount 3051SFA Annubar Flowmeter			
		Classic MV (8:1 flow turndown)	Ultra for flow (14:1 flow turndown)
Ranges 2–3		±1.15% of flow rate	±0.80% of flow rate
Rosemount 3051SFC_A Compact Annubar Flowmeter - Rosemount Annubar option A			
		Classic MV (8:1 flow turndown)	Ultra for flow (14:1 flow turndown)
Ranges 2–3	Standard	±1.60% of flow rate	±1.55% of flow rate
	Calibrated	±1.00% of flow rate	±0.80% of flow rate
Rosemount 3051SFC Compact Orifice Flowmeter - Conditioning option C			
		Classic MV (8:1 flow turndown)	Ultra for flow (14:1 flow turndown)
Ranges 2–3		±1.45% of flow rate	±1.15% of flow rate
Rosemount 3051SFC Compact Orifice Flowmeter - Orifice option P[3]			
		Classic MV (8:1 flow turndown)	Ultra for Flow (14:1 flow turndown)
Ranges 2–3	$\beta = 0.4$	±1.45% of flow rate	±1.30% of flow rate
	$\beta = 0.50, 0.65$	±1.45% of flow rate	±1.30% of flow rate
Rosemount 3051SFP Integral Orifice Flowmeter			
		Classic MV (8:1 flow turndown)	Ultra for flow (14:1 flow turndown)
Ranges 2–3	$\beta < 0.1$	±2.65% of flow rate	±2.60% of flow rate
	$0.1 < \beta < 0.2$	±1.60% of flow rate	±1.40% of flow rate
	$0.2 < \beta < 0.6$	±1.25% of flow rate	±0.95% of flow rate
	$0.6 < \beta < 0.8$	±1.80% of flow rate	±1.60% of flow rate

1. Measurement types 2–4 assume the unmeasured variables are constant. Additional uncertainty will depend on the variation in the unmeasured variables.
2. Range 1 flowmeters experience an additional uncertainty up to 0.9 percent. Consult your Emerson Representative for exact specifications.
3. For line size less than 2-in. (50 mm) or greater than 8-in. (200 mm), add an additional 0.5 percent uncertainty.

Table 5. Flow Performance - Flow Reference Accuracy (Measurement Type D)[1][2][3]

Rosemount 3051SFA Annubar Flowmeter				
		Classic (8:1 flow turndown)	Ultra (8:1 flow turndown)	Ultra for flow (14:1 flow turndown)
Ranges 2–3		±1.25% of flow rate	±0.95% of flow rate	±0.80% of flow rate
Rosemount 3051SFC_A Compact Annubar Flowmeter - Rosemount Annubar option A				
		Classic (8:1 flow turndown)	Ultra (8:1 flow turndown)	Ultra for flow (14:1 flow turndown)
Ranges 2–3	Uncalibrated	±1.70% of flow rate	±1.65% of flow rate	±1.55% of flow rate
	Calibrated	±1.25% of flow rate	±0.95% of flow rate	±0.80% of flow rate
Rosemount 3051SFC Compact Orifice Flowmeter – Conditioning option C				
		Classic (8:1 flow turndown)	Ultra (8:1 flow turndown)	Ultra for flow (14:1 flow turndown)
Ranges 2–3		±1.40% of flow rate	±1.25% of flow rate	±1.15% of flow rate
Rosemount 3051SFC Compact Orifice Flowmeter - Orifice Option P[4]				
		Classic (8:1 flow turndown)	Ultra (8:1 flow turndown)	Ultra for Flow (14:1 flow turndown)
Ranges 2–3	$\beta = 0.4$	±1.80% of flow rate	±1.35% of flow rate	±1.30% of flow rate
	$\beta = 0.65$	±1.80% of flow rate	±1.35% of flow rate	±1.30% of flow rate

ROSEMOUNT INC.
3051SFA - Annubar Flowmeter
CALCULATION DATA SHEET

EMERSON Process Management

GENERAL DATA

Customer:	
Project:	Pavelka FY12 Q3
S. O. No:	
P. O. No:	
Calc. Date:	
Model No:	3051SFADL100CSHPS2T100032AA1A2
Tag No:	Enercon

PRODUCT DESCRIPTION

Product Type:	Pak-Lok	Instrument Valve:	
Sensor Size:	Sensor Size 2	Valve Material:	
Wetted Material:	316 Stainless Steel	Line Size:	10-in. (250 mm)
Transmitter Conn.:	Direct-Mount, Integral 3-valve Manifold	Pipe Sch.:	40
Mounting Conn. Material:	316 Stainless Steel	Pipe Orientation:	Horizontal
Mounting Type:	Compression/Threaded Connection		

INPUT DATA

Fluid Type:	Liquid	Wall:	0.365 inch
Fluid Name:	WATER		
Pipe I.D. (Span):	10.020 inch		
Body I.D.:	10.020 inch	Base Pressure:	14.696 psia
Duct Width:	inch	Base Temperature:	60.00 F
Pressure:	22.000 psig		
Temperature at Flow:	100.00 F		
Absolute Viscosity:	0.68120 cP	Base Density:	62.3800 lb/ft3
Isentropic Exponent:		Atmospheric Pressure:	14.696 psia
Compressibility at Flow:			
Density at Flow:	62.0046 lb/ft3		

Flow Rates

Minimum:	500.00 USGPM
Normal:	1000.00 USGPM
Maximum:	2000.00 USGPM
Full Scale:	2000.00 USGPM

CALCULATED DATA

(Calculation Performed at Normal Conditions, DP in inH2O@68F)

DP at Min Flow:	2.316 inH2O@68F	Flow Coefficient:	0.5754
DP at Normal Flow:	9.265 inH2O@68F		
DP at Max Flow:	37.060 inH2O@68F	Rod Reynolds Number (Minimum):	24327
DP at Full Scale Flow:	37.060 inH2O@68F	Rod Reynolds Number (Normal):	48654
Resonant Frequency:	468 Hz	Gas Expansion Factor:	
Wake Frequency:	9 Hz	Permanent Pressure Loss:	
Blockage:	0.13	at Normal Flow:	1.25 inH2O@68F
		at Maximum Flow:	4.99 inH2O@68F
		Velocity at Max Flow:	8.13 ft/sec

GUIDELINES

Primary Element Min Limit:		256.92 USGPM	Recommended Min Rod Reynolds Number:	12500
Structural Limit (Flow):		8281.80 USGPM	Recommended Min DP:	0.250 inH2O@68F
Structural Limit (DP):		635.5 inH2O@68F		
Max. Allow. Pressure@Temp.:	1440.0 psig	100 F	Max. Allow. Temp.:	500 F
Design Pressure/Temperature:	22.00 psig	100.00 F		

WARNINGS

NOTES

Printed On: 21-Aug-2012

REFERENCE 4

RS-485 Specications (only available on H345)	
2 wire / Half duplex, Baud rate: 9600 baud, 1ms delay per character, 32 Nodes Maximum on Bus. Optically and magnetically isolated for ground loop elimination	
MECHANICAL	
Bezel	3.92” x 2.0” x 0.52” (99.8mm x 51.9mm x 132mm)
Depth	3.24” (82.3mm) behind panel
Panel cutout	3.62” x 1.77” (92mm x 45mm) 1/8 DIN
Weight	10 oz. (283.5 g)
Cover	NEMA 4X Rated front panel
ELECTRICAL	
Accuracy	Listed as % of reading at 25°C. Add 100ppm/°C to compensate for drift. Tested at 50Hz, include +/-1 count for every 100Hz above 50 Hz
Transient Overvoltage	Installation Category III, Pollution Degree 2
Analog Output	Sampling Rate = 100 mSec. Reaction Time 0 to Full Scale = 10 µSec

Table 1 - 1

Input Board Type	Range	Resolution 4-1/2	Resolution 3-1/2	Input Impedance	Overload	Accuracy 4-1/2	Accuracy 3-1/2
DC Voltage	200 mV	10 µV	.1 mV	1M Ω	5 DCV	± .05% of reading ± 1 count	± .1% of reading ± 1 count
	2 V	.1 mV	1 mV	1M Ω	5 DCV	± .05% of reading ± 1 count	± .1% of reading ± 1 count
	20 V	1 mV	10 mV	1M Ω	300 DCV	± .05% of reading ± 1 count	± .1% of reading ± 1 count
	200 V	10 mV	.1 V	1M Ω	300 DCV	± .05% of reading ± 1 count	± .1% of reading ± 1 count
	600 V	.1 V	1 V	1M Ω	1K DCV	± .1% of reading ± 1 count	± .2% of reading ± 1 count

Table 1 - 2

Input Board Type	Range	Resolution 4-1/2	Resolution 3-1/2	Input Impedance	Overload	Accuracy 4-1/2	Accuracy 3-1/2
DC Current	200 µA	10 nA	.1 µA	1K Ω	4.5 mA DC	± .05% of reading ± 1 count	± .1% of reading ± 1 count
	2 mA	.1 µA	1 µA	100 Ω	45 mA DC	± .05% of reading ± 1 count	± .1% of reading ± 1 count
	20 mA	1 µA	10 µA	10 Ω	200 mA DC	± .05% of reading ± 1 count	± .1% of reading ± 1 count
	200 mA	10 µA	.1 mA	1 Ω	600 mA DC	± .05% of reading ± 1 count	± .1% of reading ± 1 count
	2 A	.1 mA	1 mA	.013 Ω	5.5 A DC	± .2% of reading ± 1 count	± .3% of reading ± 1 count
	5 A	1 mA	10 mA	.013 Ω	5.5 A DC	± .2% of reading ± 1 count	± .3% of reading ± 1 count

Table 1 - 3

Input Board Type	Range	Resolution 4-1/2	Resolution 3-1/2	Input Impedance	Overload	Accuracy 4-1/2	Accuracy 3-1/2
AC Voltage	200 mV	10 µV	.1 mV	200K Ω	5 DCV	± .05% of reading ± 1 count	± .1% of reading ± 1 count
	2 V	.1 mV	1 mV	200K Ω	5 DCV	± .05% of reading ± 1 count	± .1% of reading ± 1 count
(Same for TRMS	20 V	1 mV	10 mV	1M Ω	300 DCV	± .05% of reading ± 1 count	± .1% of reading ± 1 count
* @ 60 Hz)	200 V	10 mV	.1 V	1M Ω	300 DCV	± .05% of reading ± 1 count	± .1% of reading ± 1 count
	600 V	.1 V	1 V	1M Ω	1K DCV	± .1% of reading ± 1 count	± .2% of reading ± 1 count

Table 1 - 4

Input Board Type	Range	Resolution 4-1/2	Resolution 3-1/2	Input Impedance	Overload	Accuracy 4-1/2	Accuracy 3-1/2
AC Current	200 µA	10 nA	.1 µA	1K Ω	4.5 mA DC	± .1% of reading ± 1 count	± .2% of reading ± 2 count
	2 mA	.1 µA	1 µA	100 Ω	45 mA DC	± 1% of reading ± 2 count	± .2% of reading ± 2 count
(Same for TRMS	20 mA	1 µA	10 µA	10 Ω	200 mA DC	± .1% of reading ± 2 count	± .2% of reading ± 2 count
* @ 60 Hz)	200 mA	10 µA	.1 mA	1 Ω	600 mA DC	± .1% of reading ± 2 count	± .2% of reading ± 2 count
	2 A	.1 mA	1 mA	.013 Ω	5.5 A DC	± .2% of reading ± 2 count	± .3% of reading ± 2 count
	5 A	1 mA	10 mA	.013 Ω	5.5 A DC	± .2% of reading ± 2 count	± .3% of reading ± 2 count

REFERENCE 5

■ INPUT/OUTPUT MODULE SPECIFICATIONS

ANALOG INPUT MODULE (Model GX90XA or GX/GP main unit options /Uxx0)

GX90XA

- Number of inputs: 10
- Input Type:

Suffix Code	Input Type	Description
-U2	DC voltage, standard signal, thermocouple (TC), resistance temperature detector (RTD), DI (voltage, contact), and DC current (by adding an external shunt resistor)	Universal
-C1	DC current (mA), DC current standard signal (4-20 mA)	Current input
-L1	DC voltage, standard signal, thermocouple (TC), DI (voltage, contact), and DC current (by adding an external shunt resistor)	Low withstand voltage relay
-T1	DC voltage, standard signal, thermocouple (TC), DI (voltage, contact), and DC current (by adding an external shunt resistor)	Electromagnetic relay

- Measurement interval: 100 [*1] [*2], 200 [*1] [*2], 500 ms[*1], 1, 2, 5 s
- Input range: -5% or more and 105% or less (accuracy is guaranteed in the range from 0% to 100% inclusive)
- Measurement ranges and accuracies[*3] (However, the number of display digits can be increased by scaling.)

*1 Cannot be specified for the electromagnetic relay scanner type (Type Suffix Code: -T1).
*2 Cannot be specified for L-model DCV/TC/DI, scanner type (Type Suffix Code: -L1).
*3 The following specifications apply to operation of the recorder under standard operation conditions.
Temperature: 23 ± 2 °C, Humidity: 55% ± 10% RH, Power supply voltage: 90 to 132 or 180 to 264 VAC, Power supply frequency: 50/60 Hz ± 1%, Warm-up time: At least 30 min. Other ambient conditions such as vibration should not adversely affect recorder operation.

Input Type	Range	Measurement range	Measurement accuracy (digital display)		Max. resolution of digital display
			A/D integration time: 16.7ms or more	A/D integration time: 1.67ms	
DCV	20 mV	-20.000 to 20.000 mV	±(0.05 % of rdg + 12 μV)	±(0.1 % of rdg + 40 μV)	1 μV
	60 mV	-60.00 to 60.00 mV	±(0.05 % of rdg + 0.03 mV)	±(0.1 % of rdg + 0.15 mV)	10 μV
	200 mV	-200.00 to 200.00 mV	±(0.05 % of rdg + 0.03 mV)	±(0.1 % of rdg + 0.4 mV)	10 μV
	1 V	-1.0000 to 1.0000 V	±(0.05 % of rdg + 1.2 mV)	±(0.1 % of rdg + 4 mV)	100 μV
	2 V	-2.0000 to 2.0000 V	±(0.05 % of rdg + 1.2 mV)	±(0.1 % of rdg + 4 mV)	100 μV
	6 V	-6.000 to 6.000 V	±(0.05 % of rdg + 3 mV)	±(0.1 % of rdg + 15 mV)	1 mV
	20 V	-20.000 to 20.000 V	±(0.05 % of rdg + 3 mV)	±(0.1 % of rdg + 40 mV)	1 mV
	50 V	-50.00 to 50.00 V	±(0.05 % of rdg + 0.03 V)	±(0.1 % of rdg + 0.15 V)	10 mV
Standard signal	0.4-2V	0.3200 to 2.0800 V	±(0.05 % of rdg + 1.2 mV)	±(0.1 % of rdg + 4 mV)	100 μV
	1-5V	0.800 to 5.200 V	±(0.05 % of rdg + 3 mV)	±(0.1 % of rdg + 15 mV)	1 mV
DC current	0-20mA	0.000 to 20.000 mA	±(0.3 % of rdg + 5 μA)	±(0.3 % of rdg + 90 μA)	1 μV
DC current (standard signal)	4-20mA	3.200 to 20.800 mA			
TC (Excluding RJC accuracy)	R *4	0.0 to 1760.0 °C	±(0.15 % of rdg + 1.0 °C) However, R, S; 0.0 to 800.0 °C: ±2.2 °C, B; 400.0 to 800.0 °C: ±3.0 °C Accuracy at less than 400.0 °C is not guaranteed.	±(0.2 % of rdg + 6.0 °C) However, R, S; 0.0 to 800.0 °C: ±7.6 °C, B; 400.0 to 800.0 °C: ±11.0 °C Accuracy at less than 400.0 °C is not guaranteed.	0.1 °C
	S *4	0.0 to 1760.0 °C			
	B *4	0.0 to 1820.0 °C			
	K *4	-270.0 to 1370.0 °C	±(0.15 % of rdg + 0.7 °C) However, -200.0 to 0.0 °C: ±(0.35 % of rdg + 0.7 °C) Accuracy at less than -200.0 °C is not guaranteed	±(0.2 % of rdg + 5.0 °C) However, -200.0 to 0.0 °C: ±(3 % of rdg + 5.0 °C) Accuracy at less than -200.0 °C is not guaranteed	0.1 °C
		-200.0 to 500.0 °C			
	E *4	-270.0 to 800.0 °C	±(0.15 % of rdg + 0.5 °C) However, -200.0 to 0.0 °C: ±(0.35 % of rdg + 0.5 °C) Accuracy at less than -200.0 °C is not guaranteed	±(0.2 % of rdg + 4.0 °C) However, -200.0 to 0.0 °C: ±(2 % of rdg + 4.0 °C) Accuracy at less than -200.0 °C is not guaranteed	0.1 °C
	J *4	-200.0 to 1100.0 °C			
	T *4	-270.0 to 400.0 °C	±(0.15 % of rdg + 0.5 °C) However, -200.0 to 0.0 °C: ±(0.35 % of rdg + 0.5 °C) Accuracy at less than -200.0 °C is not guaranteed	±(0.2 % of rdg + 2.5 °C) However, -200.0 to 0.0 °C: ±(2 % of rdg + 2.5 °C) Accuracy at less than -200.0 °C is not guaranteed	0.1 °C
	N *4	-270.0 to 1300.0 °C	±(0.15 % of rdg + 0.7 °C) However, -200.0 to 0.0 °C: ±(0.7 % of rdg + 0.7 °C) Accuracy at less than -200.0 °C is not guaranteed	±(0.3 % of rdg + 6.0 °C) However, -200.0 to 0.0 °C: ±(5 % of rdg + 6.0 °C) Accuracy at less than -200.0 °C is not guaranteed	0.1 °C
	W *5	0.0 to 2315.0 °C	±(0.15 % of rdg + 1.5 °C)	±(0.3 % of rdg + 14.0 °C) However, more than 1000.0 °C: ±(0.8 % of rdg + 9.0 °C)	0.1 °C
	L *6	-200.0 to 900.0 °C	±(0.15 % of rdg + 0.5 °C) Less than 0.0 °C: ±(0.5 % of rdg + 0.5 °C)	±(0.2 % of rdg + 4.0 °C) Less than 0.0 °C: ±(3 % of rdg + 4.0 °C)	0.1 °C
	U *6	-200.0 to 400.0 °C	±(0.15 % of rdg + 0.5 °C) Less than 0.0 °C: ±(0.7 % of rdg + 0.5 °C)	±(0.2 % of rdg + 2.5 °C) Less than 0.0 °C: ±(3 % of rdg + 2.5 °C)	0.1 °C
	WRe3-25 *7	0.0 to 2320.0 °C	±(0.2 % of rdg + 2.5 °C)	±18.0 °C More than 2000.0 °C: ±0.9 % of rdg	0.1 °C

REFERENCE 6

Transmitter accuracy

Sensor options	Sensor reference	Input ranges		Minimum span(1)		Digital accuracy(2)		Enhanced accuracy(3)	D/A accuracy(4)(5)
2-, 3-, 4-wire RTDs		°C	°F	°C	°F	°C	°F	°C	
Pt 100 (α = 0.00385)	IEC 751	–200 to 850	–328 to 1562	10	18	±0.10	±0.18	±0.08	±0.02% of span
Rosemount™ X-well™ Pt 100 (α = 0.00385)	IEC 751	–50 to 300	–58 to 572	10	18	±0.29	±0.52	N/A	±0.02% of span
Pt 200 (α = 0.00385)	IEC 751	–200 to 850	–328 to 1562	10	18	±0.22	±0.40	±0.176	±0.02% of span
Pt 500 (α = 0.00385)	IEC 751	–200 to 850	–328 to 1562	10	18	±0.14	±0.25	±0.112	±0.02% of span
Pt 1000 (α = 0.00385)	IEC 751	–200 to 300	–328 to 572	10	18	±0.10	±0.18	±0.08	±0.02% of span
Pt 100 (α = 0.003916)	JIS 1604	–200 to 645	–328 to 1193	10	18	±0.10	±0.18	±0.08	±0.02% of span
Pt 200 (α = 0.003916)	JIS 1604	–200 to 645	–328 to 1193	10	18	±0.22	±0.40	±0.176	±0.02% of span
Ni 120	Edison Curve No. 7	–70 to 300	–94 to 572	10	18	± 0.08	± 0.14	±0.64	±0.02% of span
Cu 10	Edison Copper Winding No. 15	–50 to 250	–58 to 482	10	18	±1.00	±1.80	±0.08	±0.02% of span
Pt 50 (α=0.00391)	GOST 6651-94	–200 to 550	–328 to 1022	10	18	±0.20	±0.36	±0.16	±0.02% of span
Pt 100 (α=0.00391)	GOST 6651-94	–200 to 550	–328 to 1022	10	18	±0.10	±0.18	±0.08	±0.02% of span
Cu 50 (α=0.00426)	GOST 6651-94	–50 to 200	–58 to 392	10	18	±0.34	±0.61	±0.272	±0.02% of span
Cu 50 (α=0.00428)	GOST 6651-94	–185 to 200	–301 to 392	10	18	±0.34	±0.61	±0.272	±0.02% of span
Cu 100 (α=0.00426)	GOST 6651-94	–50 to 200	–58 to 392	10	18	±0.17	±0.31	±0.136	±0.02% of span
Cu 100 (α=0.00428)	GOST 6651-94	–185 to 200	–301 to 392	10	18	±0.17	±0.31	±0.136	±0.02% of span
Thermocouples(6)									
Type B(7)	NIST Monograph 175, IEC 584	100 to 1820	212 to 3308	25	45	±0.75	±1.35	N/A	±0.02% of span
Type E	NIST Monograph 175, IEC 584	–50 to 1000	–58 to 1832	25	45	±0.20	±0.36	N/A	±0.02% of span
Type J	NIST Monograph 175, IEC 584	–180 to 760	–292 to 1400	25	45	±0.25	±0.45	N/A	±0.02% of span
Type K(8)	NIST Monograph 175, IEC 584	–180 to 1372	–292 to 2501	25	45	±0.25	±0.45	N/A	±0.02% of span
Type N	NIST Monograph 175, IEC 584	–200 to 1300	–328 to 2372	25	45	±0.40	±0.72	N/A	±0.02% of span
Type R	NIST Monograph 175, IEC 584	0 to 1768	32 to 3214	25	45	±0.60	±1.08	N/A	±0.02% of span

Ambient temperature effect

Table A-1. Ambient Temperature Effect

Sensor options	Digital accuracy per 1.0 °C (1.8 °F) change in ambient[(1)(2)]	Range	D/A effect[(3)]
2-, 3-, or 4- wire RTDs			
Pt 100 (α = 0.00385)	0.0015 °C (0.0027 °F)	Entire sensor input range	0.001% of span
Rosemount X-well Pt 100 (α = 0.00385)	0.0058 °C (0.0104 °F)	Entire sensor input range	0.001% of span
Pt 200 (α = 0.00385)	0.0023 °C (0.00414 °F)	Entire sensor input range	0.001% of span
Pt 500 (α = 0.00385)	0.0015 °C (0.0027 °F)	Entire sensor input range	0.001% of span
Pt 1000 (α = 0.00385)	0.0015 °C (0.0027 °F)	Entire sensor input range	0.001% of span
Pt 100 (a = 0.003916)	0.0015 °C (0.0027 °F)	Entire sensor input range	0.001% of span
Pt 200 (a = 0.003916)	0.0023 °C (0.00414 °F)	Entire sensor input range	0.001% of span
Ni 120	0.0010 °C (0.0018 °F)	Entire sensor input range	0.001% of span
Cu 10	0.015 °C (0.027 °F)	Entire sensor input range	0.001% of span
Pt 50 (a = 0.00391)	0.003 °C (0.0054 °F)	Entire sensor input range	0.001% of span
Pt 100 (a = 0.00391)	0.0015 °C (0.0027 °F)	Entire sensor input range	0.001% of span
Cu 50 (a = 0.00426)	0.003 °C (0.0054 °F)	Entire sensor input range	0.001% of span
Cu 50 (a = 0.00428)	0.003 °C (0.0054 °F)	Entire sensor input range	0.001% of span
Cu 100 (a = 0.00426)	0.0015 °C (0.0027 °F)	Entire sensor input range	0.001% of span
Cu 100 (a = 0.00428)	0.0015 °C (0.0027 °F)	Entire sensor input range	0.001% of span
Thermocouples			
Type B	0.014 °C 0.029 °C – (0.0021% of [T – 300]) 0.046 °C – (0.0086% of [T – 100])	R ≥ 1000 °C 300 °C ≤ R < 1000 °C 100 °C ≤ R < 300 °C	0.001% of span
Type E	0.004 °C + (0.00043% of T)		0.001% of span
Type J	0.004 °C + (0.00029% of T) 0.004 °C + (0.0020% of absolute value T)	T ≥ 0 °C T< 0 °C	0.001% of span
Type K	0.005 °C + (0.00054% of T) 0.005 °C + (0.0020% of absolute value T)	T ≥ 0 °C T < 0 °C	0.001% of span
Type N	0.005 °C + (0.00036% of T)	All	0.001% of span
Types R	0.015 °C 0.021 °C – (0.0032% of T)	T ≥ 200 °C T < 200 °C	0.001% of span
Types S	0.015 °C 0.021 °C – (0.0032% of T)	T ≥ 200 °C T < 200 °C	0.001% of span
Type T	0.005 °C 0.005 °C + (0.0036% of absolute value) T)	T ≥ 0 °C T < 0 °C	0.001% of span
DIN Type L	0.0054 °C + (0.00029% of T) 0.0054 °C + (0.0025% of absolute value T)	T ≥ 0 °C T < 0 °C	0.001% of span
DIN Type U	0.0064 °C 0.0064 °C + (0.0043% of absolute value T)	T ≥ 0 °C T < 0 °C	0.001% of span

Sensor options	Digital accuracy per 1.0 °C (1.8 °F) change in ambient[(1)(2)]	Range	D/A effect[(3)]
Type W5Re/W26Re	0.016 °C 0.023 °C + (0.0036% of T)	T ≥ 200 °C T < 200 °C	0.001% of span
GOST Type L	0.005 °C 0.005 °C + (0.003% of T)	T ³ 0 °C T < 0 °C	0.001% of span
Millivolt Input	0.00025 mV	Entire sensor input range	0.001% of span
2-, 3-, 4-wire Ohm Input	0.007 ohms	Entire sensor input range	0.001% of span

1. Change in ambient is in reference to the calibration temperature of the transmitter (20 °C [68 °F]).
2. Ambient temperature effect specification valid over minimum temperature span of 28 °C(50 °F).
3. Applies to HART/4–20 mA devices.

Transmitters may be installed in locations where the ambient temperature is between –40 and 85 °C (–40 and 185 °F).

To maintain excellent accuracy performance, each transmitter is individually characterized over this ambient temperature range at the factory.

Temperature effects example

When using a Pt 100 (α = 0.00385) sensor input with a 0 to 100 °C span at 30 °C ambient temperature, the following statements would be true:

Digital temp effects

- 0.0015 °C/°C × (30 °C–20 °C) = 0.015 °C

D/A effects (HART/4–20 mA only)

- (0.001% /°C of span) × |(ambient temp–calibrated temp)| = D/A effects
- (0.001% /f °C 100) × |(30–20)| = 0.01 °C

Worst case error

- Digital + D/A + digital temp effects + D/A effects

= 0.10 °C + 0.02 °C + 0.015 °C + 0.01 °C = 0.145 °C

Worst case error

Digital + D/A + digital temp effects + D/A effects
= 0.10 °C + 0.02 °C + 0.015 °C + 0.01 °C = 0.145 °C

Total probable error

$$\sqrt{0.10^2 + 0.02^2 + 0.015^2 + 0.01^2} = 0.10\ °C$$

Process temperature effects

Table A-2. Ambient and Process Temperature Difference Effect on Digital Accuracy

Sensor option	Sensor reference	Effects per 1.0 °C(1.8 °F) difference in ambient and process temperature[(1)]	Input temperature (T)
Rosemount X-well Pt 100 (α = 0.00385)	IEC 751	± 0.01 °C (0.018 °F)	Entire sensor input range

1. Valid under steady state process and ambient conditions.

Temperature effects example

When using a Pt 100 (α = 0.00385) sensor input with a 0 to 100 °C span at 30 °C ambient temperature, the following statements would be true:

Digital temp effects

- $0.0015\ \frac{°C}{°C} \times (30 - 20\ °C) = 0.015\ °C$

D/A effects (HART/4–20 mA only)

- $[0.001\%/°C of span] \times 100\ °C \times |(30 - 20°C)| = °C$ DA effect
- $[0.001\%/°C \times 100] \times |(30 - 20)| = 0.001°C$

Worst case error

- Digital + D/A + Digital temp effects + D/A effects
  = 0.10 °C + 0.02 °C + 0.015 °C + 0.01 °C = 0.145 °C

1.1. PERFORMANCE SPECIFICATIONS

ELECTRICAL

Detector Input Range	1 x 10^{-12} to 1 x 10^{-4} A
Output Range	30 mW - 1 MW
Decades covered	8
Total Ranges	16
Accuracy	±3% from 30 mW to 10 W ±1% from 10 W to 10 KW ±0.5% from 10 KW to 1 MW
Temp Drift %/°C	±0.05%
Response Time (0 - 63%)	200 mSec from 30 mW to 10 W 1.5 mSec from 10 W to 10 KW 0.8 mSec from 10 KW to 1 MW
Bistable Trip Contact Ratings	2 A @ 28 Vdc 0.3 A @ 117 Vac
Service Conditions	0 to 60°C, 10% to 95% RH
Power	117 Vac ±10%, 60Hz, 2 A

MECHANICAL

Size (H x W x D)	8.75 x 19 x 22 in.
Weight	35 lbs.