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National Ocean Survey

EVALUATION of AANDERAA TEMPERATURE, CONDUCTIVITY, and PRESSURE SENSORS

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Oceanographic
Instrumentation
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Evaluation of Aanderaa Temperature, Conductivity and Pressure Sensors

by

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Temperature, Conductivity and
Pressure Sensors

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ABSTRACT

The performance and environmental capabilities of the temperature, conductivity, and pressure measurement channels of three (3) Aanderaa Model 4 Recording Current Meters were evaluated. Performance test results over a five-week period indicate that the overall measurement accuracy (a maximum probable error determined by taking the square root of the sum of the squares of each of the worst case errors attributed to nonrepeatability, nonlinearity, hysteresis, etc., associated with each measurement channel) of the temperature, conductivity, and pressure channels are approximately $\pm 0.04°C$, ± 0.10 mho x 10^{-3}/cm, and ± 0.07 kg/cm^2 ($\pm 0.5\%$ full range or FR), respectively. Environmental tests indicate the channel calibrations are not adversely affected when the instrument is exposed to extreme variations in temperature (-28°C to +65°C) and mechanical vibrations (0.030" and 0.003" peak amplitudes at upper frequencies of 15 Hz and 50 Hz, respectively); pressure up to 14 kg/cm^2 does not noticeably affect the temperature or conductivity sensor calibrations. Calibrations on all three measurement channels change with time, but the pressure channels were observed to be the worst with maximum differences as much as $|0.53\%$ FR$|$; a 5% zero shift in the pressure channel calibration occurred on one instrument during a pressurization test.

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1.0 INTRODUCTION

The National Oceanic and Atmospheric Administration's (NOAA), Marine Ecosystems Analysis (MESA) Program requires relevant data collected either by search of existing data banks or by establishing and implementing new acquisition systems. Because instrumentation plays such an important role in acquiring and recording the variables of desired physical, chemical, and biological processes of interest, as much as possible must be known about instrument performance prior to field deployment to associate maximum credibility with its output. For this reason, the MESA Program tasked the National Oceanographic Instrumentation Center (NOIC) to perform instrument evaluation tests on three Aanderaa Model 4 Recording Current Meters (RCM), one of the many types of environmental measuring instruments to be used in the MESA Program. Only the conductivity, temperature, and depth sensing channels of the model 4 RCM were tasked by MESA.

2.0 OBJECTIVE

The objectives in performing evaluation tests on the conductivity, temperature, and depth (pressure) sensing channels of three Aanderaa Model 4 RCMs were the following: examine sensor performance characteristics, determining the effect on sensor performance due to exposure to different instrument environmental conditions both operational and nonoperational, and determine realistic measurement accuracy. Three units were used for testing, S/N's 714, 715 and 716. Two units (715 and 716) were used to examine sensor performance and one unit (714) was used to evaluate environmental effects. From the test data collected on all three units, an attempt was made to estimate a realistic static measurement accuracy for each sensing channel using both NOIC's and manufacturer's calibration data.

Tests were performed at NOIC, Navy Yard Annex, Washington, D.C. from the period April to June 1973.

3.0 INSTRUMENT DESCRIPTION

The Aanderaa Model 4 Recording Current Meter is a self-contained instrument designed to measure and record (according to a pre-programmed sampling scheme) sea water conductivity, temperature, depth (pressure), current speed, and current direction. Since NOIC's tests pertained only to the CTD channels, the remainder of this description as well as the report will deal primarily with these three variables.

The self-contained underwater recording unit senses conductivity with an inductively coupled toroidal cell, temperature with a thermistor, and pressure with a bourdon tube driven potentiometer. Measurement of each sensor channel output is achieved by sequentially switching each output into an automatically controlled bridge balancing circuit, the heart of which is a rotary encoder. The encoder consists of ten switches and thus, can provide a balance in ten binary steps with the least significant bit (LSB) representing 1 part in 1024 of the sensing channel measurand range. Switching of a sensor output to the balancing bridge is accomplished by a channel selector switch which is advanced by a pin attached to the periphery of the encoder cover plate. As each binary data bit is being encoded

("1" or "0"), it is recorded on a capstan drive, constant speed magnetic tape recorder as either a short pulse ("1") or long pulse ("0"). The data pulses are also sent to two other locations: (1) to an acoustic transducer which will allow remote monitoring and/or recording of the measured values via underwater acoustic transmission to a hydrophone receiver; and (2) to a direct electrical readout terminal which will allow remote monitoring and/or recording of measured values via electrical cable.

A single measuring cycle consists of the following measurements:

1. Reference (Measures the ratio between two fixed resistors and serves as a control on the performance of the instrument and as an identification number for the instrument).
2. Temperature
3. Conductivity
4. Pressure
5. Current Direction (Compass)
6. Current Speed

After the end of each measuring cycle an end of record pulse is generated and recorded.

As mentioned previously, the instrument is designed to measure and record according to a pre-programmed sampling scheme. The sampling rate is controlled by programable battery powered interval timer referenced to a quartz crystal oscillator (16.385 kHz). Changing the sampling interval is accomplished by inserting different triggering interval plug-ins (14 pin dual in line plugs), 1/2, 1, 2, 5, 10, 20, 30, 60, 120, and 240 minute intervals.

The instrument requires two battery supplies for operation consisting of one each carbon zinc and mercury batteries. The carbon zinc battery powers the bulk of the recording unit while the mercury battery powers only the interval timer.

For deployment at sea the instrument is designed to mount on a vane assembly which incorporates a spindle at either end for shackling it into a mooring line. In this mounting arrangement, the recording unit can swing freely around the spindle allowing the vane to align itself in the direction of the ocean current.

4.0 PERFORMANCE SPECIFICATIONS (S/N's 714, 715 and 716)

4.1 Reference

Range:	Fixed output; S/N 714 = 644, S/N 715 = 71, and S/N 716 = 316
Accuracy:	Drifts 1 to 2 units as the temperature of recording unit is lowered from 20°C to 0°C

4.2 Temperature (°C)

Range:	-2.46 to 21.40
Resolution:	≈0.02 (LSB)
Accuracy:	±0.1 (interpolating manufacturers calibration table)
Time Constant:	About one minute

4.3 Conductivity (mho x 10^{-3}/cm)

Range:	0-60
Resolution:	≈0.06 (LSB)
Accuracy:	Not specified

4.4 Pressure (kg/cm^2)

Range:	0-14.06
Resolution:	≈0.01 (LSB)
Accuracy:	Better than ±1% of range

4.5 General

Sampling Interval:	10 minutes
Measuring Speed:	4.5 seconds per channel
Recording System	
Technique:	Serial recording of 10-bit binary words on 1/4 inch magnetic tape
Encoding:	Pulse width with return to zero magnetization form
Storage Capacity:	60,000 words on 600 feet of tape
Power:	Batteries Clock 4 VDC Electronics 9 VDC

5.0 TESTS

5.1 Performance (S/N's 714 and 716)

5.1.1 Static Measurement Accuracy

5.1.1.1 Temperature Channel

a. Procedure

The two instrument recording units were immersed in a temperature controlled water bath (NOIC FAC #21, Adjustment Facility). Three temperature cycles consisting of the following temperatures (21°C, 19°C, 15°C, 11°C, 7°C, 3°C, -1°C, 3°C, 7°C, 11°C, 15°C, 19°C, and 21°C) were subjected to both instruments simultaneously.

At each test point, after the bath reached temperature stability of 1 m°C or less, a temperature reading was obtained from each instrument by recording its 10 bit binary temperature word, available on the direct data readout electrical terminal, on an analog strip chart recorder. Four temperature bridge readings were obtained using a temperature standard consisting of an L&N Platinum Thermometer and Meuller Bridge; standard test temperatures (defined on the International Practical Temperature Scale, 1968) were determined by averaging the four temperature bridge readings and were estimated to be better than ±0.005°C.

b. Results

The test data collected on each instrument's temperature channel was reduced and the following determined.

Temperature Channel (°C)

Parameter	S/N 715	S/N 716
Nonrepeatability[1] (See Figures 5.1 & 5.2)	±0.025	±0.010
Nonlinearity (includes temperature effect, if any; see Figures 5.1 & 5.2)	±0.209	±0.202
Calibration Errors[2] (See Figure 5.3)	-0.166 to -0.105	-0.005 to +0.016

[1]May include the effects of quantization error in the LSB.
[2]Worst case mean errors for three (3) calibration cycles. The decimal equivalent of the temperature channel outputs were converted to indicated temperatures (°C) by interpolating the manufacturer's calibration table supplied with each instrument.

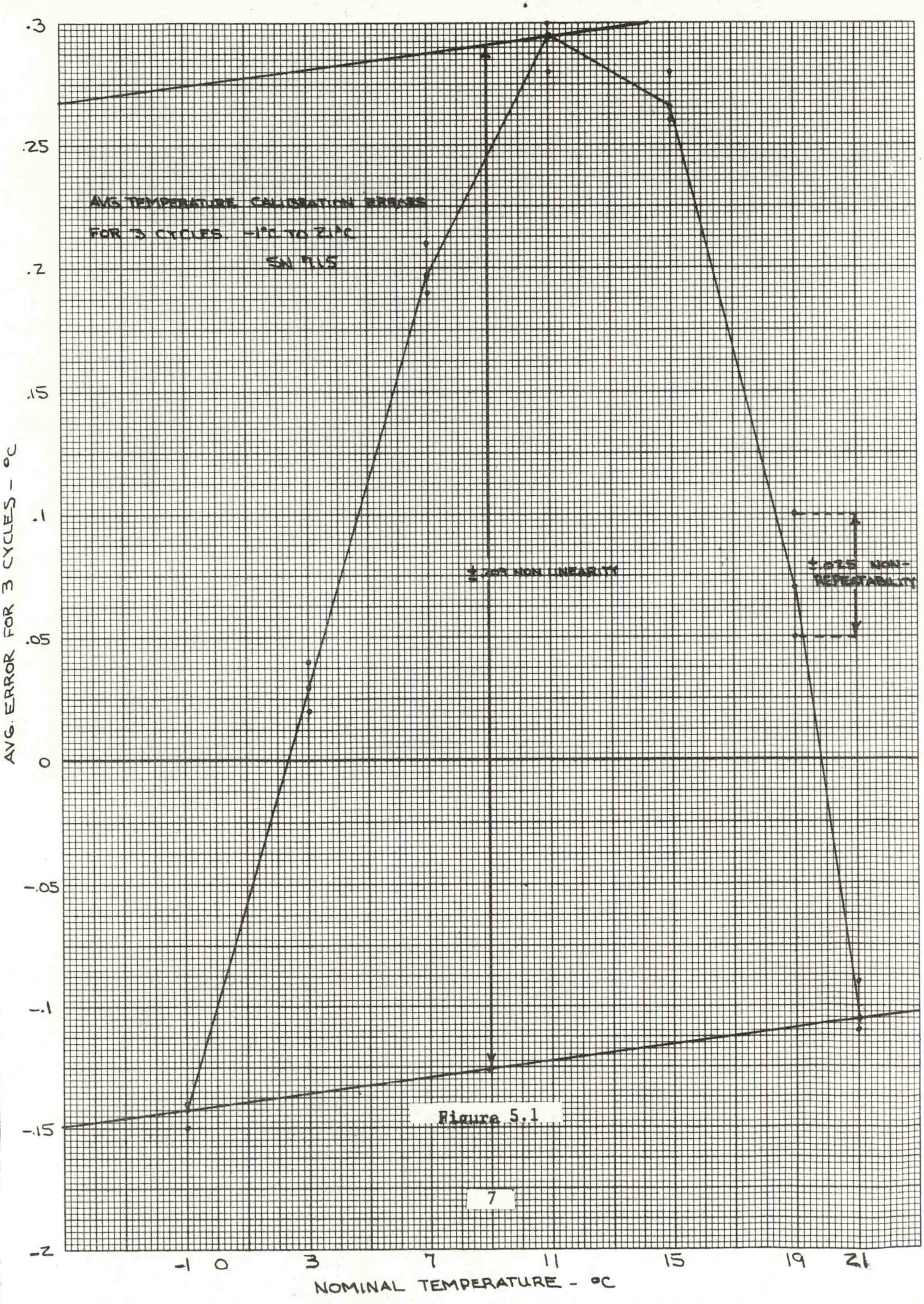

AVG. TEMPERATURE CALIBRATION ERRORS
FOR 3 CYCLES -1°C TO 21°C
SN 11.5
NON LINEARITY
±.025 NON-REPEATABILITY
AVG. ERROR FOR 3 CYCLES - °C
.3
.25
.2
.15
.1
.05
0
-.05
-.1
-.15
-.2
-1
0
3
7
11
15
19
21
NOMINAL TEMPERATURE - °C

Figure 5.1

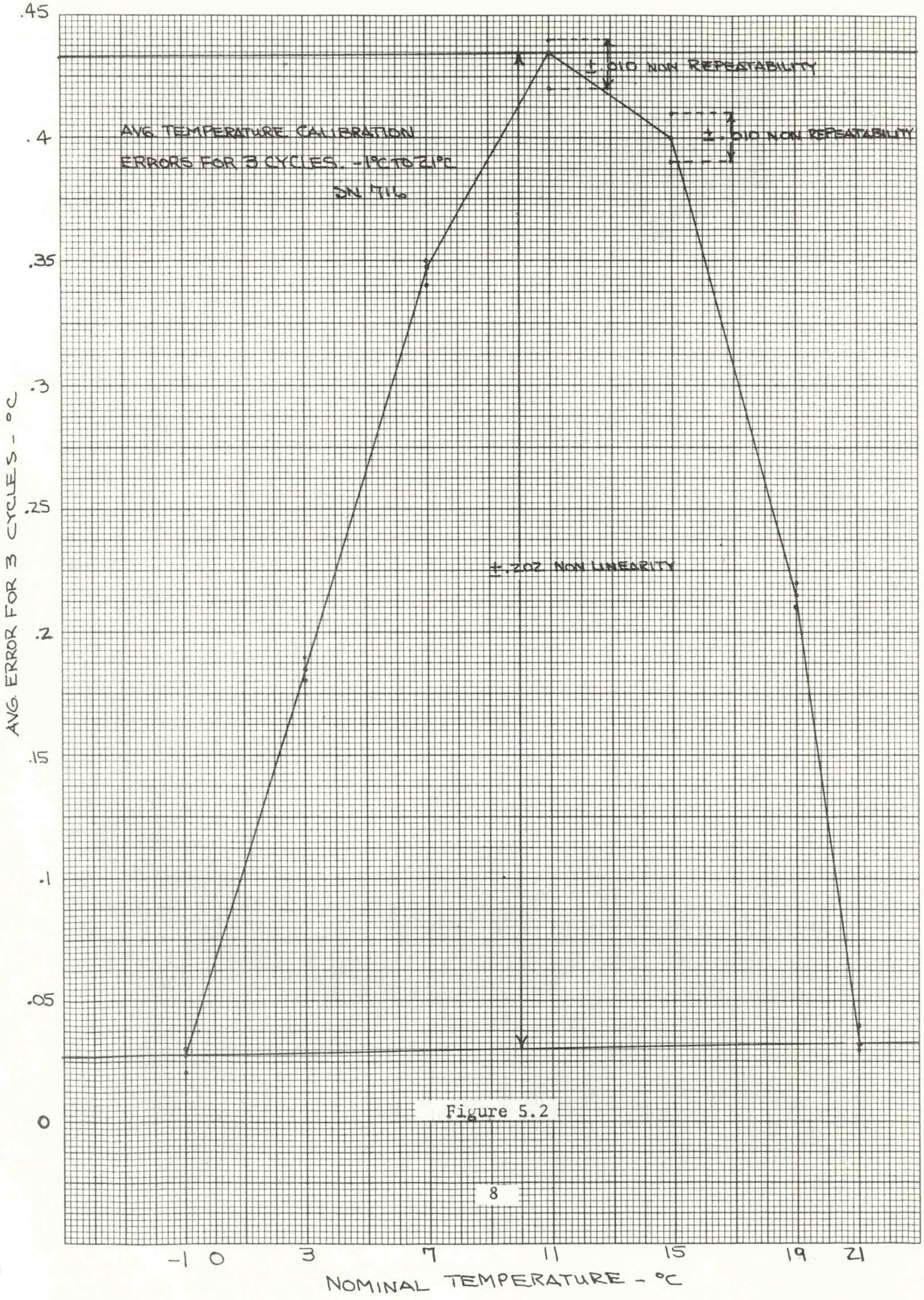

AVG. TEMPERATURE CALIBRATION
ERRORS FOR 3 CYCLES. -1°C TO 21°C
SN 716
± .010 NON REPEATABILITY
± .010 NON REPEATABILITY
± .202 NON LINEARITY
AVG. ERROR FOR 3 CYCLES - °C
.45
.4
.35
.3
.25
.2
.15
.1
.05
0
-1
0
3
7
11
15
19
21
NOMINAL TEMPERATURE - °C

Figure 5.2

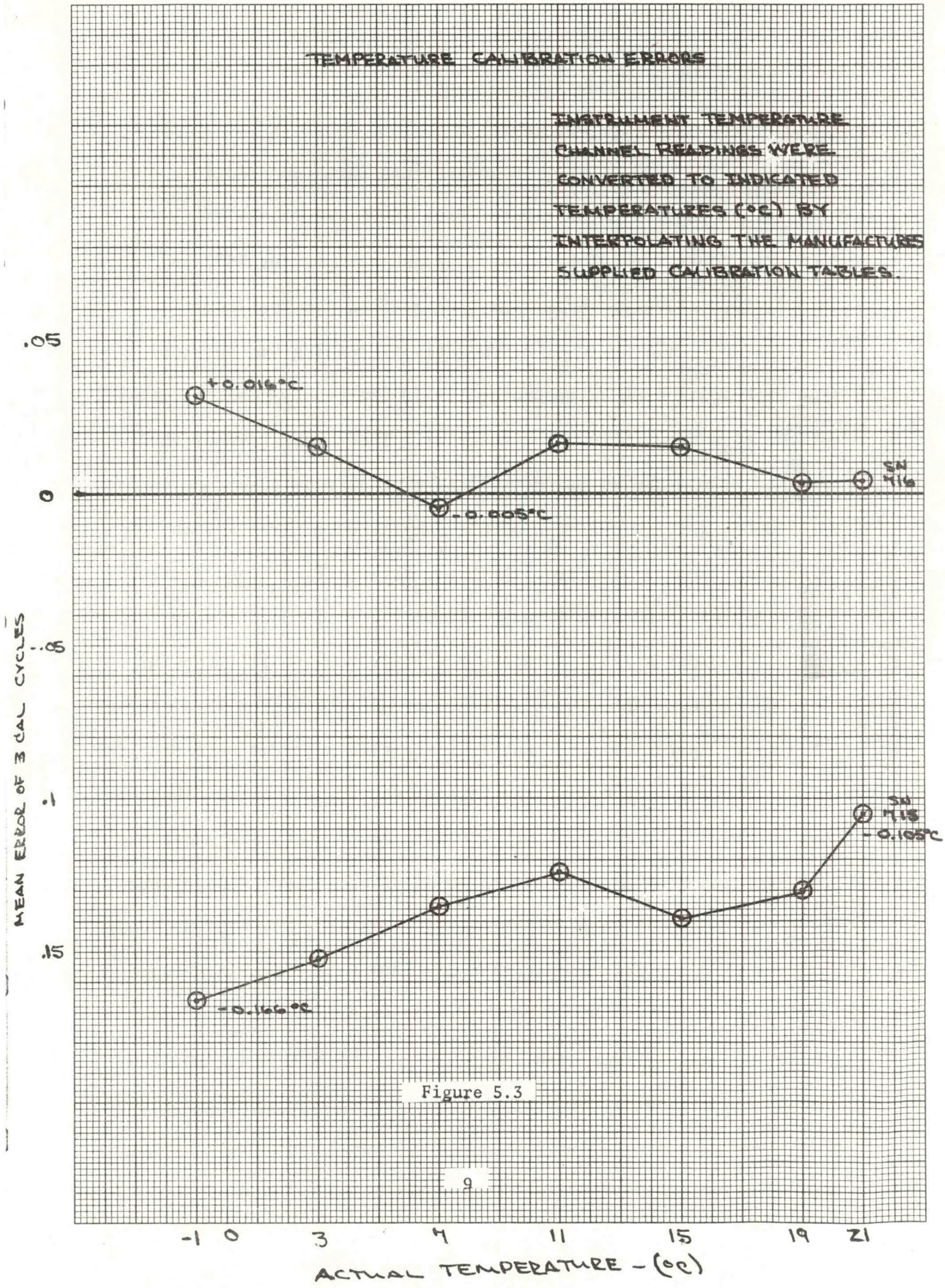

TEMPERATURE CALIBRATION ERRORS
INSTRUMENT TEMPERATURE CHANNEL READINGS WERE CONVERTED TO INDICATED TEMPERATURES (°C) BY INTERPOLATING THE MANUFACTURES SUPPLIED CALIBRATION TABLES.
.05
0
-.05
-.1
.15
+0.016°C
-0.005°C
SN 716
SN 715
-0.105°C
-0.166°C
MEAN ERROR OF 3 CAL CYCLES
-1
0
3
7
11
15
19
21
ACTUAL TEMPERATURE - (°C)

Figure 5.3

5.1.1.2 Conductivity Channel

a. Procedure

The two instruments were immersed in a temperature controlled salt water bath (NOIC FAC #2, Salinity Facility) controlled at a temperature and salinity of 15°C and 35 ppt, respectively. After the bath reached a temperature stability of 1 m°C or less, a conductivity reading was obtained from each instrument by recording its 10 bit binary conductivity word on an analog strip chart recorder. The temperature of the bath was also measured using the same procedure as described in paragraph 5.1.1.1.a, and two bottle samples were taken. Both units were then removed from the bath, dried off, and had inserted a loop of insulated wire through the bore of its conductivity sensor (toroidal cell). A rubber putty was used to fill the insides of the bore and the ends sealed around the wire with a sealant (GE RTV-102 White, Silicone Rubber Sealant) to prevent an electrical current from flowing out of the bore except via the wire. The units were returned to the above bath and allowed to stabilize under the same environmental conditions; the ends of each loop of wire were connected to a resistance decade box (L&N Catalog No. 4757-S; 0.001Ω resolution). The bath was again stabilized to the previous temperature (within ± 1 m°C) and the decade boxes adjusted to obtain the same conducting reading from each instrument as recorded under in situ conditions; decade settings of the resistance boxes were recorded. Data from the above two exercises and empirical relationships were used to calculate loop resistance values required for discrete simulated test conductivities. The relationships and computed resistances values for each instrument are shown below; the uncertainty in these values to actual in situ conductivity conditions were estimated to be better than ± 0.02 mho x $\frac{10^{-3}}{cm}$.

S/N 715

Exercise 1

Bath Conditions

Salinity = 35.312 ppt

Temperature = 15.005°C

715 Conductivity Indication = 42.760 $\frac{\text{mho x } 10^{-3}}{\text{cm}}$

Exercise 2

Bath Conditions

Salinity = 35.312 ppt

Temperature = 15.005°C

715 Conductivity Indication = 42.760 $\frac{\text{mho x } 10^{-3}}{\text{cm}}$

Resistance of Wire Loop (R) = 62.73Ω

Calculations (The computer symbol * is used below to indicate multiplication)

ϕ (conductivity ratio from UNESCO Tables) = 1.00795 @ 35.312 ppt, 15°C

$C_{S,15} = \phi_{S,15} * C_{35,15} = \phi_{S,15} * 42.9$

$C_{35.312,15} = 1.00795 * 42.9 = 43.241$ mho * 10^{-3}/cm

$C_{35.312,15.005} = 43.241 + 0.005 = 43.246 \frac{\text{mho} * 10^{-3}}{\text{cm}}$

K (cell constant) = RC = $62.73 * 43.246 * 10^{-3} = 2.713 \text{ cm}^{-1}$

$R_x C_x = C_{35,15} * R_{35,15}$

$$R_{35,15} = \frac{R_x C_x}{C_{35,15}} = \frac{62.73 * 43.246 * 10^{-3}}{42.9 * 10^{-3}} = 63.236\Omega$$

$$R_x = \frac{63.236 * 42.9 * 10^{-3}}{C_x}$$

Test Point (mho*10^{-3}/cm)	R_x (ohms)
0	∞
10	271.282
20	135.641
30	90.427
40	67.821
50	54.256
60	45.214
67	40.490

S/N 716

Exercise 1

Bath Conditions

Salinity = 35.312 ppt

Temperature = 15.005°C

716 Conductivity Indication = 42.823 $\frac{\text{mho x } 10^{-3}}{\text{cm}}$

Exercise 2

Bath Conditions

Salinity = 35.312 ppt

Temperature = 15.005°C

716 Conductivity Indication = 42.823 $\frac{\text{mho x } 10^{-3}}{\text{cm}}$

Resistance of Wire Loop (R) = 62.93Ω

Calculations (* indicates multiplication)

ϕ (conductivity ratio from UNESCO Table) = 1.00795 @ 35.312 ppt, 15°C

$C_{35.312,15.005}$ = 43.246 mho x 10^{-3}/cm (from S/N 715 above)

K (cell constant = RC = 62.93*43.246*10^{-3} = 2.721 cm^{-1}

$R_xC_x = C_{35,15} * R_{35,15}$

$R_{35,15} = \frac{R_xC_x}{C_{35,15}} = \frac{62.93*43.246*x\ 10^{-3}}{42.9*10^{-3}} = 63.438\Omega$

$R_x = \frac{63.438*42.9}{C_x}$

Test Point (mho*10^{-3}/cm)	R_x (ohms)
0	∞
10	272.147
20	136.074
30	90.716
40	68.037
50	54.429
60	45.358
67	40.619

Three simulated conductivity cycles (0, 10, 20, 30, 40, 50, 60, 67, 60, 50, 40, 30, 20, 10, and 0 mho*10^{-3}/cm) were subjected to both units at bath temperatures of 3, 11, and 19°C. Instrument output readings were recorded in the same manner as described above.

b. Results

The test data collected on each instruments's conductivity channel was reduced and the following determined.

Conductivity Channel (mho x 10^{-3}/cm)

Parameter	S/N 715	S/N 716
Nonrepeatability[1] (See Figures 5.4 & 5.5)	±0.034	±0.030
Nonlinearity (@ 11°C instrument temperature; See Figures 5.4 & 5.5)	±0.028	±0.080
Temperature Effects (See Figures 5.6 & 5.7)	Within LSB (≈0.07)	Within LSB (≈0.07)
Calibration Errors[2] (See Figures 5.6 & 5.7)	-0.790 to 0.001	-0.508 to 0.069

[1]May include the effects of quantization error in the LSB.
[2]Worse case mean errors for three (3) calibration cycles at instrument temperature of 11°C. The decimal equivalent of the conductivity channel outputs were converted to indicated conductivities (mho x 10^{-3}/cm) by straight line equations supplied by the manufacturer for each instrument. The two equations were $G = 0.06897N_{10}-0.07$ and $G = 0.06907N_{10}$ (where G is conductivity (mho x 10^{-3}/cm) and N_{10} is the instrument reading in decimal) for S/N's 715 and 716, respectively.

SN 715
TEMP. 11°C

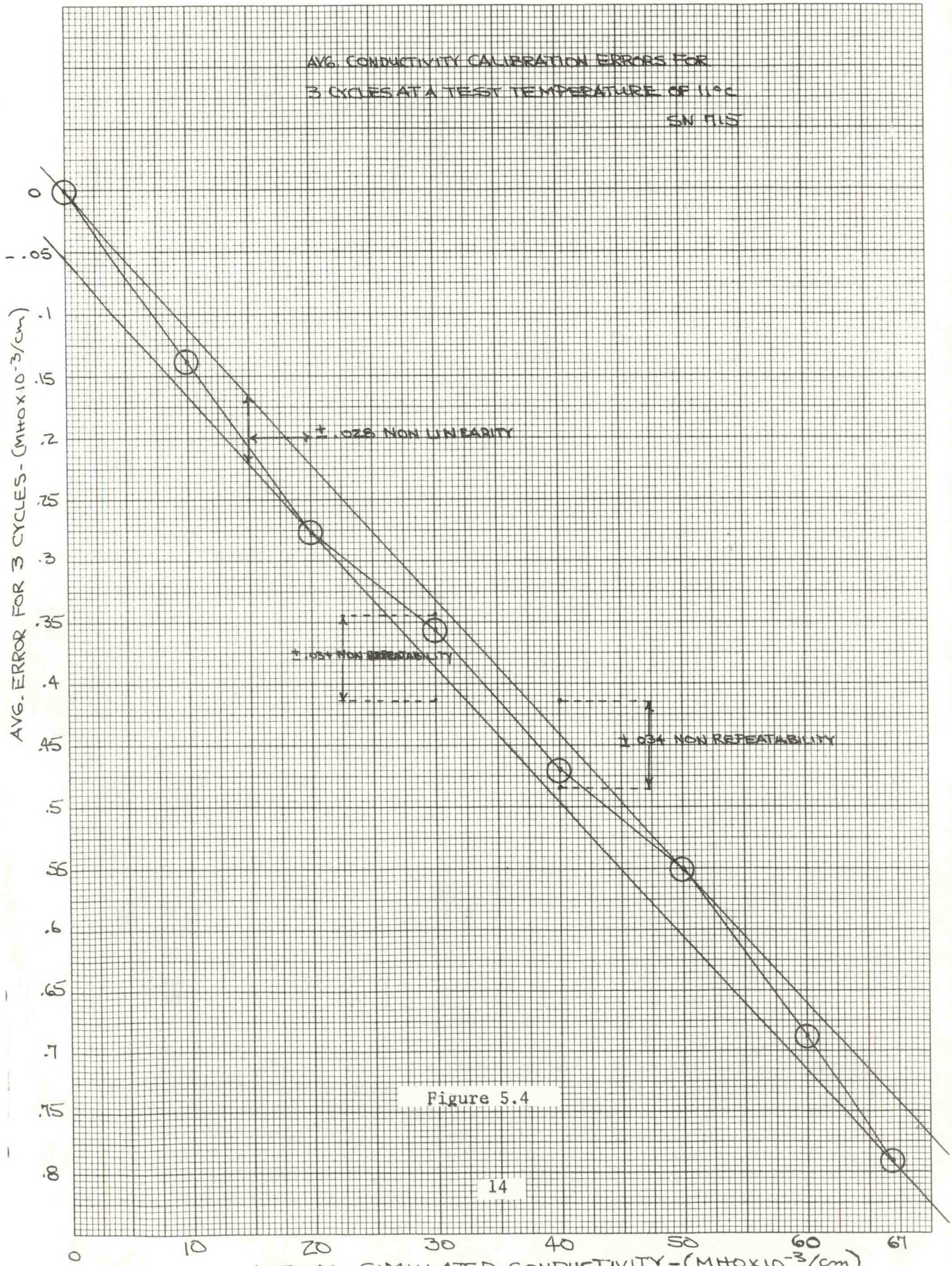


Figure 5.4

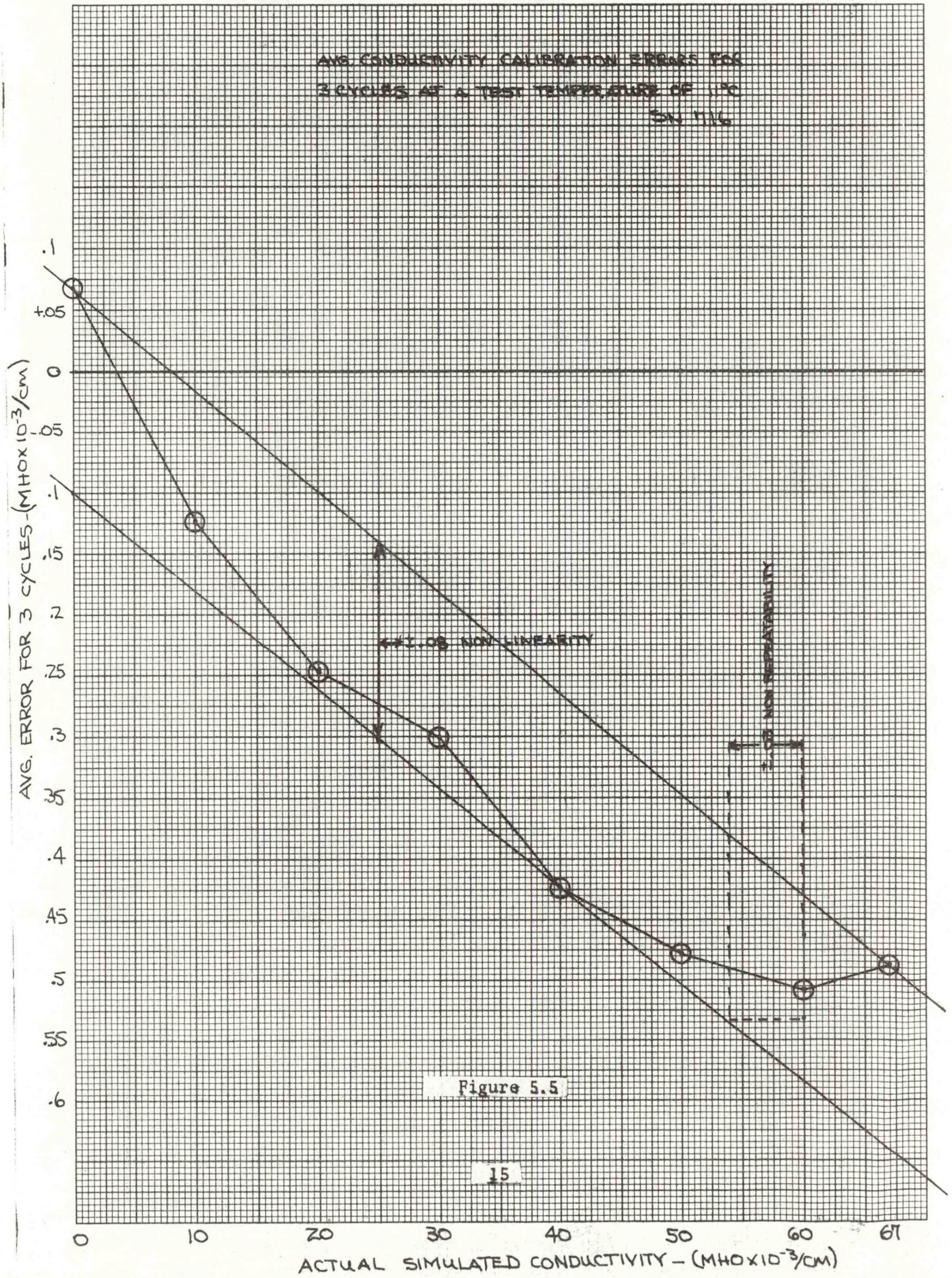

AVG. CONDUCTIVITY CALIBRATION ERRORS FOR
3 CYCLES AT A TEST TEMPERATURE OF 11°C
SN 716
±.08 NON-LINEARITY
NON-REPEATABILITY
AVG. ERROR FOR 3 CYCLES-(MHO X 10⁻³/CM)
.1
+.05
0
.05
.1
.15
.2
.25
.3
.35
.4
.45
.5
.55
.6
0
10
20
30
40
50
60
67
ACTUAL SIMULATED CONDUCTIVITY – (MHO X 10⁻³/CM)

Figure 5.5

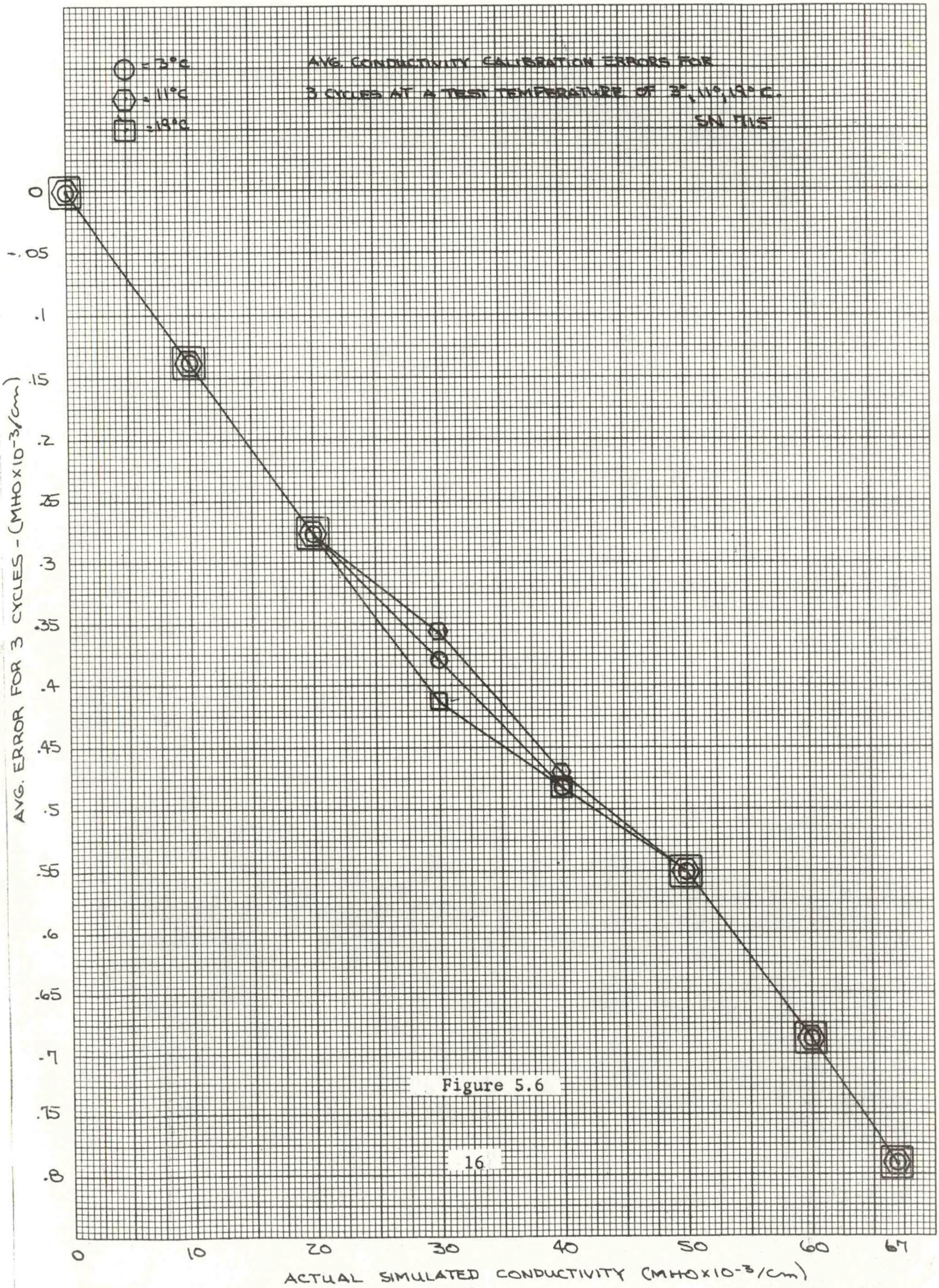

○ = 3°C
⬡ = 11°C
□ = 19°C
AVG. CONDUCTIVITY CALIBRATION ERRORS FOR
3 CYCLES AT A TEST TEMPERATURE OF 3°, 11°, 19° C.
AVG. ERROR FOR 3 CYCLES - (MHO×10⁻³/Cm)
0
-.05
.1
.15
.2
.25
.3
.35
.4
.45
.5
.55
.6
.65
.7
.75
.8
0
10
20
30
40
50
60
67
ACTUAL SIMULATED CONDUCTIVITY (MHO×10⁻³/Cm)

Figure 5.6

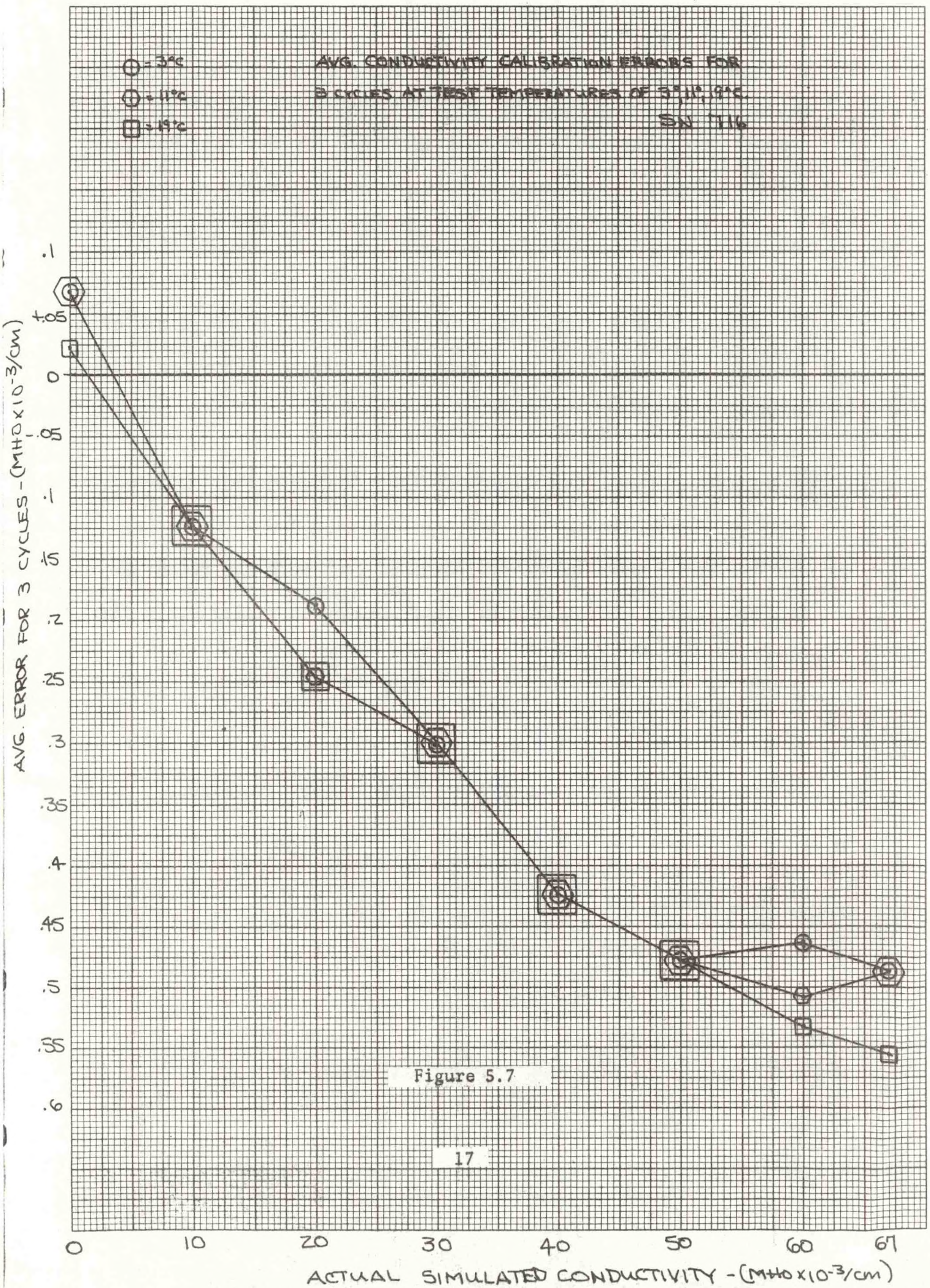

○ - 3°C
⊕ - 11°C
□ - 19°C
AVG. CONDUCTIVITY CALIBRATION ERRORS FOR
3 CYCLES AT TEST TEMPERATURES OF 3°, 11°, 19°C.
SN 716
AVG. ERROR FOR 3 CYCLES - (MHO x 10⁻³/CM)
.1
+.05
0
-.05
.1
.15
.2
.25
.3
.35
.4
.45
.5
.55
.6
0
10
20
30
40
50
60
67
ACTUAL SIMULATED CONDUCTIVITY - (MHO x 10⁻³/CM)

Figure 5.7

5.1.1.3 Pressure Channel

a. Procedure

The two recording units were immersed in a temperature controlled water bath (NOIC FAC #2, Salinity Facility) controlled at a temperature of 11°C. Three (3) pressure cycles (0, 3, 6, 9, 12, 14, 12, 9, 6, 3, 0 kg/cm^2) were applied simultaneously to the pressure port of each instrument using a Ruska Dead Weight Gauge Model 5100-5 (Range 0.35 to 84.37 kg/cm^2). Uncertainty of the generated pressures above atmospheric were estimated to ±0.04% of reading.

The above three pressure test cycles were repeated at bath instrument temperatures of 3 and 19°C. In all test cycles, pressure readings were obtained from each instrument by recording its 10 bit binary pressure word on an analog strip chart recorder.

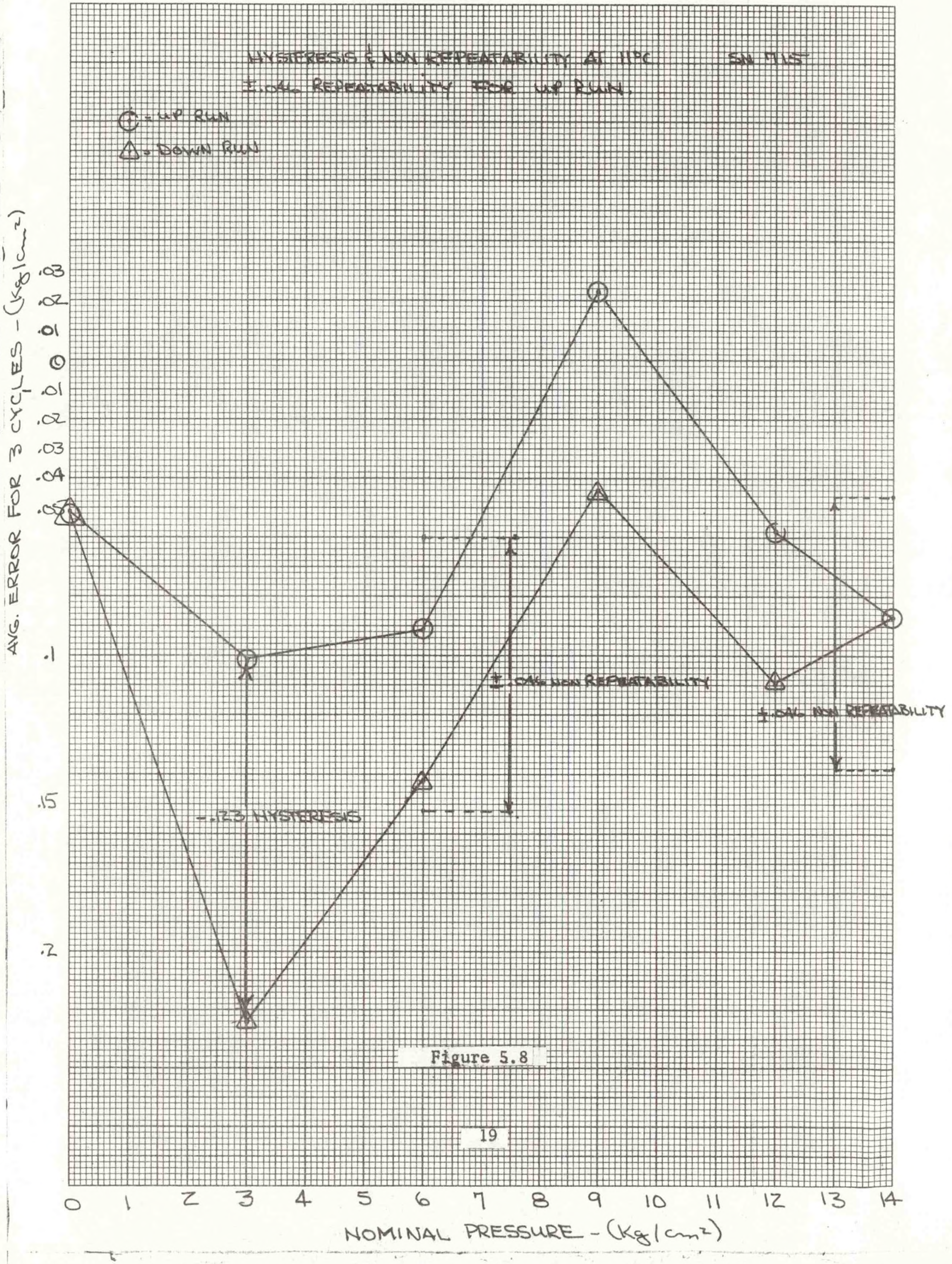
b. Results

The test data collected on each instrument's pressure channel was reduced and the following determined.

Pressure Channel (kg/cm^2)

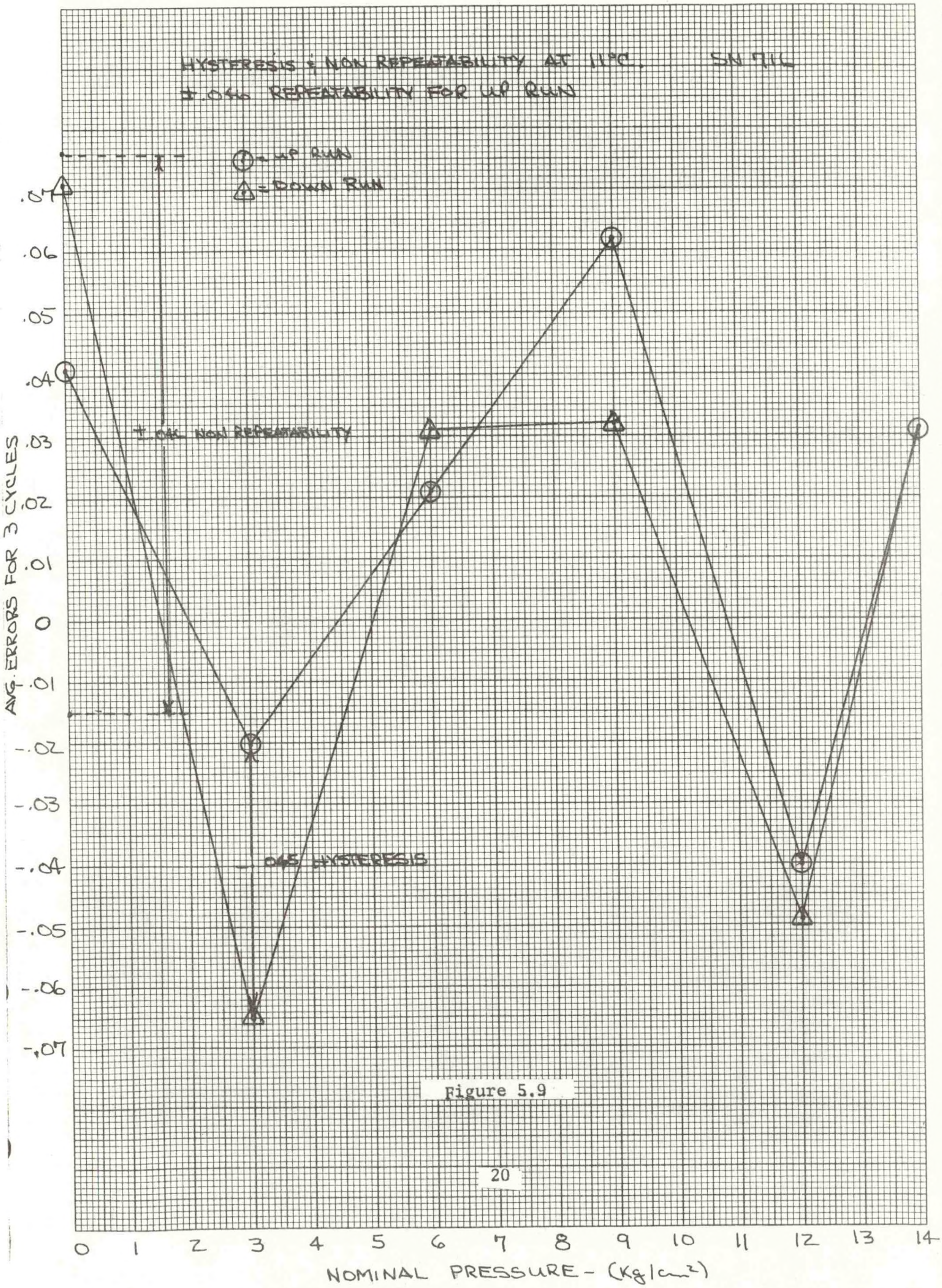
Parameter	S/N 715	S/N 716
Nonrepeatability[1] (@ 11°C instrument temperature; See Figures 5.8 & 5.9)	±0.046	±0.046
Hysteresis[2] (@ 11°C; See Figures 5.8 & 5.9)	-0.123	-0.045
Nonlinearity (@ 11°C; See Figures 5.10 & 5.11)	±0.066	±0.048

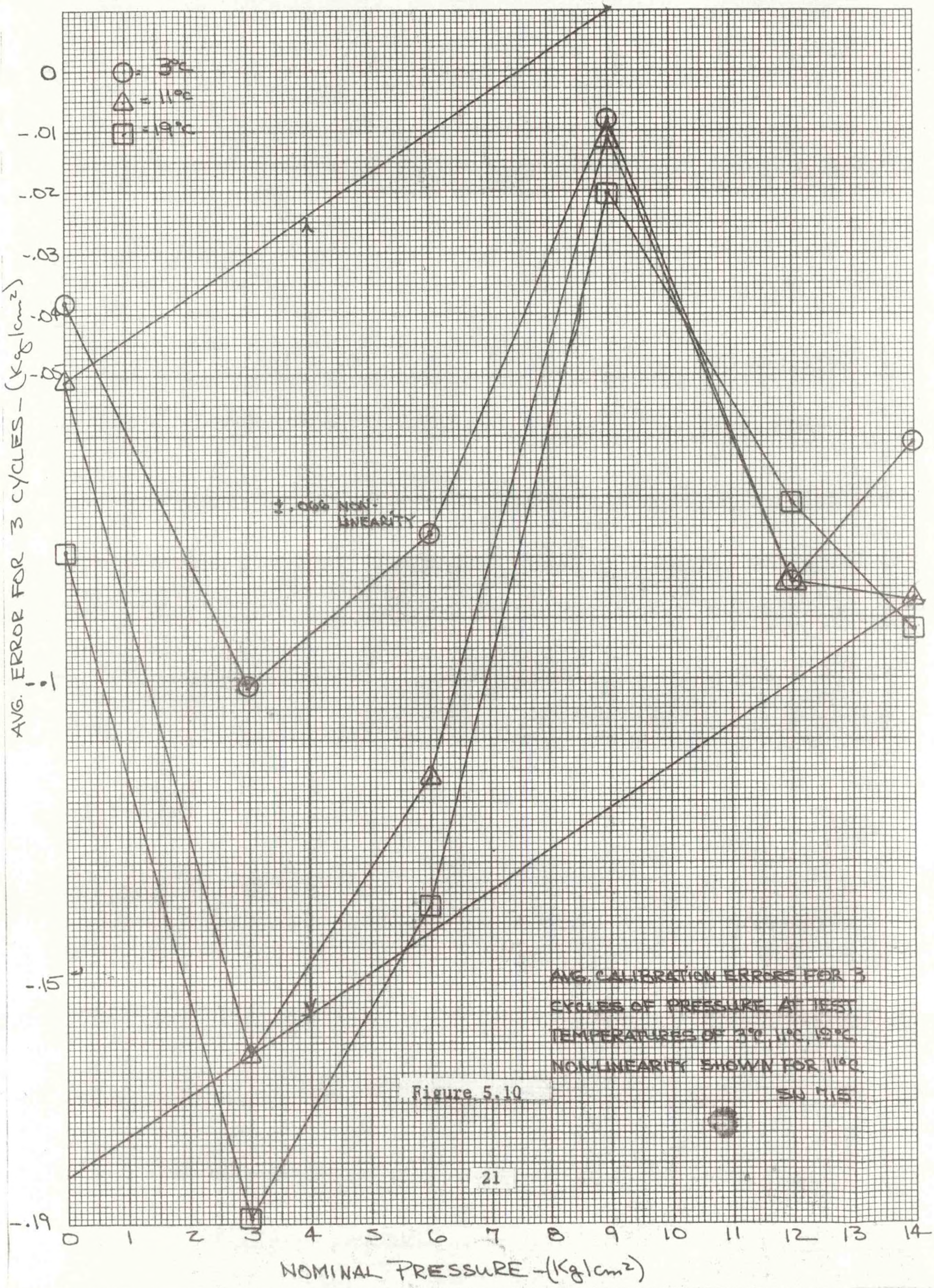
[1]May include the effects of quantization error in the LSB.
[2]Worst case difference between average down and up loading error values.



HYSTERESIS & NON REPEATABILITY AT 11°C
SN 7115
±.046 REPEATABILITY FOR UP RUN.
= UP RUN
= DOWN RUN
AVG. ERROR FOR 3 CYCLES - (Kg/cm²)
.03
.02
.01
0
.01
.02
.03
.04
.05
.1
.15
.2
-.123 HYSTERESIS
±.046 NON REPEATABILITY
±.046 NON REPEATABILITY
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
NOMINAL PRESSURE - (Kg/cm²)

Figure 5.8


HYSTERESIS & NON REPEATABILITY AT 11°C. SN 716
±.046 REPEATABILITY FOR UP RUN
⊙ = UP RUN
△ = DOWN RUN
±.046 NON REPEATABILITY
.045 HYSTERESIS
AVG. ERRORS FOR 3 CYCLES
.07
.06
.05
.04
.03
.02
.01
0
-.01
-.02
-.03
-.04
-.05
-.06
-.07
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
NOMINAL PRESSURE - (Kg/cm²)
Figure 5.9



○ = 3°C
△ = 11°C
□ = 19°C
± .066 NON-LINEARITY
AVG. ERROR FOR 3 CYCLES - (Kg/cm²)
0
-.01
-.02
-.03
-.04
-.05
-.1
-.15
-.19
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14
NOMINAL PRESSURE - (Kg/cm²)
AVG. CALIBRATION ERRORS FOR 3 CYCLES OF PRESSURE AT TEST TEMPERATURES OF 3°C, 11°C, 19°C. NON-LINEARITY SHOWN FOR 11°C
SN 715

Figure 5.10

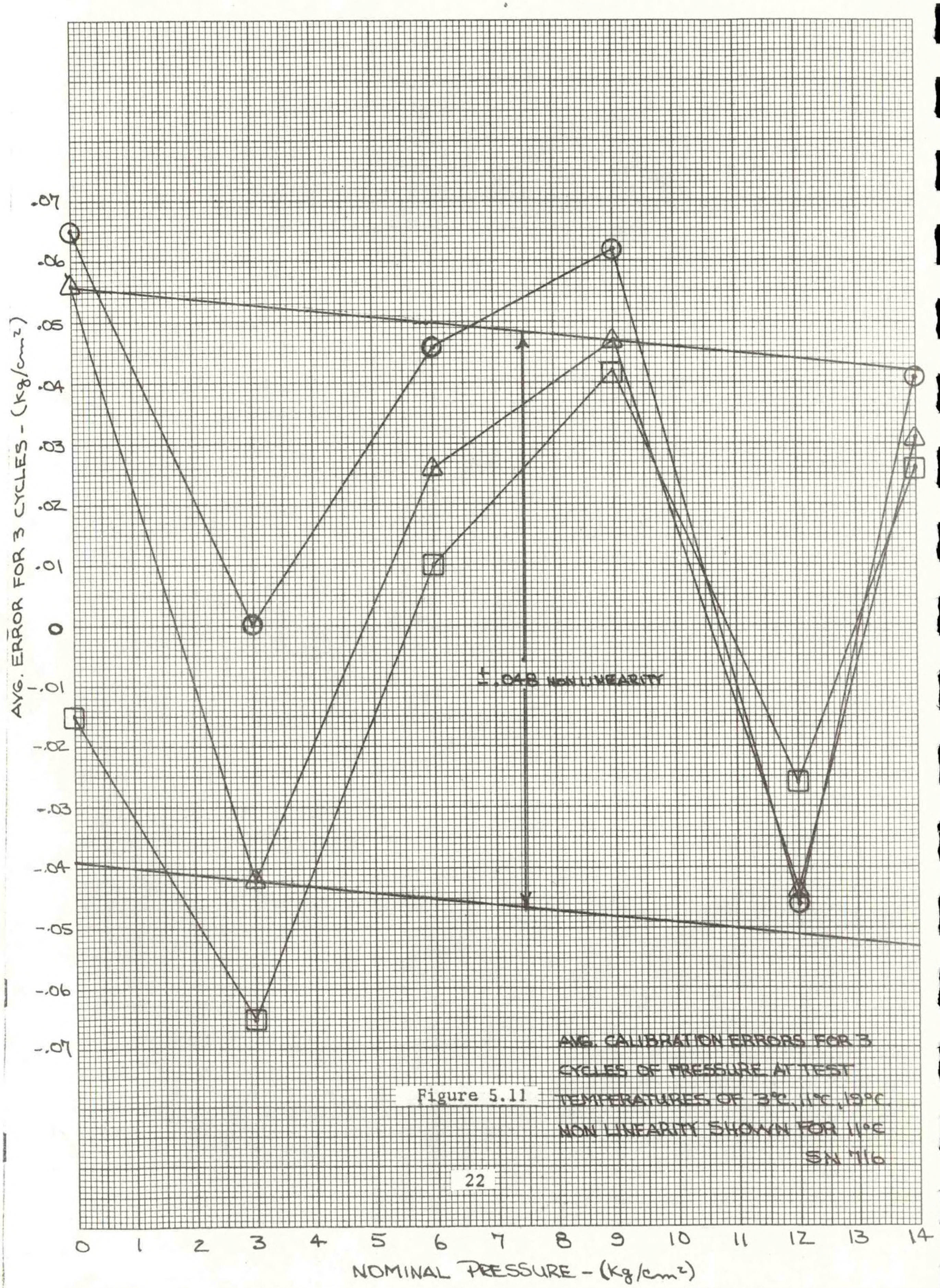

AVG. ERROR FOR 3 CYCLES - (Kg/cm²)
.07
.06
.05
.04
.03
.02
.01
0
-.01
-.02
-.03
-.04
-.05
-.06
-.07
±.048 NON LINEARITY
AVG. CALIBRATION ERRORS FOR 3 CYCLES OF PRESSURE AT TEST TEMPERATURES OF 3°C, 11°C, 19°C. NON LINEARITY SHOWN FOR 11°C
SN 716
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
NOMINAL PRESSURE - (Kg/cm²)

Figure 5.11

Pressure Channel (kg/cm^2) continued

Parameter	S/N 715	S/N 716
Temperature Effects (3 to 19°C)[3]	±0.044 @ 3	±0.040 @ 0
Calibration Errors (@ 11°C; See Figure 5.12)[4]	-0.087 to -0.012	-0.059 to 0.056

5.1.2 Time Constant

5.1.2.1 Temperature Channel

a. Procedure

In order to provide an electrical analog temperature output for the time constant test, the instrument was modified in the following manner.

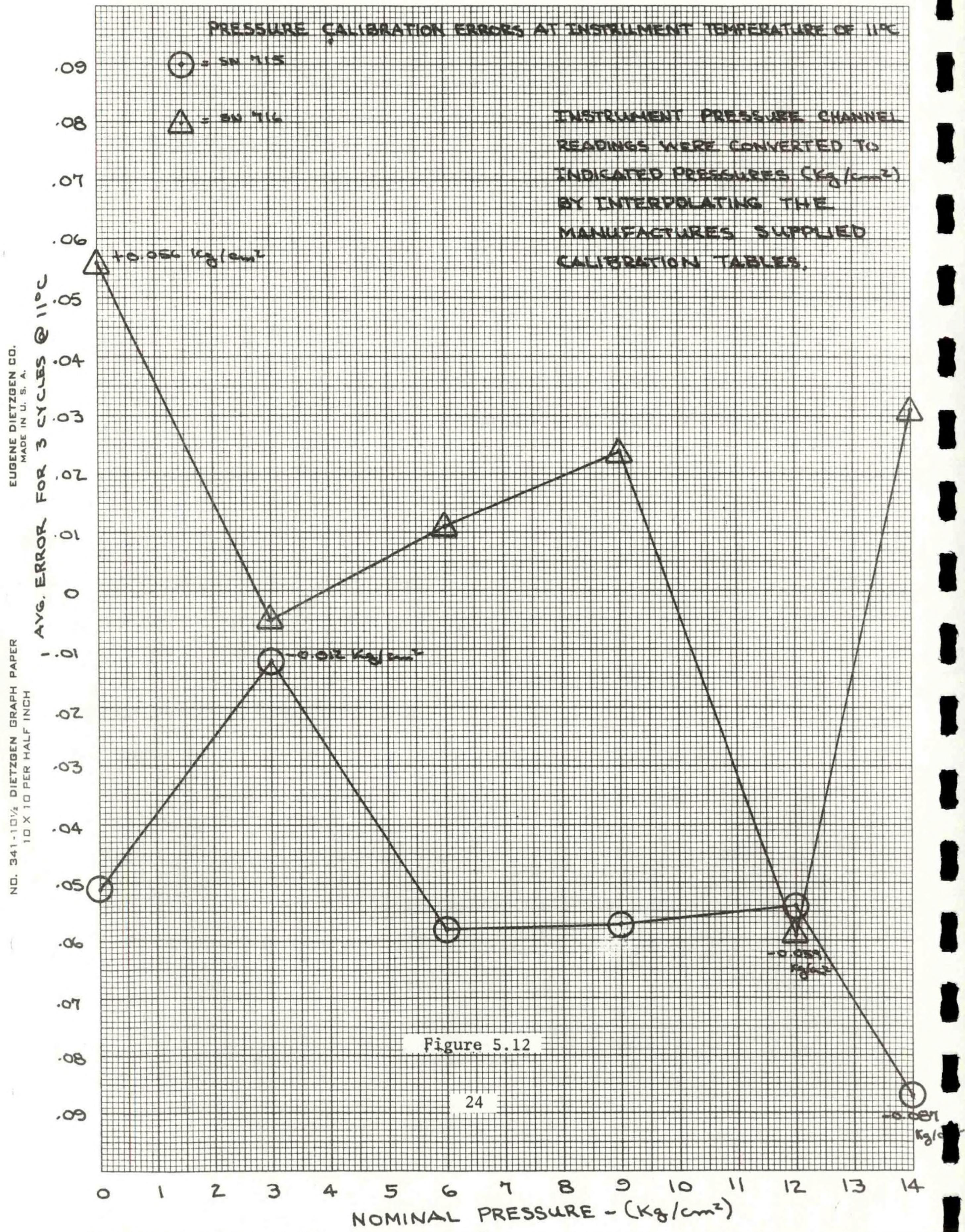
(1) Wires connected to pins (2) and (4) on the electronics board and the wire connected to the bulkhead electrical connector were removed.

(2) A 1.5 VDC penlight cell was taped firmly to the internal electronics/recorder assembly and electrical connections were made according to schematic shown in Figures 5.13 and 5.14.

A waterproof electrical cable was connected externally to the bulkhead electrical connector and a wire was connected externally to the body of the instrument; the other ends of the above were connected to an analog strip chart recorder (Brush MK 280) as shown in Figures 5.13 and 5.14.

[3]Worst case value

[4]Worst case mean errors for three (3) calibration cycles. The decimal equivalent of the pressure channel readings were converted to indicated pressures (kg/cm^2) by interpolating the manufacturer's calibration table supplied with each instrument.


PRESSURE CALIBRATION ERRORS AT INSTRUMENT TEMPERATURE OF 11°C
= SN 715
= SN 716
INSTRUMENT PRESSURE CHANNEL READINGS WERE CONVERTED TO INDICATED PRESSURES (Kg/cm²) BY INTERPOLATING THE MANUFACTURES SUPPLIED CALIBRATION TABLES.
+0.056 Kg/cm²
-0.012 Kg/cm²
-0.059 Kg/cm²
-0.087 Kg/cm²
AVG. ERROR FOR 3 CYCLES @ 11°C
NOMINAL PRESSURE - (Kg/cm²)
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14
.09 .08 .07 .06 .05 .04 .03 .02 .01 0 -.01 -.02 -.03 -.04 -.05 -.06 -.07 -.08 -.09
EUGENE DIETZGEN CO. MADE IN U. S. A.
NO. 341-10½ DIETZGEN GRAPH PAPER 10 X 10 PER HALF INCH
Figure 5.12

A negative step temperature change, from 20°C to 10°C, was performed separately on each instrument by first soaking the instrument in a bath at 20°C and then removing it and immediately immersing it into another bath controlled at 10°C. The flow rate in the latter bath was approximately 0.6 cm/sec and in a direction longitudinal with the instrument case. The flow impinged on the sensor end first.

b. Results

Figures 5.13 and 5.14 show the relative thermistor response against time for the negative step changed imposed on each sensor. A dead time of 1.0 and 1.2 seconds, and a time constant (time required after dead time for output to reflect 63.2% of total change in output due to a step change in input) of 8.4 and 9.2 seconds were determined graphically from S/N 715 and 716 response curves, respectively.

5.1.3 Battery Voltage Variation Effects

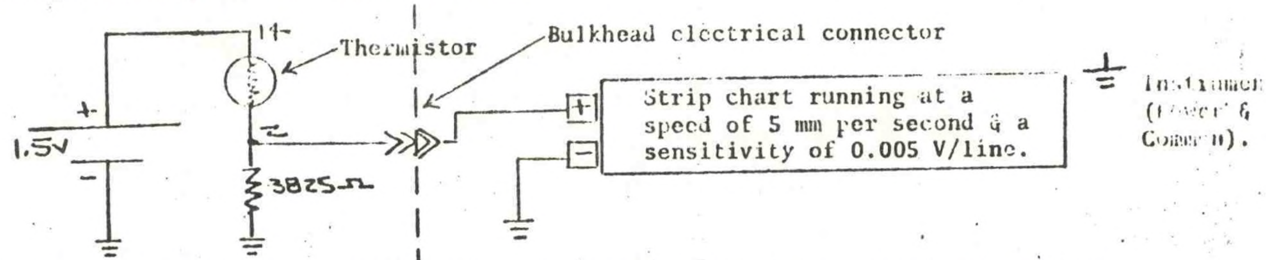
5.1.3.1 Temperature Channel

a. Procedure

The voltage variation test was performed by substituting a variable D.C. power supply (Sorenson Model QRB 40.75) for the 9 VDC battery in each instrument and applying voltages of 7.0, 7.5, 8.0, and 9.8 VDC while they were controlled at temperatures of 3, 12, and 19°C. Constant test temperatures were maintained on the thermistors by embedding them in a piece of styrofoam (approximately 1/2" x 1/2" x 1-1/2") and placing the instruments (with pressure tubes removed) in an air temperature controlled environmental chamber (NOIC FAC #7, Bethlehem Environmental Chamber); air temperature was monitored with a quartz thermometer (Hewlett Packard Model 2801A). Embedding

FIG. 5.13

The method of obtaining the time response of the temperature channel thermistor was accomplished by disconnecting and isolating the existing wiring from pins 14 & 2 and rewiring according to the schematic below.



Instrument was soaked in a bath at 20°C and then removed and immediately placed into a bath controlled at 10°C. The following recording shows the time response of the thermistor.

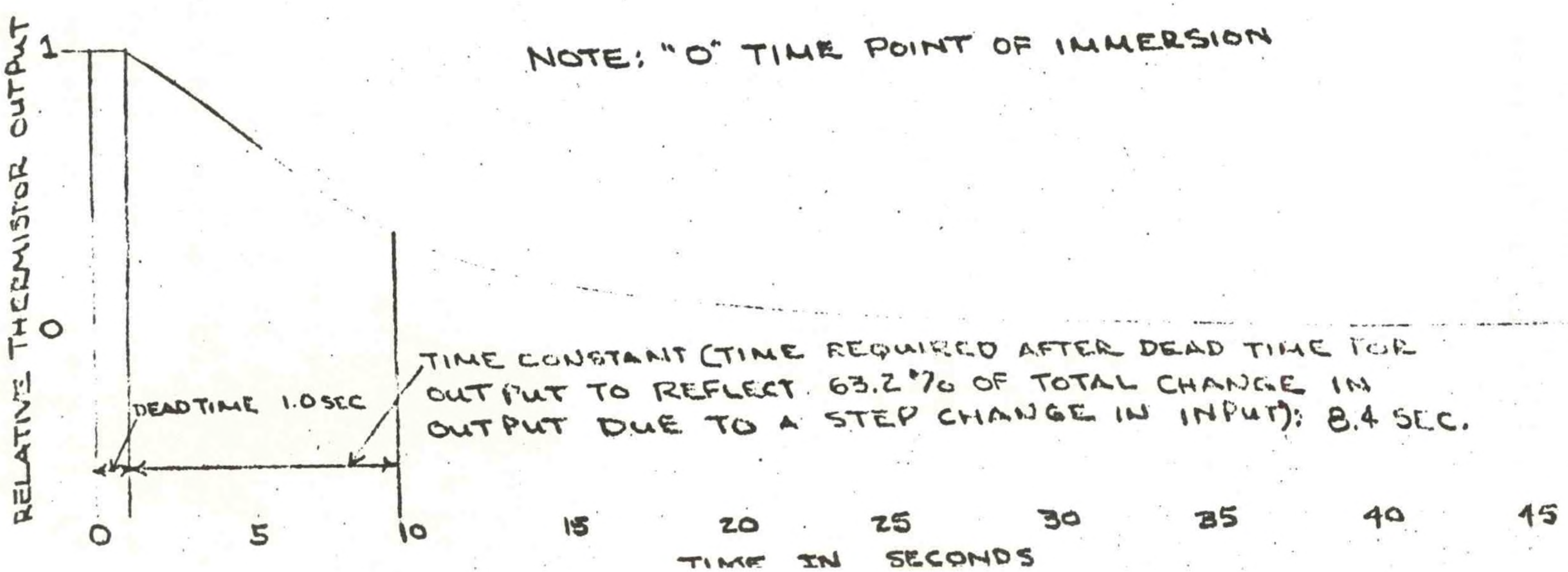
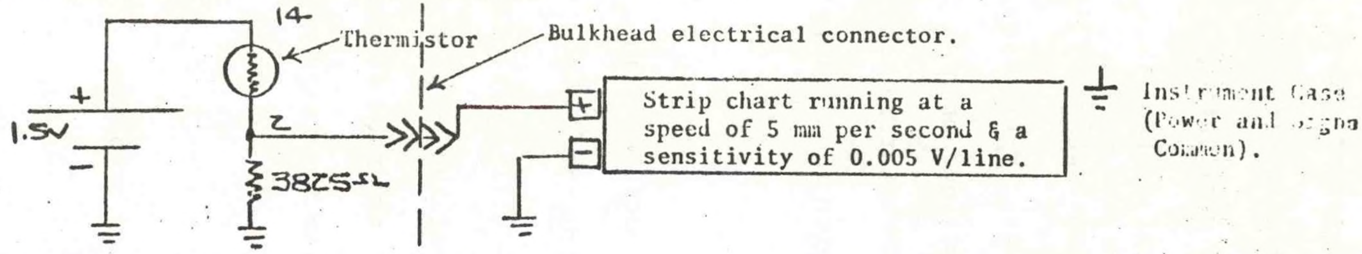
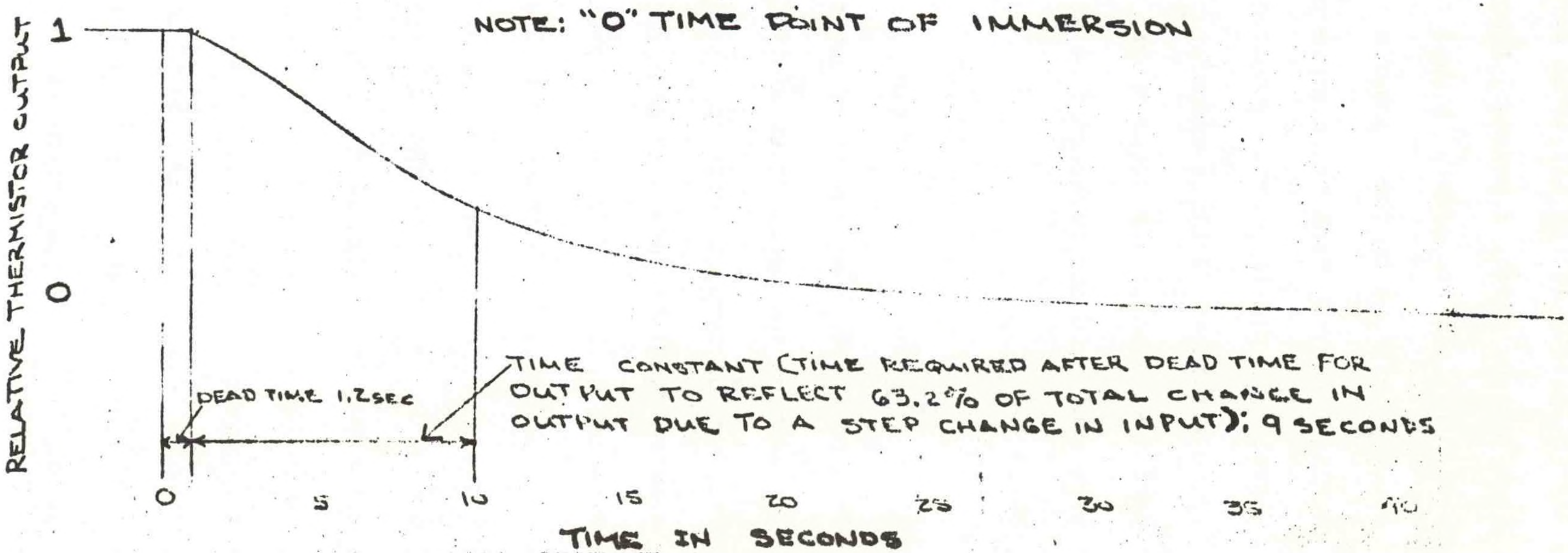


FIG. 5.14

The mothod of obtaining the time response of the temperature channel thermistor was accomplished by disconnecting and isolating the existing wiring from pins 14 & 2 and rewiring according to the schematic below.



Instrument was soaked in a bath at 20°C and then removed and immediately placed into a bath controlled at 10°C. The following recording shows the time response of the thermistor.



the thermistor in the styrofoam created an almost constant short-term (approximately 2 minutes) temperature environment on it even though the air temperature around the insulator was oscillating about ± 0.5°C due to the chamber's temperature control system. During these constant temperature periods, on the same region of a control cycle to provide repeated test temperatures, (estimated to be within ± 0.02°C), a temperature reading was obtained from each instrument. The power supply voltages at each test temperature were monitored and recorded from an accurate voltmeter (John Fluke Model 873A).

B. Results

Table 5.1 shows the measurements obtained from the voltage variation effect test on both instruments. Considering the total uncertainty (± 0.015°C) in the Δ's as well as Δ values of zero, in certain cases, it indicates that the temperature channel readings (measurements) for each instrument are not adversely affected by changes in battery operating voltage over the range tested.

5.1.3.2 Conductivity Channel

a. Procedure

The same proceudre was used to simulate battery voltage variation as described in paragraph 5.1.3.1.a. Operating voltages of 7.0, 7.5, 8.0, and 9.8 VDC were applied to each instrument while the conductivity sensors were subjected to simulated conductivities of 10, 40, and 67 mho x 10^{-3}/cm using the resistance wire-loop technique. The ambient temperature of the instruments during this test was approximately 22°C.

b. Results

At each test conductivity, there were no observable changes in either instruments conductivity channel readings (measurements) while its battery operating voltage was varied as indicated.

5.1.3.3 Pressure Channel

a. Procedure

The same procedure was used to simulate battery voltage variation as described in paragraph 5.1.3.1.a. Operating voltages of 7.0, 7.5, 8.0, and 9.8 VDC were applied to each instrument while the pressure sensors were subjected to applied pressures of 3, 9, and 14 kg/cm^2 using a dead weight gauge (Ruska Model 5100-5; range 0.35 to 84.37 kg/cm^2). The ambient temperature of the instruments during this test was approximately 22°C.

b. Results

Table 5.2 shows the measurements obtained from the voltage variation effect test on the pressure channel of both instruments. Considering the total uncertainty ($\pm$0.005 kg/cm^2) in the Δ's as well as Δ values of zero, in certain cases, it indicates that the pressure channel readings (measurements) for each instrument are not adversely affected by changes in battery operating voltage over the range tested.

5.1.4 Stability

5.1.4.1 Temperature Channel

a. Procedure

The instruments were subjected to the same test conditions as described in paragraph 5.1.1.1.a.

TABLE 5.1

Battery Voltage Variation Effects on Temperature Channel

Test Temp. (°C)	Applied Voltage (VDC)	Instrument Indication (Decimal)	Instrument Indication (°C)	Variation Δ (°C)
		(S/N 715)		
≃ 3	9.8	243	3.21	
"	8.0	244	3.23	±0.010
"	7.5	243	3.21	
"	7.0	243	3.21	
		(S/N 715)		
≃ 12	9.8	613	11.86	
"	8.0	612	11.84	±0.025
"	7.5	612	11.84	
"	7.0	611	11.81	
		(S/N 715)		
≃ 19	9.8	936	19.41	
"	8.0	936	19.41	±0.010
"	7.5	936	19.41	
"	7.0	937	19.43	
		(S/N 716)		
≃ 3	9.8	243	3.21	
"	8.0	244	3.23	±0.010
"	7.5	244	3.23	
"	7.0	244	3.23	
		(S/N 716)		
≃ 12	9.8	612	11.84	
"	8.0	612	11.84	0.00
"	7.5	612	11.84	
"	7.0	612	11.84	
		(S/N 716)		
≃ 19	9.8	913	18.87	
"	8.0	913	18.87	±0.025
"	7.5	913	18.87	
"	7.0	915	18.92	

1. $\Delta = \dfrac{\text{Algebraic max.} - \text{Algebraic min.}}{2}$
2. Estimated uncertainty in a single measurement: 1/2 LSB ≃ ±0.01°C
   Test ≃ ±0.02
   $RSS = \sqrt{(\pm 0.01)^2 + (\pm 0.02)^2} = 0.022°C$
3. Estimated uncertainty in Δ values:
   $Q = \pm 0.022/\sqrt{2} = \pm 0.015°C$

TABLE 5.2

Battery Voltage Variation Effects on Pressure Channel

Test Pressure (kg/cm^2)	Applied Voltage (VDC)	Instrument Indication (Decimal)	Instrument Indication (kg/cm^2)	Variation Δ (kg/cm^2)
		(S/N 715)		
≃ 3	9.8	233	2.768	
"	8.0	232	2.753	±0.008
"	7.5	232	2.753	
"	7.0	232	2.753	
		(S/N 715)		
≃ 9	9.8	631	8.890	
"	8.0	631	8.890	0.000
"	7.5	631	8.890	
"	7.0	Test Error		
		(S/N 715)		
≃ 14	9.8	960	13.950	
"	8.0	960	13.950	0.000
"	7.5	960	13.950	
"	7.0	960	13.950	
		(S/N 716)		
≃ 3	9.8	233	2.858	
"	8.0	232	2.842	±0.008
"	7.5	232	2.842	
"	7.0	232	2.842	
		(S/N 716)		
≃ 9	9.8	632	8.922	
"	8.0	632	8.922	0.000
"	7.5	632	8.922	
"	7.0	Test Error		
		(S/N 716)		
≃ 14	9.8	968	14.030	
"	8.0	968	14.030	±0.008
"	7.5	968	14.030	
"	7.0	967	14.016	

1. $\Delta = \dfrac{\text{Algebraic max.} - \text{Algebraic min.}}{2}$

2. Estimated uncertainty in a single measurement: $\pm 1/2 LSB \simeq \pm 0.007\ kg/cm^2$
   Test ≃ negligible
   RSS = $\pm 0.007\ kg/cm^2$.

3. Estimated uncertainty in Δ values:
   $Q = \pm 0.007/\sqrt{2} = \pm 0.005\ kg/cm^2$.

b. Results

Figures 5.15 and 5.16 show the average temperature calibration errors for the three test cycles and those obtained earlier shown in Figures 5.1 and 5.2 for S/N 715 and 716, respectively. The worst case shift over the approximate five (5) week period was -0.035°C and +0.015 for S/N 715 and 716, respectively. The uncertainty of the difference (shift) values was estimated to be ≈ ±0.006°C.

5.1.4.2 Conductivity Channel

a. Procedure

The instruments were subjected to three simulated conductivity calibration cycles at 11°C in the same manner as described in paragraph 5.1.1.2.a.

b. Results

Figures 5.17 and 5.18 show the average conductivity calibration errors for the three test cycles at instrument temperatures of 11°C and those obtained earlier shown in Figures 5.4 and 5.5 for S/N 715 and 716, respectively. The worst case shift over the approximate 4-1/2 week period was -0.057 and -0.069 mho x 10^{-3}/cm for S/N 715 and 716, respectively. The uncertainty of the difference (shift) values was estimated to be ≈0.017 mho x 10^{-3}/cm.

5.1.4.3 Pressure Channel

a. Procedure

The instruments were subjected to three pressure calibration cycles at 11°C in the same manner as described in paragraph 5.1.3.a.

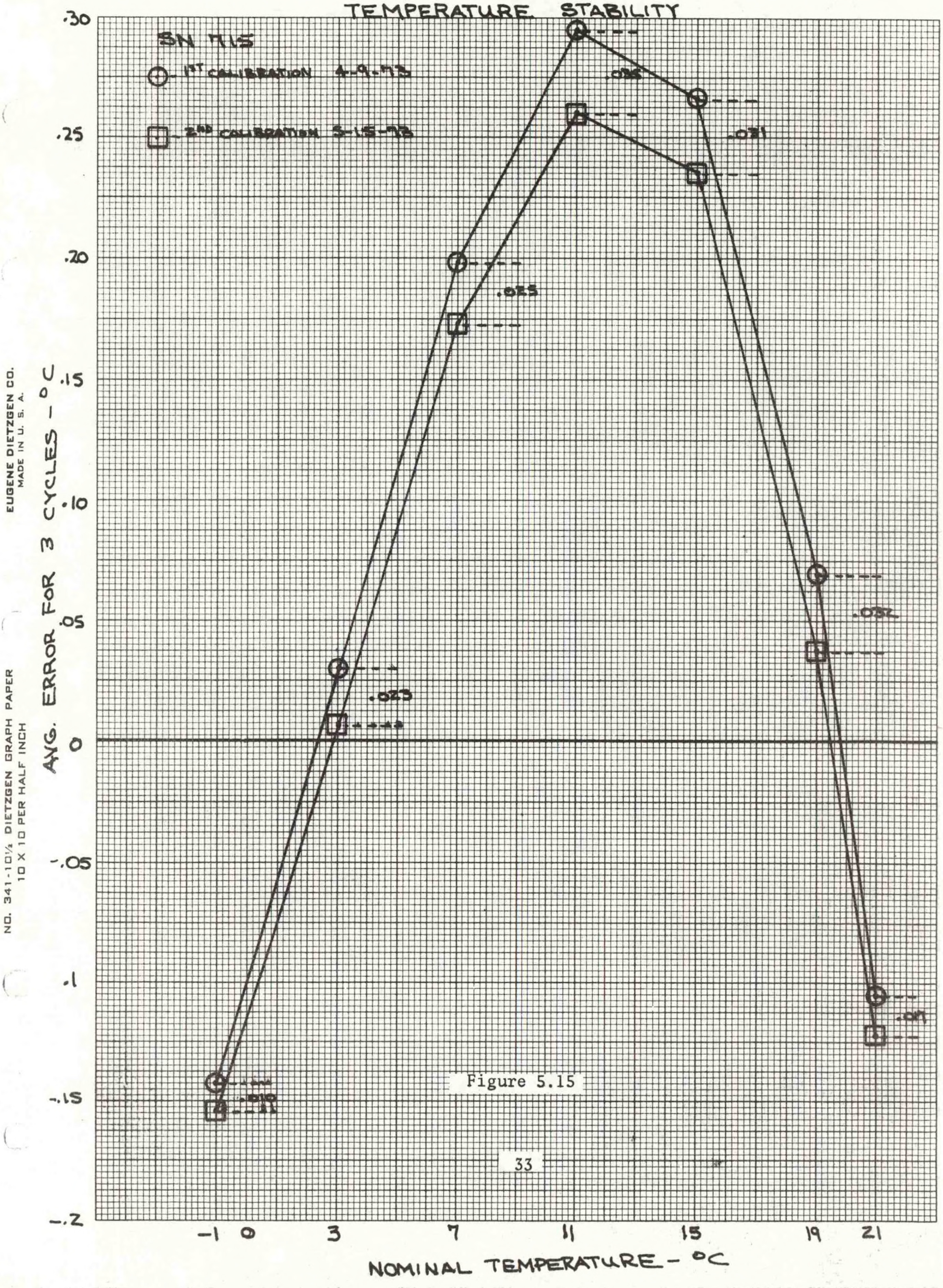

TEMPERATURE STABILITY
SN 715
1ST CALIBRATION 4-9-73
2ND CALIBRATION 5-15-73
.035
.031
.025
.032
.023
.010
.30
.25
.20
.15
.10
.05
0
-.05
-.1
-.15
-.2
AVG. ERROR FOR 3 CYCLES - °C
-1
0
3
7
11
15
19
21
NOMINAL TEMPERATURE - °C
NO. 341-10½ DIETZGEN GRAPH PAPER
10 X 10 PER HALF INCH
EUGENE DIETZGEN CO.
MADE IN U. S. A.

Figure 5.15

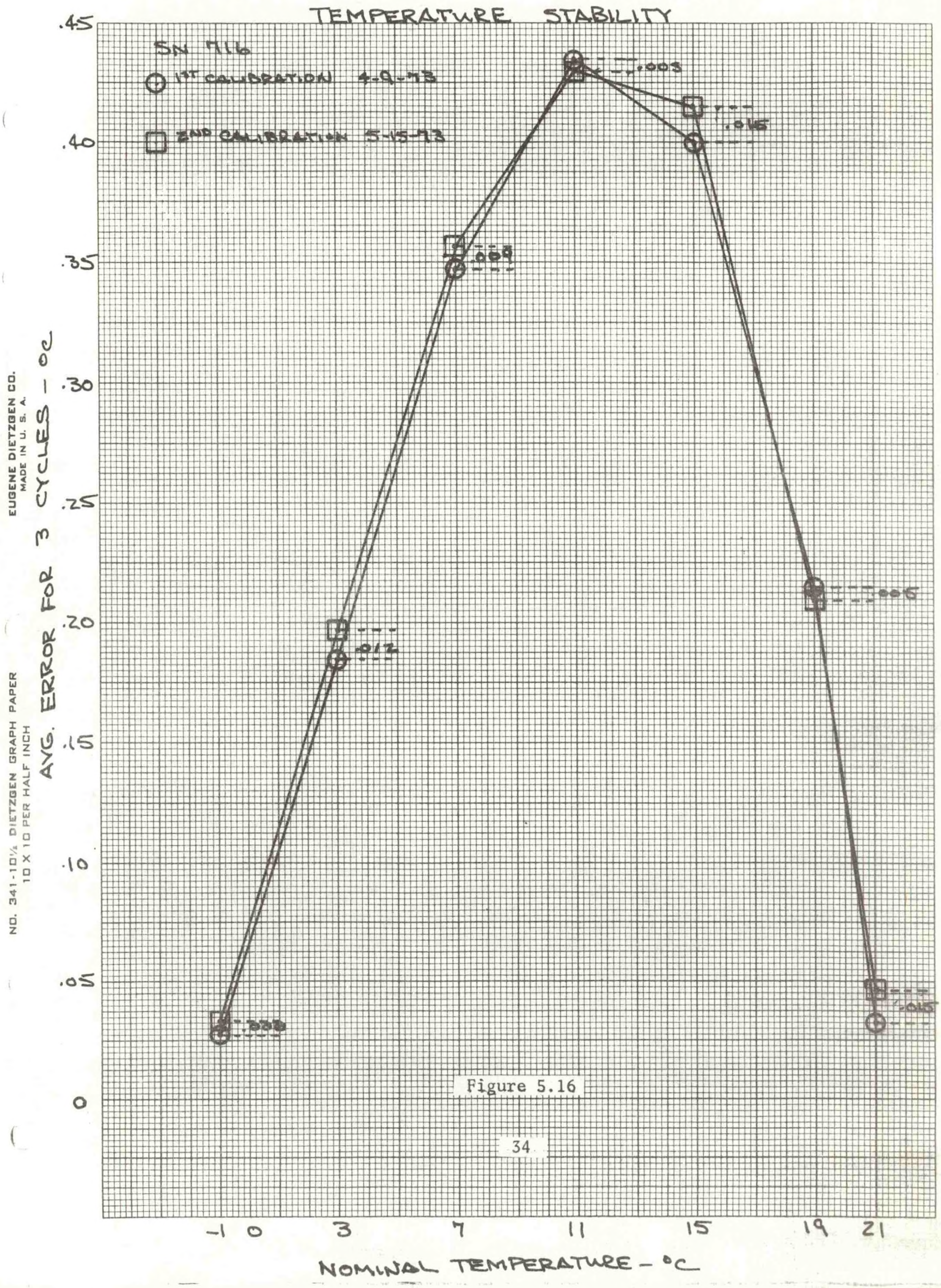
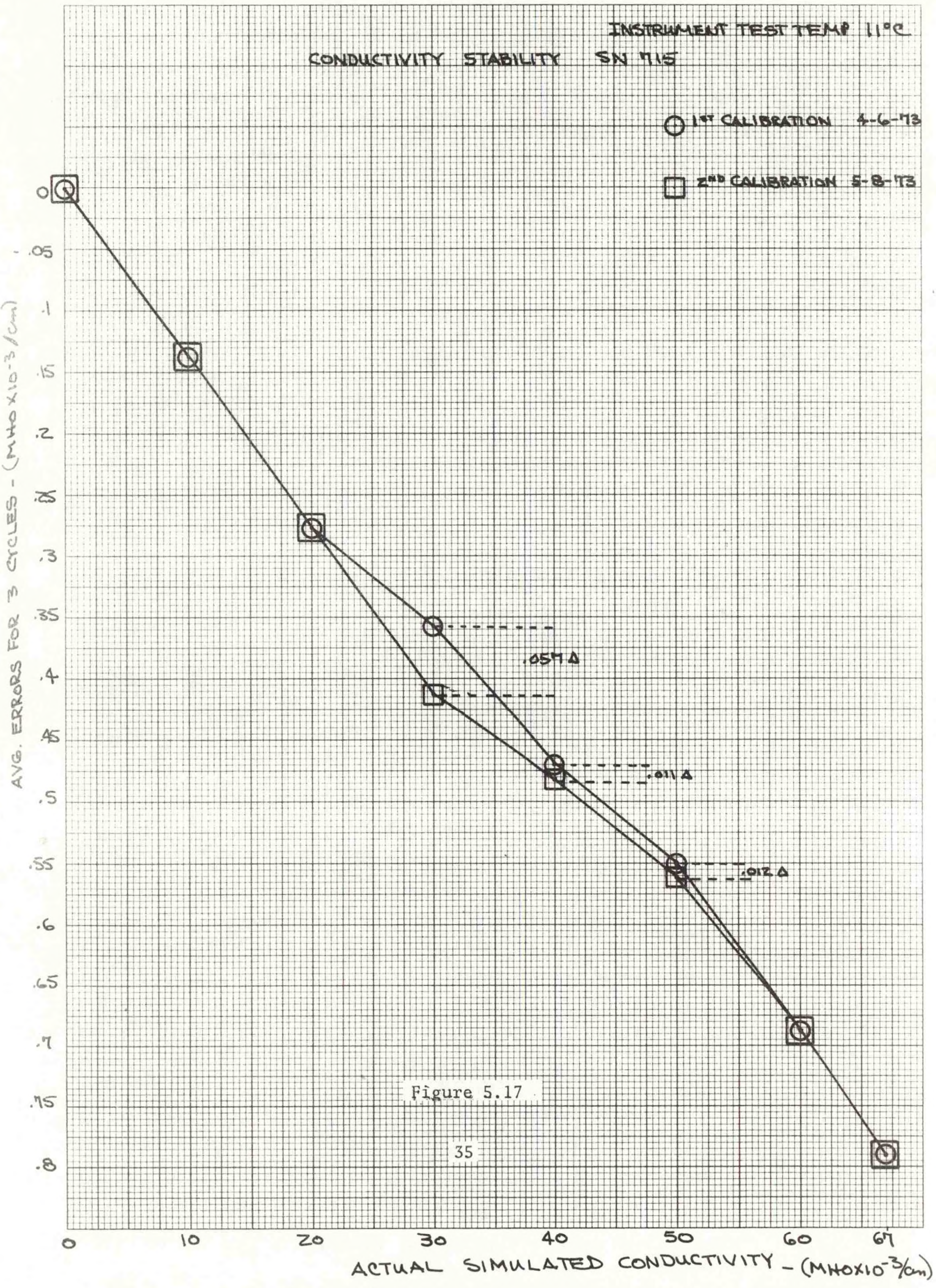

TEMPERATURE STABILITY
SN 716
1ST CALIBRATION 4-9-73
2ND CALIBRATION 5-15-73
.003
.015
.009
.012
.005
.015
.45
.40
.35
.30
.25
.20
.15
.10
.05
0
AVG. ERROR FOR 3 CYCLES - °C
-1 0
3
7
11
15
19
21
NOMINAL TEMPERATURE - °C
NO. 341-10½ DIETZGEN GRAPH PAPER
10 X 10 PER HALF INCH
EUGENE DIETZGEN CO.
MADE IN U. S. A.

Figure 5.16



INSTRUMENT TEST TEMP 11°C
CONDUCTIVITY STABILITY SN 715
1ST CALIBRATION 4-6-73
2ND CALIBRATION 5-8-73
.057 Δ
.011 Δ
.012 Δ
0
.05
.1
.15
.2
.25
.3
.35
.4
.45
.5
.55
.6
.65
.7
.75
.8
AVG. ERRORS FOR 3 CYCLES - (MHO X10^-3/cm)
0
10
20
30
40
50
60
67
ACTUAL SIMULATED CONDUCTIVITY - (MHOX10^-3/cm)
NO. 341-10T, DIETZGEN GRAPH PAPER 10 X 10 PER HALF INCH
EUGENE DIETZGEN CO. MADE IN U.S.A.

Figure 5.17

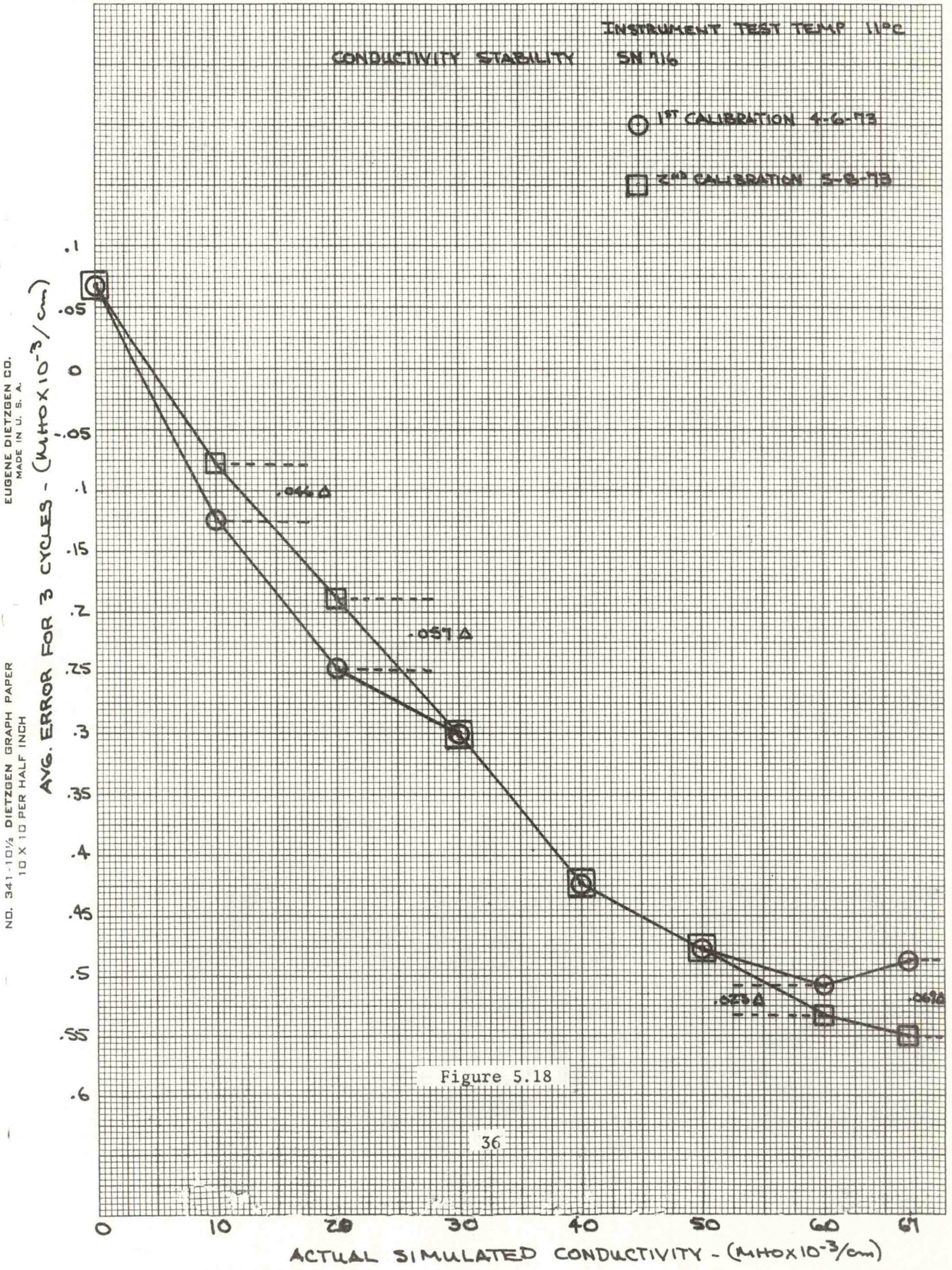

INSTRUMENT TEST TEMP 11°C
CONDUCTIVITY STABILITY SN 716
1ST CALIBRATION 4-6-73
2ND CALIBRATION 5-8-73
AVG. ERROR FOR 3 CYCLES - (MHO X 10⁻³/cm)
ACTUAL SIMULATED CONDUCTIVITY - (MHO X 10⁻³/cm)
.046 Δ
.057 Δ
.025 Δ
.1
.05
0
-.05
-.1
.15
.2
.25
.3
.35
.4
.45
.5
.55
.6
0
10
20
30
40
50
60
67
EUGENE DIETZGEN CO. MADE IN U. S. A.
NO. 341-10½ DIETZGEN GRAPH PAPER 10 X 10 PER HALF INCH

Figure 5.18

b. Results

Figures 5.19 and 5.20 show the average pressure calibration errors for the three test cycles at instrument temperatures of 11°C and those obtained earlier shown in Figures 5.10 and 5.11 for S/N 715 and 716 respectively. The worst case shift over the approximate five (5) week period was 0.065 and -0.074 kg/cm^2 for S/N 715 and 716, respectively. The uncertainty of the difference (shift) values was estimated to be ≈ $\pm$0.006 kg/cm^2.

5.2 Environmental (S/N 714)

5.2.1 Initial Three (3) Point Calibrations

a. Procedure

Three point calibrations were performed on the temperature, conductivity, and pressure channels. Applied measurand values were nominally 3, 11, and 19°C; 0, 30, and 67 mho x 10^{-3}/cm; and 0, 9 and 14 kg/cm^2 for temperature, conductivity, and pressure, respectively. Procedures for obtaining these datum were identical to those described in paragraphs 5.1.1.1a, 5.1.1.2a, and 5.1.1.3a, respectively.

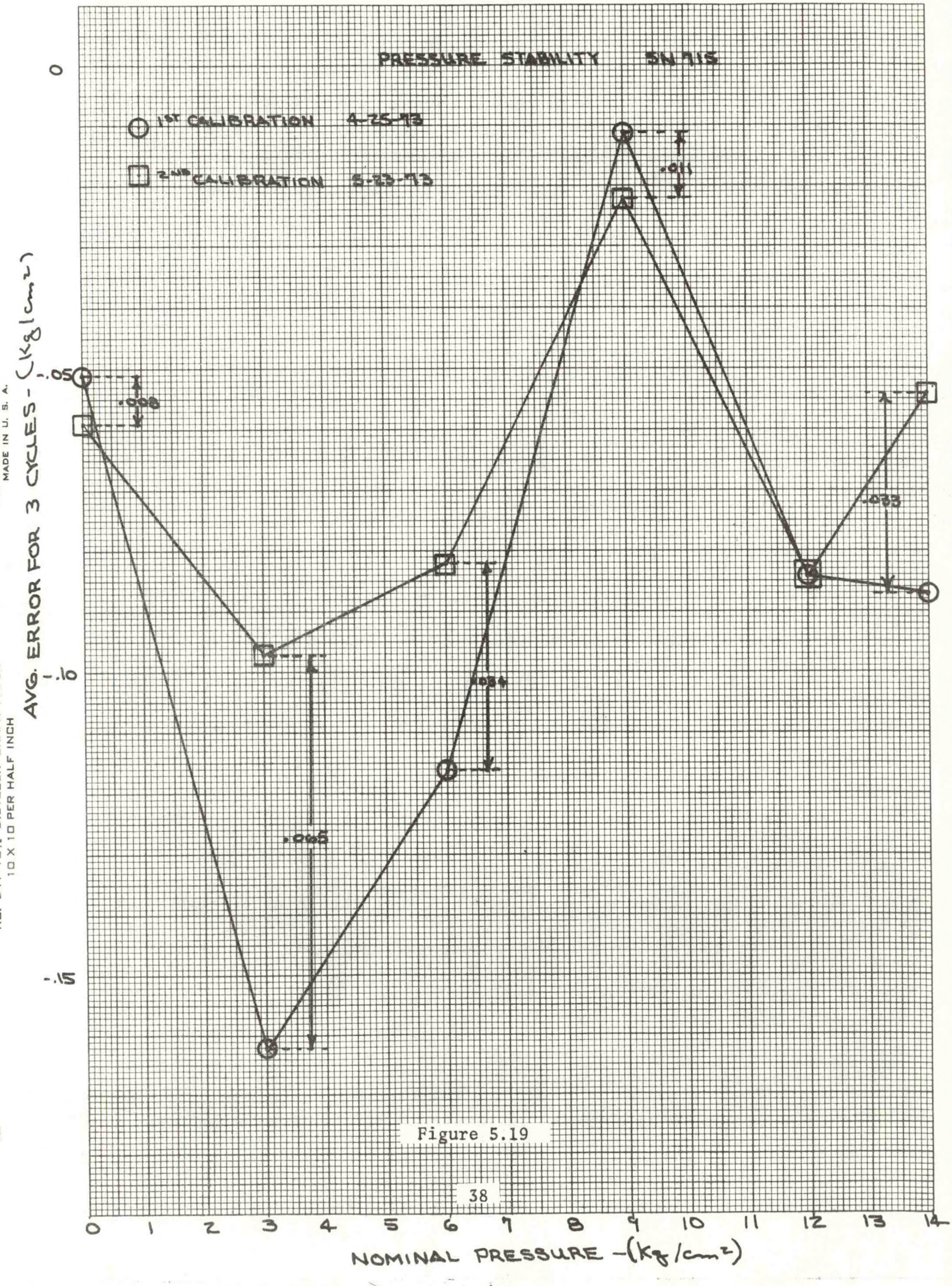
b. Results

Tables 5.3, 5.4, and 5.5 show the initial calibration error values for temperature, conductivity, and pressure, respectively.

5.2.2 Temperature

A. Procedure

The instrument was subjected to an environmental temperature test as outlined in paragraph 4.5.8.2.2 of military specification MIL-E-16400F (Navy), 24 February 1966. Basically, this test involved operating the instrument after stabilizing at temperatures



PRESSURE STABILITY SN 715
1ST CALIBRATION 4-25-73
2ND CALIBRATION 5-23-73
AVG. ERROR FOR 3 CYCLES - (Kg/cm²)
0
-.05
-.10
-.15
.008
.065
.034
.011
.033
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14
NOMINAL PRESSURE -(Kg/cm²)

Figure 5.19

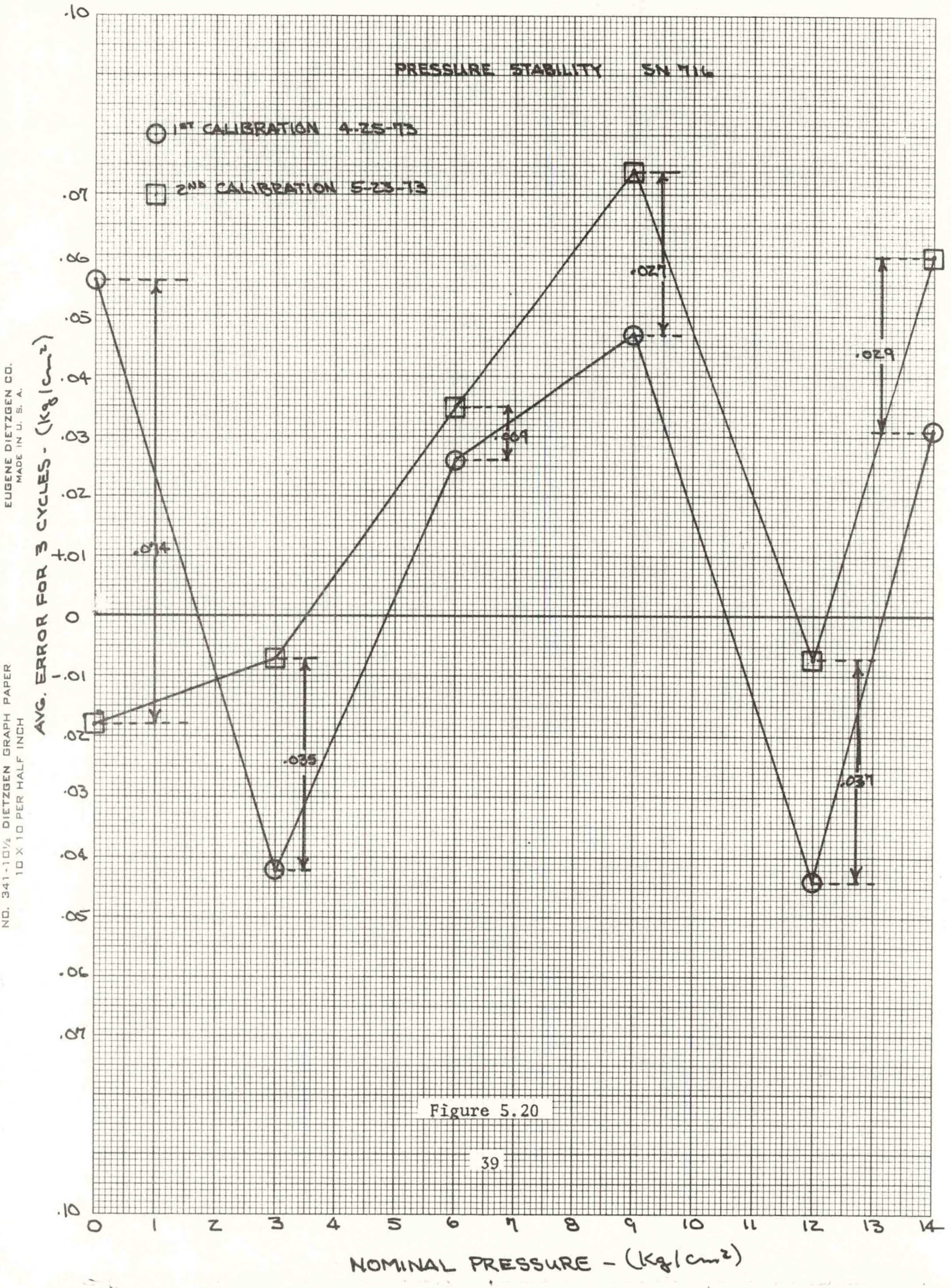

PRESSURE STABILITY SN 716
1ST CALIBRATION 4-25-73
2ND CALIBRATION 5-23-73
AVG. ERROR FOR 3 CYCLES - (Kg/cm²)
NOMINAL PRESSURE - (Kg/cm²)
.074
.035
.009
.027
.037
.029
EUGENE DIETZGEN CO. MADE IN U. S. A.
NO. 341-10½ DIETZGEN GRAPH PAPER 10 X 10 PER HALF INCH

Figure 5.20

TABLE 5.3

Aanderaa Model 4 RCM Serial #714 - 3 Point Temperature Calibrations

Initial 4/4/73			After 6/6/73 MIL 16400			After 6/22/73 Pressurization			After 7/17/73 MIL 167		
Actual Temp °/C	Instr. Ind.	ΔT	Actual Temp °/C	Instr. Ind.	ΔT	Actual Temp °/C	Instr. Ind.	ΔT	Actual Temp °/C	Instr. Ind.	ΔT
19.001	19.221	+0.220	18.997	19.221	+0.224	18.994	19.221	+0.227	18.896	19.221	+0.325
11.006	11.484	+0.478	11.009	11.484	+0.475	11.003	11.461	+0.458	11.006	11.461	+0.455
3.014	3.233	+0.219	3.026	3.233	+0.227	3.022	3.233	+0.211	3.023	3.257	+0.234

TABLE 5.4

Aanderaa Model 4 RCM Serial #714 - 3 Point Simulated Conductivity Calibrations @ 11°C

Initial 4/4/73			After 6/6/73 MIL 16400			After 6/22/73 Pressurization			After 7/17/73 MIL-167		
Actual $mho \times 10^{-3}$	Instr. Ind.	ΔC	Actual $mho \times 10^{-3}$	Instr. Ind.	ΔC	Actual $mho \times 10^{-3}$	Instr. Ind.	ΔC	Actual $mho \times 10^{-3}$	Instr. Ind.	ΔC
0	-0.004	-0.004	0	-0.004	-0.004	0	-0.004	-0.004	0	-0.004	-0.004
30	29.590	-0.410	30	29.590	-0.410	30	29.590	-0.410	30	29.590	-0.410
67	66.631	-0.369	67	66.631	-0.369	67	66.499	-0.501	67	66.499	-0.501

TABLE 5.5

Aanderaa Model 4 RCM Serial #714 - 3 Point Pressure Calibrations @ 11°C

Initial 4/4/73			After 6/6/73 MIL 16400			After 6/22/73 Pressurization			After 7/17/73 MIL 167		
Actual Kg/Cm^2	Instr. Ind.	ΔP	Actual Kg/Cm^2	Instr. Ind.	ΔP	Actual Kg/Cm^2	Instr. Ind.	ΔP	Actual Kg/Cm^2	Instr. Ind.	ΔP
0	0.153	+0.153	0	0.199	+0.199	0	0.917	+0.917	0	0.672	+0.672
8.998	9.262	+0.254	8.998	9.214	+0.216	8.998	9.917	+0.919	8.998	9.779	+0.781
						11.997	12.942	+0.945	11.997	12.896	+0.899
14.000	14.276	+0.276	14.000	14.210	+0.210	14.000	Out of Range		14.000	Out of Range	

of -28°C and 65°C; the test was performed in NOIC FAC #8, Parce Environmental Temperature Chamber. After the environmental temperature test, three point calibrations were repeated on the temperature, conductivity, and pressure channels as described in pargraph 5.2.1.a.

b. Results

The instrument failed to operate at the -28°C because the battery voltage had sunken to approximately 5 VDC due to the extreme cold temperature. (A previous test has indicated that the instrument(s) will not work when battery terminal voltage had sunken below 6.5 VDC, under no load conditions.) However, when the instrument was raised to the 65°C test temperature it did resume satisfactory operation (meaning that the instrument turned on and outputed six 10 bit binary words); no other adverse effects were observed. Tables 5.3, 5.4, and 5.5 show the after environmental temperature test calibration error values for temperature, conductivity, and pressure channels, respectively.

5.2.3 Pressure

a. Procedure

The instrument was placed in NOIC FAC #3, ARC Temperature Facility filled with tap water. Direct electrical readout and wire loop electrical connections were brought out through a bulkhead electrical connector with the electrical readout going to the analog strip chart recorder and the wire loop connections going to the resistance decade box. Three pressure cycles (0, 9, 14, 9 and 0 kg/cm^2) were subjected to the instrument at a temperature of 11°C; resistance of the decade box was set to a value to simulate a conductivity of 42.9 mho x 10^{-3}cm. After the pressure test, three point calibrations were repeated on the temperature, conductivity, and pressure channels as described in paragraph 5.2.1.a.

b. Results

There was no noticeable pressure effects on either the temperature or conductivity sensor calibrations while the sensors were being exposed to pressures up to 14 kg/cm^2. Tables 5.3, 5.4, and 5.5 show the after pressure calibration error values for temperature, conductivity, and pressure channels, respectively. As can be noted from Table 5 a zero shift of approximately ± 0.7 kg/cm^2 occurred in the pressure calibration error values; a calibration at 11 kg/cm^2 was additionally performed since the applied 14 kg/cm^2 value caused the pressure channel to read out of range. No explanation could be given as to what caused the pressure shift except that the shift probably occurred in the pressure transducer because there was no noticeable shift in the other sensing channels. The above tests were subjected to S/N 715 and 716 and the results showed no noticeable shifts in any of the sensing channels.

5.2.4 Vibration

a. Procedure

The instrument was subjected to an environmental vibration test as outlined in military specification MIL-STD-167 (Ships) for Type I equipment. After the vibration test three point calibrations were repeated on the temperature, conductivity, and pressure channels as described in paragraph 5.2.1.a.

b. Results

A visual inspection of the instrument after the vibration test showed no loose or broken parts; also the data recorded from the instrument during the test when it was turned on aperiodically showed no operational breakdowns or signs of erratic instrument behavior. Tables 5.3, 5.4, and 5.5 show the after vibration calibration error values for temperature, conductivity, and pressure channels, respectively.

6.0 ACCURACY COMPUTATIONS

6.1 Temperature Channel

The overall static measurement accuracy of the temperature channel for S/N's 715 and 716 was determined using the RSS (Root Sum of Squares) method as shown below in Table 6.1

Table 6.1
Accuracy
Temperature Channel (°C)

Parameter	Results	
	S/N 715	S/N 716
Nonrepeatability	±0.025	±0.010
Nonlinearity (includes temperature effect, if any)	±0.209	±0.202
Battery Voltage Variation Effect (7.0-9.8 VDC)	±0.025	±0.025
Stability (5 weeks)	-0.035	+0.015
RSS Accuracy (Using best straight line to relate output to temperature)	±0.214	±0.204
RSS Accuracy (Using a calibration table or equation to relate output to temperature to essentially eliminate the systematic error due to nonlinearity)	±0.043	±0.031

6.2 Conductivity Channel

The overall static measurement accuracy of the conductivity channel for S/N's 715 and 716 was determined using the RSS method as shown below in Table 6.2.

Table 6.2
Accuracy
Conductivity Channel (mho x 10^{-3}/cm)

Parameter	Results	
	S/N 715	S/N 716
Nonrepeatability	±0.034	±0.030
Nonlinearity	±0.028	±0.080
Temperature Effects (3-19°C)	0.070	0.070
Battery Voltage Variation Effect (7.0-9.8 VDC)	0	0
Stability (4-1/2 weeks)	-0.057	-0.069
RSS Accuracy (Using best straight line to relate output to conductivity	±0.100	±0.130
RSS Accuracy (Using a calibration table or equation to relate output to conductivity to essentially eliminate the systematic error due to nonlinearity)	±0.096	±0.103

6.3 Pressure Channel

The overall static measurement accuracy of the pressure channel for S/N's 715 and 716 was determined using the RSS method as shown below in Table 6.3.

Table 6.3
Accuracy
Pressure Channel (kg/cm^2)

Parameter	Results	
	S/N 715	S/N 716
Nonrepeatability	±0.046	±0.046
Hysteresis	±0.062	±0.022
Nonlinearity	±0.066	±0.048
Temperature Effects (3-19°C)	±0.044	±0.040

Table 6.3 (Continued)

Battery Voltage Variation Effect (7.0-9.8 VDC)	±0.008	±0.008
Stability (5 weeks)	0.065	-0.074
RSS Accuracy (Using best straight line to relate output to pressure)	±0.129	±0.114
RSS Accuracy (Using calibration table or equation to relate output to pressure to essentially eliminate the systematic error due to non-linearity)	±0.110	±0.099

7.0 CONCLUSIONS

The electronics section of the Aanderaa Model 4 RCM works very satisfactorily and reliably. No failures were encountered on any of the three instruments tested.

Manufacturer's supplied temperature channel calibrations were in error as much as -0.17°C (S/N 715) in comparison to NOIC's, whereas S/N 716 compared better than ±0.02°C. The overall RSS static temperature channel measurement accuracy for the RCM was determined to be about ±0.04°C. An accurate calibration table or equation must be used to relate channel output to temperature to eliminate the systematic error due to the nonlinear response which was determined to be approximately ±0.2°C.

Manufacturer's supplied conductivity channel calibrations were in error as much as -0.79 mho x 10^{-3}/cm in comparison to NOIC's. The overall RSS static conductivity channel measurement accuracy was determined to be about ±0.10 mho x 10^{-3}/cm. An accurate calibration table or equation must be used to relate channel output to conductivity to eliminate the systematic error due to the nonlinear response which was determined to be as much as ±0.08 mho x 10^{-3}/cm (S/N 716).

The overall RSS static pressure channel measurement accuracy was determined to be about ± 0.1 kg/cm^2. An accurate calibration table or equation must be used to relate channel output to pressure to eliminate the systematic error due to the nonlinear response which was determined to be as much as ± 0.07 kg/cm^2 (S/N 715).

The RCM reference word appears to provide some quality control on the operational performance of the instrument. The worst case variation of the reference word from the three instruments tested was ± 2 LSB over the range of instrument operating conditions.

The RCM should be capable of withstanding, without adverse effects, extremes in ambient temperature variations -28 to +65°C and mechanical vibrations with amplitudes (peak) of 0.030" and 0.003" with upper frequencies of 15 Hz and 50 Hz, respectively. Pressure tests indicate that the RCM is capable of withstanding ambient pressure cycling from 0 to 14 kg/cm^2 (gauge) without leakage; also, the temperature and conductivity sensor calibrations are not affected by pressure variations over the same range.

The 5% shift noted in the pressure channel calibration on S/N 714 after the ambient pressurization test was probably due to the pressure sensor. A similar occurrence was noted on two other RCM's tested at the Center back in November 1972 where the shifts on both instruments were about 25%. Usually after these shifts occur the pressure channel calibrations remain fairly stable, indicating that possibly some sensors are being precycled before factory calibration and others not as much or not at all.

A primary note of importance is that the temperature, conductivity, and pressure channel calibrations are not stable with time. Over a five week test period, maximum difference in calibration error values of |0.15% FR|, |0.10% FR|, and |0.53% FR| were observed in the temperature, conductivity, and pressure measurement channels, respectively.

List of Figures and Tables

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