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# EVALUATION OF WATER LEVEL AND WAVE SENSORS FOR GEOTECHNICAL AND HYDRAULIC LABORATORY USE

by

C. A. Lennon, Jr.

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By: C. A. Lennon, Jr.

September 1980

Power and Instrumentation Branch
Division of Research
Engineering and Research Center
Denver, Colorado

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United States Department of the Interior
Water and Power Resources Service

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September 1980

## ABSTRACT

Tests of several manufacturers offerings of water level and wave sensors were conducted related to studies of earth slides in large reservoirs and resulting wave action and to uses on the triaxial shear testing machines. The test results are reported with indications of usefulness in these areas.

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## Section I: Introduction

This project started as a need by the Geotechnical and Hydraulics Branches for more water level probes. We had the options of building an internally designed unit or looking for a commercial product. We decided to look for a commercial transducer from sources like the Gold Book (Transducers, Liquid Level; Controls, Liquid Level) and "Measurements and Control Magazine," issue dated April 1980, Buyers Guide Section called Level Measurement and Control.

A total of 42 companies were contacted and asked if they could continuously measure surface waves on water with a 0.254 m (10 inch) span and 2.54 mm (0.1 inch) maximum error. The response had to be faster than 100 samples per second for computer digitizing. We were looking for 17 probes for the Hydraulics Branch, initially. A group of 11 companies looked promising and stated that they could maybe do the job. Those that said no had various reasons like maximum-minimum detection only, compensation for waves, or too slow of a response. Of the 11 promising companies, 4 were tested and the rest dropped out due to lateness, lack of interest, or not actually meeting our needs when the product was studied in detail.

The Geotechnical Branch pressurization needs were included after the initial round of contacts so only the 11 promising companies were asked about this need. Five said that they could be pressurized and used in this application. Two were tested and a third is being purchased for such testing. Due to the late inclusion of the Geotechnical Branch needs, some of the 31 companies that said no initially may be able to meet their needs if there was time to redo the contacting. Appendix A lists the companies contacted and their initial responses.

The four companies evaluated and tested by us have their results included in Sections II through V of this report. Appendix B has diagrams and sketches of the test apparatus used. Section VI is the conclusions reached for this report.

## Section II: Bailey Scientific Model PC-50

On August 18, 1980, we received the Bailey Scientific Model PC-50 Process Controller, Serial No. 113. The system for measuring water level included the main electronics in a 0.254-m (10-inch) by 0.203-m (8-inch) by 0.102-m (4-inch) NEMA-4X (fiberglass) box, sonic sensor UT-40 in PVC housing, thermistor on cable for temperature compensation, and operation manual.

In studying the manual and installing the hardware, I found the manual was incomplete and did not contain physical layout drawings or circuit schematics. The component descriptions for the Full Scale Span thumbwheels did not have a one-tenth-inch digit as indicated in the manual. None of the six connectors on the electronics box were labeled nor referred to specifically in the manual. There were three that were alike and mated with the 120 Vac power cord, two alike that mated with the thermistor cable, and only one that was obviously for the sensor BNC connector. I opened the electronics box and traced the wiring.

After connecting the cables properly, the system was installed in the environmental chamber with the temperature cycle set from 55°C to 5°C and back so that 1 hour was allowed for transition from one extreme to the other and the stable temperature was maintained for 2 hours. This ran for several complete cycles as shown in Figure 1. The following was observed: (1) The 4-20 mA output was consistently noisy at the 55°C temperature. (2) The output contained noise bursts of 5-minute duration at approximately 15-minute intervals at the 5°C temperature. (3) The transitions from 55°C to 5°C produced a very noisy and inconsistent output signal while the 5°C to 55°C transitions produced a quiet output signal. (4) The output signal occasionally would go to 4 mA (minimum) indicating a signal loss or some abnormal condition.

One problem with the output signal is that it goes to the 4 mA (minimum) value on an overrange condition which makes the detection of such conditions difficult and the span level checking difficult. Also, the output signal has hard limits at 4 mA and 20 mA so that all underrange and overrange situations are lost data. Some out of range ability would be very useful.

The system was moved to the Hydraulics Laboratory for wave and linearity tests. The linearity test revealed that the thumbwheel setup procedure is difficult and not well described in the manual. After several tries we were able to get some meaningful data shown in Figure 2 which indicated that the output was very nonlinear at the lower end, i.e., below 5 mA. Also, the span was not correct since for a span setting of 0.178 m (7.0 inches) and an offset of 0.925 m (36.4 inches), the output only changed for 0 percent to 86.6 percent for a 0.178 m (7.0 inches) actual level change of the water.

The wave tests of Figure 3 revealed that the 1-second interval sampling rate of the PC-50 was too slow for our application. Even though the manufacturer can raise the sampling rate, the wave cannot have a slope of more than 20° to 25° from the horizontal before the echo is lost, which makes the system inadequate for our wave measurements.

The dynamic tests of Figure 4 and 5 were acceptable at the low frequency of 0.01 Hz with only small fluctuations in the output for small water level changes. The 0.1 Hz frequency test revealed a very digitized output which vaguely resembled the input signal. The 1 Hz frequency was faster than the probe could handle as noted in Figure 5.

The Model PC-50 does not meet our current applications of continuous wave measurement. Since the sonic sensor cannot be pressurized, it is not applicable to the triaxial shear water level measurements which require pressurization of up to 6.7 megapascals (1,000 psi).

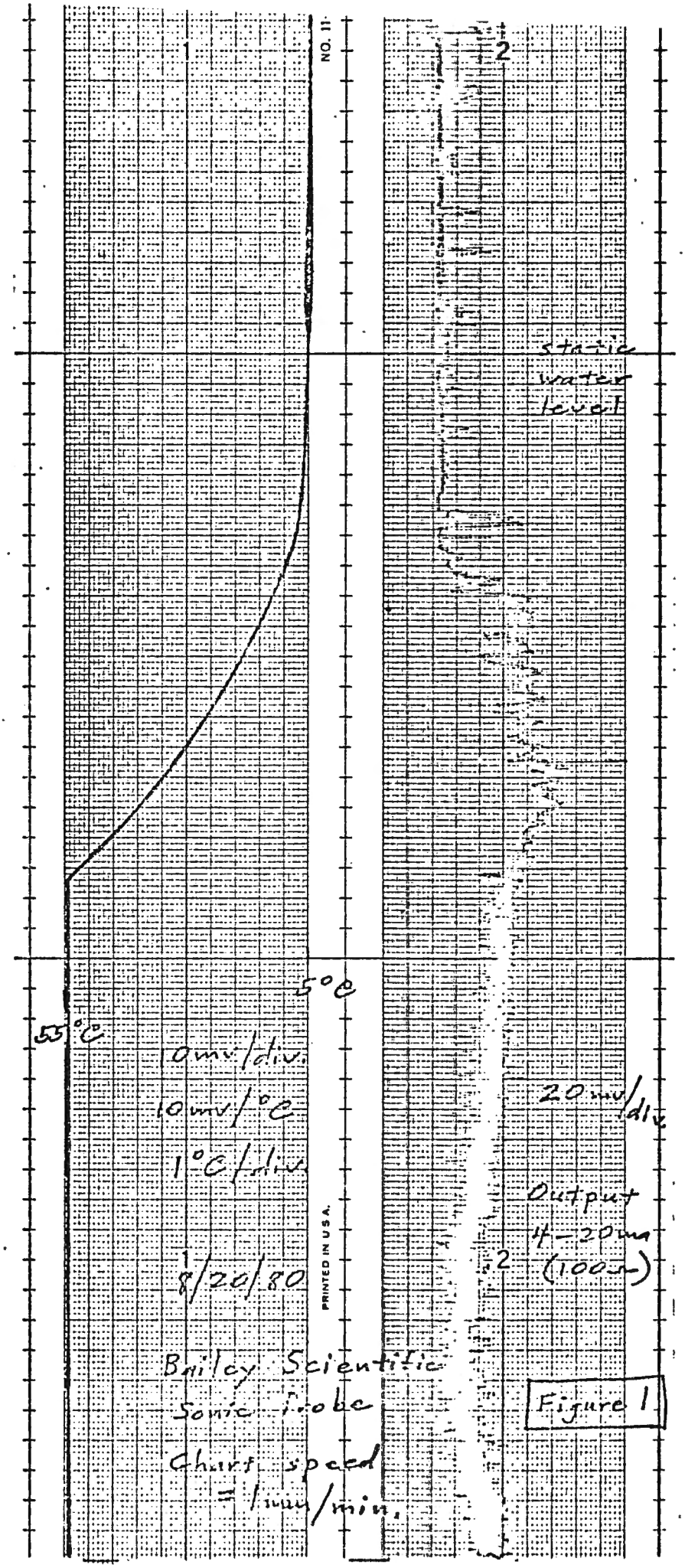

1
2
NO. 11
static water level
5°C
55°C
10mv/div.
10mv/°C
1°C/div
8/20/80
20mv/div
Output 4-20ma (100Ω)
PRINTED IN U.S.A.
Bailey Scientific Sonic Probe
Chart speed = 1/mm/min.

Figure 1

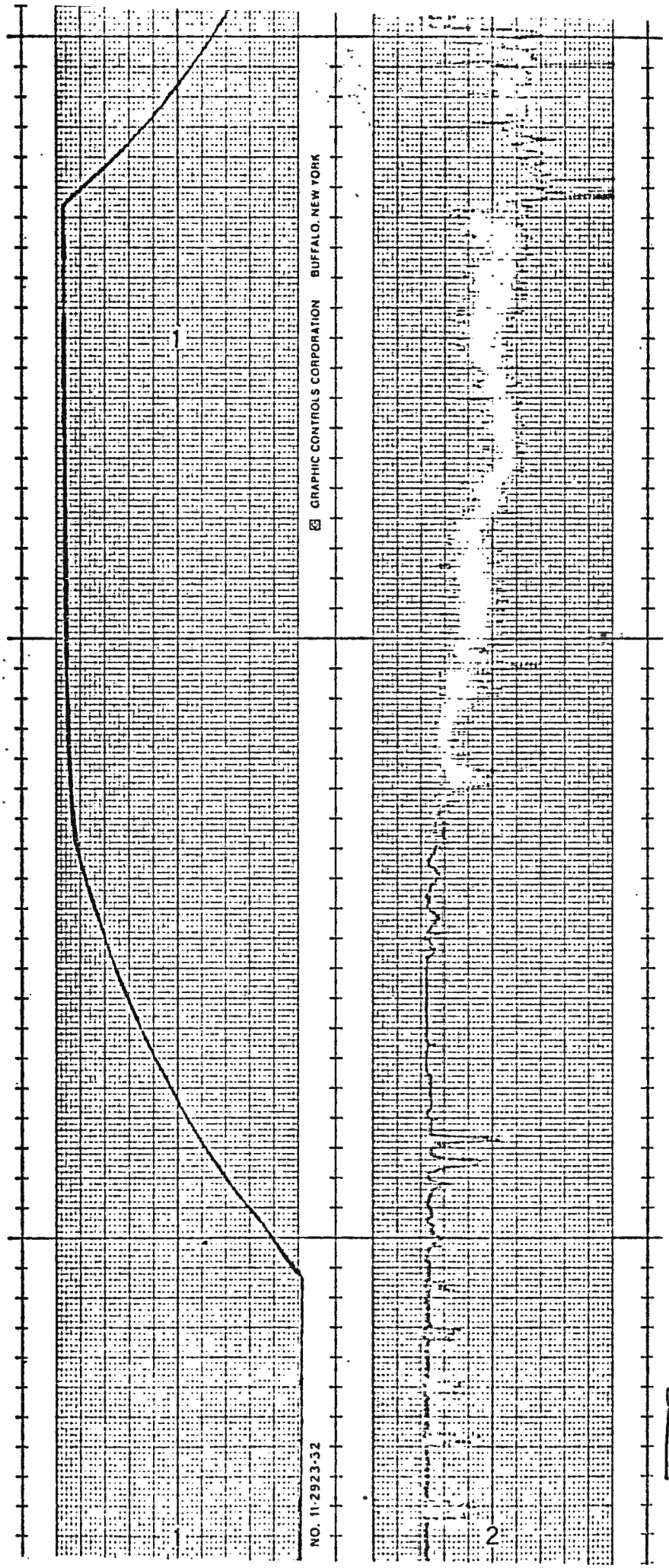



Figure 1 (Cont.)

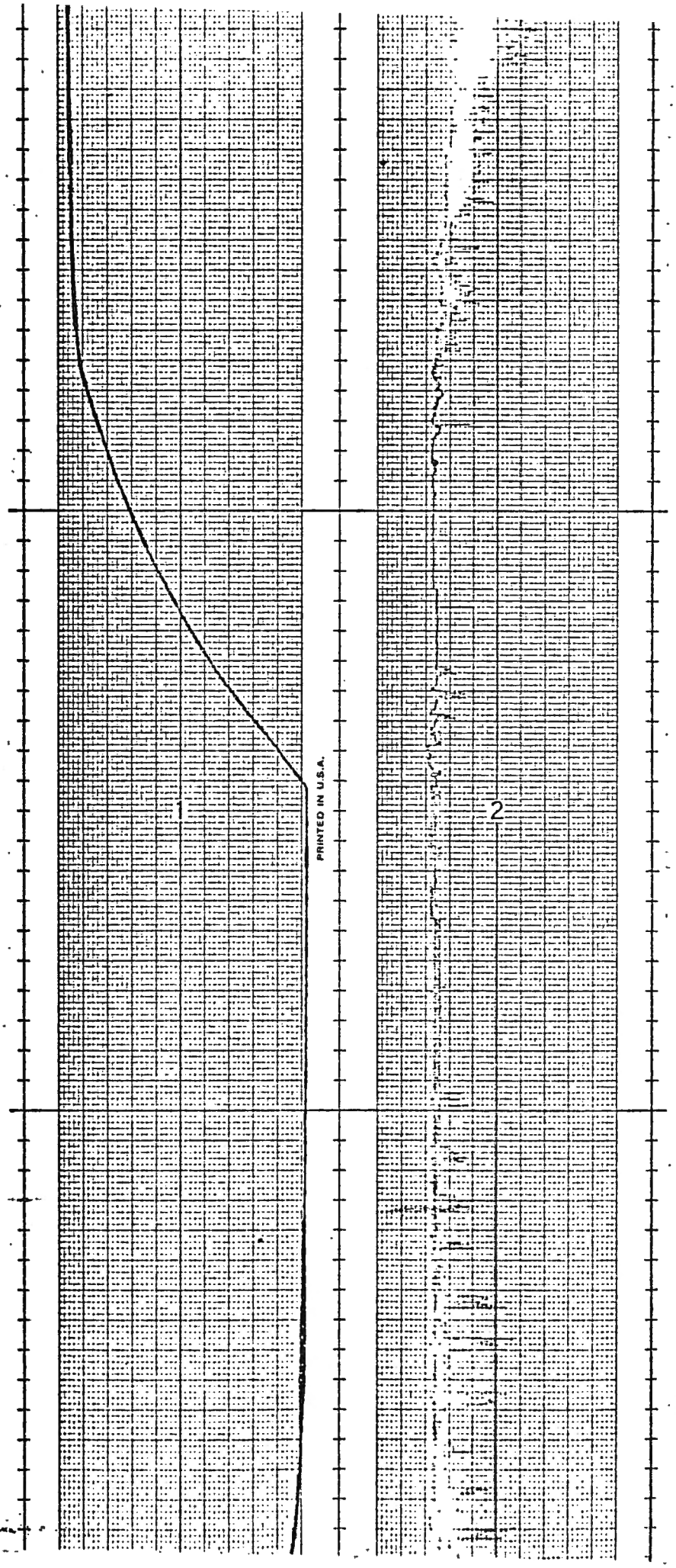



Figure 1 (Cont.)

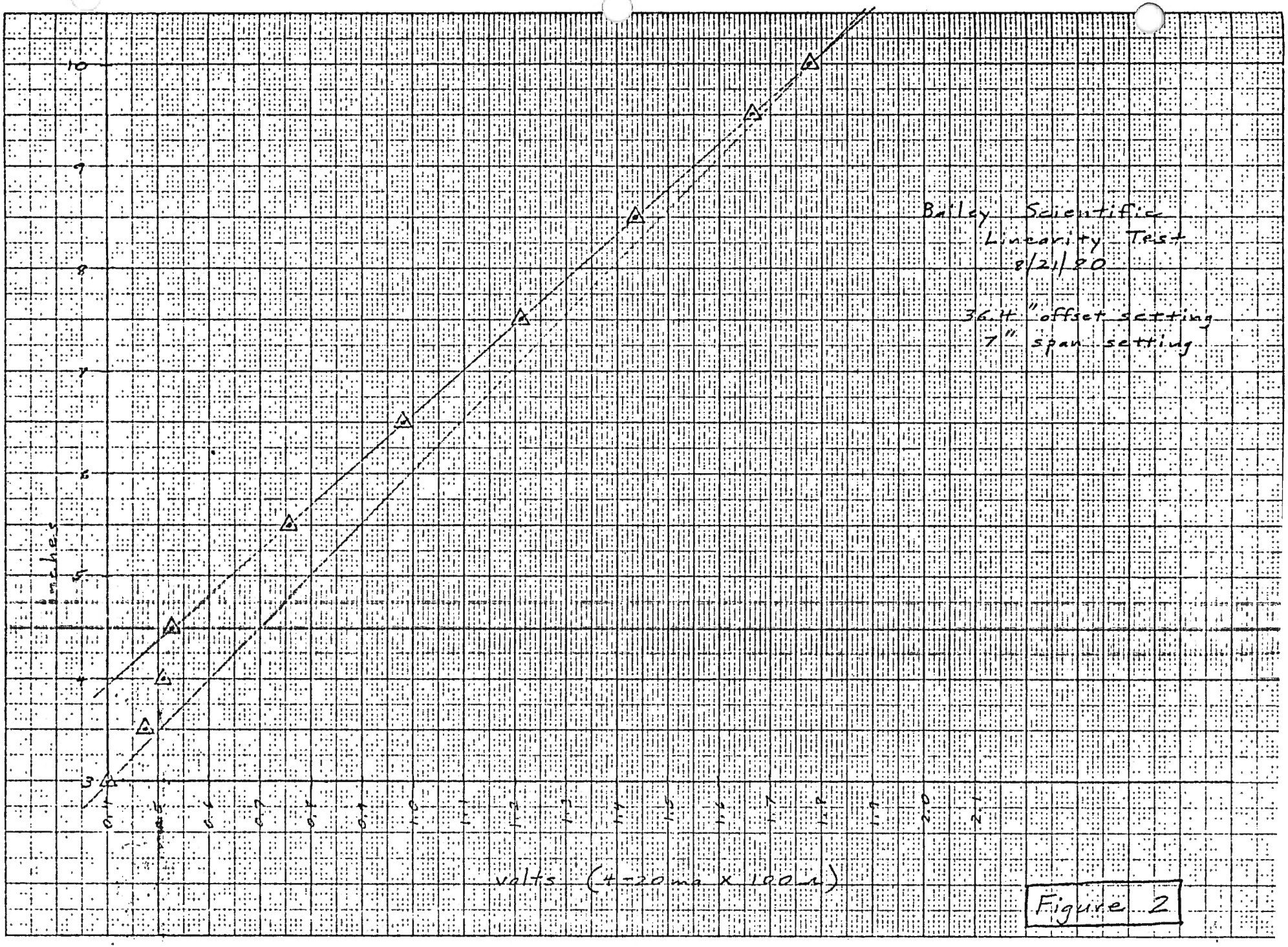
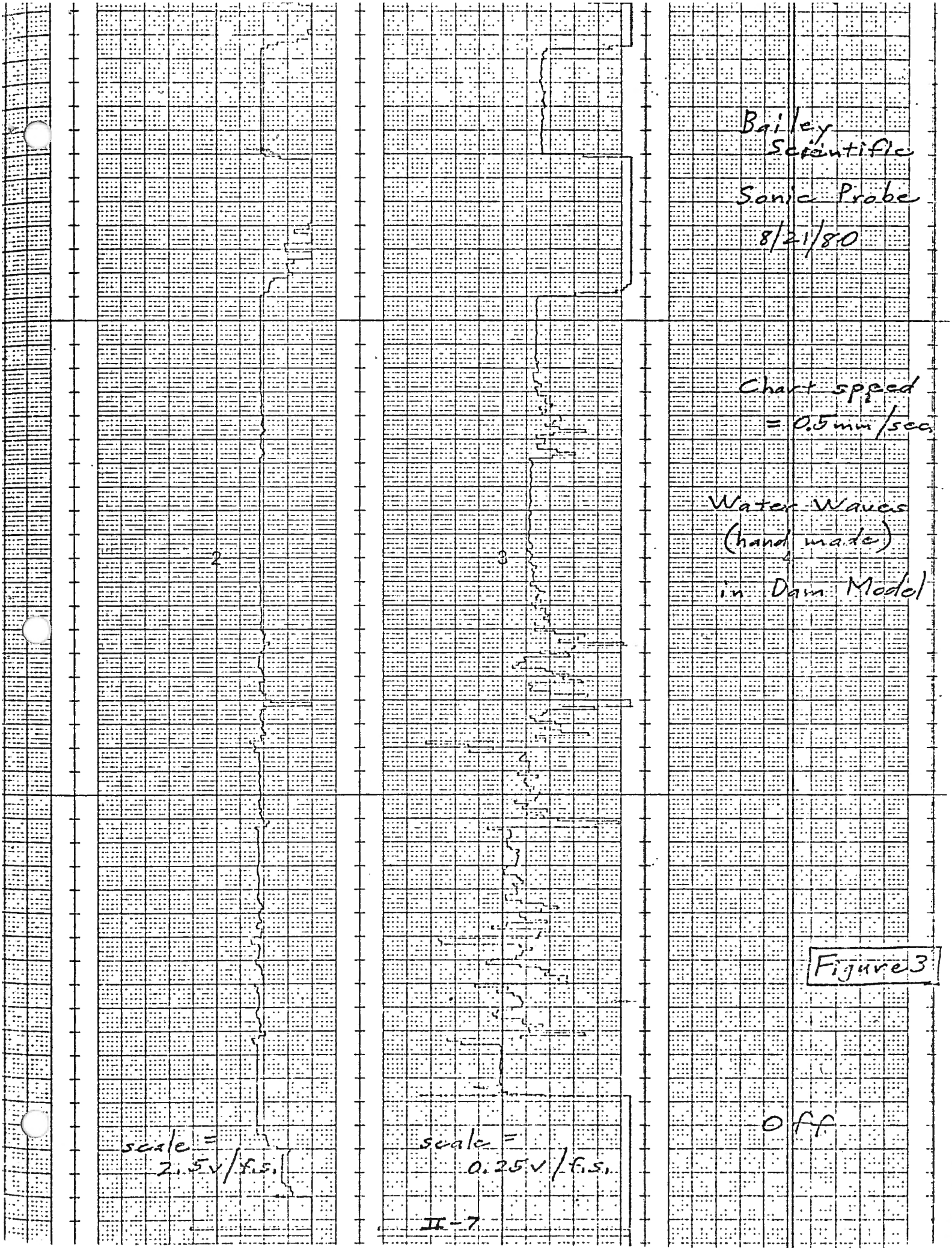

Bailey Scientific
Linearity Test
8/21/80
36.4" offset setting
7" span setting
inches
3
4
5
6
7
8
9
10
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1.0
1.1
1.2
1.3
1.4
1.5
1.6
1.7
1.8
1.9
2.0
2.1
volts (4-20 ma x 100 Ω)

Figure 2


Bailey Scientific
Sonic Probe
8/21/80
Chart speed = 0.5 mm/sec
Water Waves (hand made) in Dam Model
2
3
4
Figure 3
Off
scale = 2.5v/f.s.
scale = 0.25v/f.s.

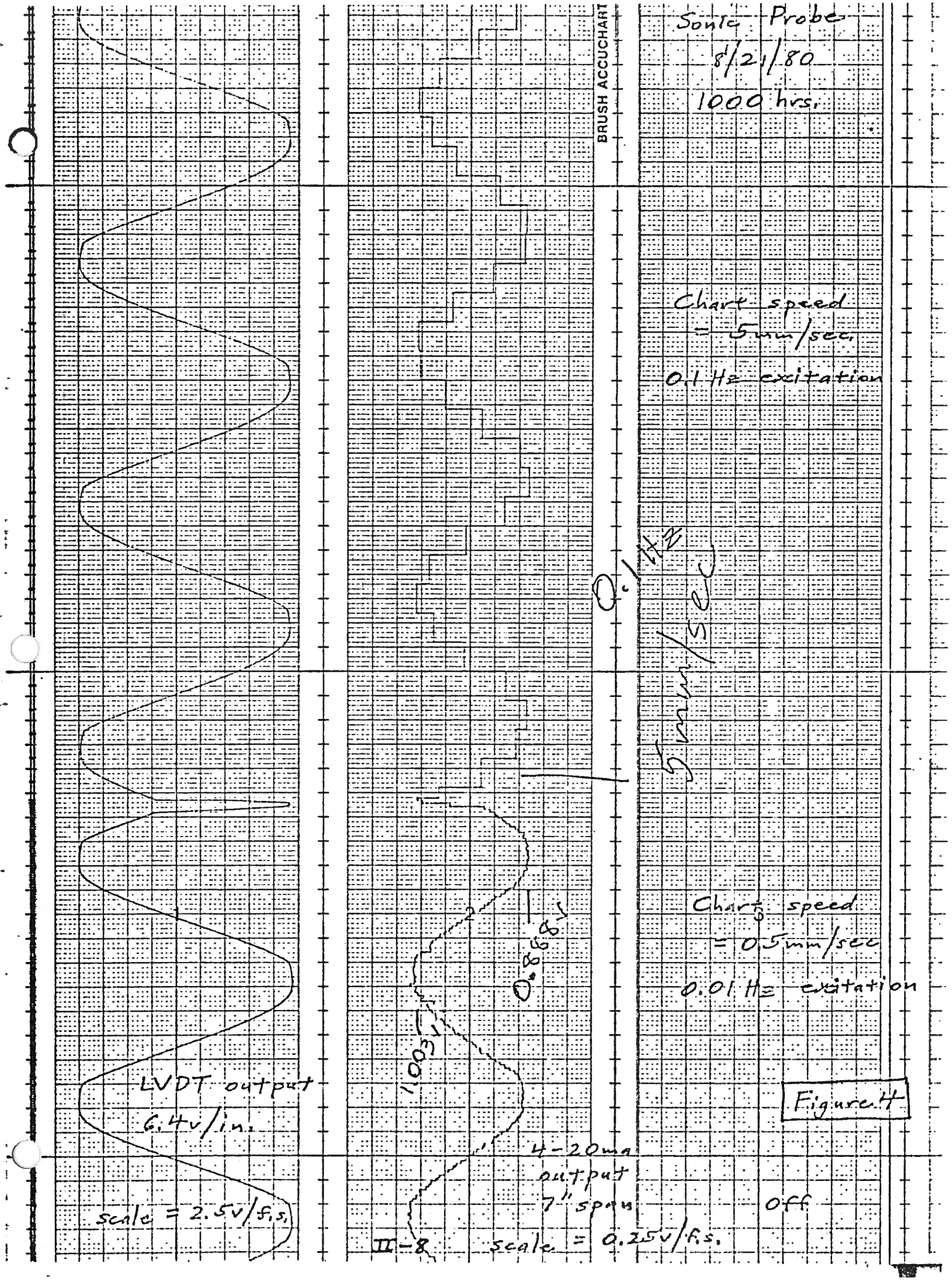
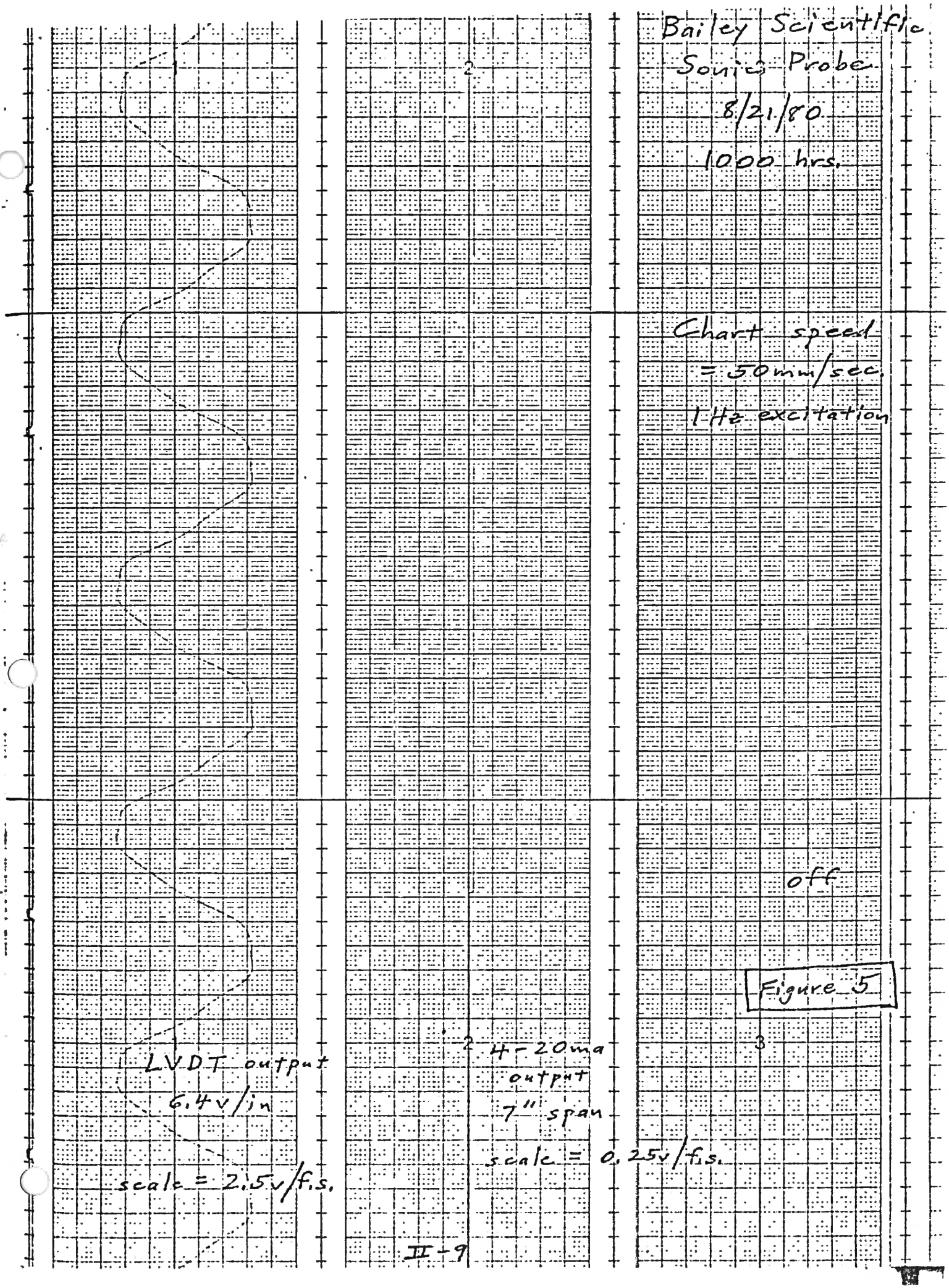

BRUSH ACCUCHART
Sonic Probe
8/21/80
1000 hrs.
Chart speed
= 5mm/sec.
0.1 Hz excitation
0.1 Hz
5mm/sec
Chart speed
= 0.5mm/sec
0.01 Hz excitation
LVDT output
6.4v/in.
scale = 2.5v/f.s.
4-20ma
output
7" span
off
scale = 0.25v/f.s.

Figure 4


Bailey Scientific
Sonic Probe
8/21/80
1000 hrs.
Chart speed
= 50mm/sec.
1 Hz excitation
off
Figure 5
LVDT output
6.4v/in
scale = 2.5v/f.s.
4-20ma
output
7" span
scale = 0.25v/f.s.

## Section III: Robertshaw Controls Model 160

The Robertshaw Controls Model 160 Water Level Transmitter was a capacitance measuring electronics unit with a 12.7-mm (1/2-inch) o.d. teflon-coated, stainless steel rod. The probe is placed in the water and the level is determined by the capacitance change as the water raises or lowers on the side of the rod. The electronics were an externally powered two-wire 4-20 mA current loop with output proportional to calibrated level. The unit contained independent span and zero adjustments with a coarse switch and fine 22-turn trimpot controls in each case.

On July 31, 1980, we received the unit for evaluation. After studying the unit and setting up all the test apparatus, we began the testing in the Hydraulics Laboratory. It was determined that the 12.7-mm (1/2-inch) o.d. probe was too large for the wave measurements. The water climbed the front face and an unusable trough and wake were generated behind the probe. This distorted the wave considerably. The electronics were very sensitive and responded quite well to the waves.

The linearity tests were done in static water by moving the probe up and down on a calibrated arm. The results were very good, with the only error being experimental in nature. The probe is linear over its complete span and does have some overrange and underrange ability as shown in Figures 1 and 2.

The dynamic tests were performed with the setup using a torque motor with pivot arm and variable-frequency electrical drive. The mechanical movement was measured by a linear LVDT and the probe was suspended by a cable from the pivot arm. The water was held static and the probe was moved up and down a small amount. The LVDT output and probe output were displayed on a strip chart recorder as shown in Figures 3, 4, and 5. The results at 0.01-Hz frequency showed the probe tracked the mechanical oscillations very closely. At 0.1-Hz frequency the probe showed a flattening of the peaks but not severely. This was due to the meniscus effect on the probe. At the 1-Hz frequency the up peak was tracked but the down stroke resulted in mechanical oscillations in the probe support cable. These oscillations were partly due to the probe's large relative weight and freedom of movement in the test apparatus. Good sensitivity was noted in the pickup of the mechanical ringing by the electronics.

The environment chamber test of Figure 6 showed that the output was not noisy with temperature changes. The output did drift by about 0.75 mA with a temperature change of 50°C and had a slight downward trend due to water evaporation at the higher temperature. The drift was measured as a 4.7 percent change which is repeatable and tracks the temperature cycles.

After the temperature tests the probe was pressure tested in the Geotechnical Triaxial Shear Laboratory. The probe was subjected to 1.38 megapascals (200 psi) with a 12 percent change in output for a corresponding zero change in water level. At 3.45 megapascals (500 psi) there was no additional change in output, but when returned to atmospheric pressure, the probe output showed a value of 5 percent higher than initial setup conditions. We examined the probe and noticed that the teflon sheath was deformed. A second linearity test was conducted, and as shown in Figure 7, the probe's output was not linear at the low end. The local representative explained that the probe had a small hole in the teflon and was caused by a loose sheath. This would account for the deformation and nonlinearity of the output after pressurization.

A smaller diameter rigid rod is necessary for the wave measurements and use in the smaller triaxial shears. A good size appears to be 3.1-mm (1/8-inch) o.d. with a tight fitting teflon sheath. The manufacturer states that the smallest diameter rigid rod they will make is 9.5-mm (3/8-inch) o.d. of any length needed. The electronics are adequate and will fit our present measurement applications of larger triaxial shear testing.

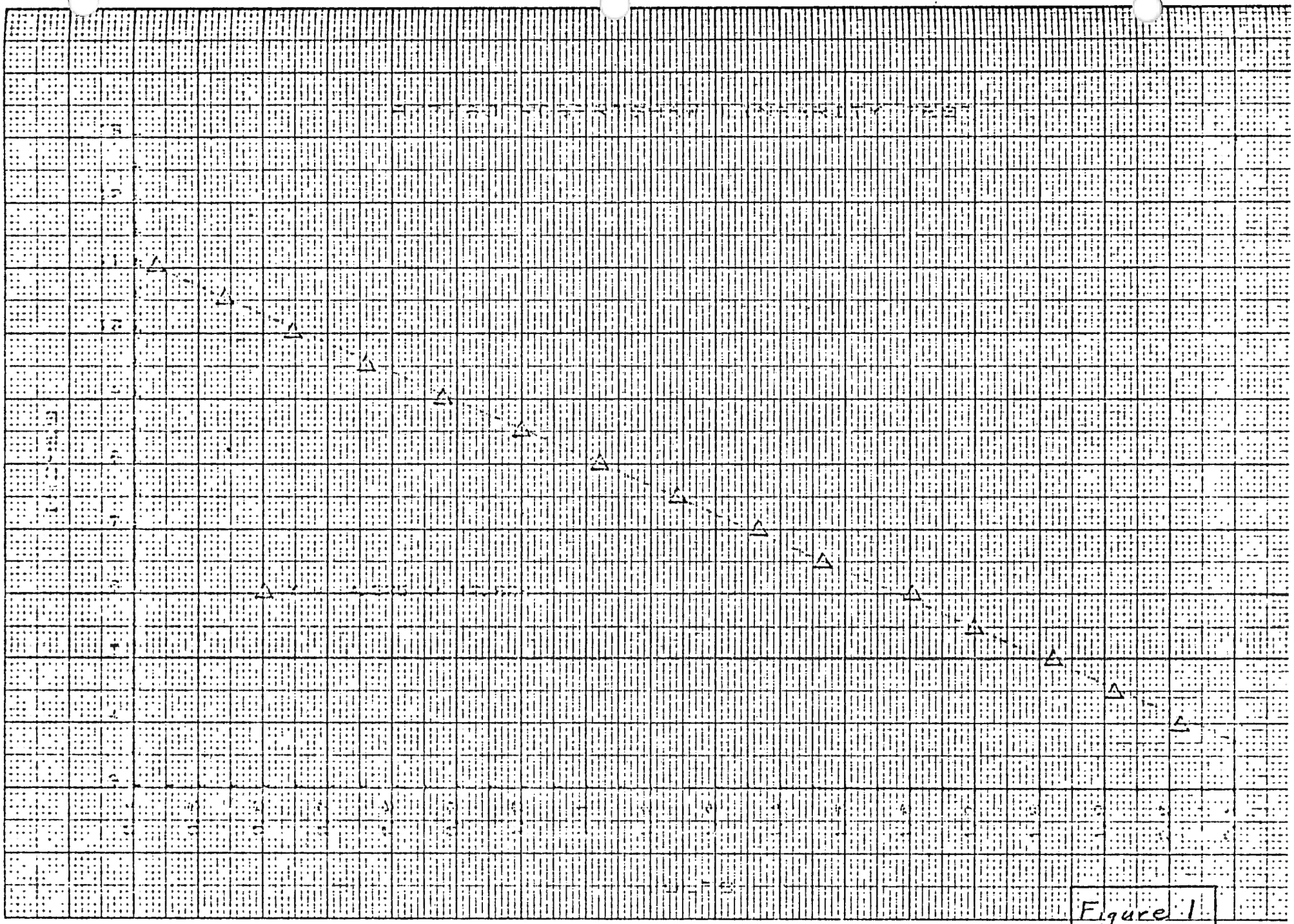


Figure 1

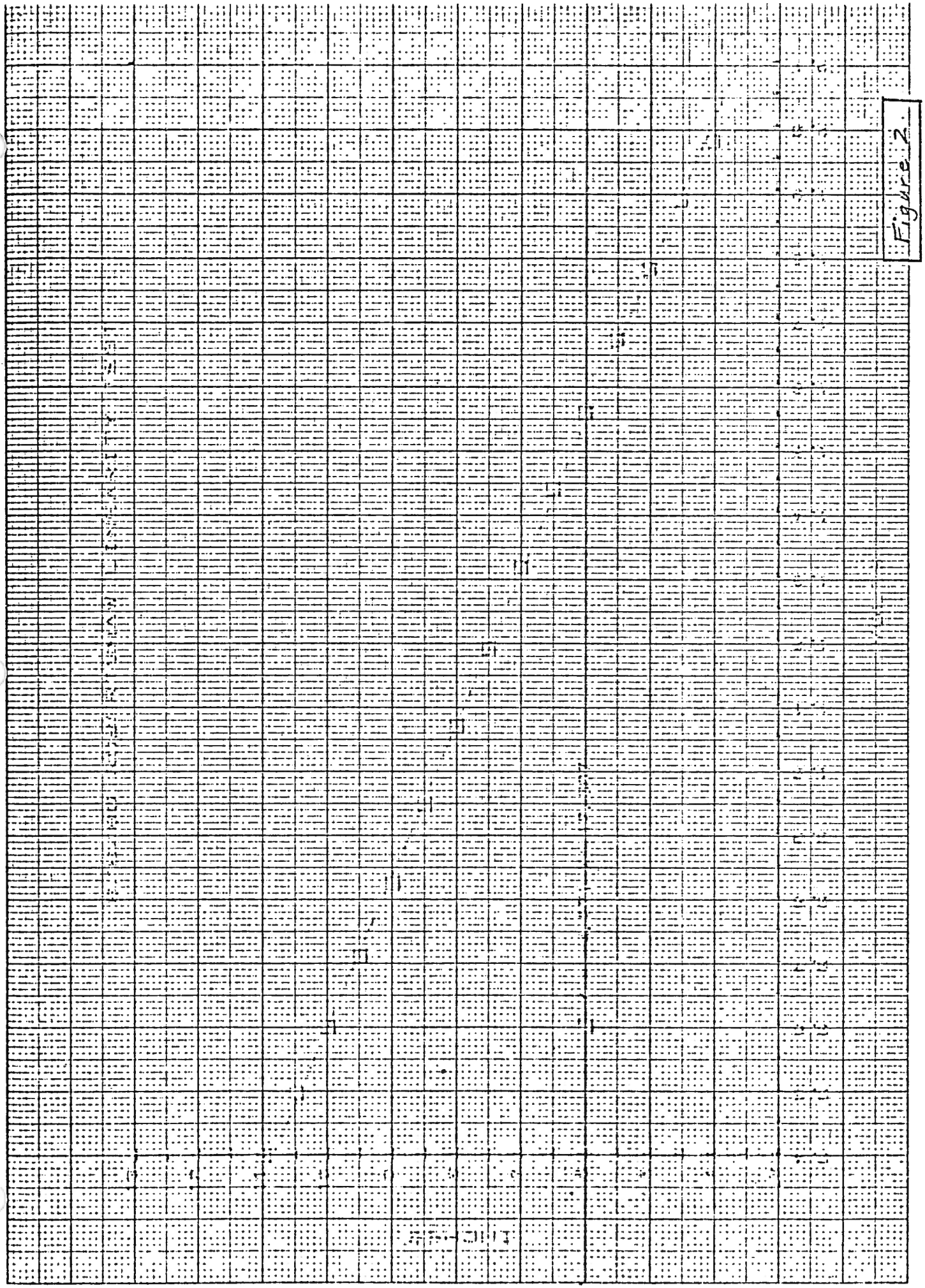
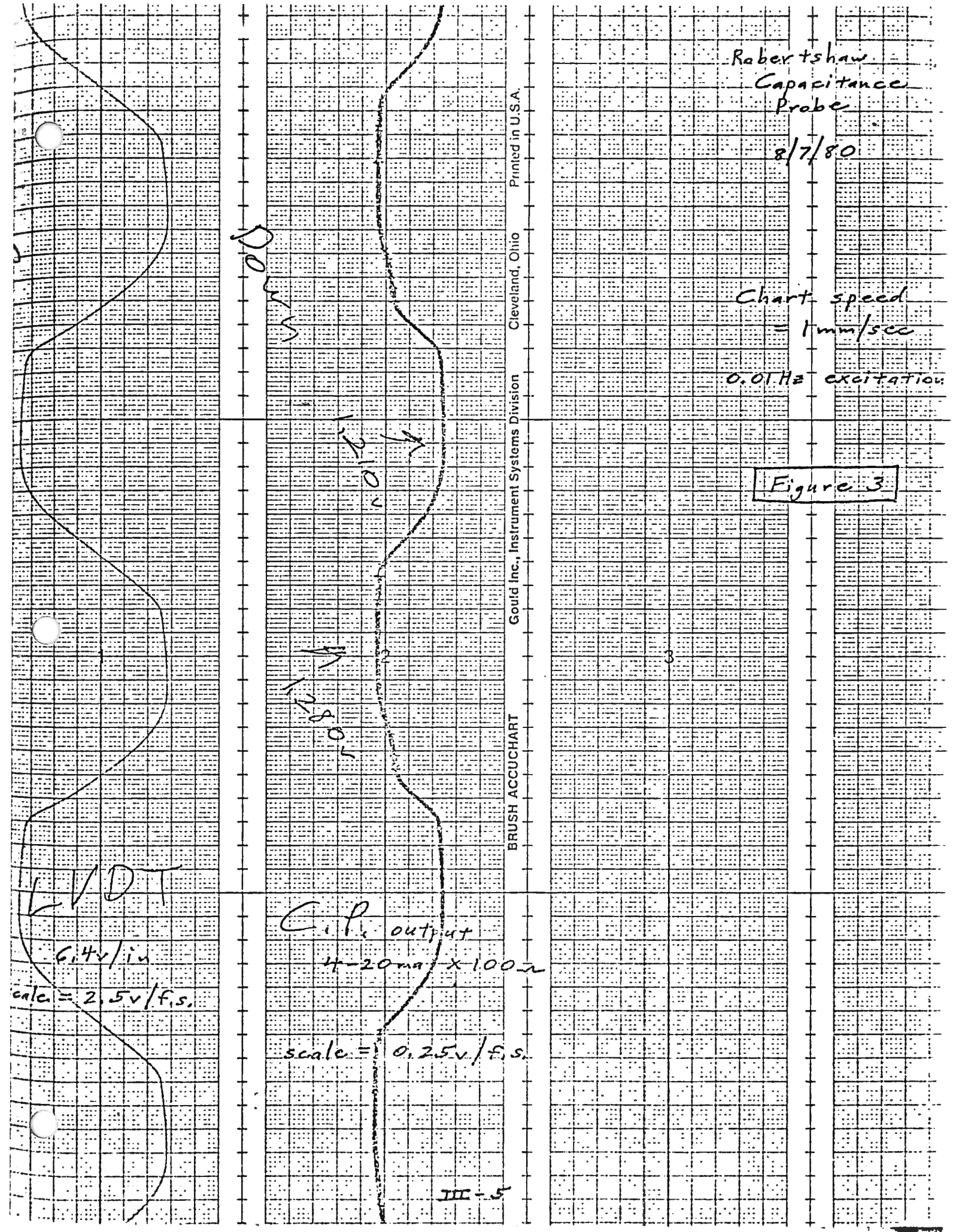
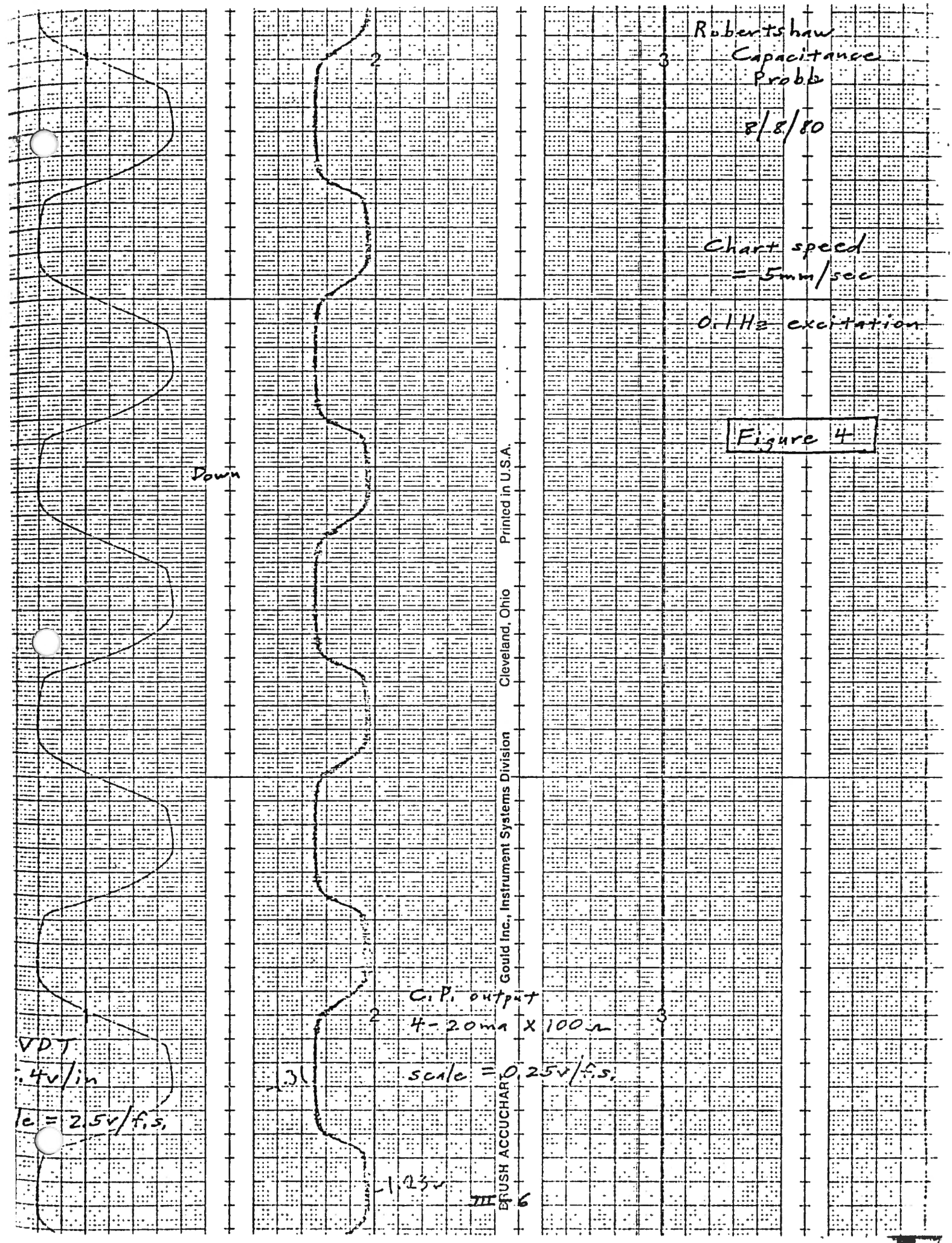


Figure 2


Robertshaw
Capacitance
Probe
8/7/80
Chart speed
= 1mm/sec
0.01 Hz excitation
Figure 3
LVDT
6.4v/in
scale = 2.5v/f.s.
C.P. output
4-20ma x 100Ω
scale = 0.25v/f.s.
Gould Inc., Instrument Systems Division
Cleveland, Ohio
Printed in U.S.A.
BRUSH ACCUCHART


Robertshaw
Capacitance
Probe
8/8/80
Chart speed
= 5mm/sec
0.1Hz excitation
Figure 4
Down
C.P. output
4-20ma x 100Ω
scale = 0.25v/f.s.
1.25v
VDT
.4v/in
le = 2.5v/f.s.
Gould Inc., Instrument Systems Division Cleveland, Ohio Printed in U.S.A.
BRUSH ACCUCHART

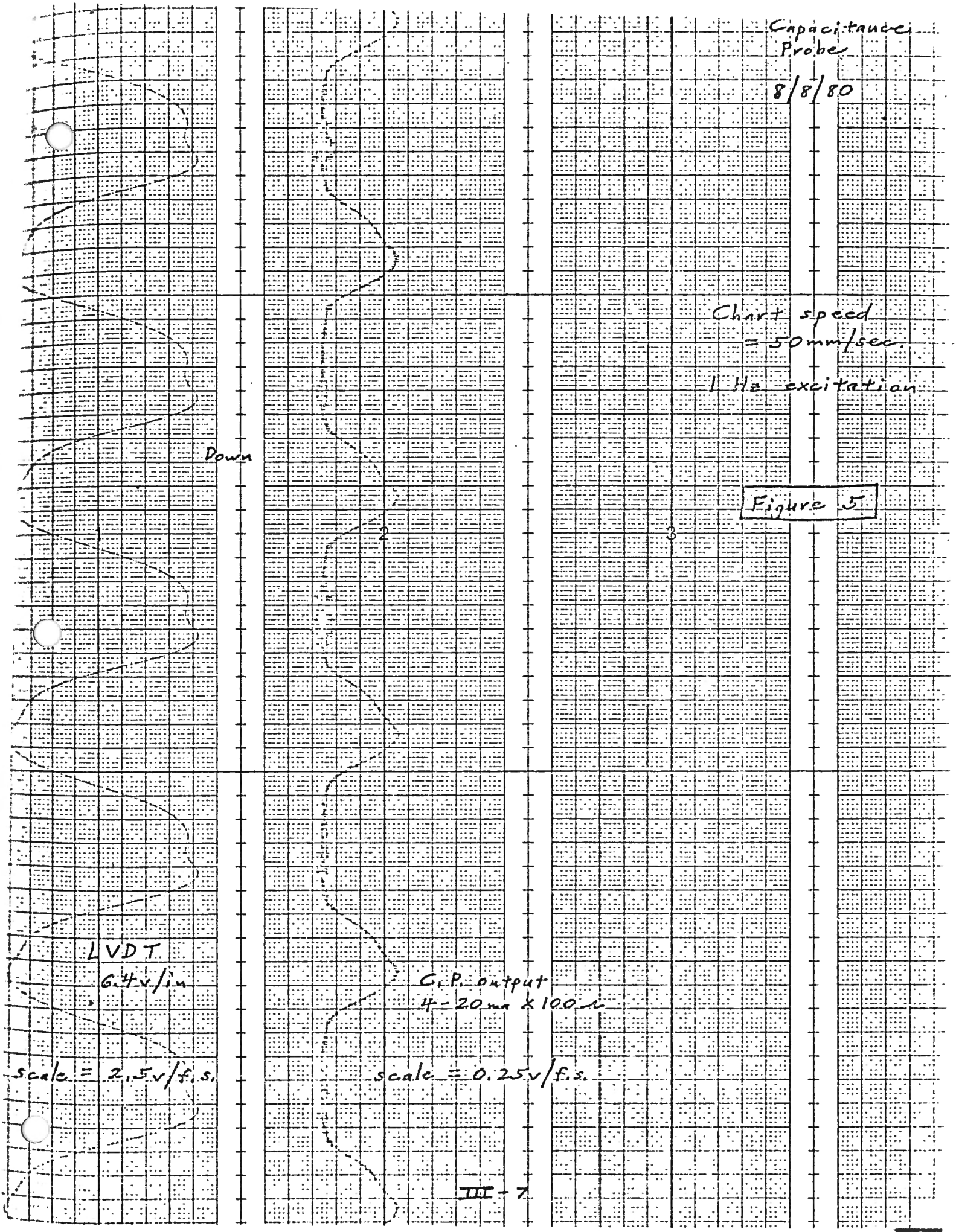

Capacitance Probe
8/8/80
Chart speed = 50mm/sec.
1 Hz excitation
Down
1
2
3
LVDT
6.4v/in
scale = 2.5v/f.s.
C.P. output
4-20ma x 100Ω
scale = 0.25v/f.s.

Figure 5

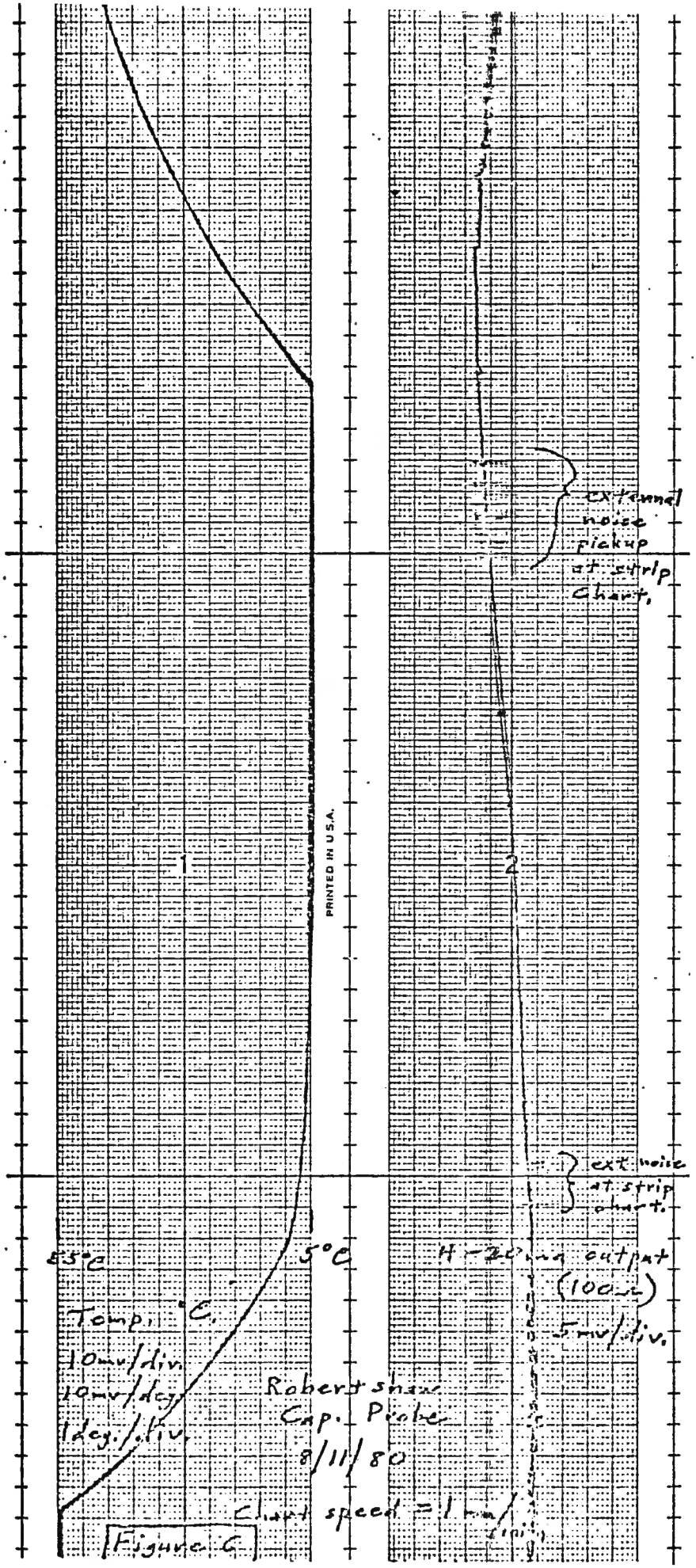

extenuel noise pickup at strip chart.
ext noise at strip chart.
1
2
PRINTED IN U.S.A.
35°C
5°C
Temp. °C.
10mv/div
10mv/deg
1deg./div
Robertshaw Cap. Probe
8/11/80
Chart speed = 1 mm/min
output
(100 ~)
5mv/div.

Figure 6

Figure 6 (Cont.)

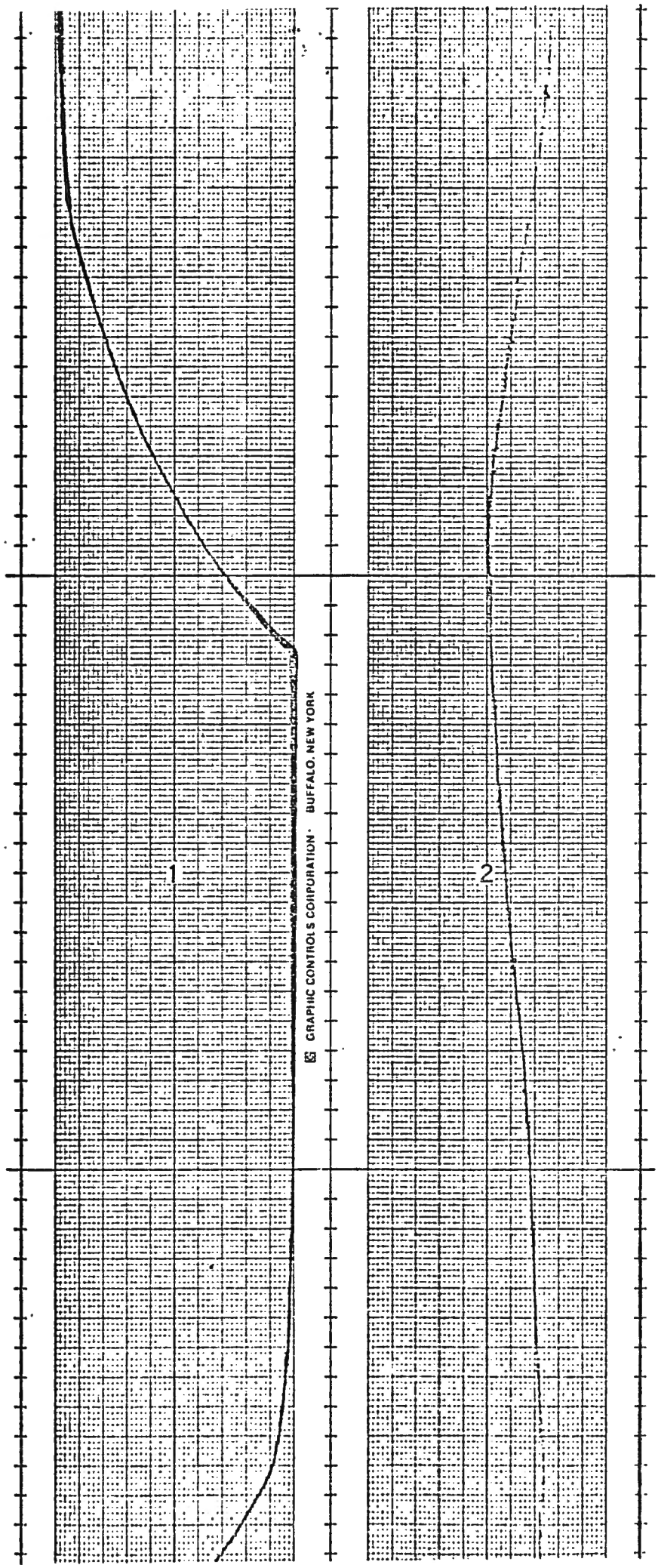
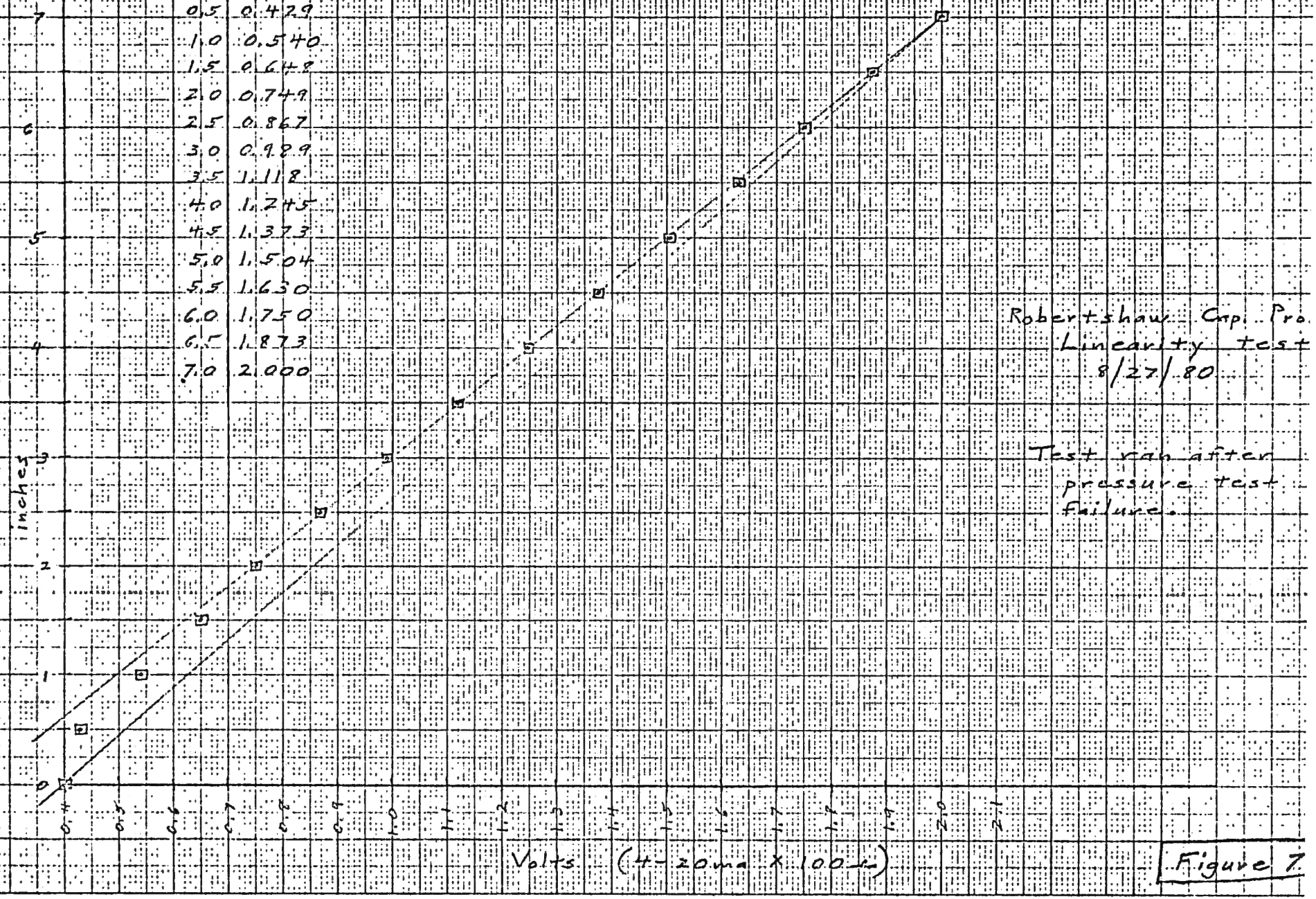



Figure 6 (Cont.)

| inch | Output (v) |
|---|---|
| 0" | 0.398 |
| 0.5 | 0.429 |
| 1.0 | 0.540 |
| 1.5 | 0.648 |
| 2.0 | 0.749 |
| 2.5 | 0.867 |
| 3.0 | 0.989 |
| 3.5 | 1.118 |
| 4.0 | 1.245 |
| 4.5 | 1.373 |
| 5.0 | 1.504 |
| 5.5 | 1.630 |
| 6.0 | 1.750 |
| 6.5 | 1.873 |
| 7.0 | 2.000 |




Robertshaw Corp. Pro.
Linearity test
8/27/80

Test ran after pressure test failure.

Figure 7

## Section IV: Drexelbrook Engineering Model 408-6200

On August 4, 1980, we received the Drexelbrook Engineering Model 408-6200 Water Level Transmitter for evaluation and possible applications of measuring water waves and level changes under pressure. The transmitter is of the capacitance change variety where the 12.7-mm (1/2-inch) rigid rod with Teflon coating goes into the water and the level is determined by the capacitance change as the water moves up and down the outside of the Teflon. The electronic unit is mounted separate from the probe, has a 4-20 mA current-loop output, is powered externally, and has independent span and zero adjustments. The zero adjustment has a coarse range switch selector and a fine range 22-turn potentiometer, and the span adjustment has a coarse range switch selector and a fine range 3/4-turn knob potentiometer.

The setup and calibration were very easy, and the associated manual was complete and thorough. The unit was placed in the environmental chamber for stability testing under temperature changes from 55°C to 5°C to 55°C. A 25-volt power supply located external to the chamber was used, and the current-loop measurements were voltages across 100-ohm resistors. The temperature was cycled from 5°C to 55°C and back on a 3-hour cycle for each change with 1 hour for transition and 2 hours at the limit. The results of several cycles are shown in Figure 1. The output changed about 20 percent with the 50°C change, indicating an unreasonable temperature coefficient. The output was not very noisy except for one cycle where an 8 percent peak noise existed for 1-1/2 hours at 5°C. This could not be explained and only occurred once. There were some discontinuities and jumps in the output as the electronic components changed temperature independently, but none were larger than 0.3 percent of span.

After the environmental chamber tests, the probe was moved to the Hydraulics Laboratory for linearity, wave, and dynamic tests. The linearity tests of Figures 2 and 3 show a definite second order relationship, but the correlation to a straight line is also good. The linearity tests were made in static water by moving the probe up and down on a calibrated arm. The wave tests showed reasonable sensitivity and response as shown in Figure 4. The 12.7-mm (1/2-inch) o.d. rigid rod with Teflon coating was too large for wave measurements due to the bad distortion of the wave front and large trough generated behind the probe. The dynamic test setup used a static water surface and moved the probe up and down a small amount using a torque motor with variable frequency electrical drive. The probe was suspended from a moment arm on the torque motor by a cable and the mechanical motion was measured using a linear LVDT. Figures 5, 6, and 7 show the output of the LVDT and the probe at 0.01 Hz, 0.1 Hz, and 1 Hz excitation, respectively. At the 0.01 Hz frequency, the probe tracked the mechanical motion exactly. At the 0.1 Hz frequency, the probe showed some meniscus effects. The down peak was flattened and rippled, and the up peak was actually two peaks as the water ran off the outside of the probe and the meniscus reformed. At the 1 Hz excitation

of Figure 7, the probe tracked the up peak but the down peak was distorted. This was due to some mechanical distortion of the support cable and lateral movement of the probe in the water. The dynamic tests did show that the probe is repeatable and able to accurately track the water surface.

Next, the probe was placed in a large triaxial shear located in the Geotechnical Branch Soils Testing Laboratory for pressure tests. The probe was calibrated at room pressure and the water level was set at a known value. The chamber was pressurized to 1.38 megapascals (200 psi) for several days with no significant drift during pressurizing or under sustained pressure. The pressure was then raised to 3.45 megapascals (500 psi) with no significant change after several days of testing. Thus, the long term stability and accuracy of the probe is quite good.

The probe had many good features and favorable test results but will not meet our needs for wave measurements or small triaxial shear tests. This is due to the manufacturer not making a rigid rod smaller than 9.5-mm (3/8-inch) o.d., whereas the wave measurements cannot tolerate a rod larger than 3.2-mm (1/8-inch) o.d. and the small triaxial shear needs a rod smaller than 6.4-mm (1/4-inch) o.d. The probe does work very well in the large triaxial shears. Due to the special features and characteristics, this unit has potential for future applications in other laboratory areas.

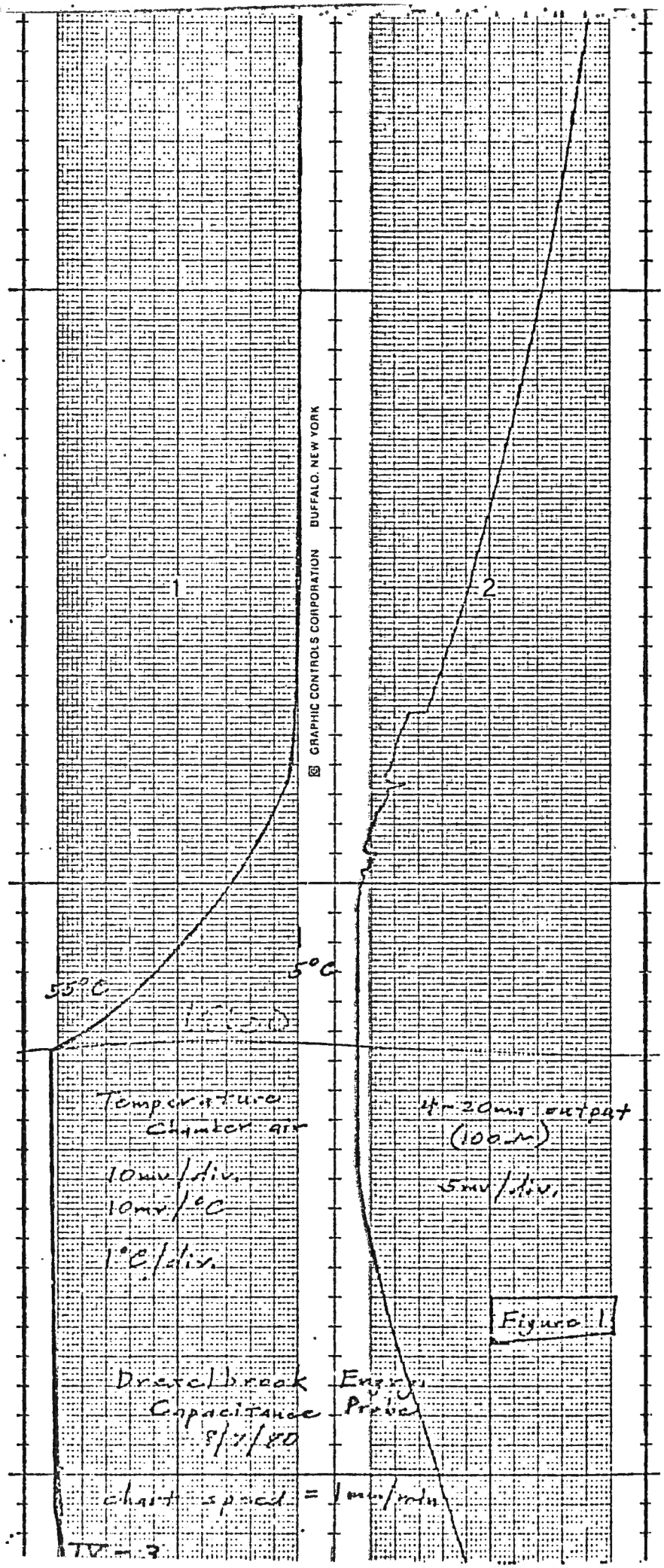

GRAPHIC CONTROLS CORPORATION BUFFALO, NEW YORK
1
2
55°C
5°C
Temperature
Chamber air
10mv/div.
10mv/°C
1°C/div.
4-20ma output
(100Ω)
5mv/div.
Breakbreak
Capacitance
8/7/80
Engine
Prior
chart speed = 1mm/min
TV-7

Figure 1

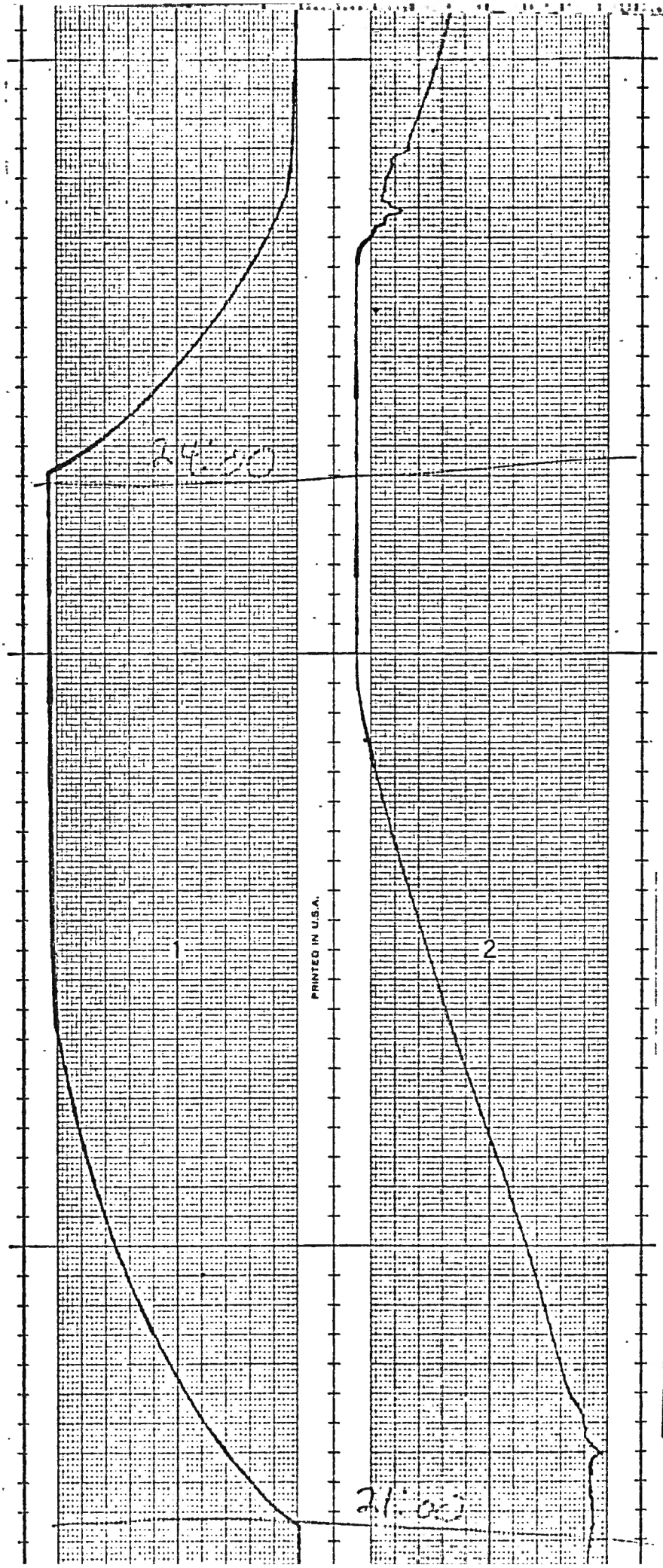



Figure 1
(Cont.)

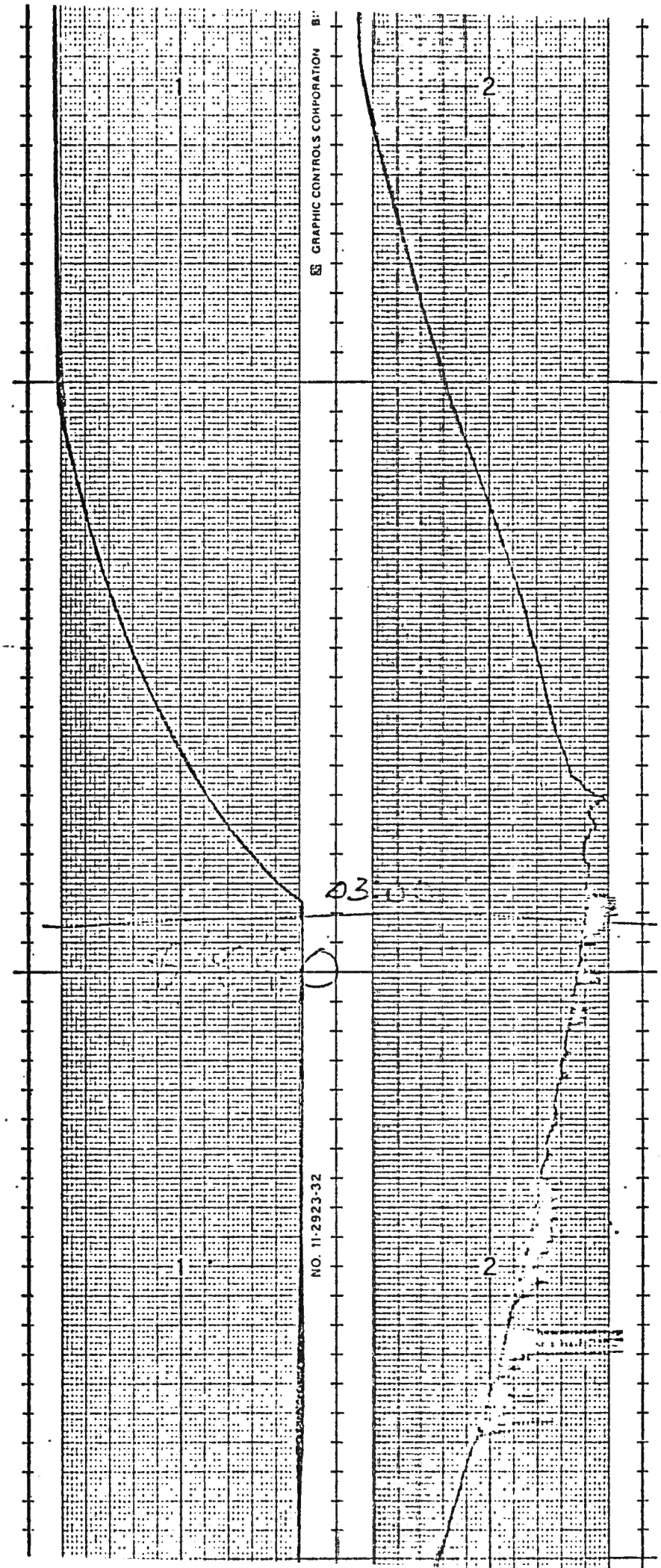



Figure 1 (cont.)

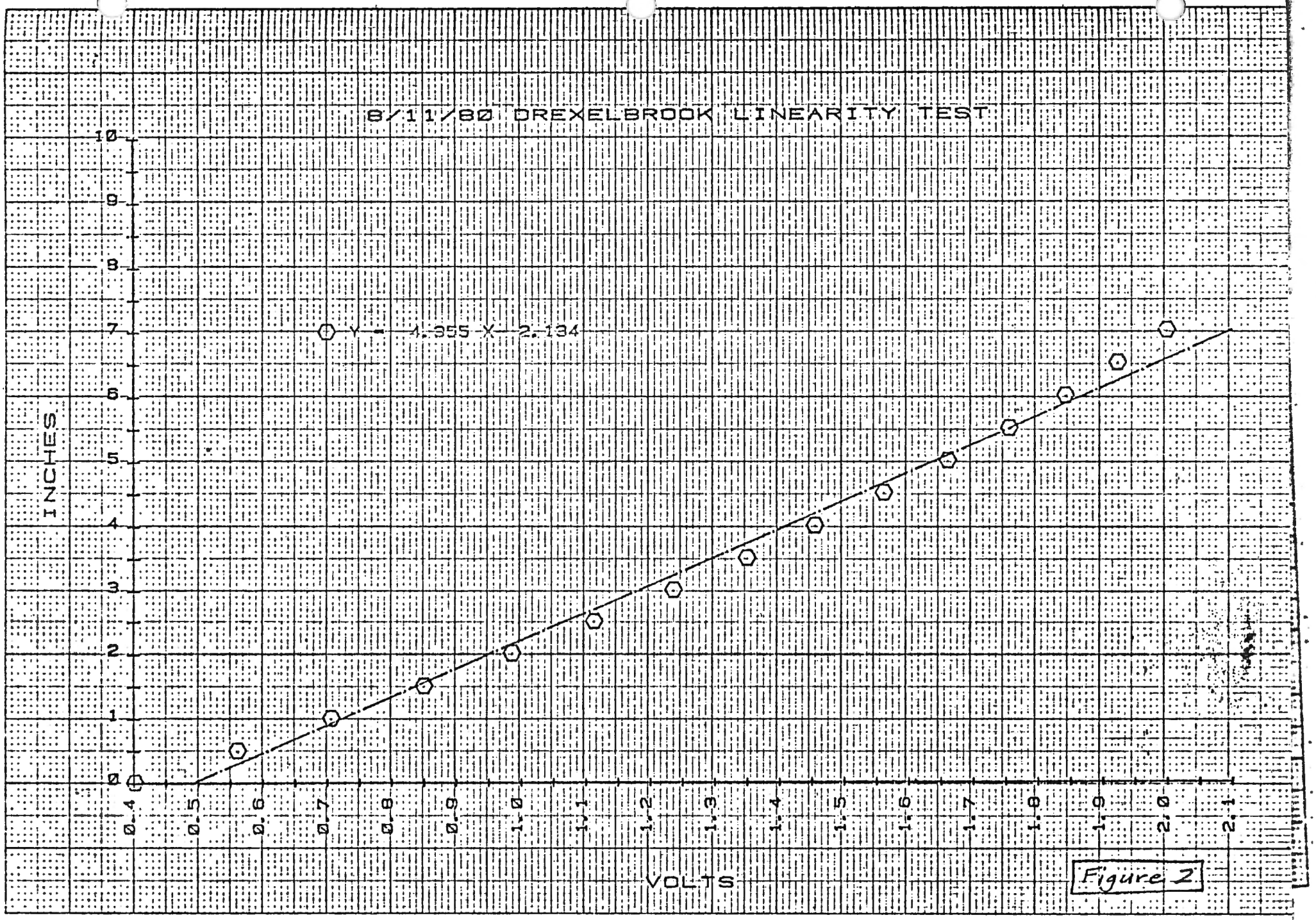

8/11/80 DREXELBROOK LINEARITY TEST
Y = 4.355 X - 2.134
INCHES
VOLTS
0
1
2
3
4
5
6
7
8
9
10
0.4
0.5
0.6
0.7
0.8
0.9
1.0
1.1
1.2
1.3
1.4
1.5
1.6
1.7
1.8
1.9
2.0
2.1

Figure 2

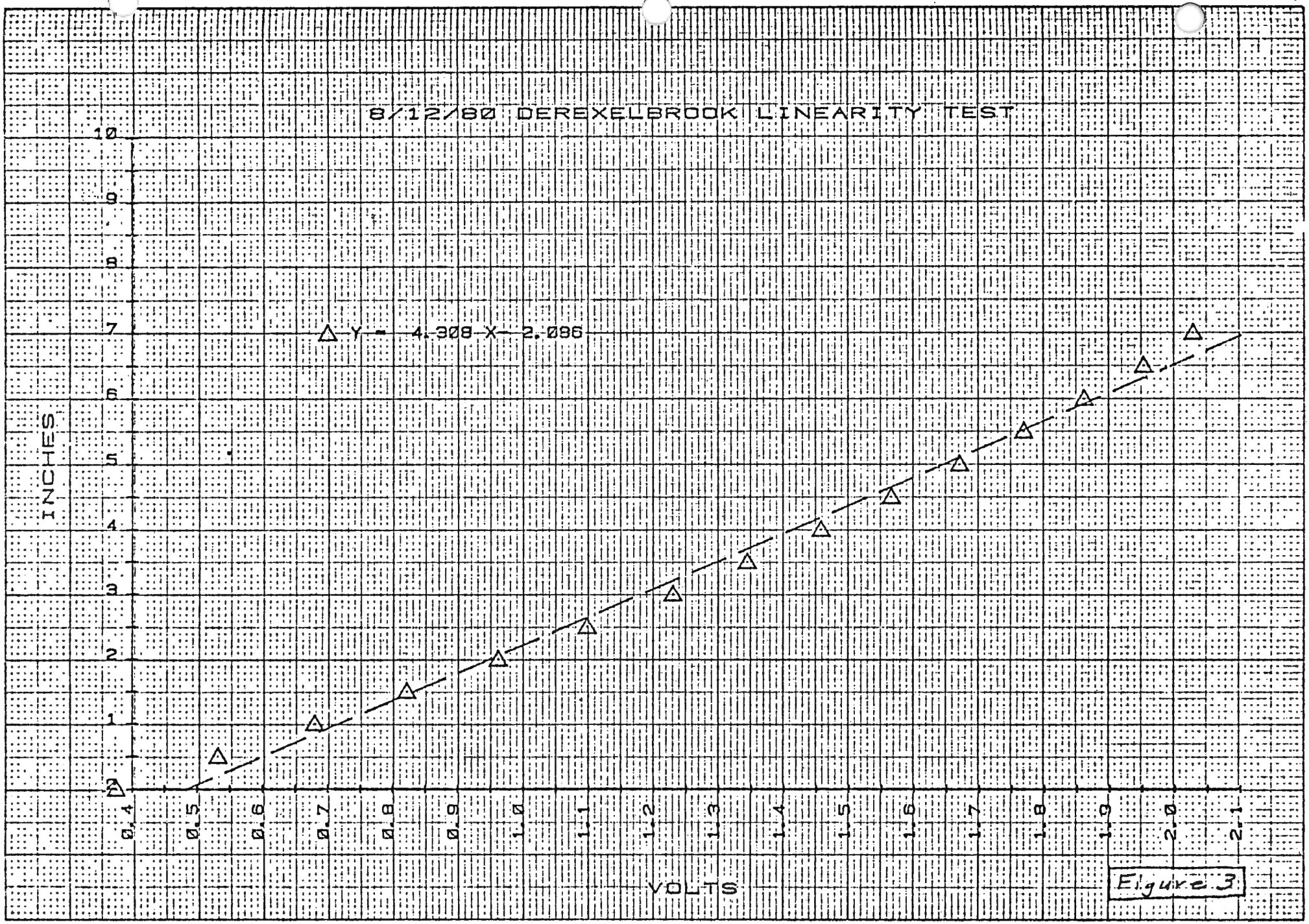
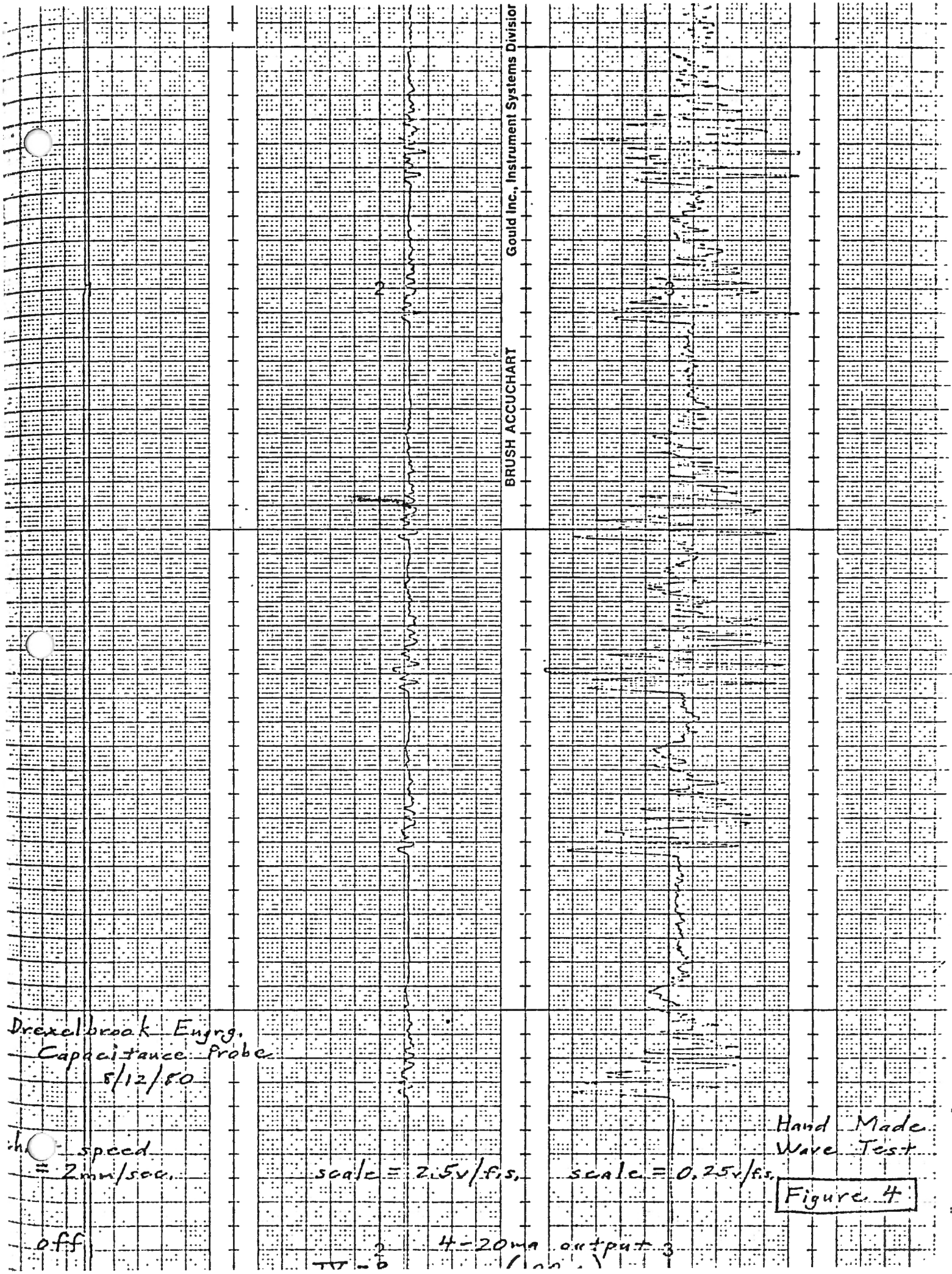
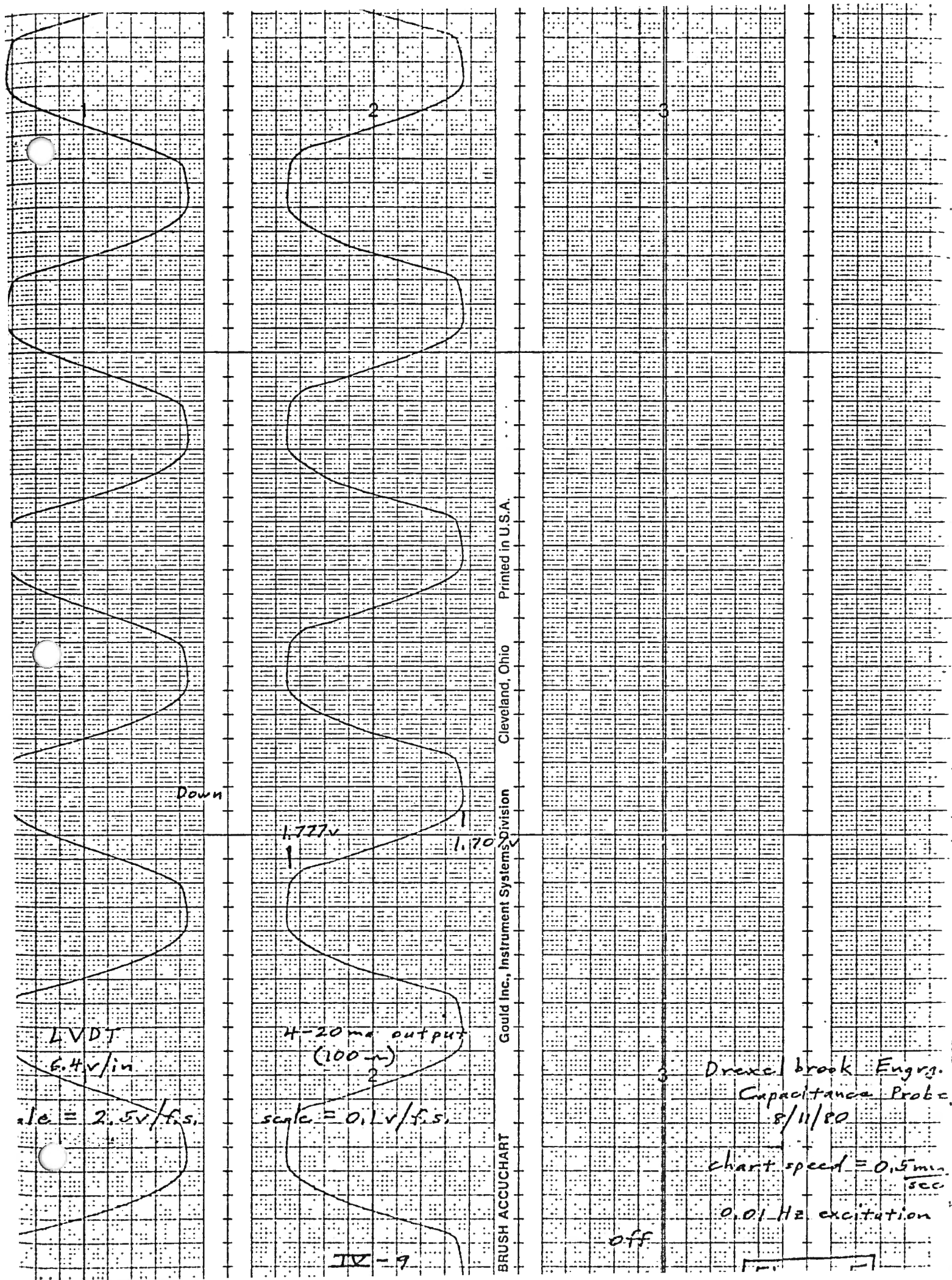
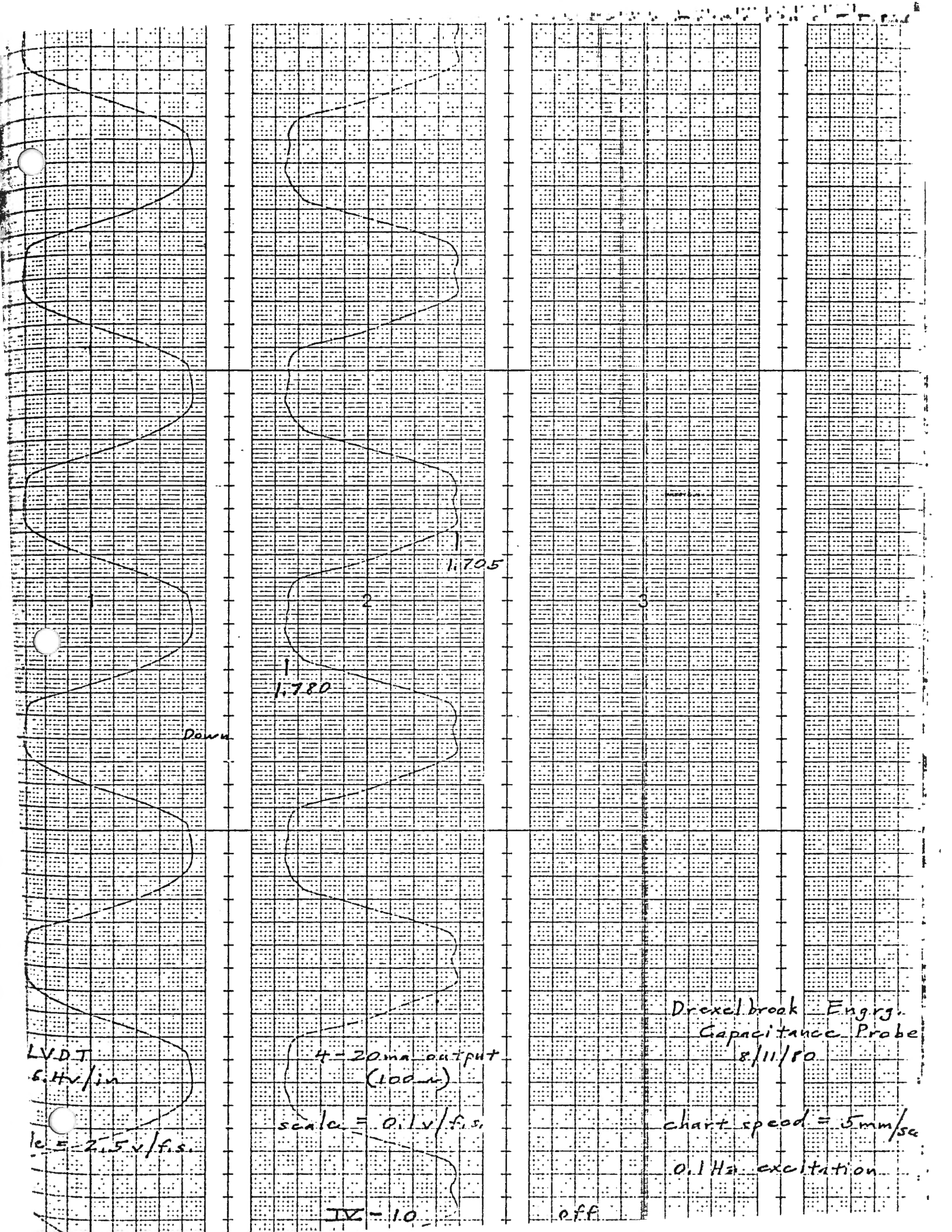
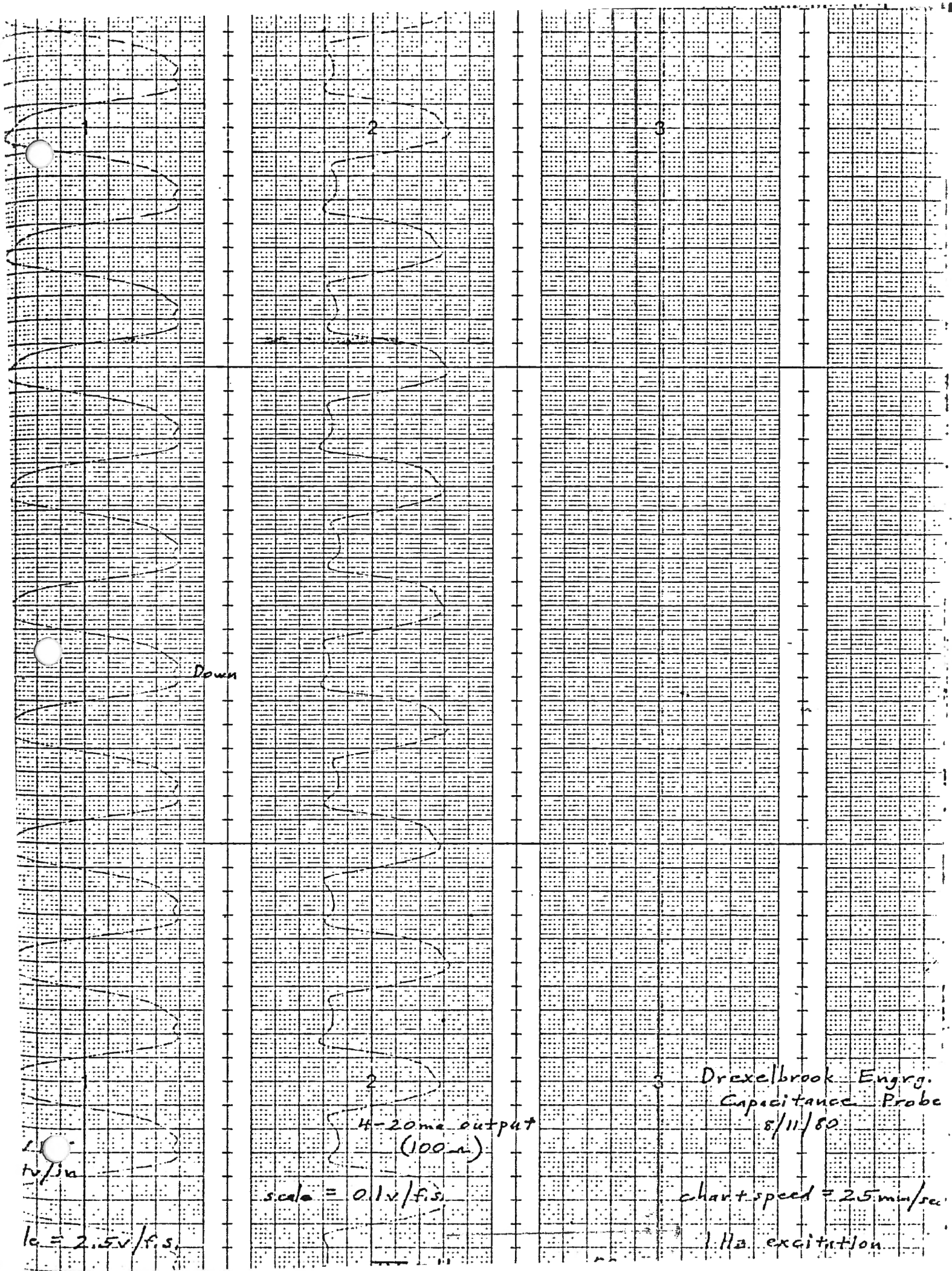

8/12/80 DEREXELBROOK LINEARITY TEST
Y = 4.308 X - 2.096
INCHES
10
9
8
7
6
5
4
3
2
1
0
0.4
0.5
0.6
0.7
0.8
0.9
1.0
1.1
1.2
1.3
1.4
1.5
1.6
1.7
1.8
1.9
2.0
2.1
VOLTS

Figure 3


Gould Inc., Instrument Systems Division
BRUSH ACCUCHART
2
3
Drexelbrook Engrg.
Capacitance Probe
5/12/80
speed
= 2mm/sec.
scale = 2.5v/f.s.
scale = 0.25v/f.s.
Hand Made
Wave Test
Figure 4
off
4-20ma output


1
2
3
Down
1.727v
1.70v
LVDT
6.4v/in
4-20 ma output
(100 Ω)
scale = 2.5v/f.s.
scale = 0.1v/f.s.
Drexel brook Engrg.
Capacitance Probe
8/11/80
chart speed = 0.5 mm/sec
0.01 Hz excitation
off
IV-9
Printed in U.S.A.
Cleveland, Ohio
Division
Gould Inc., Instrument Systems
BRUSH ACCUCHART


1.705
2
3
1
1.780
Down
LVDT
6.4v/in
4-20ma output
(100Ω)
scale = 0.1v/f.s.
le = 2.5v/f.s.
Drexelbrook Engrg.
Capacitance Probe
8/11/80
chart speed = 5mm/sec
0.1 Hz excitation
IV-10
off


1
2
3
Down
1
2
3
Drexelbrook Engrg.
Capacitance Probe
8/11/80
4-20ma output
(100Ω)
tv/in
scale = 0.1v/f.s.
chart speed = 25mm/sec
le = 2.5v/f.s.
1 Hz excitation

## Section V: Delavan Electronics Model CS54

On August 25, 1980, we received the Delavan Electronics Model CS54 Continuous Capacitance Controller. This is a high-sensitivity, high-speed (50 msec time constant), capacitance measuring water level probe. It contained a 0.254-m (10-inch) long, 3.2-m (1/8-inch) o.d. rigid rod with Teflon sheath and had both a 0-10 Vdc output and 4-20 mA current loop output. The unit was self contained with 120 Vac input power. The adjustments were a 22-turn trimpot for zero set, a 22-turn trimpot for fine span set, a 3/4-turn pot for coarse span, a 3/4-turn pot for 4 mA set, and a 3/4-turn pot for gain set. The unit came calibrated from the factory for 0.254-m (10-inch) span, so we did not need to change any of the settings.

The first tests were the linearity, wave, and dynamic tests in the Hydraulics Laboratory. The linearity tests were conducted using a static water level and moving the probe up and down on a calibrated arm. The results shown in Figures 1 and 2 were very good, especially in Figure 1. Figure 2 was not as good due to the fact that some water leaked into the Teflon sheath overnight and was not detected until after the test. The sheath was dried and the small hole patched. The data of Figure 2 also appear to have a consistent reading error due to the operator. The corrected results are quite good. The wave test shown in Figure 3 was made while the large hydraulic model was being drained, and a steady source of small waves was present. The output showed good sensitivity and response to the waves with no noticeable discontinuities or irregularities. The dynamic tests were made using a static water level and moving the probe up and down. The movement was accomplished using a torque motor with a moment arm and variable frequency electrical input. The probe was supported by a cable from the moment arm, and the mechanical motion was measured using a linear LVDT. The output at a 0.01-Hz and 0.1-Hz frequency tracked the mechanical input quite well with very little meniscus effects or surface distortion as shown in Figure 4. At the 1-Hz frequency shown in Figure 5, the output was badly distorted due to lateral motion of the probe and mechanical oscillation of the support cable. Thus, the probe shows good linearity, sensitivity, and response to waves.

The environmental chamber tests consisted of cycling the ambient temperature from 5°C to 55°C to 5°C with 1 hour for transition and 2 hours at each extreme. Several 3-hour cycles are shown in Figure 6. The results show that both the current loop and voltage outputs were stable with temperature. They drifted by about 5 percent from one temperature extreme to the other and contained very little noise as temperatures changed. Both showed repeatable results over many temperature cycles. The temperature tests were very favorable.

Since the particular unit we received could not be pressurized, we were not able to test it in the Geotechnical Branch Soil Testing Laboratory. The probe will physically fit in any of the triaxial shears and from the other tests appears to meet the needs for long term, pressurized, water level measurements.

The Model CS54 capacitance water level probe was very stable and linear. The 3.2-mm (1/8-inch) o.d. rigid rod did not disturb the surface waves appreciably and measured them quite well. Thus, the unit will work for the surface wave measurement application.

The manufacturer notes that they can make a stainless steel rigid rod as small as 1.3 to 1.5 mm (0.005 to 0.006 inches) plus the Teflon sheath. They do have probes that can handle 3.45 megapascals (500 psi) and 6.90 megapascals (1,000 psi) with the possibility of 13.4 megapascals (2,000 psi) if needed.

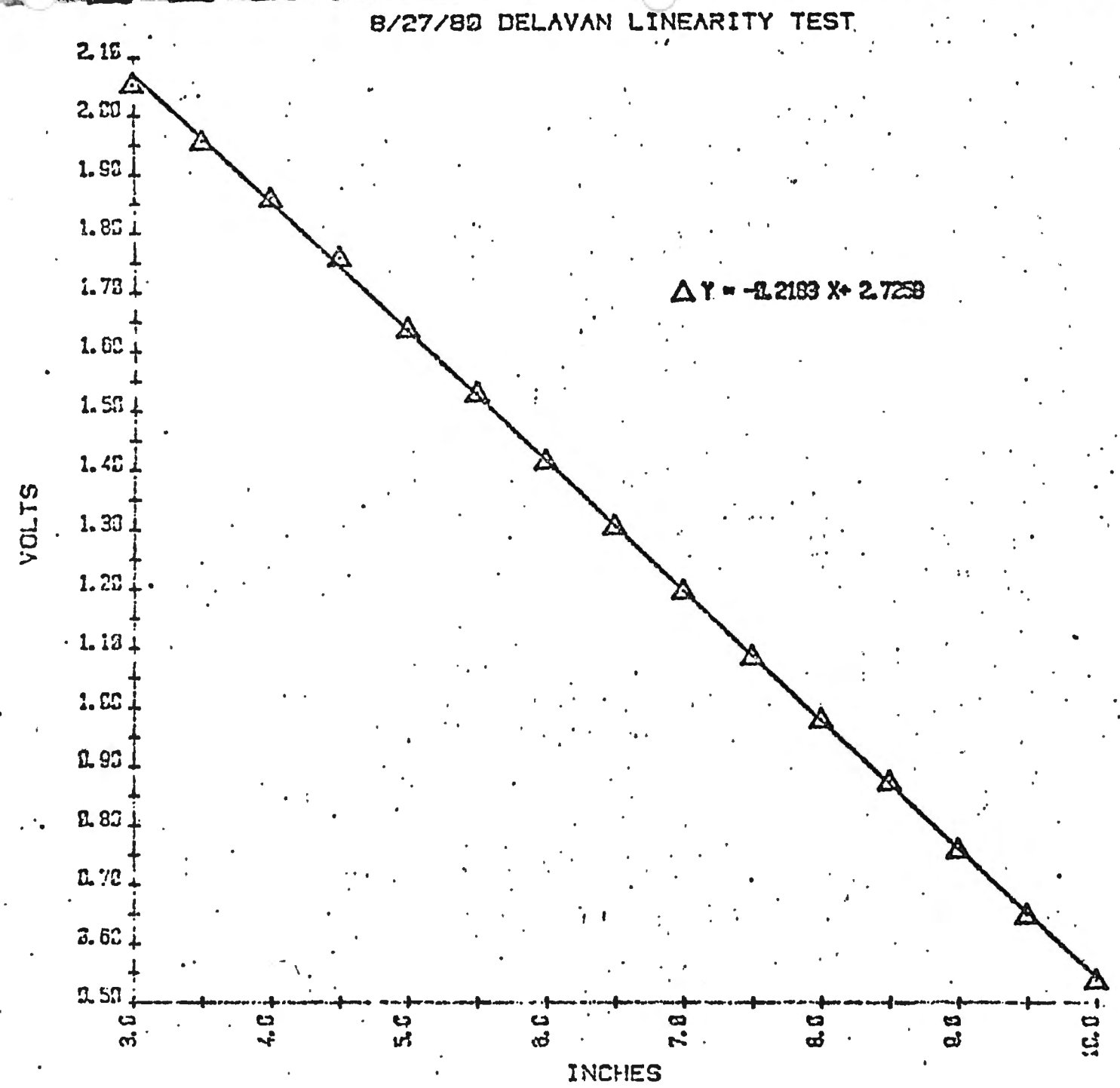

8/27/80 DELAVAN LINEARITY TEST
VOLTS
INCHES
Δ Y = -0.2183 X+ 2.7258
2.10
2.00
1.90
1.80
1.70
1.60
1.50
1.40
1.30
1.20
1.10
1.00
0.90
0.80
0.70
0.60
0.50
3.0
4.0
5.0
6.0
7.0
8.0
9.0
10.0

Figure 1

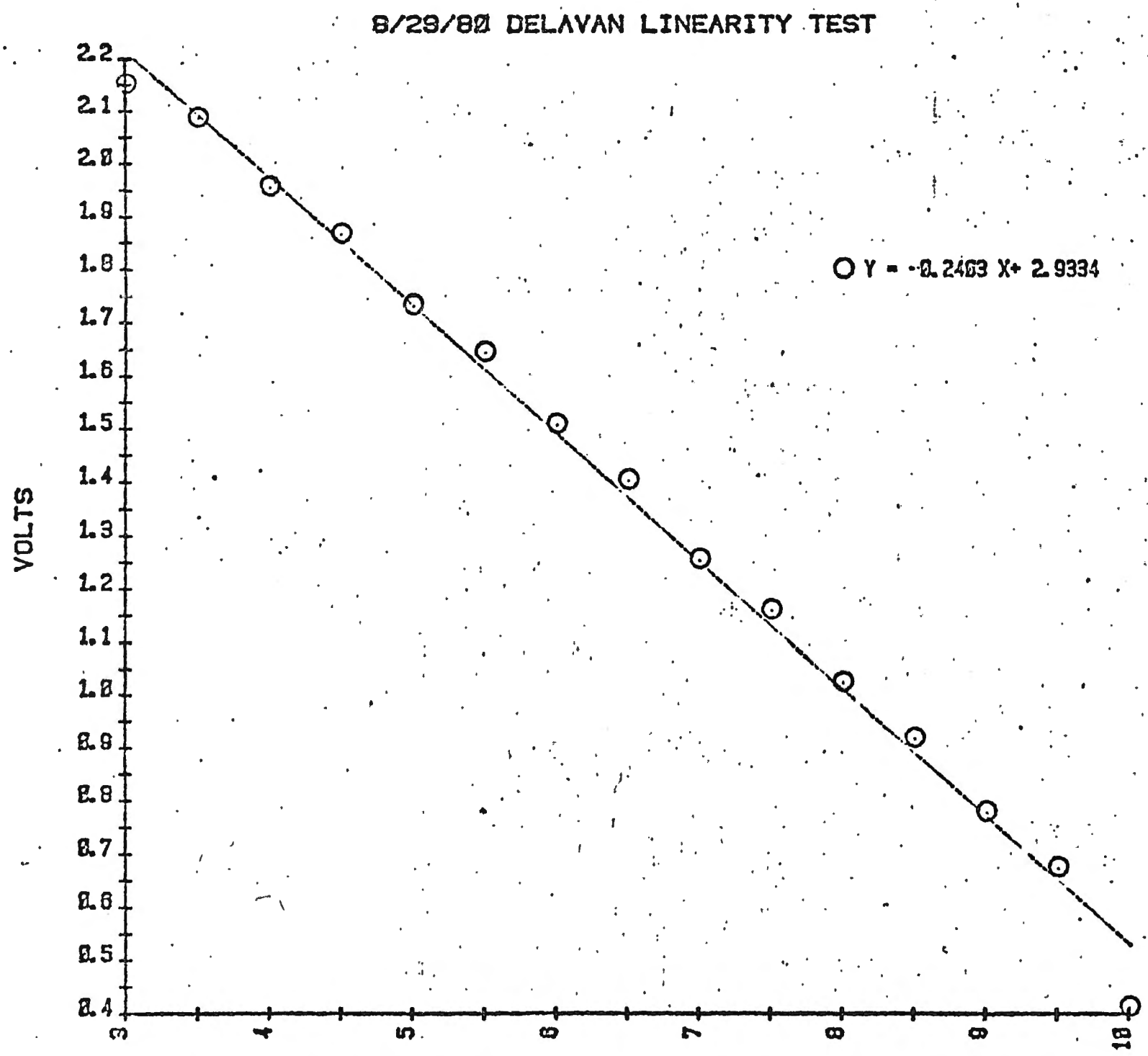

8/29/80 DELAVAN LINEARITY TEST
VOLTS
2.2
2.1
2.0
1.9
1.8
1.7
1.6
1.5
1.4
1.3
1.2
1.1
1.0
0.9
0.8
0.7
0.6
0.5
0.4
3
4
5
6
7
8
9
10
Y = -0.2403 X+ 2.9334

Figure 2

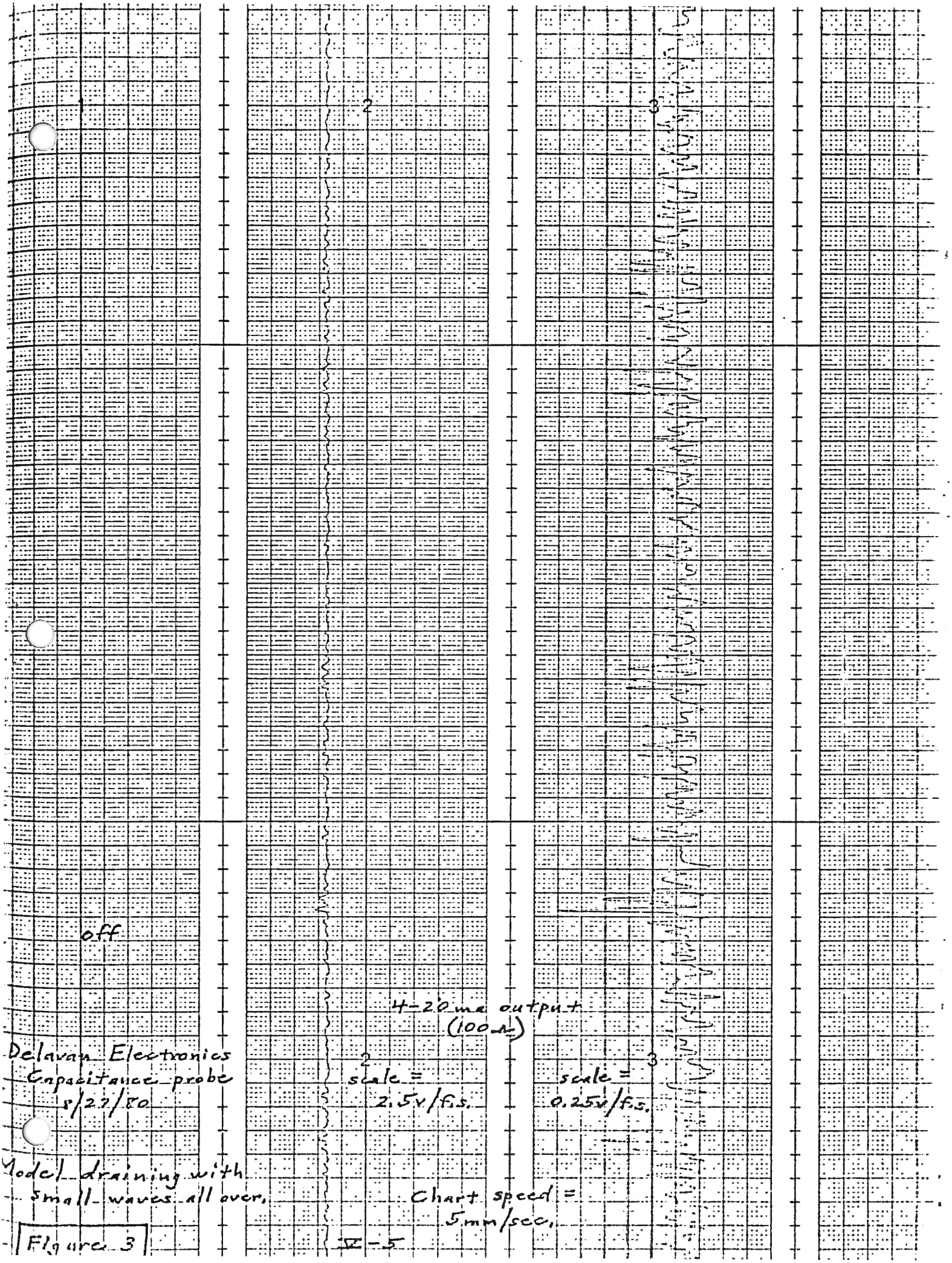

1
2
3
off
4-20 ma output
(100 Ω)
Delavan Electronics
Capacitance probe
8/27/80
2
scale =
2.5v/f.s.
3
scale =
0.25v/f.s.
Model draining with
small waves all over.
Chart speed =
5mm/sec.

Figure 3

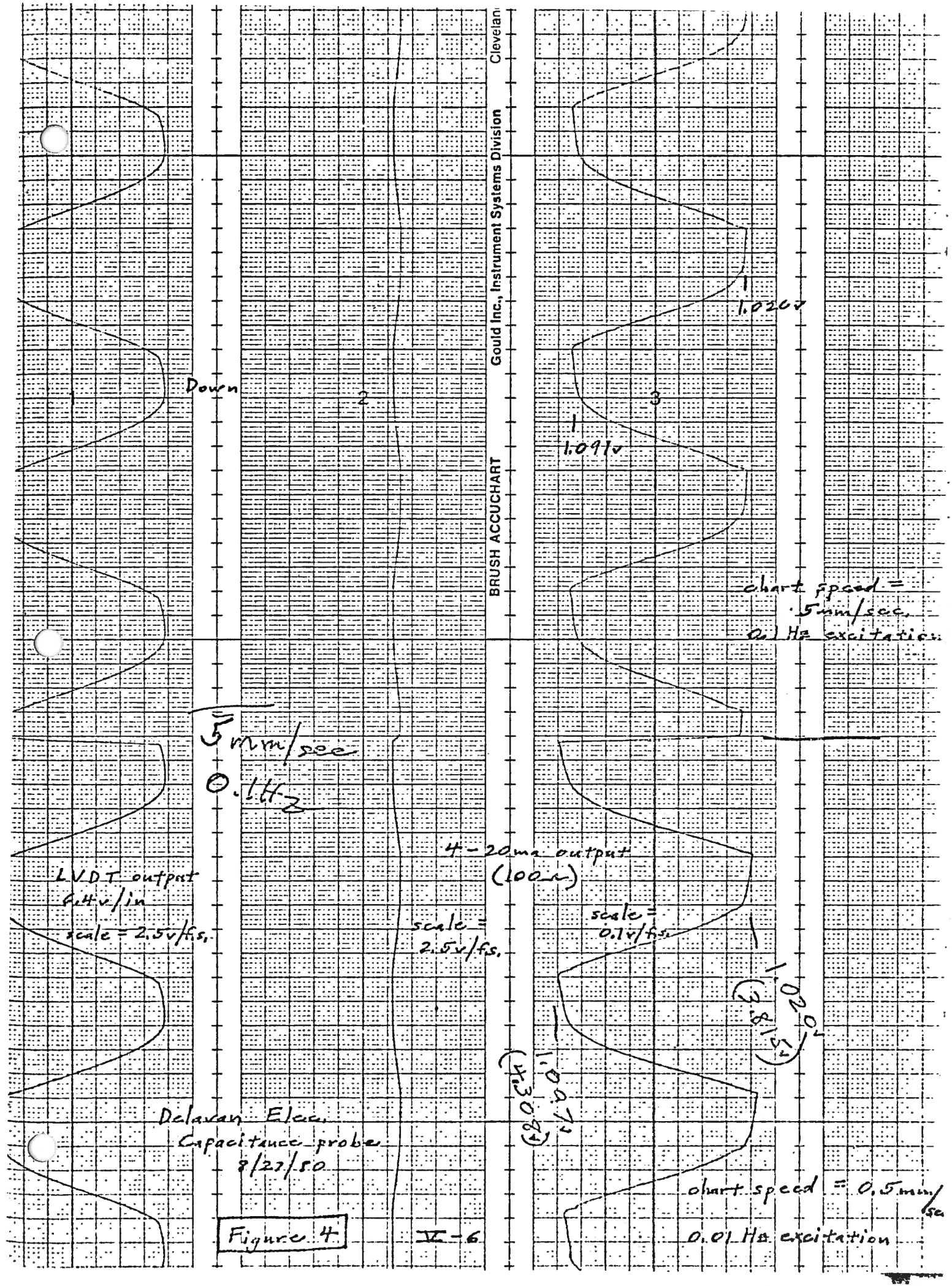
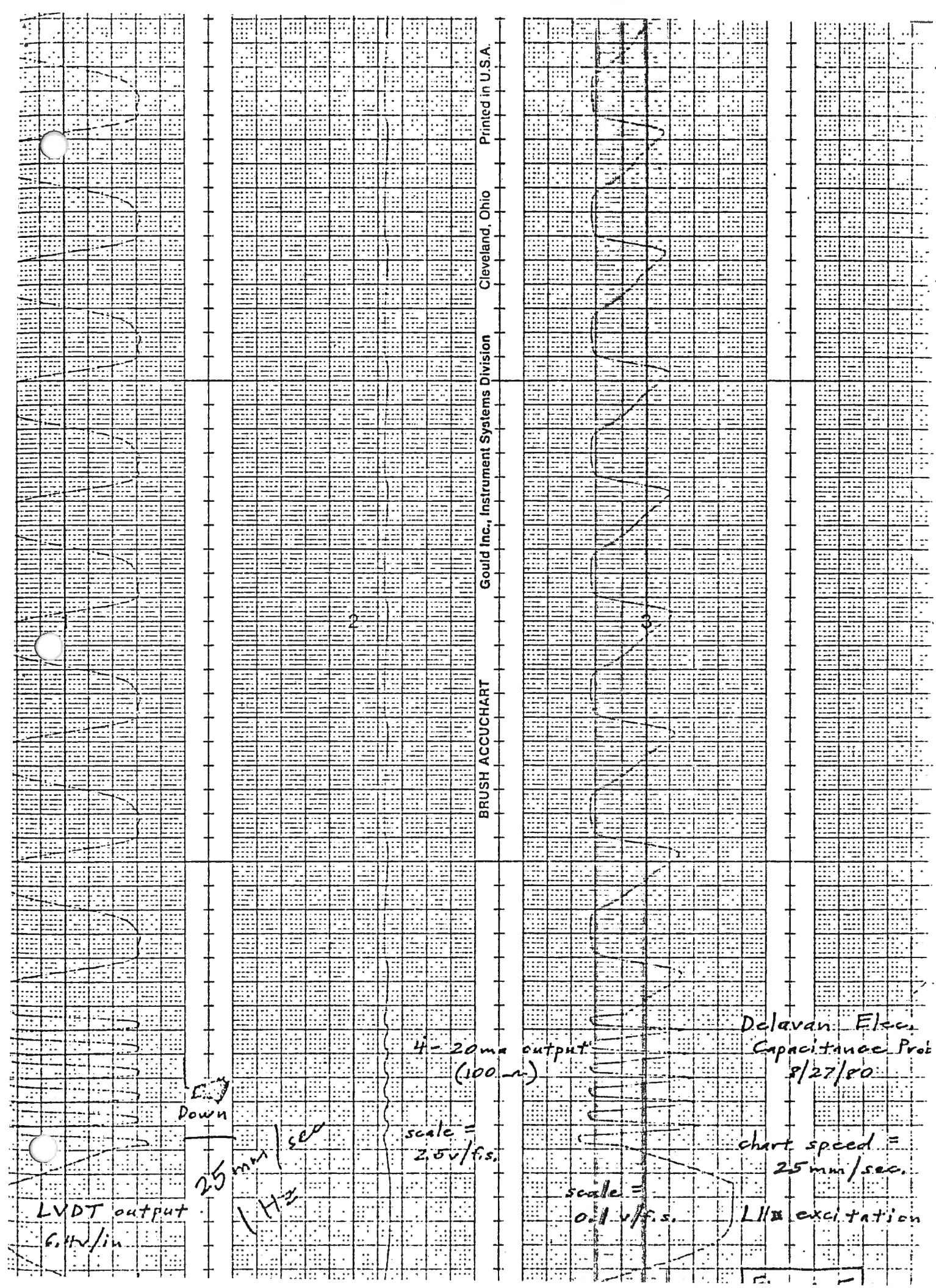
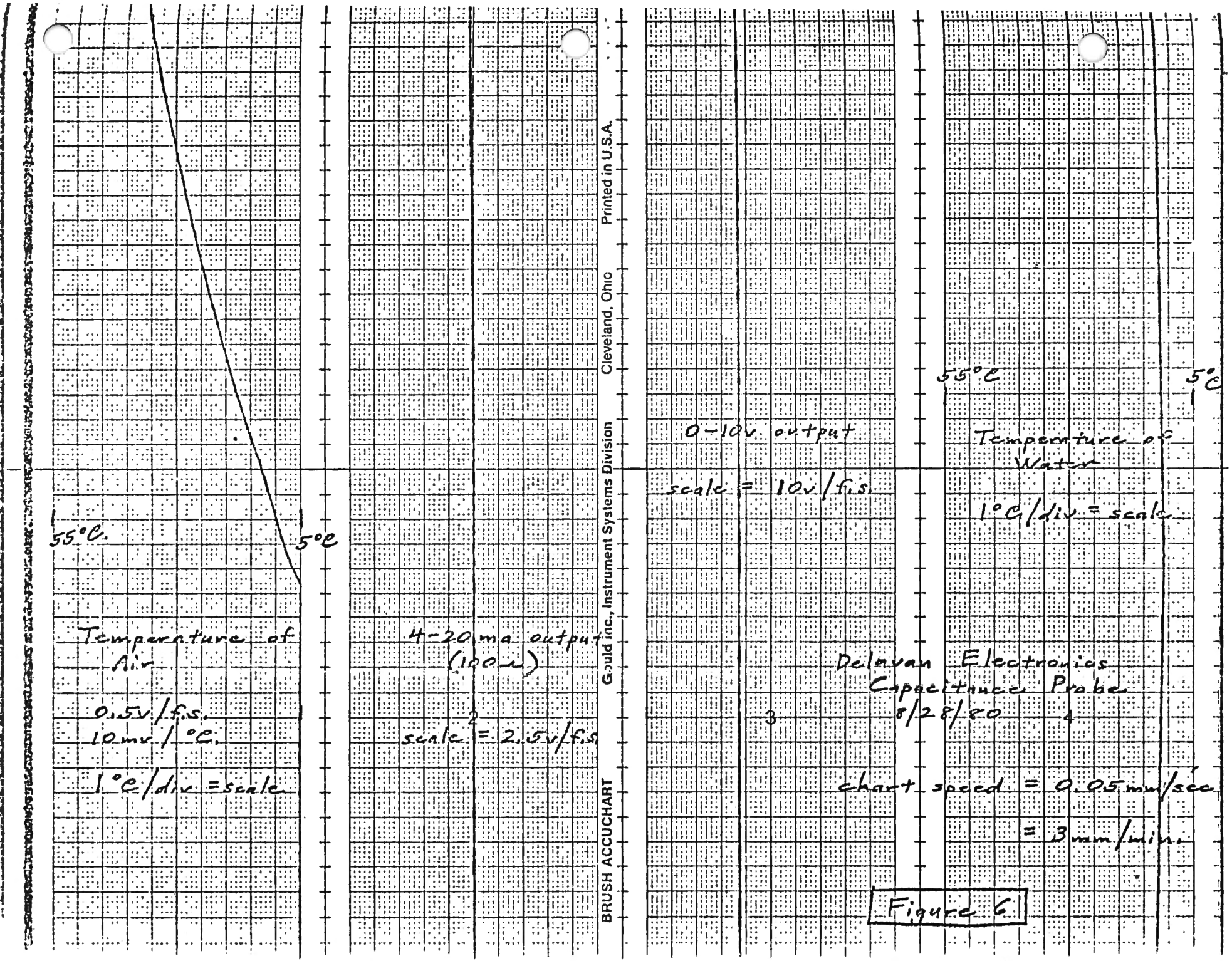

Cleveland
Gould Inc., Instrument Systems Division
BRUSH ACCUCHART
Down
1
2
3
1.020v
1.091v
chart speed = .5mm/sec.
0.1 Hz excitation
5 mm/sec
0.1 Hz
4-20ma output (100Ω)
LVDT output 6.4v/in
scale = 2.5v/f.s.
scale = 2.5v/f.s.
scale = 0.1v/f.s.
1.020v (3.81ma)
1.091v (4.30ma)
Delavan Elec.
Capacitance probe
8/27/80
chart speed = 0.5mm/sec
0.01 Hz excitation

Figure 4


Printed in U.S.A.
Cleveland, Ohio
Gould Inc., Instrument Systems Division
BRUSH ACCUCHART
2
3
Delavan Elec.
Capacitance Prob
8/27/80
4-20ma output
(100 Ω)
Down
25 mm
sec
scale =
2.5v/f.s.
chart speed =
25 mm/sec.
scale =
0.1 v/f.s.
LVDT output
6.4v/in
1 kHz excitation


55°C.
5°C
Temperature of Air
0.5v/f.s.
10mv/°C.
1°C/div = scale
4-20 ma output (100Ω)
scale = 2.5v/f.s.
0-10v. output
scale = 10v/f.s.
55°C
5°C
Temperature of Water
1°C/div = scale
Delavan Electronics
Capacitance Probe
8/28/80
chart speed = 0.05 mm/sec
= 3 mm/min.
Figure 6
BRUSH ACCUCHART
Gould Inc., Instrument Systems Division
Cleveland, Ohio
Printed in U.S.A.

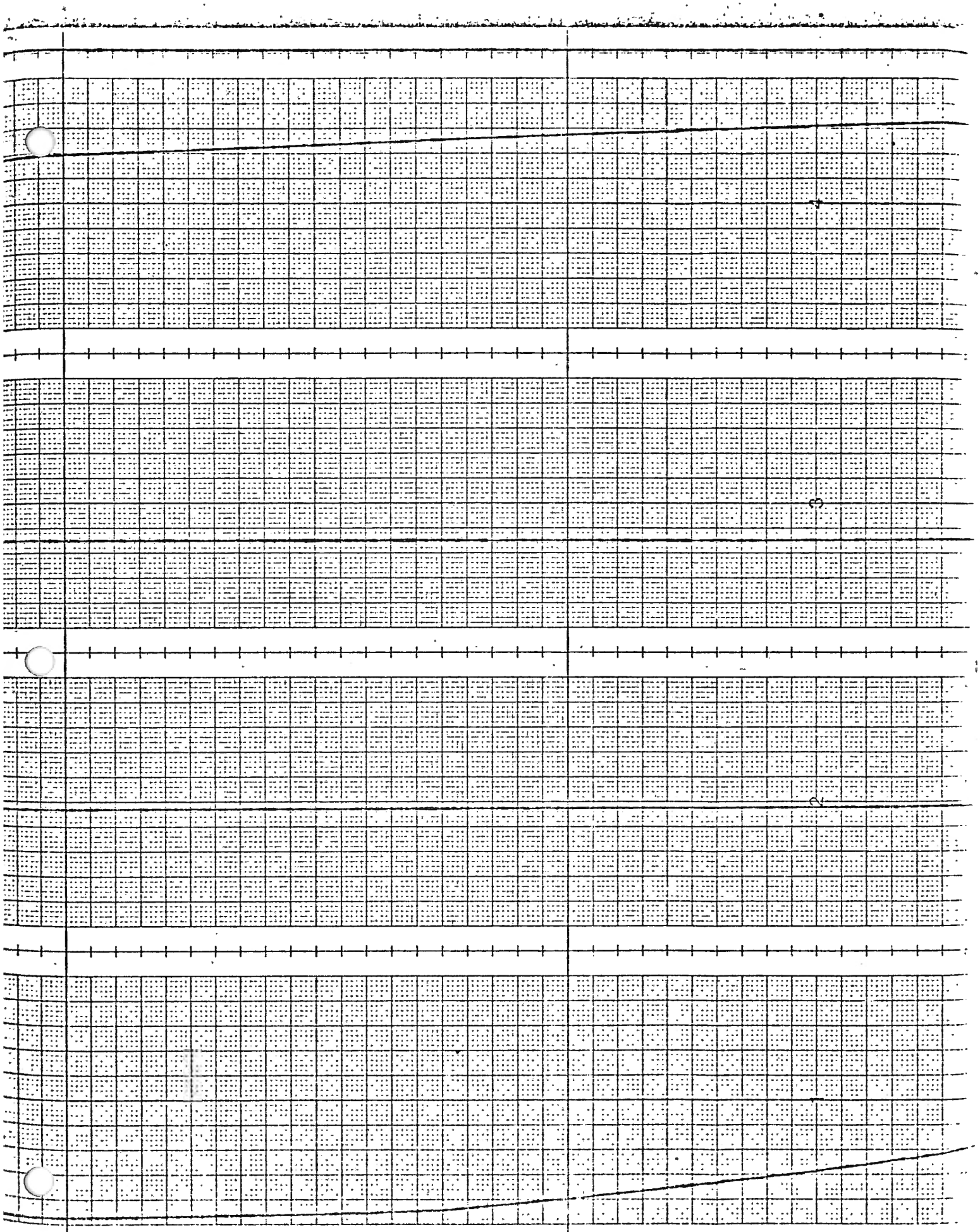


Figure 6

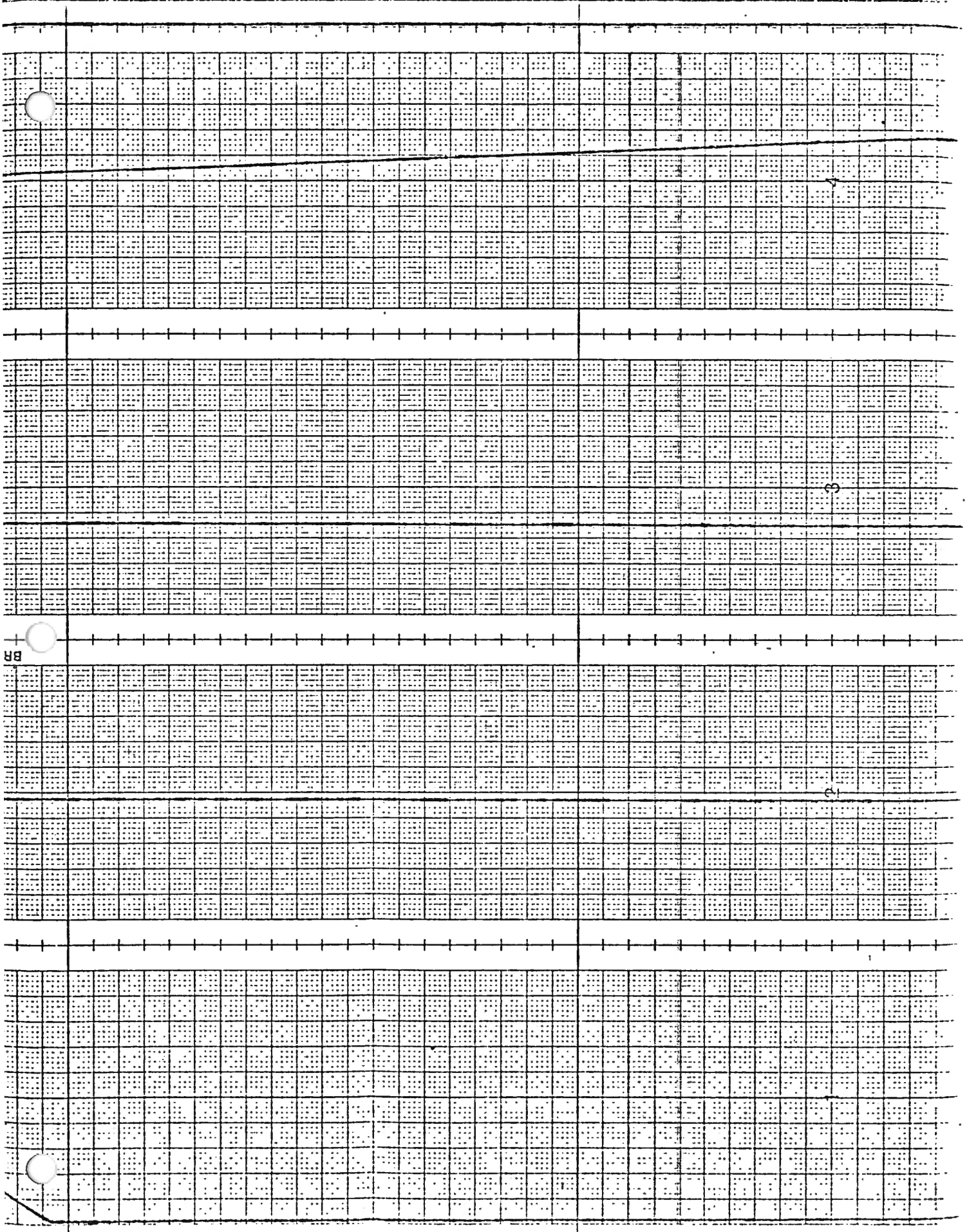
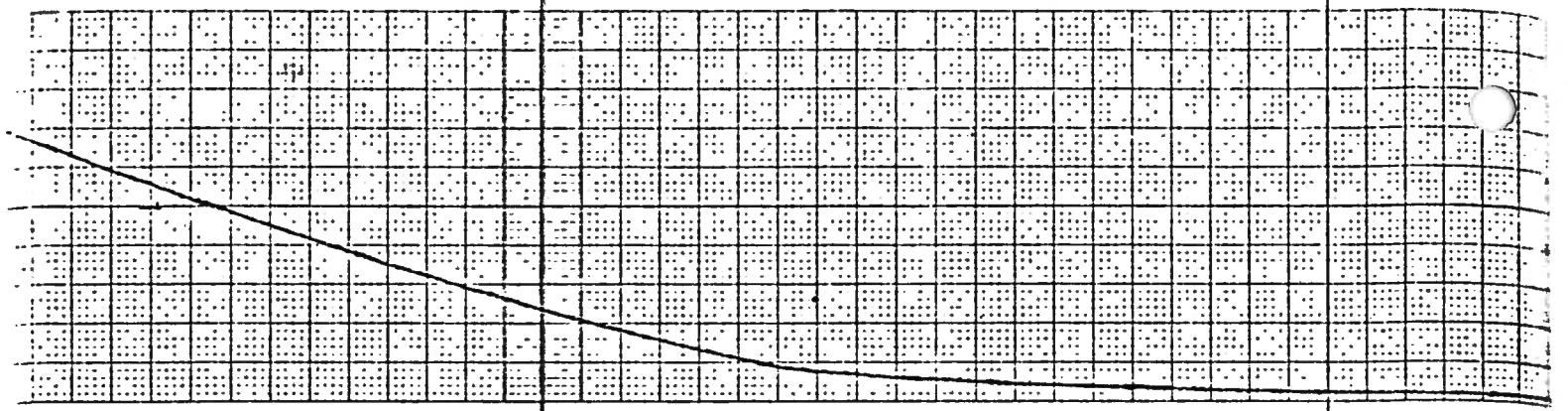
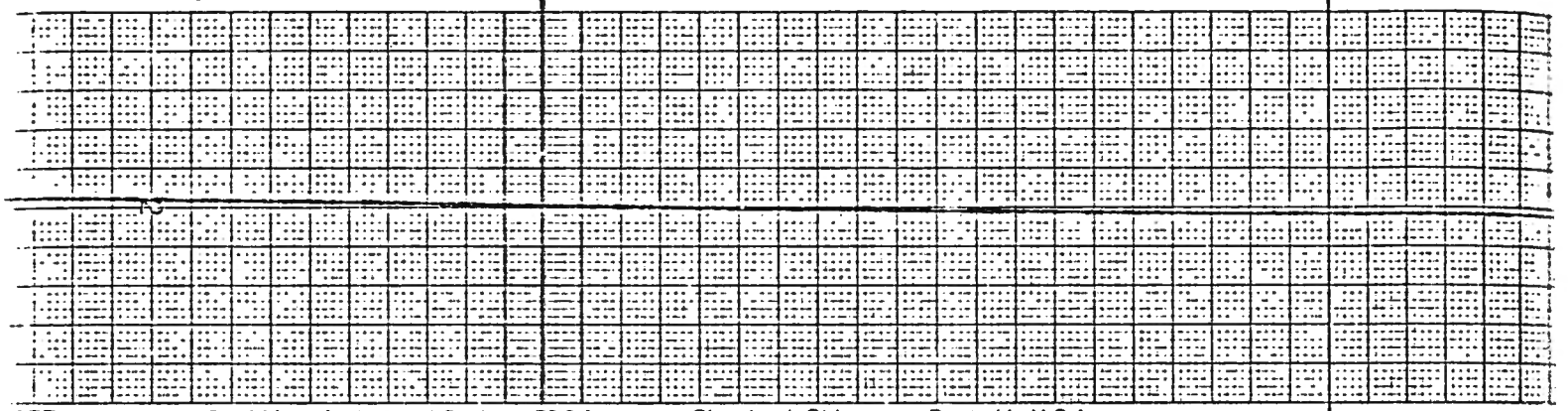
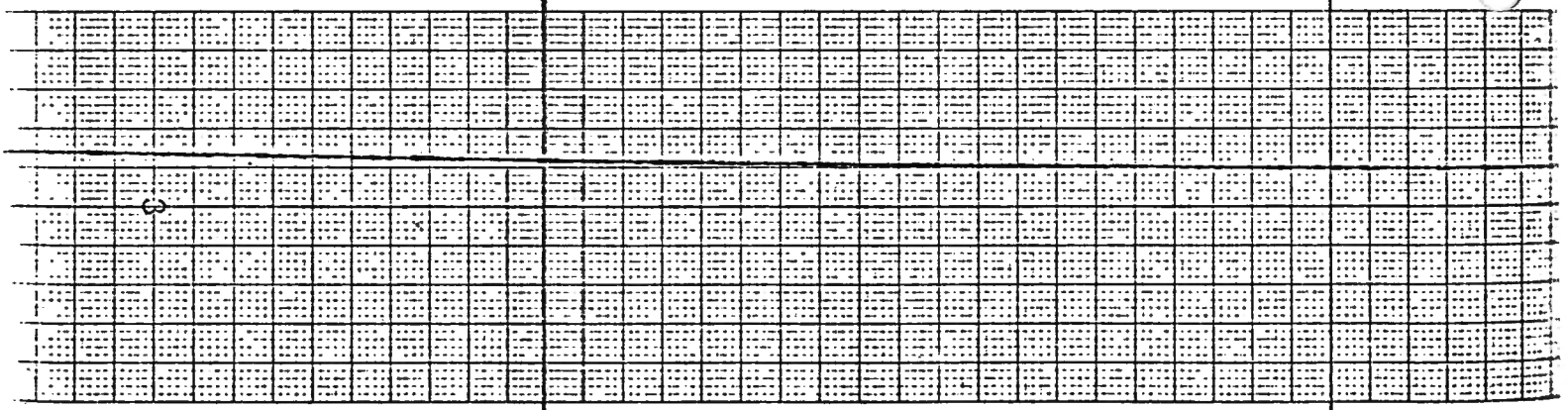


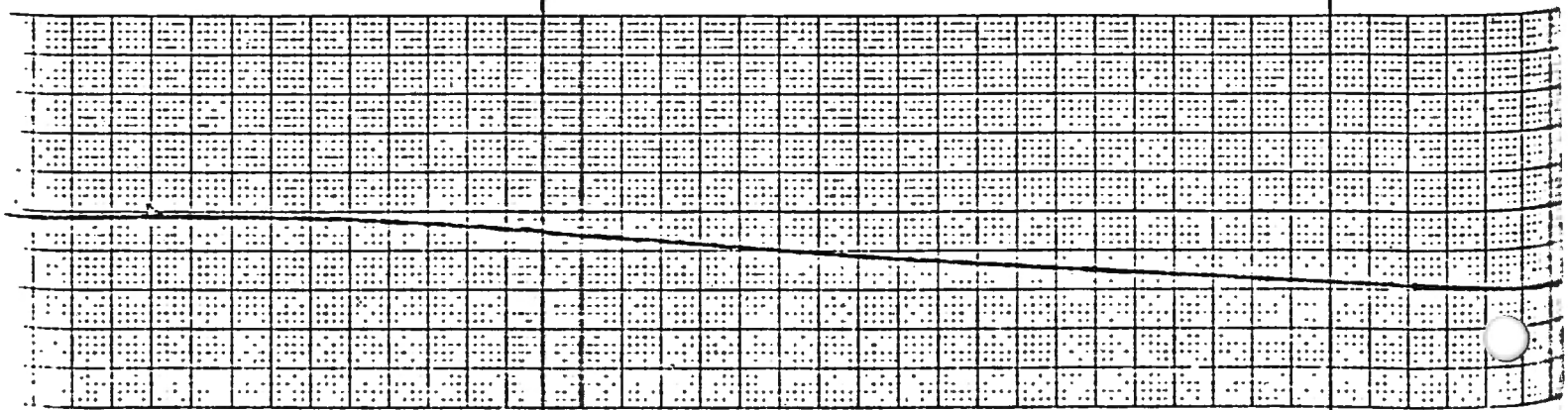
Figure 6





ART Gould Inc., Instrument Systems Division Cleveland, Ohio Printed in U.S.A.





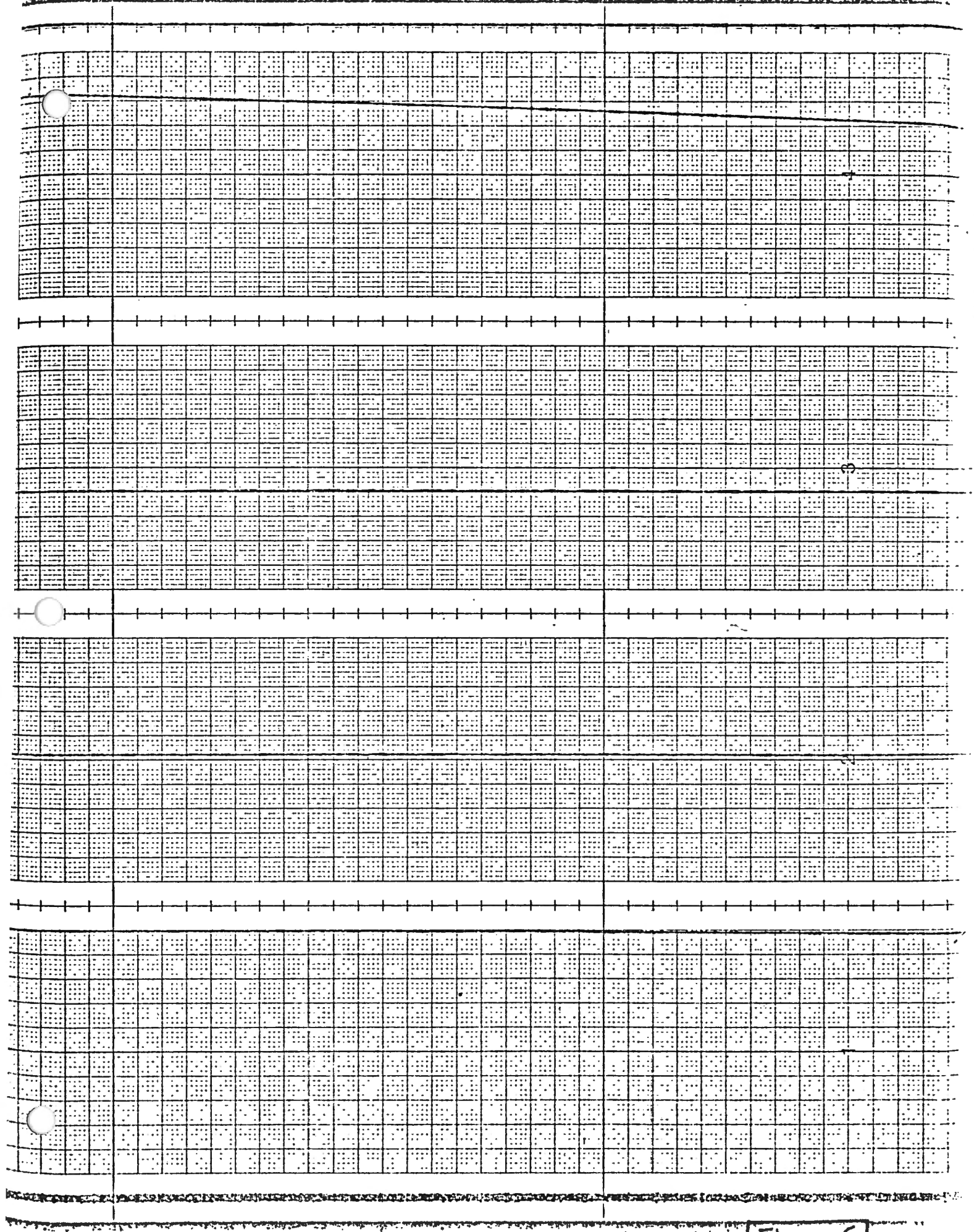


Figure 6

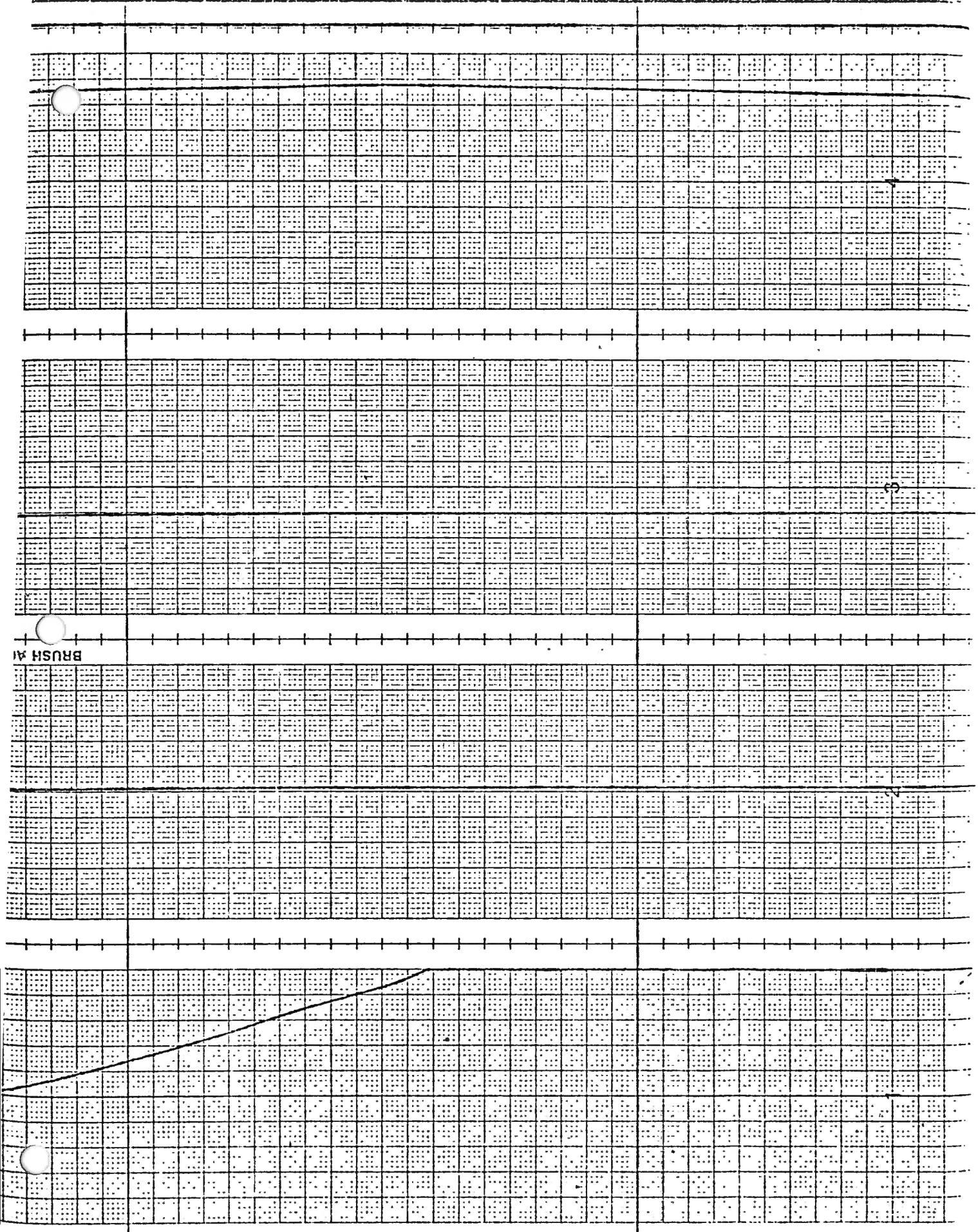
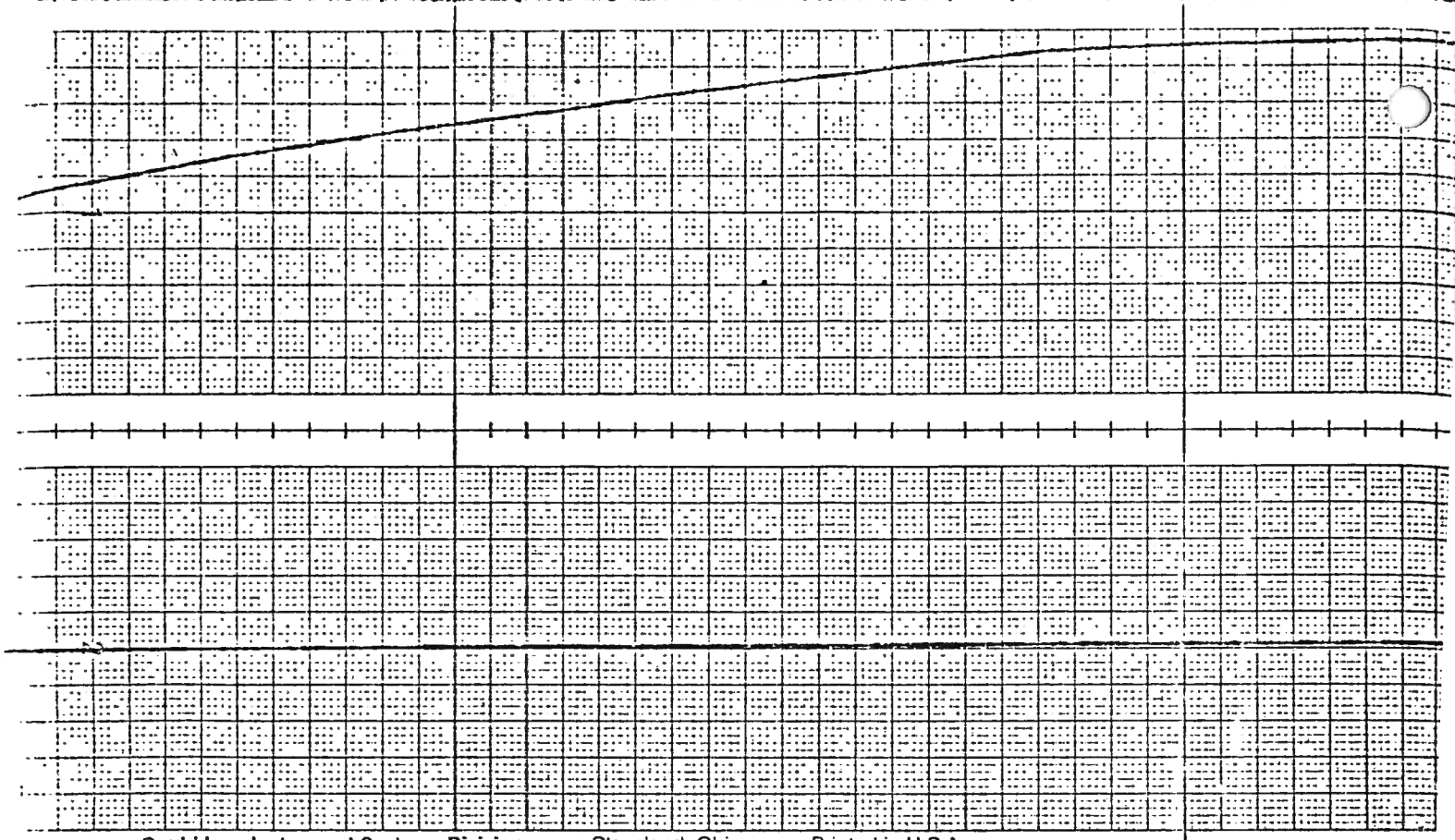


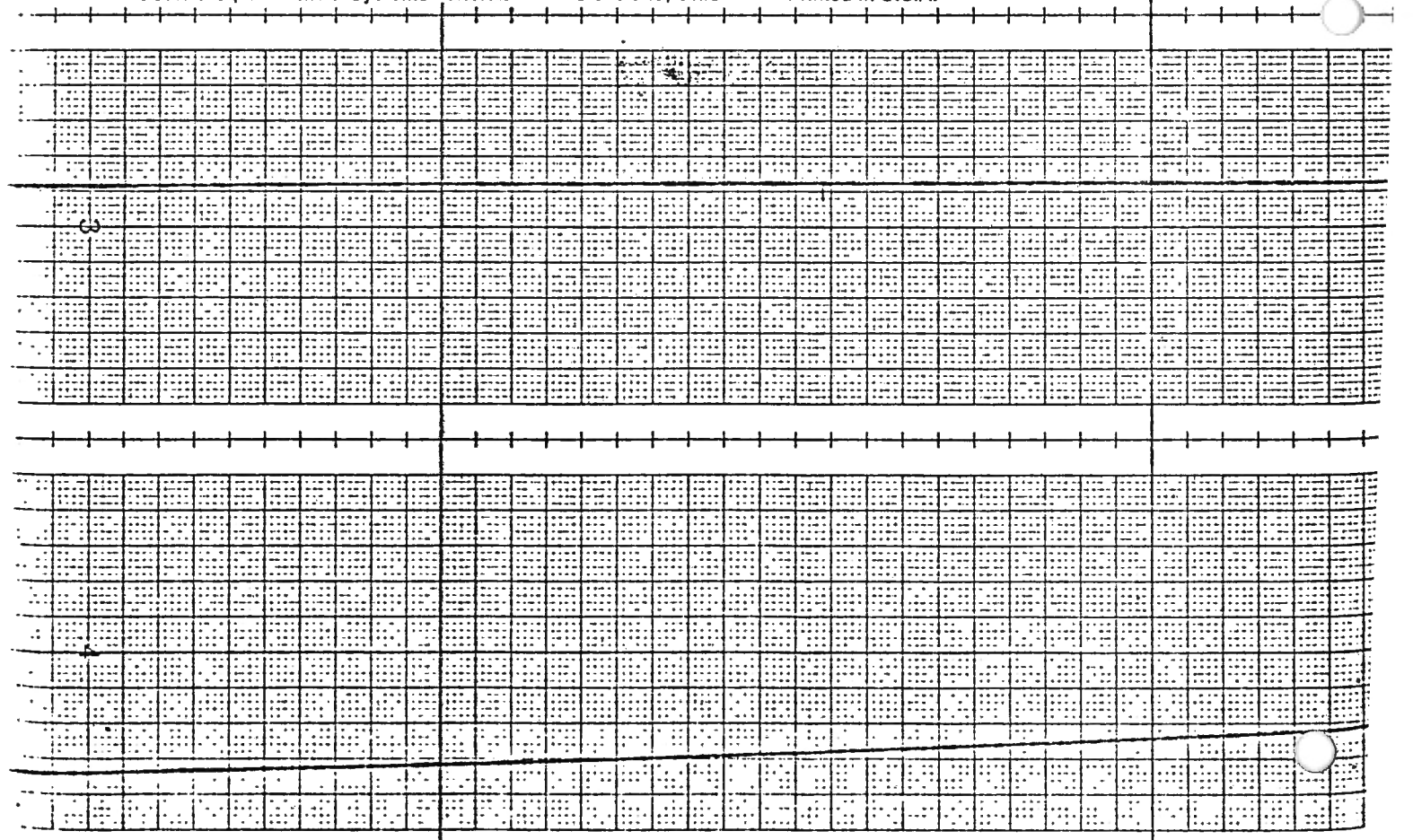

Figure 6
(Cont)

Figure 6 (Cont.)

IX-14



Gould Inc., Instrument Systems Division Cleveland, Ohio Printed in U.S.A.



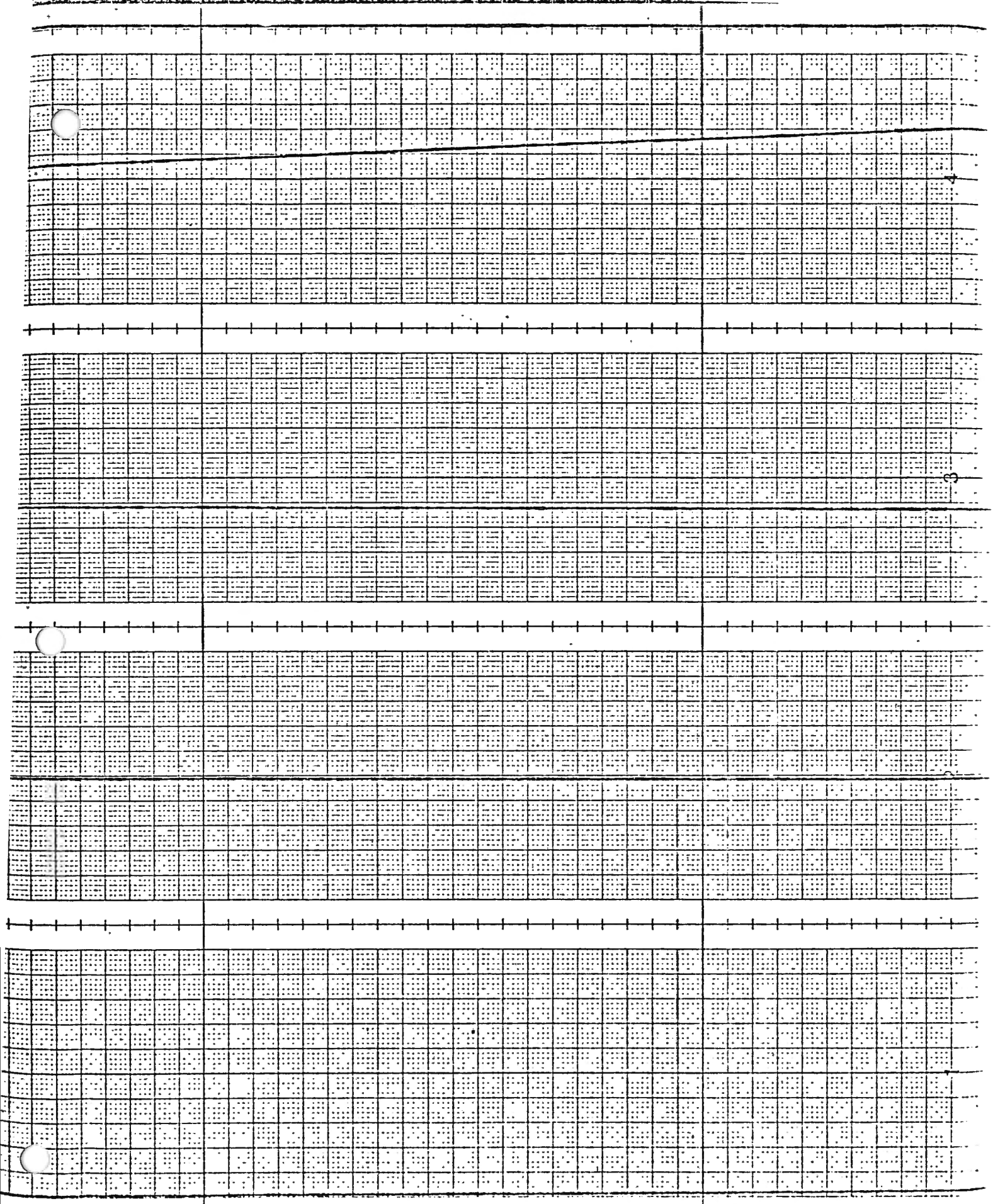


Figure 6 (cont.)

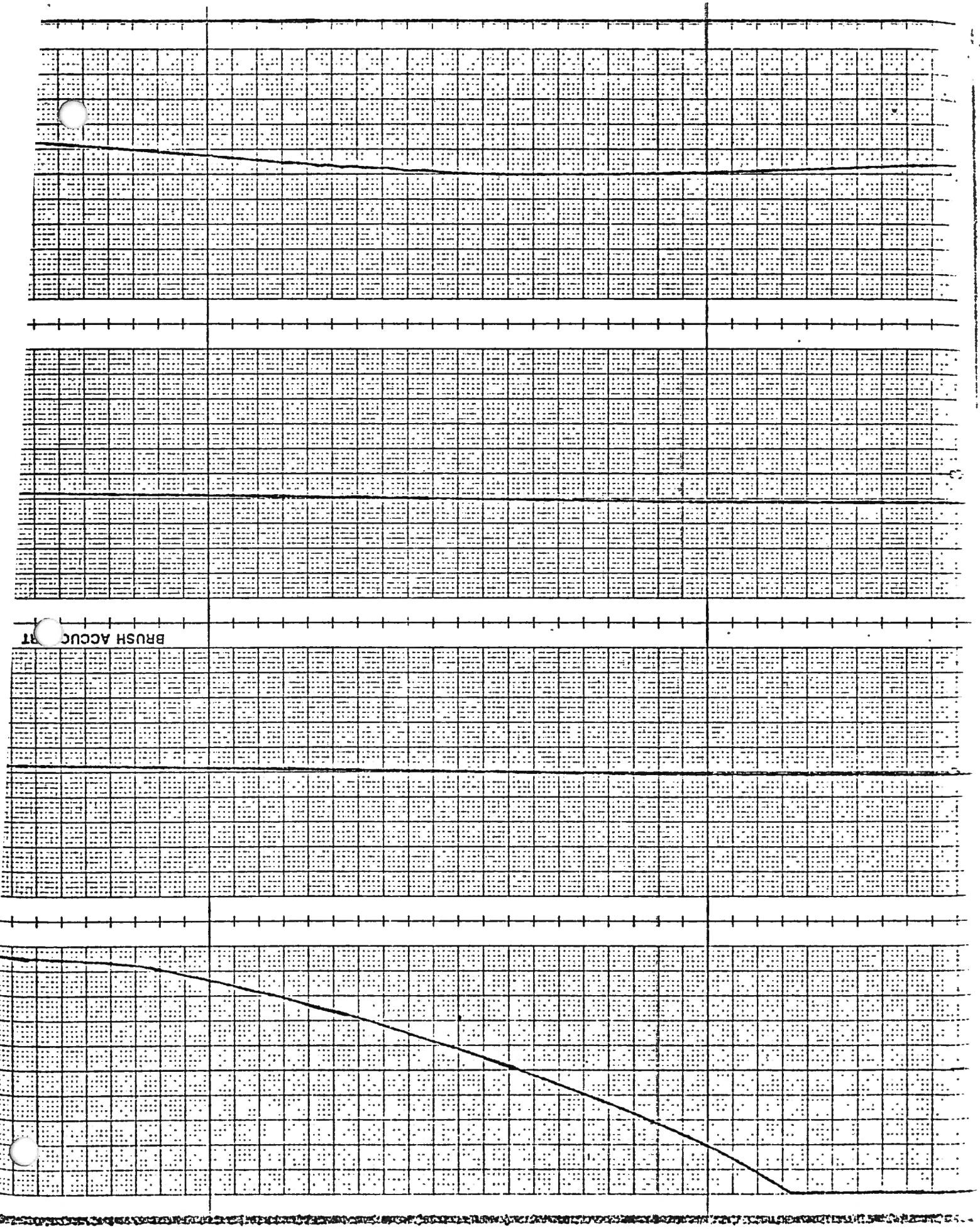
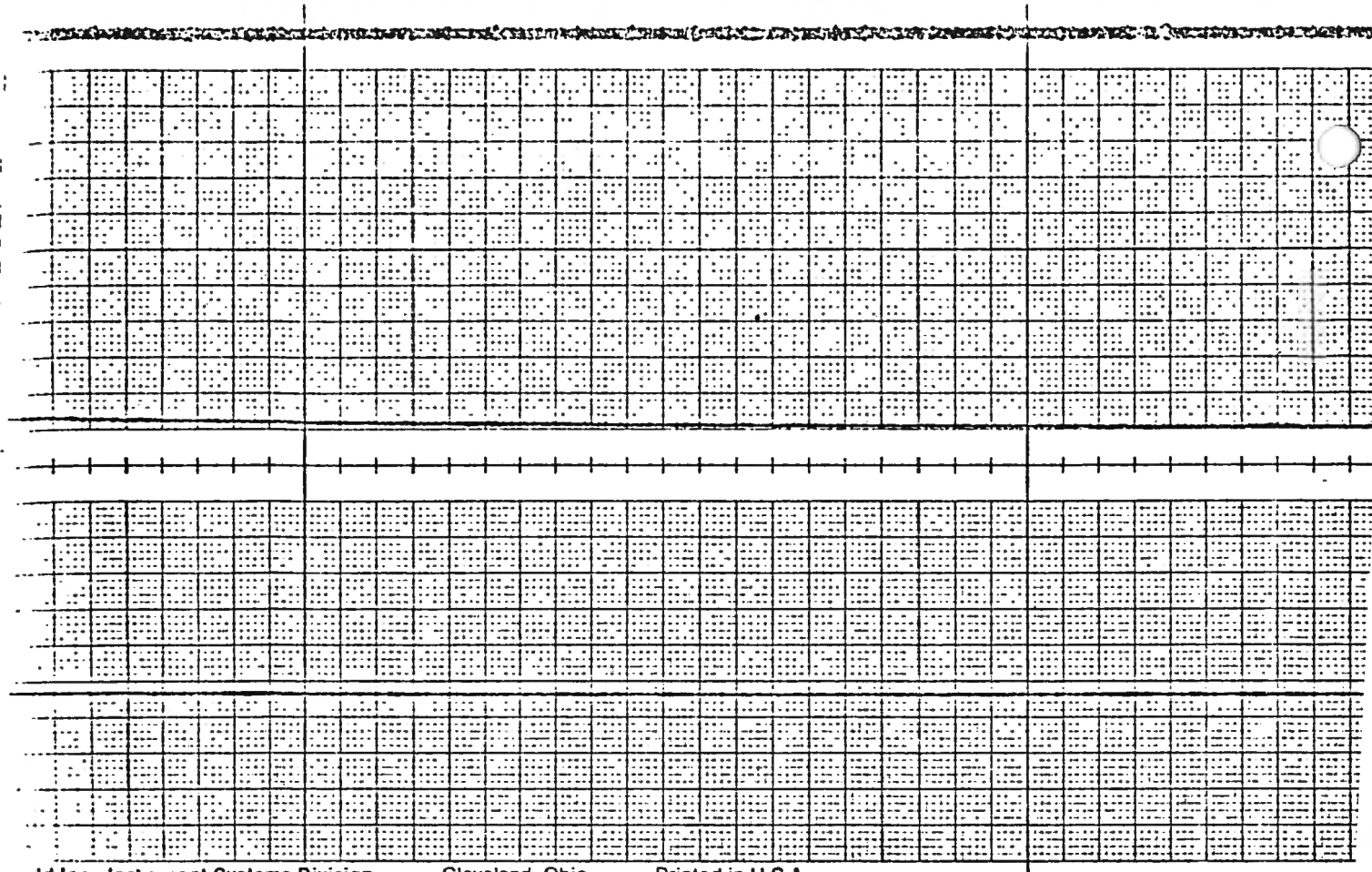


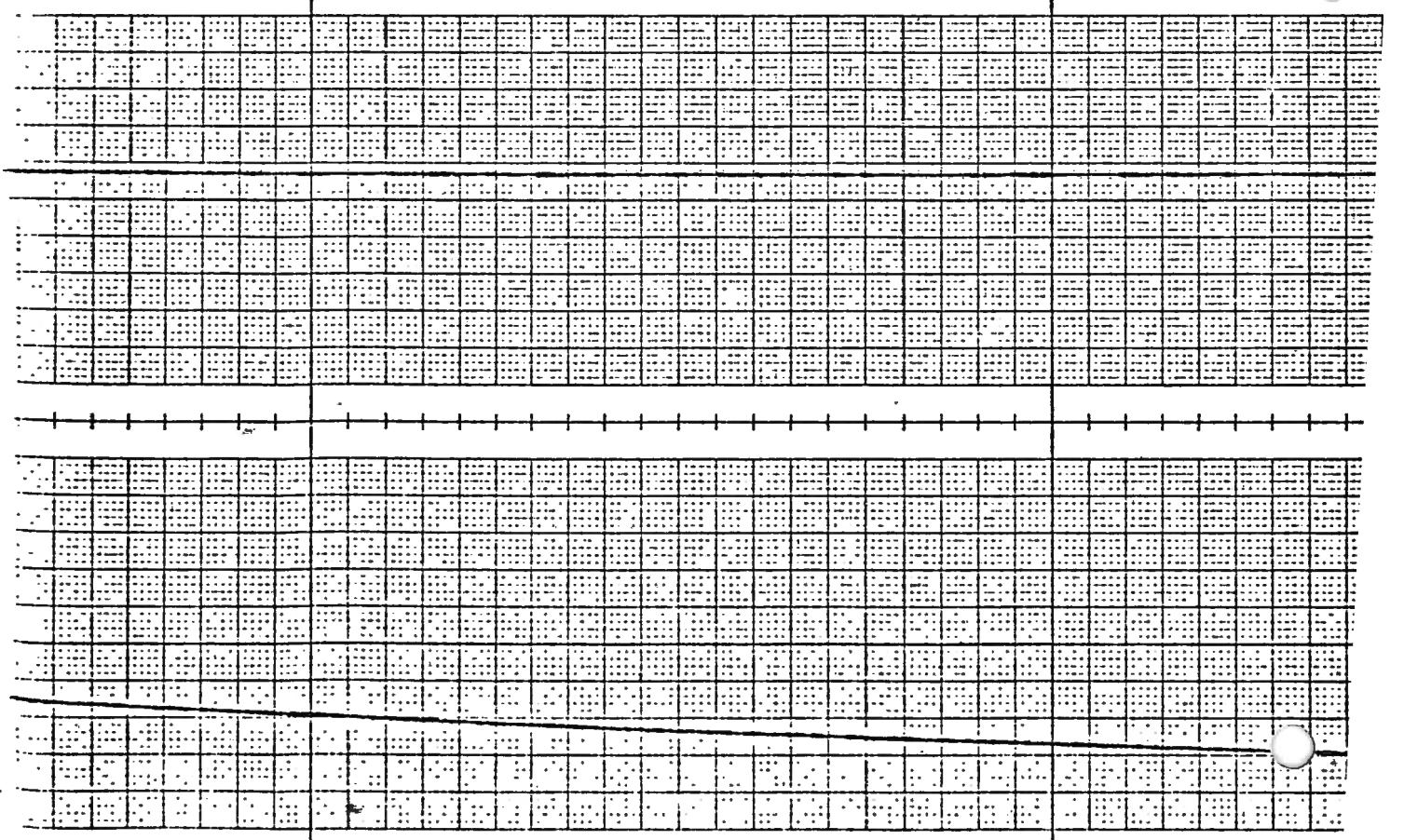

Figure 6 (Cont.)

Figure 6 (cont)

IV-17



uld Inc., Instrument Systems Division Cleveland, Ohio Printed in U.S.A.



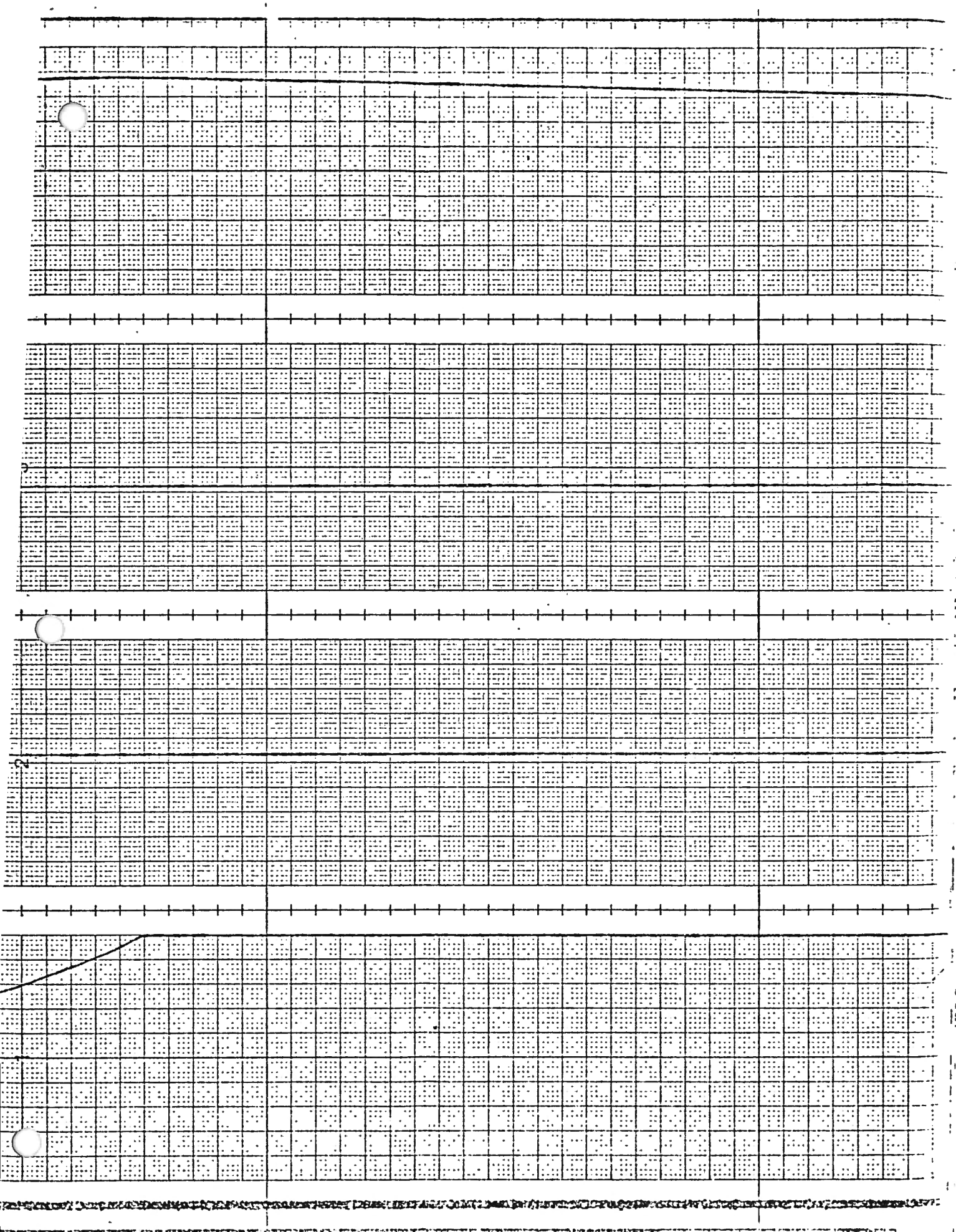




Figure 6
(Cont.)

## Section VI: Conclusions

Of the four products tested, only one will meet the Hydraulics Branch needs for measuring surface waves in water. This one is the Delavan Electronics Model CS54 and is due to it having a small enough probe so as not to disrupt the waves. The Robertshaw Controls Model 160 and Drexelbrook Engineering Model 408-6200 were satisfactory in all tests except for the wave distortion due to rod size. The Bailey Scientific Model PC-50 was not acceptable due to several reasons (for details see Section II).

The pressurization tests for the Geotechnical Branch were conducted on the Robertshaw Controls and Drexelbrook Engineering units. The later proved quite adequate while the former would also work with a new probe designed for pressure use. The Delavan Electronics Model CS54 that we received could not be pressurized so another one built for pressure is being purchased at this time. It should prove satisfactory for all of the triaxial shears due to its pressurability and small rod diameter.

Thus, there are a few companies that can and do meet our needs for water level and wave measurements. The commercial units come ready to use and can be easily set up by a technician. They provide easy connection to test equipment, computers, and recorders. They are reliable, accurate, stable, and interchangeable, and if they fail, the factory will repair under warranty or for a nominal charge. Therefore, our investigation showed that private companies are in this business and with a little product searching the right ones for the desired application can be located.

## APPENDIX A

### Companies Contacted

MANUFACTURER PROVIDING UNIT FOR EVALUATION:

1. Delavan Electronics, Scottsdale, Arizona, (602) 948-6350
   Reply: Product was applicable and unit was evaluated.

2. Robertshaw Controls, Anaheim, California, (714) 535-8151
   Reply: Product was applicable and unit was evaluated.

3. Drexelbrook Engineering, Horsham, Pennsylvania, (215) 674-1234
   Reply: Product was applicable and unit was evaluated.

4. Bailey Scientific, Sacramento, California, (916) 371-1472
   Reply: Product was applicable and unit was evaluated.

MANUFACTURERS INDICATING THEIR PRODUCTS MIGHT BE SUITED TO OUR APPLICATION:

5. Engineering Design, Denver, Colorado, (303) 427-1955
   Reply: Product was applicable and no evaluation unit received in time.

   Combustion Engineering, Tulsa, Oklahoma, (918) 932-5671
   Reply: Product was applicable and evaluation unit not received in time.

7. Crane Company, Paoli, Pennsylvania, (215) 265-7212
   Reply: Product was applicable and would not send us unit for evaluation.

8. Endress and Hauser, Greenwood, Indiana, (317) 535-7138
   Reply: Product was applicable and company was not interested in being evaluated.

9. Metritape, Inc., W. Concord, Massachusetts, (617) 369-7500
   Reply: Product appeared applicable but was not after detailed study.

10. Rosemount Inc., Minneapolis, Minnesota, (612) 941-5560
    Reply: Product appeared applicable but was not after detailed study.

11. Monitek, Redwood City, California, (415) 471-8300
    Reply: Product was applicable and company would not provide evaluation unit.

MANUFACTURERS INDICATING THEIR PRODUCTS ARE NOT SUITED TO OUR APPLICATION OR NOT RESPONDING:

12. Dover Corp., Boulder, Colorado, (303) 530-9600
    Reply: Product was not applicable.

13. Liquid Level Lectronics, Porter, Texas, (713) 354-2163
    Reply: Product was not applicable.

14. Aztec, Inc., Houston, Texas, (713) 468-7971
    Reply: Product was not applicable.

15. Automation Products, Houston, Texas, (713) 869-0361
    Reply: Product was not applicable.

16. Compac Engineering, Paradise, California, (916) 872-2042
    Reply: Product was not applicable.

17. Dynamic Sciences, Van Nuys, California, (213) 997-6414
    Reply: Product was not applicable.

18. Datron System, Inc., Los Angeles, California, (213) 247-7060
    Reply: Product was not applicable.

19. Kavlico Corp., Chatsworth, California, (213) 882-2400
    Reply: No response.

20. Senso-Metrics, Van Nuys, California, (213) 988-6070
    Reply: Product was not applicable.

21. Celesco Corp., Los Angeles, California, (213) 884-6360
    Reply: Product was not applicable.

22. Computer Instruments, Hempstead, New York, (516) 483-8200
    Reply: No response.

23. Data Instruments, Lexington, Massachusetts, (617) 861-7450
    Reply: Product was not applicable.

24. ElectroSyn Corp., Canton, Massachusetts, (617) 828-2840
    Reply: Product was not applicable.

25. Fenwal Elec., Framingham, Massachusetts, (617) 872-8841
    Reply: Product was not applicable.

26. Advanced Instrumentation, Santa Cruz, California, (408) 423-8317
    Reply: Product was not applicable.

7. Curtis Industries, Milwaukee, Wisconsin, (414) 354-1500
Reply: Product was not applicable.

8. Vega Controls U.S., Wakefield, Massachusetts, (617) 246-0026
Reply: No response.

29. Schaevitz Engineering, Pennsauken, New Jersey, (609) 662-8000
Reply: Product was not applicable.

30. Zi-Tech. Div.; Aikenwood Corp., Palo Alto, California, (415) 326-2151
Reply: Product was not applicable.

31. Foxboro Co., Foxboro, Massachusetts, (617) 543-8750
Reply: Product was not applicable.

32. Temposonics, Inc., Plainview, New York, (516) 349-1950
Reply: No response.

33. Exactel Instr. Div.,; Technical Devices, Culver City, California, (213) 870-3751
Reply: Products are all custom OEM only.

34. Controlotron Corp., Hauppauge, New York, (516) 231-3600
Reply: Product was not applicable.

35. Curtis Industries, Milwaukee, Wisconsin, (414) 354-1500
Reply: Product was not applicable.

36. Magnetrol International, Downers Grove, Illinois, (312) 969-4000
Reply: Product was not applicable.

37. Milltronics, Inc., Arlington, Texas, (817) 649-8540
Reply: Product was not applicable.

38. National Sonics Div.; Envirotech Corp., Hauppauge, New York, (516) 273-6600
Reply: Product was not applicable.

39. Petrometer Corp., New Hyde Park, New York, (516) 488-5777
Reply: Product was not applicable.

40. Princo Instru., Southhampton, Pennsylvania, (215) 355-1500
Reply: Product was not applicable.

41. Rexnord Instrument, Malvern, Pennsylvania, (215) 647-2400
Reply: Product was not applicable.

42. Sirco Controls, Vancouver, B.C., (604) 261-9321
Reply: No response.

## APPENDIX B

### Test Apparatus

Figure 1 - Wave test setup

Figure 2 - Linearity test setup

Figure 3 - Dynamic test setup

Figure 4 - Environmental test setup

The pressure tests used a standard large triaxial shear in the Soils Testing Laboratory. The tests were conducted by the Geotechnical Branch personnel with only minor assistance by us.

7-1654 (7-73)
Bureau of Reclamation

| BY | DATE | PROJECT | SHEET ____ OF ____ |
|---|---|---|---|
| C.A. Lennon | Sept., 1980 | WPR-PAI-80-3 | |
| CHKD BY | DATE | FEATURE | |
| | | Figure 1 | |

DETAILS Wave Test Setup

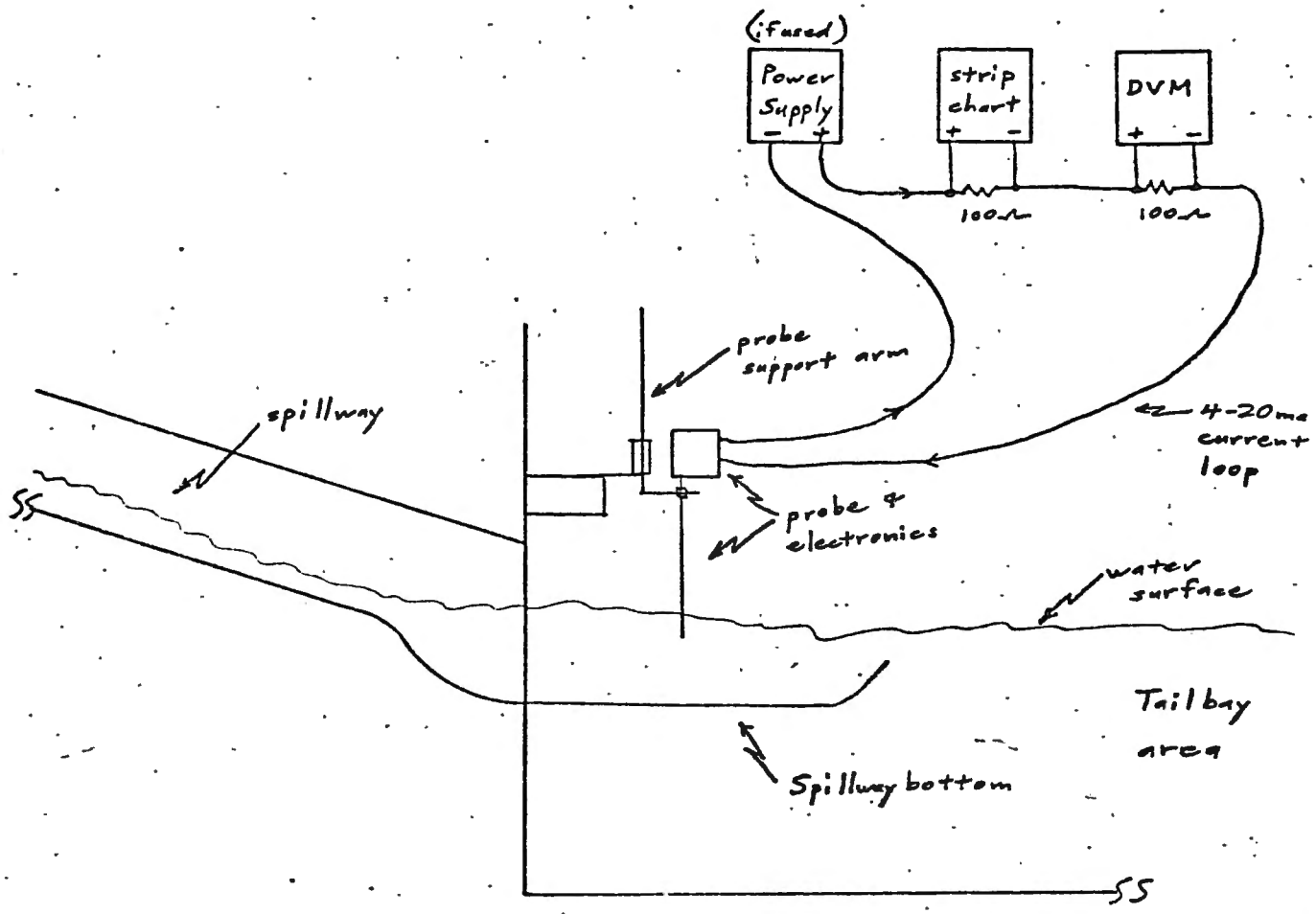



Figure 1 - Wave Test Setup - general view.

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|---|---|---|---|
| C. A. Lennon | Sept. 1980 | WPR - PAI - 80 - 3 | |
| CHKD BY | DATE | FEATURE | |
| | | Figure 2 | |
| DETAILS | | | |
| Linearity Test Setup | | | |

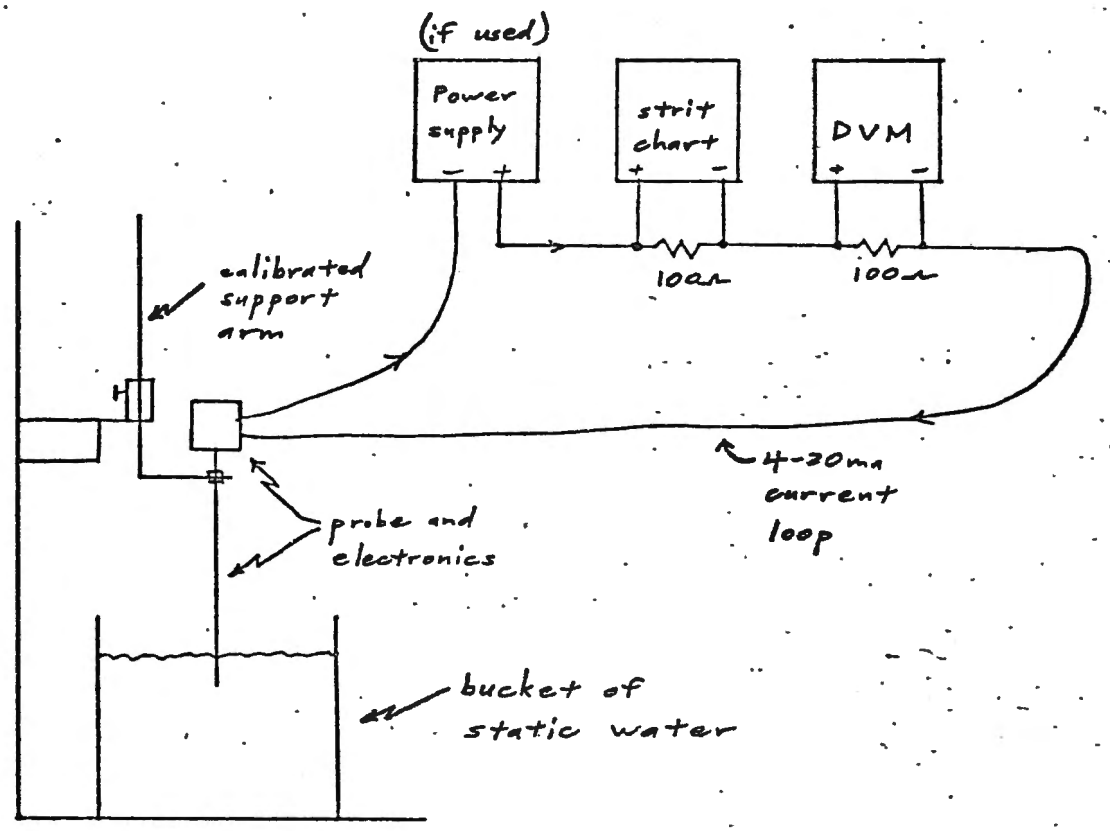


Figure 2 - Linearity Test Setup - general view.

7-1654 (7-73)
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**COMPUTATION SHEET**

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| CHKD BY | DATE | FEATURE | |
| | | Figure 3 | |

DETAILS Dynamic Test Setup

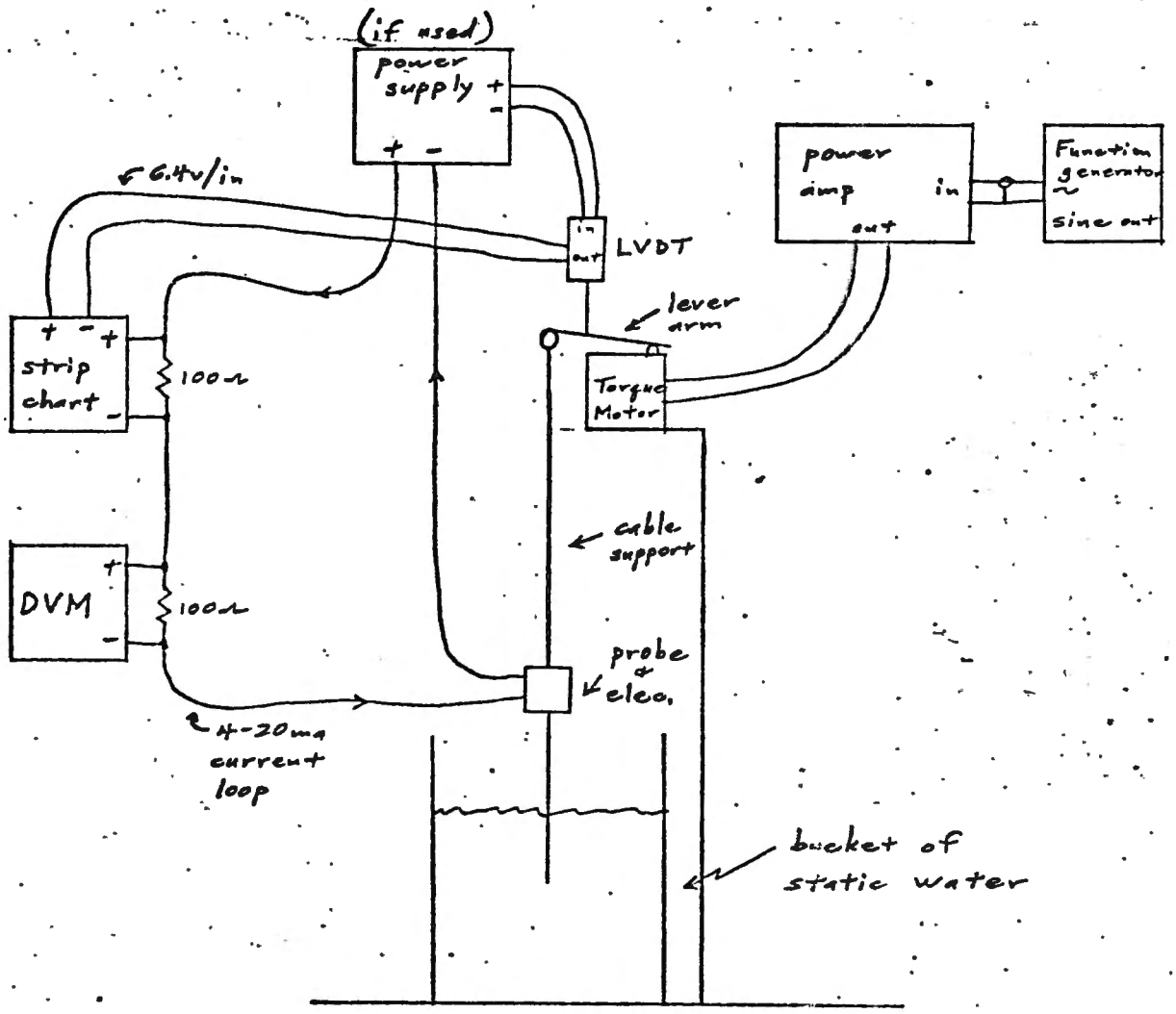


Figure 3 - Dynamic Test Setup - general view.

5-1654 (7-73)
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|---|---|---|---|
| C.A. Lennon | Sept. 1980 | WPR - PAI - 80 - 3 | |
| CHKD BY | DATE | FEATURE Figure 4 | |
| DETAILS Environmental Test Setup | | | |

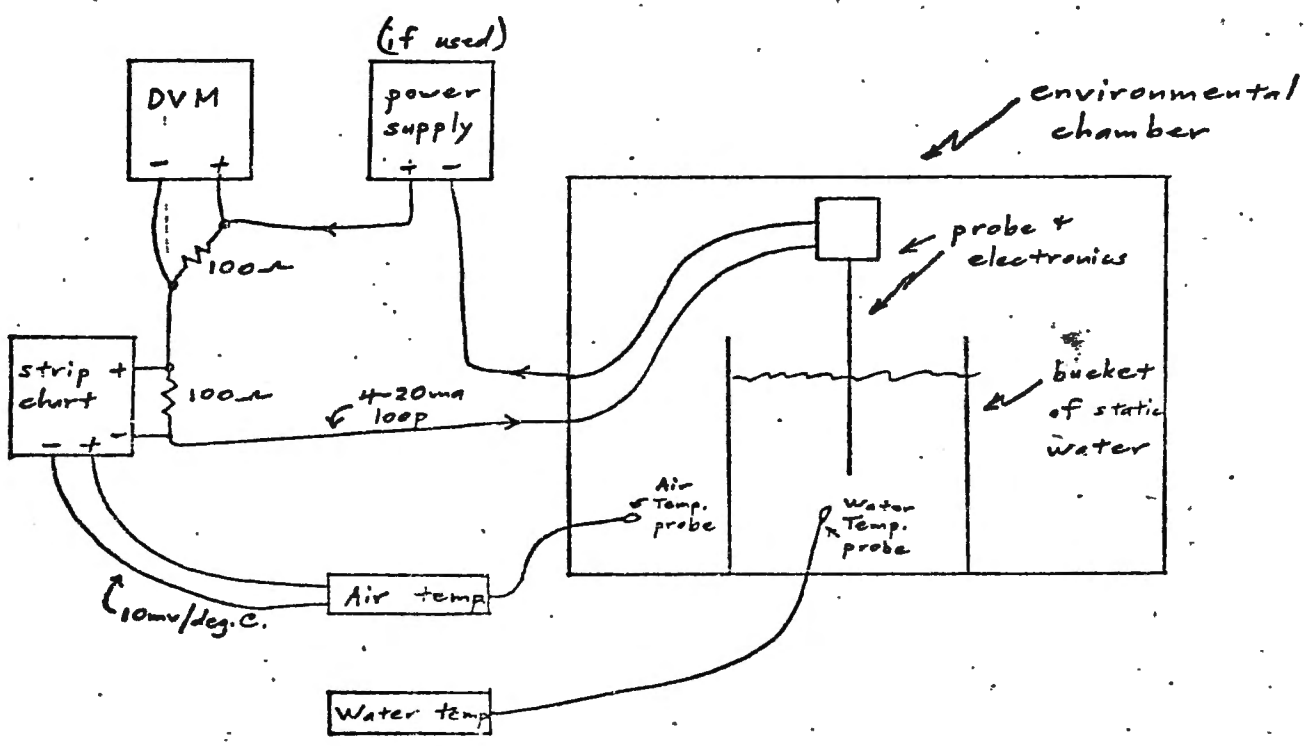


Figure 4 - Environmental Test Setup - general view.