

University of Michigan
Department of Mechanical Engineering
Cavitation and Multiphase Flow Laboratory

Report No. UMICH 320711-1-I

PROFICORDER EXAMINATIONS OF AEROJET SPECIMENS

by

Peter G. Felbeck

for

M.E. 490 project

under

Prof. F. G. Hammitt

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ENGINEERING LIBRARY

Supported by Aerojet Liquid Rocket Company and Internal
University of Michigan (Work Study and SEP) funds

April 14, 1978

Engr

UMR

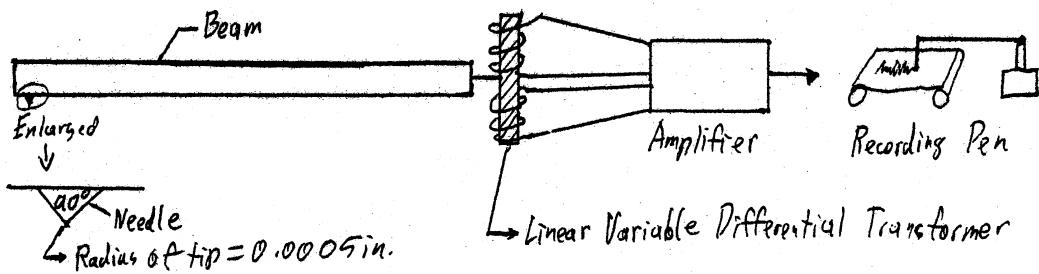
1437

0.1

PROFICORDER

The following is an explanation of the process of analysis of cavitation samples through the use of the proficorder.

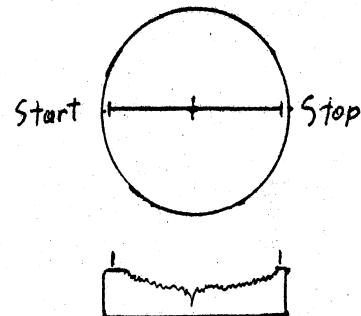
A proficorder is a device that gives you a profile, along a straight line, of the surface contour of a specimen. This device consists of the following: a beam approximately ten to fourteen inches long upon one end of which is mounted



a needle with a diamond tip. This tip rides, very lightly over the surface of the specimen as the beam is slowly pulled across it. Any change in tilt or angle of the beam induces a change in voltage of the linear variable differential transformer at the other end. This change of voltage is then amplified and sent to the recording pen.

To take a sample of a cavitation specimen the distance moved by the pen is first set.

Because most cavitation samples have a ring of undamaged surface around the outside, I tried to start and stop the needle in these



areas. These undamaged areas also serve as zero points for the recording pen.

Samples are never level when placed under the needle:

so to obtain a level pen-trace with the starting and stopping points at zero, the beam must be moved at an angle relative to the sample to obtain a level reading.

The proficorder has different sensitivities available. These vary from sample to sample, with a low sensitivity for a deeply damaged specimen to very high sensitivities for marginally damaged specimens. The sensitivities used for each specimen is indicated on the recording pen copy.

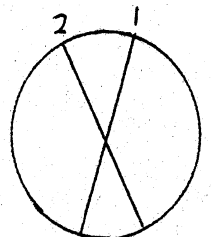
There were three different paper speeds available. The slowest speed was chosen because faster speeds didn't show anything more, and the shorter paper lengths were more easily mounted and viewed.

ANALYSIS OF SAMPLES

I was given several Aerojet specimens to analyze. These consisted of two aluminum, five titanium, and two stainless steels. The analysis consisted of taking proficorder traces and surface photographs.

For aluminum only one proficorder trace was taken because upon examination of the photographs, the damage appeared to be consistently random. Thus one trace is as good as another.

For the remaining titanium and stainless samples more than one proficorder trace was taken at various angles, so as to compare traces. These traces are either numbered (1 or 2), or given symbols. These numbers/



symbols are marked on the side of each specimen and indicate the start of the trace. In every case the trace went as near as possible through the middle of the sample.

In all the following proficorder traces except one, the vertical sensitivity is set at 1000 microinches per division. This is so one can become accustomed to the scale, thus allowing inter-comparison of samples without conversion.

P.4

ALUMINUM

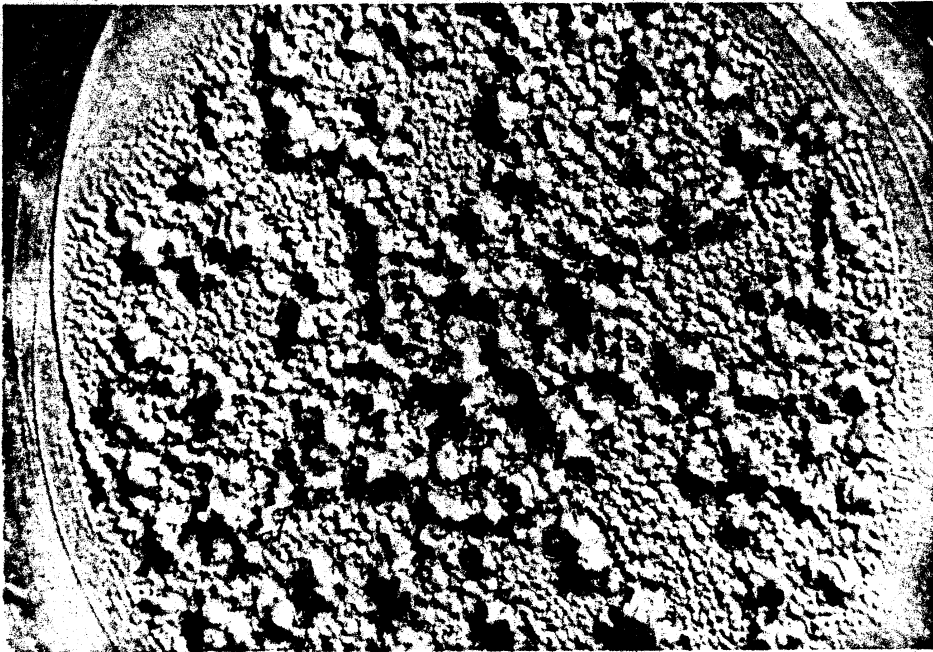
Al 1100#9

Al #16-A:Aerojet

For the aluminum samples the cavitation is fairly random, with the heaviest damage done near the center.

The maximum depth of penetration is greater than 9 mils. Even though the vertical sensitivity was set at the least sensitive level the readings still went off scale.

DS



.424"

photo # 1

AL 1100 #9

1.0 mils, 80°F
Sea water, 1 atm

magnification
factor = 10.14

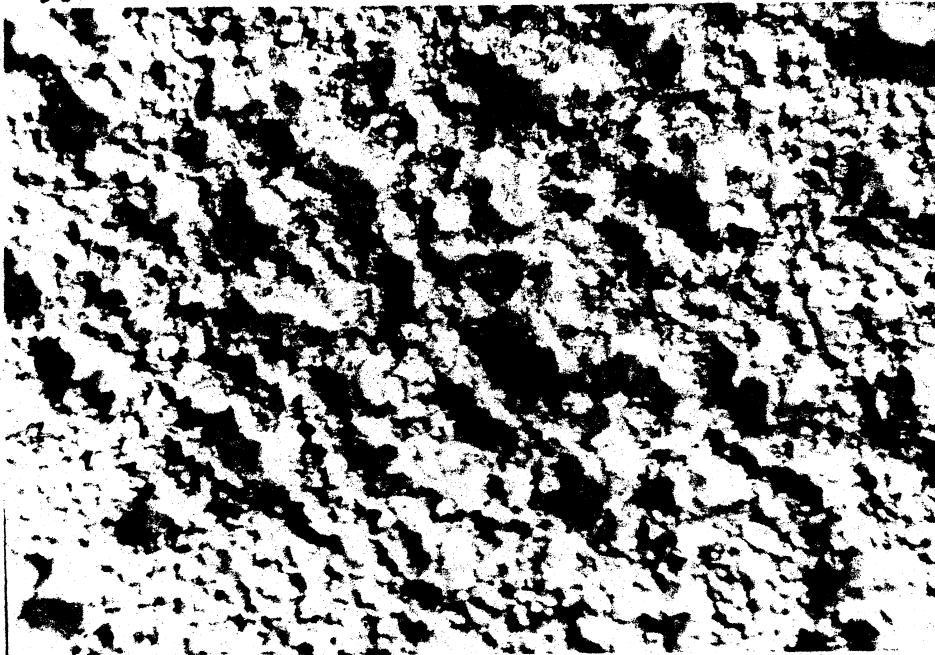
MDPR = 7.018 $\frac{m}{h}$

Depth_{max} = +9 mils

MDP(cum) = 2.06

$$\frac{\text{Depth (max)}}{\text{MDP (cum)}} = 4.36$$

35



.156"

photo # 35

AL #16-A

1.0 mils, 80°F
Sea water, 1 atm

magnification
factor = 16.67

MDPR = 6.18 $\frac{m}{h}$

Depth_{max} = +9

MDP(cum) = 2.36

$$\frac{\text{Depth (max)}}{\text{MDP (cum)}} = 3.81$$

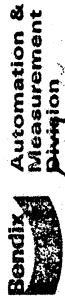
816

AR# 17-A 1.0 miles 80°F
 1100 1 atm Sea Water

Horizontal = .025 $\frac{in}{div}$
 Vertical = 1000 $\frac{microinches}{division}$

(1) => indicates (on side of specimen) start
 (H) => 11 11 11 11 11 11 finish

CHART NO. 70434086

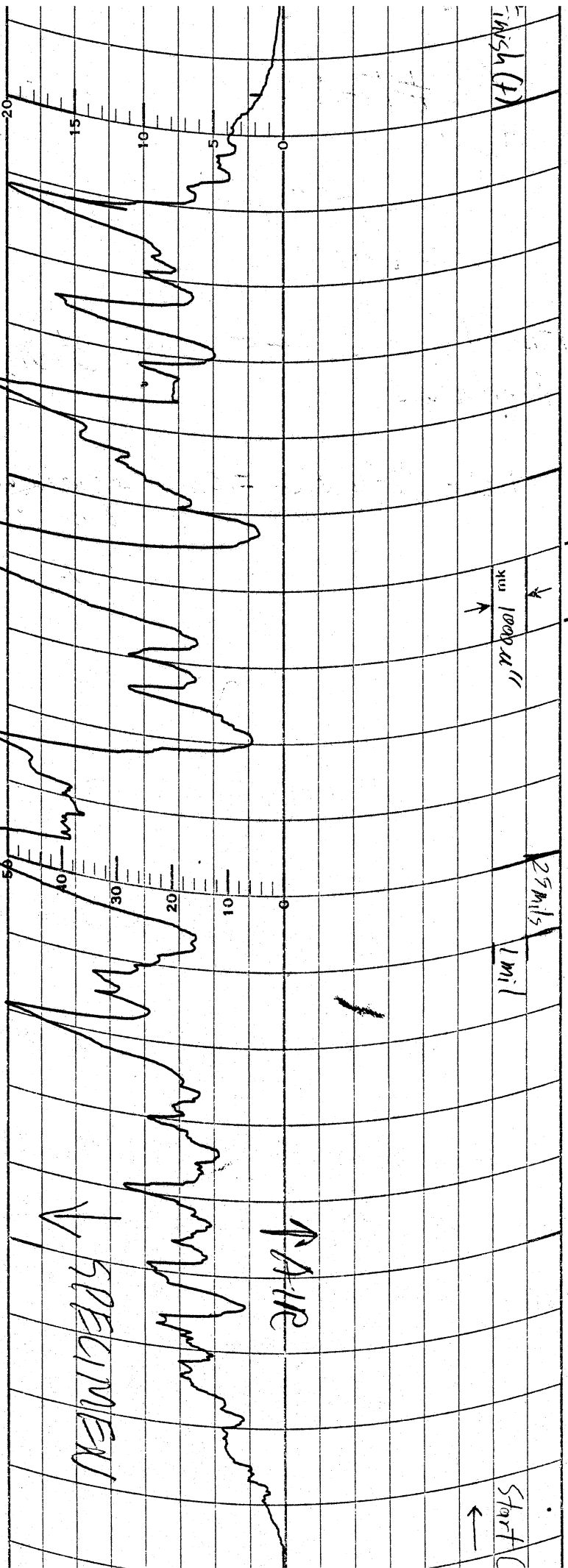


Dayton, Ohio

ALE

ARITH. AVE. SCALE

ARITH. AVE. SCALE



TOTAL

MICROORDER
 PROFICORDER

DATE

.0001

33

STAINLESS STEEL

SS 17-4 (w) #8

For this sample the heaviest damage appeared to be concentrated at or near the center of the sample. The maximum depth of penetration is 5 mils occurring at the center; the diameter of this hole is 5.7 mils. There are several other holes, near the center, ranging from 2 to 4 mils in depth.

The other radial traces indicate the many different types of holes near the center.

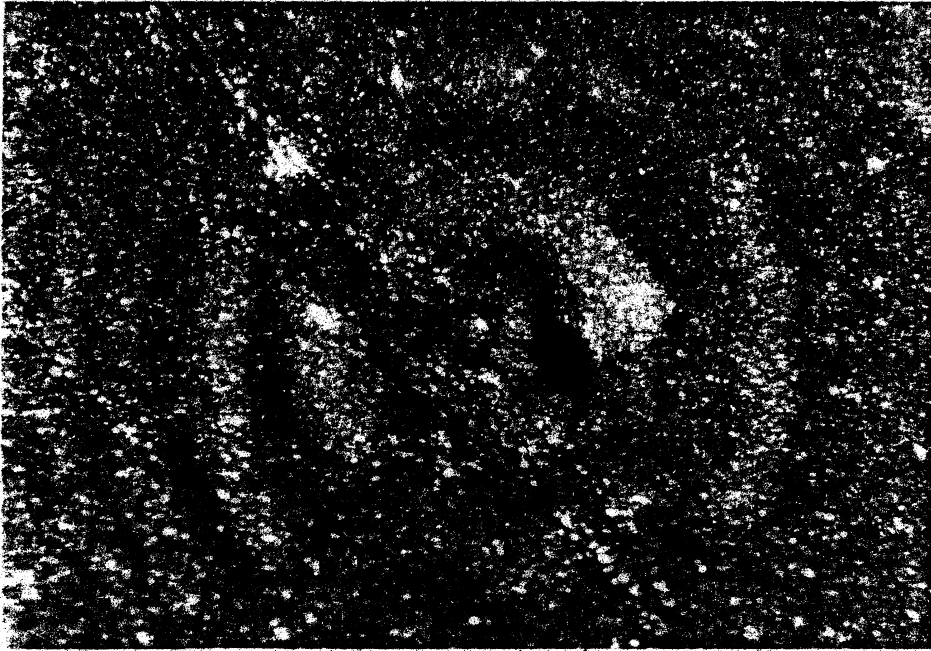
There is also a broken pattern of rings in the form of concentric circles. This phenomena will be covered in Titanium.

SS 17-4c #3

This sample appears to have one major oblong shaped hole at the center. The maximum depth of penetration is 6 mils; the length of the oblong is 26 mils with the width being approximately 5 mils.

P.9

25



1.0057" |

photo #25

SS17-4#8 (w)
 1.0mils 80°E
 latm Sea W

Magnification
 factor = 100

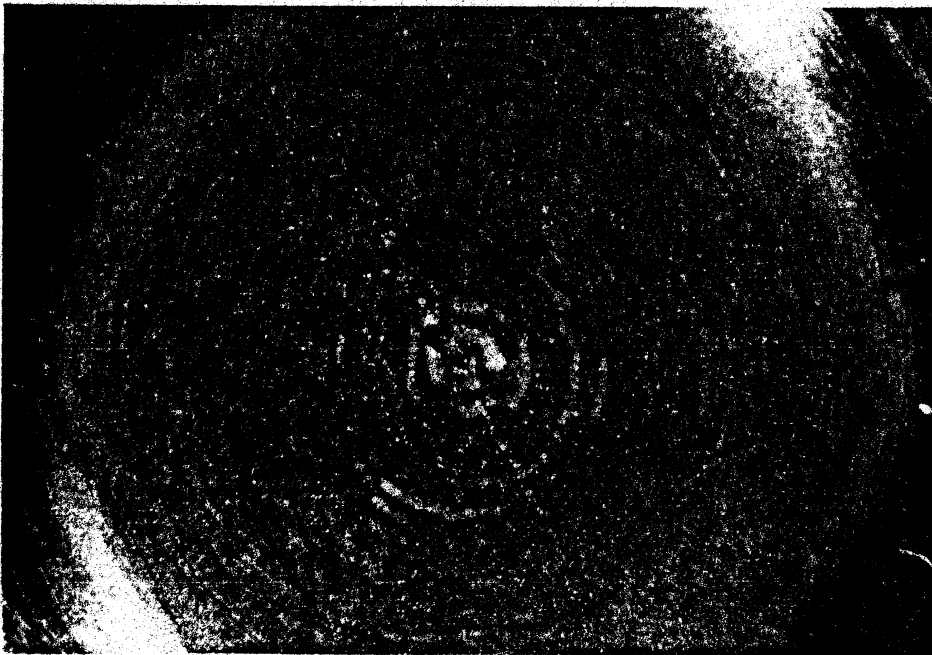
$$MDPR = 198 \frac{w}{lc}$$

$$Depth_{max} = 5 \text{ mil}$$

$$MDP(cum) = 0.158$$

$$\frac{Depth (max)}{MDP(cum)} = 36.23$$

21



1.067" |

photo #21

SS17-4#8 (w)
 1.0mils 80°E
 latm Sea Wat

$$MDPR = 198 \frac{w}{lc}$$

Magnification
 factor = 10.45

$$Depth_{max} = 5 \text{ m}$$

P.10
 Vertical = 10000 microinches
 Horizontal = 0.025 in/div

SS17-4 #8 (W) 1.0 mils (S) 80°F
 1 atm Sea water

Trace = Red #1

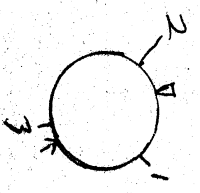


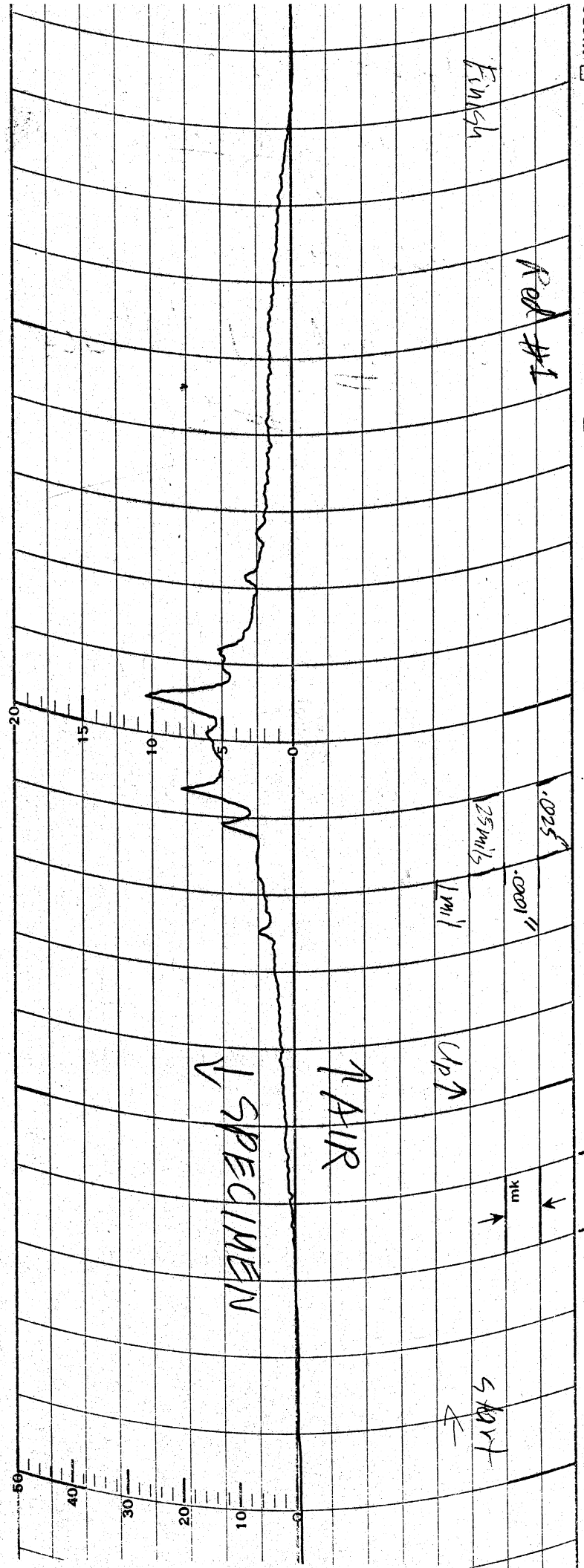
CHART NO. 70434086

Automation & Measurement Division
 Dayton, Ohio



ARITH. AVE. SCALE _____

ARITH. AVE. SCALE _____



MICRO
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 RC

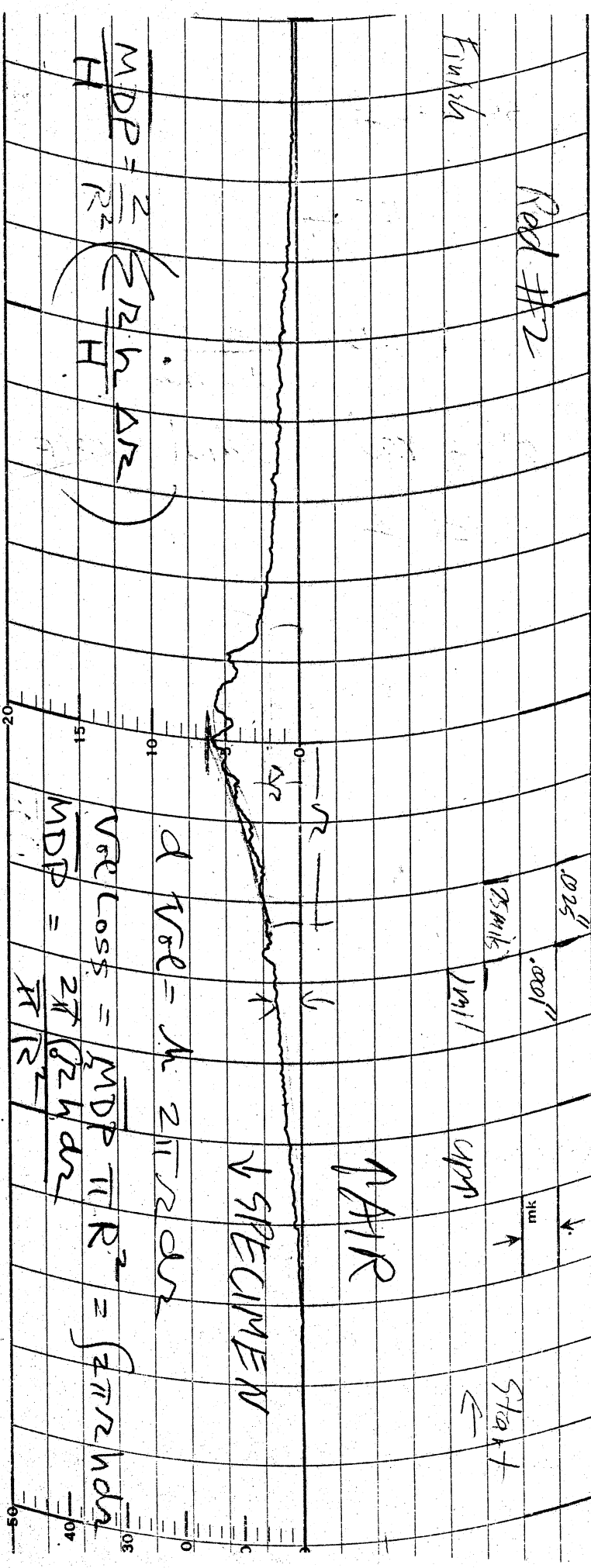
.0001
 .0005
 3/32

.003
 .010
 .030

TOTAL WAVINESS
 PROFILE: WAVINESS ROUGHNESS

MICROORDER
 PROFICORDER
 LINEAR
 ROTARY

DATE _____ PART NO. _____
 STYLUS R. _____ CUTOFF: _____ RPM _____



$$\frac{MDP}{H} = \frac{2}{R^2} \left(\frac{R^2 h}{H} \Delta R \right)$$

$$d \text{ Vol} = 4\pi R^2 dr$$

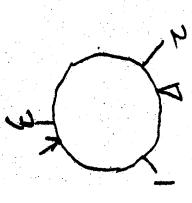
$$\text{Vol Loss} = \int MDP \pi R^2 = \int \pi R^2 h dr$$

$$\frac{MDP}{H} = \frac{2\pi R^2 h}{4\pi R^2}$$

SS17-4 #8(W) 1.0 mils (5) 80°F Trace = Rod #2
 1 atm Sea Water

Horizontal = 0.025 in (Char)
 Vertical = 10000 microinches/div

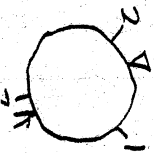
CHART NO. 70434086
 ARITH. AVE. SCALE
 Dayton, Ohio
 Bendix Automation & Measurement Division



P.12

Horizontal = 0.025 in/div
 Vertical = 1000 microinches/div
 SS17-4 #8 (W) 1.0 mils (S) 80°F
 1 atm Sea Water

Trace = Red #3



3434086

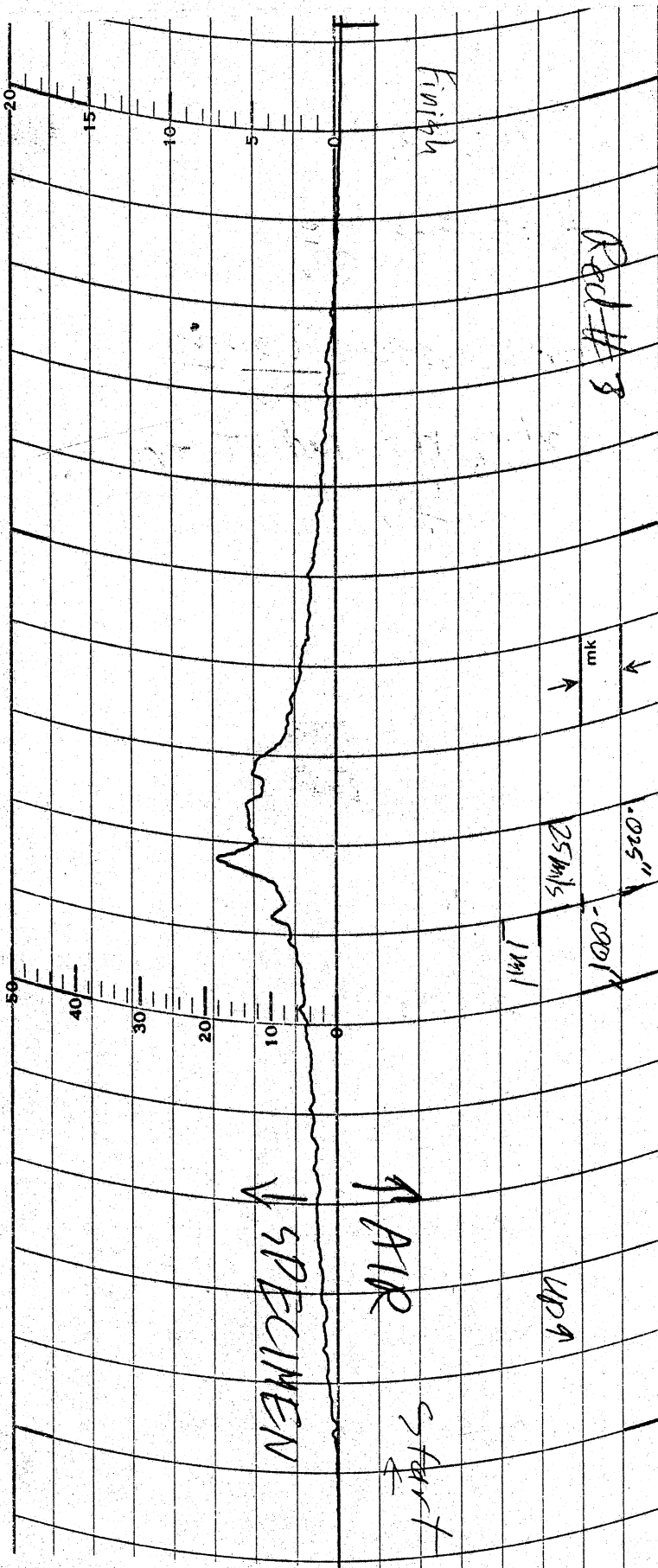


Automation &
Measurement
Division

Dayton, Ohio

ARITH. AVE. SC.

ARITH. AVE. SCALE



.003
 .010
 .020
 .030
 .040
 .050
 .060
 .070
 .080
 .090
 .100
 .125
 .150
 .200
 .250
 .300
 .400
 .500
 .600
 .700
 .800
 .900
 1.000
 1.250
 1.500
 2.000
 2.500
 3.000
 4.000
 5.000
 6.000
 7.000
 8.000
 9.000
 10.000

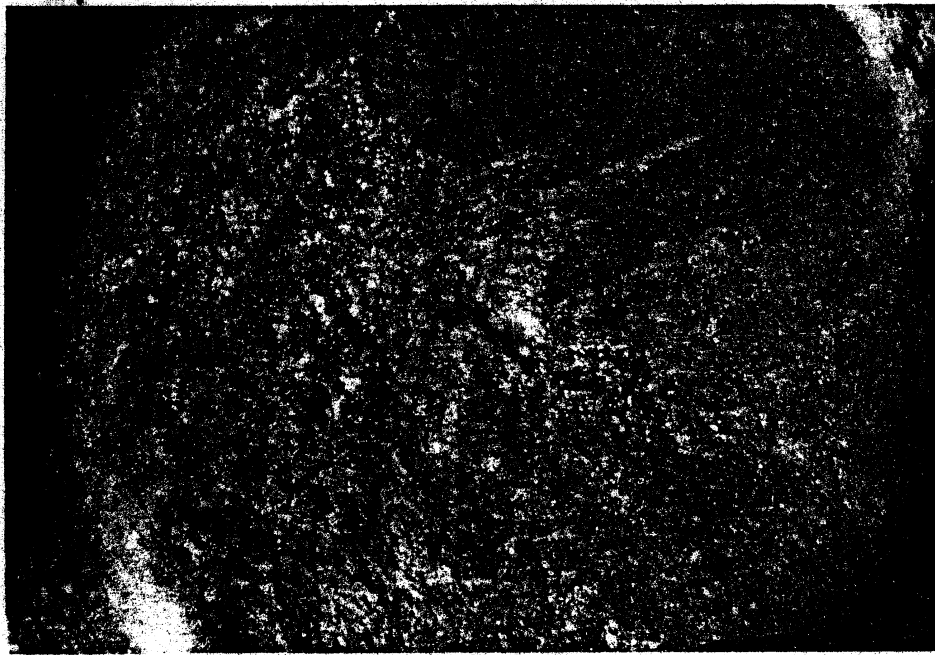
TOTAL WAVINESS
 DAUGHTER

MICROORDER
 PROFICORDER
 LINEAR
 ROTARY

DATE _____

p. 13.

27



→ | ← .022"

photo # 27

SS17-4C #3
1.0mils 90°F
1atm Sea Wat

Magnification
factor 13.64

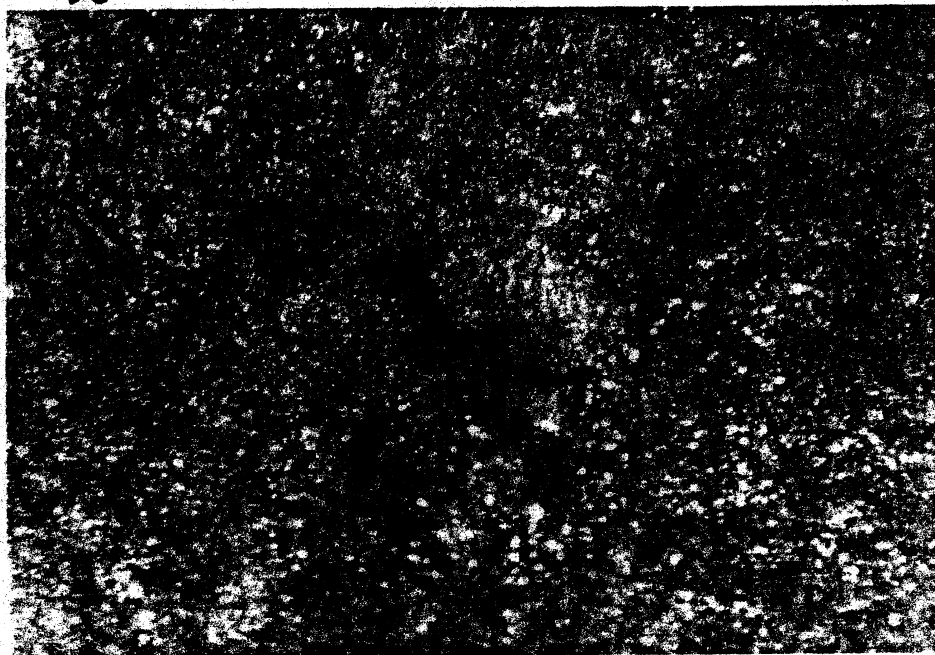
$$MDPR = 138.6 \frac{mi}{100}$$

$$Depth_{max} = 6 \text{ mils}$$

$$MDP(cum) = 0.32 h$$

$$\frac{Depth(max)}{MDP(cum)} = 18.75$$

30



/.026" /

photo # 30

SS17-4C #3
1.0mils 90°F
1atm Sea Wat

Magnification
factor 42.31

P.14

80°F = 1 atm
1.0 mils, Sea water

Vertical = 1000 micrometers
Div.

Horizontal = 0.025 mils

Trace #1

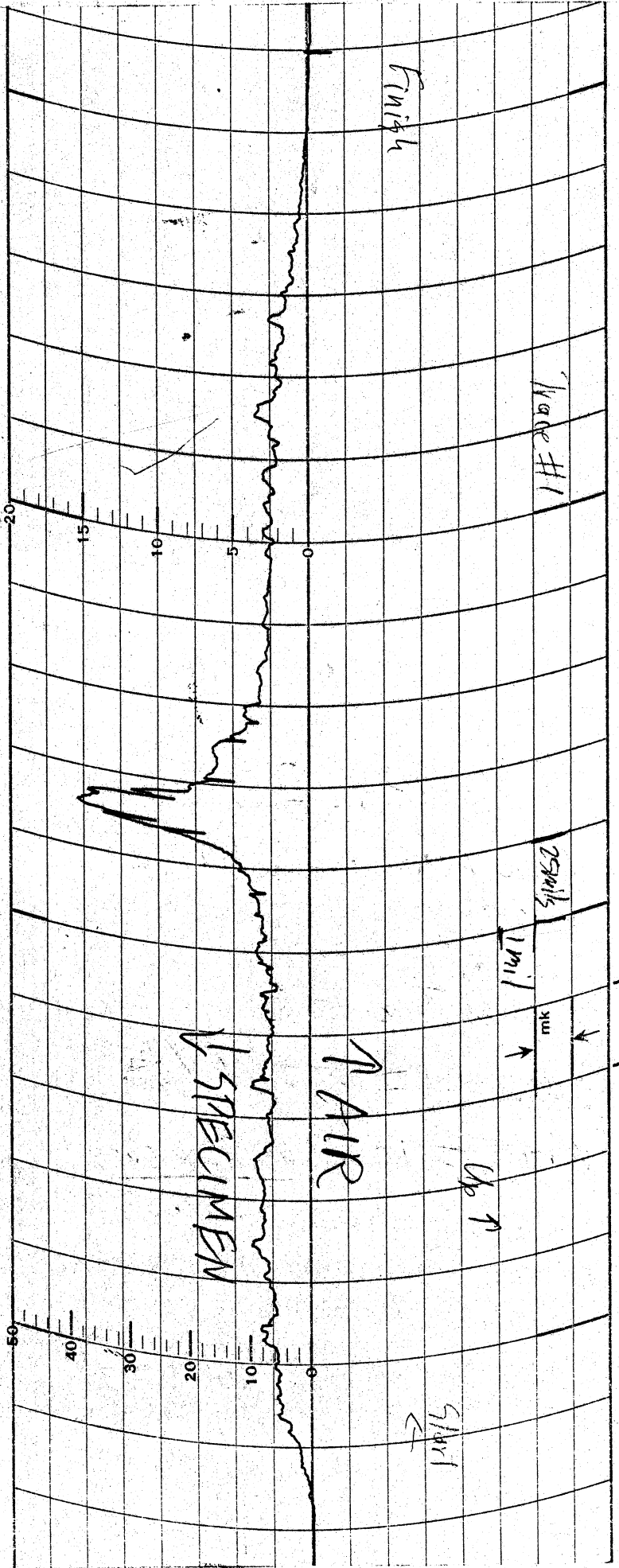
SS17-UC#3

CHART NO. 70434086

Bendix **NEW CHART**
Automatically Measuring Division
Ohio

ARITH. AVE. SCALE

ARITH. AVE. SCALE



MICRORECORDER
 PROFICORDER
 LINEAR
 ROTARY

TOTAL
 WAVELENGTH
 WAVELENGTH

.003
 .010
 .030

.0001
 .0005
 3/32

CUTOFF: STYLUS R. DATE _____
 PART NO. _____

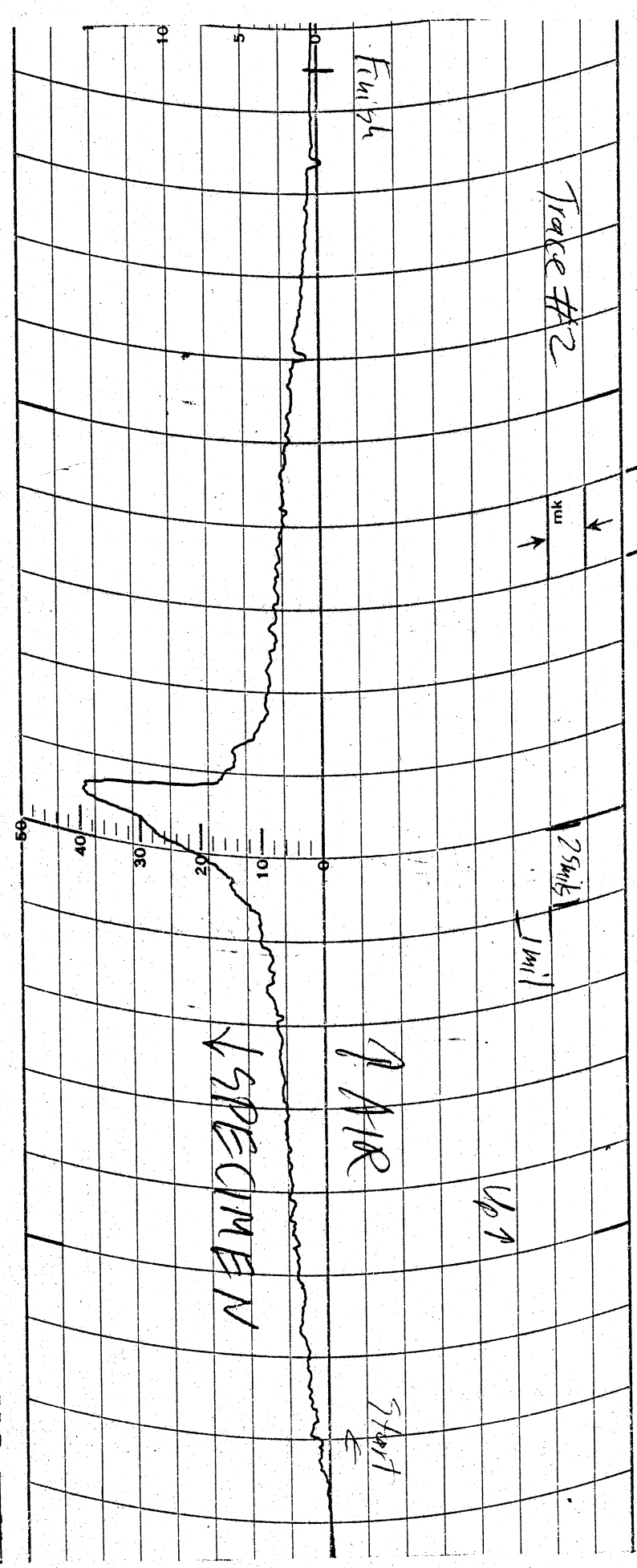
RPM

@

518

Vertical = 1000 microinches/div
 Horizontal = 0.025 in/div
 80°F 1 atm
 SS17-UC #3 1.0 mils sea water
 Trace #2

ARITH. AVE. SCALE **RESEARCH** **CHART** ARITH



TOTAL WAINESS
 MICROORDER
 PROFICORDER
 LINEAR
 DATE _____
 .0001
 .0005

P16

TITANIUM

Ti #16-A

This sample has a damaged surface consisting of concentric circles made up of grooves and ridges. The approximate distance between grooves is 3 mils. Near the center there are two deep grooves (or possibly one circular groove) with maximum depths of 2 mils. The proficorder did not go through the central hole but from the photographs it has a diameter of 6.1 mils.

Ti #11

Titanium #11 has smooth even damage with a fairly even maximum depth of penetration of 1 mil. Upon close examination of photo #15 rings can be seen, but whether they are concentric circles or a helix cannot be determined from the picture.

Ti #18-A

This sample is similar to the previous samples because it too has concentric circles with a maximum penetration of 2 mils, but examination of photo #17 will show a helix at the center, which proceeds for approximately 2 revolutions before turning into concentric circles. Again, the proficorder did not go through the central hole. Photo #20 shows that the rings go all the way out to the edge.

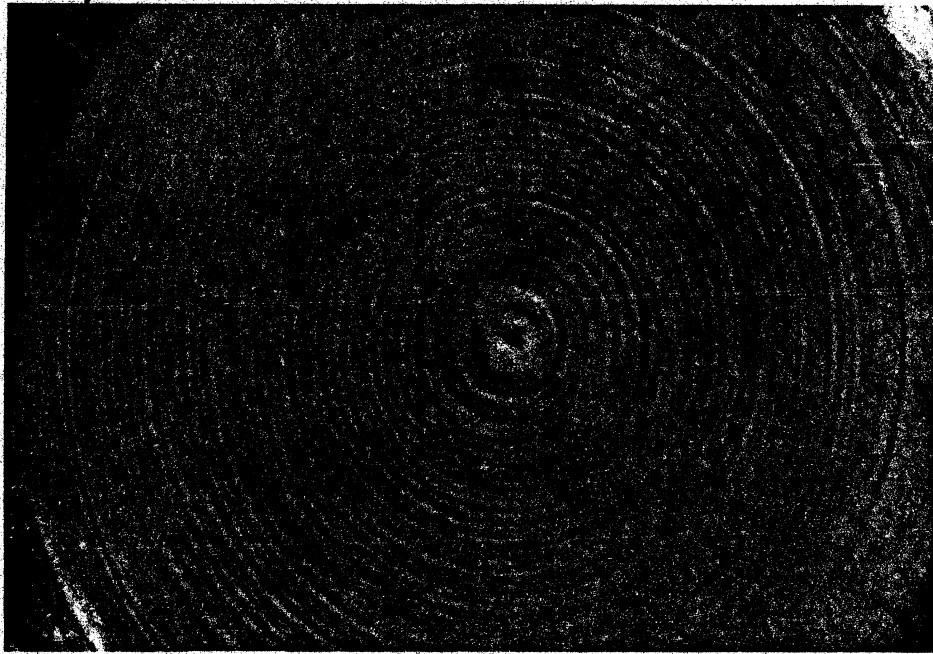
NOTE:

The occurrence of the rings, which were not apparent before damage, appears to be too regular to be a natural phenomena. The regularity of the circles (and the helix at the center of Ti #18-A) appear to be a result of machining. Upon talking to the machinist (Francis Smith), who made Ti #16-A and Ti #11, he didn't know what could have caused the rings, nor did he know what his tool advance was.

Not knowing what the heat treatment for the Titanium was I found that the average elongation to fracture for Titanium 6AL4V was 12.5% S.D.*=2.5%. Nowhere else, except a little in SS17-4#8(W), do these rings occur.

Perhaps an explanation for the rings would be that in manufacture on the lathe, the surface of the sample has been cold-worked in such a way so as to cause the rings to be produced during cavitation so that the location of failure coincides with that of cold-work (or it's absence). No further explanation can be suggested at this time.

p18



.468"

photo # 7

Ti #16-A AeroSe
 1.0 mils 90°F
 latin Sea water

Magnification
 factor 10.00

$$MDPR = 111.34 \frac{\text{mil}}{1000}$$

$$\text{Depth}_{\text{max}} = 2 \text{ mi}$$

$$MDP(\text{cum}) = 0.486 \text{ m}$$

$$\frac{\text{Depth}(\text{max})}{MDP(\text{cum})} = 4.11$$

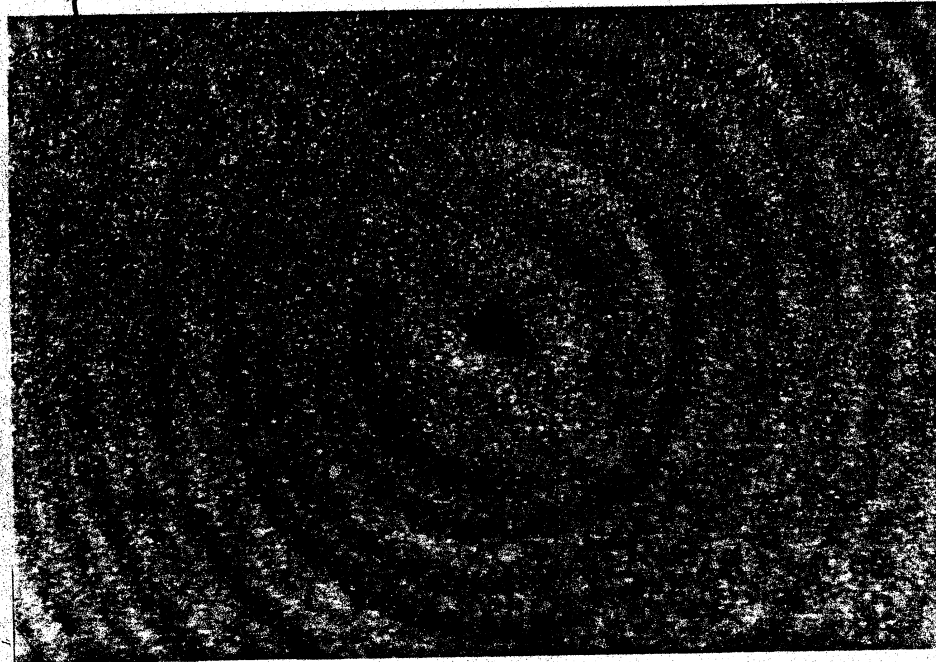


photo # 9

Diameter of center hole = 0.0061"

Ti #16-A
 1.0 mils 90°F
 latin Sea water

Magnification
 factor = 41

Δ between = .00
 rings

Vertical = 1000 Microinches/Div

Horizontal = 0.025 in/Div

Radical Trace #1

Sea Water

80°F

Tc #16-A 1.0 mils Latex

CHART



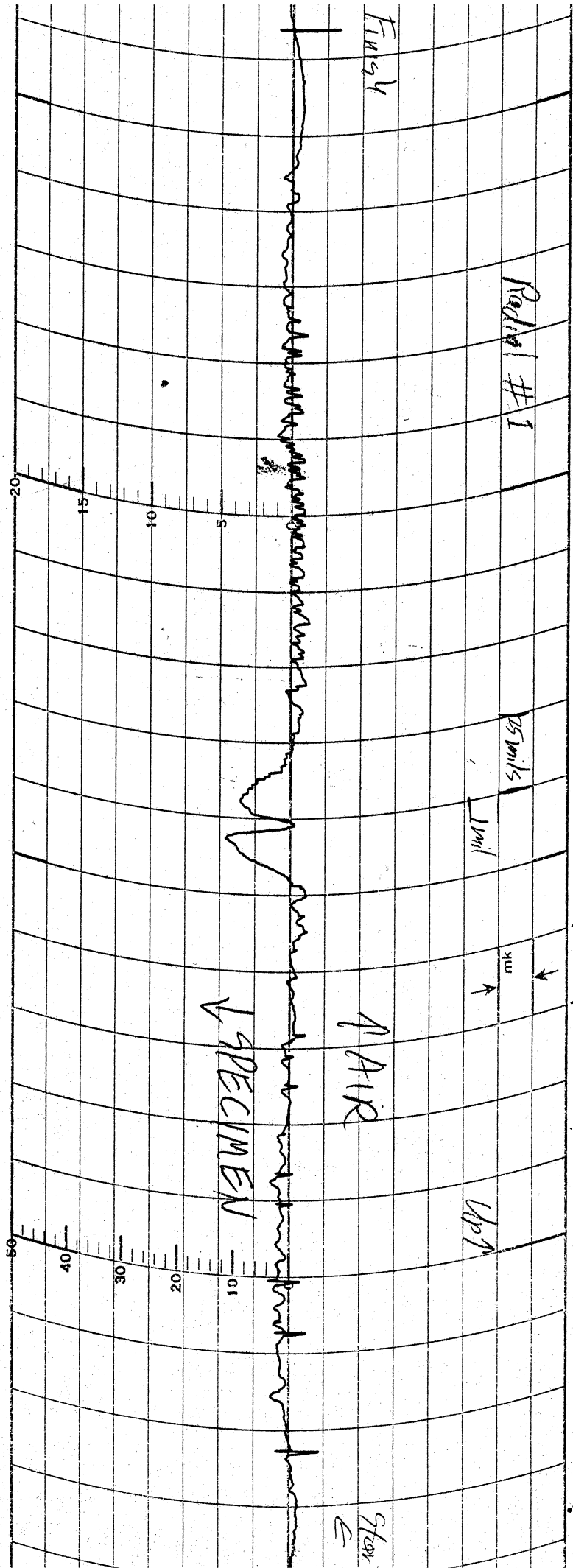
Automatic Measurement Division

CHART

ARITH. AVE. SCALE

CHART NO. 70434086

ARITH. AVE. SCALE



MICROORDER
 PROFICORDER
 LINEAR

TOTAL
 WAVINESS

.003
 .010

.0001
 .0005

DATE

STOP

FINISH

20

Vertical = 1000 microwholes/div

Horizontal = 0.025 inches/div

80°F Sea Water

Ti #16-A 1atm 1.0 mils

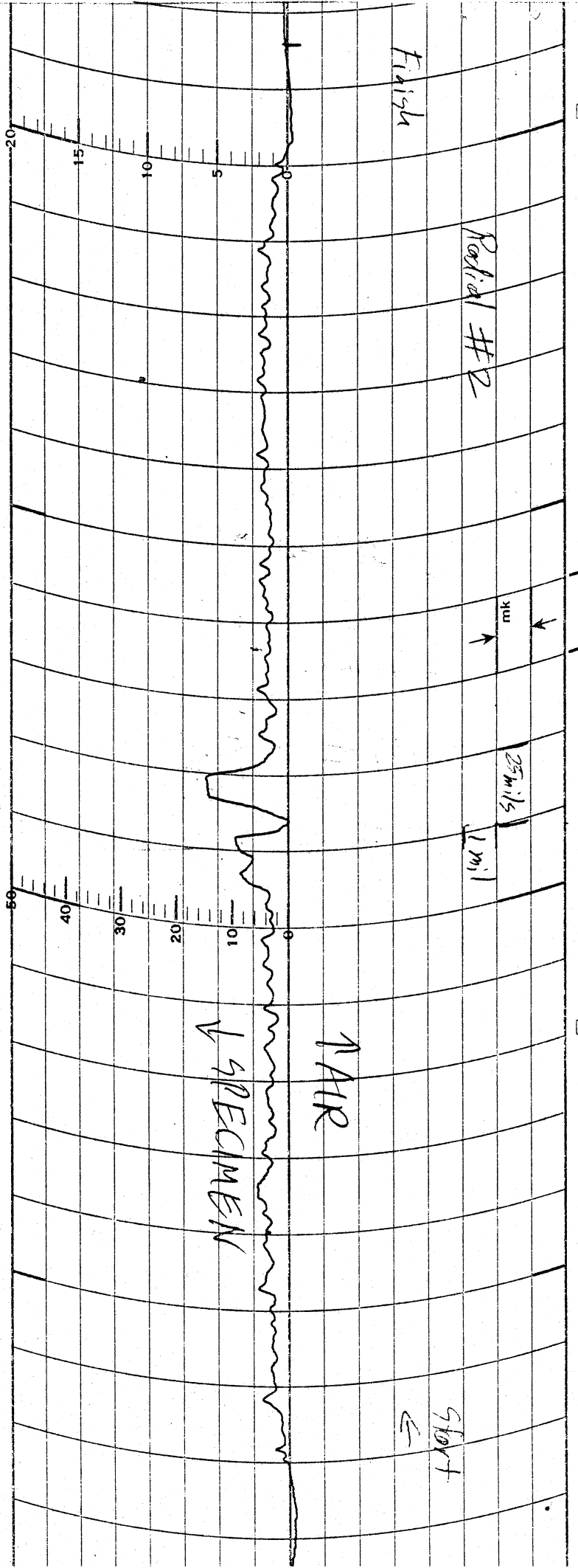
Radial # 2

CHASE NO. 70434086

RESERVE WATCH ART
Ohio
Measurement Division

ARITH. AVE. SCALE

ARITH. AVE. SCALE



.003

TOTAL

MICROORDER
 PROFICORDER

DATE

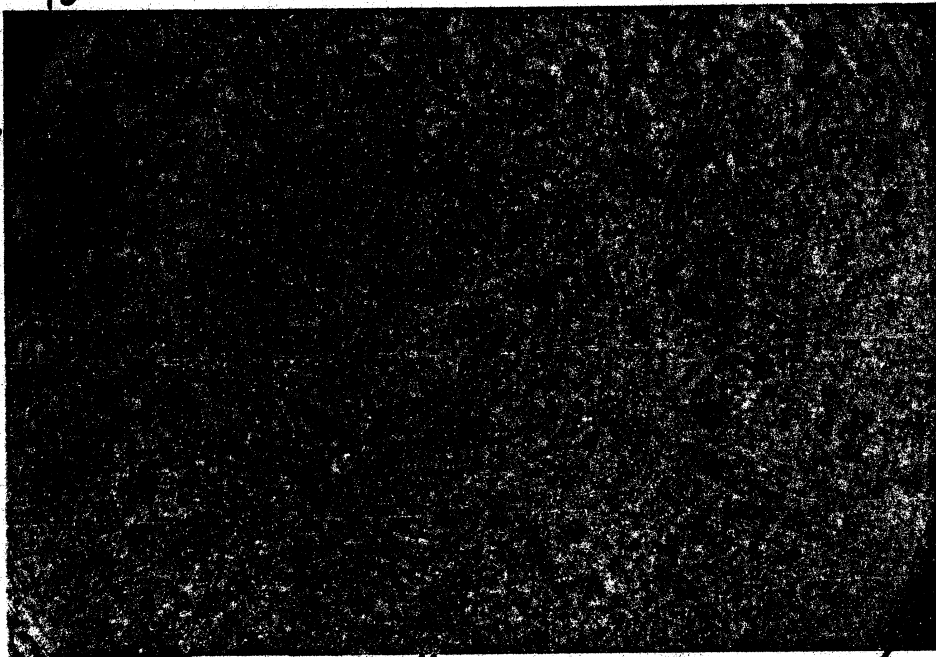
.0001

Start

p21.

photo # 15

15



.513"

Tc # 11
10 mils 90°F
catn Sea Water

Price of Damage = 0.513"

Magnification
factor 10.33

MDPR = 158.2 $\frac{\text{mils}}{1000 \text{ hr}}$

Depth_{max} = 1 mil.

MDP(cum) = 0.468 mils.

$\frac{\text{Depth (max)}}{\text{MDP(cum)}} = 2.13$

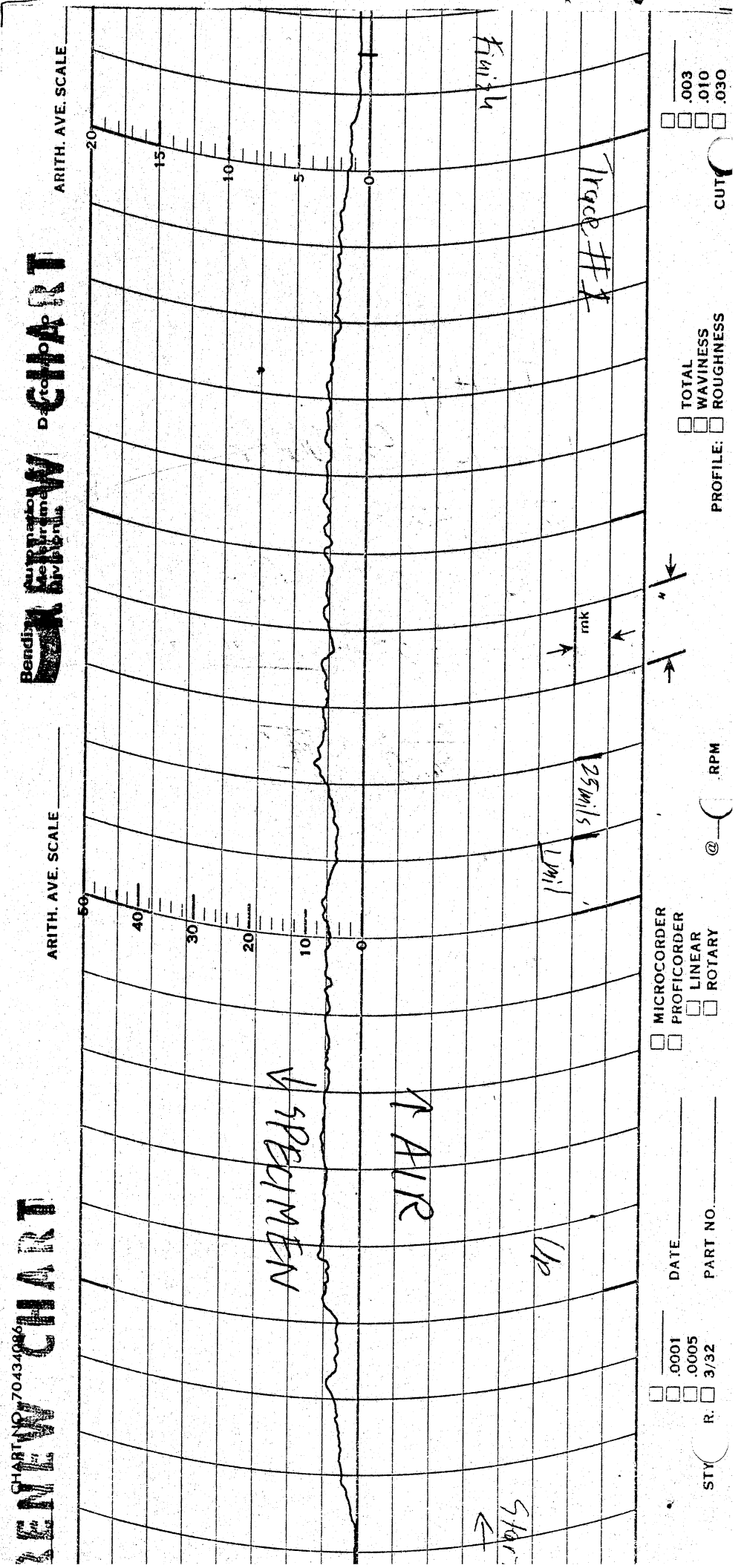
2nd

Horizontal = 0.025 in./div.
Vertical = 1000 microinches/div.

1.0 mils Sea Water
1 atm. 80°F

Radial trace #1

Li #11



RENEW CHART

RENEW CHART

ARITH. AVE. SCALE

ARITH. AVE. SCALE

STY .0001 .0005 R 3/32

DATE _____ PART NO. _____

MICROCORDER PROFICORDER
 LINEAR ROTARY

RPM _____

PROFILE: TOTAL WAVINESS
 ROUGHNESS

CUT

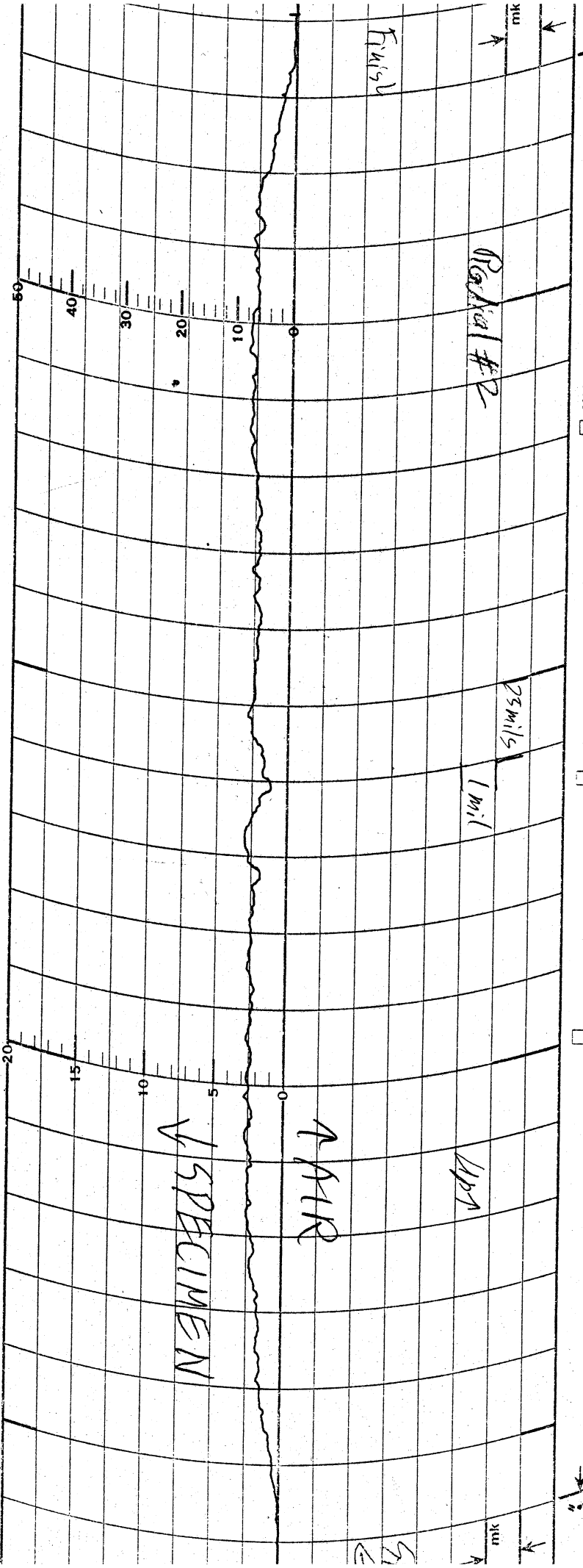
.003 .010 .030

223

Vertical = 10000 microinches/div
Horizontal = 0.025 in/div
80°F Sea Water
1.0 mils Latex
Trace #2

Automation & Measurement Division
Dayton, Ohio
RENEW CHART
ARITH. AVE.

CHART NO. 70434086
RENEW CHART
SCALE



MICRORECORDER
 PROFICORDER
 LINEAR
 ROTARY

DATE _____ PART NO. _____

.001
 .005
 3/32

STYLUS R. _____

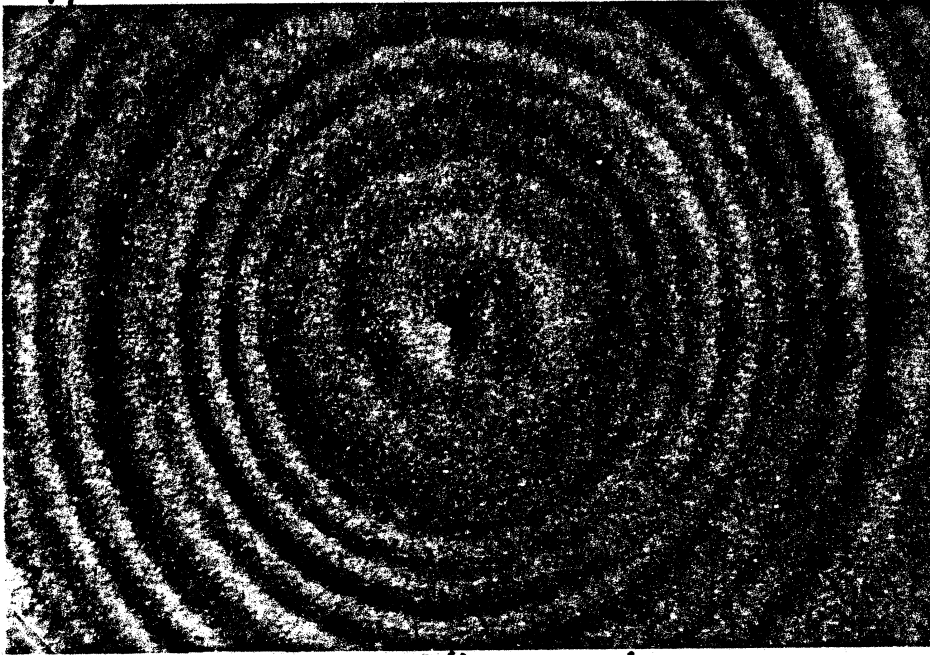
.003
 .010
 .030

CUTOFF: _____

TOTAL
 WAVINESS
 PROFILE: _____
 ROUGHNESS

P24

17



.047"
photo # 17

TC # 18-A Aero J-
1.0 mils 90°F
water Sea Water.

Magnification
factor 40.43

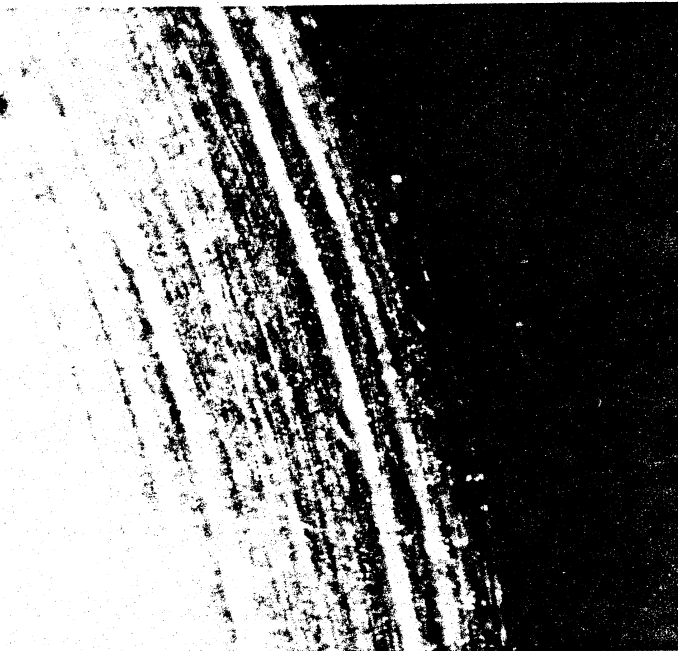
$$MDPR = 108 \frac{\text{mil}}{1000 \mu}$$

$$\text{Depth}_{\text{max}} = 2 \text{ mils}$$

$$MDP(\text{cum}) = 0.706 \text{ mi.}$$

$$\frac{\text{Depth}(\text{max})}{MDP(\text{cum})} = 2.83$$

20



.019"

photo #20

TC # 18-A
1.0 mils 90°F
water Sea Water

Magnification
factor 47.77

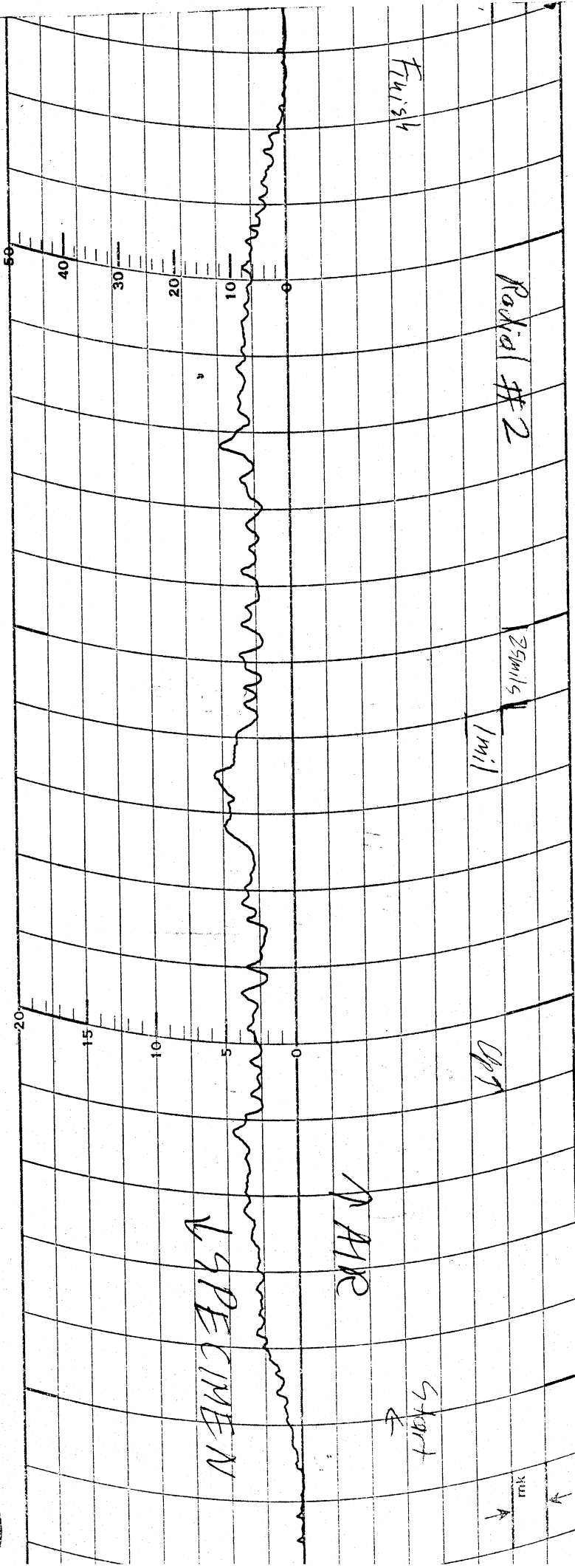
RENEW CHART

CHART NO. 70434086

RENEW CHART

Dayton

Automation & Measurement Division



MICRORECORDER
 PROFICORDER
 LINEAR
 ROTARY

DATE: _____ PART NO. _____

.0001
 .0005
 .001
 .005
 .010
 .030

CUTOFF: .003
 .010
 .030

PROFILE: TOTAL WAVINESS
 WAVINESS
 ROUGHNESS

RPM

Te #18-A 1.0 mils 1atm

90°F Sea Water

Horizontal = 0.0025 in/div

Vertical = 10000 microinches/div

Trace # 2

027

appendix #1

PROFICORDER SAMPLES OF
UNDAMAGED SPECIMENS

Proficorder readings of two specimens were made prior to damage. The first one 316 SS#1 shows a peak of 0.5 mils at the center and the sides hollowed out to a depth of 0.25 mils. The second sample shows a smooth surface with virtually no faults. Both specimens were made at the same sensitivities.

228

Vertical = 250 microinches per division
Horizontal = .025 in. per division

316 SS #1 Blank Trace

PART NO. 70434085

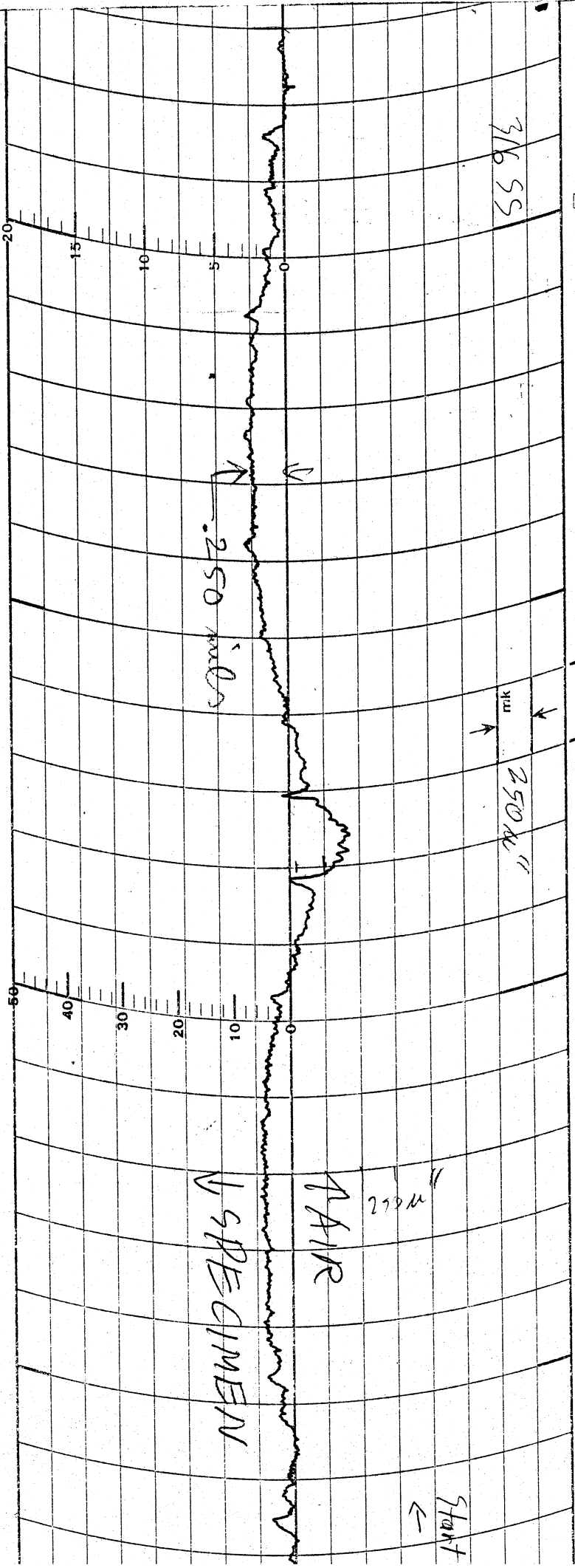


Dayton, Ohio

ARITH. AVE. SCALE

ARITH. AVE. SCALE

CHAR



MICRORECORDER
 PROFICORDER
 LINEAR
 ROTARY

TOTAL WAVINESS
 PROFILE: ROUGHNESS

.003
 .01
 .02
 .05
 .1
 .2
 .5
 1
 2
 5
 10
 20
 50
 100
 200
 500
 1000

CUTOFF: _____
 @ _____ RPM

DATE _____ PART NO. _____
 .0001 .05 2
 STYLUS R.

STYL

229

Vertical = 250 micromiles per div
Horizontal = .025 in per div.

CS 1018 #4 Blank Trace

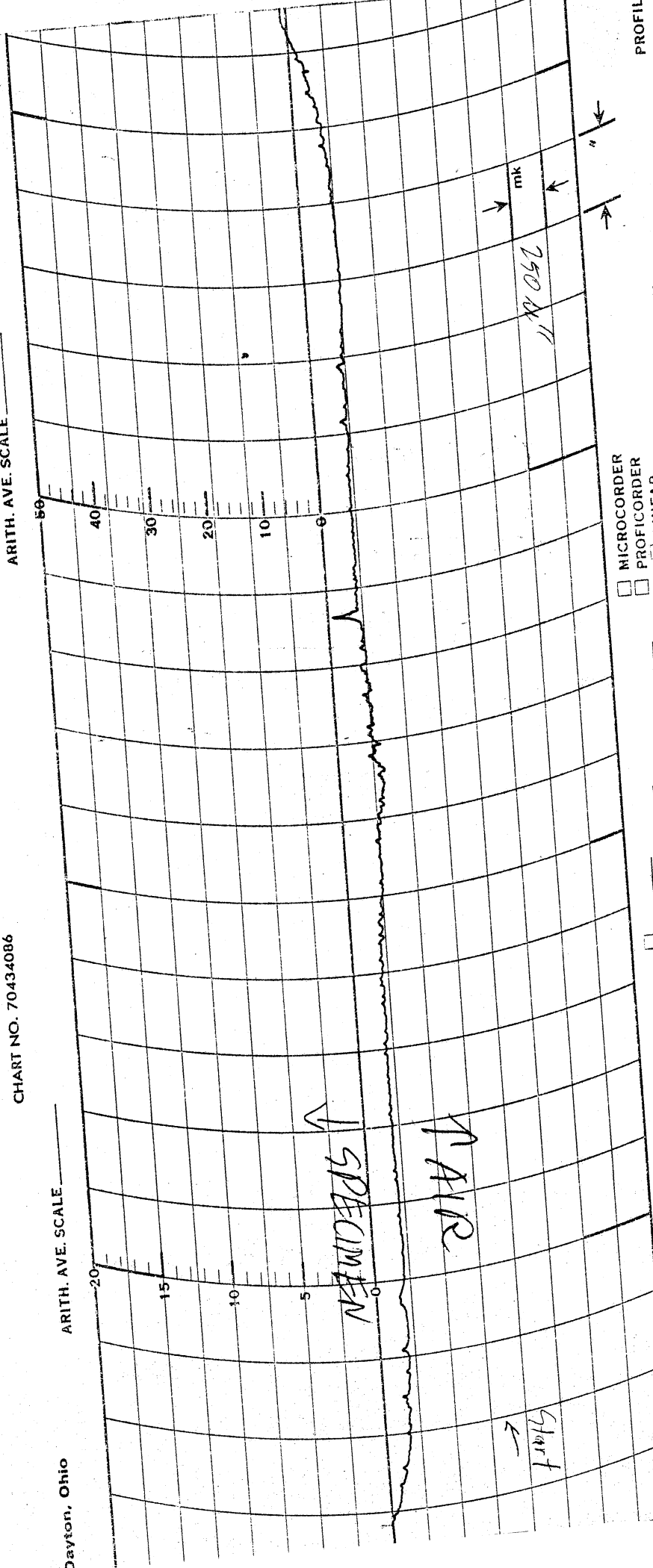


ARITH. AVE. SCALE

CHART NO. 70434086

ARITH. AVE. SCALE

Dayton, Ohio



MICRORECORDER
 PROFICORDER
 LINEAR
 ROTARY

@ _____ RPM

DATE _____

PART NO. _____

.0001
 .0005
 .010
 .030

STYLUS R. 3/32

.003
 .010
 .030

CUTOFF: _____

TOTAL
 WAVINESS
 ROUGHNESS

UNIVERSITY OF MICHIGAN



3 9015 02826 7527