MLM-MU-89-66-0001

A Study of Laseruler Accuracy and Precision (1986–1987)

Ram S. Ramachandran and Kenneth P. Armstrong

June 22, 1989

MOUND

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EG&G MOUND APPLIED TECHNOLOGIES
P.O. Box 3000, Miamisburg, Ohio 45343-0987

for the
U. S. DEPARTMENT OF ENERGY
Contract No. DE-AC04-88DP43495

DISCLAIMER

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Contents

Abstract

A study was conducted to investigate Laseruler accuracy and precision. Tests were performed on 0.050-in., 0.100-in., and 0.120-in. gauge block standards. Results showed an accuracy of 3.7 μin. for the 0.12-in. standard, with higher accuracies for the two thinner blocks. The Laseruler precision was 4.83 μin. for the 0.120-in. standard, 3.83 μin. for the 0.100-in. standard, and 4.20 μin. for the 0.050-in. standard.

Introduction

The MC3926 and 1E38 detonators were developed based on studies conducted by Quality, Production, and Development personnel. In the early stages of the programs, the tape process studies were documented in memos. To formally record these studies and make them easily available to interested persons, these memos are being compiled as Mound technical reports. This report documents research performed by R. S. Ramachandran in December 1986.

Ramachandran conducted the studies to investigate the accuracy and precision of the Laseruler, a nondestructive tool used to measure substrate thickness. In this study, the thickness of copper on finished bridge circuits was measured with the Laseruler. Three standard gauge blocks were examined. Analyses showed the Laseruler accuracy to be 3.7 μin. on the 0.120-in. standard, 2.8 μin. on the 0.100-in. standard, and 1.3 μin. on the 0.050-in. standard.

The precision (1 sigma), or total standard deviation, of the Laseruler on the gauge block standards was determined to be 4.83 μin. for the 0.120-in. standard, 3.83 μin. for the 0.100-in. standard, and 4.20 μin. for the 0.050-in. standard. A previous study on MAD-1079 bridges had shown an estimated precision of 3.62 μin. within a 164-μin. range.

Analysis of the variance showed a significant difference between measurements taken in the morning and evening and also among measurements taken on different days. In addition, a difference in measurements among operators was noted. This was caused by manual manipulation of the standards during the study and should be greatly reduced during normal inspection of bridge circuits because laseruler operation is automated.

Content

This report comprises four memos (the *Laseruler Accuracy and Precision Study* memo contains an additional memo) summarizing work performed in the tape process area. The memos are reproduced unedited.

MOUND

Inter–Office Correspondence

From: Experimental Design, Nuclear Operations, S. E. Rigdon

cc. D. B. Armstrong
File

Date: April 29, 1986

Subject: Thickness Measurements Using Laser Ruler

Reference:

To: R. S. Ramachandran

Objective

The objectives of these two experiments were to find the settings of the variables

probe weight in ounces (WEIGHT)
time spent by the probe on the tape in seconds (TIME)
shape, i.e. flat or spherical, of the probe (SHAPE).

which minimize the variability of repeated measurements when using the laser ruler to measure tape thicknesses.

Experimental Designs

The first experimental can be described as follows:

Shape	Time	Weight
S	2	2
S	2	4
S	4	2
S	4	4
S	8	4
F	2	2
F	2	4
F	4	2
F	4	4
F	8	2

Each of the above combinations was run three times on each of five 1E–38 units. For each unit, the average of the three readings and the standard deviation of the three readings were computed. The run order was randomized. Note that this design is not totally balanced; there was no run for SHAPE='S', TIME=8 and WEIGHT=2 nor was there a run for SHAPE='F', TIME=8 and WEIGHT=4. Originally, these runs were to be performed, however time constraints within one day dictated that only two runs at TIME=8 could be performed within one day.

The second experimental plan may be described as follows:

Shape	Time	Weight
S	2	2
S	2	4
S	4	2
S	4	4
S	8	2
S	8	2

Each combination was run three times on each of five units. Again, the order was randomized.

Analysis

The standard deviation of the three readings on each of the five units was treated as the response variable. Thus, for the first experiment, there were five responses for each combination of factors, yielding 50 responses. For the second experiment, there were five responses for each combination, yielding 30 responses. While these responses are not normally distributed, they should be reasonably close to a normal distribution so that analysis of variance can be performed.

Figure 1 shows, for the first experiment, the average of five standard deviations, each standard deviaiton being based on three readings on the same unit under the same conditions. The red pyramid indicates that a flat probe was used and a green pyramid indicates that a spherical probe was used. From this graph it is apparent that the flat probe yields higher variability. Also, the flat probe showed signs of deforming the surface of the tape. Thus a flat probe is not desirable. From the first experiment, it cannot be determined whether the variables TIME and WEIGHT affect the variability. For this reason the second experiment was run.

With fewer required runs per day, the second experiment could include two runs at TIME=8. As a result, the second experimental design is balanced. Again in the second experiment, the response variable was the standard deviation of three measurements on a given unit. Since there were five units, there were five standard deviations at each combination of factors. Figure 2 shows the average of five standard deviations, each standard deviaiton being based on three readings on the same unit under the same conditions. Note, in this graph, that the height of the "spikes" are all about the same. Figure 3 shows the actual standard deviations. Since the graphs are inconclusive, an analysis of variance was performed using the standard deviation as the response variable. The analysis of variance table is shown in Table 1. The F–statistics for the TIME and WEIGHT variables are 0.40 and 0.01, respectively. These are not significant at any reasonable significance level.

Conclusions

From the first experiment, it can be concluded that probe shape affects the variability of measured thickness, with the spherical probe having smaller variability. The second experiment indicates that neither time nor weight affect the variability of the laser ruler. Thus it is recommended that the laser ruler be operated with a spherical probe at the most economical levels of TIME and WEIGHT, i.e. at TIME = 2 sec. and WEIGHT = 2 oz.

Repeatability Testing

Once the levels of TIME and WEIGHT are determined, a repeatability test should be performed. An experimental plan for this experiment may be described as follows. Twenty to thirty bridges, manufactured from the process that will be used in Production, should be used. The thickness of each bridge should be gaged three to four times a day for each of three to five days. If four readings per day are done, then two technicians may be employed.

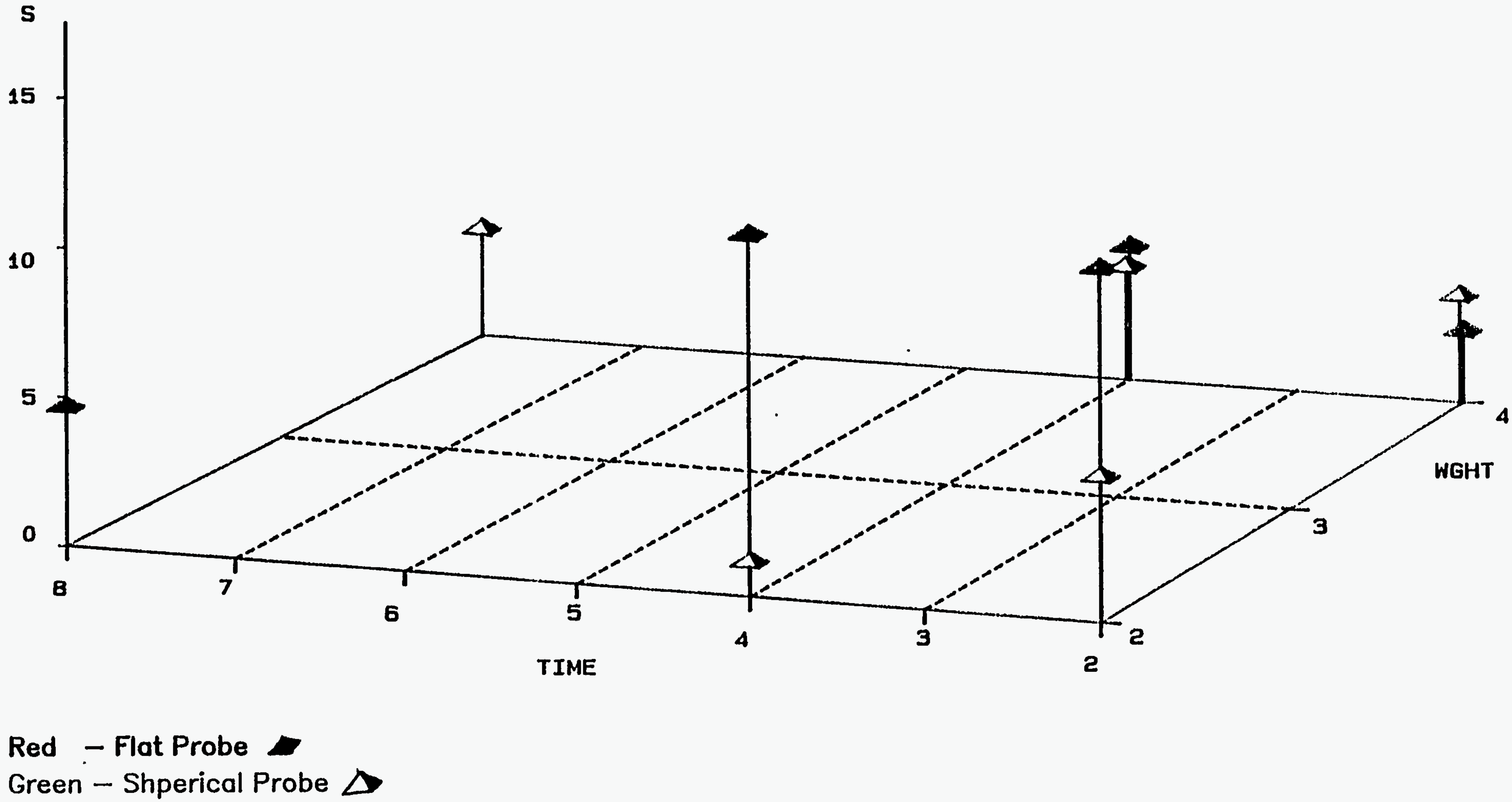
The numbers given above are only rough at this time. Further discussion may result in changes. However, some idea of the magnitude of the next study should now be apparent.

Steve

Steve Rigdon

Figure 1

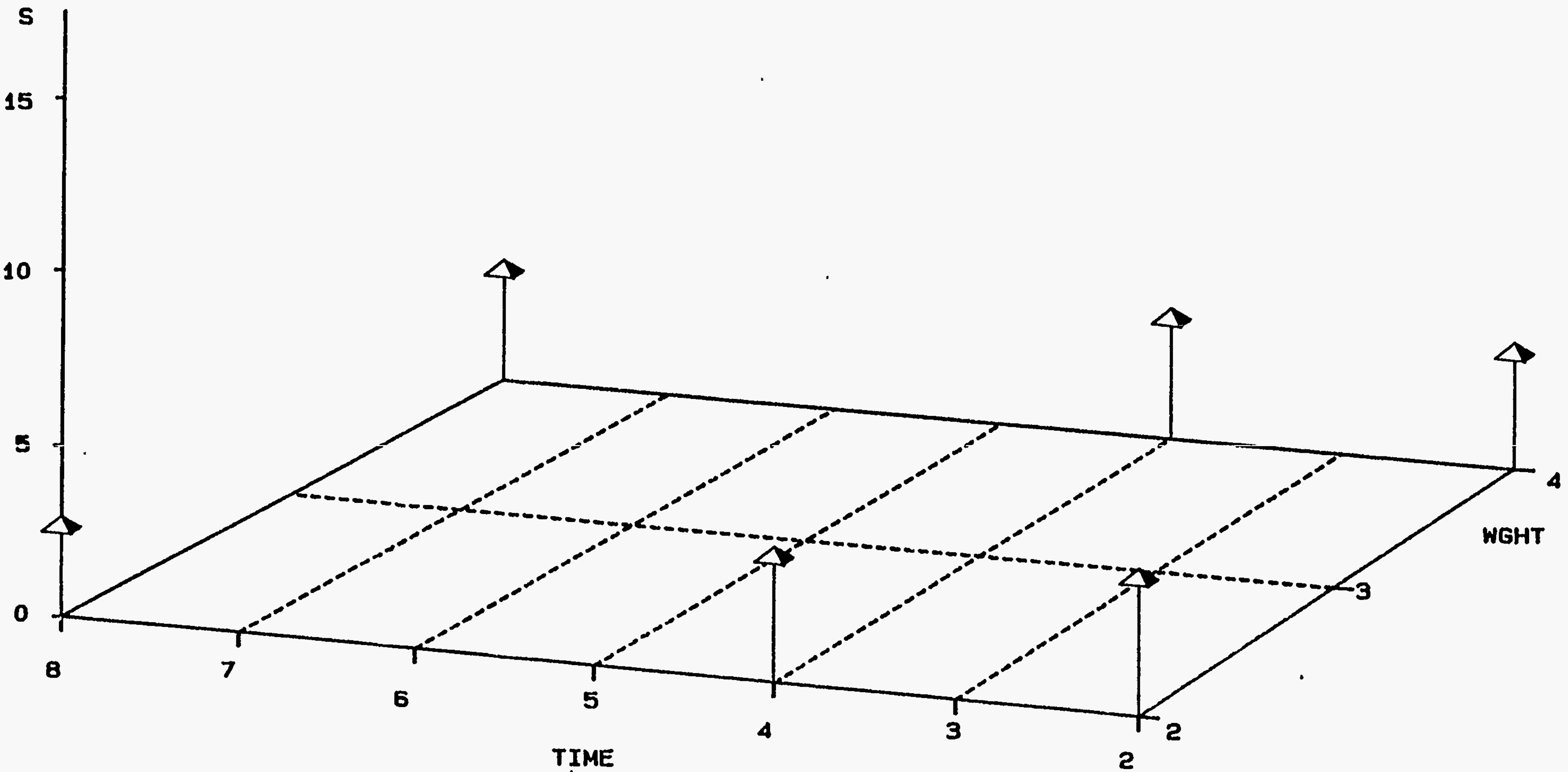
Average Standard Deviation of 3 Readings on 5 Units for Levels of Probe Shape, Weight and Time



First Experiment

Figure 2

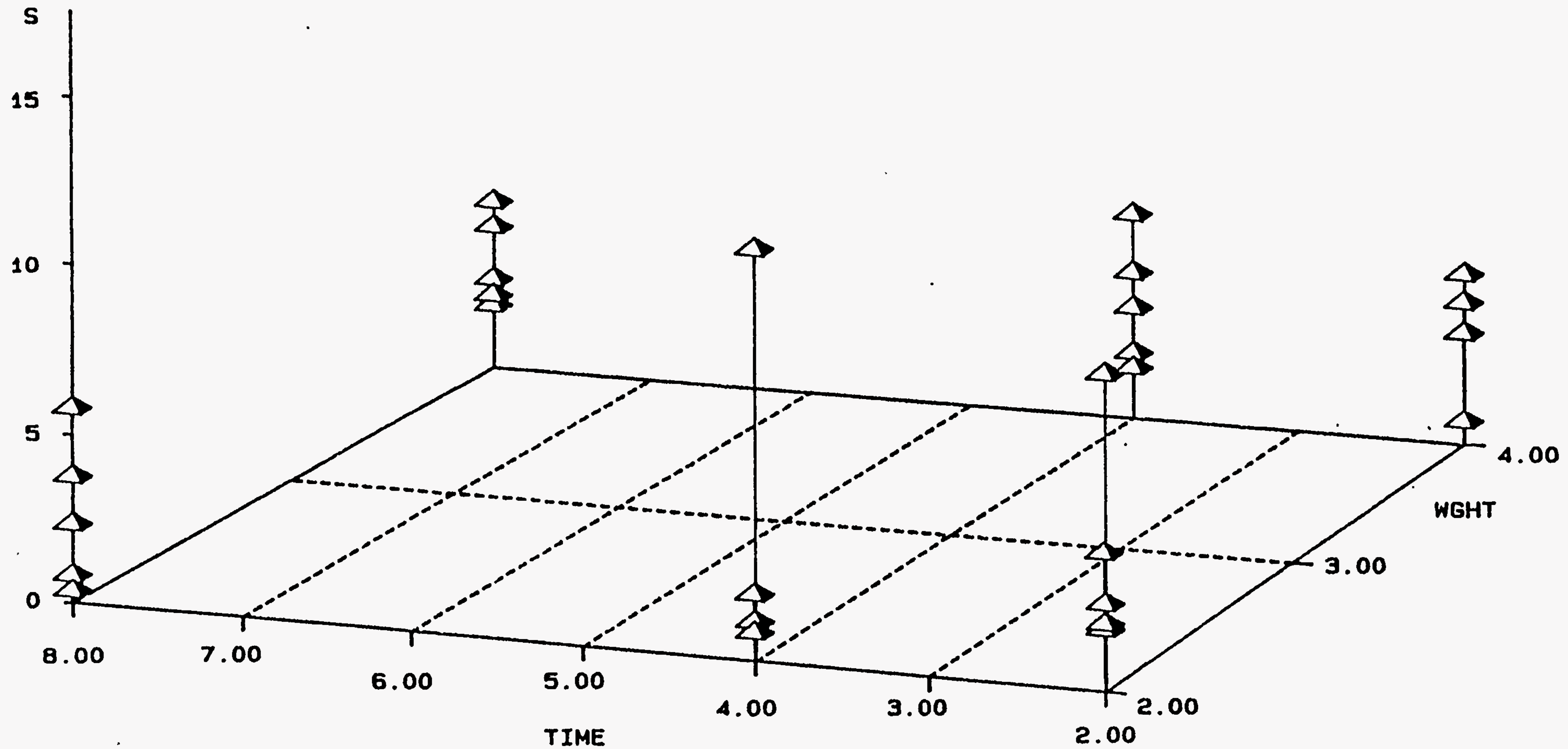
Average Standard Deviation of 3 Readings on 5 Units for Levels of Probe Shape, Weight and Time



Second Experiment

Figure 3

Standard Deviations of 3 Readings for Different Levels of Probe Shape, Weight and Time



Second Experiment

Table 1

Analysis of Variance
Table for Second Experiment

DEPENDENT VARIABLE: S

SOURCE	DF	SUM OF SQUARES	MEAN SQUARE
MODEL	2	2.79445298	1.39722649
ERROR	27	182.71576369	6.76725051
CORRECTED TOTAL	29	185.51021667	

MODEL F = 0.21 PR > F = 0.8147

R-SQUARE	C.V.	ROOT MSE	S MEAN
0.015064	74.0786	2.60139395	3.51166667

SOURCE	DF	TYPE I SS	F VALUE	PR > F
TIME	1	2.70564374	0.40	0.5325
WGHT	1	0.08880924	0.01	0.9096

PARAMETER	ESTIMATE	T FOR H0: PARAMETER=0	PR > |T|	STD ERROR OF ESTIMATE
INTERCEPT	3.91031791	2.24	0.0336	1.74683120
TIME	-0.12044085	-0.63	0.5325	0.19047935
WGHT	0.05447951	0.11	0.9096	0.47556536

$

MEMO — Inter-Office Correspondence

From	:	QC Engineering, Administration R. S. Ramachandran
Date	:	October 18, 1986
Subject	:	Laseruler Data Analysis and recording
Reference	:	CIM Engineering Data Sheet No. 2, August 6, 1986

cc : C. E. Clark
G. L. Morris
W. D. Hugo
A. Poe
S. E. Rigdon
G. L. Huston
T. M. Bruggeman

TO : D. E. Wendeln

The following information is provided to support the Computed Aided Inspection justification with regard to the above reference prepared by Advanced Manufacturing Development.

Data analysis from a repeatability study with 28 units of MAD-1079 bridges gave an estimated precision between +/- 3.62 microinches within 164 microinches range. Measurement error of the Laseruler instrument determined from the designed experiment was 2.74 microinches. Analysis of Variance showed a standard deviation for the variance components as below:

Unit-to-unit variation	- 2.95 microinches
Day-to-day variation	- 1.43 microin.
Technician-to-technician	- 1.89 microin.
Measurement error	- 2.74 microin.

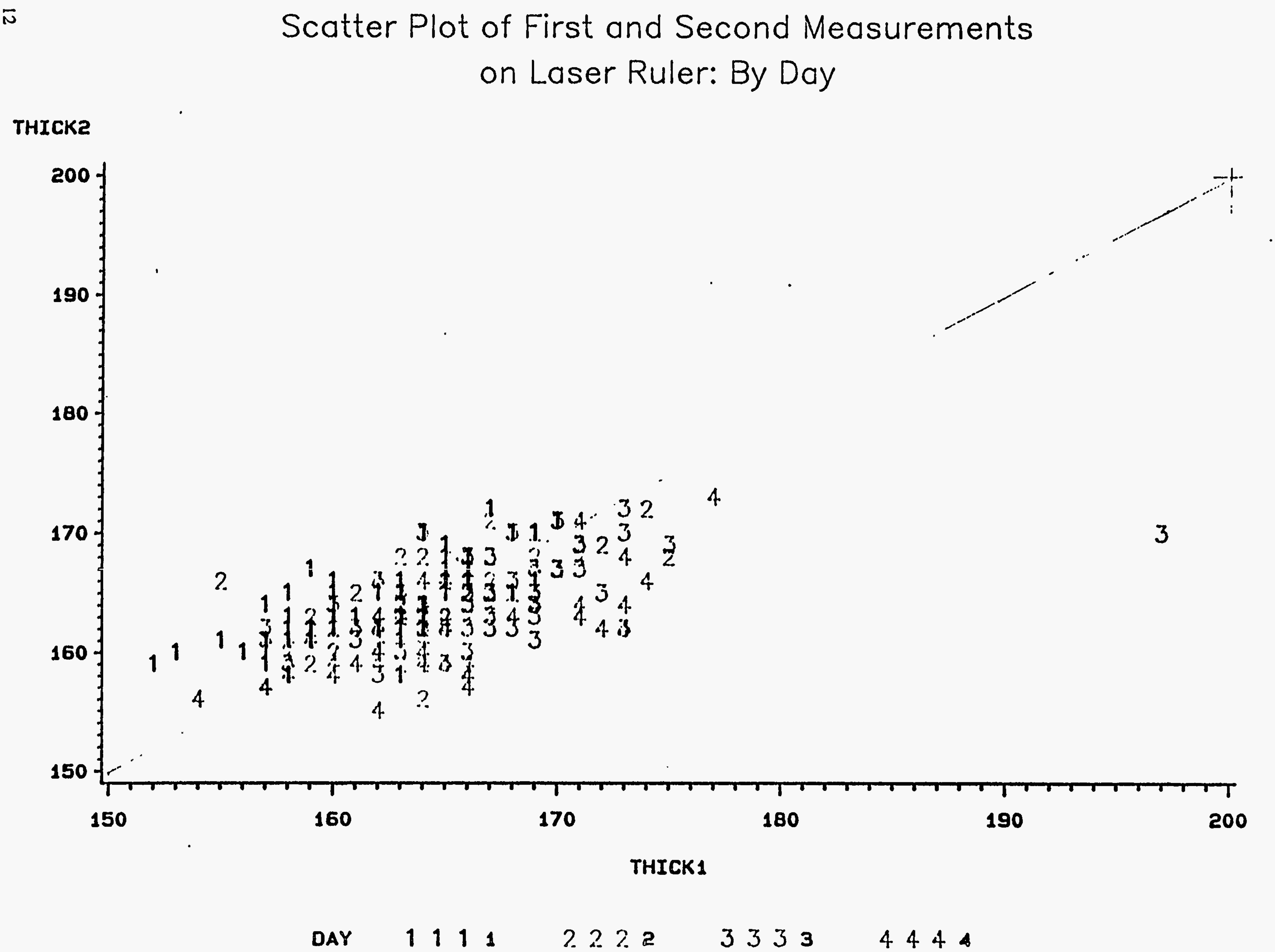
Total Measurement variability
excluding the unit variation - 3.62 microinches

Figure 1 shows no significant differences on measurements between day-to-day. The study did exhibit an operator-to-operator variability as determined by the student t-test. Also as seen in Figure 2 measurements between operators shifted slightly. Plots for Technician M is shifted to the right and up showing slight higher values than for the Technician J. The attached table provides a summary of recorded data. No significant difference between the first and second readings were noted.

R. S. Ramachandran

R. S. Ramachandran

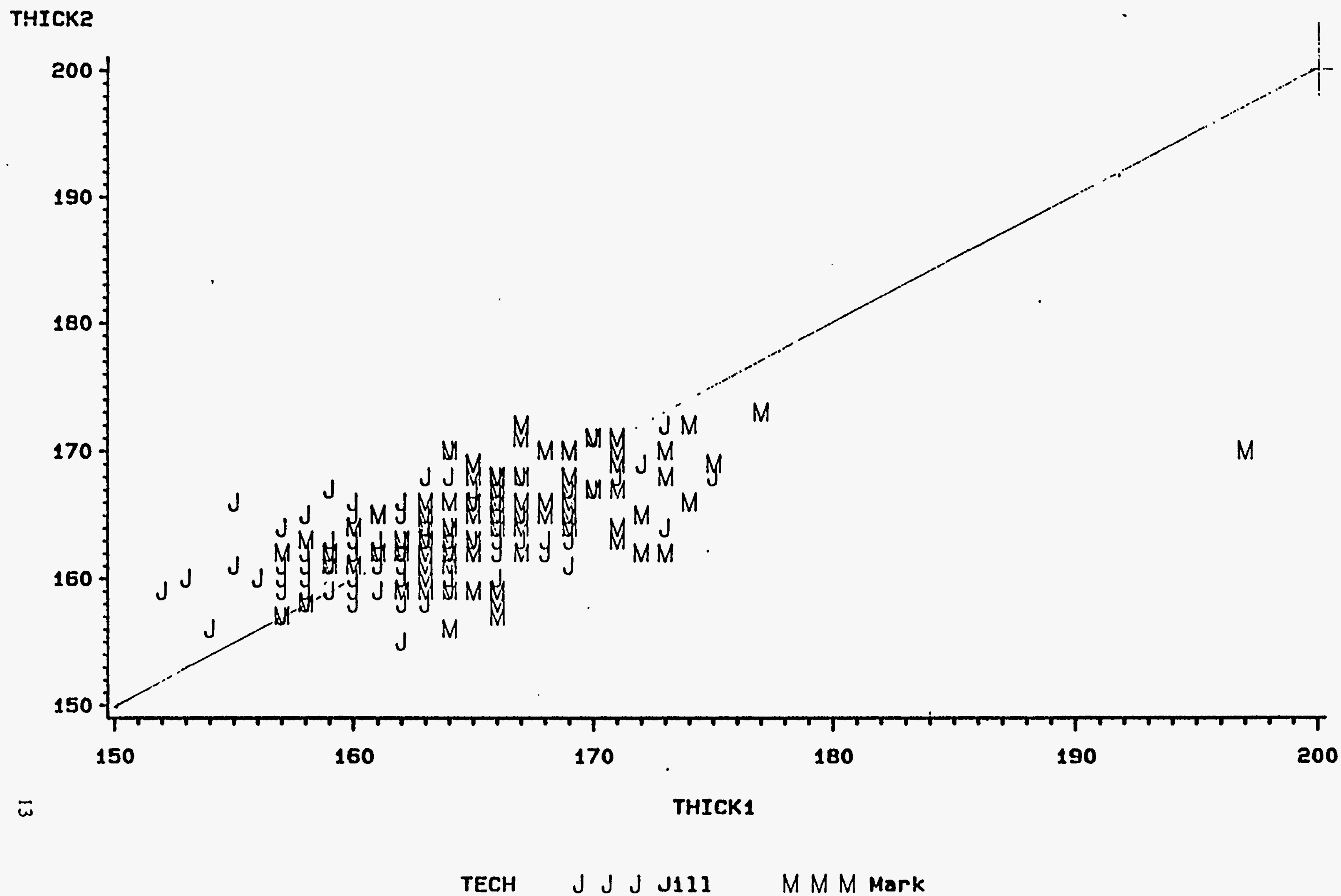
Figure 1



Scatter Plot of First and Second Measurements
on Laser Ruler: By Day
THICK2
200
190
180
170
160
150
150
160
170
180
190
200
THICK1
DAY 1 1 1 1 2 2 2 2 3 3 3 3 4 4 4 4

Figure 2

Scatter Plot of First and Second Measurements
on Laser Ruler: By Technician



Table

Laseruler measurement study

Statistics for two different runs

	Mean*	Std. Dev.	Range
Technician J			
First readings	162.62 microin.	4.448	152.00-175.00
Second readings	163.04 microin.	3.207	155.00-172.00
Technician M			
First readings	166.27 mciroin.	4.983	157.00-197.00
Second readings	164.75 microin.	3.750	156.00-173.00

* MAD-1079 bridge thickness measurement averages of 112 test data

MOUND

Inter-Office Correspondence

From : R. S. Ramachandran   cc : Distribution

Date : December 17, 1986

Subject : Laseruler Accuracy & Precision Study

Reference :

TO : A. L. Poe

Attached is the statistical report on the Laseruler accuracy and precision study with the three gauge block standards.

Analysis showed an accuracy of +1.3 microinches maximum bias on the 0.050 inch standard block. It should be noted that the bias increases with the thicker standard blocks. Manufacturer's accuracy specification for the Laseruler is 3 microinches within one inch envelope (1 cubic inch).

The precision (one sigma) of the Laseruler on three standards are 3.83 microinches (.100 inch standard), 4.20 microinches (.050 inches standard), and 4.83 microinches (.120 inch standard). The previous study on MAD 1079 bridge showed an estimated precision of 3.62 microinches within .000164 inches range.

Analysis of variance on the test data showed a significant difference within day (morning and evening measurements) and between days. Also, a statistical difference in measurements between operators was noted. This variation is because of manual manipulation of the gage block in the study. The operator-to-operator variability should be reduced greatly during the normal inspection of bridge circuits because of the automatic mode of Laserüler operation. Quality Engineering recommends that an environmental enclosure (for humidity/temperature control and to minimize external factors) be installed on the Laseruler at the actual work location to improve the accuracy and precision of measurements. Also, a finite location point on the instrument for the Laseruler probe to measure thickness dimension be considered to further improve the accuracy.

These results satisfy the level of accuracy and precision needed for the thickness measurement of microclad bridge material on Laseruler. In order to maintain the measurement capability and monitor possible trends I suggest that we initiate a control chart scheme with routine measurements on master standards and plot the X bar and R charts on a daily basis. Software modification to include SPC program should be considered to incorporate these control plots. If I can be of any assistance please do not hesitate to contact me.

R. S. Ramachandran

R. S. Ramachandran

Attachment

MOUND

Inter-Office Correspondence

From : S. E. Rigdon

Date : December 4, 1986

Subject : Laser Ruler Precision & Accuracy

Reference :

cc : D. B. Armstrong
B. T. Leahy
File

TO : R. S. Ramachandran

Objective. The objective of this experiment was to study the accuracy and precision of the Laser Ruler.

Experimental Design. Three standards, 0.05, 0.10 and 0.12 inches, were measured 5 times each hour for six hours per day for four days. Two operators measured the parts, each taking either the three morning readings or the three afternoon readings. They alternated taking the morning and afternoon shifts.

Model The statistical model is that the reading Y is influenced by the OPERATOR, DAY and TIME within DAY, that is,

$$1{,}000{,}000*(\text{Y-standard}) = \theta + \theta_{OPERATOR} + \theta_{DAY} + \theta_{TIME(DAY)} + E$$

where $\theta_{OPERATOR}$, θ_{DAY}, $\theta_{TIME(DAY)}$ and E are normally distributed with mean zero and variances σ_O^2, σ_D^2, σ_T^2, and σ_E^2.

Analysis. Estimates of these variance components are given in the following tables. (The standard deviations are in units of microinches.)

0.05 Standard	Variance	Standard Deviation
Operator	0	0
Day	0	0
Time (Day)	15.499	3.937
Error	2.121	1.456
Total	17.620	4.198

0.10 Standard	Variance	Standard Deviation
Operator	0.036	0.190
Day	6.415	2.533
Time (Day)	5.411	2.326
Error	2.829	1.682
Total	14.691	3.833

0.12 Standard	Variance	Standard Deviation
Operator	5.122	2.263
Day	5.170	2.274
Time (Day)	9.176	3.029
Error	3.867	1.966
Total	23.335	4.831

If the precision is defined as the total standard deviation, including Operator-to-operator variability, Day-to-day variability, etc. then the precision of the Laser Ruler is given in the next table. (The units are in microinches, i.e., 10^{-6} in.) The accuracy, defined as the average minus the true value of the standard is also given in the table.

Standard	Accuracy	Precision
0.05	+ 1.3	4.198
0.10	+ 2.8	3.833
0.12	+ 3.7	4.831

Plots of measurement versus run order are given on the attached plots. There appear to be some trends for some of the sets of readings by operator "S".

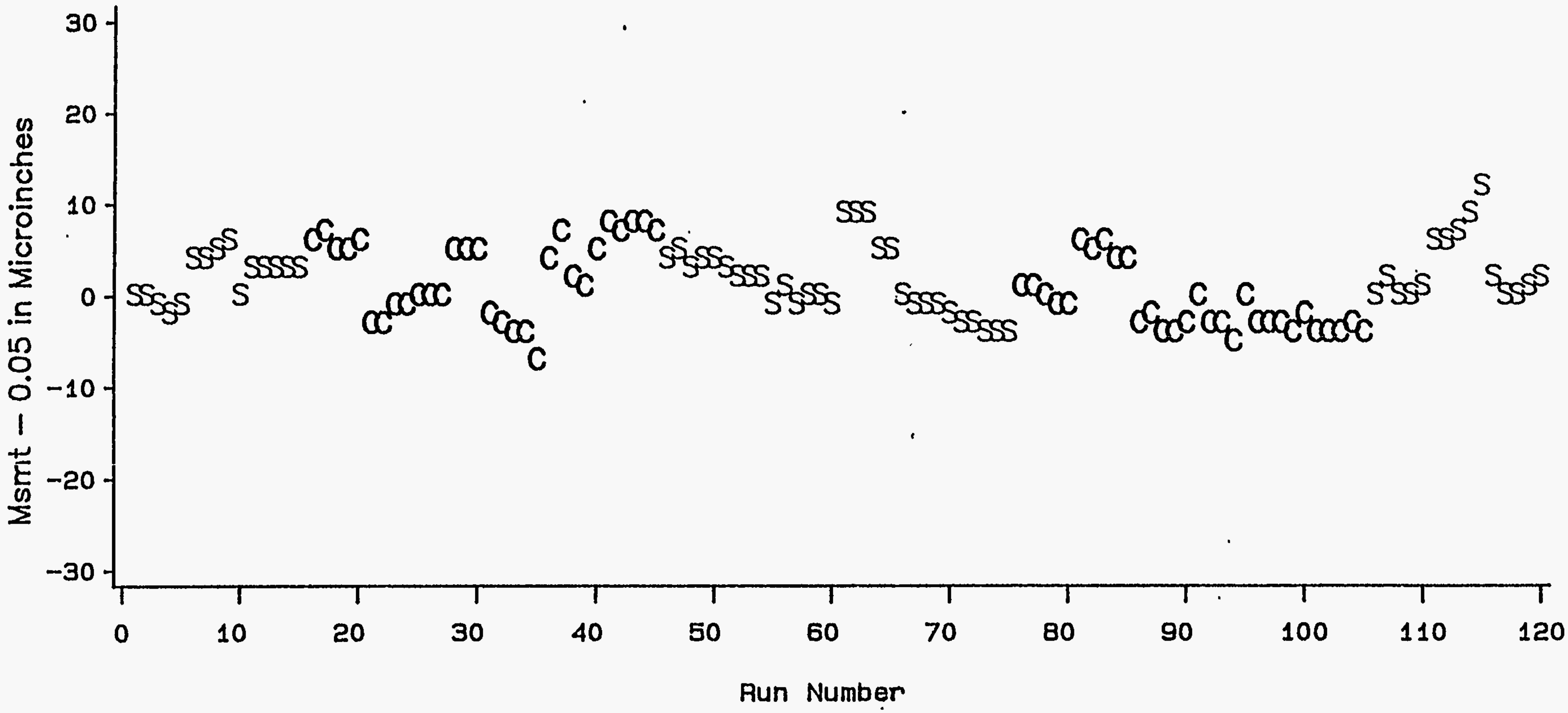
Steve

S. E. Rigdon

SER:jw

Attachments

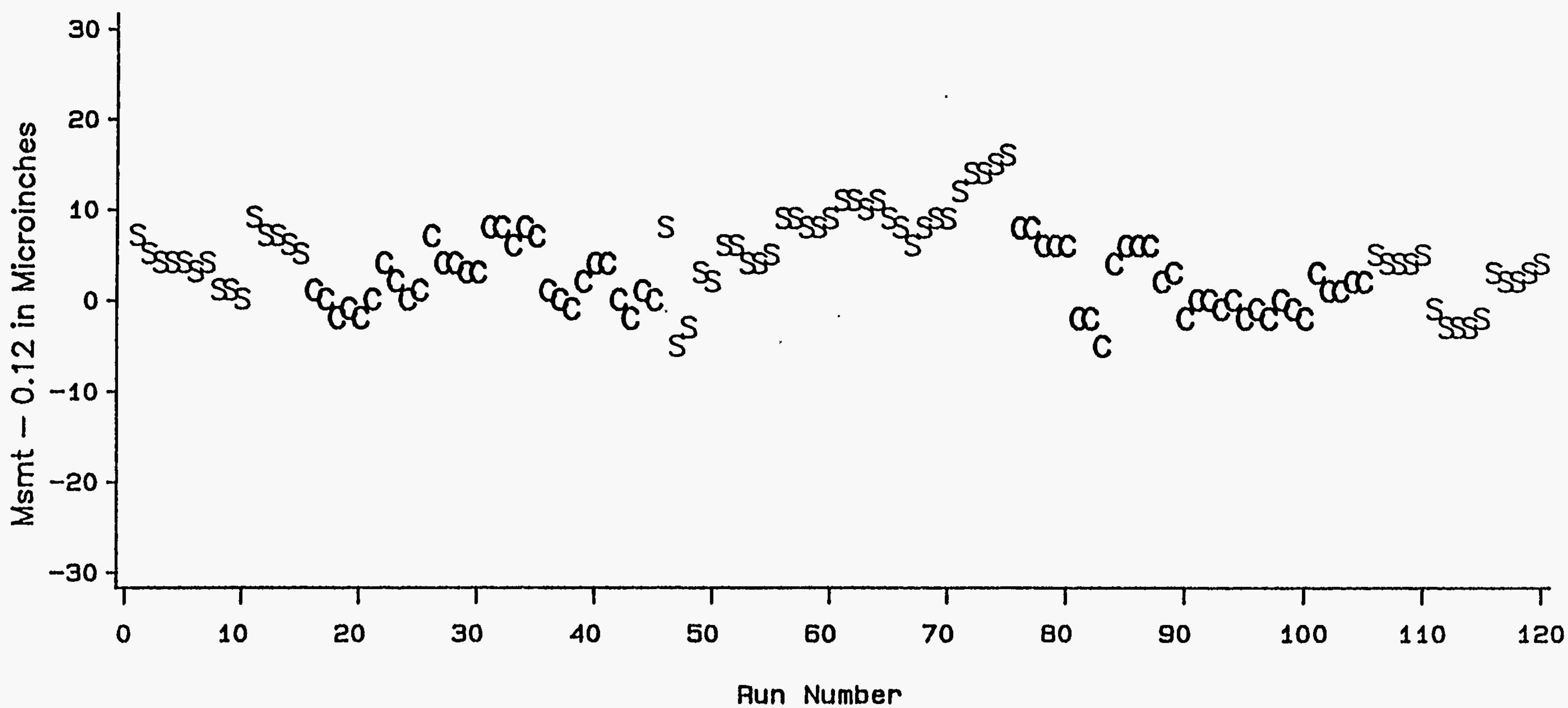
Laser Ruler Master Calibration
November 17–21, 1986



OPERATOR C C C c S S S s

0.05 Standard
SAS Program in RAM15.SAS, Data in RAM15.DAT

Laser Ruler Master Calibration
November 17–21, 1986



OPERATOR C C C c S S S s

0.12 Standard
SAS Program in RAM15.SAS, Data in RAM15.DAT

MOUND *Inter-Office Correspondence*

From :	Administration, Quality Engineering R. S. Ramachandran	cc : Distribution
Date :	August 3, 1987	
Subject :	SPC on Laseruler measurements	
Reference :	Memo from Warner to Hodapp, dated 6/18/87 "Laseruler Control Charts"	
TO :	W. J. Stitzel	

QE has completed a short term monitoring of Laseruler measurements through SPC technique (X bar and R charts) and have established the control limits for the two selected working standards of microclad bridges (WSTD). Attached charts on standards 27-027 (200 microinch thickness) and PQ8-800 (168 microinch thickness) provide the initial control limits for X bar and R charts (ignore the sigma charts).

Software modifications for calibration (probe zeroing for four times) and measurement of the standards (three readings, and calculation of average and range) are completed by Allen Poe (I & PA Group). SPC software implementation may be added for plotting the control charts after gaining the required hands-on experience with control charts by Operations.

The microclad working standards (two WSTD) are being provided to Operations for daily monitoring of Laseruler measurement reliability via SPC technique and to implement the Measurement Assurance Program (MAP) in the future. The third WSTD, steel gage standard, will be provided to you by Process Engineering group (Daryl Greywitt) in three weeks.

Step-by-step instructions for plotting the control charts and identifying an "out-of-control" conditions were explained in the above referenced memo. Technical Manual should be revised for inclusion of an operation sheet for running the Laseruler control charts.

If you need any further assistance please contact me or B.J.Warner.

R. S Ramachandran

R. S. Ramachandran

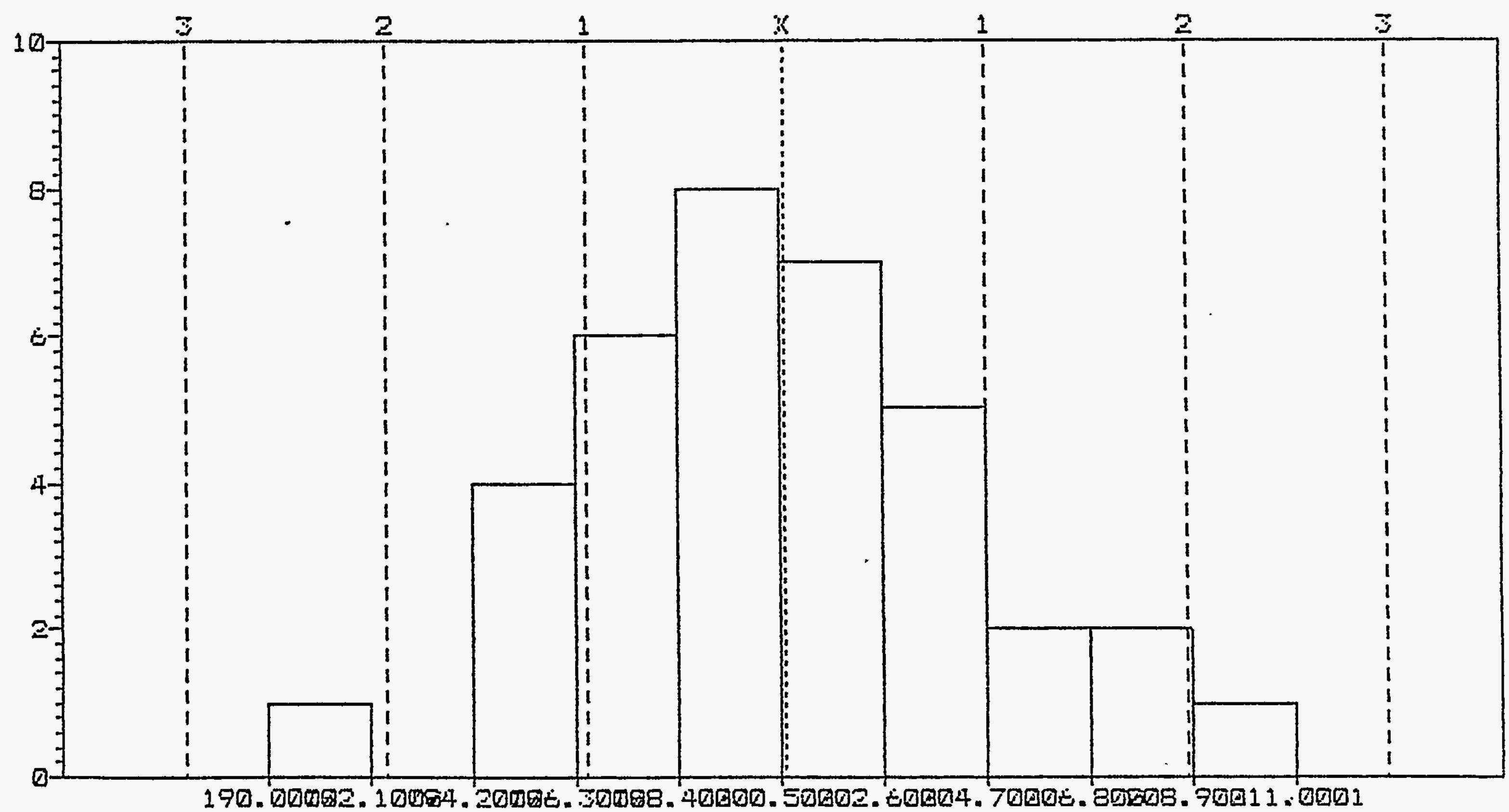
COPPER THICKNESS

07-31-1987 13:21

File:	C-27-027
Company:	MOUND
Machine:	LASERULE
Operation:	27-027
Characteristic:	COPPER THICKNESS
Sample frequency:	3

Date 07-31-1987
Interval =2.1000
All samples(n=3)
36 data points
lower boundary
Not Normal
Mean =200.6111
Sigma Indiv=4.0868
Est. Sigma =3.8393
Coeff Var =0.0204
Min. Value =190.0000
Max. Value =211.0000
Kurtosis =0.4946
Skewness =0.1555
Chi Squared=3.1021
Mean + 3s =212.8714
Mean + 2s =208.7846
Mean + 1s =204.6979
Mean - 1s =196.5243
Mean - 2s =192.4376
Mean - 3s =188.3508

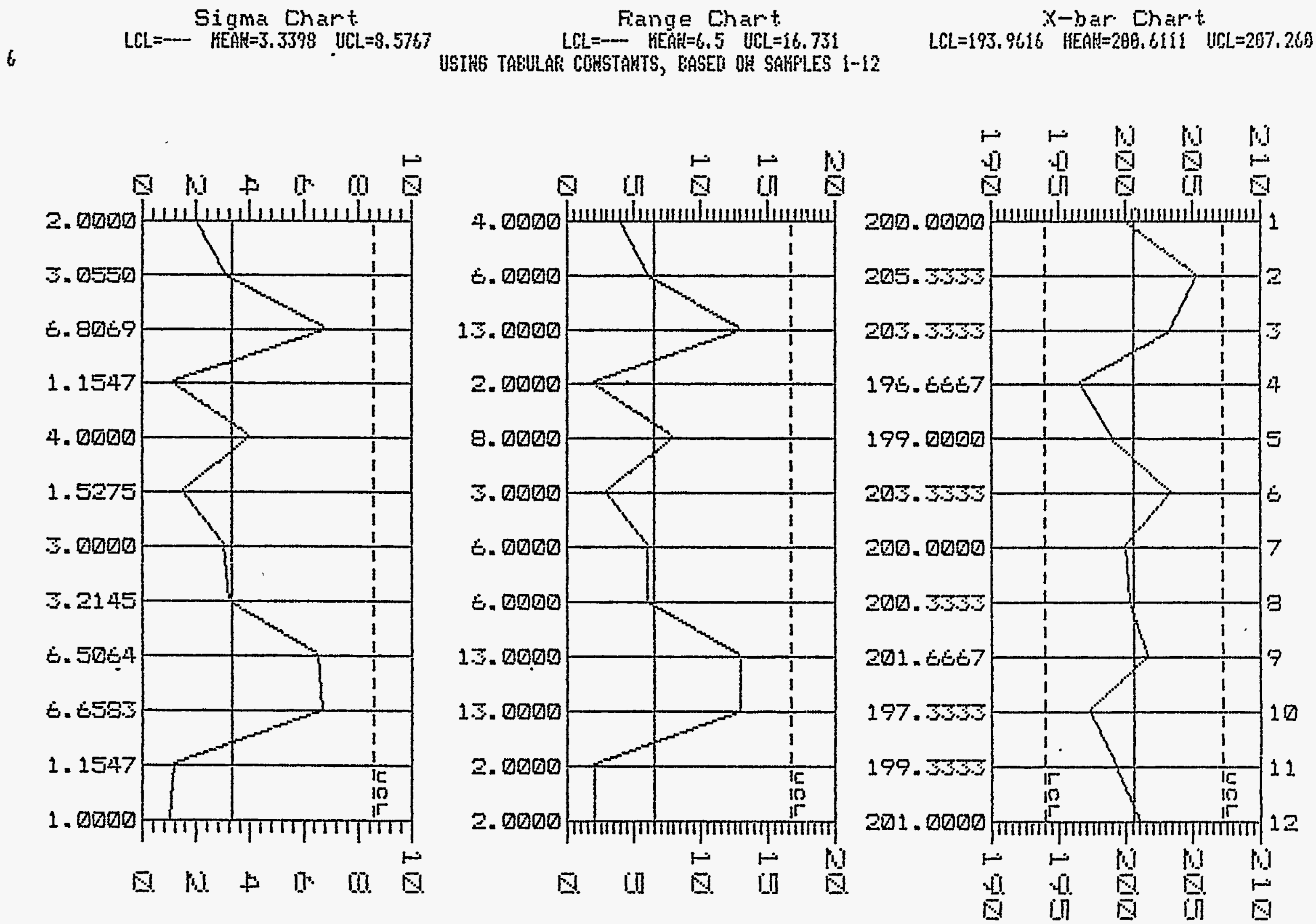
Histogram



COPPER THICKNESS

07-31-1987 13:12

File: C-27-027
Company: MOUND
Machine: LASERULE
Part number: 27-027
Characteristic: COPPER THICKNESS
Sample frequency: 3



No samples failed any out-of-control tests

Sigma Chart	Range Chart	X-bar Chart
±1 Sigma=41.7%	±1 Sigma=41.7%	±1 Sigma=58.3%
±2 Sigma=100%	±2 Sigma=100%	±2 Sigma=91.7%
±3 Sigma=100%	±3 Sigma=100%	±3 Sigma=100%

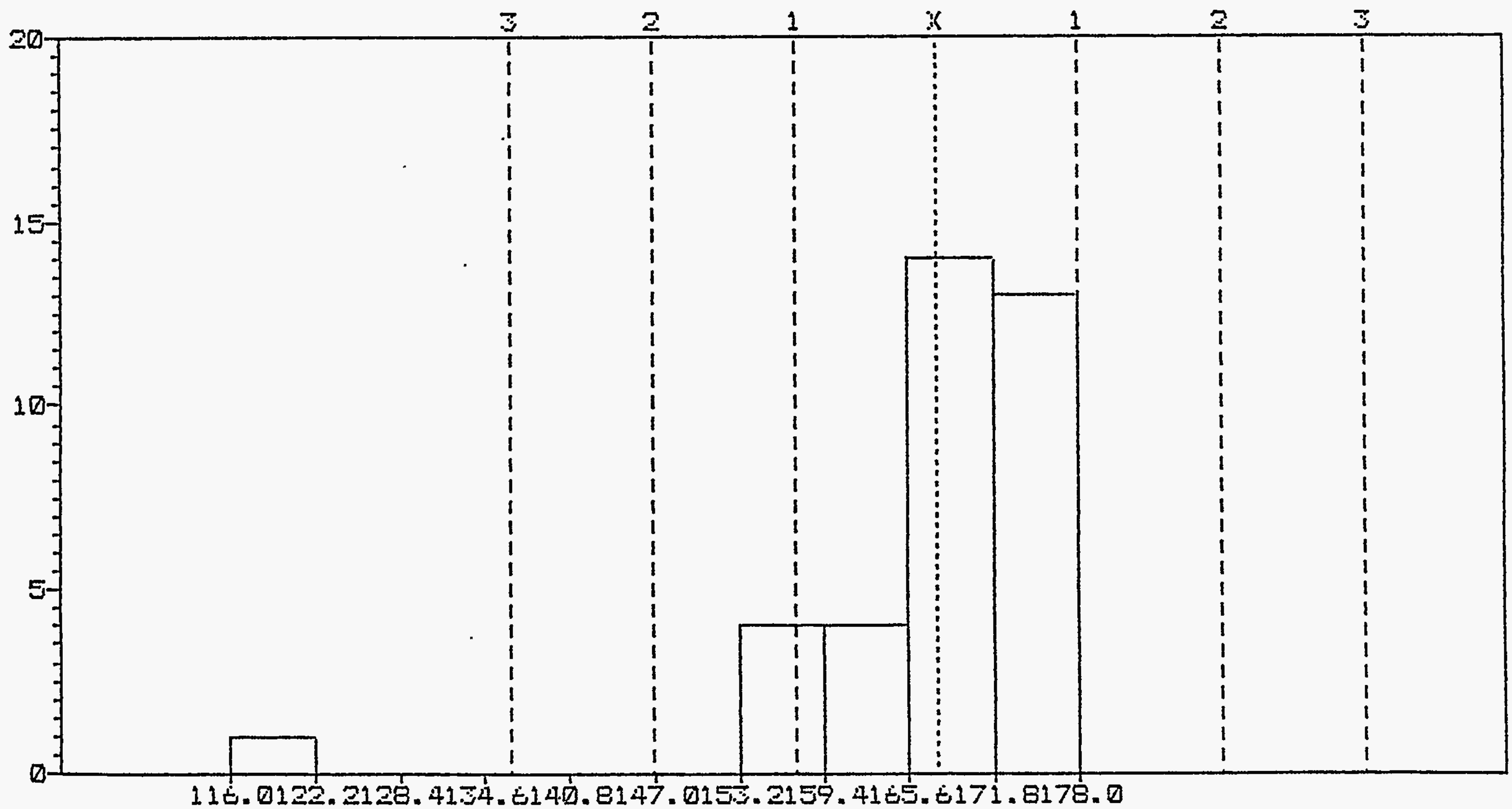
COPPER THICKNESS

07-31-1987 15:02

File: C-PQ8800
Company: MOUND
Machine: LASERULE
Operation: PQ8800
Characteristic: COPPER THICKNESS
Sample frequency: 3

Date 07-31-1987
Interval =6.2000
All samples(n=3)
36 data points
lower boundary
Not Normal
Mean =167.6944
Sigma Indiv=10.3753
Est. Sigma =6.1036
Coeff Var =0.0619
Min. Value =116.0000
Max. Value =178.0000
Kurtosis =14.3109
Skewness =-3.4228
Chi Squared=14.3039
Mean + 3s =198.8203
Mean + 2s =188.4450
Mean + 1s =178.0697
Mean - 1s =157.3191
Mean - 2s =146.9438
Mean - 3s =136.5685

Histogram



COPPER THICKNESS

07-31-1987 13:56

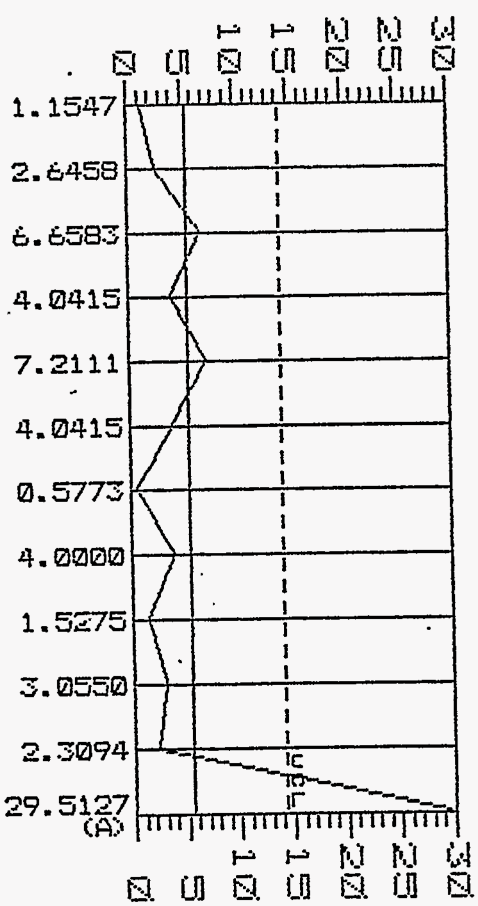
File: C-PQ8800
Company: MOUND
Machine: LASERULE
Part number: PQ8800
Characteristic: COPPER THICKNESS
Sample frequency: 3

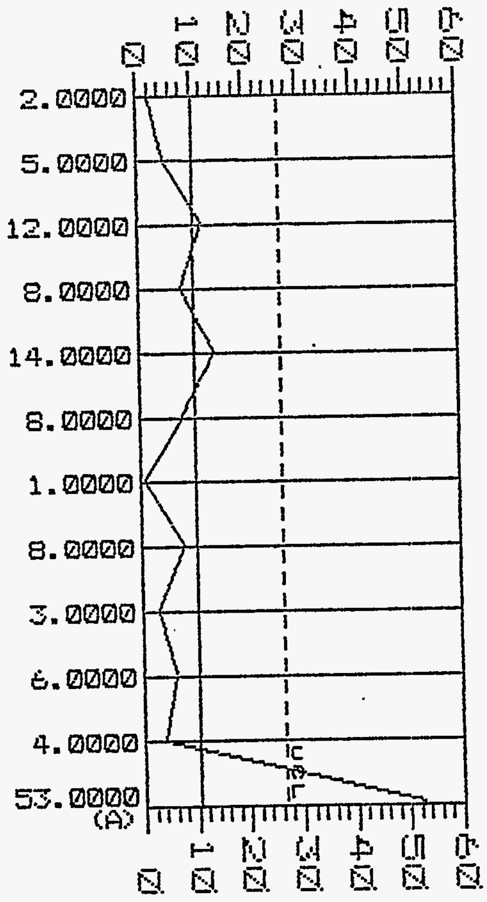
Sigma Chart
LCL=--- MEAN=5.5612 UCL=14.2813

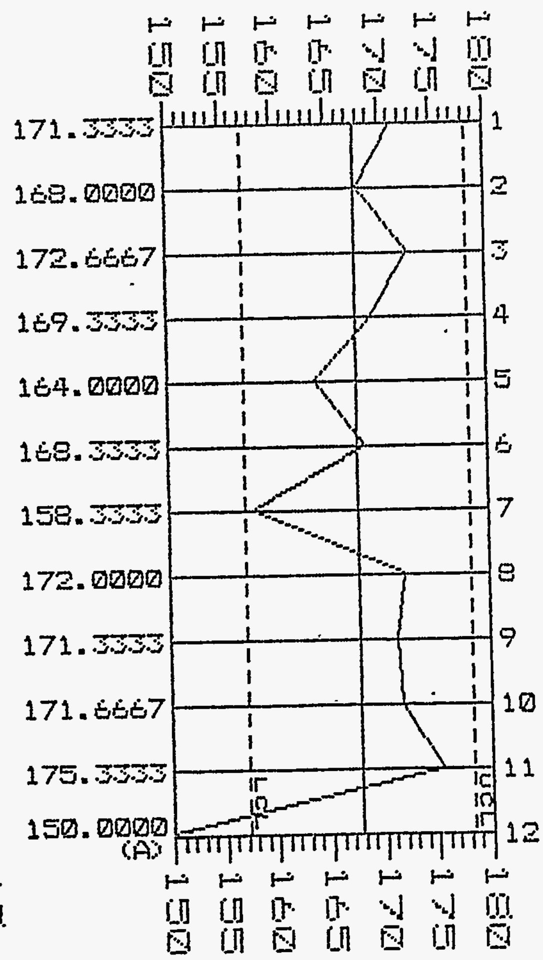
Range Chart
LCL=--- MEAN=10.3333 UCL=26.598
USING TABULAR CONSTANTS, BASED ON SAMPLES 1-12

X-bar Chart
LCL=157.1234 MEAN=167.6944 UCL=178.265

4







A = Out of Control

±1 Sigma=50%
±2 Sigma=91.7%
±3 Sigma=91.7%

±1 Sigma=58.3%
±2 Sigma=91.7%
±3 Sigma=91.7%

±1 Sigma=25%
±2 Sigma=75%
±3 Sigma=91.7%

Acknowledgments

The authors would like to thank S. E. Rigdon and A. L. Poe for their contribution to tape process development. The authors also extend special recognition to those Production, Quality, and Development personnel who contributed to the data collection and reduction. K. P. Armstrong claims no recognition for the research, only for the effort required to document it.

Glossary

Artwork	See phototool.
Bridge	Functioning copper foil portion of a slapper that drives the flyer.
Bridge Length	Dimension of a bridge parallel to the electric current.
Bridge Width	Dimension of a bridge perpendicular to the electric current.
Eddy Current	Nondestructive technique for measuring substrate thickness; used to determine copper thickness on bridge (microclad) material.
Flyer	Portion of a slapper detonator driven by rapid ionization of the bridge element (usually 0.001-in. to 0.002-in. Kapton).
Kapton	Trade name for a polyimide product produced by duPont.
LANL	Los Alamos National Laboratory.
Laseruler	Tool used to nondestructively measure substrate thickness; used to determine copper thickness on finished bridge circuits.
LLNL	Lawrence Livermore National Laboratory.
Microclad	Trade name of a copper-coated polyimide produced by Fortin Industries and used in fabricating bridges and flyers.
Phototool	Tool used to create a circuit image. A phototool contains the image of the desired circuit and exposes the image onto a chemically conditioned surface.
Radius Bridge	Bridge for which the length is defined by a radius such that the center of the bridge is in the thinnest region.
Reel	Sample of material slit to a width of 35 mm and wound around a core.
Receiving Inspection	Area at Mound where incoming material is inspected for conformance to specifications.
Roll	Sample of material as purchased from a vendor. A roll is the original width, usually 12 in. A roll is later slit to thinner widths to become reels.

SNLA	Sandia National Laboratories, Albuquerque.
Square Bridge	Bridge for which the width is uniform from end to end.
Tape Process	Method of producing flexible circuits in a reel-to-reel fashion. This process is unique to Mound.
Vidicom	Vision system produced by Vidicom to inspect bridge length and width.
Wet Processing	Process of laminating, exposing, developing, etching, and stripping a flexible circuit image.

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