A Study of Eddy Current Measurement (1986-1987)

Ram S. Ramachandran and Kenneth P. Armstrong

June 22, 1989

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Contract No. DE-AC04-88DP43495

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Ram S. Ramachandran and Kenneth P. Armstrong

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Abstract

A study was conducted in 1986 to evaluate a modified eddy current system for measuring copper thickness on Kapton. Results showed a measurement error of 0.42 $\mu\text{in.}$ for a thickness range of 165 to 170 $\mu\text{in.}$ and a measurement variability of 3.2 $\mu\text{in.}$

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 1986.

The eddy current system discussed in this report was used to determine the thickness of copper substrates on Kapton (microclad). It was used to perform receiving inspection thickness measurements on material from Fortin Industries. Microclad was used to fabricate slapper detonator bridges for which copper thickness is critical to detonator performance.

The measurement error for a thickness range of 165 to 170 $\mu\text{in.}$ was found to be 0.42 $\mu\text{in.}$ Measurement variability was determined to be 3.2 $\mu\text{in.}$ (3 sigma). These results show a considerable improvement over previous studies and are a result of improvements in vibration reduction, probe temperature control, and fixture design.

Content

This report comprises five memos 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

Date: April 17, 1986

Subject: Precision of Eddy Current Gaging of Thickness

Reference:

To: R. S. Ramachandran

OBJECTIVE

The objective of this study was to determine the following components of variability of Eddy Current gaging of thickness: within day, day-to-day, unit-to-unit and measurement error.

EXPERIMENTAL DESIGN

Twenty five units were selected for gaging thickness. Each unit was measured once. Later the same day, each unit was measured again. This was then repeated four more times on four additional days. Thus, for each unit, one measurement was taken twice a day for five days giving ten measurements per unit.

ANALYSIS

The model is assumed to be as follows:

$$\text{THICKNESS} = \mu + \theta_{\text{UNIT}} + \theta_{\text{DAY}} + \theta_{\text{WITHIN DAY}} + \epsilon$$

where θ_{UNIT} , θ_{DAY} , $\theta_{\text{WITHIN DAY}}$ and ϵ are normally distributed

with mean zero and variances σ_{UNIT}^2 , σ_{DAY}^2 ,

$\sigma_{\text{WITHIN DAY}}^2$ and σ_{ERROR}^2 , respectively. The following

estimates for these quantities were obtained:

$$\hat{\sigma}_{\text{UNIT}}^2 = 0.121$$

$$\hat{\sigma}_{\text{DAY}}^2 = 0.644$$

$$\hat{\sigma}_{\text{WITHIN DAY}}^2 = 0.0017$$

$$\hat{\sigma}_{\text{ERROR}}^2 = 2.966.$$

The largest single variance component is the measurement error. The attached plots show this clearly. The first plot, titled 'Scatter Plot of First and Second Thickness Readings' shows little correlation between the first measurement and the second measurement taken on each day. Ideally, all measurements would lie on the 45° line. The second plot, titled 'Unit to Unit Variability in Thickness Readings' shows for each unit, the ten measurements made. For nearly all units, the measured thicknesses range from 165 to 170. This plot indicates that the measurement error is much larger than the variability of the process which produced the units. The third plot titled 'Day to Day Variability in Thickness Readings' shows the variability of the 25 units on each of the five days.

CONCLUSION

Within the range of thicknesses considered, 165 to 170 μ in., the Eddy Current method of gaging thickness is quite variable. The overall variability, excluding the process variability, is $\sigma_{\text{overall}} = 1.90$

μ in.

Steve Rigdon

Scatter Plot of First and Second Thickness Readings

DAY X X X 1 □ □ □ 2 ◇ ◇ ◇ 3 # # # 4 * * * 5

Unit to Unit Variability in Thickness Readings

Day to Day Variability in Thickness Readings

From : QC Engineering, Administration
R. S. Ramachandrar

Date : November 21, 1986

Subject : Receiving Inspection of Microclad Material

Reference :

TO : G. L. Morris

cc: D. R. Bohl
G. L. Houston
W. D. Hugo
L. J. Karnowski
B. J. Warner
J. W. Fisher
B. E. Hubbard
J. A. Thomes
T. M. Bruggeman
D. J. Gorman
W. J. Stitzel
K. P. Armstrong
J. D. Hastings

Qual lot production of 1E38 bridges is scheduled for next week. Quality level of the microclad material needs to be verified prior to the production.

Eddy current instrument was modified for measurement improvement and the last study showed a significant improvement in precision and accuracy of the equipment. The test showed a measurement error of 0.42 microinches in the PVD thickness ranging from 165 to 170 microinches. Total measurement variability (excluding the process variation) was 3.2 microinches. The accuracy test on six ranges of standards (75 to 170 microinches) showed a maximum bias of +/- 2.5 microinches.

We could use the eddy current instrument in DS-123 for the verification of the microclad material going into the qual production with the following limitations:

1. Standards for calibration will be PVD material and there is a bias between the readings of microclad and PVD.
2. An estimate of the absolute value of microclad material based on PVD calibration could be determined with a small test of bridge material between Laseruler and Eddy current checks.
3. The acceptance specification of 150 to 200 microinches needs to be adjusted based on Item # 2 above.
4. Reliability of the data is based on the Accuracy and Precision study concluded from the 25 PVD samples.
5. Eddy current is equipped with 35 mm reel to reel fixture operation. (12 inch width materials will have to be slit prior to QC acceptance testing).
6. A sampling criterion needs to be established. All incoming 35 mm reels with a certain number of checks per reel will be ideal. For the initial qual lot production, the reels will be measured randomly within every two feet - a total of approximately 50 readings/reel.
7. Receiving Inspection technician to be trained by the Component Development personnel. Scheduling of other technicians is also necessary.

8. An operating procedure needs to be drafted. This will include set up procedure (standards and calibration before and after testing) and running of the test.

9. On a later date the eddy current instrument needs to be certified by Mound's Standards Lab.

An Accuracy and Precision study with microclad material is planned by QC Engineering and Mound is awaiting the master standards. Preparation of the standards for microclad material has been initiated with a round robin study (Mound, LANL and Fortin) planned for early next year.

A handwritten signature in cursive script, reading "R. S. Ramachandran".

R. S. Ramachandran

From : Administration, Quality Engineering
R. S. Ramachandran, S. E. Rigdon
Date : December 3, 1986
Subject : Eddy current Measurement Study
Reference :
TO : G. L. Morris

cc : G. L. Houston
R. J. Finney
W. D. Hugo
D. B. Armstrong
B. E. Hubbard
J. D. Hastings
J. R. Brinkman
D. R. Bohl
D. L. Coffey
B. J. Warner
J. A. Thomes
K. P. Armstrong
L. J. Karnowski
J. C. Hanna

Summary: A statistical study from the modified Eddy Current test instrument showed an improvement in the measurement error from 1.72 to 0.42 microinches in the PVD thickness ranging from 165 to 170 microinches. Total measurement variability (excluding the process variability) improved by 40% (5.7 vs. 3.2 microinches - 3 sigma) with the reduction of vibration of Eddy Current equipment, control of the probe temperature and fixture redesign for positive hold of the PVD samples. The accuracy study on six ranges of standard (75 to 170 microinches) showed a maximum bias of +/- 2.5 microinches.

Background: The previous conclusion from the Eddy Current method of gaging thickness was that the measurements were quite variable. The overall measurement variability of Eddy Current gaging of thickness was 0.4 times the product tolerance and the measurement error was determined to be much larger than the process variability. Accuracy of the instrument (ability to measure PVD materials) was a maximum of 8.9 microinches. The test run also indicated a shift in the calibration and the data showed a day-to-day variation.

Design of Experiment: The same twenty five PVD units, used in the previous test (April 1986), were selected for this repeat study. Each unit was measured twice a day, morning and afternoon, for five days giving ten measurements per unit. The six PVD standards were also measured as above for accuracy determination.

Results of the analysis:

1. Analysis of variance showed a significant (F ratio values) difference between the following observations. Refer to the attached table #1.
 - a) The first readings and the second readings (measurements in the mornings were higher than the afternoon measurements) indicate a time effect. From figure #1 it could be seen that the first readings are higher (except for Day #3) than the second readings.
 - b) Day-to-day variability is real.
 - c) Not all units are the same.

Results of the Analysis: (Contd.)

2. The precision study showed an improvement from the April 1986 measurement tests (refer to the attached table #2).
 - a) Measurement error improved from 1.72 to 0.42 microinches in the range of PVD thickness 165 to 170 microinches.
 - b) Total measurement variability improved from 1.90 to 1.06 microinches with the modification of the measuring equipment.
3. Accuracy study on six standards, ranging from 75 to 170 microinches, showed a maximum bias of 2.5 microinches (see attached figure #2).
4. Measurement capability of the Eddy Current barely detects the large to small measurements of true process as determined from the ratio of total measurement variability to unit-to-unit variability (1.22). In other words, the instrument is not sensitive enough to detect small variations or the process is too good to give large variations.

Recommendations:

1. Preparation of a microclad standard for measurement of tape processing raw material should be expedited.
2. Staging station for microclad and reel-to-reel fixture need redesign for improving the stability of measurements.
3. Improvements in the systems electrical noise levels need to be studied. This could involve replacement of existing computer.
4. Further study to improve calibration shift in levels within the system needs attention.
5. A measurement capability study with microclad material testing on the Eddy Current needs to be initiated. Determine accuracy and precision with microclad material to include copper impurity and microscopic voids in the raw material.

R. S. Ramachandran

S. E. Rigdon

TABLE 1
ANALYSIS OF VARIANCE
EDDY CURRENT MEASUREMENT STUDY

<u>SOURCE</u>	<u>DF</u>	<u>SS</u>	<u>F VALUE</u>	<u>PR > F</u>
Unit	24	183.29816000	42.56	0.0
Day	4	116.91576000	162.87	0.0
Time (Day)	5	90.59260000	100.96	0.0

TABLE 2
ESTIMATED STANDARD DEVIATION
EDDY CURRENT PRECISION STUDY

<u>Source</u>	<u>Current Study</u>	<u>April Study</u>
Unit-to-Unit	0.864	0.348
Day-to-Day	0.471	0.802
Time-to-Time Within Day	0.847	0.041
Measurement Error	0.424	1.722
<hr/>		
Total Variability	1.365	1.932
Total Measurement Variability	1.057	1.900

Precision Study on Eddy Current Gaging of Thickness Scatter Plot of First and Second Thickness Readings by Day

DAY 1 1 1 1 2 2 2 2 3 3 3 3 4 4 4 4 5 5 5 5

Accuracy (Bias) Study on Eddy Current Gaging of Thickness
Run Chart of Bias from Measurements on Standards

From : R. S. Ramachandran
Quality Engineering
Date : December 5, 1986
Subject : Microclad Thickness Measurement
Variation - Eddy Current
Reference :

cc : S. Houston
L. Karnowski
G. Morris
D. Hastings
J. Fisher
R. Finney
D. Bohl

TO : B. Hubbard

The analysis of two sets of data generated after the modification of staging station vacuum attachment and electrical systems checks are summarized below:

Test #1

Repeatability of eddy current to measure the copper microclad material ranging from 143-149 microinches is 0.922 microinches (0.6%). This is calculated from the three replicate readings at 10 locations of the tape reel-#1-1 (QC #36396).

Test #2

- a. Measurement variability including the process variation is 12.07 microinches for the mean thickness of 142.9 microinches (range 134.04-150.18 microinches).
- b. Measurement variation within 6" strips of microclad samples (including the process variation) is 6.10 microinches.

These calculations are made from 15 subgroup measurements from five 6" strip materials.

It should be noted that the instrument was calibrated with PVD standards (134.3, 169.7 and 200.6 microinches) and there appears to be a significant bias in the absolute value from the tested assumed 175 microinches material.

The ratio of measurement capability of eddy current to product tolerances is about four (4). Good reference materials for microclad materials are required to minimize the bias. Efforts are underway to determine the thickness level of the sample - Betaback scatter and x-ray fluorescence method of measurement.

R. S. Ramachandran
R. S. Ramachandran

RSR:sj

From : Administration, Quality Engineering
R. S. Ramachandran

Date : October 5, 1987

Subject : MC3926 Bridge Thickness Variation

Reference :

cc :

TO : K. P. Armstrong/B. J. Warner

This is to document the discussions and decisions made during the two days of meetings. During the 9/30/87 meeting the attached Chart #1 showing a strong bias between Eddy Current (EC) and Laseruler (LR) was presented. It was felt that the Laseruler is measuring correct thicknesses of the bridge reel #207-3 (QC #37833) because the Laseruler SPC chart was not out-of-control.

We knew that the EC bias is not constant and the correction factor could be either a product or a sum. Also the "Variable Bias" needs to be established for every batch or shipment from the vendor to determine the true level of copper thickness. This is because Eddy Current measures conductivity of the bridge material and is affected by the density, composition, impurities, voids and scratches on the material.

As for the verification of the thickness data, during the 10/1/87 meeting, additional information (Chart #2) on the same 26 bridges measured by X-Ray Fluorescence (XRF) and Beta Backscatter (BB) techniques were presented. It is very evident that the LR measurement level is that of XRF thickness measurement. XRF has a higher level of detection sensitivity and gives a better precision than LR (See Table 1).

It should be noted that EC measurement level did not change from the past materials but the actual thickness is higher. Now, the question is, has the material changed from the previously accepted raw material in composition or impurities?

The fluctuation in BB readings is due to the instrument instability and use of a new source (Lithium 147). It takes about 6 to 8 hours of warm up time and as the source decays, the output value will change. It was for a quick study, in determining the BB level of measurement, this data was generated. For a good comparison of vendor BB results with Mound BB data, a round robin test needs to be designed.

Armstrong/Warner

October 5, 1987

The Microclad Standards from Laseruler were checked for thickness measurements on the four measuring systems with no significant differences (Table 2). This confirms that all the four systems are good for measuring thicknesses and for our application, XRF is the best.

The final conclusions were:

1. Accept the Laseruler data and disposition the bridges accordingly.
2. It is tedious to establish the EC "Variable Bias" for each batch of raw material received. Discontinue EC technique for Tape Lab. bridge material acceptance.
3. Move the XRF from T building (W. Dudley's office) to DS building and train technicians to perform the thickness of microclad copper raw materials for QC acceptance.

R. S. Ramachandran

CHART 1

MC3926 Bridge Thickness Measurements

Microclad Copper Thickness in uinches

CHART 2

MC3926 BRIDGE THICKNESS

QC 37.833; REEL #207-3

TABLE 1

MC3926 BRIDGE THICKNESS (QC#37833, Reel #207-3)

No.	ID #	EC 9/30	EC+32	EC 10/1	EC+32	LR	XRF	BB
1	5273	138.7	170.7	143.3	175.3	200	195	207
2	5274	131.1	163.1	144.5	176.5	201	191	207
3	5275	138	170	143.3	175.3	201	193	210
4	5276	132.3	164.3	145.2	177.2	197	194	204
5	5277	142.9	174.9	138.3	170.3	203	189	211
6	5278	132.4	164.4	147.7	179.7	194	197	203
7	5279	141.8	173.8	145.4	177.4	201	197	199
8	5280	140.5	172.5	141	173	204	193	199
9	5281	137.9	169.9	142.6	174.6	196	197	202
10	5282	139.6	171.6	143.2	175.2	194	195	210
11	5283	139.4	171.4	141.9	173.9	195	196	218
12	5284	133.6	165.6	145.1	177.1	192	195	211
13	5285	146.5	178.5	152	184	200	194	218
14	5286	139.8	171.8	141.8	173.8	204	200	210
15	5287	137	169	146.5	178.5	204	198	213
16	5288	139	171	147.5	179.5	204	198	215
17	5289	136.5	168.5	139.6	171.6	197	195	219
18	5290	140.2	172.2	143.6	175.6	193	195	214
19	5291	140.8	172.8	142.2	174.2	203	197	210
20	5292	141.3	173.3	140.3	172.3	198	196	205
21	5293	139.5	171.5	143.9	175.9	193	196	206
22	5294	138.6	170.6	142.3	174.3	211	195	186
23	5295	137.6	169.6	145.4	177.4	199	195	199
24	5296	136.8	168.8	141.3	173.3	199	197	166
25	5297	137.8	169.8	145	177	200	194	198
26	5298	138.4	170.4	141.7	173.7	201	190	174
Average		138.3846	170.3846	143.6384	175.6384	199.3846	195.0769	204.3846
Std. Dev.		3.372914	3.372914	2.876536	2.876536	4.454902	2.480694	12.59230
High		146.5	178.5	152	184	211	200	219
Low		131.1	163.1	138.3	170.3	192	189	166

TABLE 2
MICROCLAD STANDARDS COPPER THICKNESS MEASUREMENTS IN uin.

	Master	Standards
	PQ8 - 800	027-27
Certified	168	200
Uncertainty	2	3
Laseruler	171.5	199.5
Eddy Current + 32	169.6	—
X-Ray Fluorescence	168	201
Beta Backscatter	166	203

RSR/10-5-87

Acknowledgments

The authors would like to thank S. E. Rigdon and B. E. Hubbard 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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