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of Transportation

**Federal Railroad
Administration**

Experimental Residual Stress Measurement of New and Used Commuter Rail Wheels

Office of Research & Development
Washington, DC 20590

FRA/ORD-94/12

January 1994

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This report outlines the procedures used and presents the data obtained during the wheel saw-cutting portion of the Cracked Wheel Investigation. The procedure was conducted at the Norfolk-Southern laboratory in Alexandria, Virginia on February 21, 22, and March 31, 1992. The purpose of the wheel saw cutting experiment was to determine the magnitude and direction of the residual stresses in a new, as well as a service-worn, "L" grade, 32 inch diameter, railroad wheel. These wheels were instrumented and then radially cut at two locations (180 degrees apart) to relieve the residual stresses. Data were taken using strain gages, a clip-on displacement gage, and moire interferometry. Data from all three measurement techniques and a description of the experimental procedure and equipment are included. A brief discussion of the results of the experiment emphasizes the high degree of consistency between each measurement method and compares the stress-state of each wheel. Initial data analysis indicates that the new wheel has a higher level of compressive residual stress than the service-worn wheel. Annotated test data were forwarded to the Volpe National Transportation Systems Center (VNTSC) for analysis in conjunction with the overall investigation of wheel cracking phenomena occurring in commuter rail wheels sponsored by the Federal Railroad Administration. Appendices included with this report present all data collected for each of the three measurement methods.

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TABLE OF CONTENTS

SUMMARY

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1. INTRODUCTION

1.1 Background

This report is the sixth in a series on the results of an engineering study of the effects of service loads on railroad vehicle wheels. The study, entitled Cracked Wheel Investigation, was initiated in September 1991 in response to a request for assessment of contributing factors and corrective actions taken regarding high rates of crack occurrence in certain multiple unit (MU) powered cars used in commuter service. The ultimate goal of the study is the evaluation of safe limits on performance demand (weight carried per wheel, maximum speed, vehicle braking rate) as a function of wheel design, material selection, and manufacture as well as percentage of braking effort absorbed through the wheel tread in service. Engineering tests to support this study include a review of wheel maintenance records of the affected railroads to confirm the general nature of the crack occurrence patterns, destructive testing of two service-worn, thermally cracked wheels to obtain quantitative data on the number and size of the cracks, and a test analyzing the thermal environment of commuter rail wheels under revenue service conditions. Metallurgical examinations of wheel samples, including metallographic and fractographic studies as well as hardness tests, were also conducted by the Volpe National Transportation Systems Center (VNTSC).

Test reports covering the thermal measurement and the wheel crack census tests are being published separately, other reports pertinent to the investigation are available from VNTSC. The results from these tests were used by VNTSC as empirical references in the formulation of finite element computer modeling programs designed to analyze the thermal and mechanical stress state of railroad wheels and to evaluate the potential for different types of wheels to resist cracking under various combinations of service conditions. The models developed in the study are intended to provide the capability for similar engineering design analyses of other railroad vehicle wheels besides the types used on MU cars.

The purpose of the wheel saw-cutting procedure was to measure and compare the magnitude and direction of the residual stresses in a new "L" grade, 32 inch diameter, transit rail wheel with those found in a wheel of the same design that was previously used in routine commuter rail service by New Jersey Transit Rail Operations (NJTRO). The used wheel was selected from a group of service-worn wheels and had visible thermal crack indications over the entire tread surface. This wheel had run on car #1501 at the number 1 position. Both wheels were manufactured by Edgewater Steel and shipped to ENSCO, Inc., Springfield, Virginia, for instrumentation.

Data presented in this report have been forwarded to VNTSC for use in this investigation. The scope of this report is therefore limited to the reporting of the experimental objectives and procedure, and a presentation of the data including general observations that were made during data collection and the preparation of this report.

1.2 Location and Dates

The saw-cutting procedure was conducted in two phases. The first phase took place on February 21 and 22, 1992. During this phase, both wheels were saw-cut approximately two-thirds of the way through the rim, at both locations, and moire interferometry, strain gage and clip-on displacement gage measurements were made and recorded. After preliminary results were obtained from the moire interferometry procedure, the second phase of the procedure was conducted on March 31, 1992. No moire interferometry data were taken at this time, but strain gage and clip-on displacement gage measurements were made. Both phases of the procedure were conducted at Norfolk-Southern's laboratory in Alexandria, Virginia.

1.3 Participants

2-21-92:	Don Gray	FRA, Office of Research and Development
	Dick Fisher	FRA, Office of Safety
	Oscar Orringer	Chief Engineer, VNTSC
	Tim Ward	Engineer, Norfolk-Southern
	Bob McCown	Project Manager, ENSCO, Inc.
	Cam Stuart	Engineer, ENSCO, Inc.
	Bill Jordan	Engineer, ENSCO, Inc.
	Robert Czarnek	Consultant, Moire Interferometry
2-22-92:	Tim Ward	Engineer, Norfolk-Southern
	Bob McCown	Project Manager, ENSCO, Inc.
	Bill Jordan	Engineer, ENSCO, Inc.
	Robert Czarnek	Consultant, Moire Interferometry
3-31-92:	Don Gray	FRA, Office of Research and Development
	Dick Fisher	FRA, Office of Safety
	Tim Ward	Engineer, Norfolk-Southern
	Bob McCown	Project Manager, ENSCO, Inc.
	Cam Stuart	Engineer, ENSCO, Inc.
	Shawn Yu	Engineer, ENSCO, Inc.
	Kevin Kesler	Rail Manager, ENSCO, Inc.

2. WHEEL INSTRUMENTATION and EQUIPMENT

2.1 Clip-on Displacement Gage

Manufacturer:	MTS
Model #:	632.02B-01
Travel Range:	0.150" to 0.300"

The clip-on displacement gage was attached to the wheel using knife edges mounted to a prefabricated coupon. The coupon was designed to mount to the tip of the wheel flange using epoxy and to provide threaded holes for fastening the knife edges. The clip gage was used to measure the opening and closing of the saw kerf during the cutting procedure and its output was recorded on graph paper, in real-time, using an X-Y plotter.

2.2 Strain Gages

Manufacturer:	Measurements Group, Inc.
MODEL #:	CEA-06-062UT-120 (90 deg. "tee" rosette)
Gage Factor:	2.04 +/- 1.0%

Strain gages were installed along a radial line on the front rim face and back rim face, and across the width of the tread. The gages were evenly spaced on each surface and oriented to provide strain indications in the radial (rim faces), hoop (all surfaces), and axial (tread only) directions. Two sets of gages were installed on each wheel at opposite (approx. 180 degrees) locations. A total of 32 gages were installed at each location. Measurements of the radial location of each gage on the front and back rim surfaces were made and are included in Appendix 4.

2.3 Strain Gage Instrumentation

Manufacturer:	Vishay/Ellis Equipment	
Model #:	Digital Strain Gage Indicator:	V/E - 20A
	Switching Units:	V/E - 24
	Printer:	V/E - 22
	Scan Controller:	V/E - 25

The strain gage instrumentation provided channels for recording the output of all the gages at the particular cut location, as well as a few from the opposite wheel location. The latter were used to record the stress relief at a point 180 degrees around the circumference of the wheel from the saw-cut in progress. Minimal stress relief was detected at these locations during the first few cuts and, therefore, these "opposite side" measurements were not always made or recorded on subsequent cuts.

2.4 Moire Interferometry

Moire interferometry is a highly sensitive, laser-based technique used for measuring displacements. Its primary purpose in this experiment was to measure the displacement of a series of points on the wheel surface spanning the saw-cut opening. These measurements were designed to give a reliable approximation of the opening (or closing) of the "idealized cut"; that is, one with no material removed or plastically deformed by the cutting process. These measurements, along

with the particular material properties of the wheel steel, could then be used to calculate the stress relieved in the wheels after saw-cutting. To facilitate these measurements, a high-frequency cross-line diffraction grating was placed on the front and back rim surfaces of the wheels, near the strain gages. The saw-cut was made through this pattern during the first phase of the experiment. The moire interferometry method of displacement measurement was chosen for this experiment based on previous success using this technique to analyze stress conditions in rails[1].

2.5 Cutting Equipment

Vertical Band Saw

Blade:	Lenox 14'6" x 1.080" / .035" 4 to 6 teeth/in.
Cutting Speed:	120 feet/min.
Feed:	18 lbs. (constant force feed)

Cutting Fluid

LECO, Part# 811-024, VC-50 cutting oil
Manually applied

3. SAW-CUTTING PROCEDURE

The illustration in Figure 1 shows the wheel saw-cutting set-up along with the various forms of instrumentation used in this procedure. Though not shown in the figure, the strain gages were connected directly to the strain indicator equipment throughout the experiment.

3.1 February 21 and 22, 1992

Each wheel was positioned flat on the saw table, secured in place, and the strain gage instrumentation connected in preparation for saw-cutting. For each saw-cut location on both wheels, the pre-installed clip-on gage coupon was sawed in half before the gage was installed. This was necessary because there was inadequate space for the saw blade between the gage and the coupon. The saw was stopped before cutting the wheel flange and the gage was installed around the blade and connected to the X-Y plotter. At this point, all instrumentation was zeroed and the saw was feed into the wheel. Cutting continued until the blade reached a point approximately two-thirds of the way through the bulk of the rim, while still cutting through the moire interferometry diffraction grating. Then, strain gage readings were taken and interferometry measurements made on both rim surfaces.

Wheel surface temperatures were monitored throughout the cutting process. Though localized temperatures near the saw kerf were elevated during the cutting process, they were not

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[1] R. Czarnek, J. Lee, and S.-Y. Lin, "Moire Interferometry and Its Potential for Application to Residual Stress Measurements in Rails," *Residual Stress in Rails. Effects on Rail Integrity and Railroad Economics*, Kluwer Academic Publishers, 1992, Chapter 10, p.p. 153-167.

high enough to produce any permanent effects on the wheel. The wheel was allowed to cool to ambient temperature before final strain gage readings were taken. Throughout the procedure, photographs and a videotape recorder were used for visual documentation.

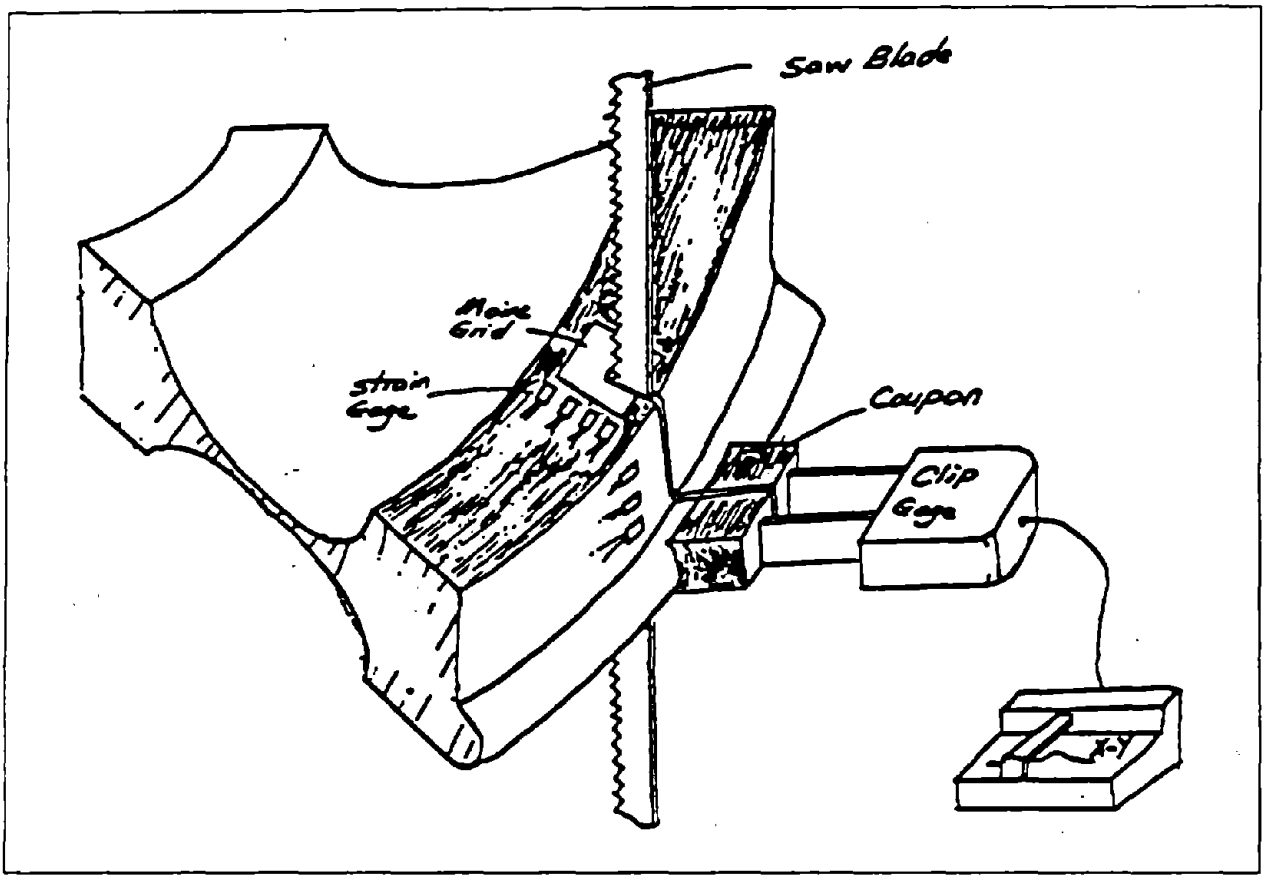


Figure 1: Wheel Saw-Cutting Set-Up

3.2 March 31, 1992

The procedure employed during the second phase of the experiment was essentially the same as the first phase, with a few notable exceptions. First, no moire interferometry measurements were made. Also, the procedure called for cutting the wheel all the way through the hub. Therefore, a new line of cut, approximately 0.25" away from the strain gages was chosen for this exercise so that complete stress relief of the wheel would occur and the resulting strains would be measured by the strain gage instrumentation. As before, clip-on displacement gages were used.

Strain gage readings were taken when the saw passed three points on the wheel. After zeroing, initial readings were recorded at the same depth of cut as in the first phase, again when the saw reached the rim/plate junction, and finally, after the cut passed through the wheel hub.

4. RESULTS

4.1 Discussion

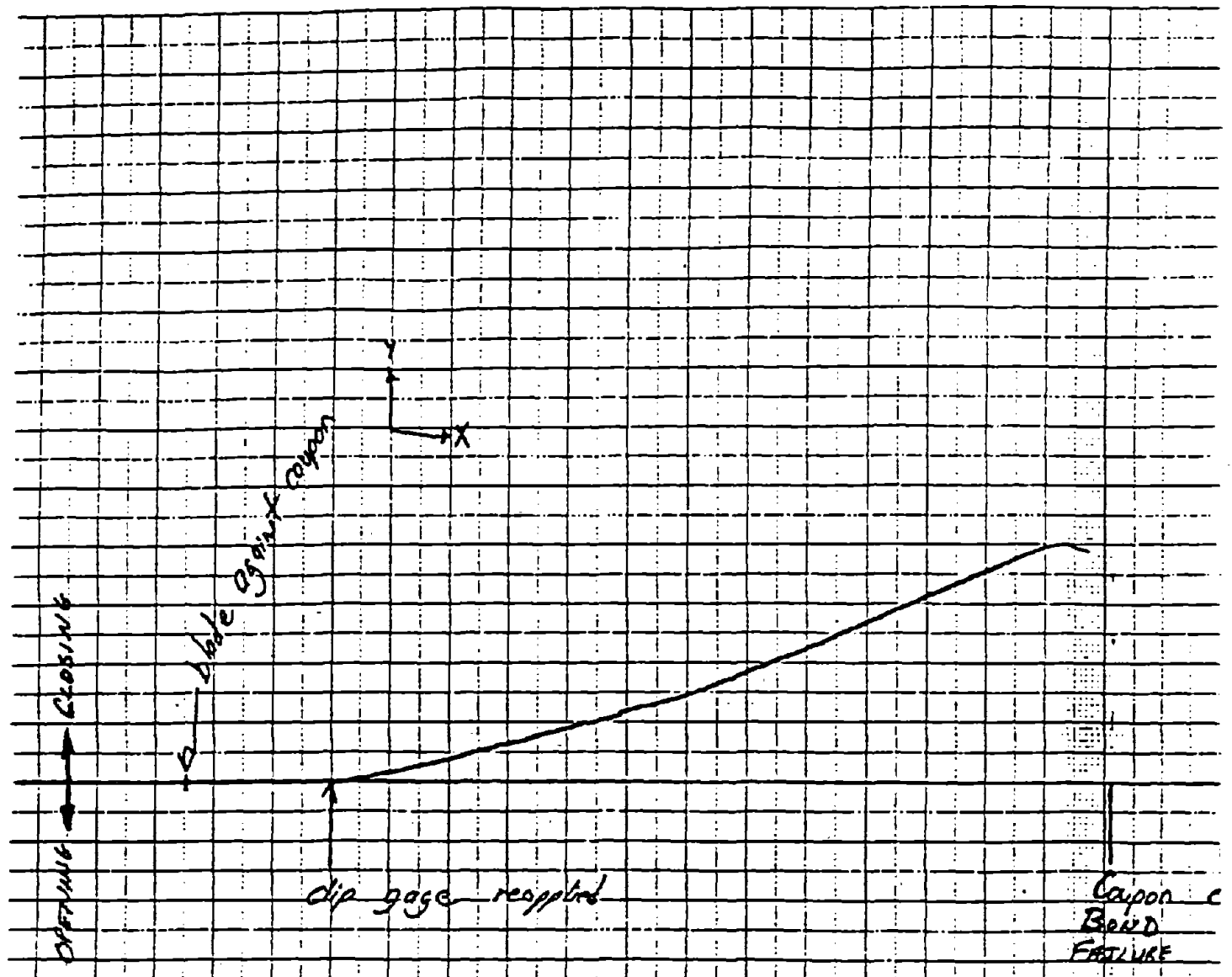
The experiment was successful in saw-cutting both wheels at the four locations and collecting data from all sources with the exception of two clip gages whose coupons became separated from the wheel flange during phase 1. Examples of the collected data are presented on the following pages; complete data packages are included in separate appendices. In general, the data from all sources produced similar results. For example, the clip-on displacement gage data on page 7, and the moire interferometry data on page 8, taken from the same cut on the new wheel, both show the cut closing in on itself, indicating that residual compressive stress was relieved. The strain gage data on page 9 reinforces the compressive stress relief results. In fact, while saw-cutting this wheel, the closing of the saw-cut was great enough to bind and trap the saw blade in the wheel.

The differences in the residual stress condition of the two wheels is most easily seen by comparing the moire interferometry results on page 8 to those on page 10. Here, it is clear that the residual compressive stress found in the new wheel was much greater than that measured in the service-worn wheel because the magnitude of the cut closing of the new wheel is significantly greater than that of the used wheel. This finding is supported by the clip gage data on pages 7 and 11. Both sets of data show a significant decrease in the degree of cut closing from the new wheel to the service-worn wheel, indicating less compressive stress present in the used wheel.

4.2 General Results

A review of the collected data revealed a high degree of consistency in the data obtained from each of these methods. Some interesting observations were made during data acquisition and the preparation of this report. First, the saw-cut opening in the new wheel remained tightly closed until the wheel was cut through the hub. This was contrary to our original expectation that once the saw blade had passed into the plate the saw kerf would open up. Also, on the front rim face of the service-worn wheel, compressive hoop stress magnitude was greatest near the rim/plate junction and was very low near the tread. On the back rim face, compressive hoop stress was greatest near the tread. Strain gage measurements showing this phenomena are included on page 12. Finally, a significantly higher level of residual compressive hoop stress was measured on the tread of the new wheel than on the service-worn wheel.

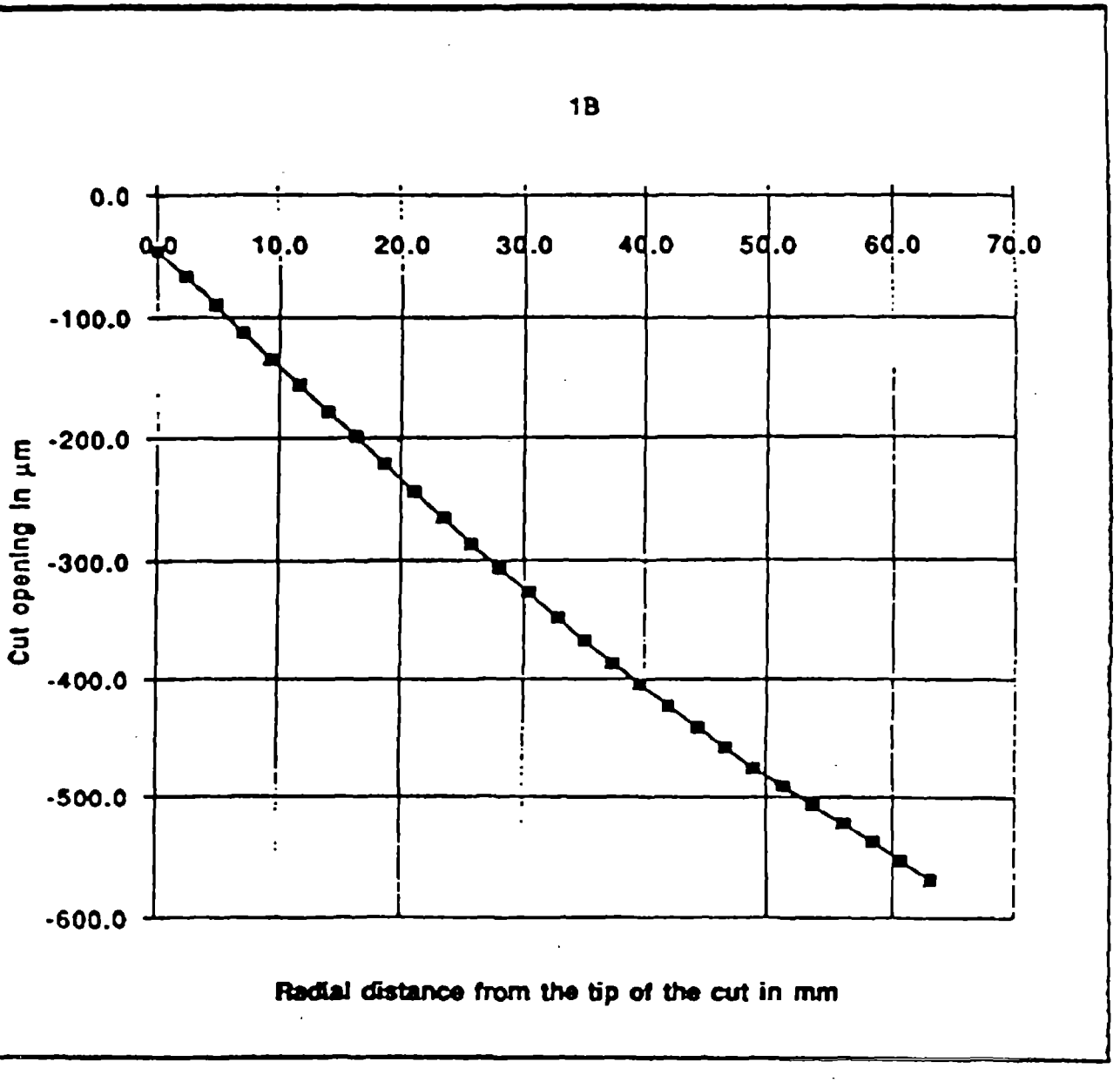
In conclusion, the results of this procedure satisfied the original goals of the exercise and provided insightful information regarding the residual stress condition of both a new and service-worn commuter rail wheel. After the experimental procedure was concluded, pie-slice sections of each wheel were cut and sent to VNTSC for further metallurgical analysis. Data collected during this exercise have been forwarded to VNTSC for review in conjunction with the overall cracked wheel investigation.



CLIP GAGE DATA FOR WHEEL SAWING
NEW WHEEL
FIRST CUT POSITION
X SCALE: 0.20 INCH OF CUT PER CHART MAJOR DIVN.
Y SCALE: 0.005 INCH OF GAP WIDTH PER MAJOR DIVN.
POSITIVE (UPWARD) TRACE INDICATES CUT CLOSING
CUT AT NS LAB, ALEXANDRIA, VA. 2/21-22/92

ENSCO results

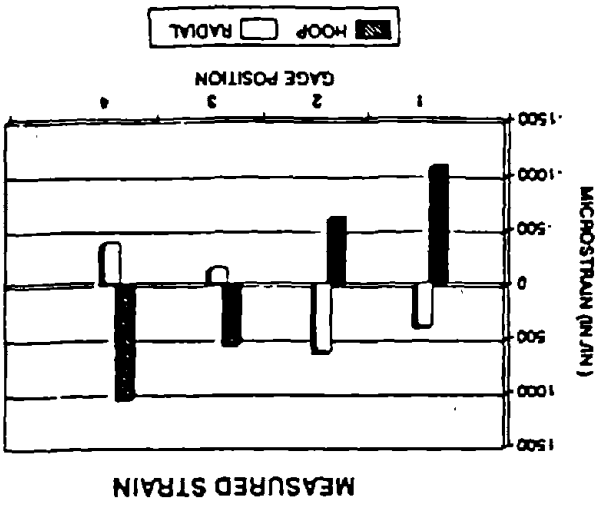
New wheel	
Cut number 1 back	
Cut opening in µm	
y	1B
0.0	-45.0
2.3	-66.0
4.7	-89.0
7.0	-112.0
9.3	-135.0
11.7	-156.0
14.0	-178.0
16.3	-199.0
18.7	-221.0
21.0	-243.0
23.4	-264.0
25.7	-286.0
28.0	-306.0
30.4	-326.0
32.7	-348.0
35.0	-367.0
37.4	-386.0
39.7	-404.0
42.0	-422.0
44.4	-440.0
46.7	-457.0
49.0	-474.0
51.4	-490.0
53.7	-507.0
56.1	-523.0
58.4	-538.0
60.7	-554.0
63.1	-569.0

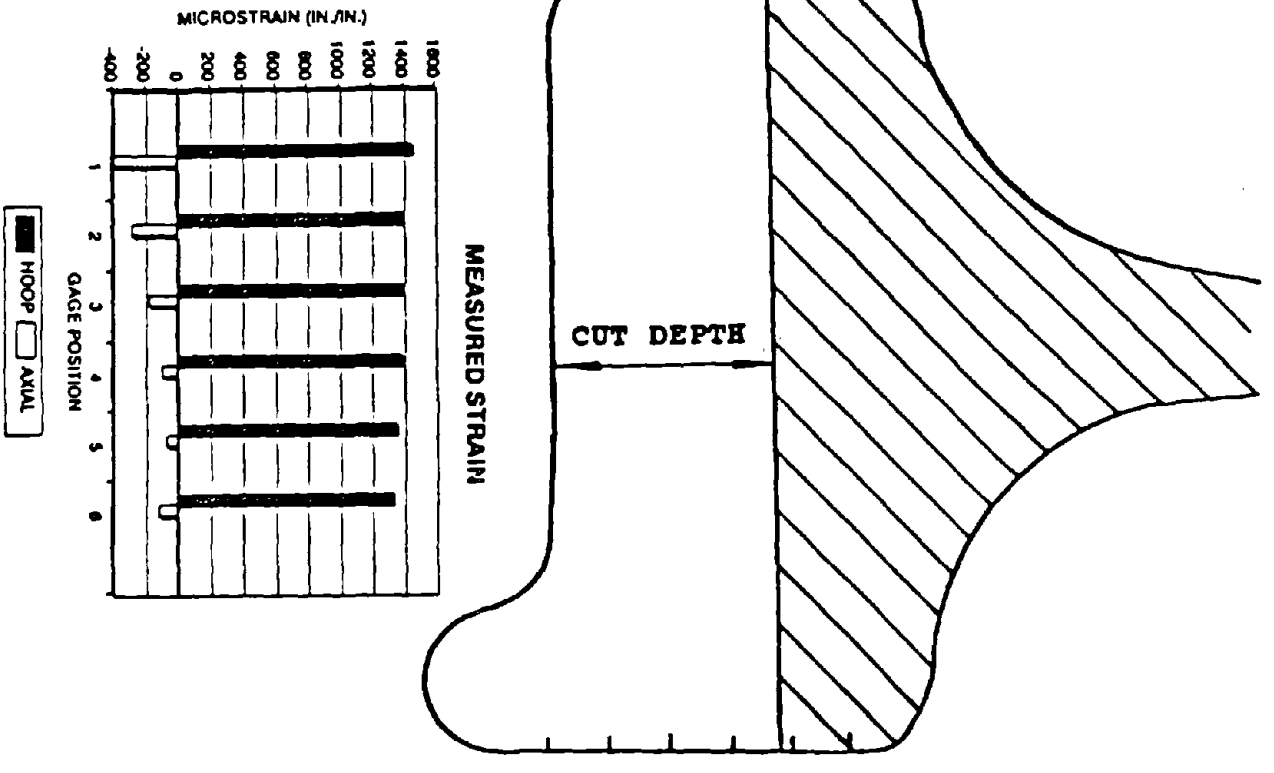


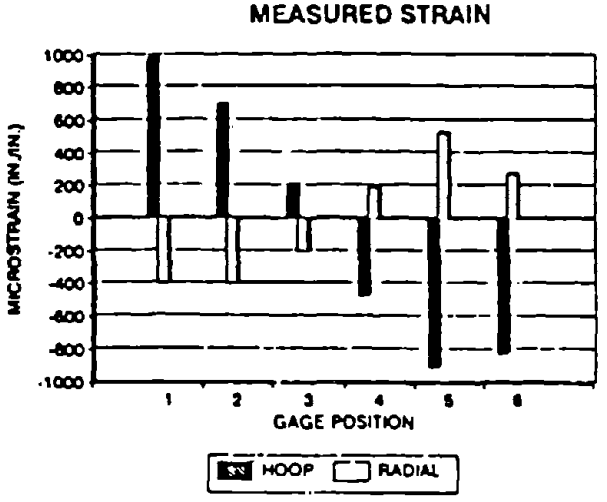
DATA DISPLAY
RIM ORIENTATION

NEW WHEEL
Position 1
2/3 of Rim Cut
Feb. 21, 1992

Positive Strain
=> Compression
Negative Strain
=> Tension







ENSCO results

Old wheel	
Cut number 4 back	
Cut opening in µm	
y	4B
0.0	-12.1
2.3	-29.2
4.7	-42.1
7.0	-52.1
9.3	-61.3
11.7	-69.6
14.0	-76.7
16.3	-85.1
18.7	-93.0
21.0	-100.1
23.4	-110.1
25.7	-118.4
28.0	-130.9
30.4	-140.5
32.7	-148.9
35.0	-153.5
37.4	
39.7	
42.0	
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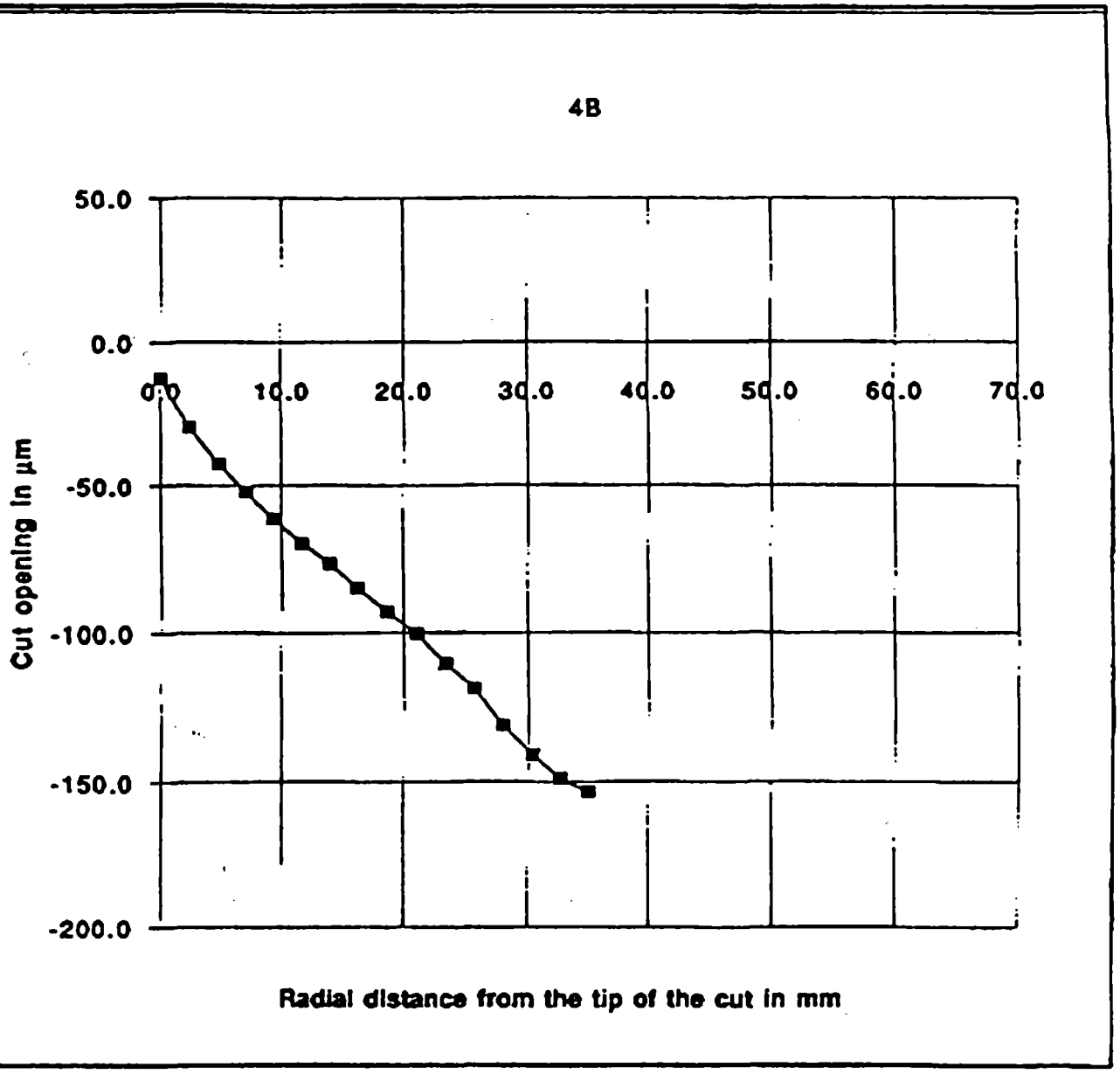
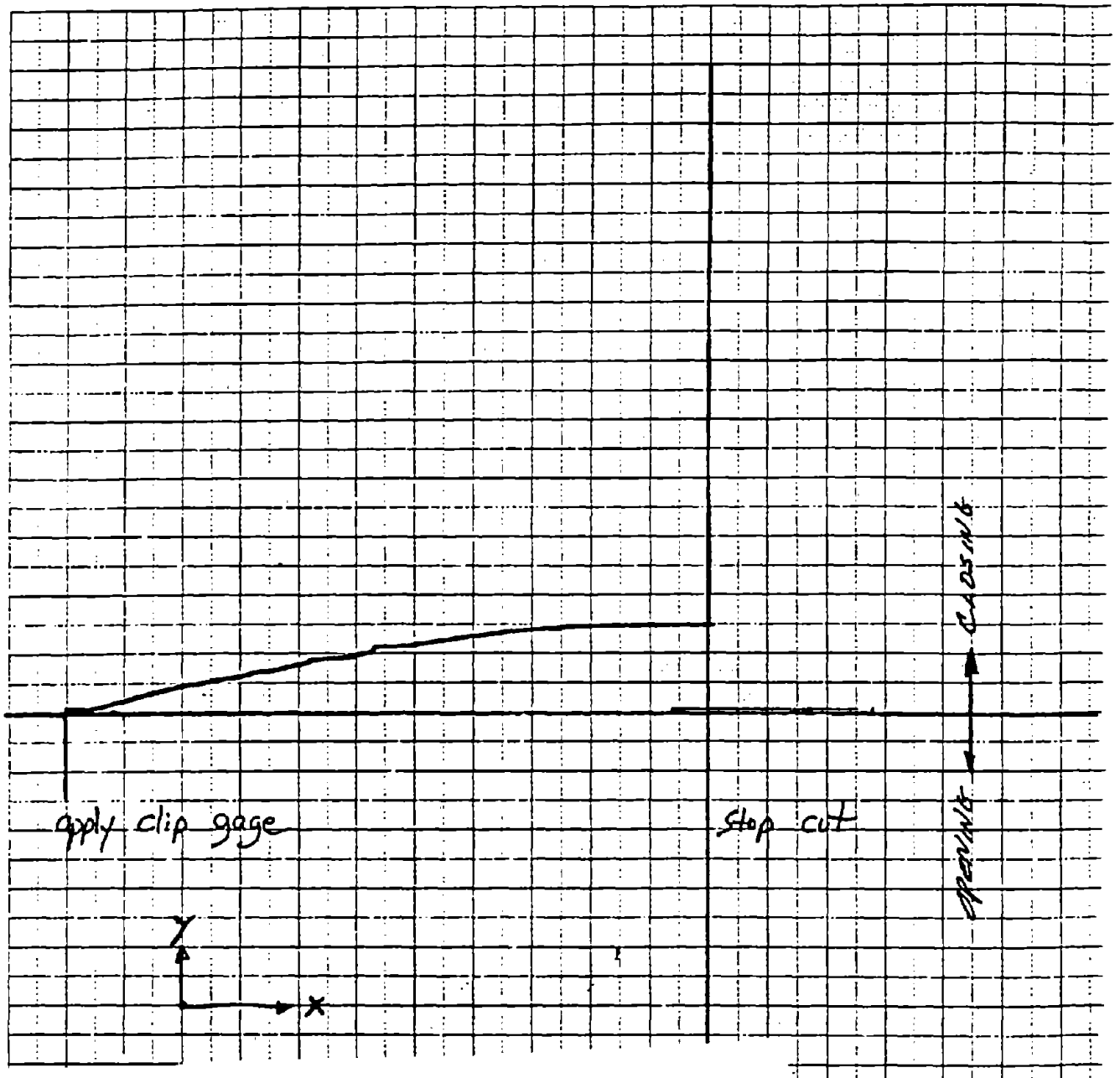
53.7	
56.1	
58.4	
60.7	
63.1	



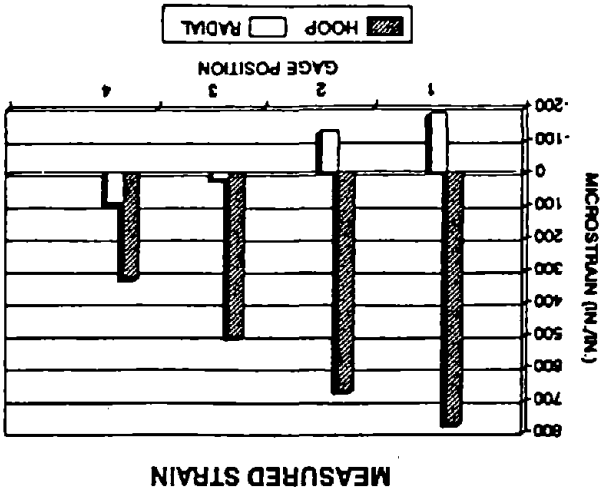


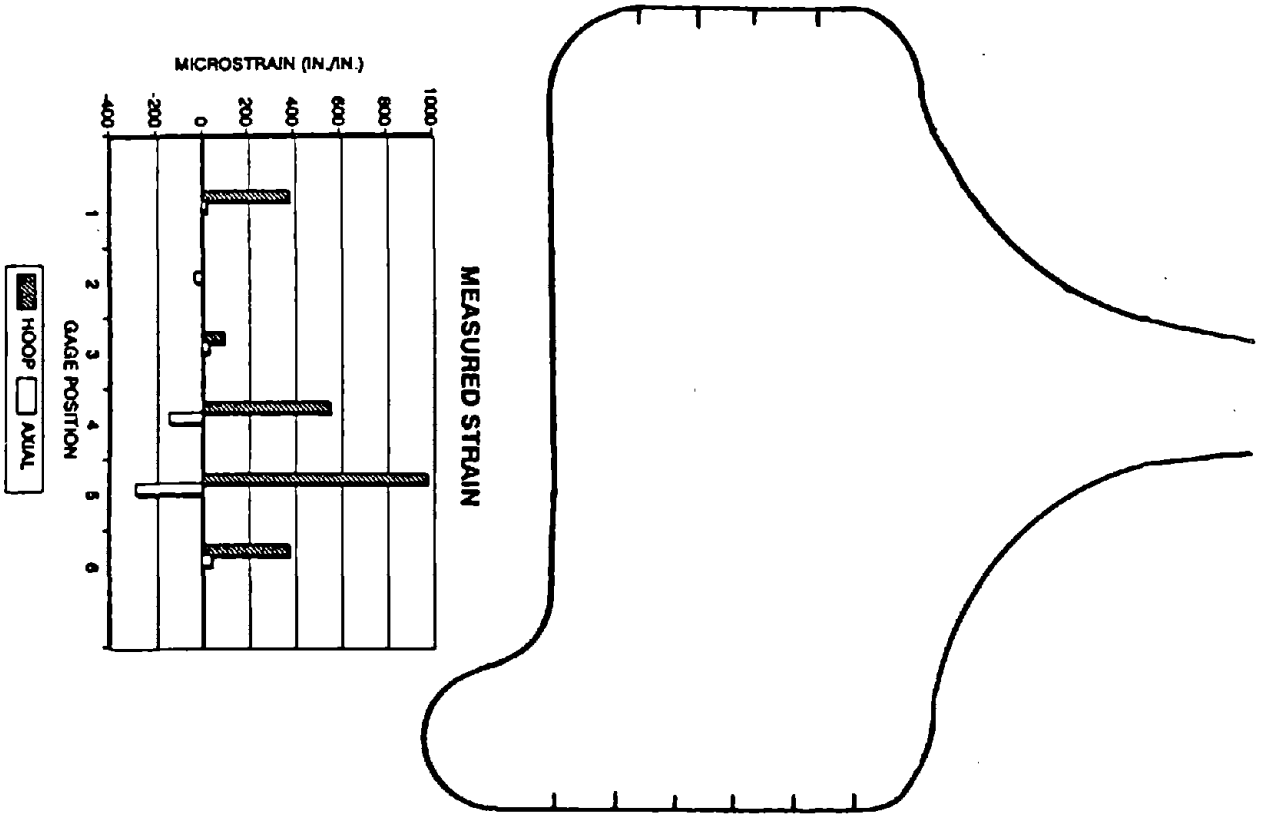
CLIP GAGE DATA FOR WHEEL SAWING
USED WHEEL FROM NJT 1501
FOURTH CUT POSITION
X SCALE: 0.20 INCH OF CUT PER CHART MAJOR DIVN.
Y SCALE: 0.005 INCH OF GAP WIDTH PER MAJOR DIVN.
POSITIVE (UPWARD) TRACE INDICATES CUT CLOSING
CUT AT NS LAB, ALEXANDRIA, VA. 2/21-22/92

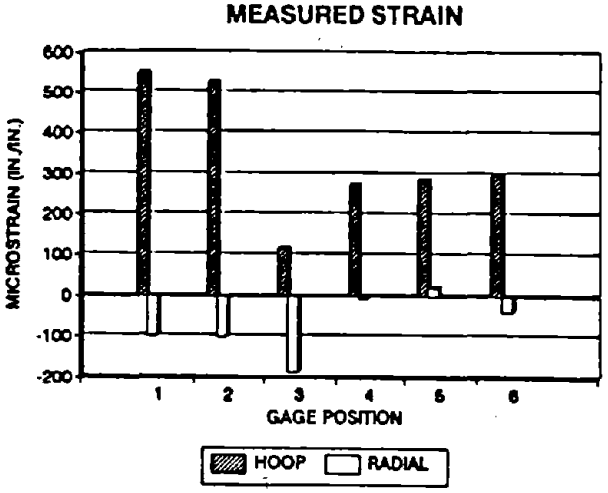
DATA DISPLAY
RIM ORIENTATION

OLD WHEEL
Position 4
Final Strain of
Thru-Hub Cut
March 31, 1992

Positive Strain
=> Compression
Negative Strain
=> Tension

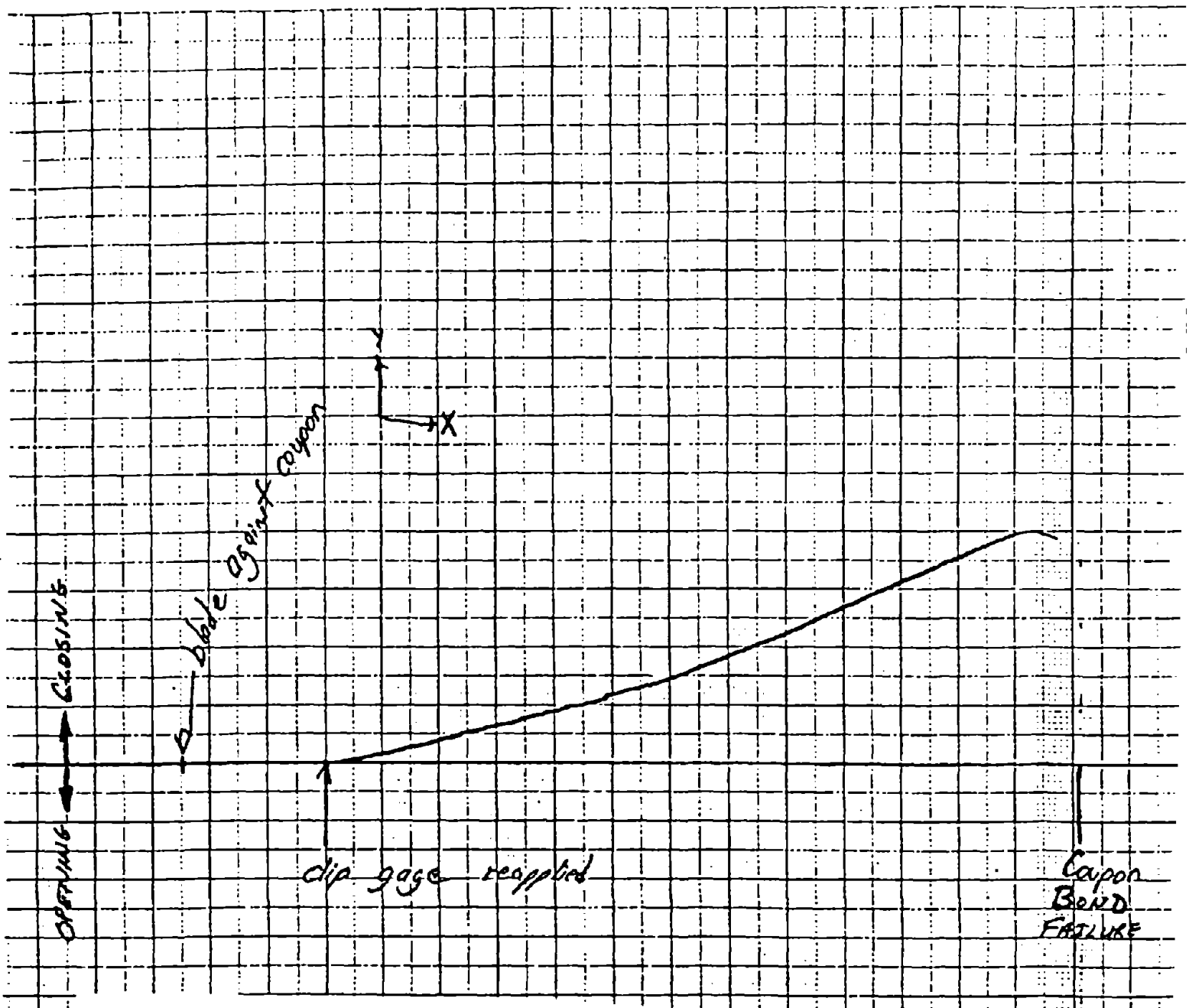




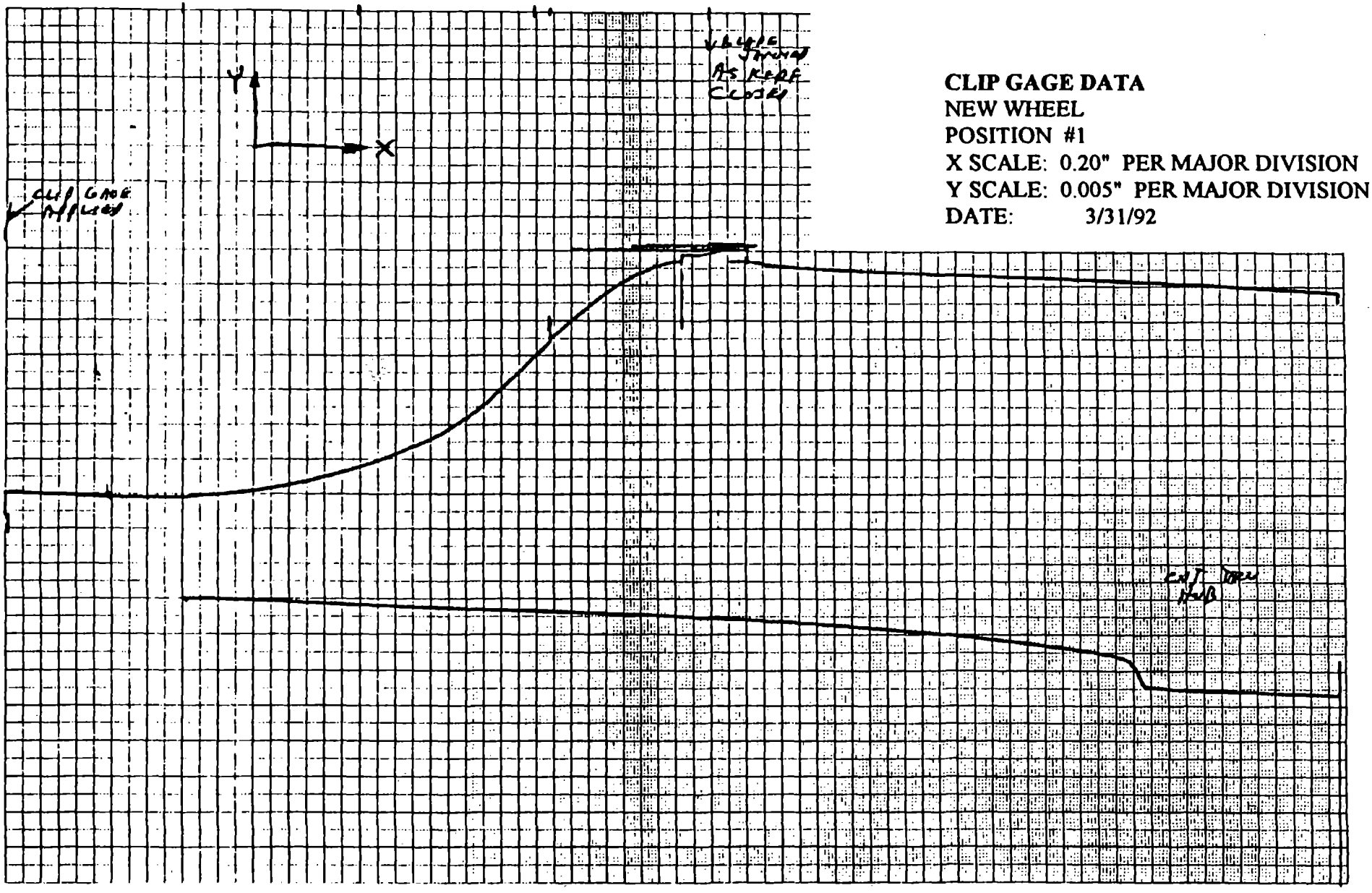


APPENDIX 1

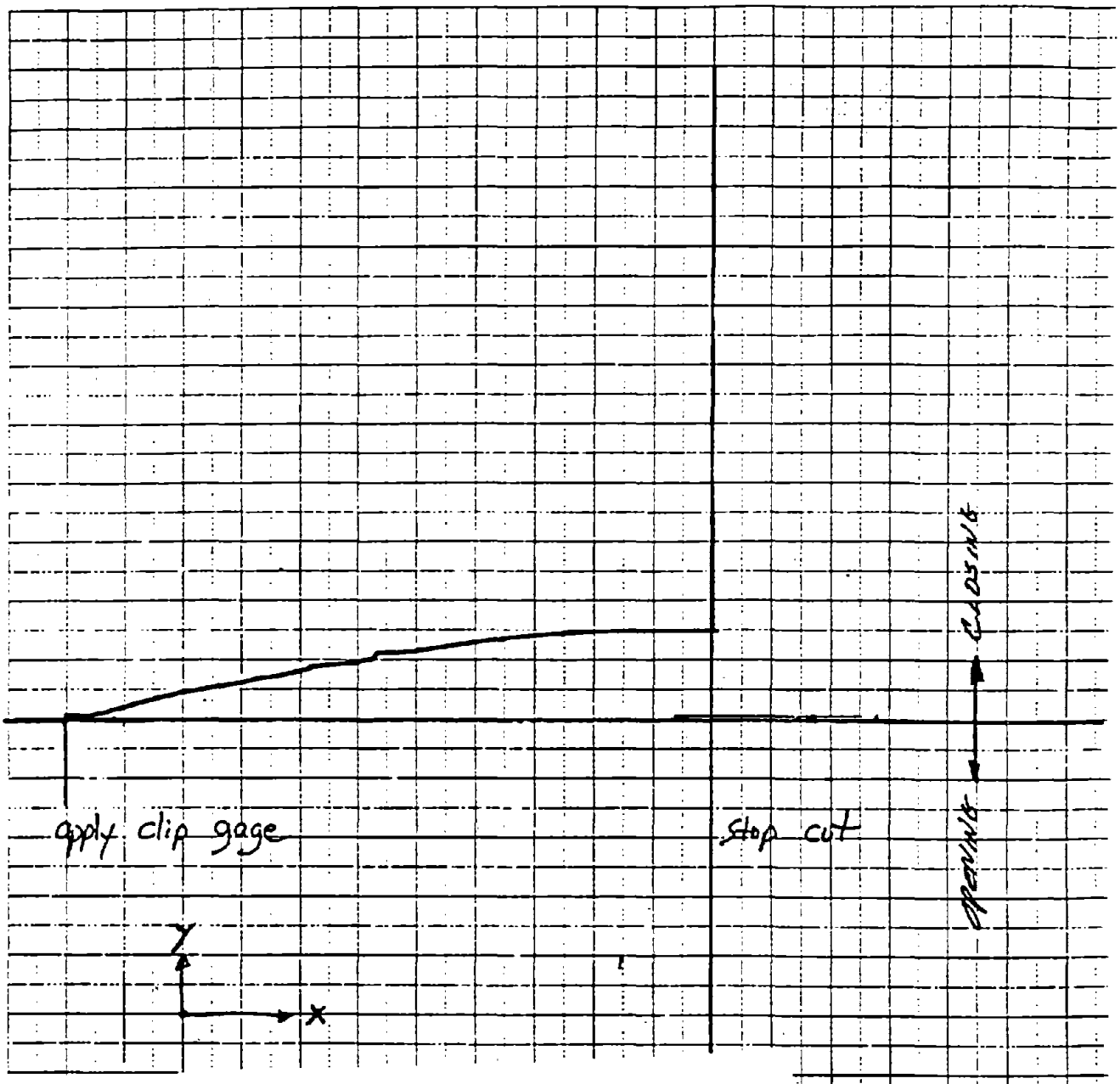
CLIP-ON
DISPLACEMENT GAGE DATA



CLIP GAGE DATA FOR WHEEL SAWING
NEW WHEEL
FIRST CUT POSITION
X SCALE: 0.20 INCH OF CUT PER CHART MAJOR DIVN.
Y SCALE: 0.005 INCH OF GAP WIDTH PER MAJOR DIVN.
POSITIVE (UPWARD) TRACE INDICATES CUT CLOSING
CUT AT NS LAB, ALEXANDRIA, VA. 2/21-22/92



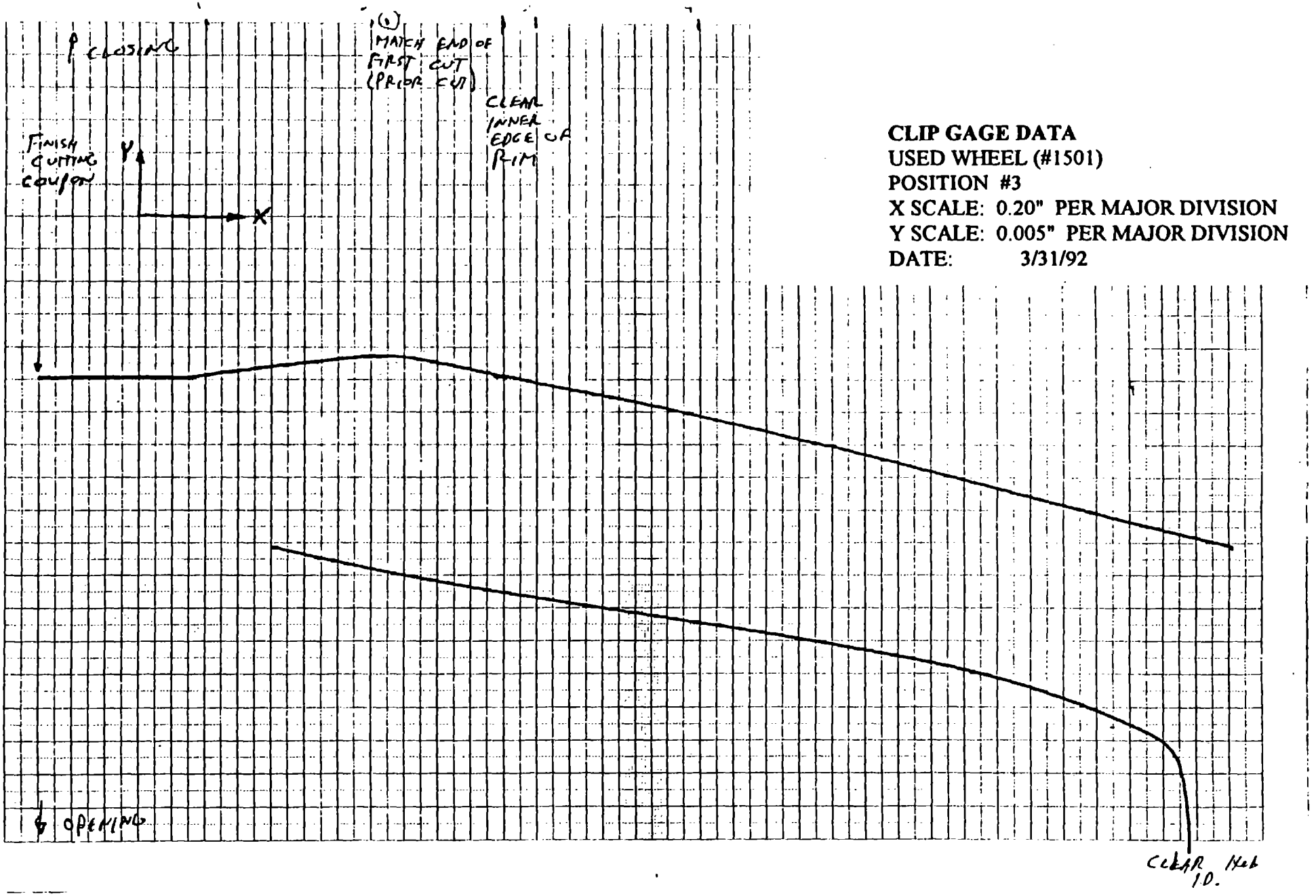
CLIP GAGE DATA
NEW WHEEL
POSITION #1
X SCALE: 0.20" PER MAJOR DIVISION
Y SCALE: 0.005" PER MAJOR DIVISION
DATE: 3/31/92



CLIP GAGE DATA FOR WHEEL SAWING
USED WHEEL FROM NJT 1501
FOURTH CUT POSITION
X SCALE: 0.20 INCH OF CUT PER CHART MAJOR DIVN.
Y SCALE: 0.005 INCH OF GAP WIDTH PER MAJOR DIVN.
POSITIVE (UPWARD) TRACE INDICATES CUT CLOSING
CUT AT NS LAB, ALEXANDRIA, VA. 2/21-22/92

AP1-4 AP-4

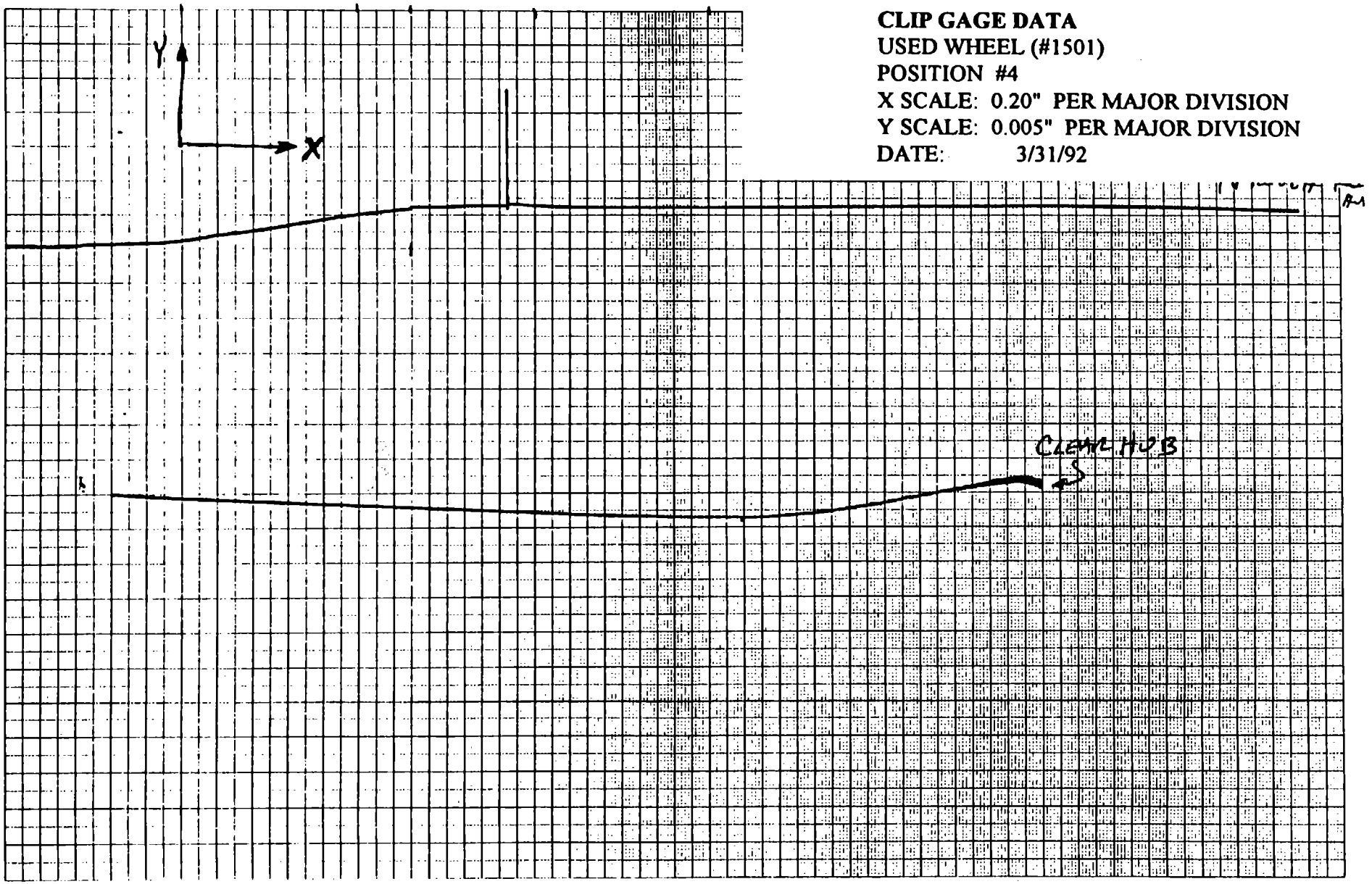
#201-5



CLIP GAGE DATA
USED WHEEL (#1501)
POSITION #3
X SCALE: 0.20" PER MAJOR DIVISION
Y SCALE: 0.005" PER MAJOR DIVISION
DATE: 3/31/92

#205

AP1-6



CLIP GAGE DATA
USED WHEEL (#1501)
POSITION #4
X SCALE: 0.20" PER MAJOR DIVISION
Y SCALE: 0.005" PER MAJOR DIVISION
DATE: 3/31/92

AP1-6

APPENDIX 2

MOIRE INTERFEROMETRY DATA

Robert Czarnek, Ph.D.
616 Fairview Avenue
Blacksburg, Virginia 24060
Tel/Fax 703-951-8813

Dr. Oscar Orringer
Transportation Systems Center
Structures and Dynamics Division (DTS-76)
Kendall Square
Cambridge, MA 02142

Dear Dr. Orringer,

Bob McCown mentioned that you might need the results of the measurements we performed on the two wheels as soon as possible so I am sending you a copy of the plots I produced for ENSCO.

Enclosed are the results of the measurements of displacements along the cuts introduced to the railroad wheels. On seven out of eight gratings the displacement data was collected successfully. Due to misalignment of the saw blade on the eighth one, the deformation could be measured on only one side of the cut, making it impossible to analyze the opening or closing of the cut on this side of the wheel. In this case the distribution of strains in the hoop direction was calculated.

The enclosed curves for hoop displacements represent the amount of closing of the edges of the cut. They were calculated as the difference in hoop displacement of points located symmetrically on opposite sides of the cuts. The distance of these points from the axis of the cuts was in all but one case 2.3 mm. In this one case, part of the grating was damaged during the cutting and the distance was 7 mm. The effect of the distance was evaluated on a couple of patterns (4F and 3F) and appears to be negligible. The difference between the measured displacements for the two sets of points is less than 5 μm and is almost constant along the cuts.

The accuracy of the method used is in the order of half of a micrometer, i.e. about two orders of magnitude higher than required in this project. However, due to the presence of the strain gauges under the instrument and the tilt that they caused some error was introduced. I estimate that this error does not exceed 10 μm for the longest cut, which is still smaller than the specified 25 μm. It can, however introduce a small but detectable error to measured strains

AP2-2 ~~AP2~~

(up to 200 μstrain). This error could slightly affect the radial displacement measurements.

If in the future more experiments of this type are going to be performed the cuts should be made far enough from the strain gauges that the interferometer can be precisely aligned. The width of the measured zone should be the maximum available with this instrument which is about 21 mm.

The cut introduced measurable plastic deformation in the new wheel in the vicinity of the tip of the cut. This plastification of the material can affect the readings of the strain gauges, especially those located near the tip of the cut. The distortion in the strain distribution was clearly visible at a distance of 10 mm from the edge of the cut. Probably a separate test would be desirable to evaluate the maximum distance of the influence of these disturbances. In spite of the large errors it can introduce in the strain readings this plastification seems to have a very small influence on the measurements of the opening of the cut.

Please let me know If I can be of any further assistance.

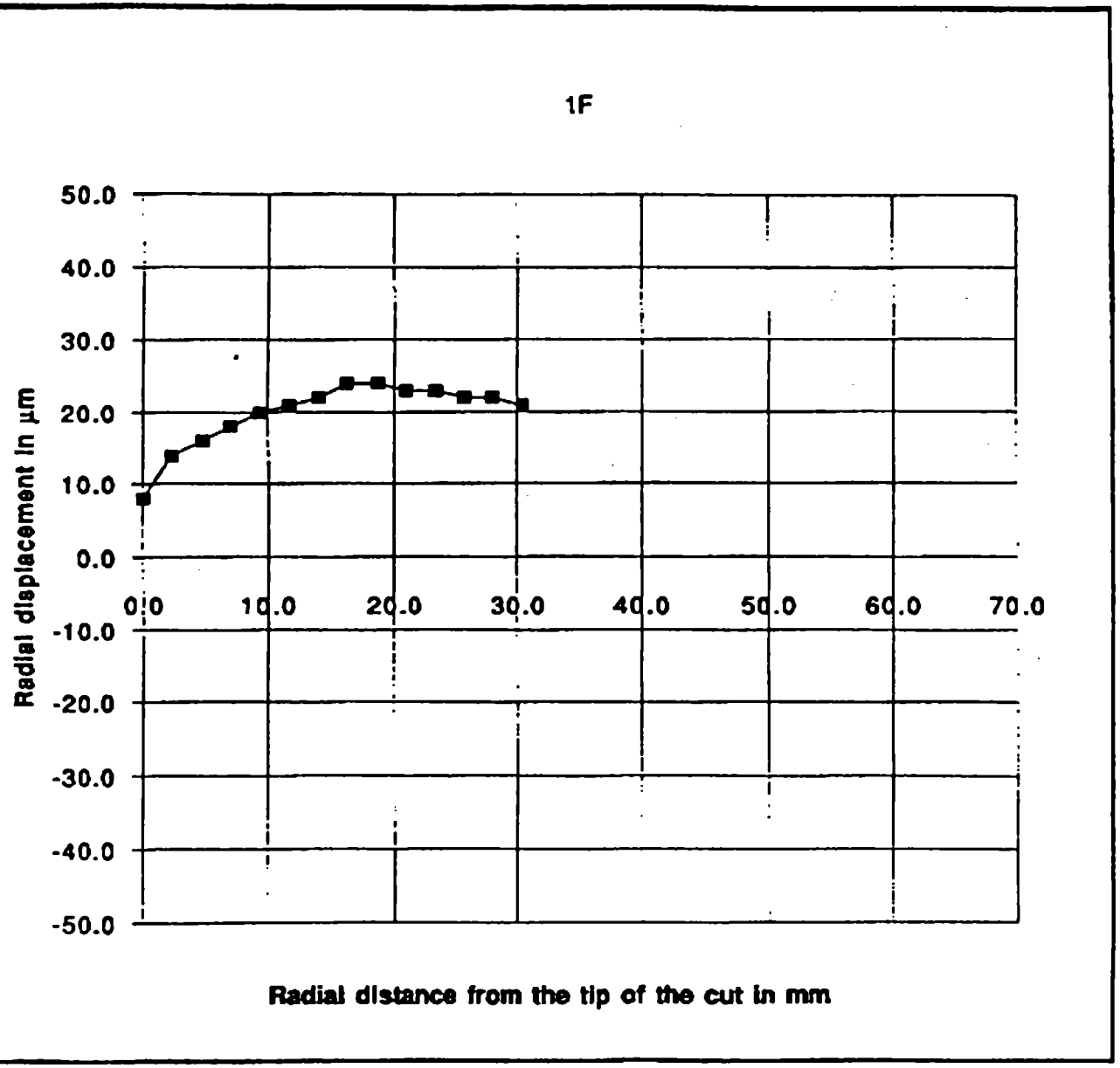
Yours sincerely,

Robert A. Cook

AP2-3 ~~AP3~~

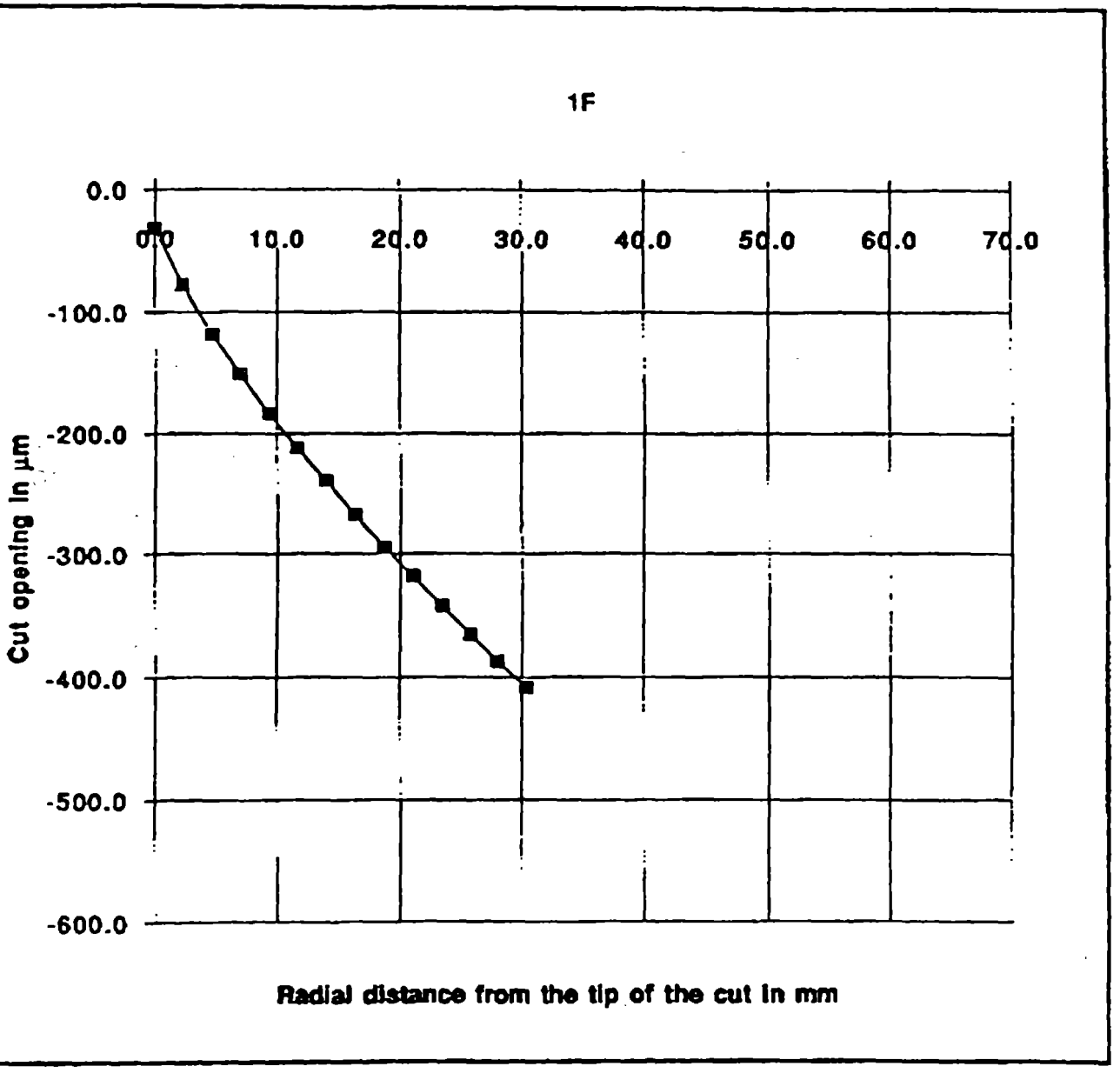
ENSCO results

New wheel	
Cut number 1 front	
Radial displacement in µm	
y	1F
0.0	8.0
2.3	14.0
4.7	16.0
7.0	18.0
9.3	20.0
11.7	21.0
14.0	22.0
16.3	24.0
18.7	24.0
21.0	23.0
23.4	23.0
25.7	22.0
28.0	22.0
30.4	21.0
32.7	
35.0	
37.4	
39.7	
42.0	
44.4	
46.7	
49.0	
51.4	
53.7	
56.1	
58.4	
60.7	
63.1	



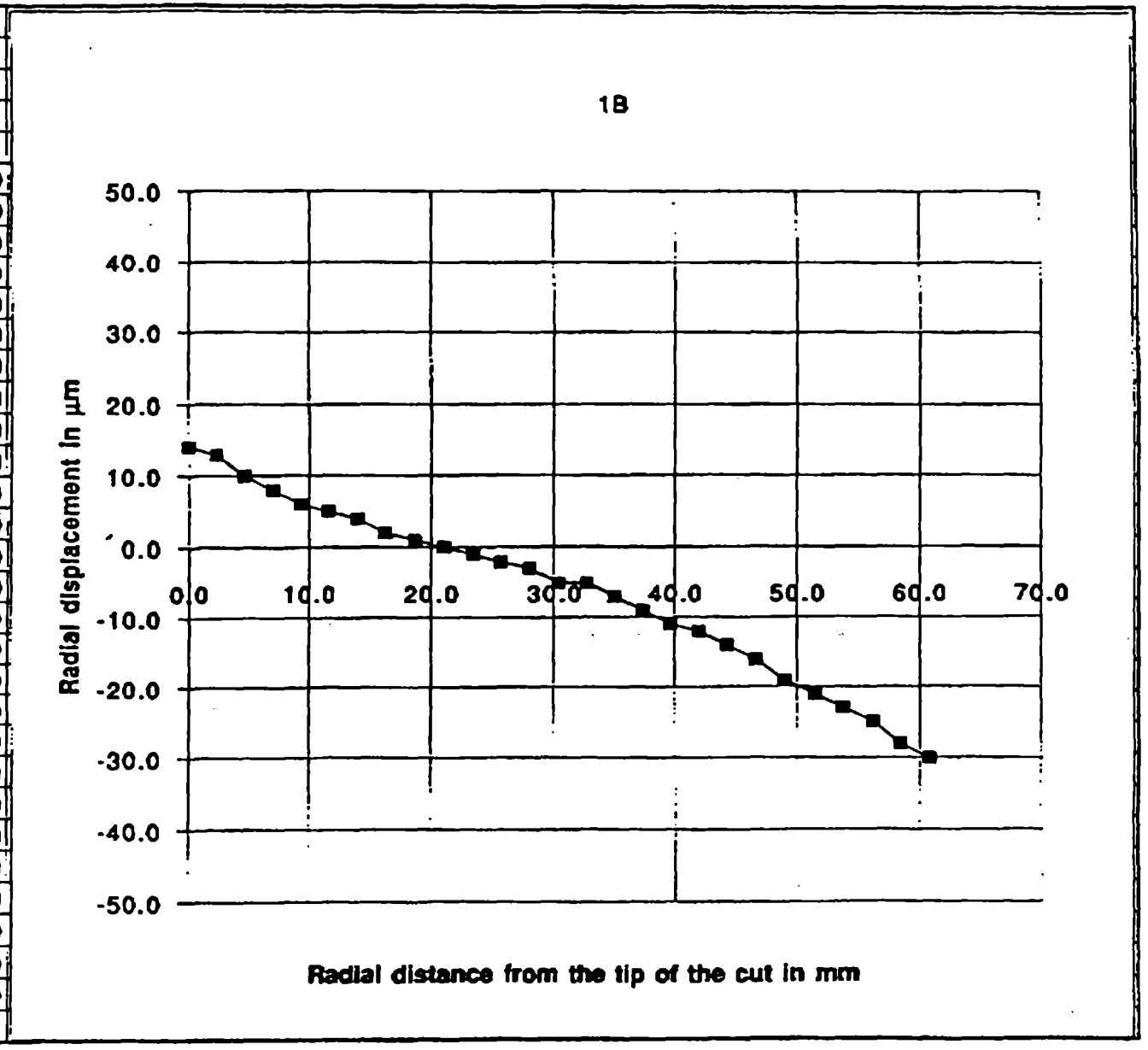
ENSCO results

New wheel	
Cut number 1 front	
Cut opening in µm	
y	1F
0.0	-31.0
2.3	-77.0
4.7	-119.0
7.0	-151.0
9.3	-183.0
11.7	-212.0
14.0	-239.0
16.3	-267.0
18.7	-294.0
21.0	-318.0
23.4	-342.0
25.7	-365.0
28.0	-387.0
30.4	-408.0
32.7	
35.0	
37.4	
39.7	
42.0	
44.4	
46.7	
49.0	
51.4	
53.7	
56.1	
58.4	
60.7	
63.1	



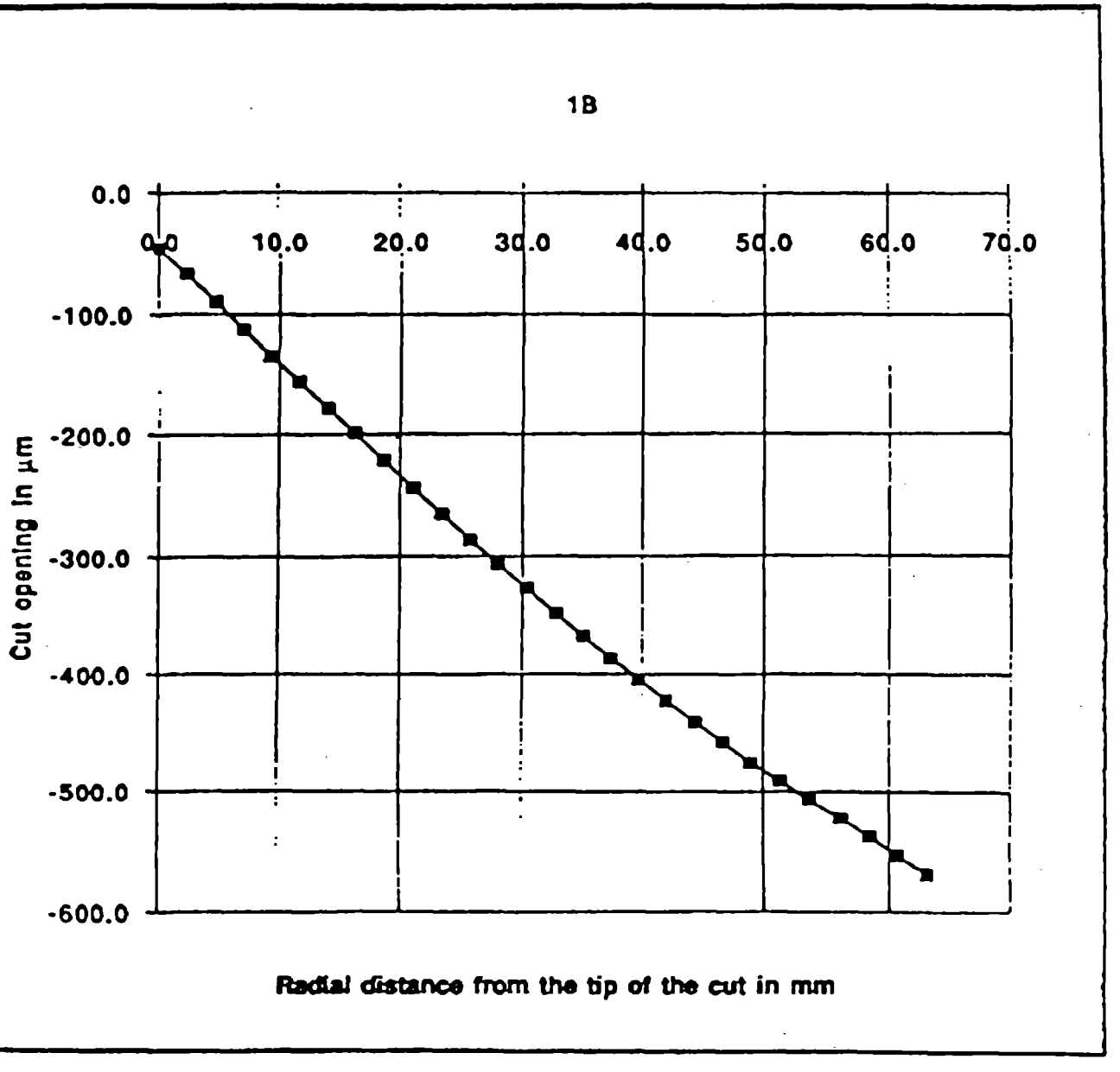
ENSCO results

New wheel	
Cut number 1 back	
Radial displacement in µm	
y	1B
0.0	14.0
2.3	13.0
4.7	10.0
7.0	8.0
9.3	6.0
11.7	5.0
14.0	4.0
16.3	2.0
18.7	1.0
21.0	0.0
23.4	-1.0
25.7	-2.0
28.0	-3.0
30.4	-5.0
32.7	-5.0
35.0	-7.0
37.4	-9.0
39.7	-11.0
42.0	-12.0
44.4	-14.0
46.7	-16.0
49.0	-19.0
51.4	-21.0
53.7	-23.0
56.1	-25.0
58.4	-28.0
60.7	-30.0
63.1	



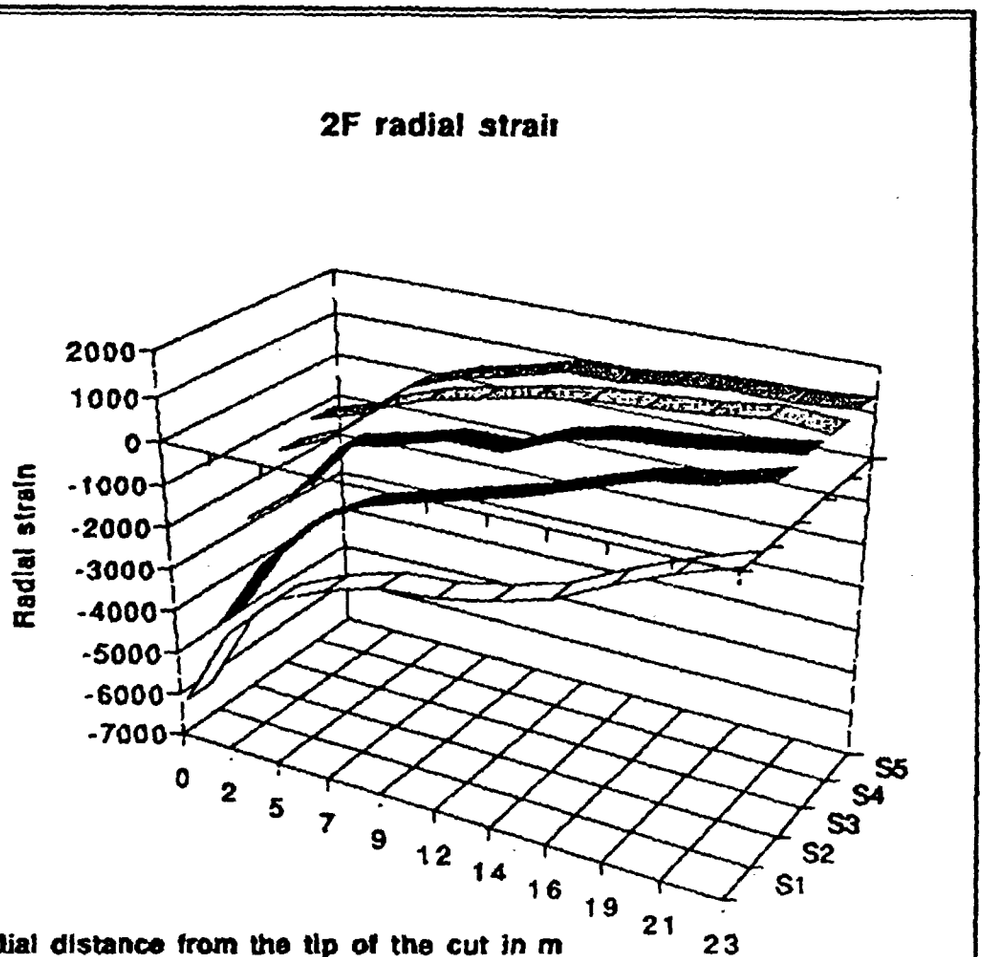
ENSCO results

New wheel	
Cut number 1 back	
Cut opening in µm	
y	1B
0.0	-45.0
2.3	-66.0
4.7	-89.0
7.0	-112.0
9.3	-135.0
11.7	-156.0
14.0	-178.0
16.3	-199.0
18.7	-221.0
21.0	-243.0
23.4	-264.0
25.7	-286.0
28.0	-306.0
30.4	-326.0
32.7	-348.0
35.0	-367.0
37.4	-386.0
39.7	-404.0
42.0	-422.0
44.4	-440.0
46.7	-457.0
49.0	-474.0
51.4	-490.0
53.7	-507.0
56.1	-523.0
58.4	-538.0
60.7	-554.0
63.1	-569.0



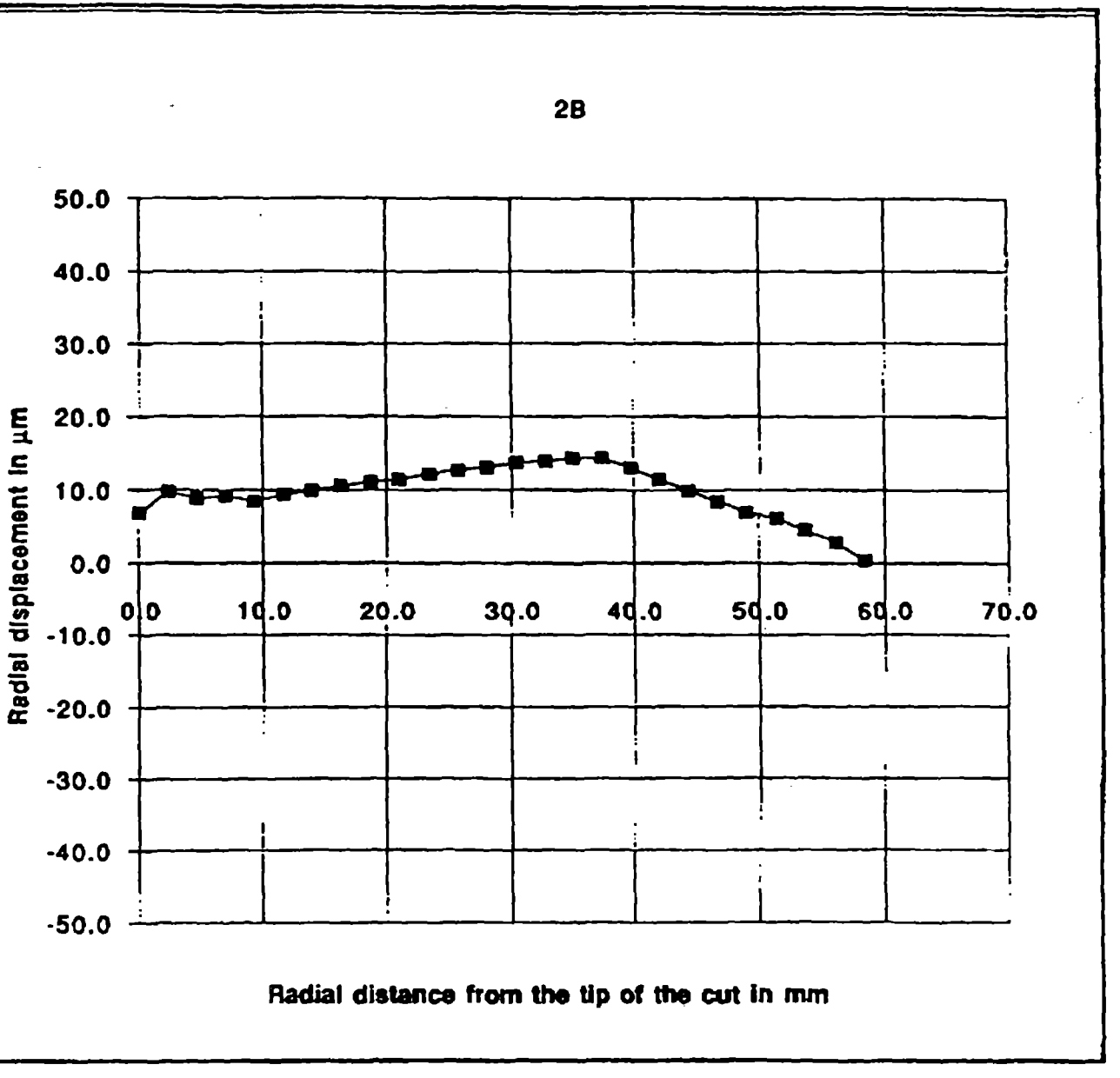
ENSCO results

New wheel					
Cut number 2 front					
Radial displacement in µm					
y	S1	S2	S3	S4	S5
0	-6248	-4998	-2856	-1607	-1250
2	-4284	-3213	-1964	-1071	-893
5	-3213	-1964	-536	-89	0
7	-2678	-1250	-268	357	446
9	-2321	-893	89	625	714
12	-2231	-536	89	893	1071
14	-1964	-179	625	1071	1071
16	-1607	268	893	1160	1250
19	-982	714	982	1250	1339
21	-446	893	1160	1428	1339
23	0	1250	1339	1339	1428
26					
28					
30					
33					
35					
37					
40					
42					
44					
47					
49					
51					
54					
56					
58					
61					
63					



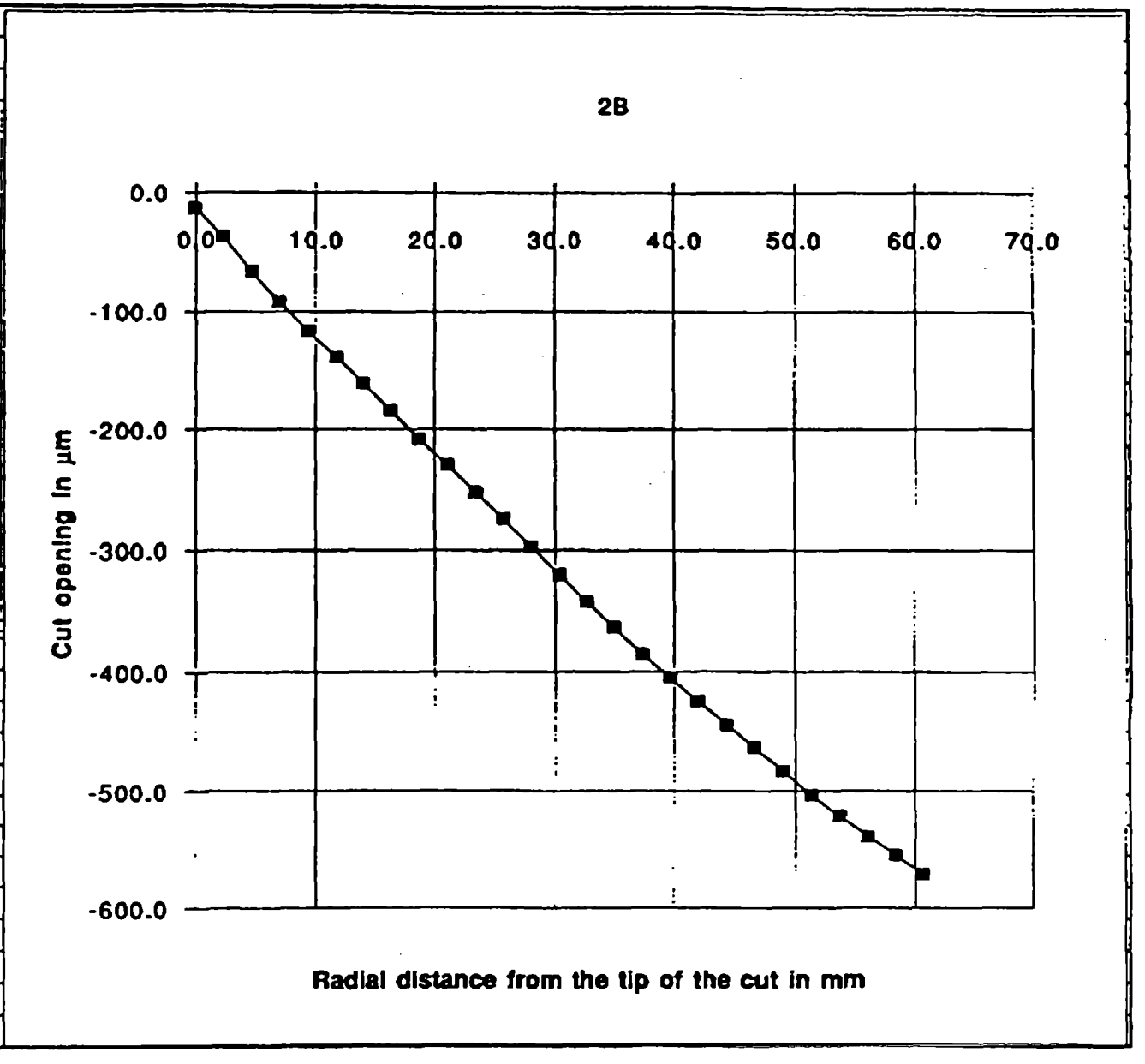
ENSCO results

New wheel	
Cut number 2 back	
Radial displacement in µm	
y	2B
0.0	6.9
2.3	9.8
4.7	9.0
7.0	9.2
9.3	8.5
11.7	9.4
14.0	10.0
16.3	10.6
18.7	11.3
21.0	11.5
23.4	12.3
25.7	12.7
28.0	13.1
30.4	13.8
32.7	14.0
35.0	14.4
37.4	14.4
39.7	13.1
42.0	11.5
44.4	10.0
46.7	8.5
49.0	7.1
51.4	6.3
53.7	4.6
56.1	2.9
58.4	0.4
60.7	
63.1	



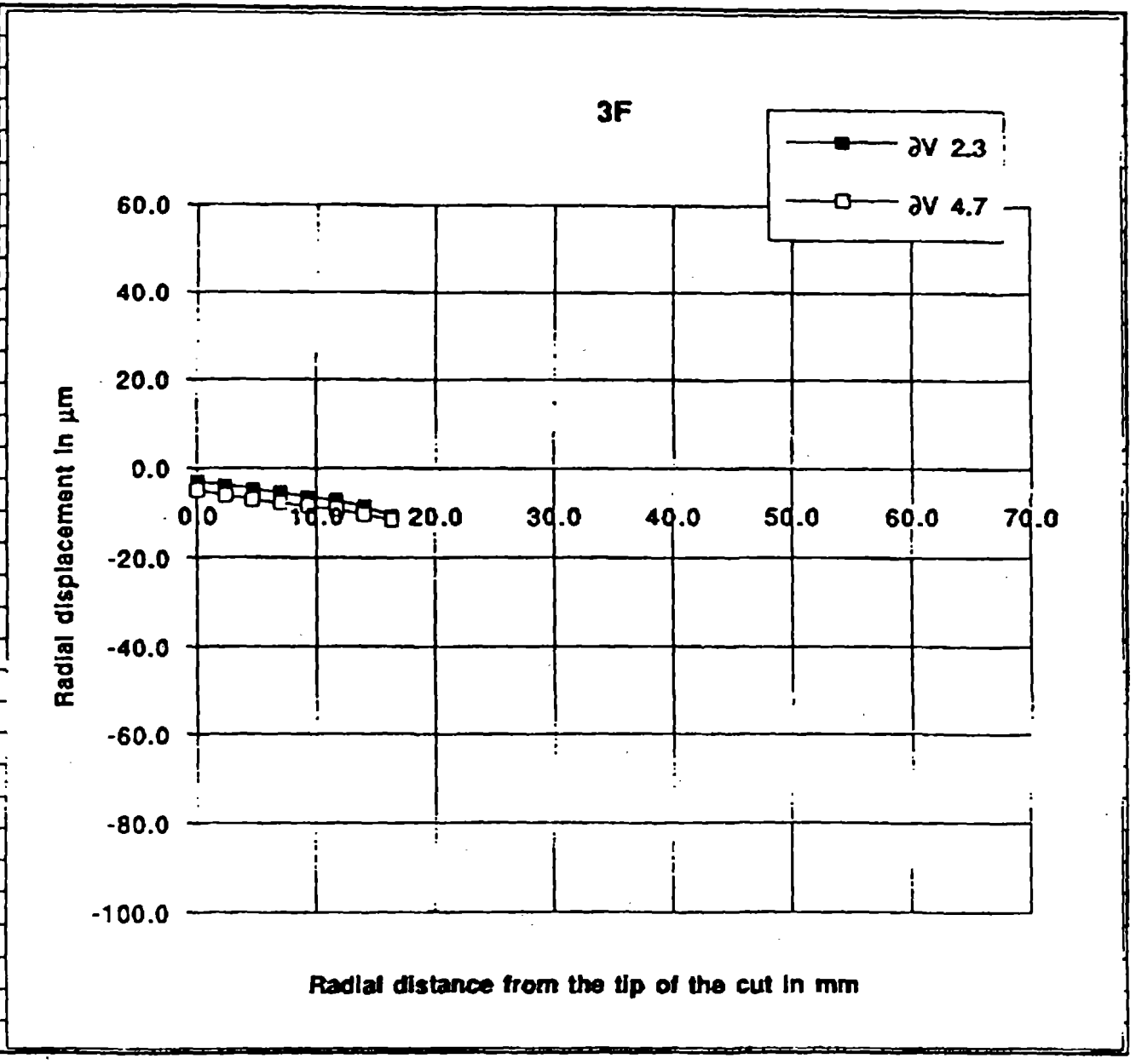
ENSCO results

New wheel	
Cut number 2 back	
Cut opening in µm	
y	2B
0.0	-12.5
2.3	-36.7
4.7	-65.9
7.0	-90.9
9.3	-115.9
11.7	-137.6
14.0	-161.0
16.3	-183.9
18.7	-207.7
21.0	-229.4
23.4	-251.0
25.7	-274.4
28.0	-296.5
30.4	-319.8
32.7	-341.5
35.0	-362.8
37.4	-384.9
39.7	-404.5
42.0	-424.5
44.4	-444.1
46.7	-463.3
49.0	-482.9
51.4	-503.3
53.7	-521.7
56.1	-538.8
58.4	-555.0
60.7	-571.3
63.1	



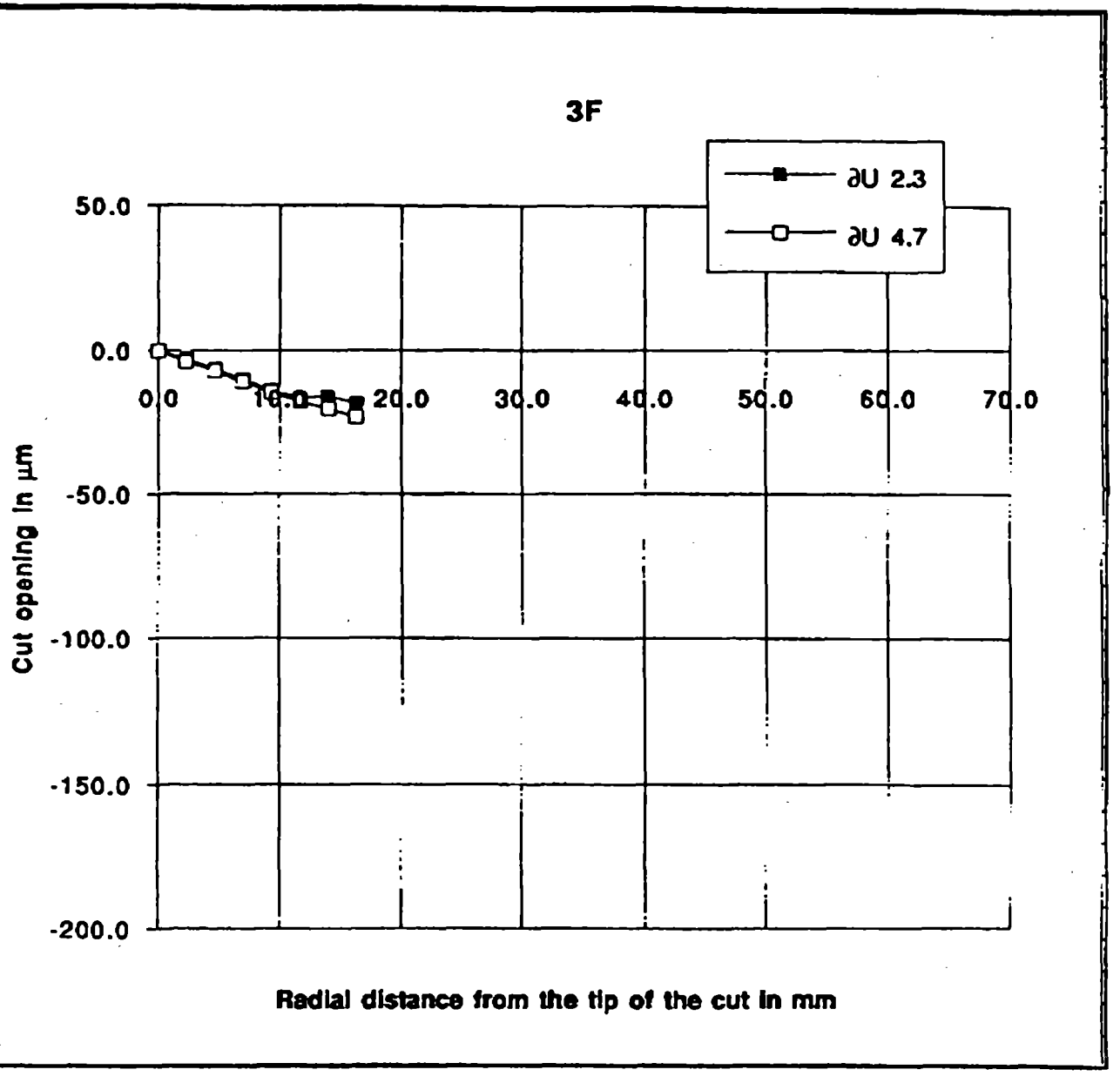
ENSCO results

Old wheel		
Cut number 3 front		
Radial displacement in µm		
y	∂V 2.3	∂V 4.7
0.0	-2.9	-5.0
2.3	-3.8	-6.0
4.7	-4.5	-6.9
7.0	-5.4	-7.7
9.3	-6.3	-8.3
11.7	-7.1	-9.2
14.0	-8.3	-10.2
16.3	-10.6	-11.5
18.7		
21.0		
23.4		
25.7		
28.0		
30.4		
32.7		
35.0		
37.4		
39.7		
42.0		
44.4		
46.7		
49.0		
51.4		
53.7		
56.1		
58.4		
60.7		
63.1		



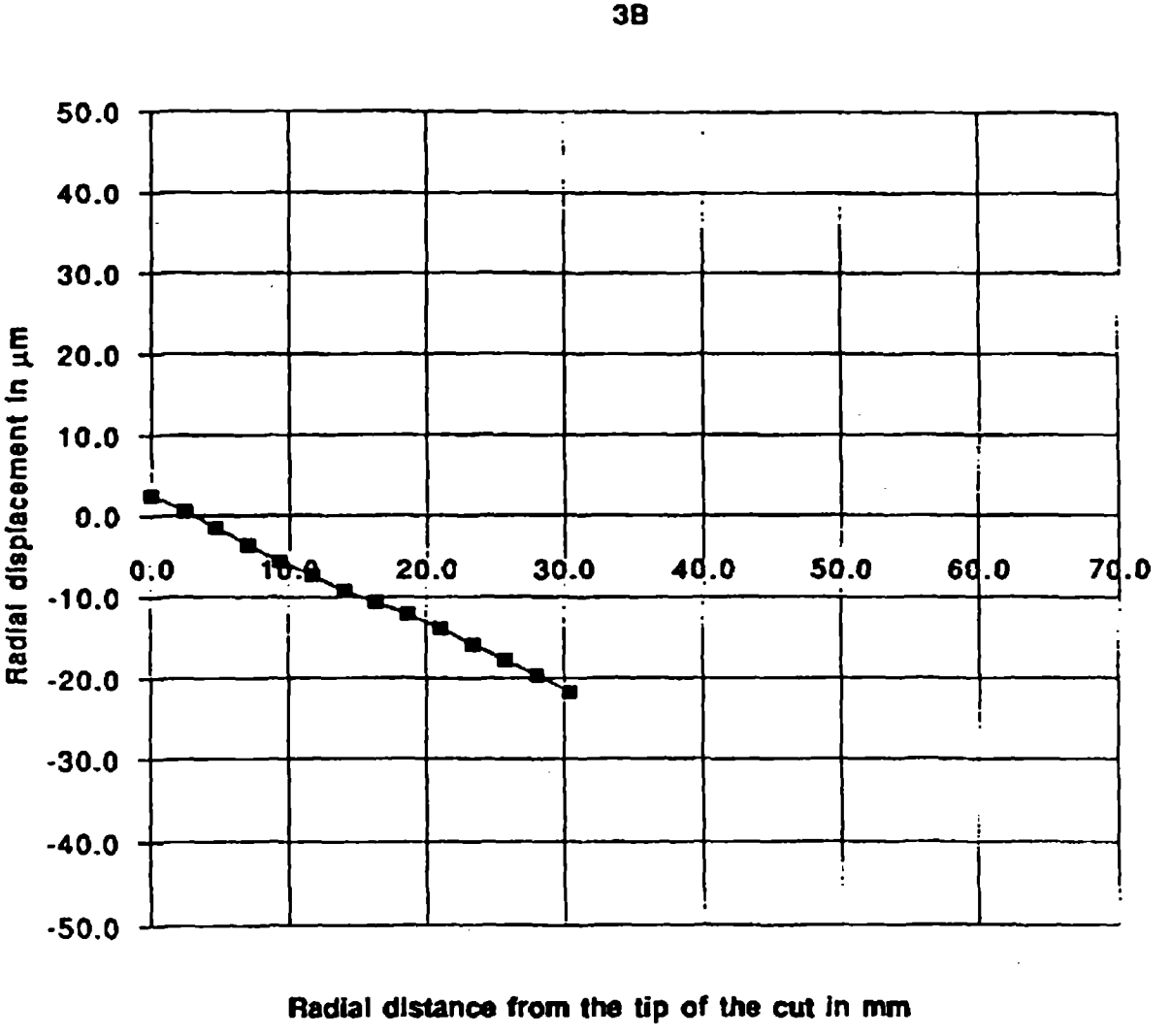
ENSCO results

Old wheel		
Cut number 3 front		
Cut opening in µm		
y	∂U 2.3	∂U 4.7
0.0	0.0	-0.4
2.3	-2.9	-3.8
4.7	-6.3	-7.1
7.0	-10.0	-10.8
9.3	-13.8	-14.6
11.7	-16.3	-17.5
14.0	-15.8	-20.0
16.3	-17.9	-22.9
18.7		
21.0		
23.4		
25.7		
28.0		
30.4		
32.7		
35.0		
37.4		
39.7		
42.0		
44.4		
46.7		
49.0		
51.4		
53.7		
56.1		
58.4		
60.7		
63.1		



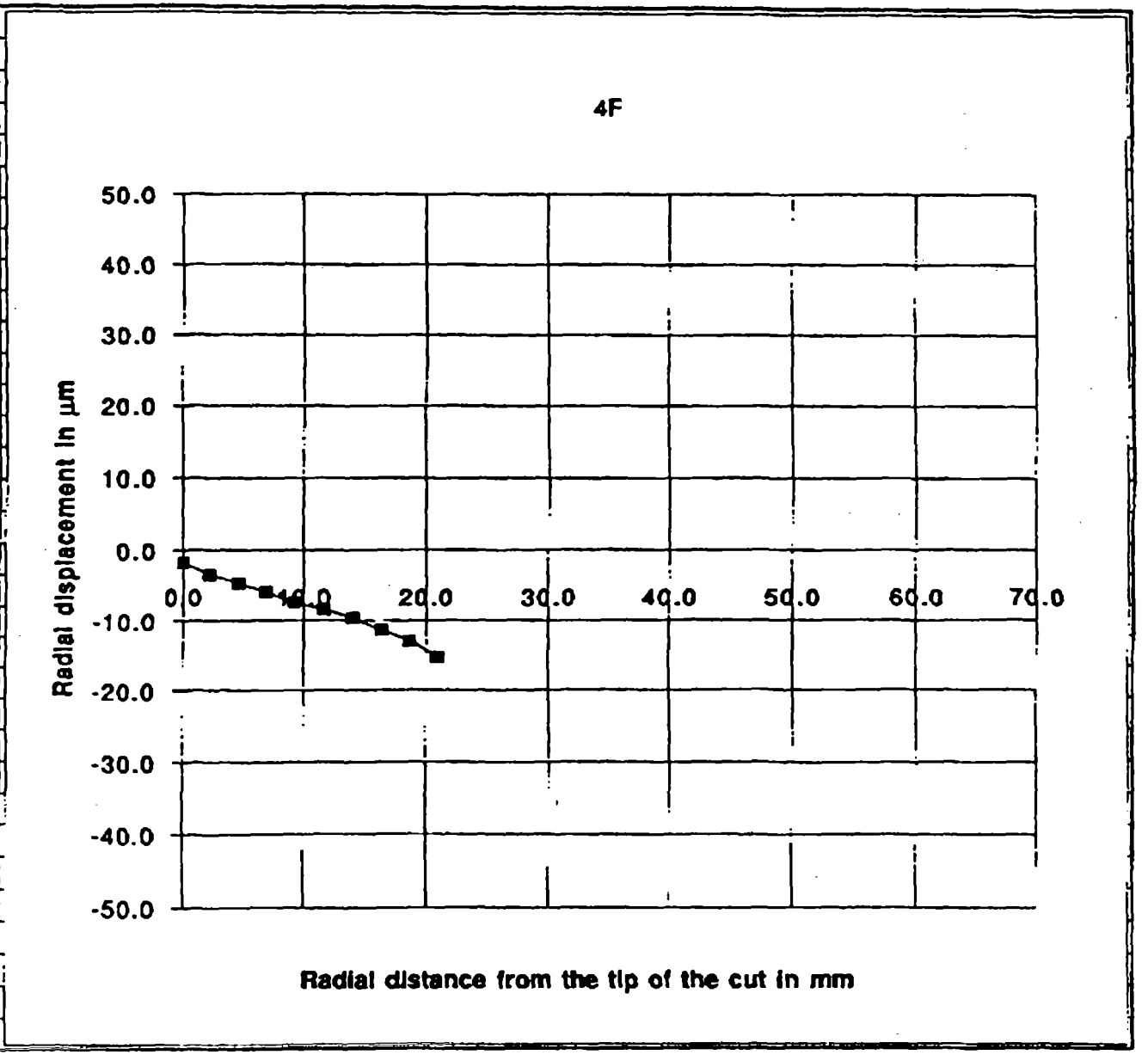
ENSCO results

Old wheel	
Cut number 3 back	
Radial displacement in µm	
y	3B
0.0	2.5
2.3	0.6
4.7	-1.5
7.0	-3.5
9.3	-5.6
11.7	-7.3
14.0	-9.2
16.3	-10.6
18.7	-12.1
21.0	-13.8
23.4	-15.8
25.7	-17.7
28.0	-19.6
30.4	-21.7
32.7	
35.0	
37.4	
39.7	
42.0	
44.4	
46.7	
49.0	
51.4	
53.7	
56.1	
58.4	
60.7	
63.1	



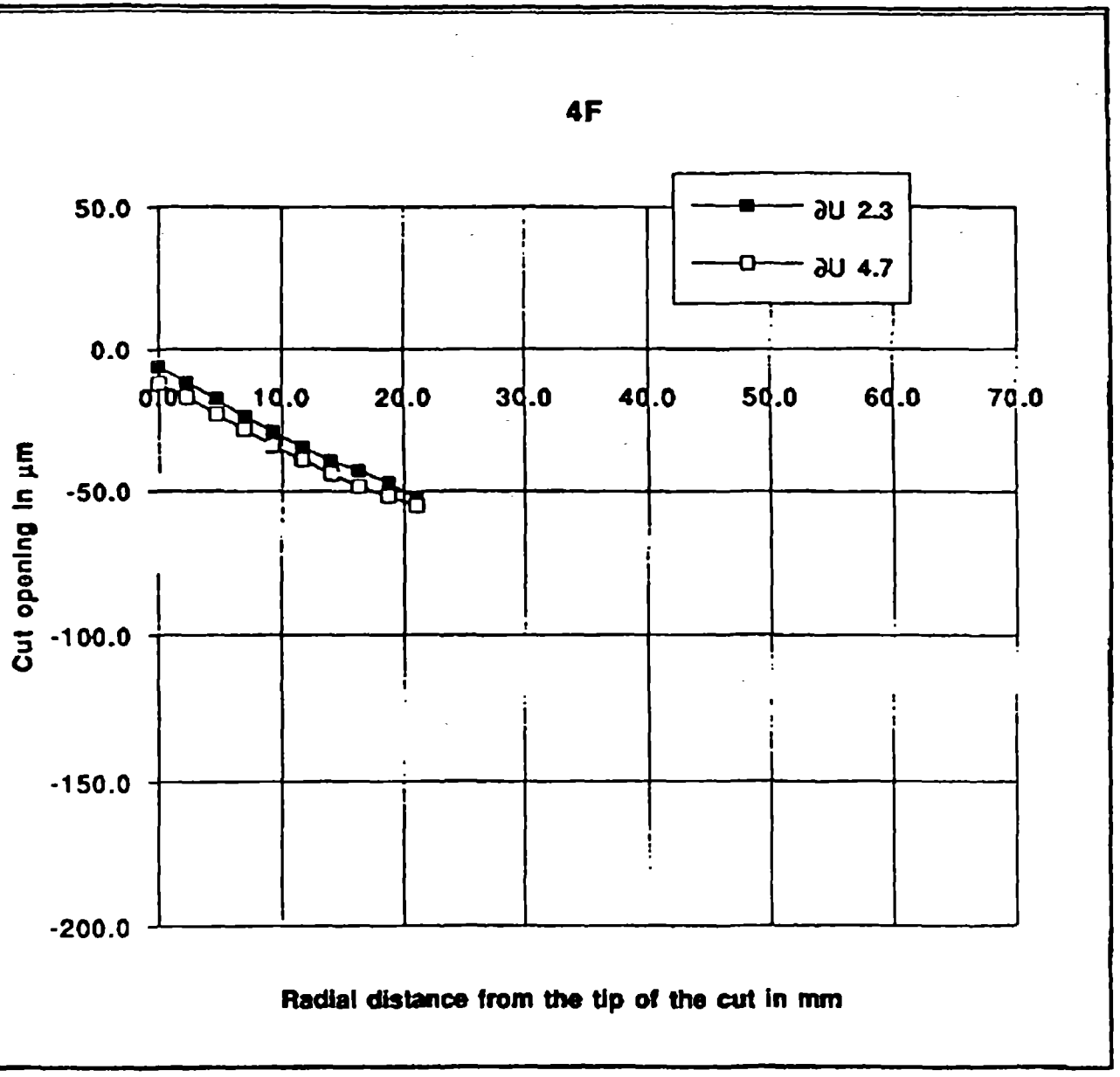
ENSCO results

Old wheel	
Cut number 4 front	
Radial displacement in µm	
y	4F
0.0	-1.7
2.3	-3.3
4.7	-4.6
7.0	-5.8
9.3	-7.3
11.7	-8.3
14.0	-9.6
16.3	-11.3
18.7	-12.8
21.0	-15.2
23.4	
25.7	
28.0	
30.4	
32.7	
35.0	
37.4	
39.7	
42.0	
44.4	
46.7	
49.0	
51.4	
53.7	
56.1	
58.4	
60.7	
63.1	



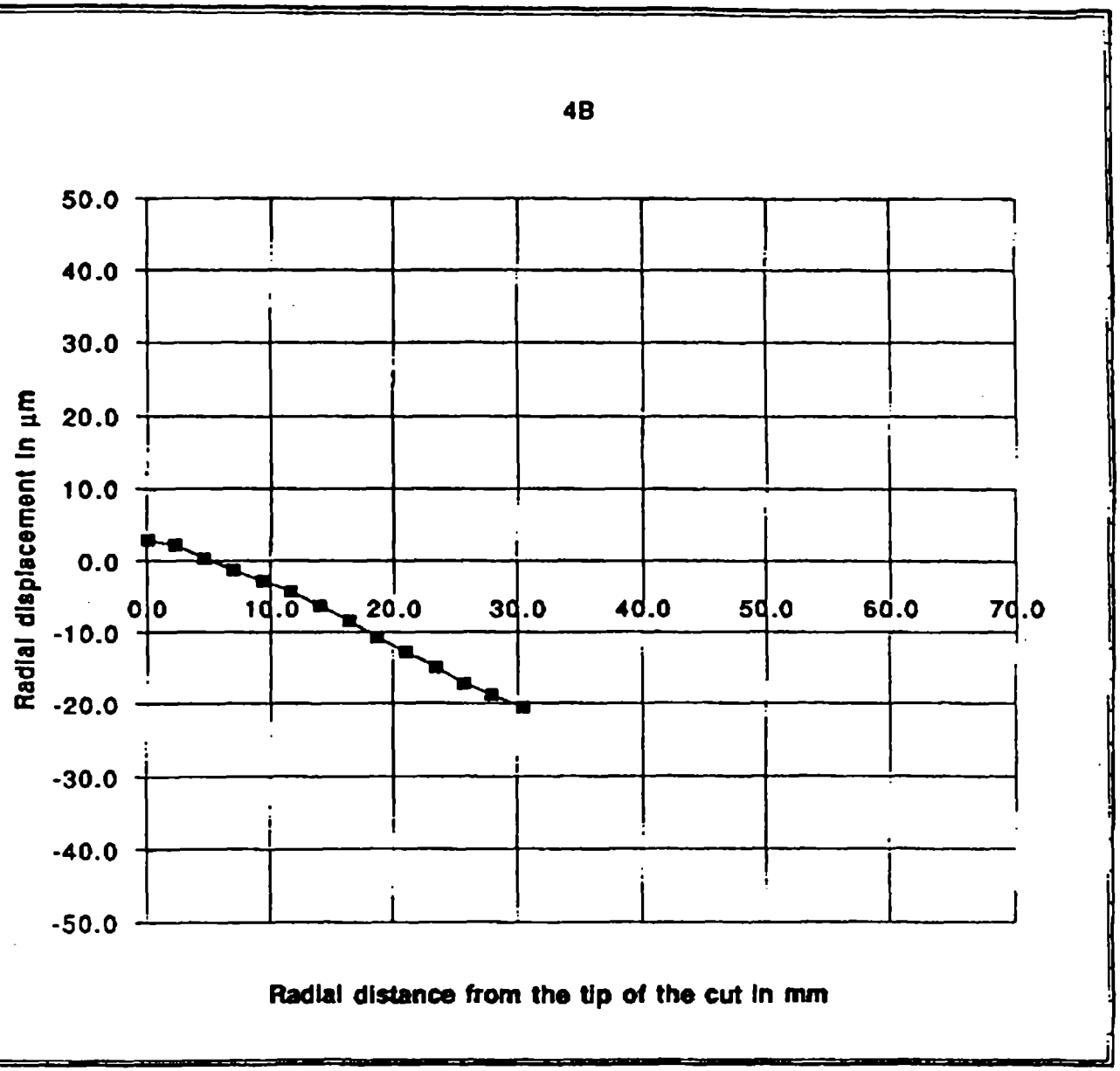
ENSCO results

Old wheel		
Cut number 4 front		
Cut opening in µm		
y	∂U 2.3	∂U 4.7
0.0	-6.3	-12.1
2.3	-11.7	-16.7
4.7	-17.1	-22.5
7.0	-23.4	-27.9
9.3	-28.8	-33.8
11.7	-34.2	-38.8
14.0	-39.2	-43.8
16.3	-42.5	-48.2
18.7	-46.7	-51.7
21.0	-52.5	-55.0
23.4		
25.7		
28.0		
30.4		
32.7		
35.0		
37.4		
39.7		
42.0		
44.4		
46.7		
49.0		
51.4		
53.7		
56.1		
58.4		
60.7		
63.1		



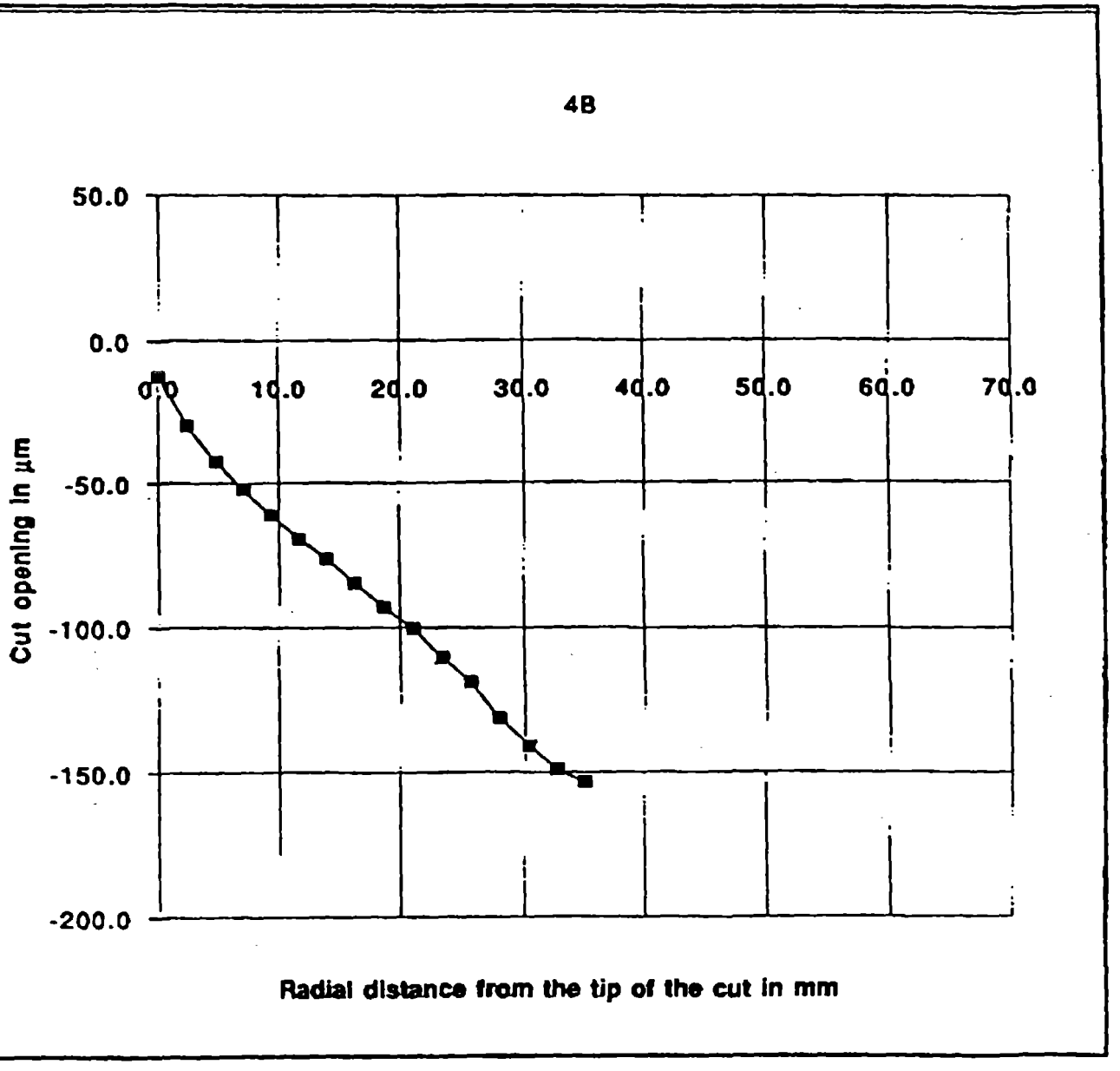
ENSCO results

Old wheel	
Cut number 4 back	
Radial displacement in µm	
y	4B
0.0	2.9
2.3	2.3
4.7	0.4
7.0	-1.3
9.3	-2.7
11.7	-4.2
14.0	-6.3
16.3	-8.3
18.7	-10.6
21.0	-12.7
23.4	-14.8
25.7	-17.1
28.0	-18.8
30.4	-20.4
32.7	
35.0	
37.4	
39.7	
42.0	
44.4	
46.7	
49.0	
51.4	
53.7	
56.1	
58.4	
60.7	
63.1	



ENSCO results

Old wheel	
Cut number 4 back	
Cut opening in µm	
y	4B
0.0	-12.1
2.3	-29.2
4.7	-42.1
7.0	-52.1
9.3	-61.3
11.7	-69.6
14.0	-76.7
16.3	-85.1
18.7	-93.0
21.0	-100.1
23.4	-110.1
25.7	-118.4
28.0	-130.9
30.4	-140.5
32.7	-148.9
35.0	-153.5
37.4	
39.7	
42.0	
44.4	
46.7	
49.0	
51.4	
53.7	
56.1	
58.4	
60.7	
63.1	



APPENDIX 3

STRAIN GAGE DATA

TABLE OF CONTENTS

AP-32 AP-2

STRAIN GAGE DATA - POSITION 1 - 2/22/92

NEW WHEEL - HOOP DIRECTION
POSITION 1 STRAIN GAGE DATA
2/22/92

WHEEL POSITION	HOOP GAGE NUMBER	ZERO CHECK	GAIN	2/3 RIM CUT FINAL	2/3 RIM CUT FINAL WITH ZERO ADJUST
	2	1	980	-1080	-1081
FRONT	4	0	981	-616	-616
RIM	6	1	980	550	549
FACE	8	0	980	1046	1046
	10	-2	980	1453	1455
	12	0	980	1401	1401
	14	-3	981	1391	1394
TREAD	16	1	980	1386	1385
	18	0	980	1353	1353
	20	3	982	1339	1336
	22	0	982	983	983
BACK	24	0	982	696	696
RIM	26	-1	981	208	209
FACE	28	0	982	-475	-475
	30	1	982	-907	-908
	32	0	979	-822	-822

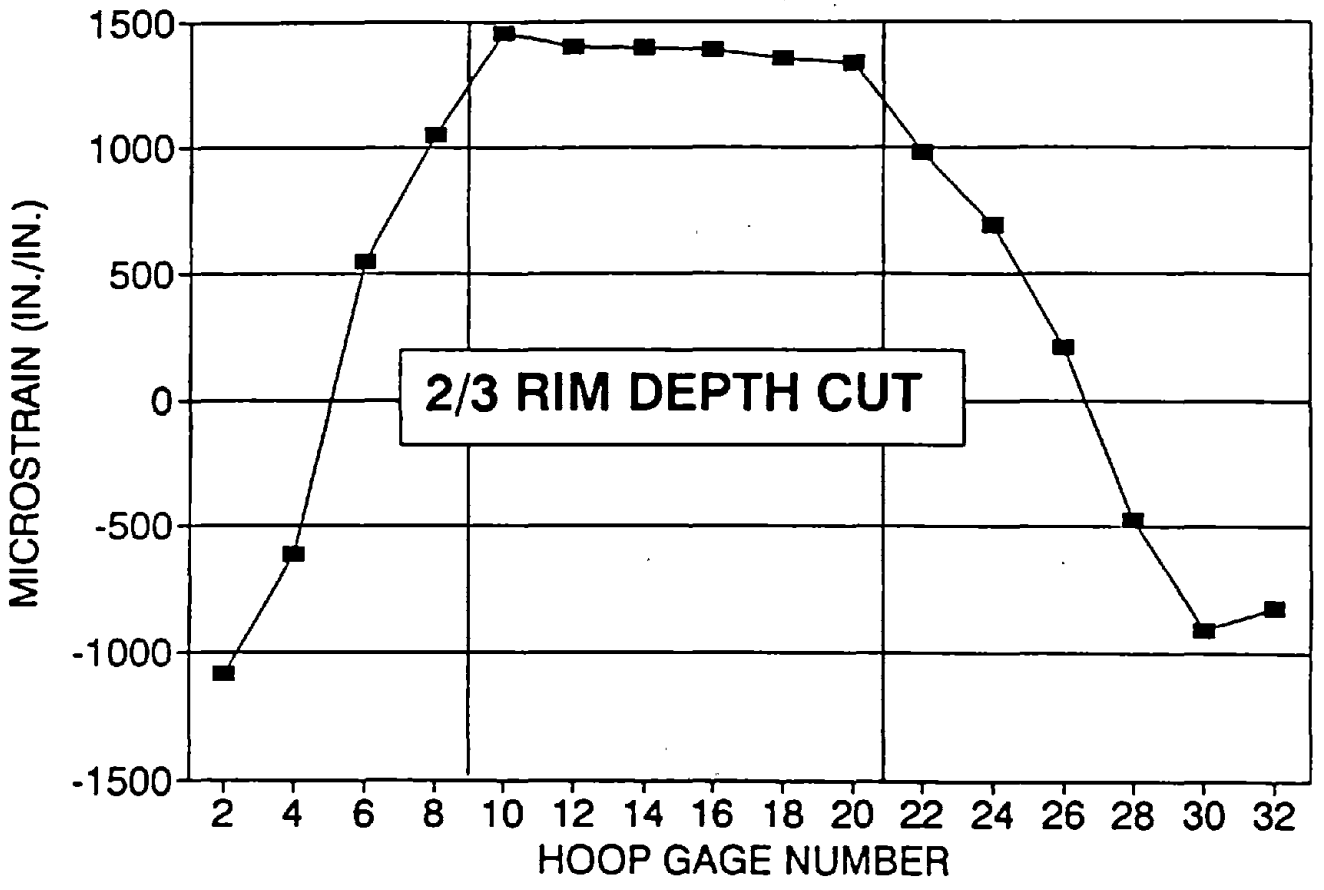
NEW WHEEL - RADIAL DIRECTION
POSITION 1 STRAIN GAGE DATA
2/22/92

WHEEL POSITION	RADIAL GAGE NUMBER	ZERO CHECK	GAIN	2/3 RIM CUT FINAL	2/3 RIM CUT FINAL WITH ZERO ADJUST
	1	0	981	389	389
FRONT	3	-1	979	621	622
RIM	5	0	981	-145	-145
FACE	7	-1	981	-382	-381
	9	-2	980	-384	-382
	11	0	981	-273	-273
	13	0	983	-167	-167
TREAD	15	2	980	-88	-90
	17	1	982	-60	-61
	19	-1	981	-108	-107
	21	-1	981	-398	-397
BACK	23	0	983	-396	-396
RIM	25	-2	982	-198	-196
FACE	27	-2	979	188	190
	29	0	982	522	522
	31	-1	979	271	272

PROCESSED 4/5/92 - C. STUART

AP-3-3 AP-3

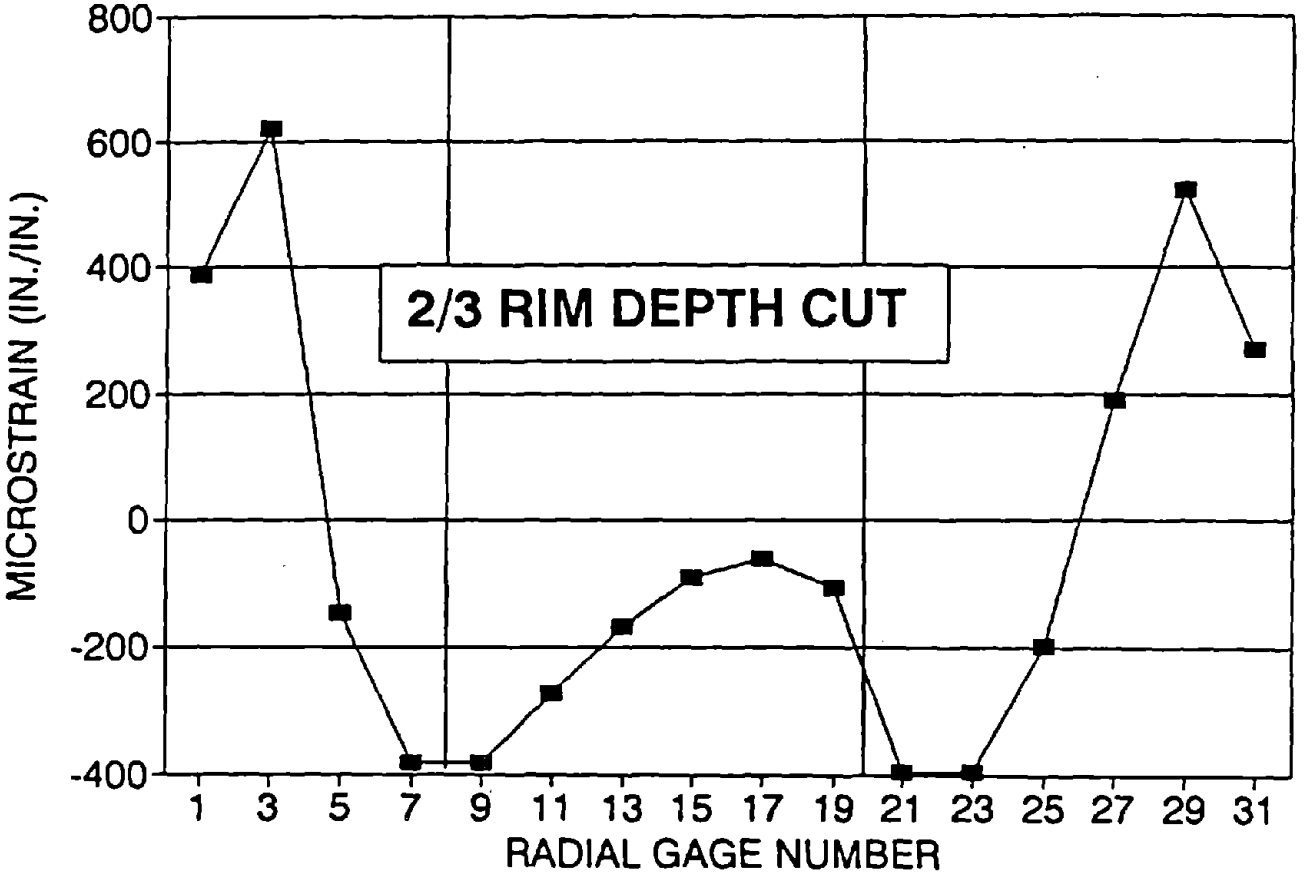
HOOP GAGE DATA - POSITION 1-(2/22/92)
2-8(FRF);10-20(TREAD);22-32(BRF)



AP3-4

AP-4

RADIAL GAGE DATA - POSITION 1-(2/22/92)
1-7(FRF);9-19(TREAD);21-31(BRF)

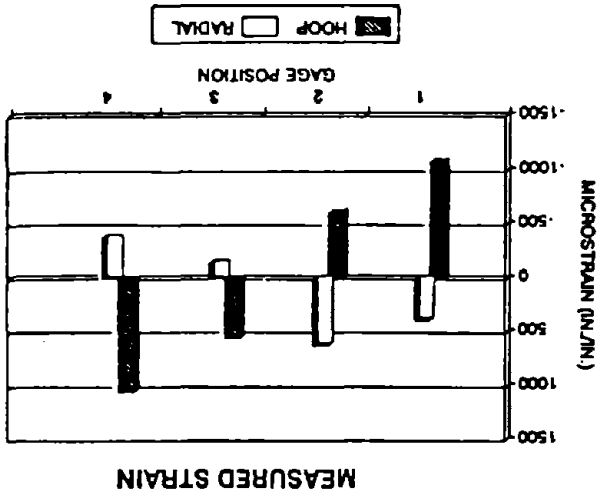


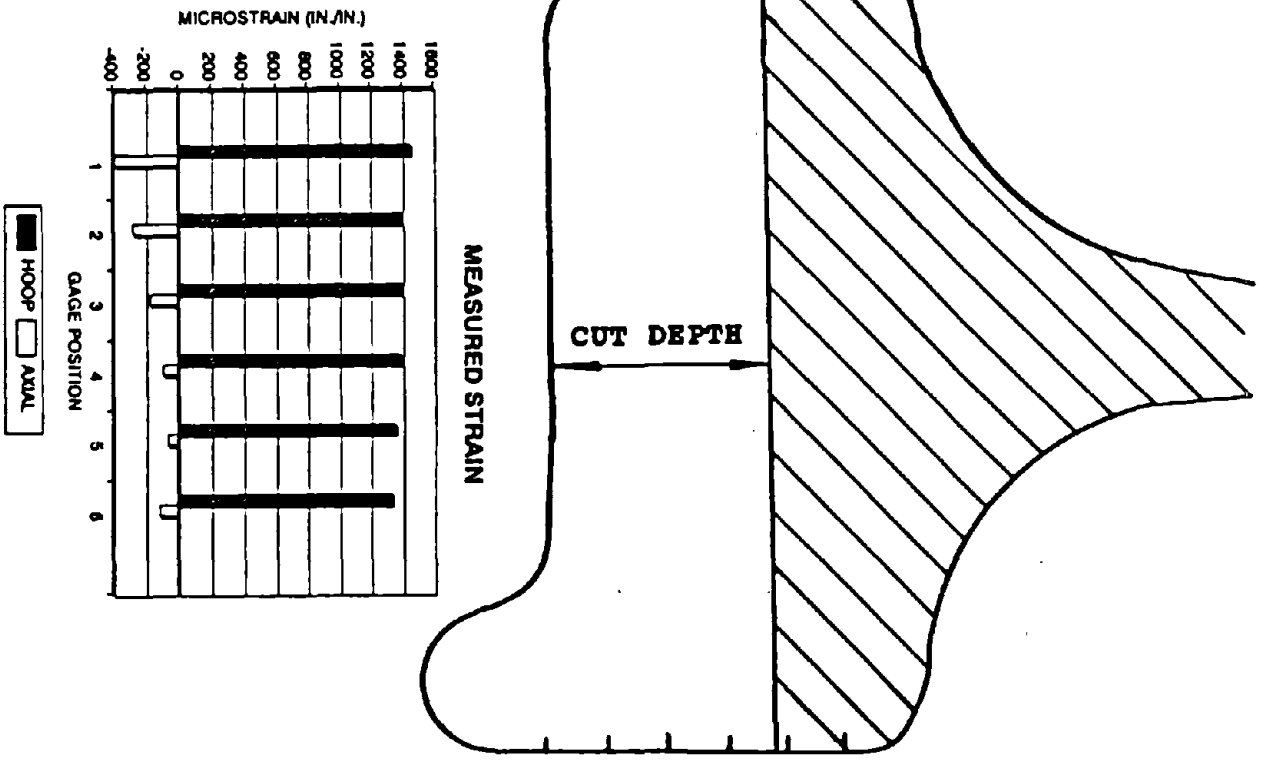
AP-3-5

DATA DISPLAY
RIM ORIENTATION

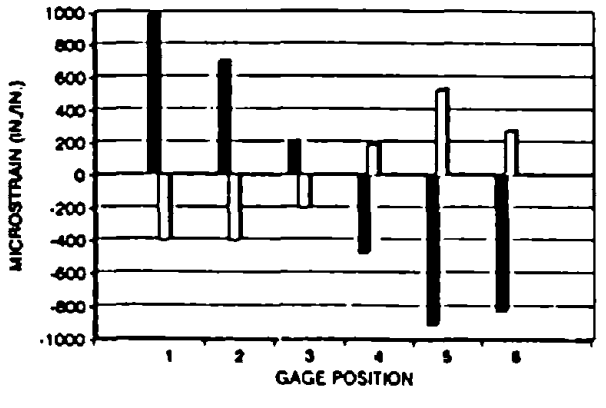
NEW WHEEL
Position 1
2/3 of Rim Cut
Feb. 21, 1992

Positive Strain
=> Compression
Negative Strain
=> Tension





MEASURED STRAIN



AP-4-
3-5
AP-6

AP3-6

STRAIN GAGE DATA - POSITION 1 - 3/31/92

NEW WHEEL - HOOP DIRECTION
POSITION 1 STRAIN GAGE DATA
3/31/92

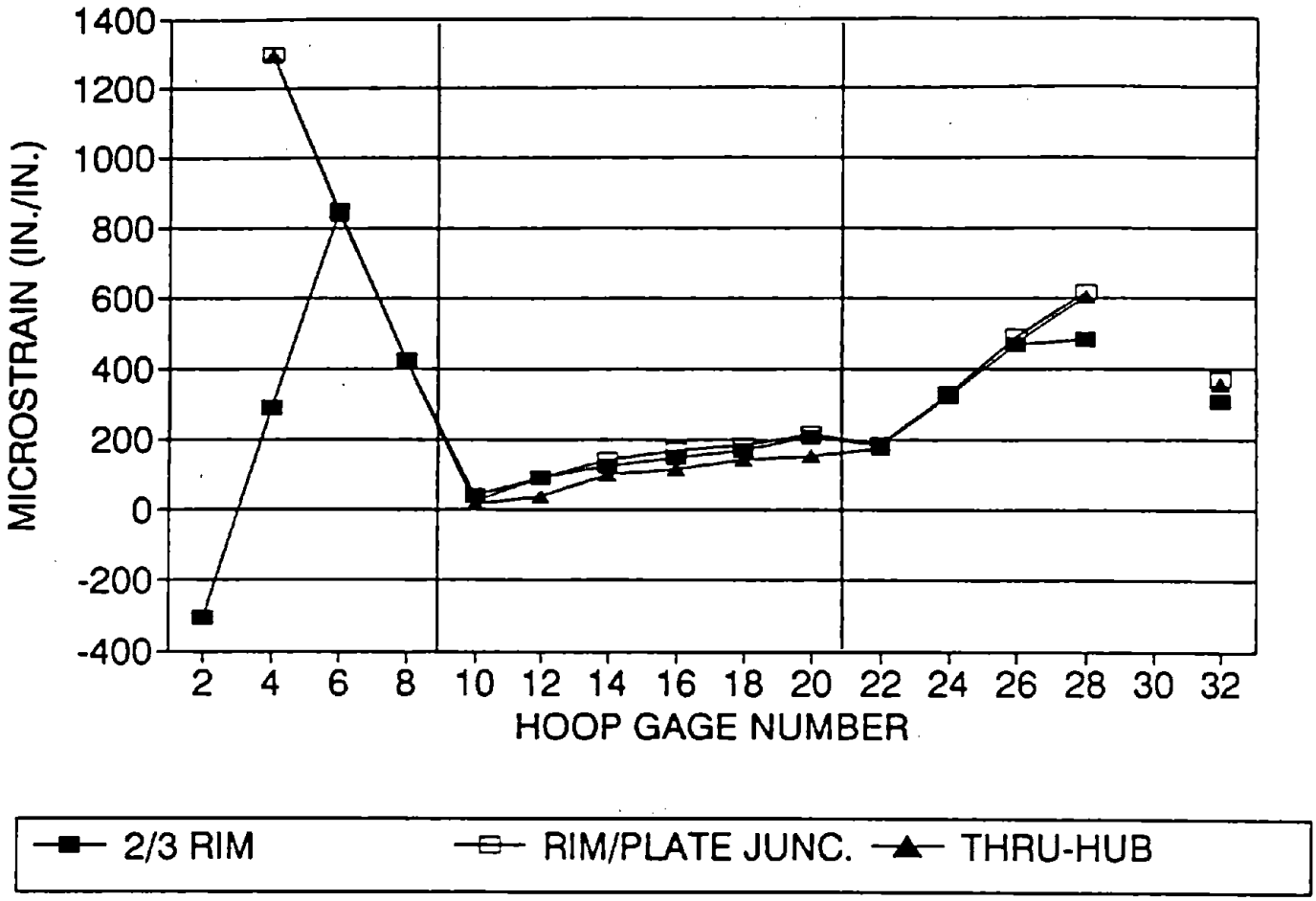
WHEEL POSITION	HOOP GAGE NUMBER	ZERO CHECK	GAIN	2/3 RIM CUT FINAL	2/3 RIM CUT FINAL WITH ZERO ADJUST	RIM/PLATE FILLET JUNCTION	RIM\PLATE FILLET JUNC. W/ ZERO ADJ.	THRU-HUB FINAL READINGS	THRU-HUB FINAL WITH ZERO ADJ.
	2	-1	981	-307	-306	OFF SCALE		NO READ	
FRONT	4	-2	980	290	292	1297	1299	1293	1295
RIM	6	0	982	850	850	847	847	837	837
FACE	8	-2	984	419	421	424	426	419	421
	10	-1	984	41	42	21	22	14	15
	12	-3	978	88	91	87	90	32	35
	14	4	982	129	125	143	139	102	98
TREAD	16	-2	980	149	151	167	169	115	117
	18	1	987	173	172	185	184	141	140
	20	-4	988	204	208	213	217	148	152
	22	-1	982	183	184	184	185	172	173
BACK	24	-3	984	322	325	324	327	OFF SCALE	
RIM	26	-1	982	471	472	489	490	473	474
FACE	28	1	982	483	482	616	615	607	606
	30	BAD	GAGE						
	32	0	977	306	306	371	371	359	359

NEW WHEEL - RADIAL DIRECTION
POSITION 1 STRAIN GAGE DATA
3/31/92

WHEEL POSITION	RADIAL GAGE NUMBER	ZERO CHECK	GAIN	2/3 RIM CUT FINAL	2/3 RIM CUT FINAL WITH ZERO ADJUST	RIM/PLATE FILLET JUNCTION	RIM\PLATE FILLET JUNC. W/ ZERO ADJ.	THRU-HUB FINAL READINGS	THRU-HUB FINAL WITH ZERO ADJ.
	1	1	985	47	46	1411	1410	NO READ	
FRONT	3	-2	982	-35	-33	-1200	-1198	NO READ	
RIM	5	-2	981	-437	-435	-291	-289	-314	-312
FACE	7	-2	981	-70	-68	-37	-35	-47	-45
	9	-1	981	-6	-5	-6	-5	OFF SCALE	
	11	0	975	-52	-52	-83	-83	18	18
	13	0	977	-77	-77	-165	-165	OFF SCALE	
TREAD	15	-4	976	-59	-55	-180	-176	OFF SCALE	
	17	0	979	-36	-36	-157	-157	-76	-76
	19	-1	979	-38	-37	-143	-142	-86	-85
	21	-1	980	-16	-15	2	3	18	19
BACK	23	-2	981	-56	-54	-15	-13	-3	-1
RIM	25	-1	983	-164	-163	-111	-110	-96	-95
FACE	27	0	980	-305	-305	-258	-258	-249	-249
	29	0	982	124	124	-322	-322	-323	-323
	31	-1	978	16	17	-109	-108	-111	-110

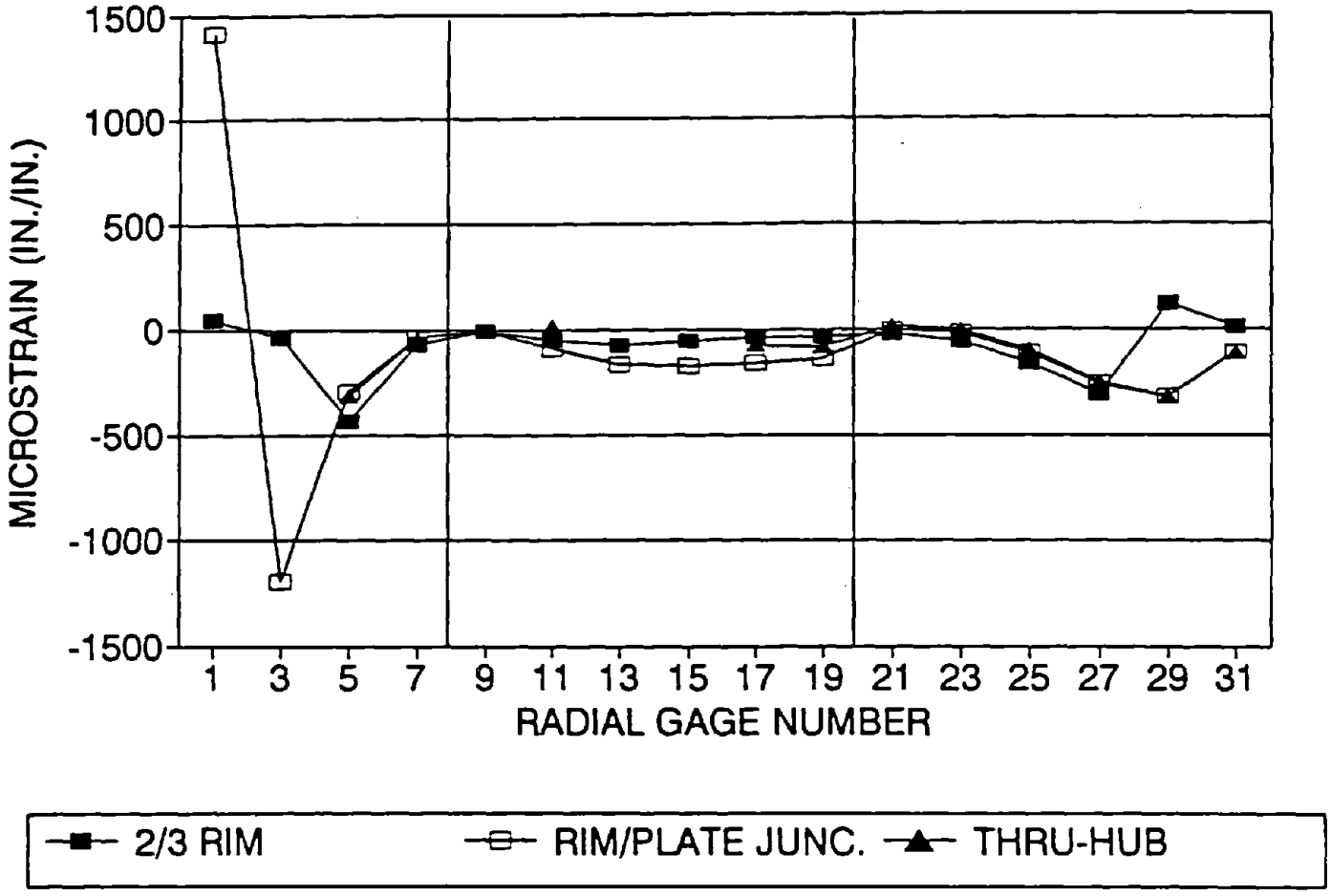
AP-3.7

HOOP GAGE DATA - POSITION 1-(3/31/92)
2-8(FRF);10-20(TREAD);22-32(BRF)



DP3-8 ~~AP-8~~

RADIAL GAGE DATA - POSITION 1-(3/31/92)
1-7(FRF);9-19(TREAD);21-31(BRF)



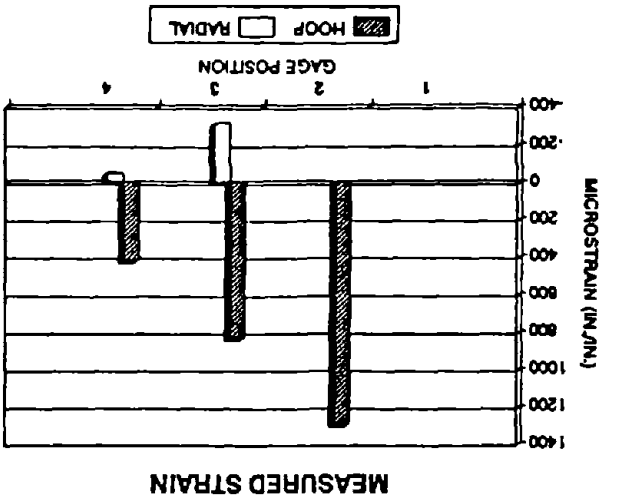
DP-9

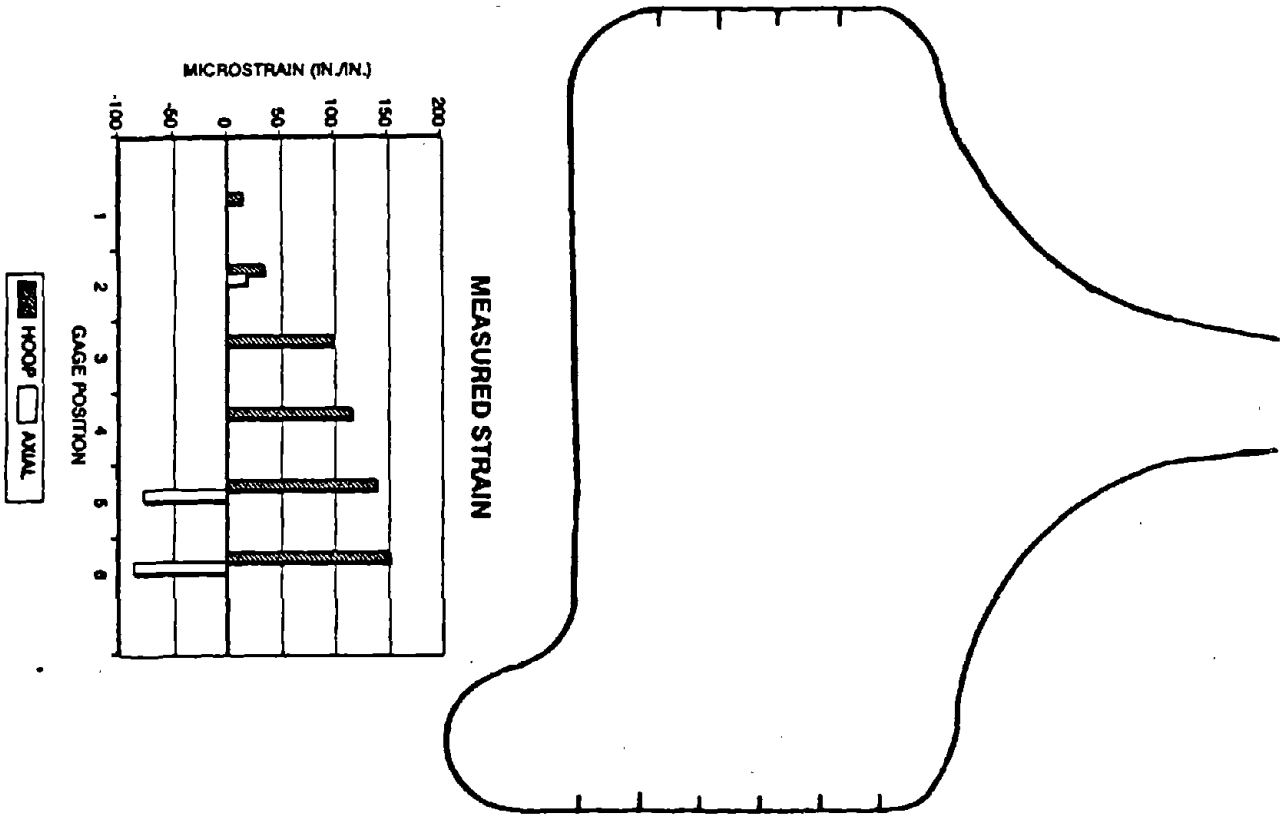
DP3-9

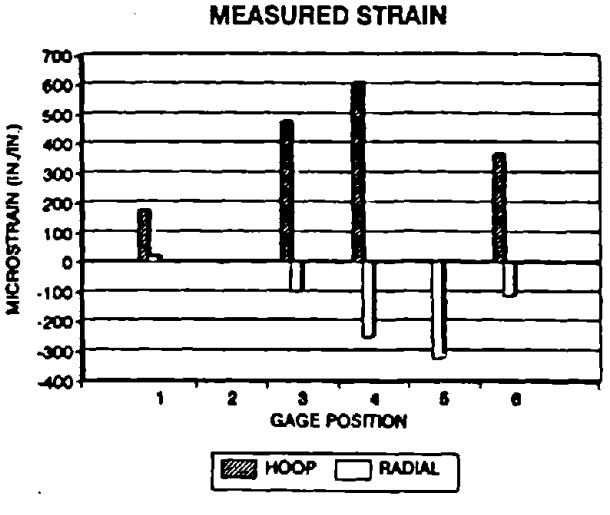
DATA DISPLAY
RIM ORIENTATION

NEW WHEEL
Position 1
Final Strain of
Thru-Hub Cut
March 31, 1992

Positive Strain
=> Compression
Negative Strain
=> Tension







AP3-10

AP3-10

STRAIN GAGE DATA - POSITION 2 - 2/2292

NEW WHEEL - HOOP DIRECTION
POSITION 2 STRAIN GAGE DATA
2/22/92

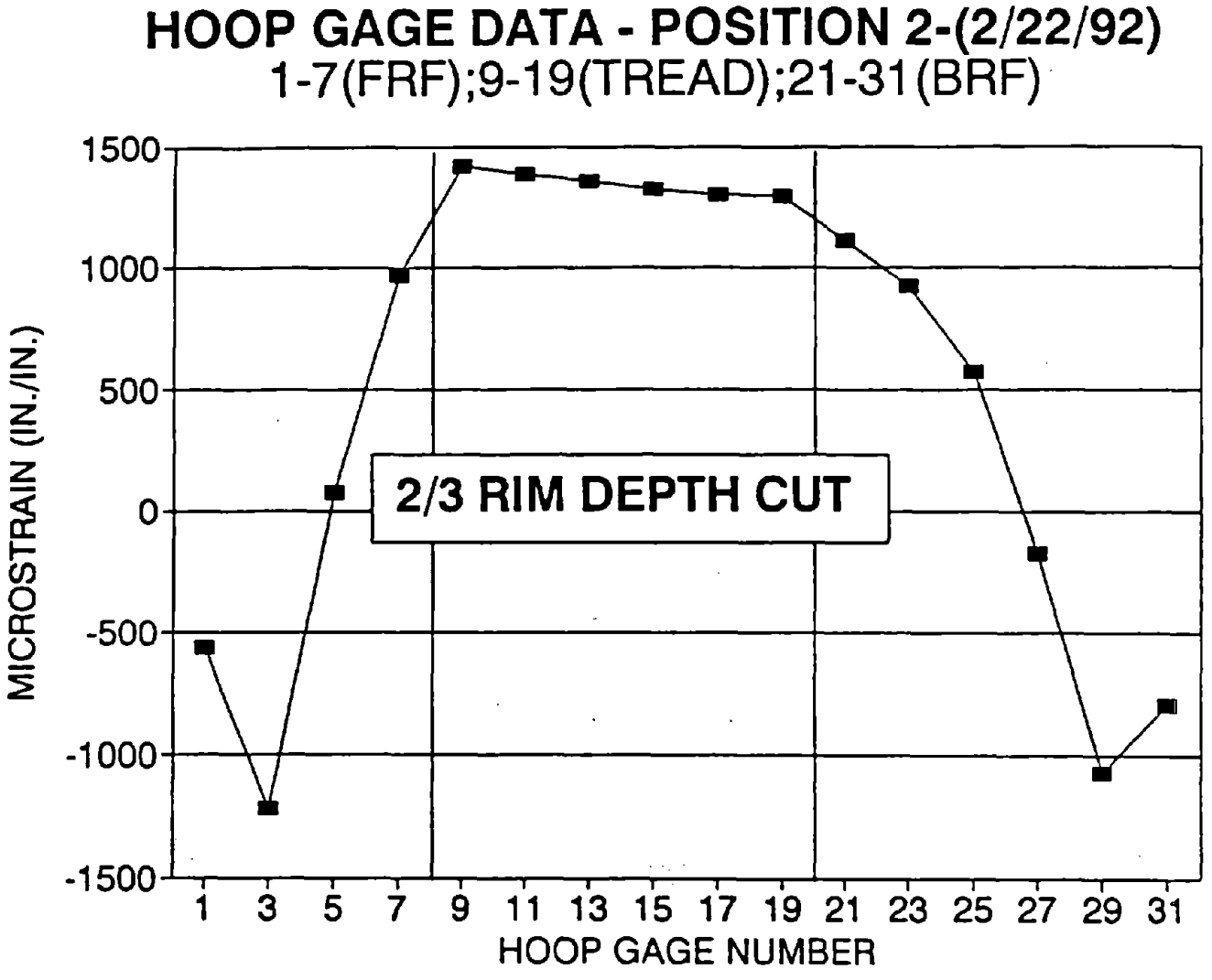
WHEEL POSITION	HOOP GAGE NUMBE	ZERO CHECK	GAIN	2/3 RIM CUT FINAL	2/3 RIM CUT FINAL WITH ZERO ADJUST
	1	0	982	-562	-562
FRONT	3	2	983	-1220	-1222
RIM	5	-2	981	73	75
FACE	7	-3	983	960	963
	9	-4	983	1416	1420
	11	-1	981	1387	1388
	13	-3	987	1357	1360
TREAD	15	0	981	1324	1324
	17	-5	979	1295	1300
	19	-3	980	1291	1294
	21	-1	976	1109	1110
BACK	23	-4	977	919	923
RIM	25	-4	978	568	572
FACE	27	1	981	-174	-175
	29	-3	979	-1070	-1067
	31	-2	980	-795	-793

NEW WHEEL - RADIAL DIRECTION
POSITION 2 STRAIN GAGE DATA
2/22/92

WHEEL POSITION	RADIAL GAGE NUMBE	ZERO CHECK	GAIN	2/3 RIM CUT FINAL	2/3 RIM CUT FINAL WITH ZERO ADJUST
	2	-1	981	326	327
FRONT	4	-2	982	894	896
RIM	6	-4	980	-90	-86
FACE	8	-2	982	-402	-400
	10	-1	980	-369	-368
	12	-2	979	-249	-247
	14	6	983	-124	-130
TREAD	16	-4	978	-61	-57
	18	-2	980	-49	-47
	20	-4	978	-94	-90
	22	-1	978	-408	-407
BACK	24	0	977	-455	-455
RIM	26	0	978	-330	-330
FACE	28	4	980	164	160
	30	2	982	739	737
	32	0	981	249	249

PROCESSED 4/5/92 - C. STUART

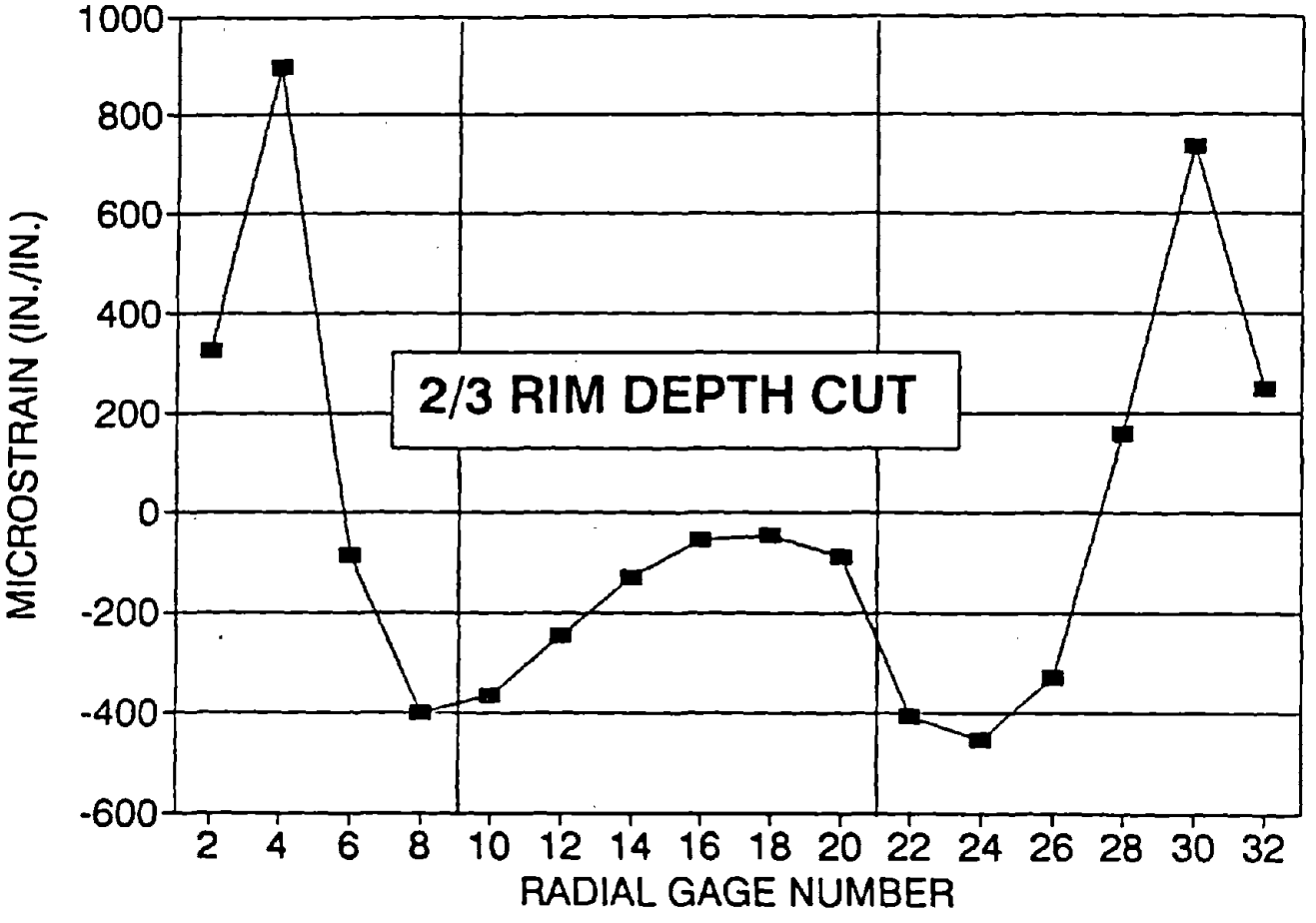
AP-3 11 AP-11


HOOP GAGE DATA - POSITION 2-(2/22/92)
1-7(FRF);9-19(TREAD);21-31(BRF)
MICROSTRAIN (IN./IN.)
1500
1000
500
0
-500
-1000
-1500
2/3 RIM DEPTH CUT
1 3 5 7 9 11 13 15 17 19 21 23 25 27 29 31
HOOP GAGE NUMBER

AP-312 ~~AP-19~~

RADIAL GAGE DATA - POSITION 2-(2/22/92)

2-8(FRF);10-20(TREAD);22-32(BRF)



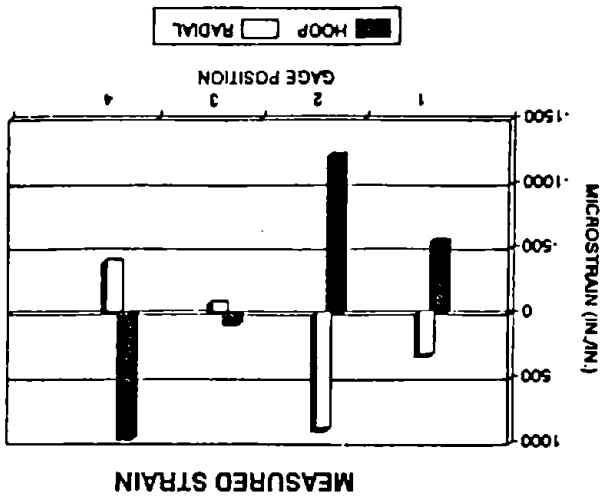
~~AP-3-13~~

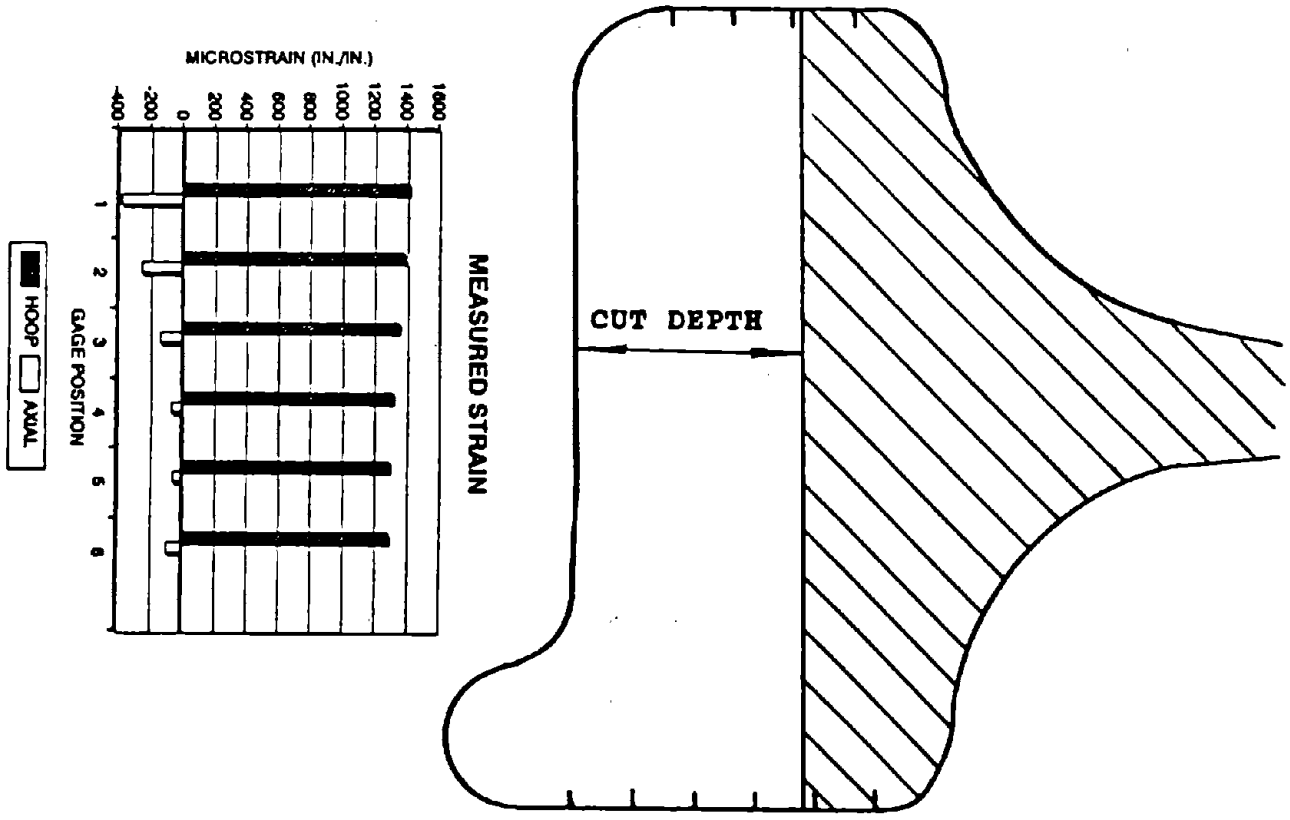
~~AP-13~~

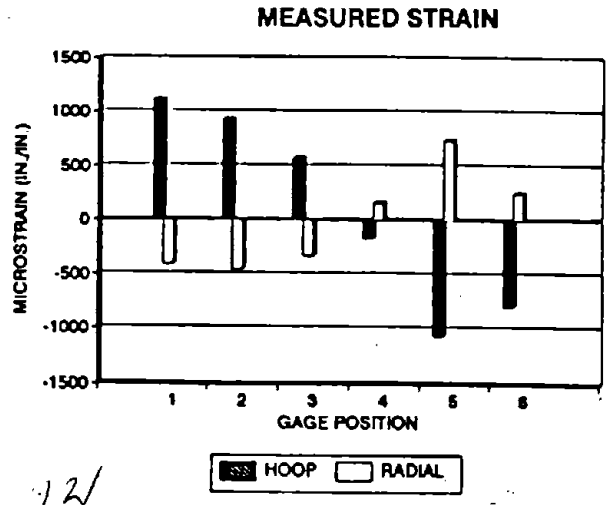
DATA DISPLAY
RIM ORIENTATION

NEW WHEEL
Position 2
2/3 of Rim Cut
Feb. 21, 1992

Positive Strain
=> Compression
Negative Strain
=> Tension







AP-3-14

AP-13

STRAIN GAGE DATA - POSITION 2 - 3/31/92

NEW WHEEL - HOOP DIRECTION
POSITION 2 STRAIN GAGE DATA
3/31/92

WHEEL POSITION	HOOP GAGE NUMBE	ZERO CHECK	GAIN	2/3 RIM CUT FINAL	2/3 RIM CUT FINAL WITH ZERO ADJUST	RIM\PLATE FILLET JUNCTION	RIM/PLATE FILLET JUNC. W/ ZERO ADJ	THRU-HUB FINAL READINGS	THRU-HUB FINAL WITH ZERO ADJ.
	1	1	981	174	173	OFF SCALE		OFF SCALE	
FRONT	3	2	980	-36	-38	1028	1026	992	-1
RIM	5	0	980	633	633	1141	1141	1139	990
FACE	7	-1	982	455	456	470	471	472	1139
	9	1	982	-45	-46	-68	-69	-72	473
	11	2	981	21	19	21	19	13	-73
	13	0	981	-15	-15	4	4	-4	11
TREAD	15	1	981	-63	-64	-40	-41	-41	-4
	17	2	983	-106	-108	-79	-81	-76	-42
	19	1	980	-4	-5	17	16	22	-78
	21	1	981	130	129	128	127	OFF SCALE	
BACK	23	1	981	278	277	271	270	272	-1
RIM	25	3	980	421	418	415	412	418	271
FACE	27	1	979	437	436	623	622	618	415
	29	1	980	-136	-137	709	708	714	617
	31	-1	977	159	160	205	206	OFF SCALE	

NEW WHEEL - RADIAL DIRECTION
POSITION 2 STRAIN GAGE DATA
3/31/92

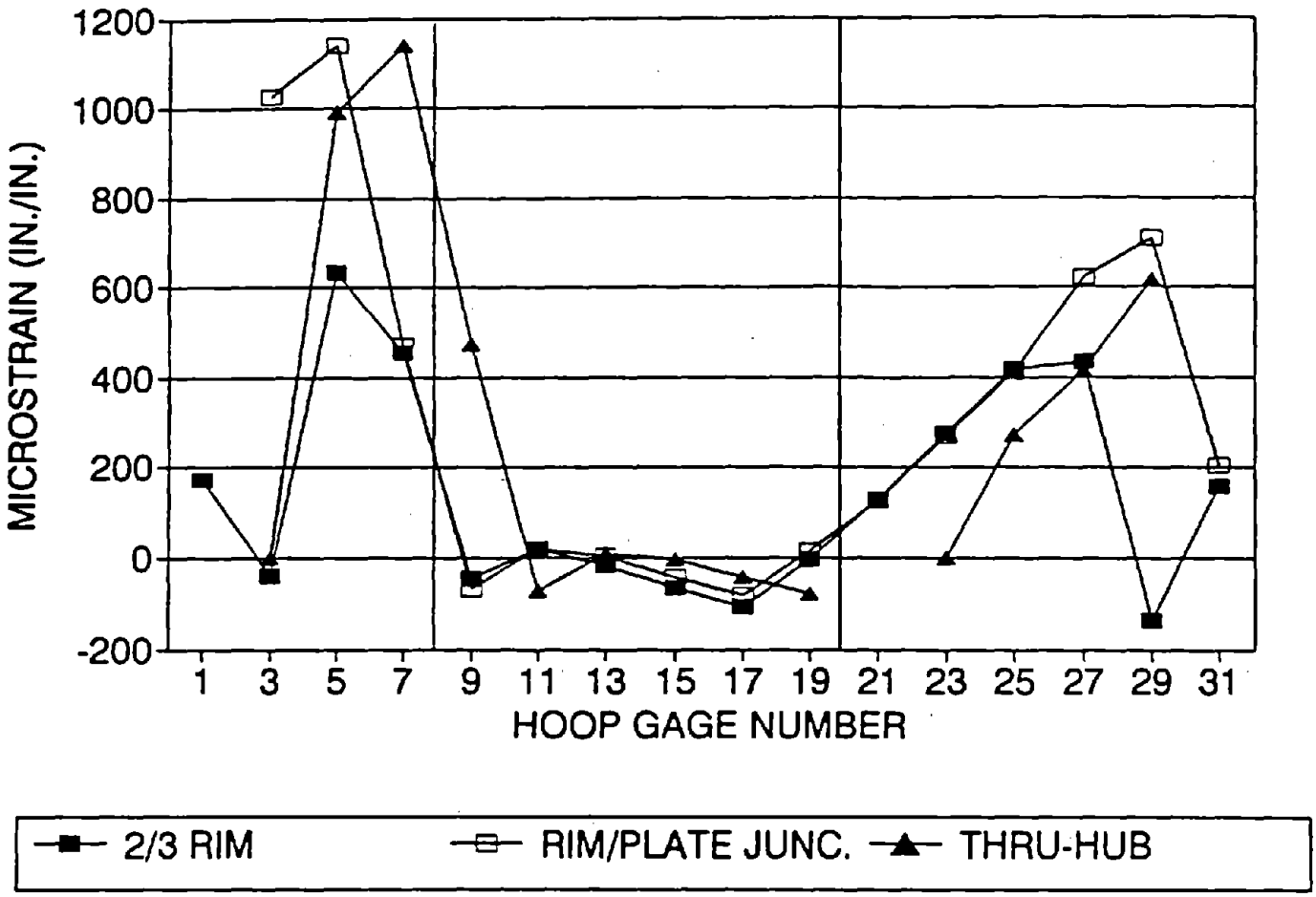
WHEEL POSITION	RADIAL GAGE NUMBE	ZERO CHECK	GAIN	2/3 RIM CUT FINAL	2/3 RIM CUT FINAL WITH ZERO ADJUST	RIM\PLATE FILLET JUNCTION	RIM/PLATE FILLET JUNC. W/ ZERO ADJ	THRU-HUB FINAL READINGS	THRU-HUB FINAL WITH ZERO ADJ.
	2	1	982	-69	-70	1244	1243	1359	1358
FRONT	4	0	982	-120	-120	-1173	-1173	-1119	-1119
RIM	6	0	979	-498	-498	-314	-314	-336	-336
FACE	8	0	981	-106	-106	-12	-12	-18	-18
	10	1	981	-11	-12	-11	-12	8	7
	12	1	976	-55	-56	-119	-120	-83	-84
	14	-3	978	-56	-53	-175	-172	-154	-151
TREAD	16	-1	977	-37	-36	-180	-179	-176	-175
	18	-2	975	-14	-12	-152	-150	-169	-167
	20	-1	978	-10	-9	-128	-127	-158	-157
	22	4	978	15	11	41	37	OFF SCALE	
BACK	24	1	977	-12	-13	47	46	OFF SCALE	
RIM	26	1	978	-130	-131	-24	-25	-5	-6
FACE	28	4	983	-250	-254	-265	-269	-247	-251
	30	1	981	-60	-61	-436	-437	-438	-439
	32	0	981	-69	-69	-28	-28	OFF SCALE	

~~AP-15~~

PROCESSED 4/10/92 - C. STUART

AP-3-25

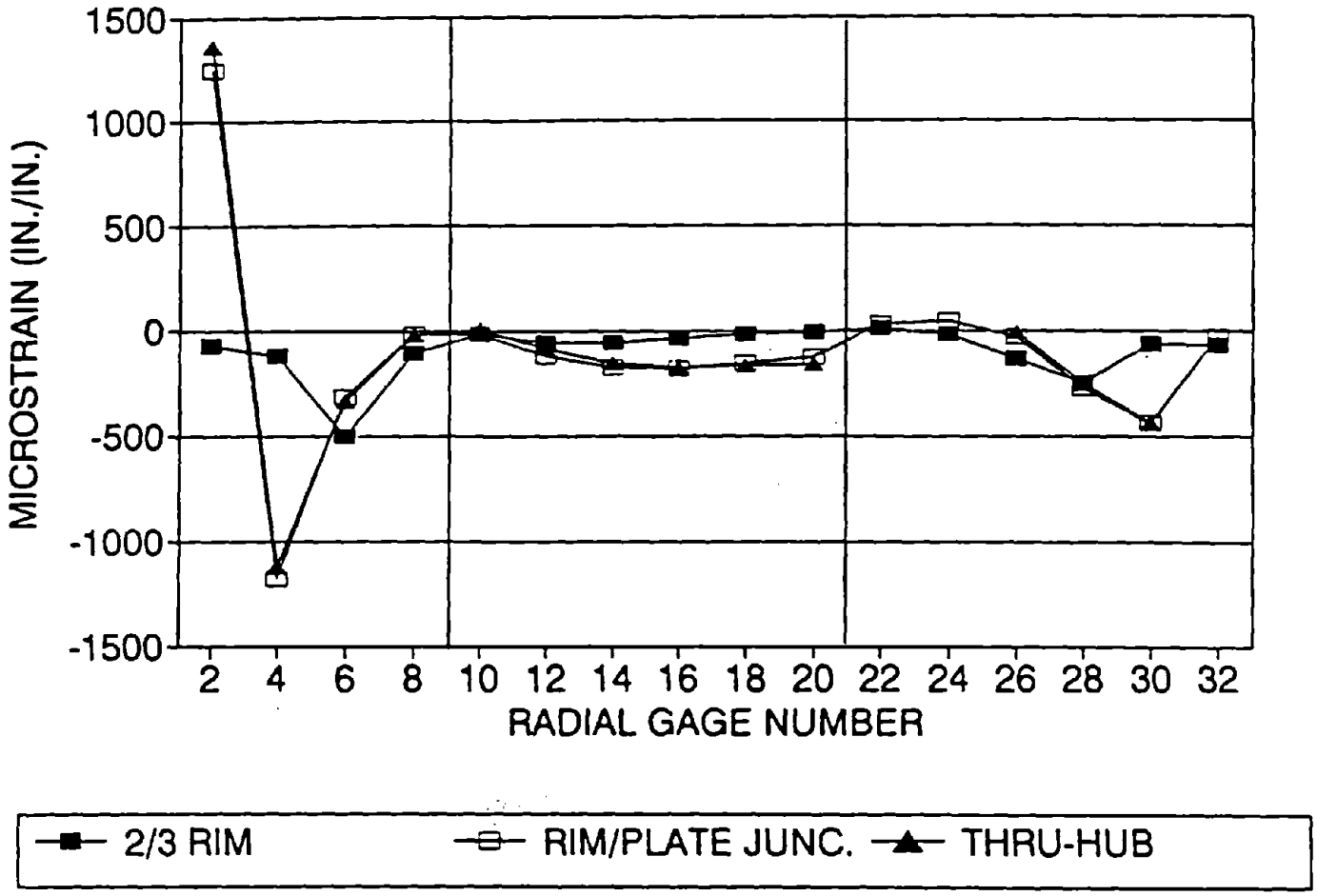
HOOP GAGE DATA - POSITION 2-(3/31/92)
1-7(FRF);9-19(TREAD);21-31(BRF)



AP-16
AP-3-16

RADIAL GAGE DATA - POSITION 2-(3/31/92)

2-8(FRF);10-20(TREAD);22-32(BRF)



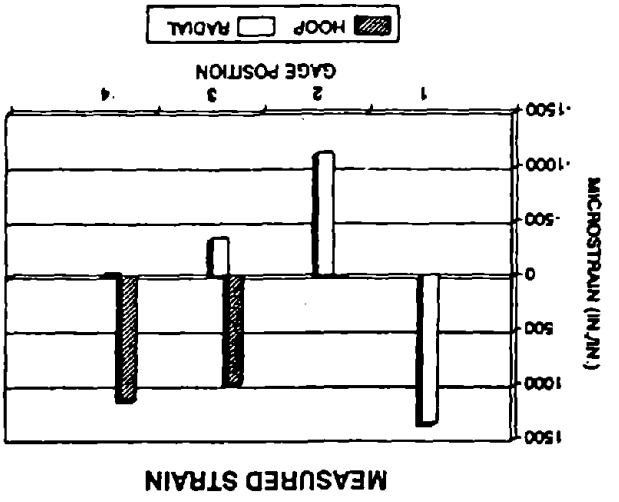
AP-17

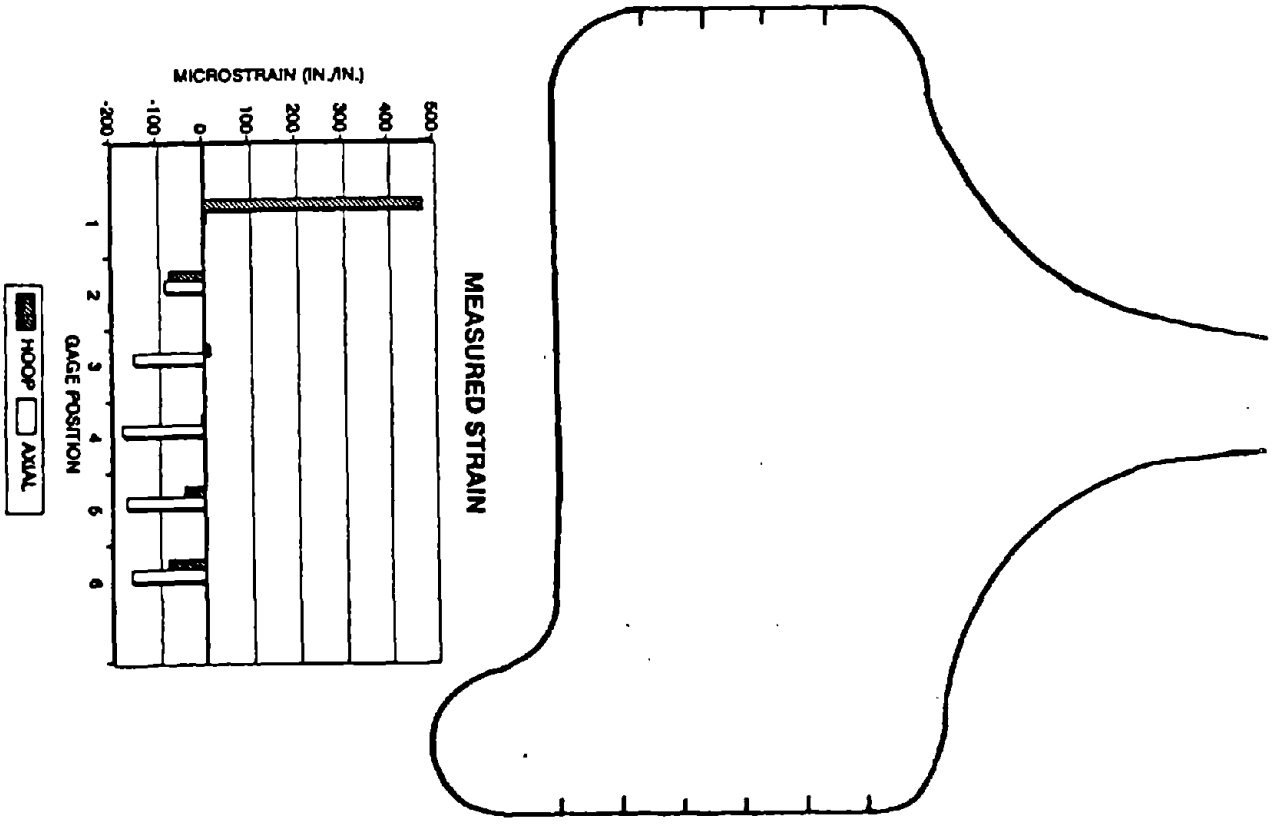
AP-3-17

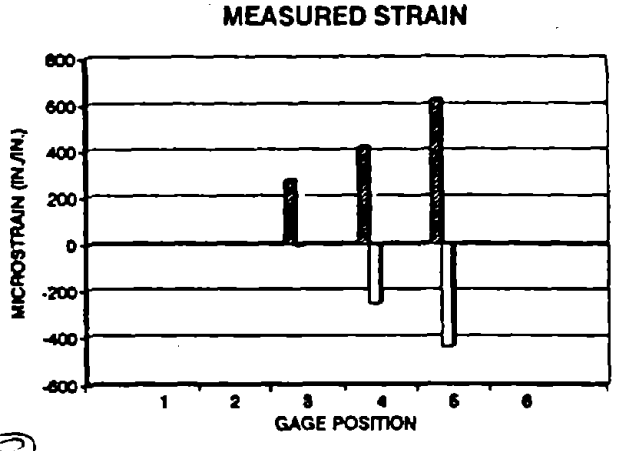
DATA DISPLAY
RIM ORIENTATION

NEW WHEEL
Position 2
Final Strain of
Thru-Hub Cut
March 31, 1992

Positive Strain
=> Compression
Negative Strain
=> Tension







AP-1B
AP 3-1B

STRAIN GAGE DATA - POSITION 3 - 2/21/92

OLD WHEEL - HOOP DIRECTION
POSITION 3 STRAIN GAGE DATA
2/21/92

WHEEL POSITION	HOOP GAGE NUMBER	ZERO CHECK	GAIN	2/3 RIM CUT FINAL	2/3 RIM CUT FINAL WITH ZERO ADJUST
	2	1	981	288	287
FRONT	4	1	979	221	220
RIM	6	2	983	117	115
FACE	8	2	980	33	31
	10	2	979	-246	-248
	12	1	980	-313	-314
	14	3	981	-283	-286
TREAD	16	0	980	-171	-171
	18	1	979	-125	-126
	20	0	979	-50	-50
	22	3	980	575	572
BACK	24	2	981	393	391
RIM	26	2	982	156	154
FACE	28	-1	981	-68	-67
	30	-1	979	-241	-240
	32	1	984	-344	-345

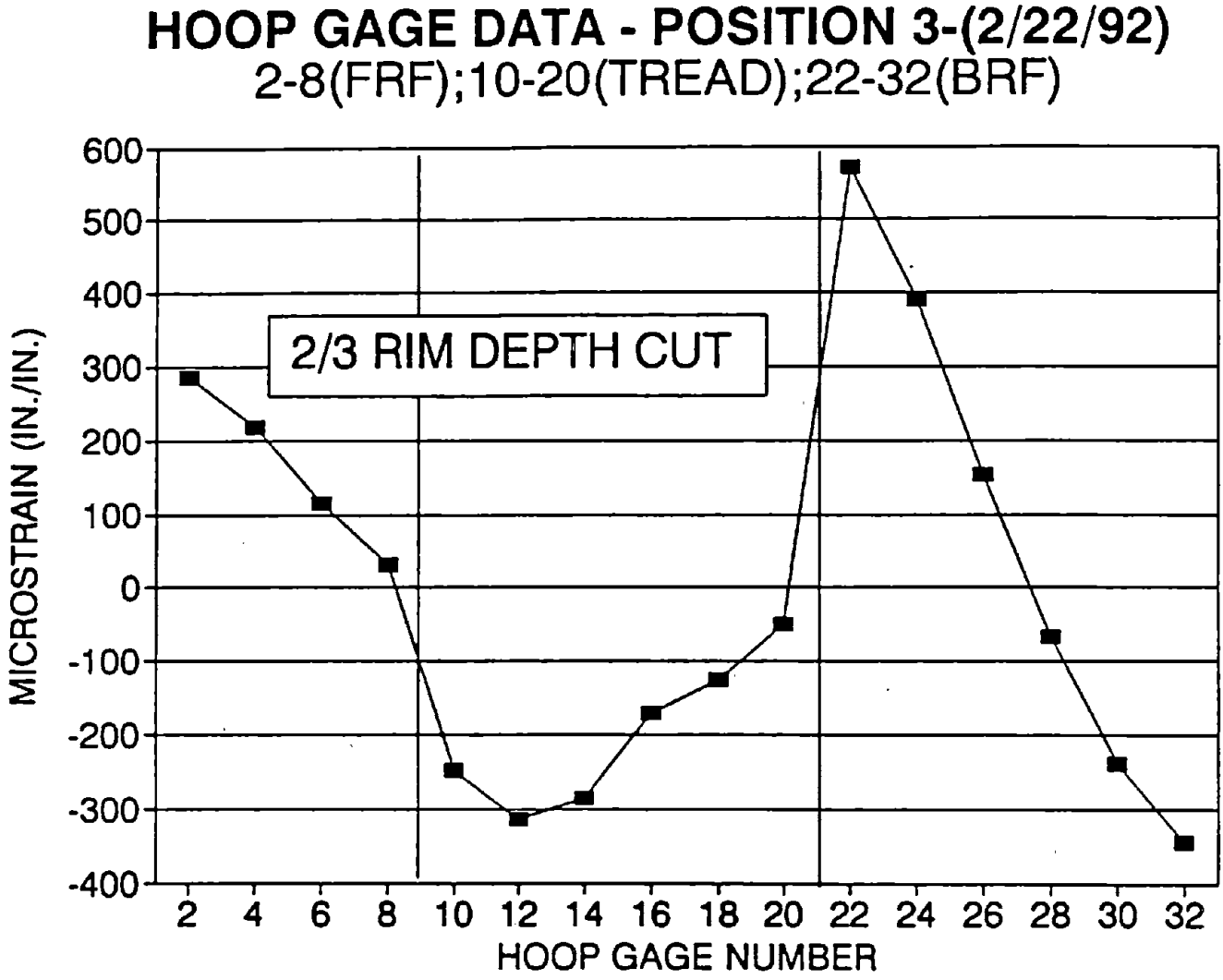
OLD WHEEL - RADIAL DIRECTION
POSITION 3 STRAIN GAGE DATA
2/21/92

WHEEL POSITION	RADIAL GAGE NUMBER	ZERO CHECK	GAIN	2/3 RIM CUT FINAL	2/3 RIM CUT FINAL WITH ZERO ADJUST
	1	1	982	-83	-84
FRONT	3	-1	981	-73	-72
RIM	5	-3	979	-32	-29
FACE	7	0	979	-6	-6
	9	0	979	81	81
	11	-1	979	129	130
	13	-6	978	99	105
TREAD	15	0	980	90	90
	17	-2	979	94	96
	19	-2	979	119	121
	21	1	981	-213	-214
BACK	23	-3	978	-163	-160
RIM	25	-1	979	-76	-75
FACE	27	0	981	25	25
	29	-1	981	91	92
	31	-1	983	96	97

AP-19

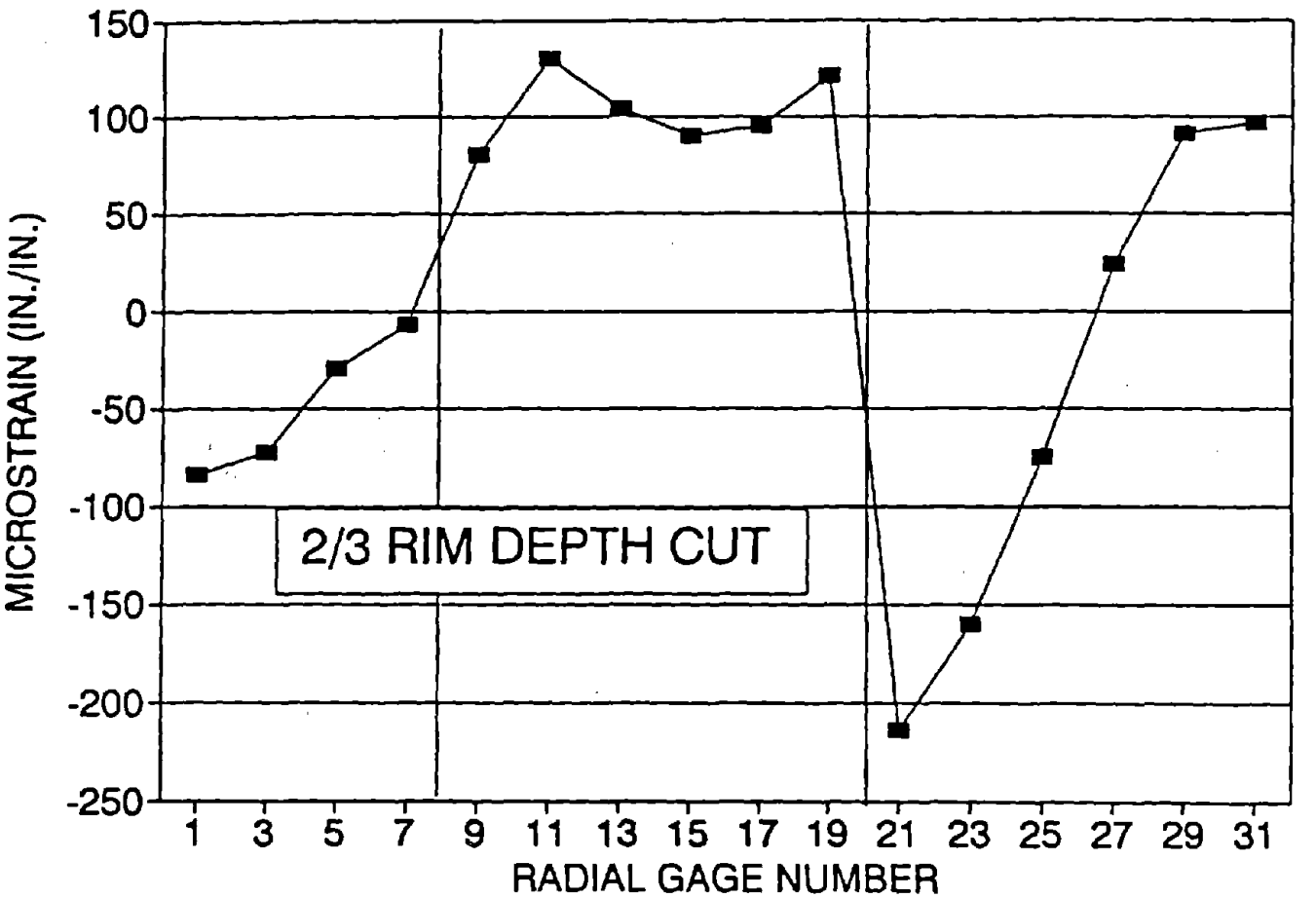
PROCESSED 4/13/92 - C. STUART

AP- 3-19


HOOP GAGE DATA - POSITION 3-(2/22/92)
2-8(FRF);10-20(TREAD);22-32(BRF)
2/3 RIM DEPTH CUT
MICROSTRAIN (IN./IN.)
600
500
400
300
200
100
0
-100
-200
-300
-400
2 4 6 8 10 12 14 16 18 20 22 24 26 28 30 32
HOOP GAGE NUMBER

~~AP-2-20~~
AP-3-20

RADIAL GAGE DATA - POSITION 3-(2/22/92)
1-7(FRF);9-19(TREAD);21-31(BRF)



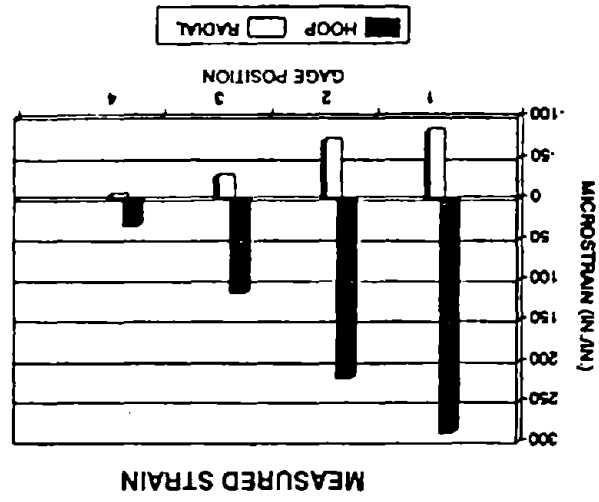
~~AP-2~~

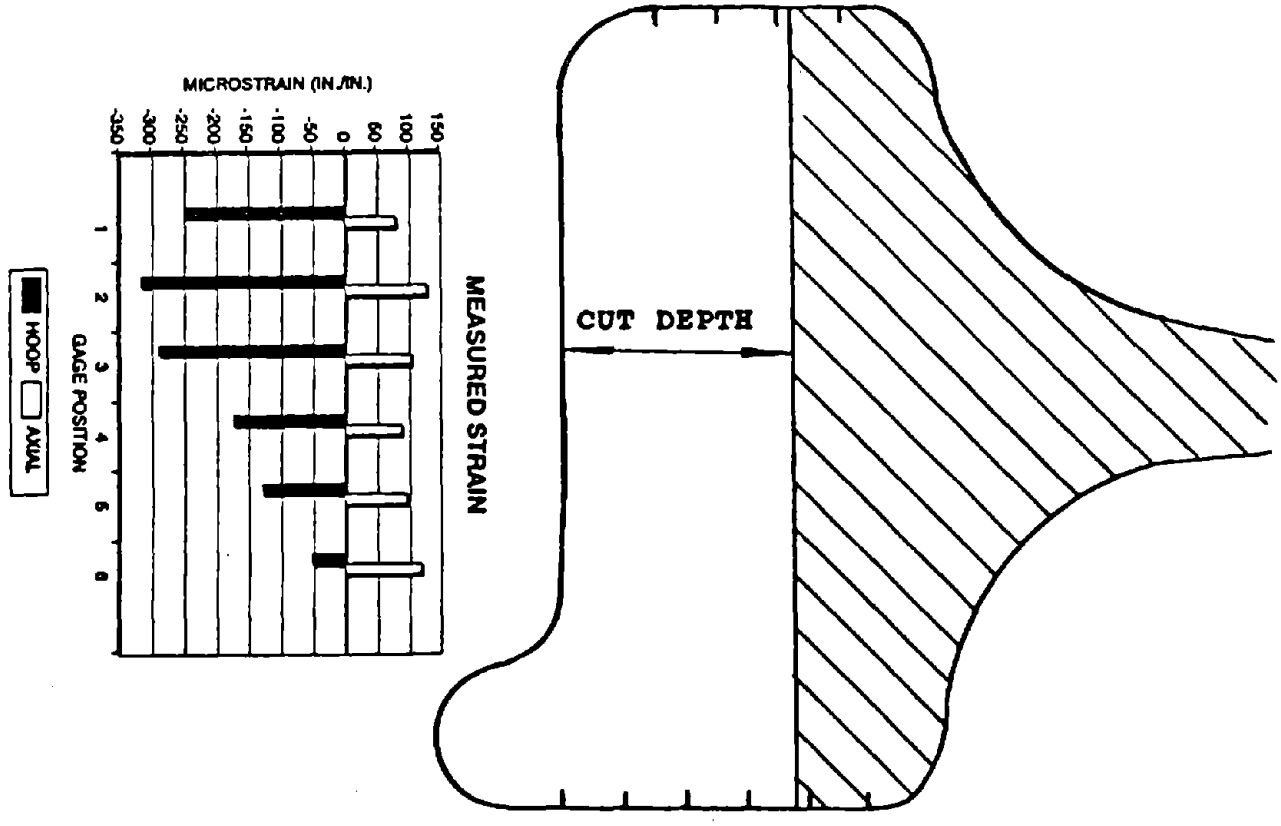
AP-3-2

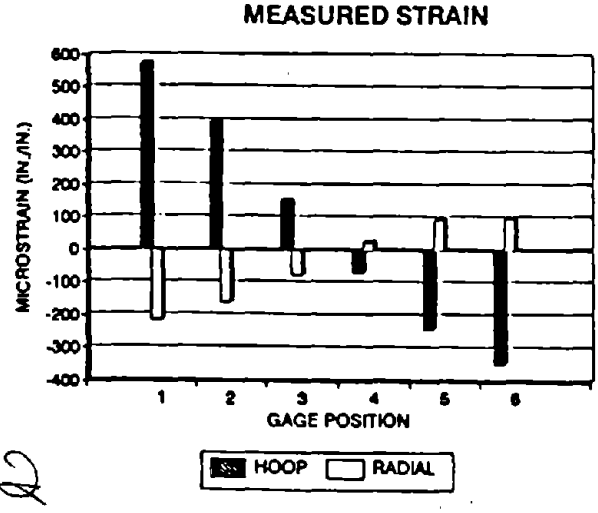
DATA DISPLAY
RIM ORIENTATION

OLD WHEEL
Position 3
2/3 of Rim Cut
Feb. 21, 1992

Positive Strain
=> Compression
Negative Strain
=> Tension







AP3-22

~~AP-22~~

STRAIN GAGE DATA - POSITION 3 - 3/31/92

OLD WHEEL HOOP DIRECTION
POSITION 3 STRAIN GAGE DATA
3/31/92

WHEEL POSITION	HOOP GAGE NUMBER	ZERO CHECK	GAIN	2/3 RIM CUT FINAL	2/3 RIM CUT FINAL WITH ZERO ADJUST	RIM\PLATE FILLET JUNCTION	RIM/PLATE FILLET JUNC. W/ ZERO ADJ	THRU-HUB FINAL READINGS	THRU-HUB FINAL WIT ZERO ADJ.
	2	0	981	122	122	219	219	146	146
FRONT	4	1	982	182	181	103	102	108	107
RIM	6	-1	981	137	138	34	35	58	59
FACE	8	0	981	56	56	-5	-5	29	29
	10	-1	980	195	196	144	145	189	190
	12	0	979	-42	-42	-89	-89	-41	-41
	14	2	979	78	76	46	44	89	87
TREAD	16	-3	980	299	302	288	291	323	326
	18	-2	978	197	199	196	198	225	227
	20	0	982	124	124	125	125	144	144
	22	0	981	655	655	669	669	673	673
BACK	24	0	981	542	542	583	583	588	588
RIM	26	1	981	329	328	490	489	491	490
FACE	28	2	985	-100	-102	479	477	481	479
	30	0	981	-216	-216	497	497	501	501
	32	-1	977	-40	-39	453	454	500	501

OLD WHEEL RADIAL DIRECTION
POSITION 3 STRAIN GAGE DATA
3/31/92

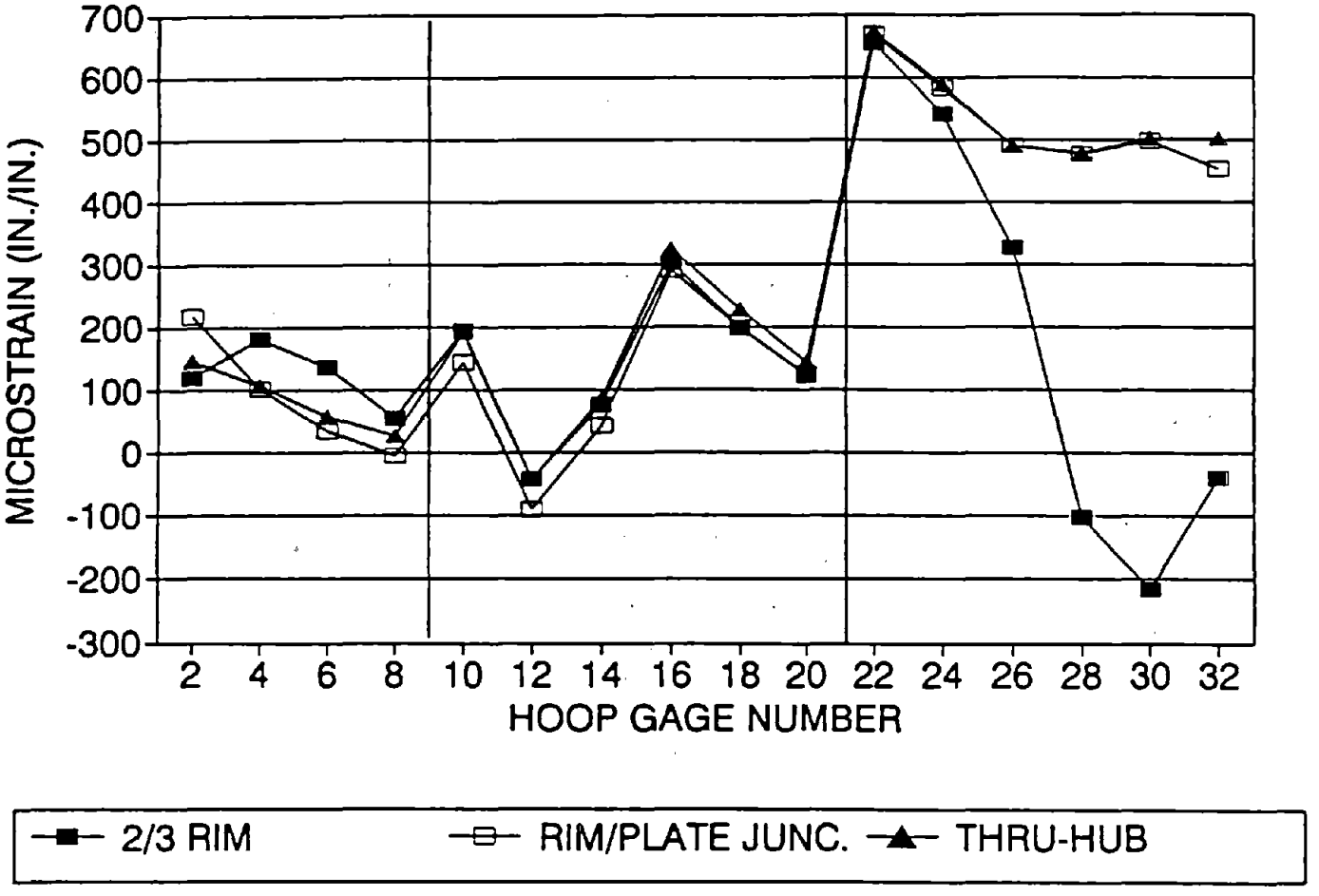
WHEEL POSITION	RADIAL GAGE NUMBER	ZERO CHECK	GAIN	2/3 RIM CUT FINAL	2/3 RIM CUT FINAL WITH ZERO ADJUST	RIM\PLATE FILLET JUNCTION	RIM/PLATE FILLET JUNC. W/ ZERO ADJ	THRU-HUB FINAL READINGS	THRU-HUB FINAL WIT ZERO ADJ.
	1	-1	981	-34	-33	-61	-60	-36	-35
FRONT	3	2	981	-69	-71	83	81	37	35
RIM	5	3	983	-11	-14	148	145	110	107
FACE	7	-2	981	79	81	160	162	139	141
	9	-4	981	-34	-30	10	14	-11	-7
	11	2	982	18	16	74	72	41	39
	13	0	982	12	12	44	44	28	28
TREAD	15	0	982	-104	-104	-76	-76	-81	-81
	17	2	984	-50	-52	-34	-36	-30	-32
	19	0	982	-21	-21	-25	-25	-15	-15
	21	1	980	-172	-173	-156	-157	-156	-157
BACK	23	1	980	-186	-187	-158	-159	-152	-153
RIM	25	2	981	-155	-157	-121	-123	-114	-116
FACE	27	-1	978	18	19	-102	-101	-94	-93
	29	-1	983	171	172	-121	-120	-98	-97
	31	0	982	51	51	-84	-84	-79	-79

~~AP-23~~

PROCESSED 4/13/92 - C. STUART

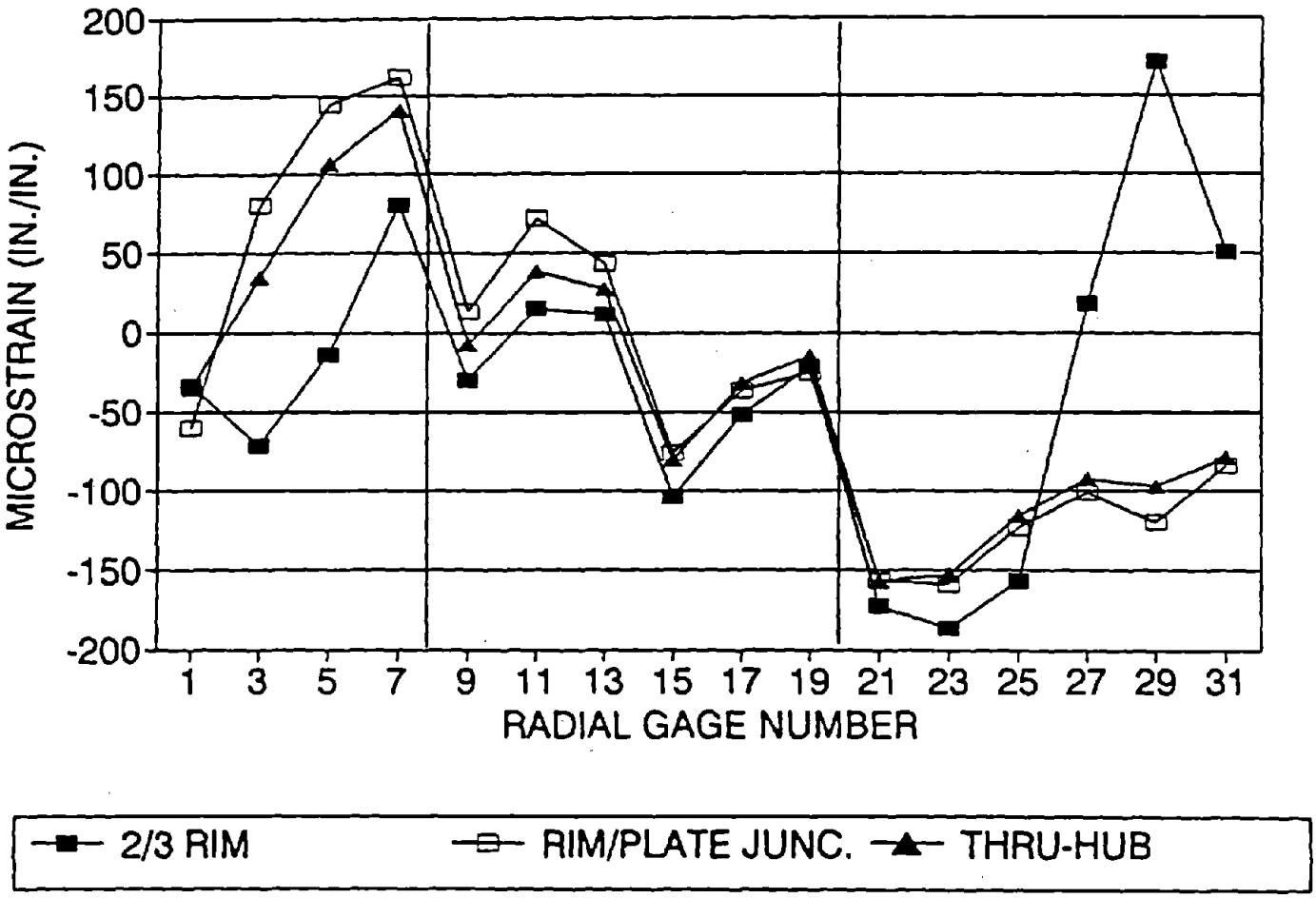
AP 3-23

HOOP GAGE DATA - POSITION 3-(3/31/92)
2-8(FRF);10-20(TREAD);22-32(BRF)



AP3-24 ~~AP24~~

RADIAL GAGE DATA - POSITION 3-(3/31/92)
1-7(FRF);9-19(TREAD);21-31(BRF)



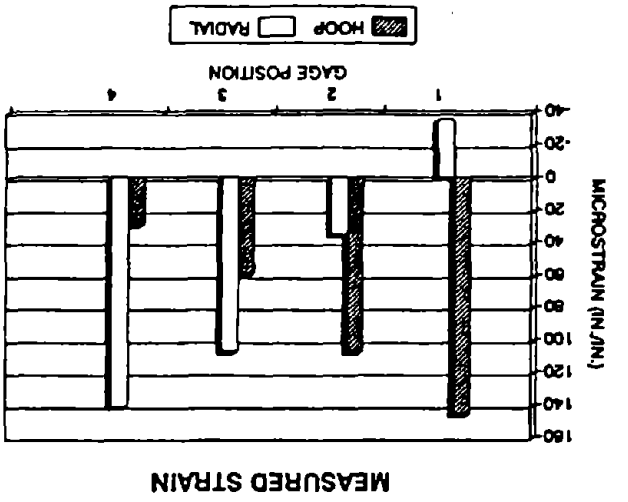
~~AP3-25~~

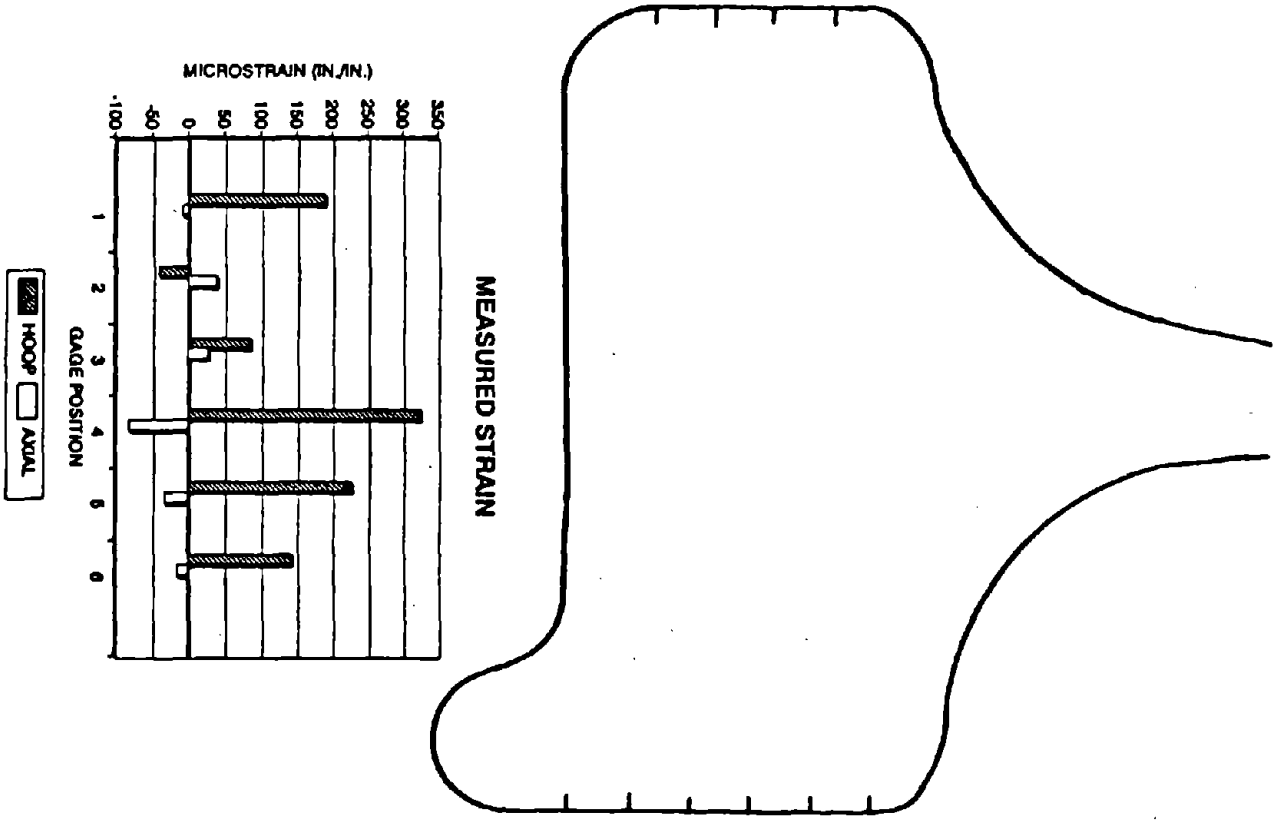
AP3-25

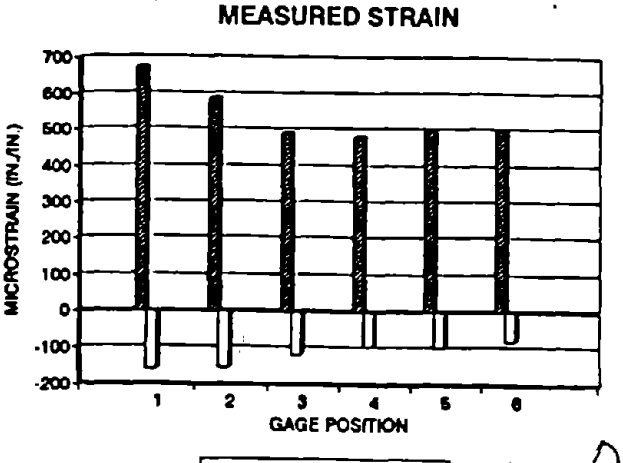
DATA DISPLAY
RIM ORIENTATION

OLD WHEEL
Position 3
Final Strain of
Thru-Hub Cut
March 31, 1992

Positive Strain
=> Compression
Negative Strain
=> Tension







AP-26

AP3-26

STRAIN GAGE DATA - POSITION 4 -2/22/92

OLD WHEEL - HOOP DIRECTION
POSITION 4 STRAIN GAGE DATA
2/22/92

WHEEL POSITION	HOOP GAGE NUMBER	ZERO CHECK	GAIN	2/3 RIM CUT FINAL	2/3 RIM CUT FINAL WITH ZERO ADJUST
	1	0	979	388	388
FRONT	3	0	979	259	259
RIM	5	1	978	80	79
FACE	7	0	979	-38	-38
	9	-3	978	17	20
	11	1	979	-367	-368
	13	3	983	-286	-289
TREAD	15	1	981	-170	-171
	17	-3	980	-58	-55
	19	1	980	-54	-55
	21	1	983	496	495
BACK	23	0	981	342	342
RIM	25	4	983	181	177
FACE	27	0	983	31	31
	29	0	985	-121	-121
	31	1	981	-260	-261

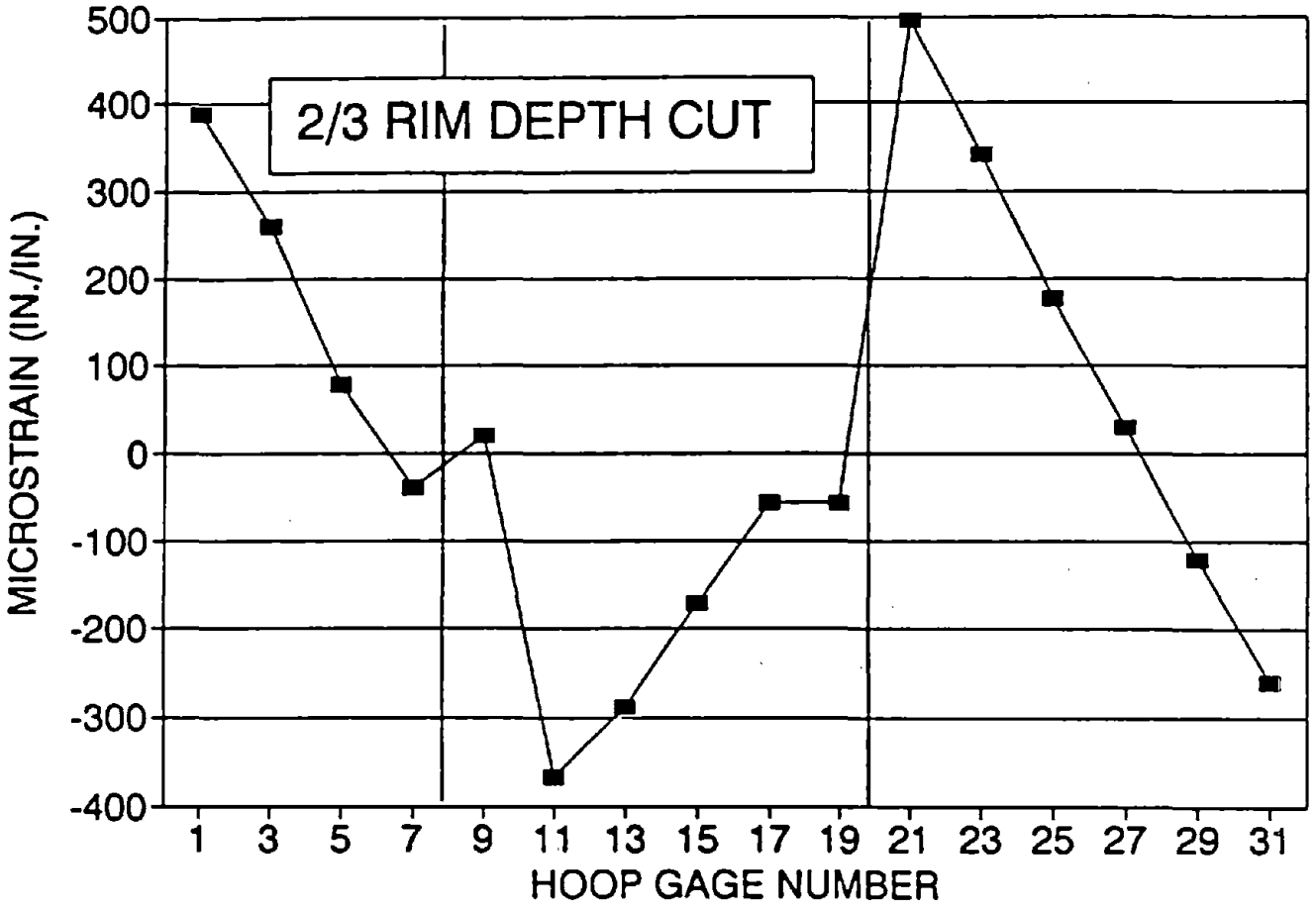
OLD WHEEL - RADIAL DIRECTION
POSITION 4 STRAIN GAGE DATA
2/22/92

WHEEL POSITION	RADIAL GAGE NUMBER	ZERO CHECK	GAIN	2/3 RIM CUT FINAL	2/3 RIM CUT FINAL WITH ZERO ADJUST
	2	0	979	-92	-92
FRONT	4	-2	976	-49	-47
RIM	6	0	979	-301	-301
FACE	8	0	977	34	34
	10	0	980	110	110
	12	-2	981	163	165
	14	0	980	131	131
TREAD	16	2	983	101	99
	18	-5	979	73	78
	20	-1	980	124	125
	22	0	981	-148	-148
BACK	24	0	983	-103	-103
RIM	26	1	984	-45	-46
FACE	28	-1	982	4	5
	30	0	983	49	49
	32	0	982	76	76

PROCESSED 4/13/92 - C. STUART

~~AP-27~~ AP3-27

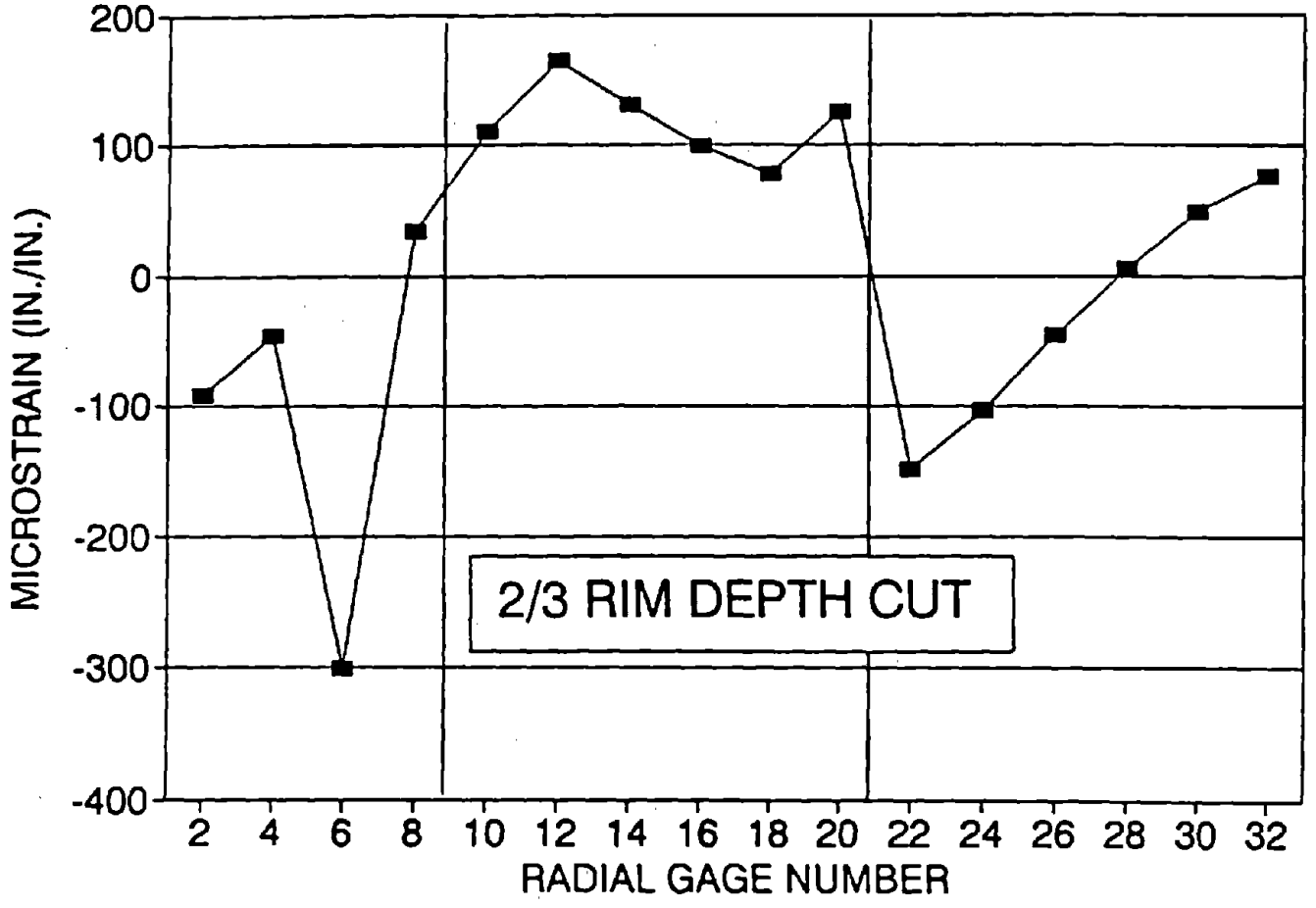
HOOP GAGE DATA - POSITION 4-(2/22/92)
1-7(FRF);9-19(TREAD);21-31(BRF)



AP-28

AP3-28

RADIAL GAGE DATA - POSITION 4-(2/22/92)
2-8(FRF);10-20(TREAD);22-32(BRF)



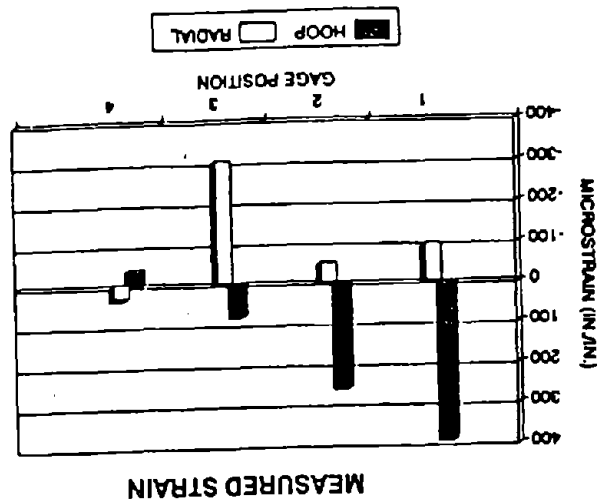
AP-29

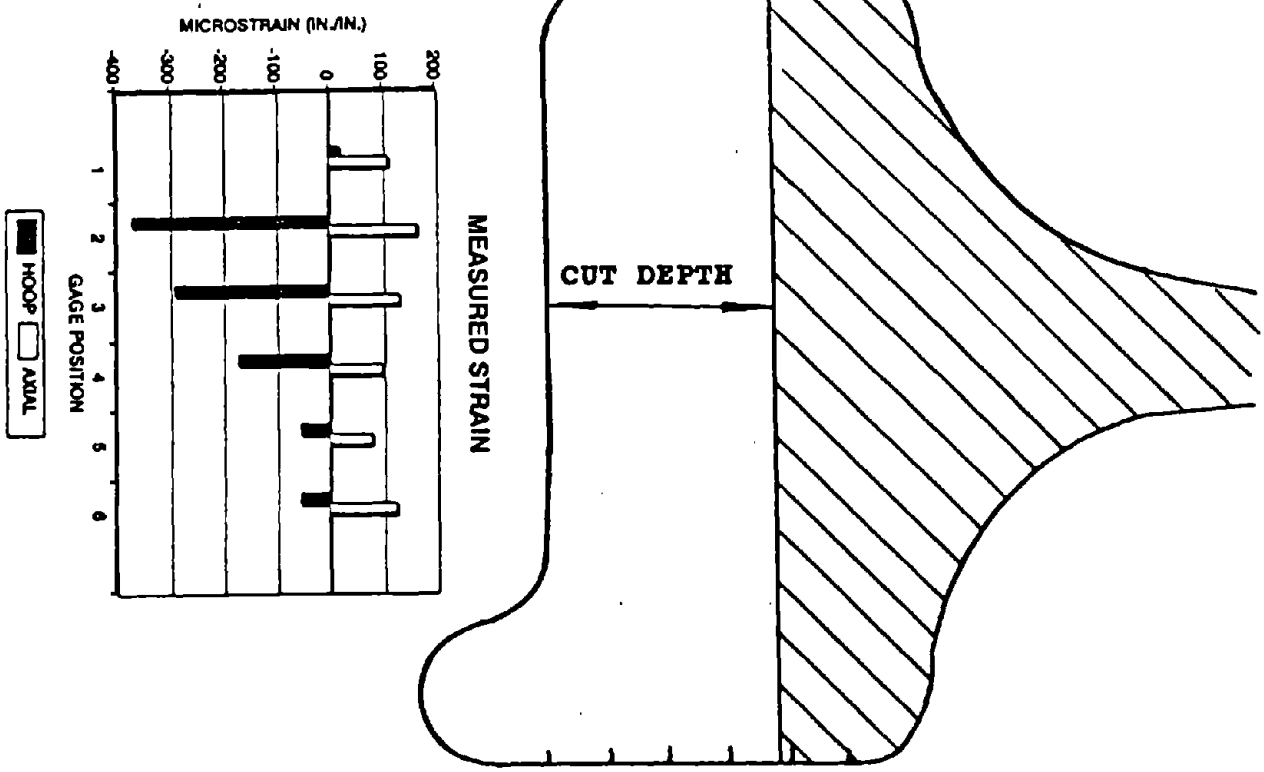
AP3-09

DATA DISPLAY
RIM ORIENTATION

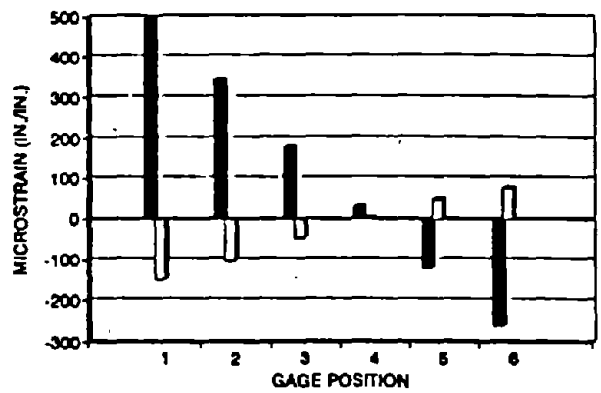
OLD WHEEL
Position 4
2/3 of Rim Cut
Feb. 21, 1992

Positive Strain
=> Compression
Negative Strain
=> Tension





MEASURED STRAIN



AP-30

AP3-30

OLD WHEEL - HOOP DIRECTION
POSITION 4 STRAIN GAGE DATA
3/31/92

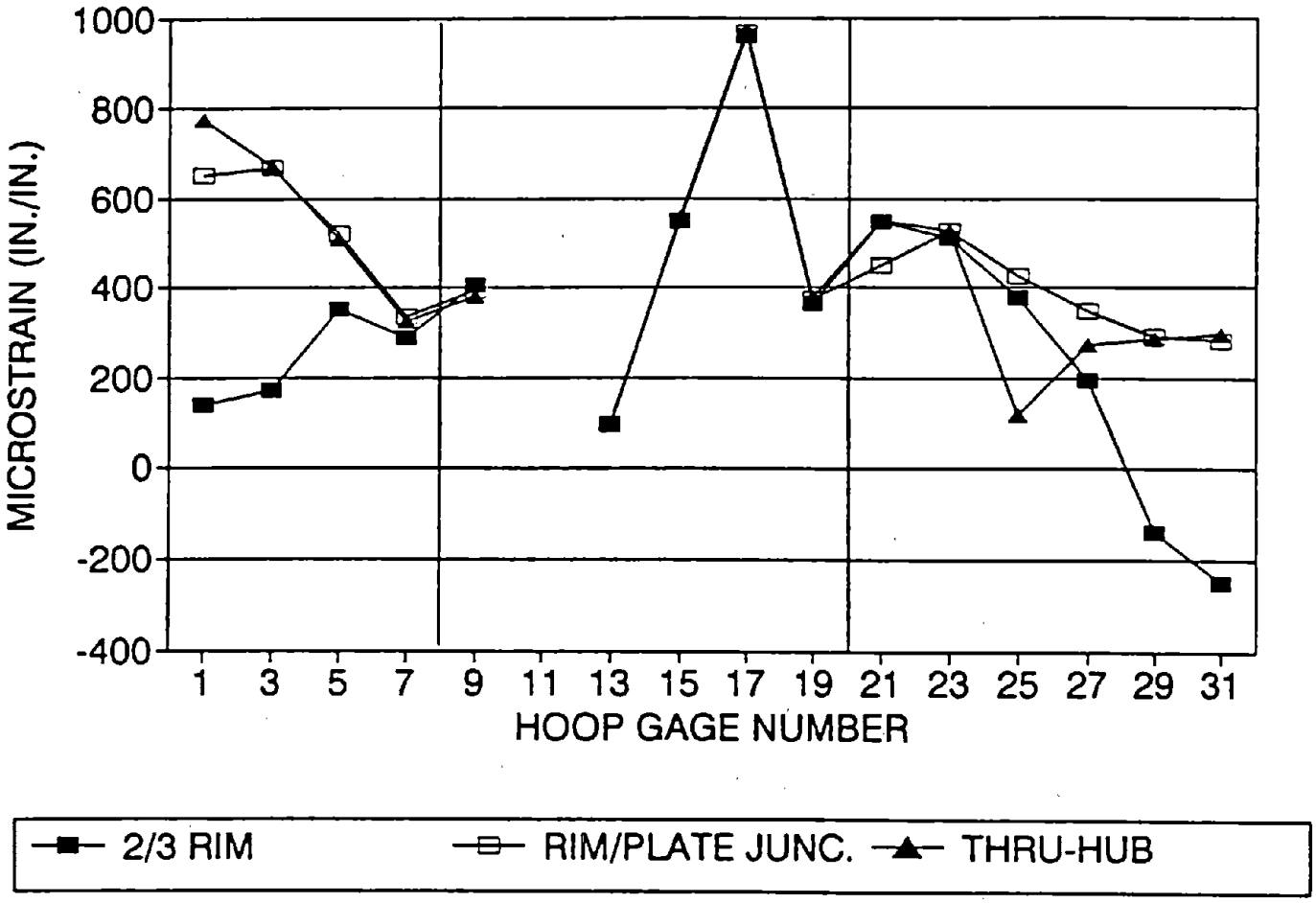
WHEEL POSITION	HOOP GAGE NUMBER	ZERO CHECK	GAIN	2/3 RIM CUT FINAL	2/3 RIM CUT FINAL WITH ZERO ADJUST	RIM\PLATE FILLET JUNCTION	RIM/PLATE FILLET JUNC. W/ ZERO ADJ	THRU-HUB FINAL READINGS	THRU-HUB FINAL WIT ZERO ADJ.
	1	-1	980	140	141	649	650	772	773
FRONT	3	0	980	173	173	668	668	669	669
RIM	5	0	979	351	351	520	520	508	508
FACE	7	-1	979	288	289	336	337	325	326
	9	0	980	406	406	393	393	380	380
	11	BAD	GAGE						
	13	1	985	97	96	99	98	97	96
TREAD	15	-2	980	545	547	548	550	553	555
	17	1	979	962	961	968	967	973	972
	19	1	981	367	366	377	376	380	379
	21	1	983	547	546	449	448	551	550
BACK	23	1	984	511	510	528	527	527	526
RIM	25	1	985	379	378	428	427	119	118
FACE	27	-1	984	194	195	349	350	272	273
	29	-2	982	-139	-137	291	293	284	286
	31	2	980	-246	-248	286	284	300	298

OLD WHEEL - RADIAL DIRECTION
POSITION 4 STRAIN GAGE DATA
3/31/92

WHEEL POSITION	RADIAL GAGE NUMBER	ZERO CHECK	GAIN	2/3 RIM CUT FINAL	2/3 RIM CUT FINAL WITH ZERO ADJUST	RIM\PLATE FILLET JUNCTION	RIM/PLATE FILLET JUNC. W/ ZERO ADJ	THRU-HUB FINAL READINGS	THRU-HUB FINAL WIT ZERO ADJ.
	2	0	981	-42	-42	-193	-193	-180	-180
FRONT	4	0	980	-58	-58	-179	-179	-128	-128
RIM	6	1	981	-52	-53	-8	-9	21	20
FACE	8	0	981	47	47	79	79	92	92
	10	0	980	-1	-1	16	16	21	21
	12	0	984	-45	-45	-31	-31	-32	-32
	14	3	979	40	37	45	42	32	29
TREAD	16	1	986	-119	-120	-126	-127	-139	-140
	18	-1	980	-263	-262	-276	-275	-284	-283
	20	-2	982	67	69	38	40	42	44
	22	1	983	-110	-111	-98	-99	-97	-98
BACK	24	-4	980	-126	-122	-104	-100	-104	-100
RIM	26	2	986	-79	-81	-59	-61	-185	-187
FACE	28	0	984	16	16	-30	-30	-6	-6
	30	0	984	201	201	-13	-13	20	20
	32	0	980	119	119	-45	-45	-39	-39

AP3-31
AP3-31

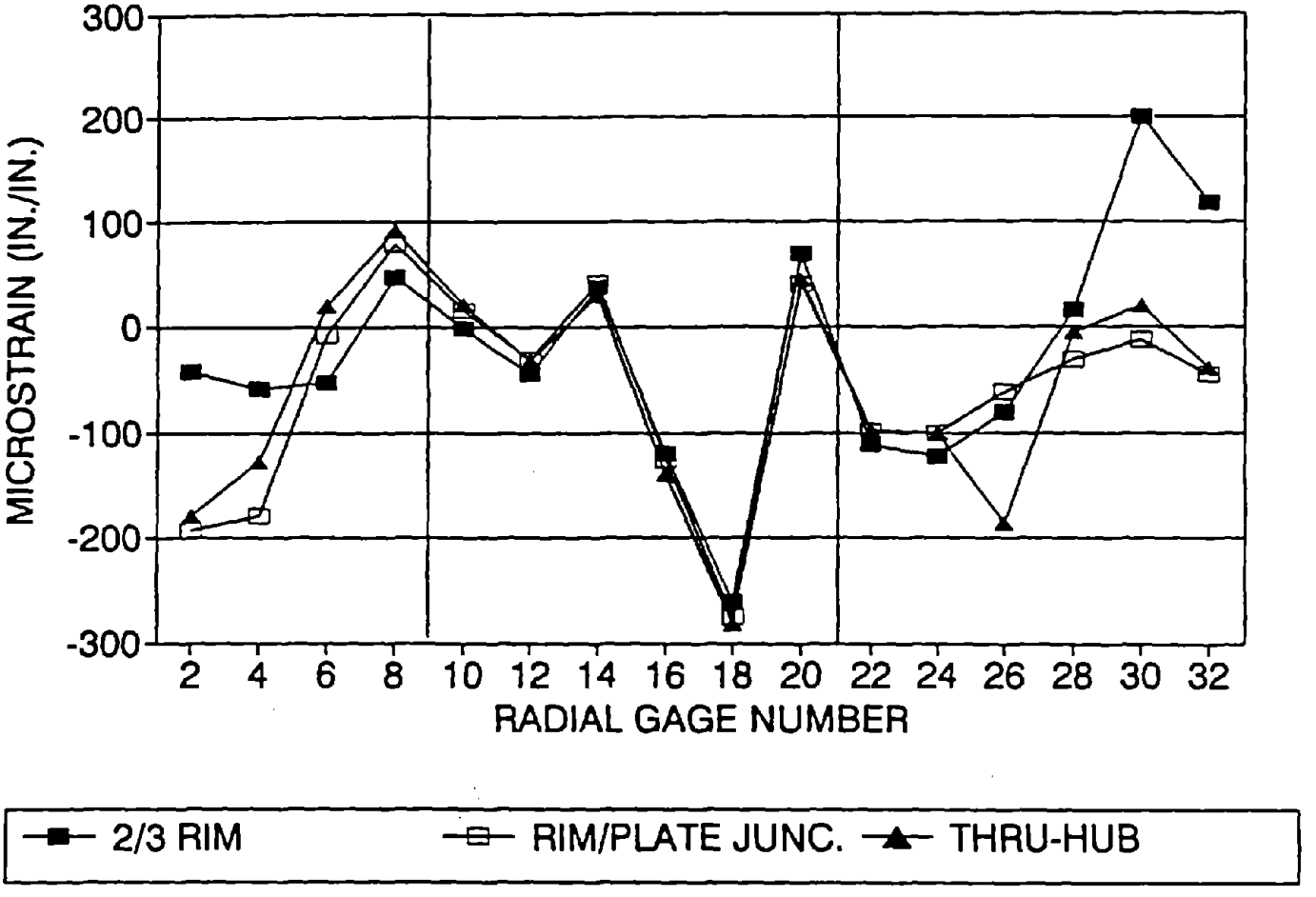
HOOP GAGE DATA - POSITION 4-(3/31/92)
1-7(FRF);9-19(TREAD);21-31(BRF)



AP-3

AP3-32

RADIAL GAGE DATA - POSITION 4-(3/31/92)
2-8(FRF);10-20(TREAD);22-32(BRF)



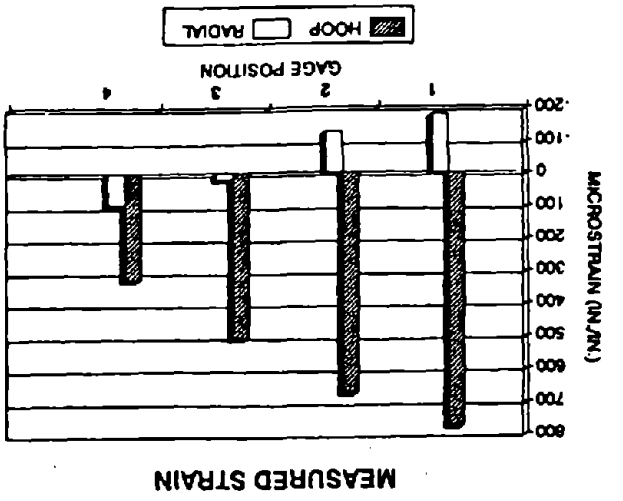
AP-4

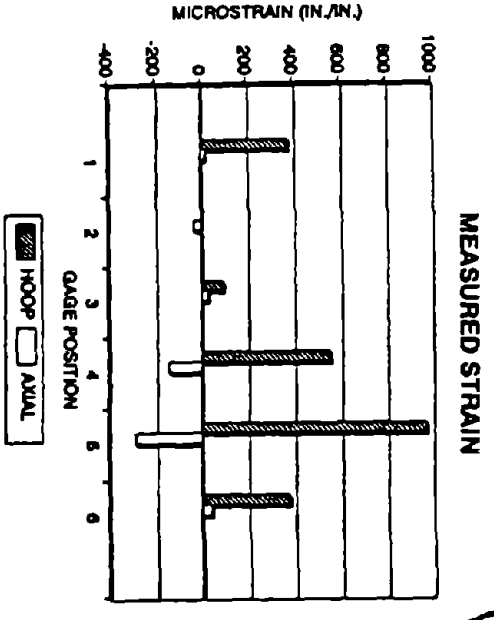
AP3-33

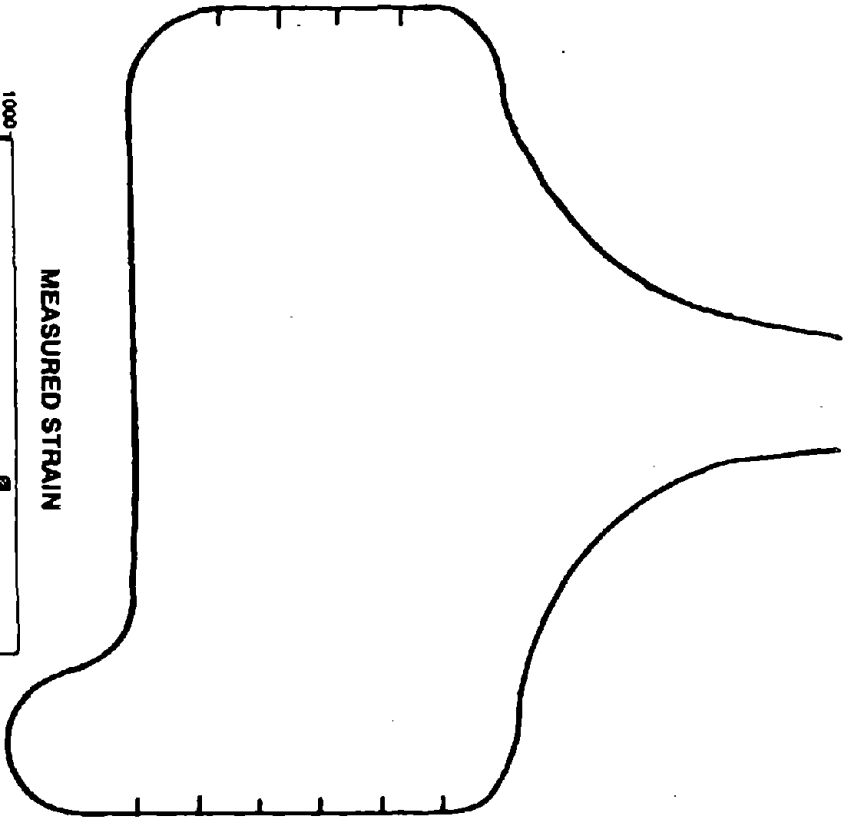
DATA DISPLAY
RIM ORIENTATION

OLD WHEEL
Position 4
Final Strain of
Thru-Hub Cut
March 31, 1992

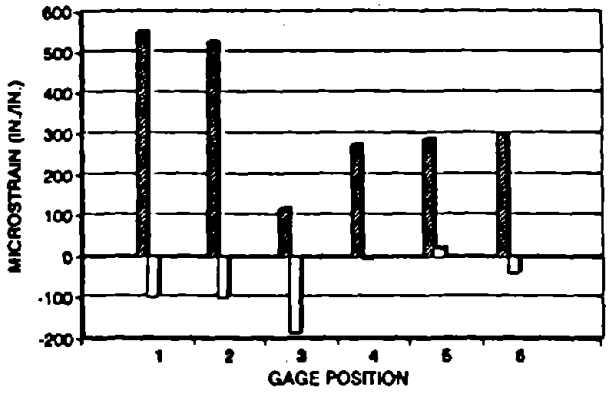
Positive Strain
=> Compression
Negative Strain
=> Tension







MEASURED STRAIN

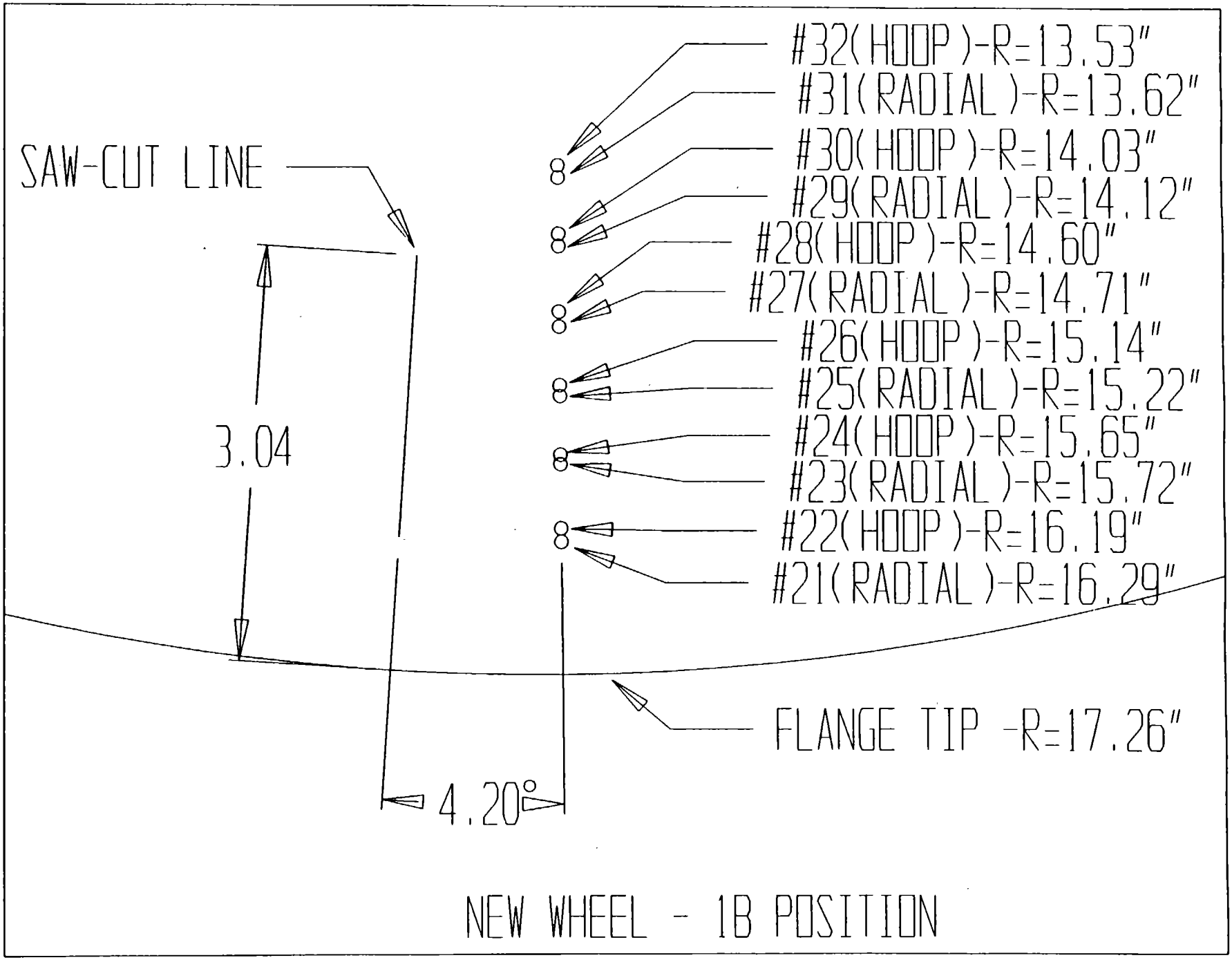


AP3-34

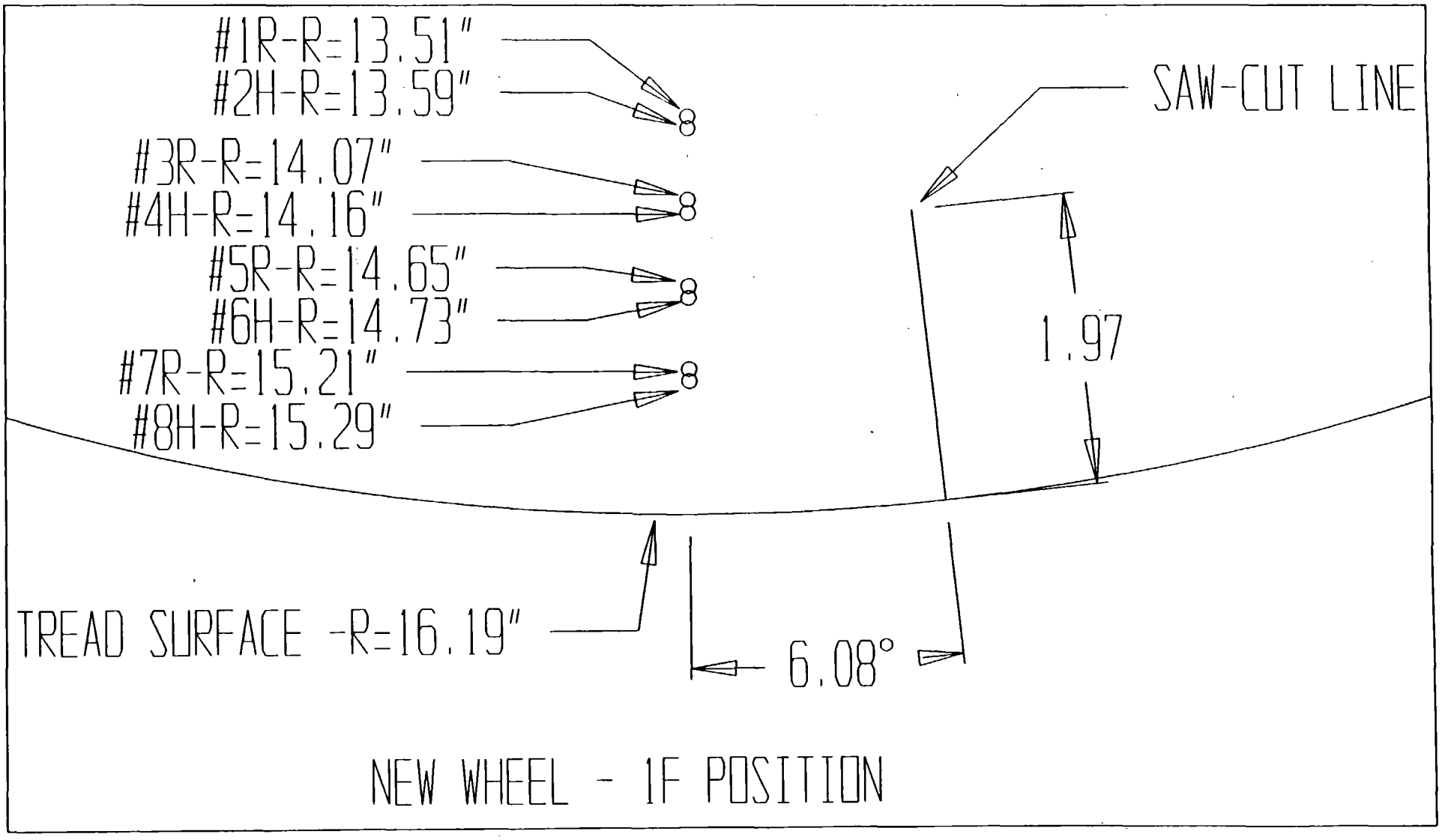
APPENDIX 4

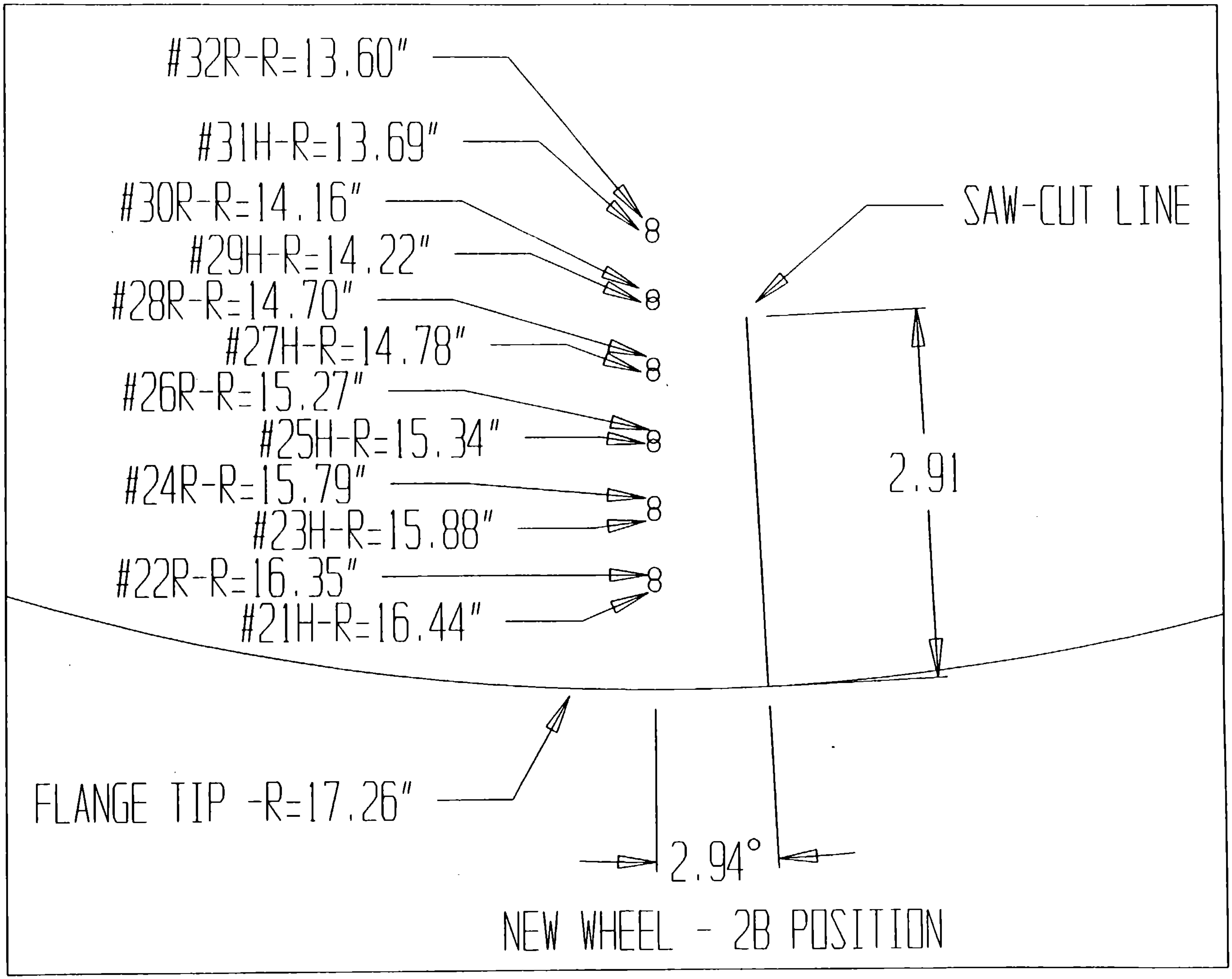
STRAIN GAGE and SAW CUT LOCATION DRAWINGS

AP3-35


#32(HOOP)-R=13.53"
#31(RADIAL)-R=13.62"
#30(HOOP)-R=14.03"
#29(RADIAL)-R=14.12"
#28(HOOP)-R=14.60"
#27(RADIAL)-R=14.71"
#26(HOOP)-R=15.14"
#25(RADIAL)-R=15.22"
#24(HOOP)-R=15.65"
#23(RADIAL)-R=15.72"
#22(HOOP)-R=16.19"
#21(RADIAL)-R=16.29"
8
SAW-CUT LINE
3.04
4.20°
FLANGE TIP -R=17.26"
NEW WHEEL - 1B POSITION

AP03-37


#1R-R=13.51"
#2H-R=13.59"
8
#3R-R=14.07"
#4H-R=14.16"
8
#5R-R=14.65"
#6H-R=14.73"
8
#7R-R=15.21"
#8H-R=15.29"
8
SAW-CUT LINE
1.97
TREAD SURFACE -R=16.19"
6.08°
NEW WHEEL - 1F POSITION

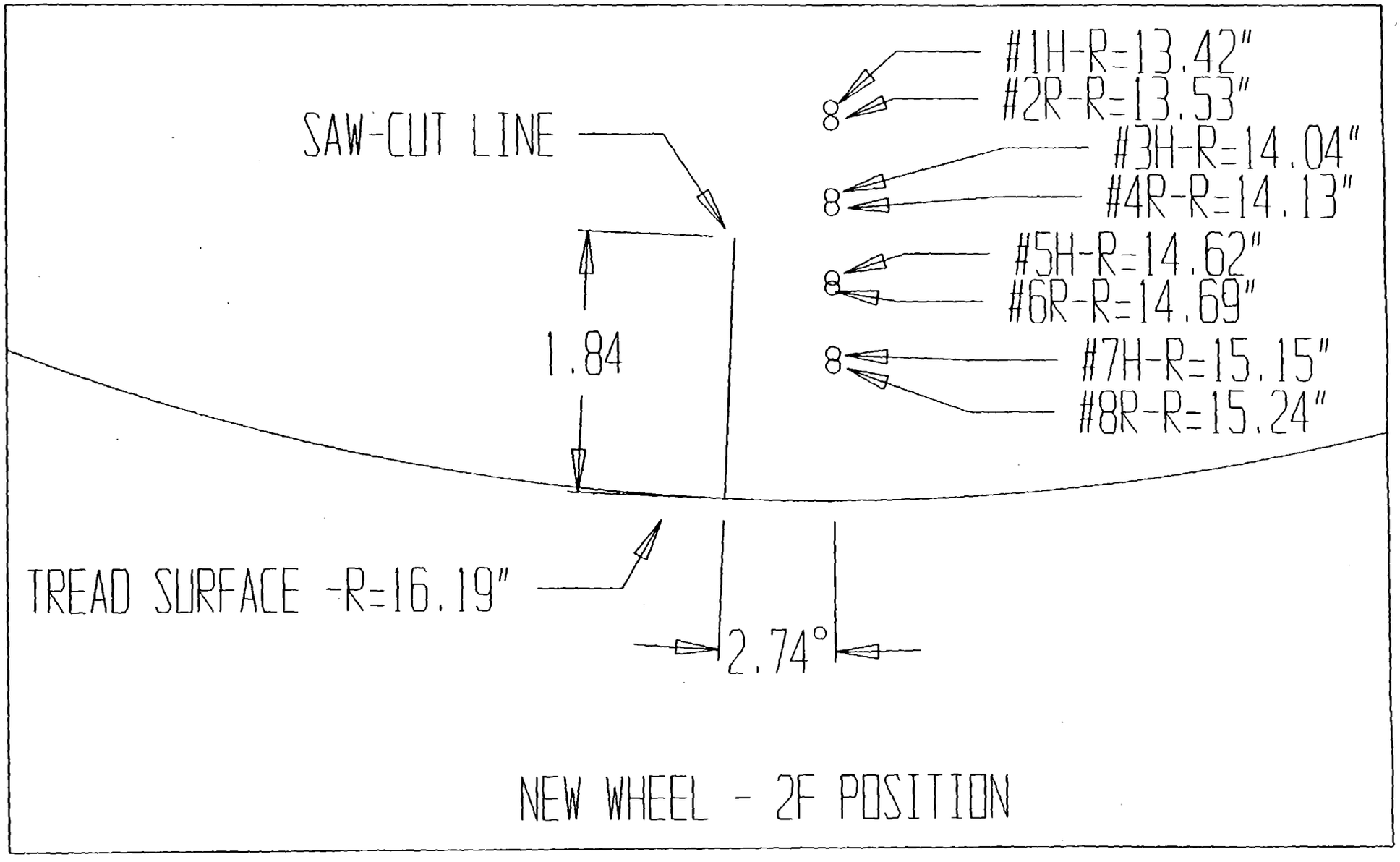

#32R-R=13.60"
#31H-R=13.69"
#30R-R=14.16"
#29H-R=14.22"
#28R-R=14.70"
#27H-R=14.78"
#26R-R=15.27"
#25H-R=15.34"
#24R-R=15.79"
#23H-R=15.88"
#22R-R=16.35"
#21H-R=16.44"
SAW-CUT LINE
2.91
FLANGE TIP -R=17.26"
2.94°
NEW WHEEL - 2B POSITION

AP-3-38

~~36~~

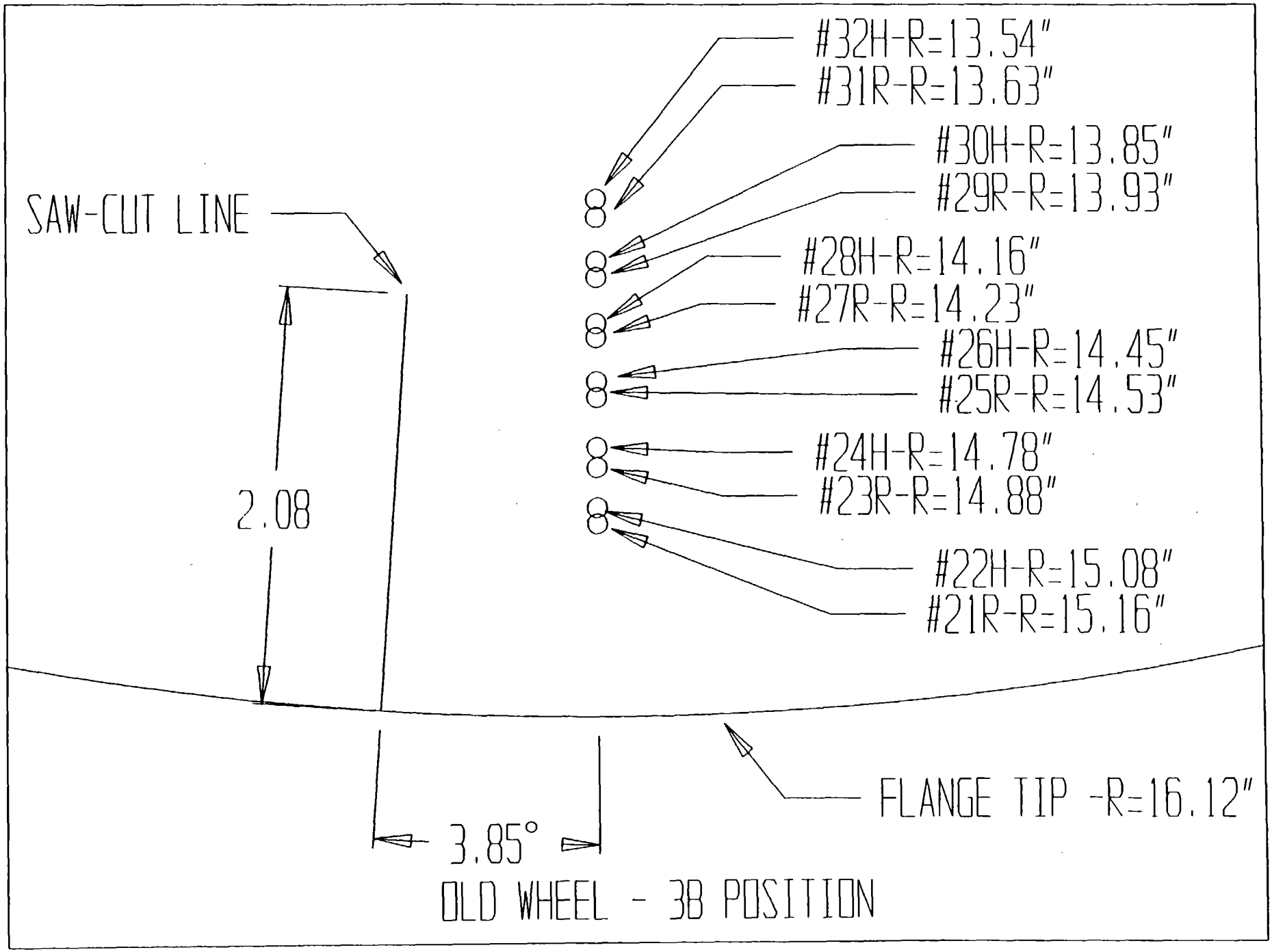
AD-3-39

37

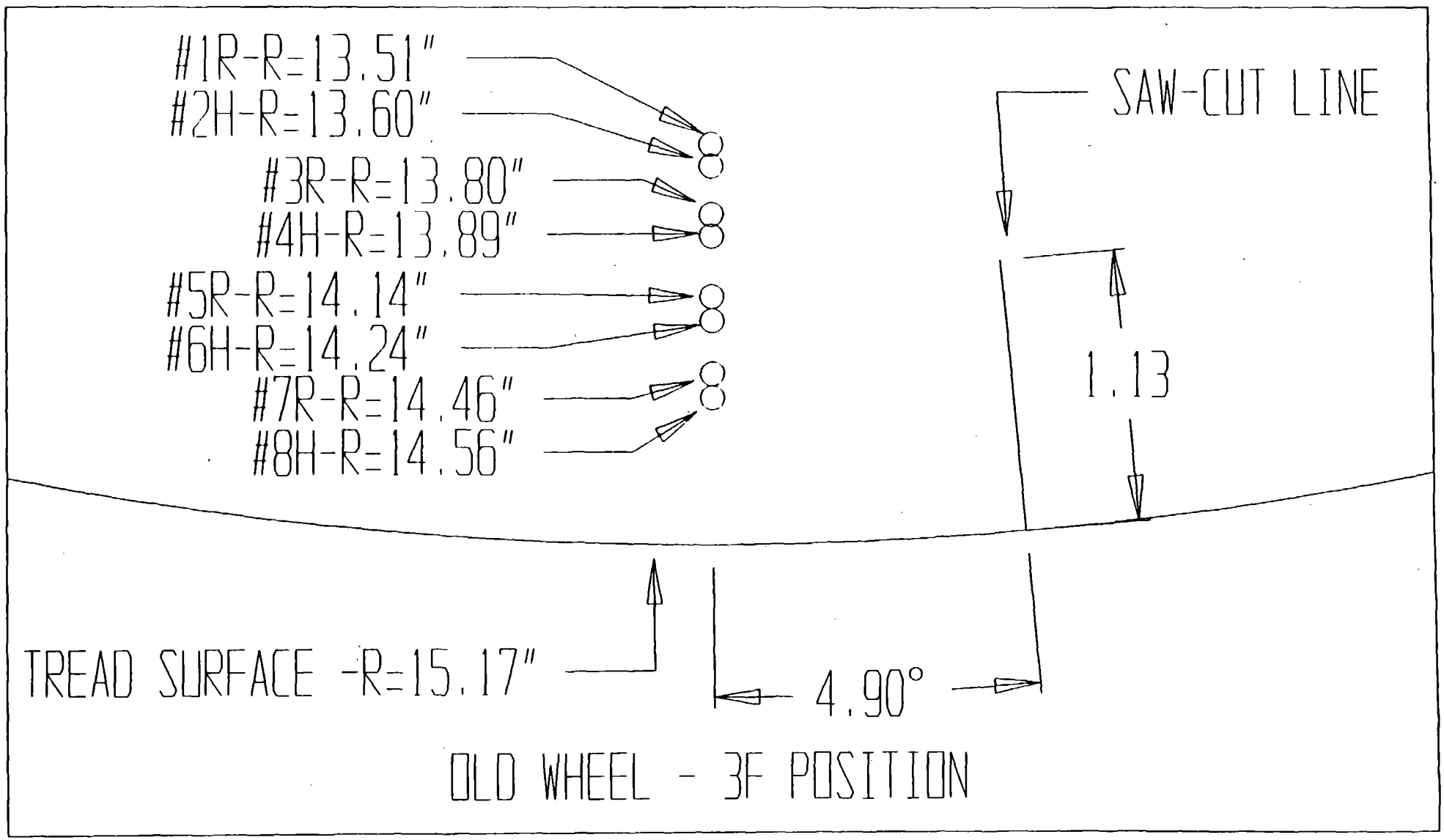

#1H-R=13.42"
#2R-R=13.53"
SAW-CUT LINE
#3H-R=14.04"
#4R-R=14.13"
#5H-R=14.62"
#6R-R=14.69"
1.84
#7H-R=15.15"
#8R-R=15.24"
TREAD SURFACE -R=16.19"
2.74°
NEW WHEEL - 2F POSITION

AP-13-42

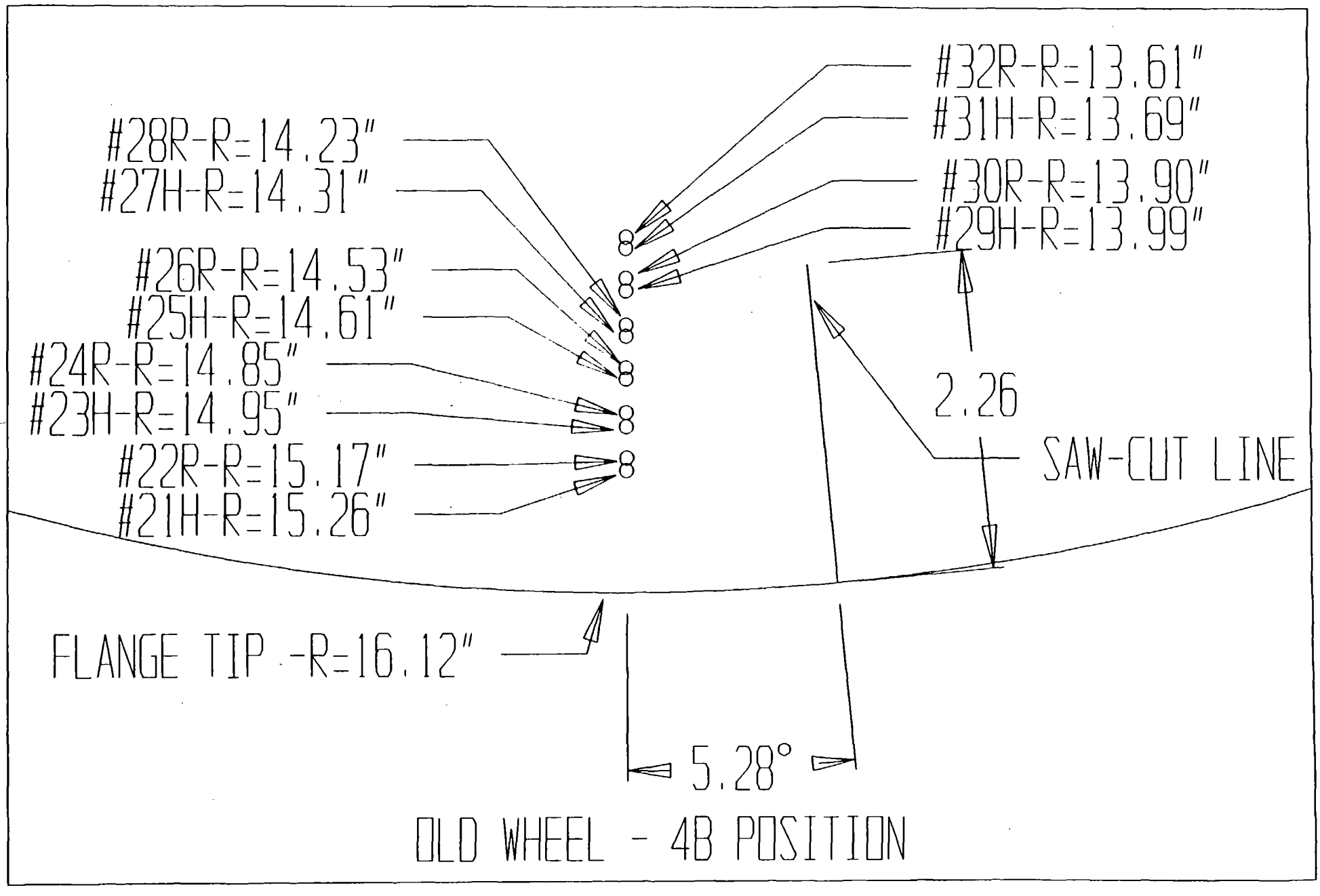
38


#32H-R=13.54"
#31R-R=13.63"
#30H-R=13.85"
#29R-R=13.93"
#28H-R=14.16"
#27R-R=14.23"
#26H-R=14.45"
#25R-R=14.53"
#24H-R=14.78"
#23R-R=14.88"
#22H-R=15.08"
#21R-R=15.16"
SAW-CUT LINE
2.08
FLANGE TIP -R=16.12"
3.85°
OLD WHEEL - 3B POSITION

AD-3-41

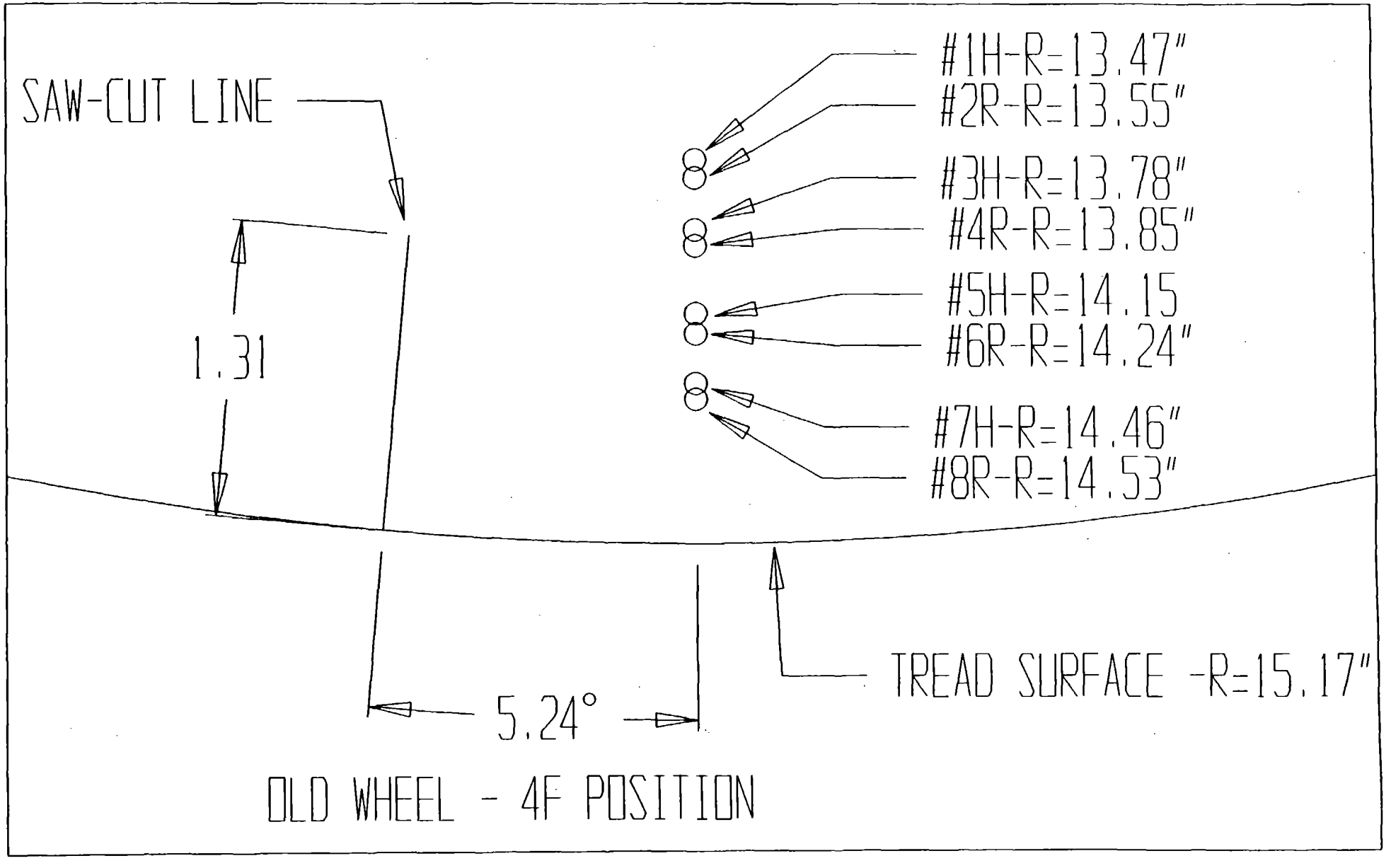

#1R-R=13.51"
#2H-R=13.60"
#3R-R=13.80"
#4H-R=13.89"
#5R-R=14.14"
#6H-R=14.24"
#7R-R=14.46"
#8H-R=14.56"
SAW-CUT LINE
1.13
TREAD SURFACE -R=15.17"
4.90°
OLD WHEEL - 3F POSITION

AD-3-92


#32R-R=13.61"
#31H-R=13.69"
#30R-R=13.90"
#29H-R=13.99"
#28R-R=14.23"
#27H-R=14.31"
#26R-R=14.53"
#25H-R=14.61"
#24R-R=14.85"
#23H-R=14.95"
#22R-R=15.17"
#21H-R=15.26"
8
8
8
8
8
8
2.26
SAW-CUT LINE
FLANGE TIP -R=16.12"
5.28°
OLD WHEEL - 4B POSITION

AD-3-44

#1


SAW-CUT LINE
1.31
#1H-R=13.47"
#2R-R=13.55"
#3H-R=13.78"
#4R-R=13.85"
#5H-R=14.15
#6R-R=14.24"
#7H-R=14.46"
#8R-R=14.53"
TREAD SURFACE -R=15.17"
5.24°
OLD WHEEL - 4F POSITION