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BENET IMPROVEMENTS MADE ON LOS ALAMOS ELECTROMAGNETIC FIELD CODE

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APRIL 1993

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"EMFLD-N" is a self-diagnostic program that computes electromagnetic properties for general two-dimensional cross-sectional geometries. The algorithm presumes the electrical potentials to be a tempered Dirac delta function; the prespecified current flows only on the surfaces of the geometric bodies. For each cross section, the code calculates the distribution of the current density and Lorentz pressure about the perimeter, and finds the impedance and resultant force vector per unit length.

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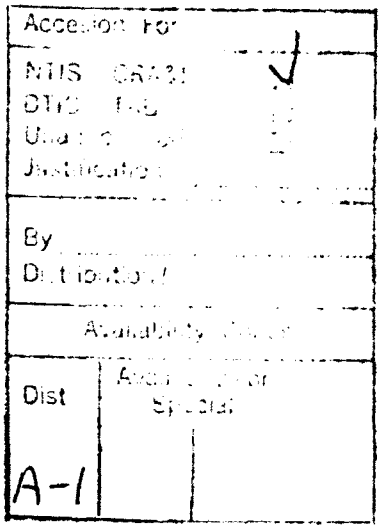
ACKNOWLEDGEMENTS

G. Peter O'Hara contributed heavily to this work. Foremost, he wrote the direct input parameter routine to evaluate general surfaces. Additionally, Pete initiated the first-draft graphics and post-processing software. His graphical layout is still seen on the monochrome terminals. Pete's accomplishments include the impedance-gradient and the original direct Lorentz force evaluation routine, both of which have since been improved.

Royce W. Soanes authored most of the error-bound analytical software, which includes the Lagrange derivatives.

Thomas Simkins' use of "MACSYMA" was invaluable.



INTRODUCTION

"EMFLD-N" is the name of a user-friendly computer program existing on the IBM mainframe that evolved from the Los Alamos "FLDLANL" code. "EMFLD-N" models the two-dimensional electromagnetic results for an infinitely long structure containing up to six individual conducting general geometries. Every conductor carries an individual potential for any finite value of infinite frequency (e.g., a pulse). This pulse will cause only the surfaces to conduct or carry the subsequent load. The evolution of "EMFLD-N" beyond "FLDLANL" is so extensive so as to warrant this report.

To date, "EMFLD-N" has been used solely as a research and development aid to the electromagnetic launcher program within Benet Laboratories. Its improved capabilities eliminate most additional post-processing of information, as well as speculation on its validity of the results.

Although the electromagnetic launcher program required analytic tools for modeling, the funding would not support tools for modeling or new software.

"FLDLANL," the original Fortran code developed at Los Alamos, satisfied most of the needs so it was decided to modify this code.

LOS ALAMOS CODE

The Los Alamos code functions as follows: First, "FLDLANL" sketches each surface's cross section. Then the code estimates the electrical current density distribution about the perimeter of the particular set of geometries assuming:

1. The geometries are infinitely long; and

2. The frequency of the voltage potential is infinite with geometries limited in number up to six inclusive and defined as either a circular or "J" rail.

"FLDLANL" simply uses subroutine "FLD9," which determines the total current and its distribution about every surface given an input set of potential gradients (one gradient per surface). This determination is made by the simultaneous integration of up to 49 cubic segments per surface over every surface. "FLDLANL" powers one surface at a time, thus obtaining the interdependence of each of the surfaces (a type of mutual-impedance potential matrix). Then after determining the correct voltage to apply to each of the modeled surfaces to achieve the total currents specified, it finds the current distribution. Lastly, the lines of electrical equipotential (magnetic flux) are plotted.

BENET CODE

"EMFLD-N" evolved from "FLDLANL" by realizing its full potential. The first modification was made by G. Peter O'Hara, who generalized the geometric variables to allow the code to model most any surface. Each geometric surface was broken up into no more than ten sections, where a section was either defined as a line segment or an arc. While this improvement expanded "EMFLD-Ns" capability, it had drawbacks:

1. It was a cumbersome task to create this surface.

2. It was impossible to detect small errors.

To alleviate these difficulties, the program "PREFLD" was developed by this author. Later as a precaution, "EMFLD-N" was modified to average any discrepancy between sections.

This author also added an automated iterative DeBoor-type knot meshing technique to minimize a prespecified error. The specification was given as a percentage of the root-mean squared value of the current distribution as a function of perimeter length. Later, a uniform error-bound algorithm for increased stability was incorporated, allowing the converged answers to be accompanied by the said bound which is in terms of current density.

Soon, the original input procedure was found to be tedious and inadequate, so a flexible procedure was written to allow:

- Step-by-step processing
- Intermediate restarting with new values
- Easy operation with legible input deck
- Defaults

In order to accomplish this goal, the code now generates in a separate file:

- Geometric limitations
- Tolerance modifications
- Converged results
- Mutual-impedance potential matrix

Post-processing was also added to enhance "EMFLD-N," and the impedance-gradient was calculated. The Lorentz force was determined by first calculating the distributed surface loads resulting from the current surface densities. These loads exhibit (1) a magnitude proportional to the square of the density at the same point, and (2) a direction in line with the concurrent E-field that is normal to the surface and inward. The integration of these loads revealed a significantly improved resultant force vector over direct evaluation. This procedure estimated the force's magnitude more accurately and approximated the location and direction. Lastly, the Lorentz force normal to the plane (e.g., behind the armature) was estimated.

Additional graphical improvements were made as described. The code's present graphical capability was initiated by first writing the missing subroutines inherent to the Los Alamos mainframe. Then symbols were made for the knots. Finally, current densities versus perimeter lengths were graphed. The graphics were colorized, while maintaining their integrity on monochrome terminals. Also added were user-defined features to adjust the pictures for:

- Visibility
- Hard copying
- Coloring
- Bordering

- Making grids
- Filling in graphs
- Placement of cross-sectional plots

Distributed loads were plotted as a function of perimeter length and shown on the geometric plot with each surface's resultant concentrated load vector.

Finally, the order of integral calculation was made using an isoparametric variable between 1 and 4. Lower orders are recommended. However, the higher orders require less knots, and for many structures to maintain error tolerances below a stable 10 percent, it will be necessary to increase the order.

Example: Order of Integration

First, we will demonstrate the program's ability to accommodate different orders of integration for a simple model shown in Figure 1. The case modeled is two sets of long wires. Each set is comprised of two 10-mm diameter round wires separated by a 10-mm gap. The ends of each set, which are not modeled, are connected into a circuit. Therefore, the current is equal and opposite in adjacent wires. The sets of wires are parallel and separated by a distance of 34.6-mm.

The code normally symmetrizes about the x-axis, but can also assume symmetry about the y-axis when nothing is in the second quadrant. However, when the assumption is in effect, the current values to the left of the y-axis are opposite to those of the right.

Using this knowledge, we reduce the model to one wire shown in Figure 2 produced by the "DRAW" command within "EMFLD-N." This wire is in the first quadrant with a positive unit potential. Thus, we can model the following shown in Table 1.

Table 1. Examples of Models

Quadrant	Potential
1	+1.000
2	-1.000
3	-1.000
4	+1.000

Below Table 2 illustrates the relationship between the integration order and the number of segments needed to uniformly cover an error bound of given tolerance.

Table 2. Integration Order Versus Number of Segments

Order	Segments	Tolerance (Percent)
1	50	7.8
2	28	1.0
3	15	1.1
4	12	1.0

These values were determined by analyzing prior solutions iteratively until convergence.

Figure 3 shows solutions for the above, which are the functions where the error is estimated. The x-axis represents the location about the wire's perimeter, and the y-axis represents the relative local current density, with each solution displaced from the others for viewability. This shows the distributive and numeric effects of the selected integration order.

Determining the actual density values for any given total current becomes a simple task of multiplying the density distribution by the desired total current value and dividing by the resultant total.

Example: Problem of Field Computation

Now we will demonstrate the program's ability to evaluate a difficult problem, Figure 4. A pair of copper rails is placed about a round bore with an aluminum rail on the outside of each. All rails are then wrapped in an oval graphite/epoxy composite jacket. Again, we have symmetric conditions as explained previously. After we input the geometry, "EMFLD-N" will check it with a "DRAW" command in the input deck. At that time the program will produce Figure 4, a single plot of the surface of each object's cross section, section by section.

A section is defined as a length along a surface's perimeter that is described by a single equation (presently line or circle). For example, in Figure 4 a section would be 1 to 2 or 6 to 7 on the copper rail.

Table 3 gives a brief description of the surfaces:

Table 3. Surface Descriptions

Surface	Material	Section	Color
1	Copper	7	Red
2	Aluminum	5	Green
3	Graphite	2	Blue

Now we are ready to do a preliminary analysis. This procedure is quite simple in nature. It places a unit potential on one surface at a time and records the subsequent current on all surfaces. Surface 3 is ignored because it passes through the y-axis and, thus, must have a null potential. Therefore, only two runs are needed. Fourth order integration is chosen because of the complexity of results. As in the previous example, the error is estimated on prior iterations. The converged results are shown in Figures 5 through 8. Figure 5 shows the converged number and locations of all the segments for this preliminary procedure. Having satisfactorily accomplished this, "EMFLD-N" will then solve a system of two equations and two unknowns for the two runs. That is:

$$c11 * p1 + c21 * p2 = c1$$

$$c12 * p1 + c22 * p2 = c2$$

where

c11 = current on surface 1 with surface 1 having unit potential and surface 2 none

c12 = current on surface 2 with surface 1 having unit potential and surface 2 none

c21 = current on surface 1 with surface 2 having unit potential and surface 1 none

c22 = current on surface 2 with surface 2 having unit potential and surface 1 none

c1 = current desired on surface 1

c2 = current desired on surface 2

p1 = resultant potential on surface 1

p2 = resultant potential on surface 2

Once run a timely preliminary analysis is not required. If in the future new values of current need to be substituted, enough information is given in the restart file to simply recompute the necessary potentials. In our case, there is no net current in the aluminum, only in the copper. Also, we will find out in the "*MAIN" run what the net current in our quarter section of graphite will be; we already know that the net current for the graphite on the whole is zero.

Unlike the previous example, we have more than one surface being activated (two runs). Therefore, the current density distributions resulting from the new calculated potentials will differ qualitatively. So the old segment distributions must be discarded and new ones determined.

With the proper potentials in hand, the code now computes the current densities distributed over the surfaces in "*MAIN" (see Figures 10 through 12). Figure 9 shows the final converged solution for the location and number of segments for all surfaces. The consequential Lorentz loads in "*POST" for each surface are shown in Figures 13 through 15. "*FIELD" merely plots the force-fields, the B-fields (magnetic), and the E-fields (electric) in Figures 16, 17, and 18, respectively. The force-field displays the distributed loads as a displacement from its origin on the surface. The resultant force vectors are shown as arrows.

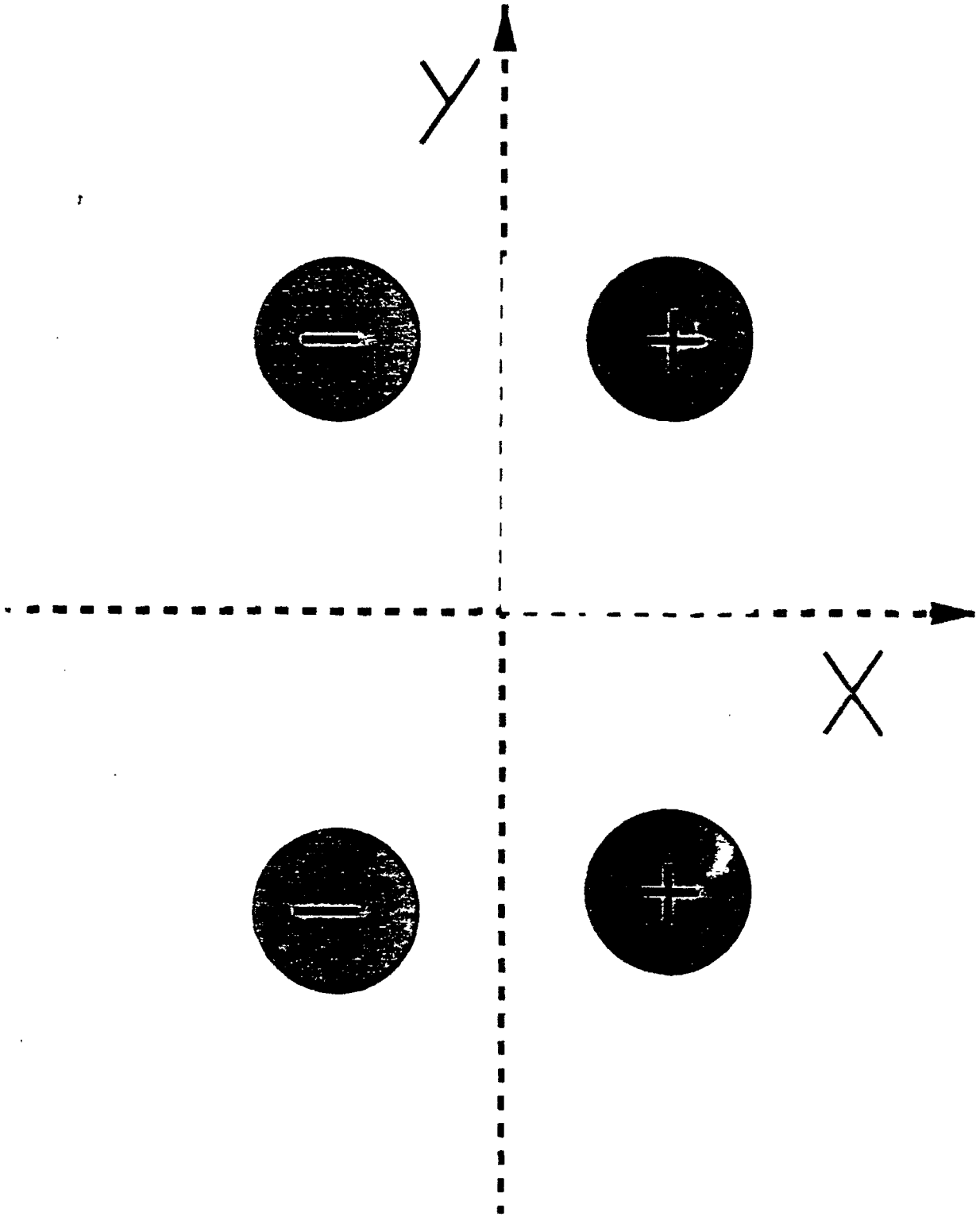


Figure 1. Full geometry used in order of integration example.

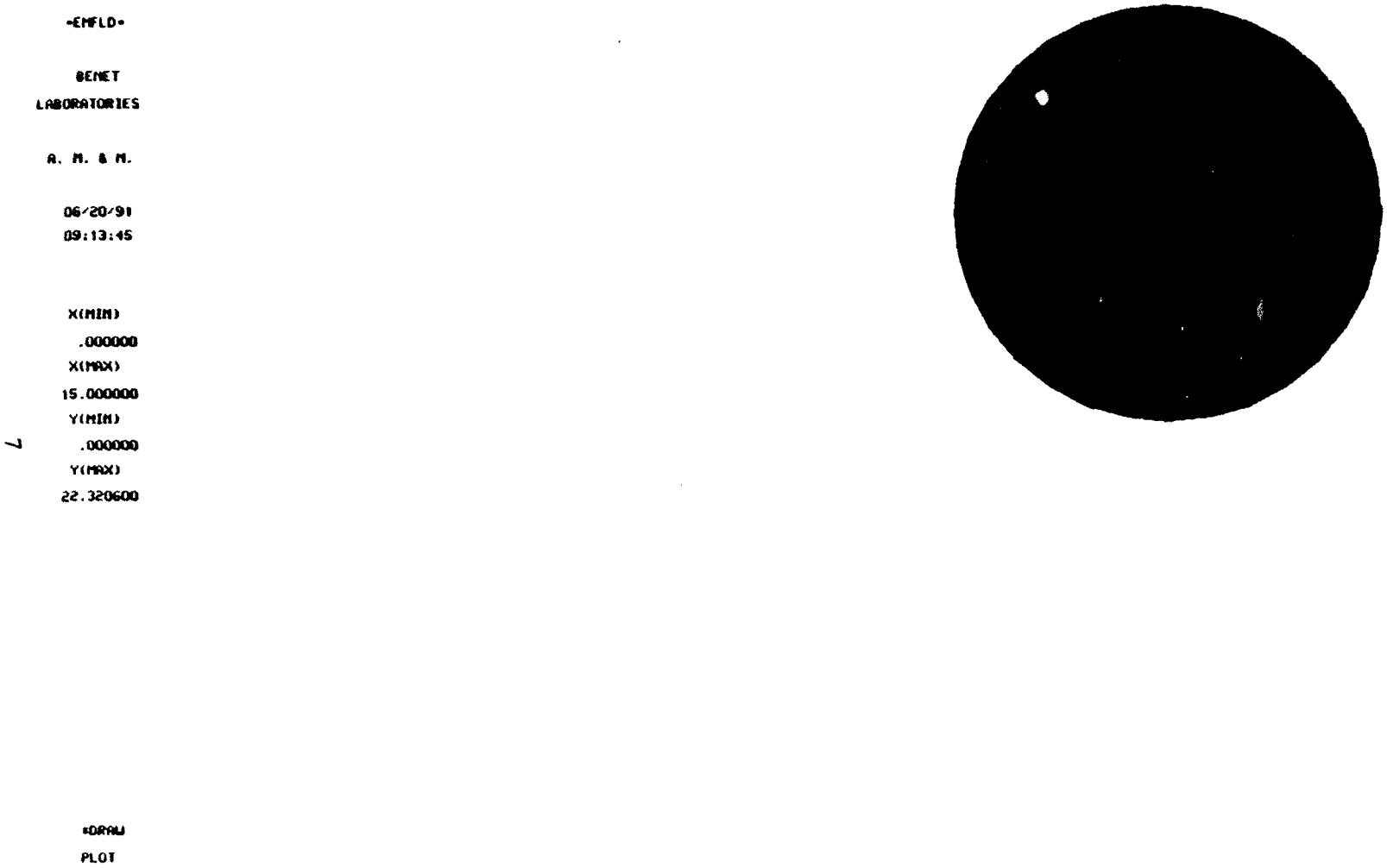


Figure 2. Single quadrant model.

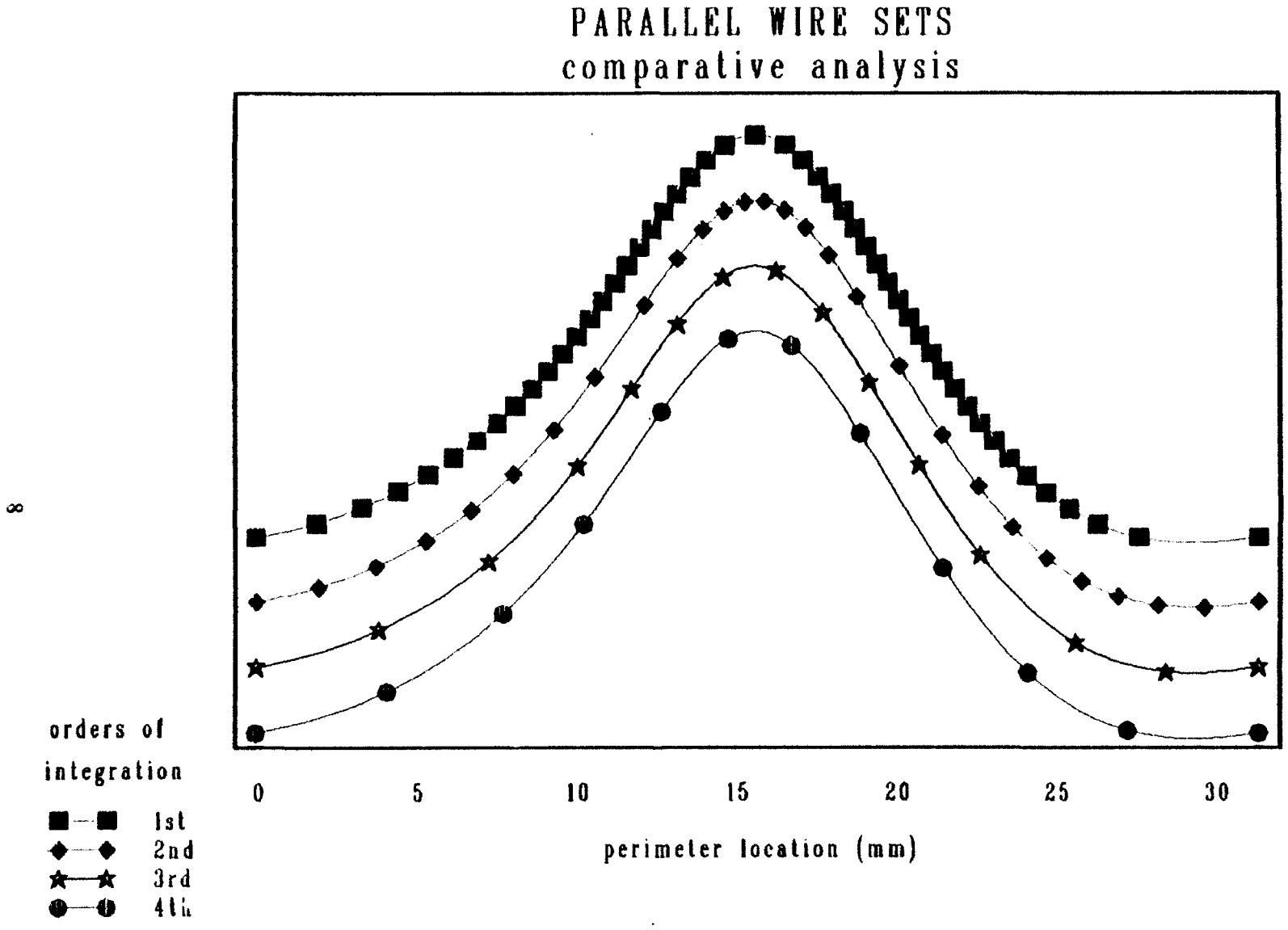


Figure 3. Transposed curves showing order of integration versus segmentation of surface.

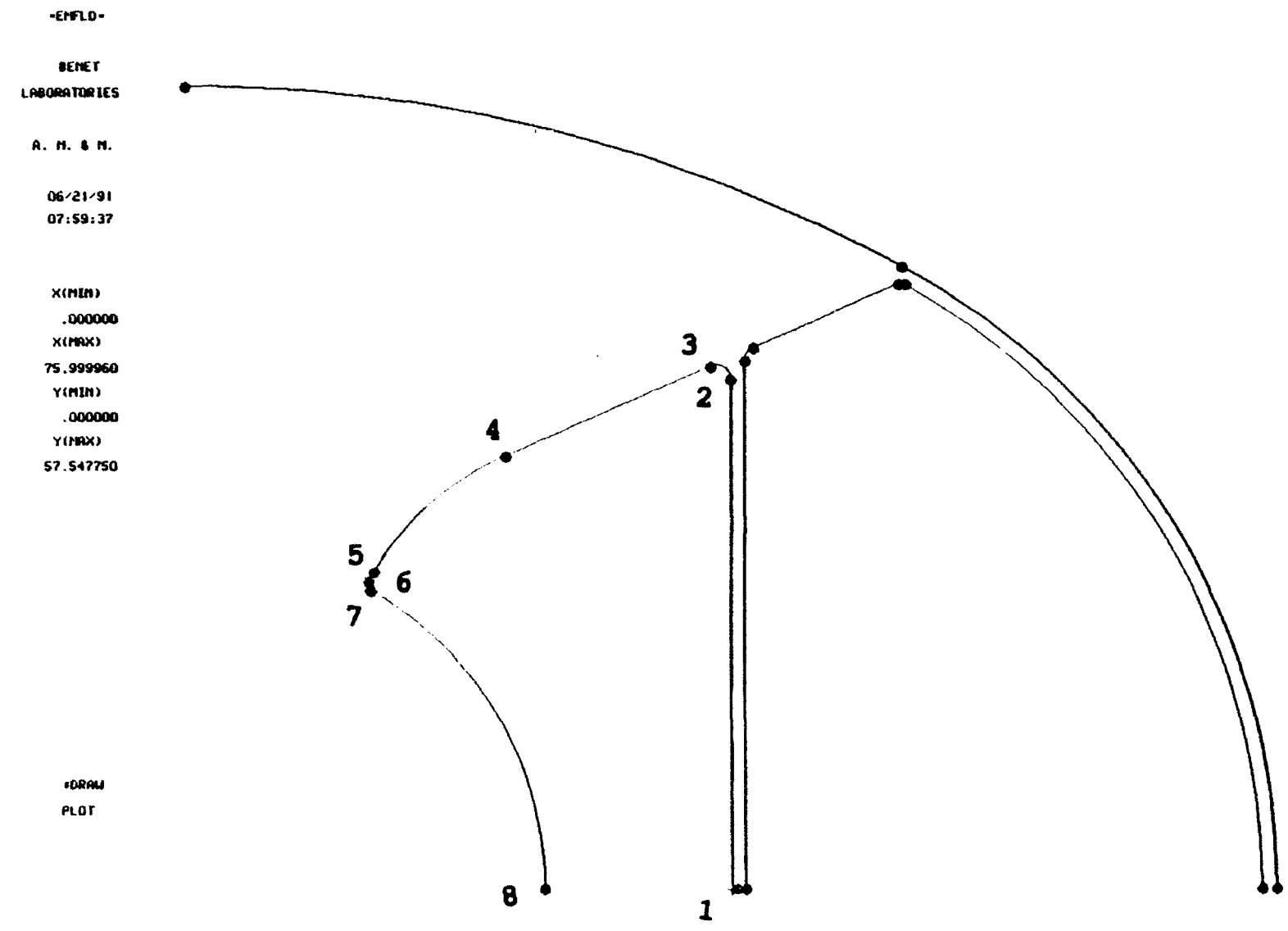


Figure 4. Single plot of the surface of each object's cross section, section by section.

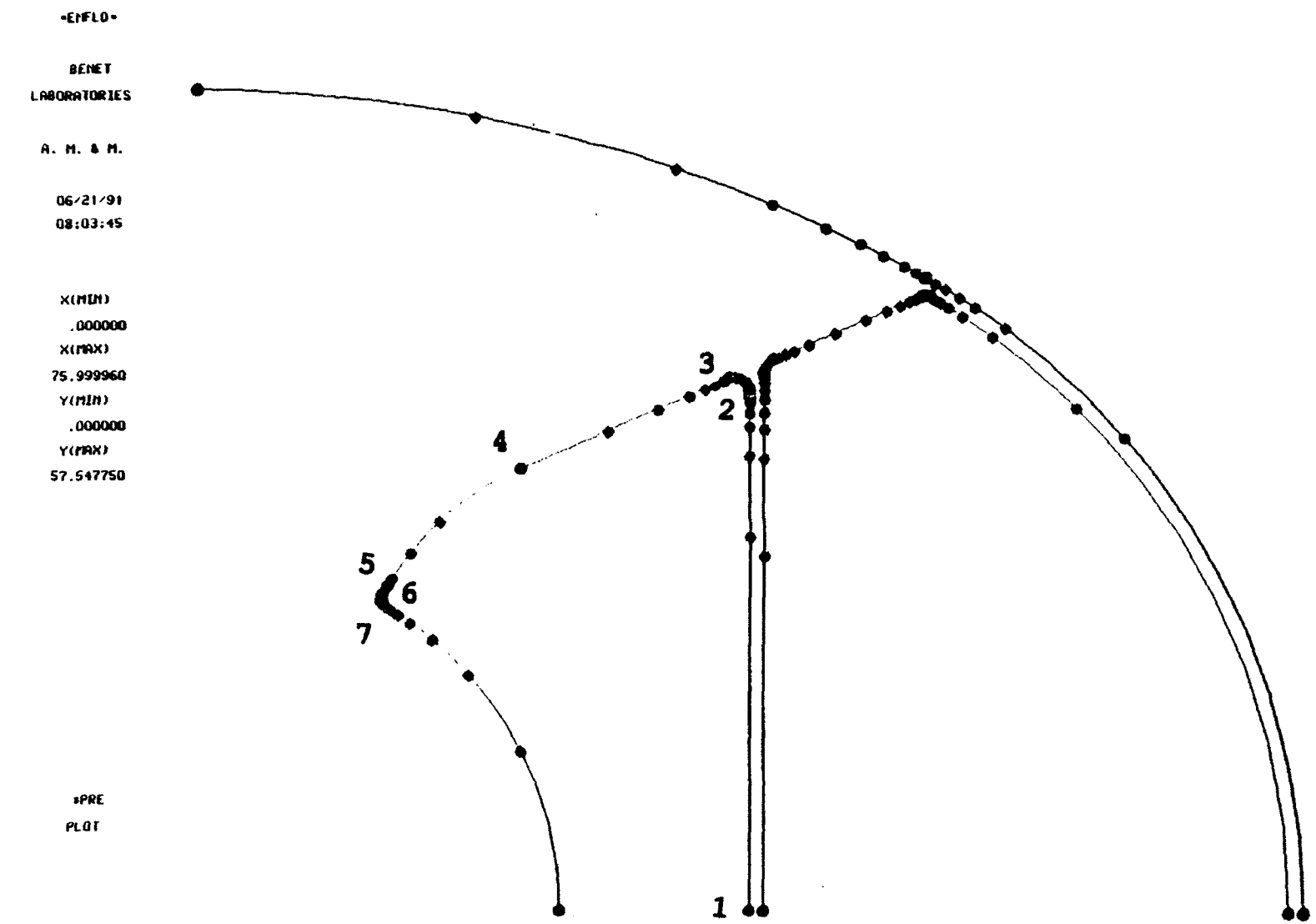


Figure 5. Converged segmentation on all surfaces for preliminary analysis.

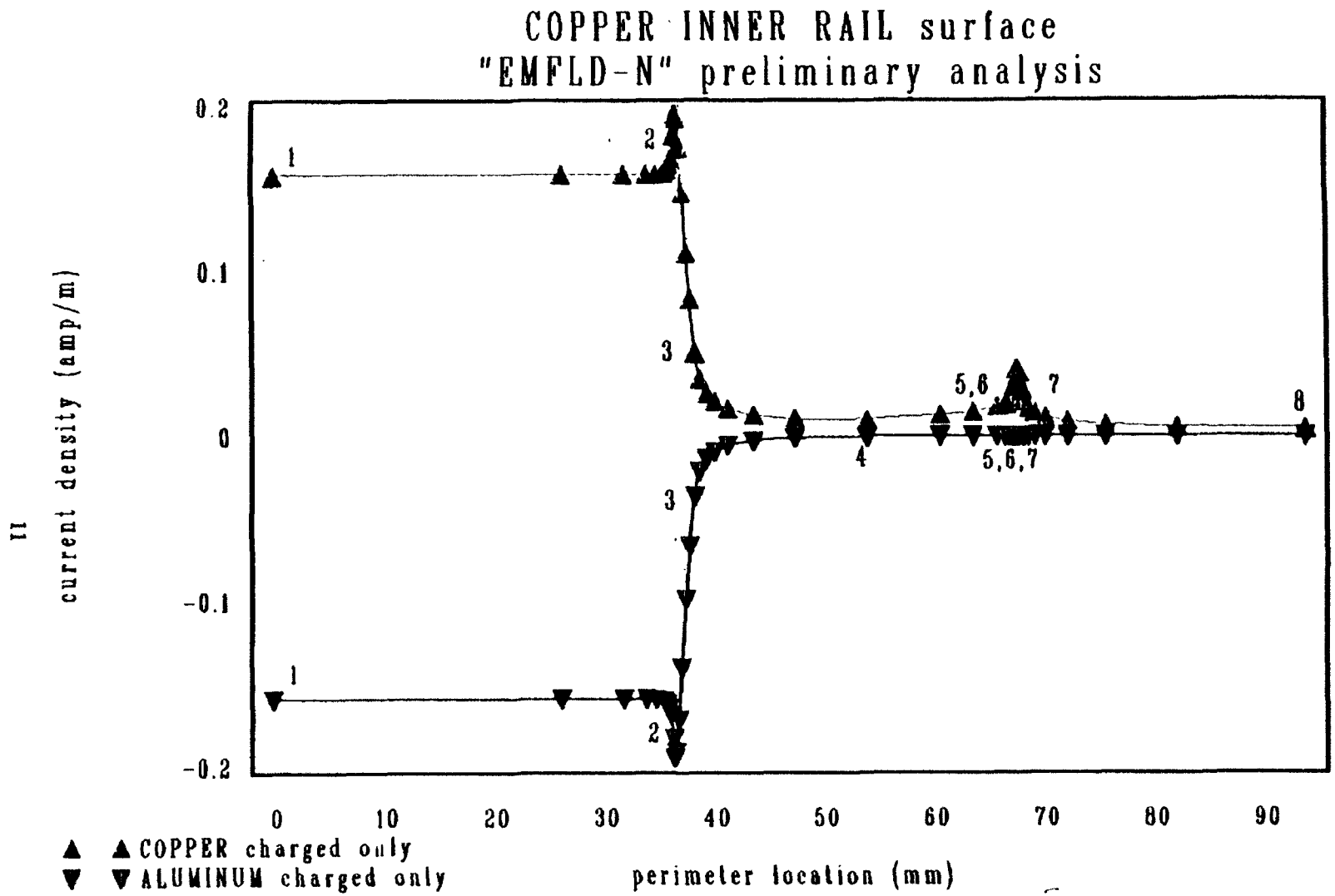


Figure 6. "EMFLD-N" preliminary analysis of copper inner rail surface.

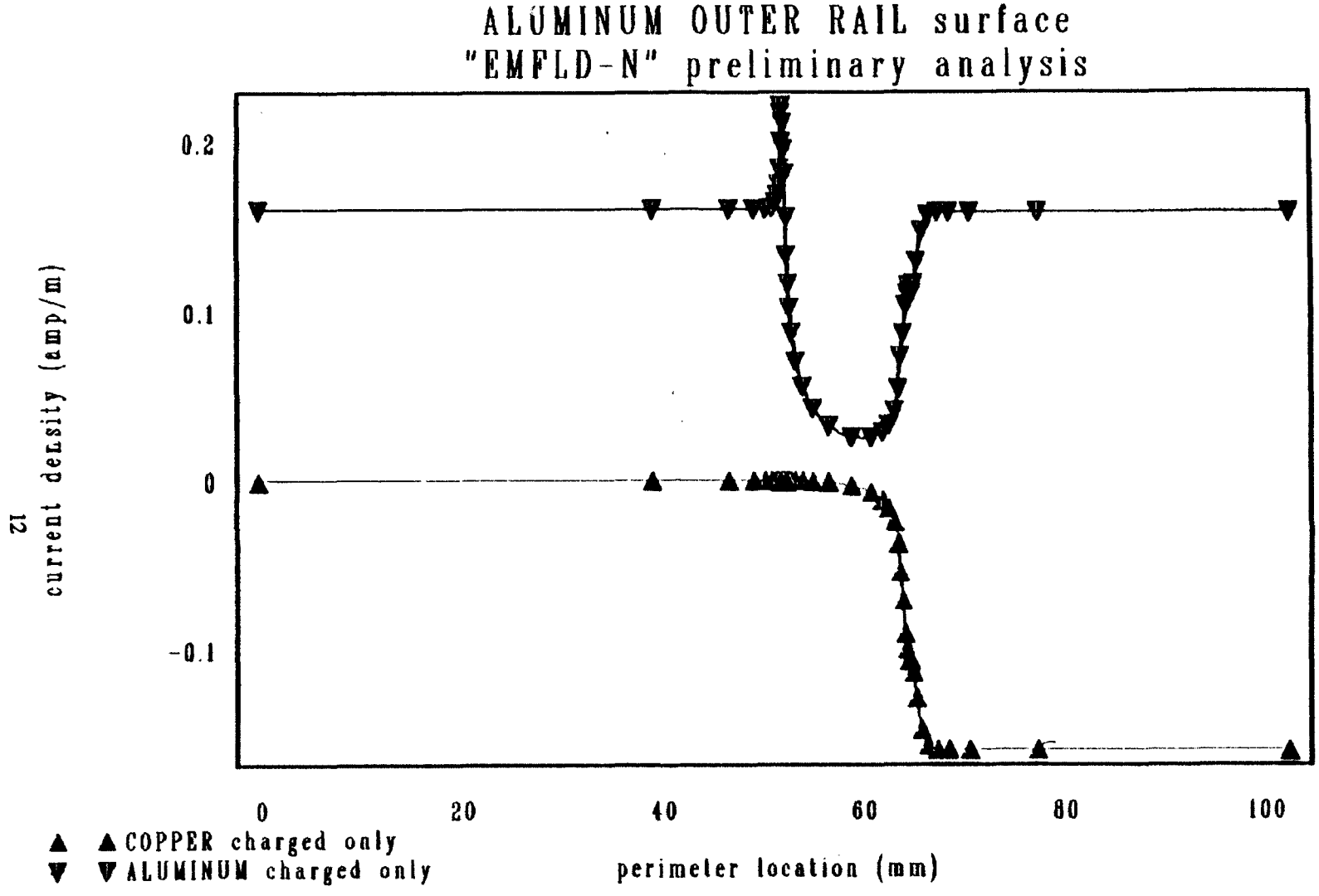


Figure 7. "EMFLD-N" preliminary analysis of aluminum outer rail surface.

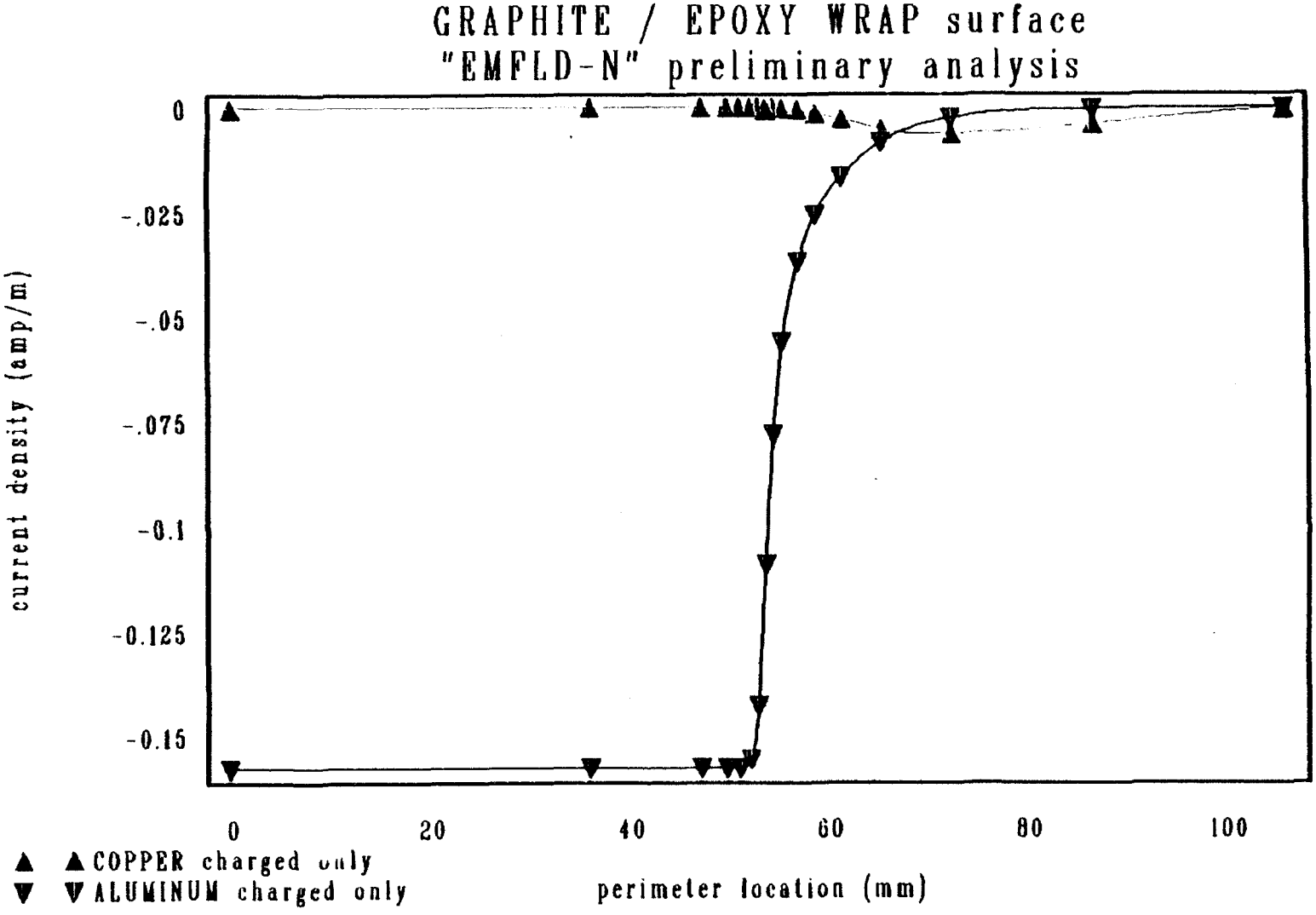


Figure 8. "EMFLD-N" preliminary analysis of graphite/epoxy wrap surface.

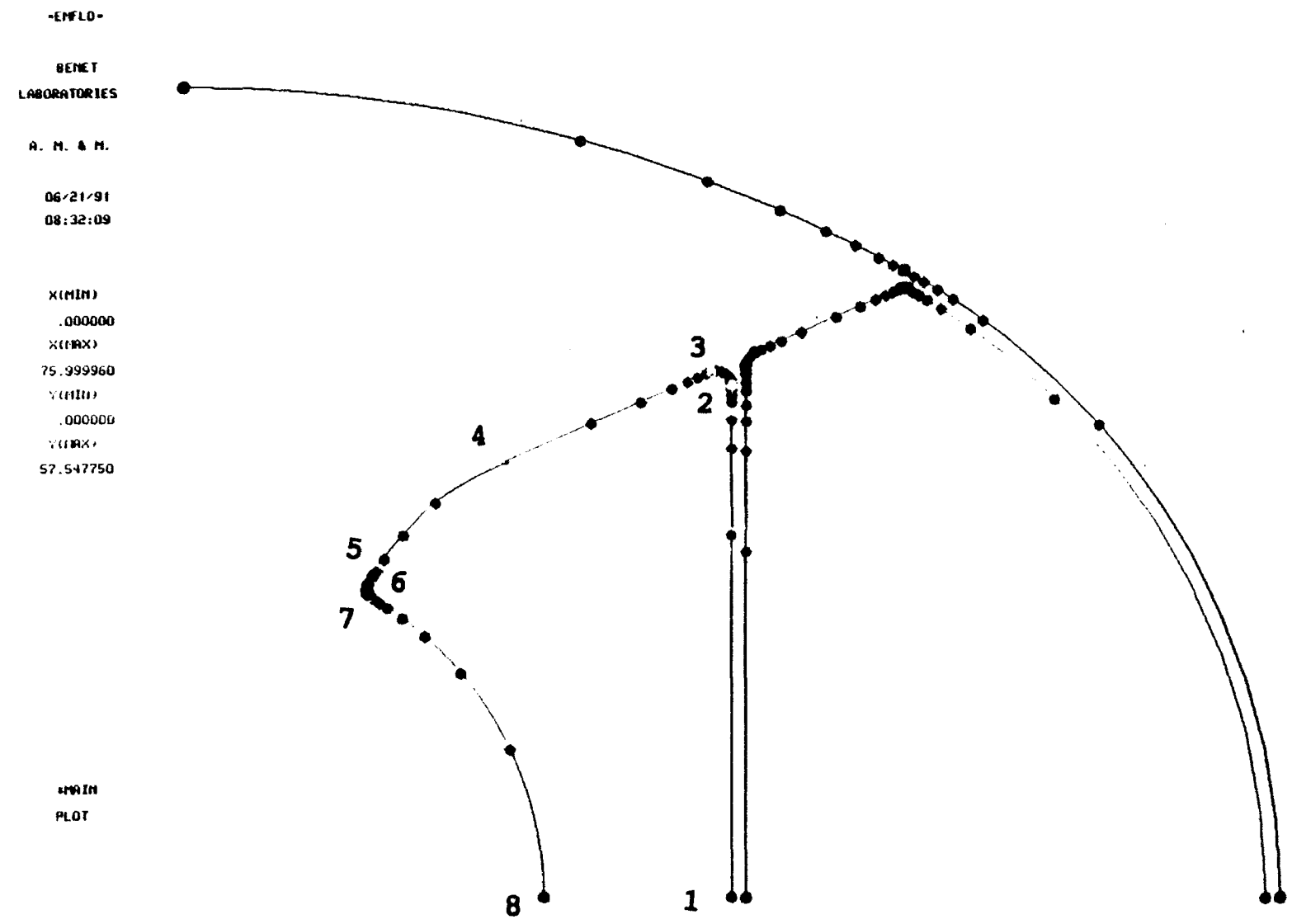


Figure 9. Converged segmentation on all surfaces for main analysis.

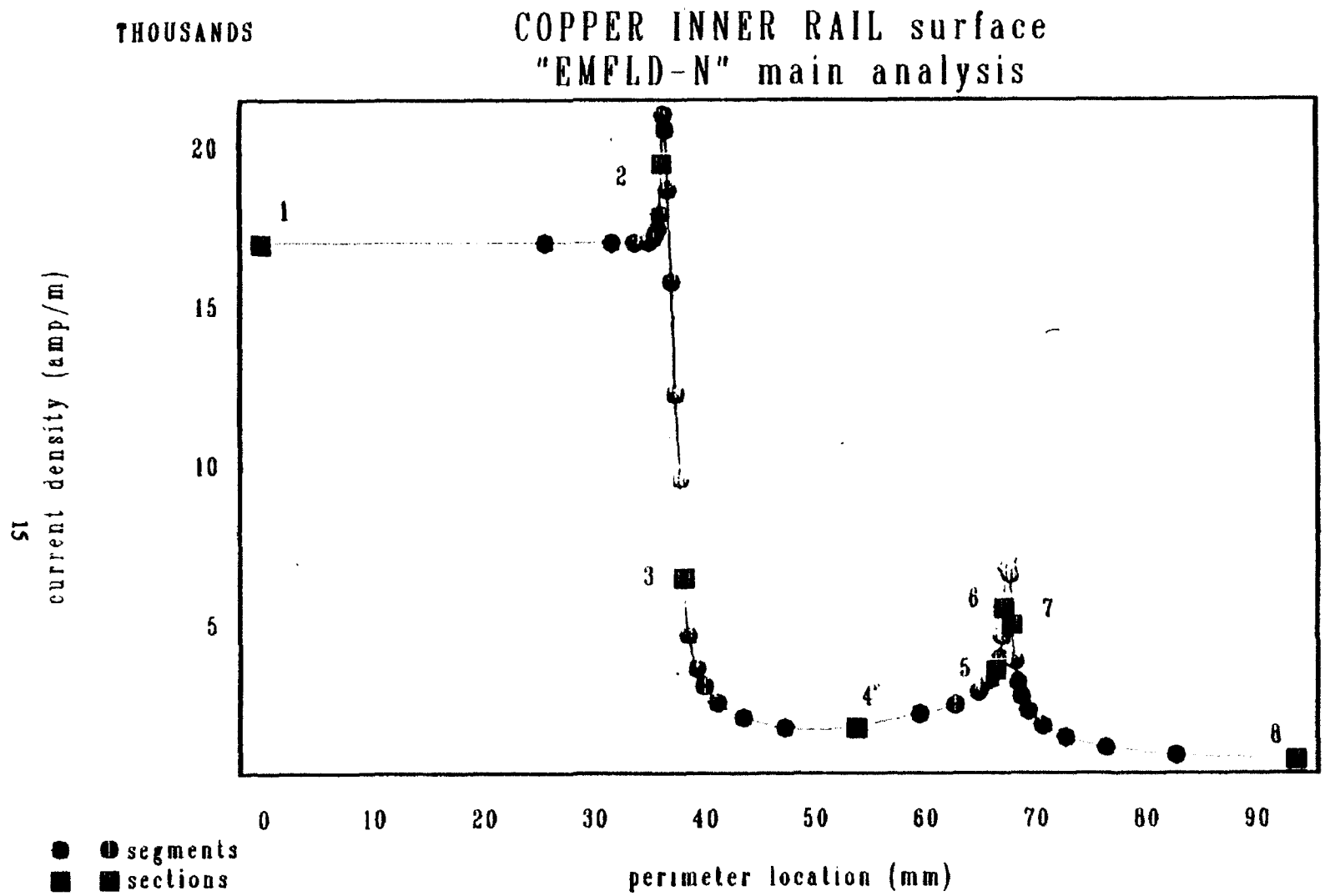


Figure 10. "EMFLD-N" main analysis of copper inner rail surface.

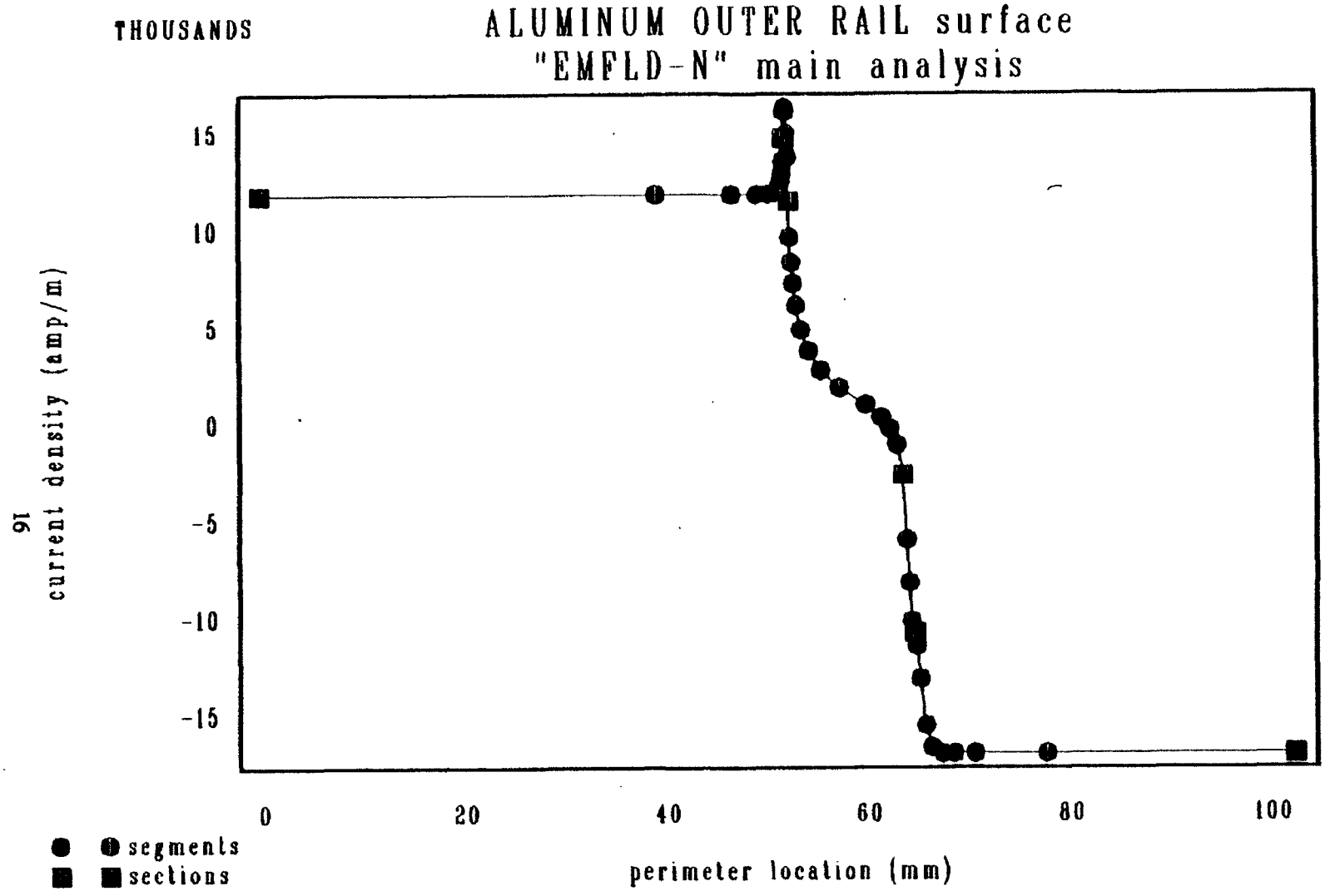


Figure 11. "EMFLD-N" main analysis of aluminum outer rail surface.

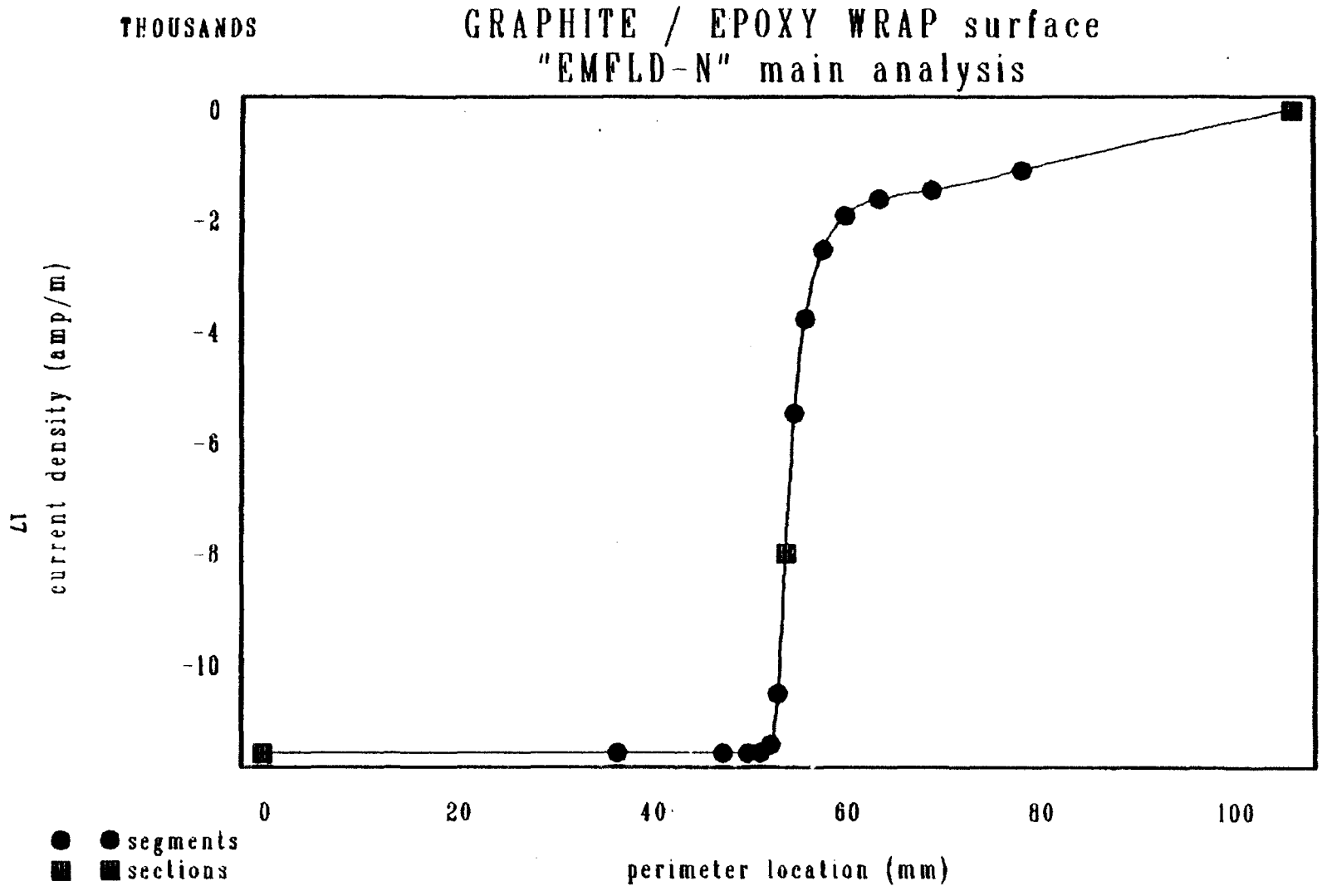


Figure 12. "EMFLD-N" main analysis of graphite/epoxy wrap surface.

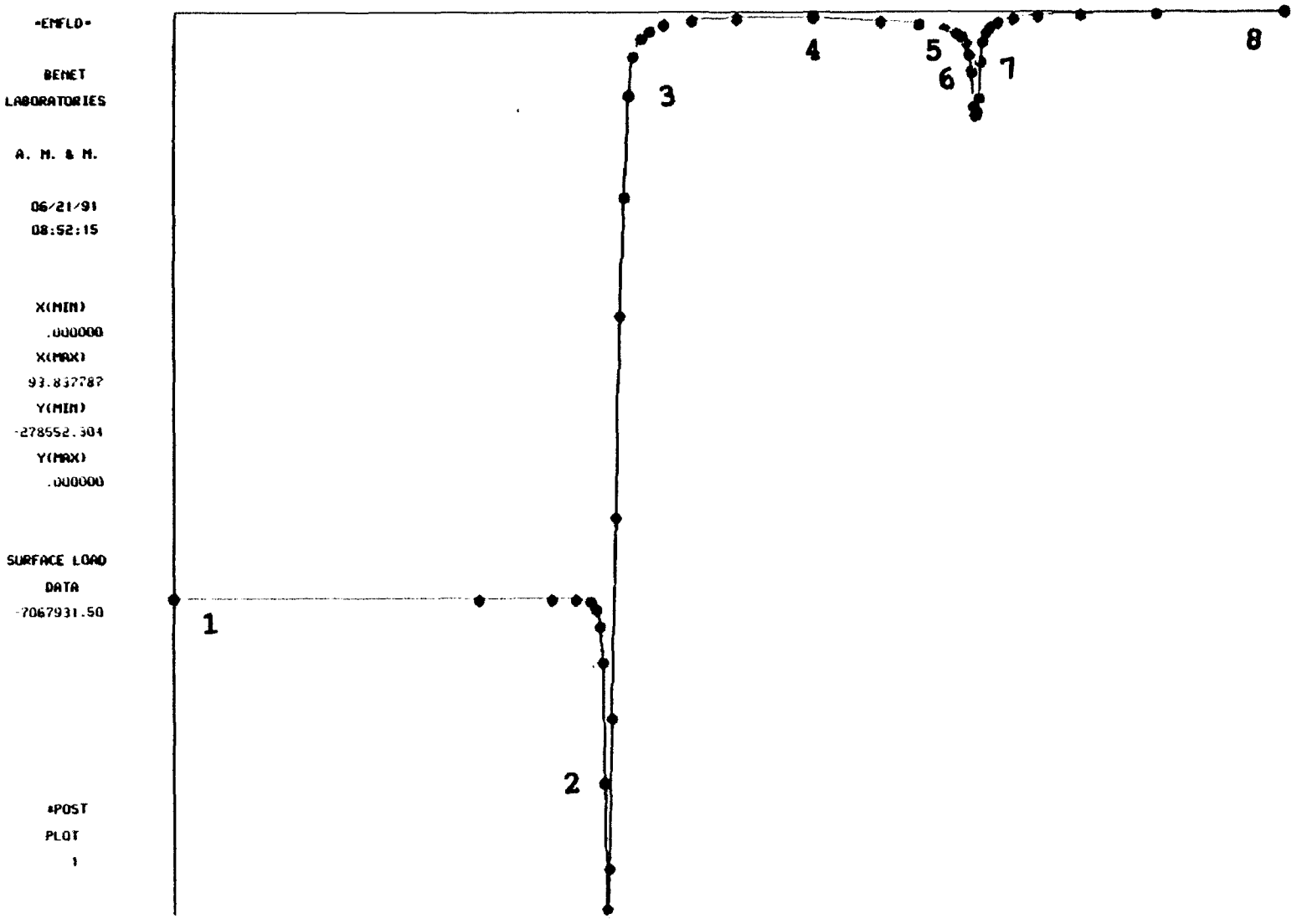


Figure 13. Consequential Lorentz load on the copper inner rail in post-process.

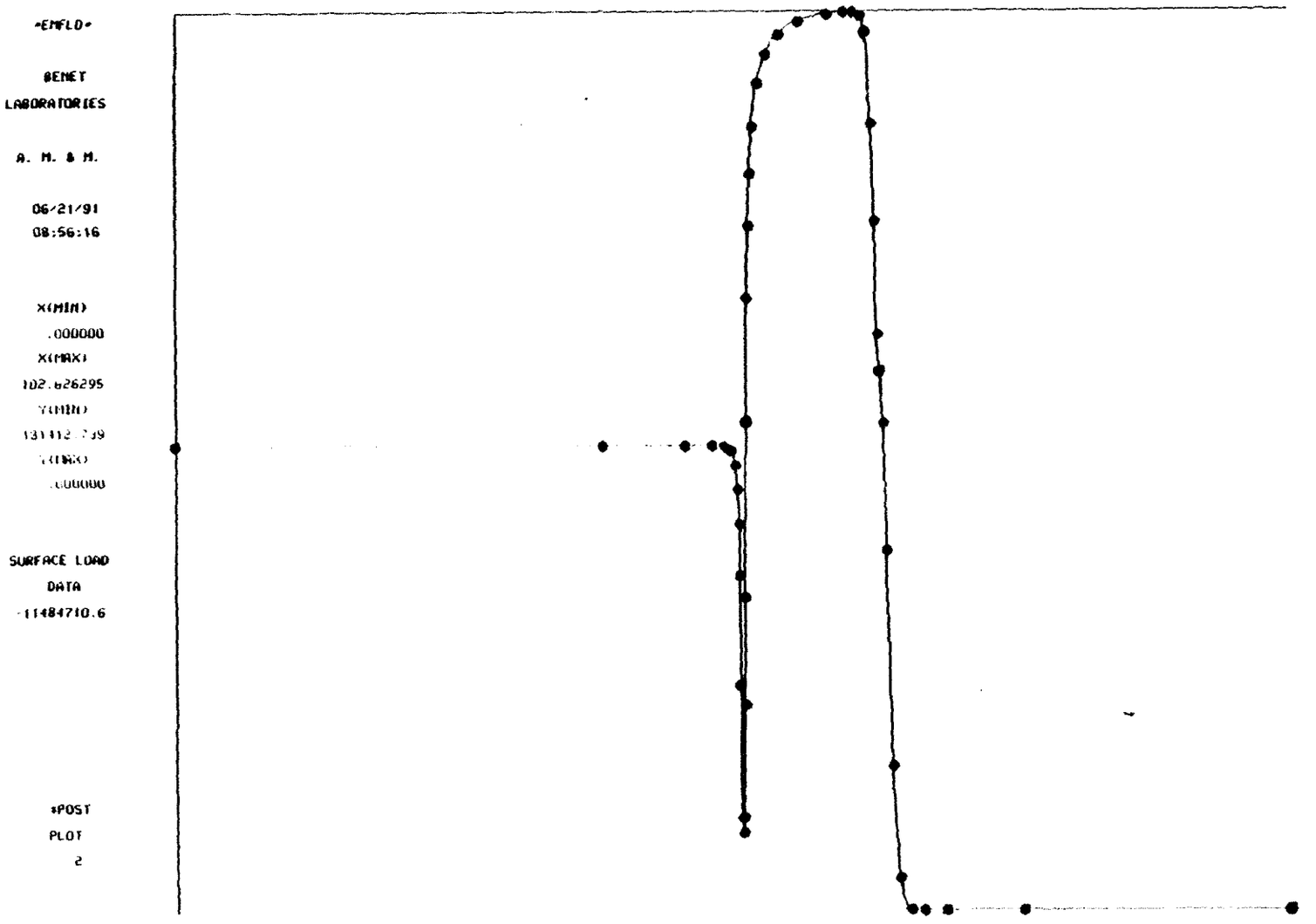


Figure 14. Consequential Lorentz load on the aluminum outer rail in post-process.

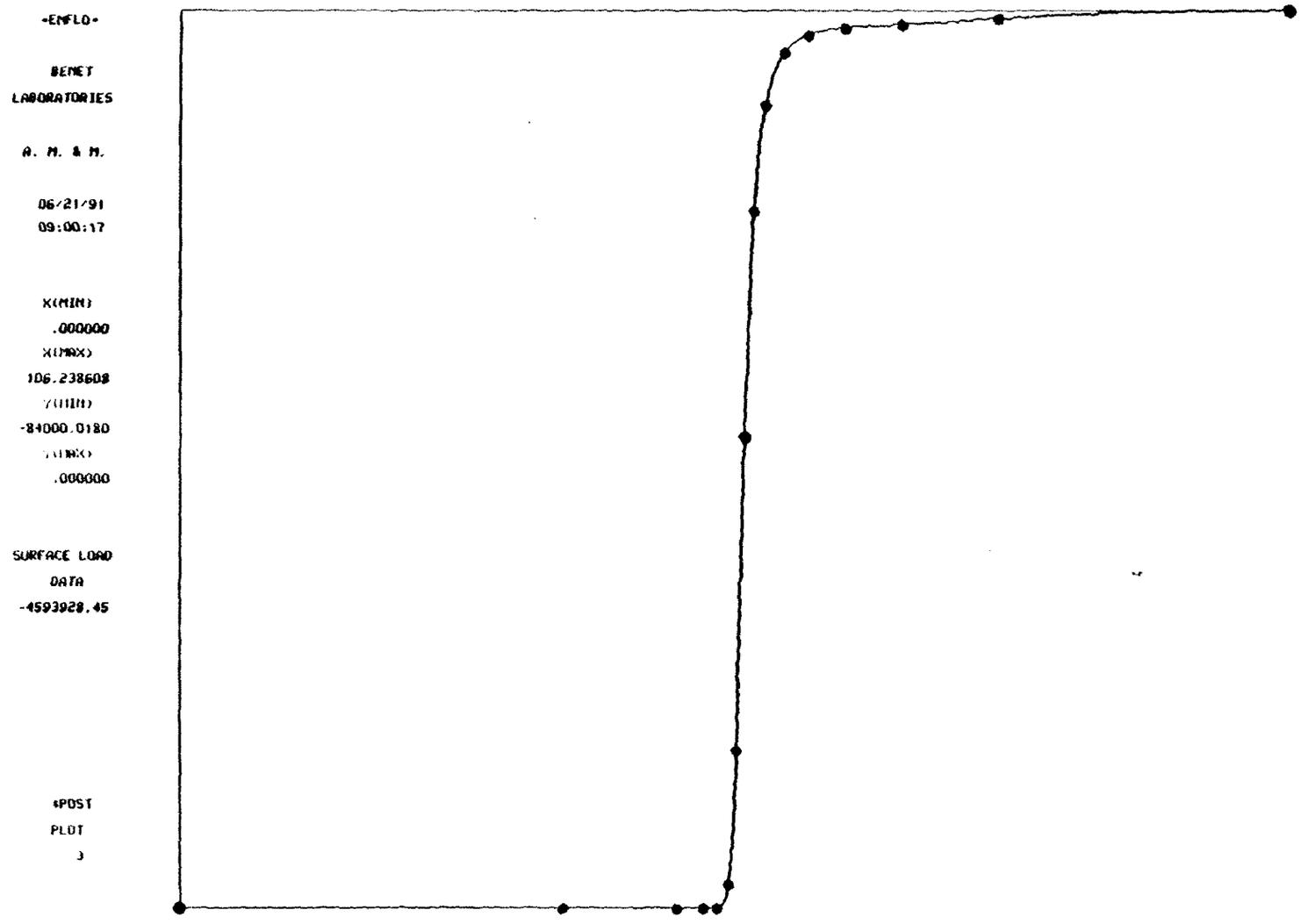


Figure 15. Consequential Lorentz load on the composite wrap in post-process.

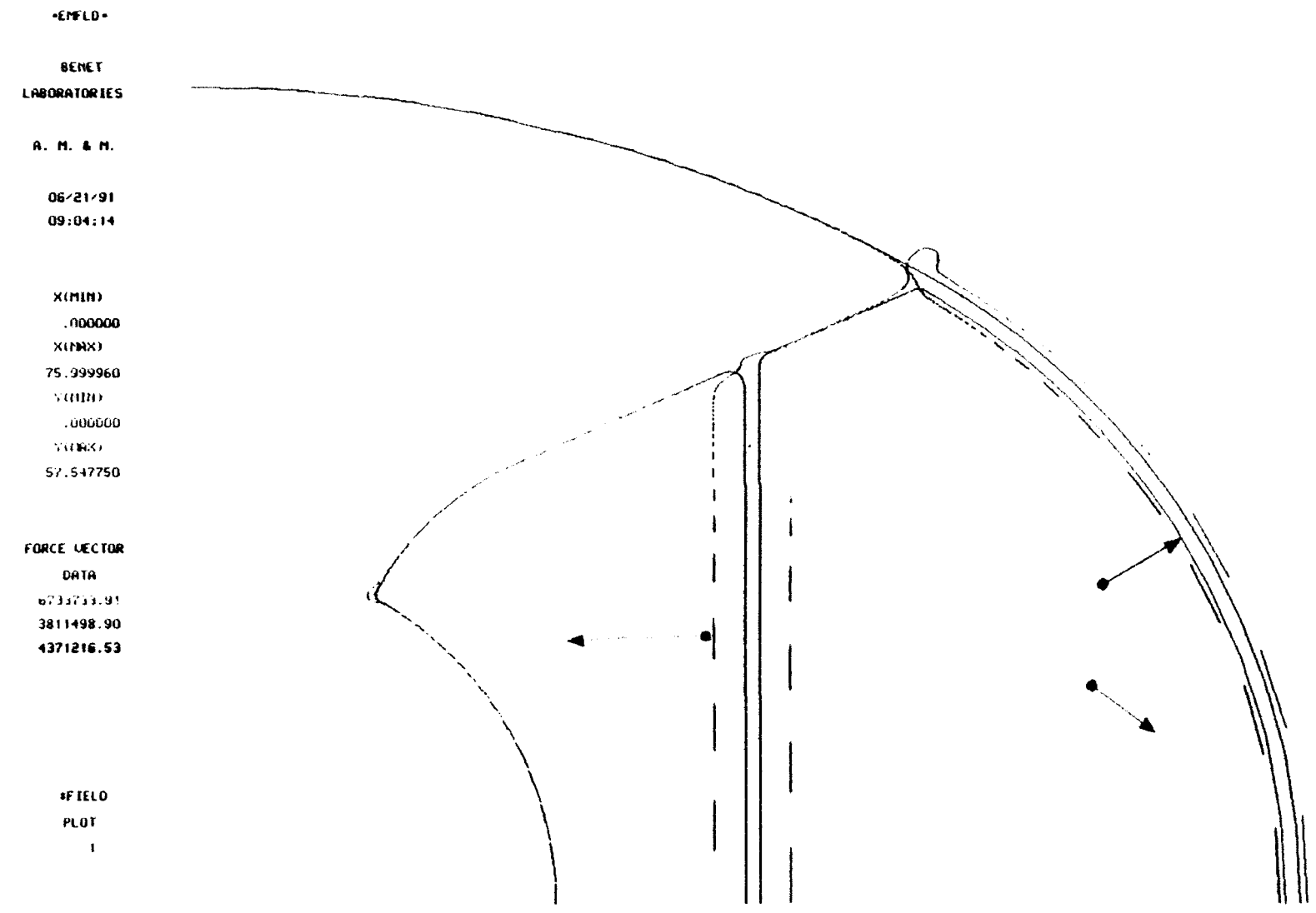


Figure 16. All surfaces with distributed loads and resultant forces.

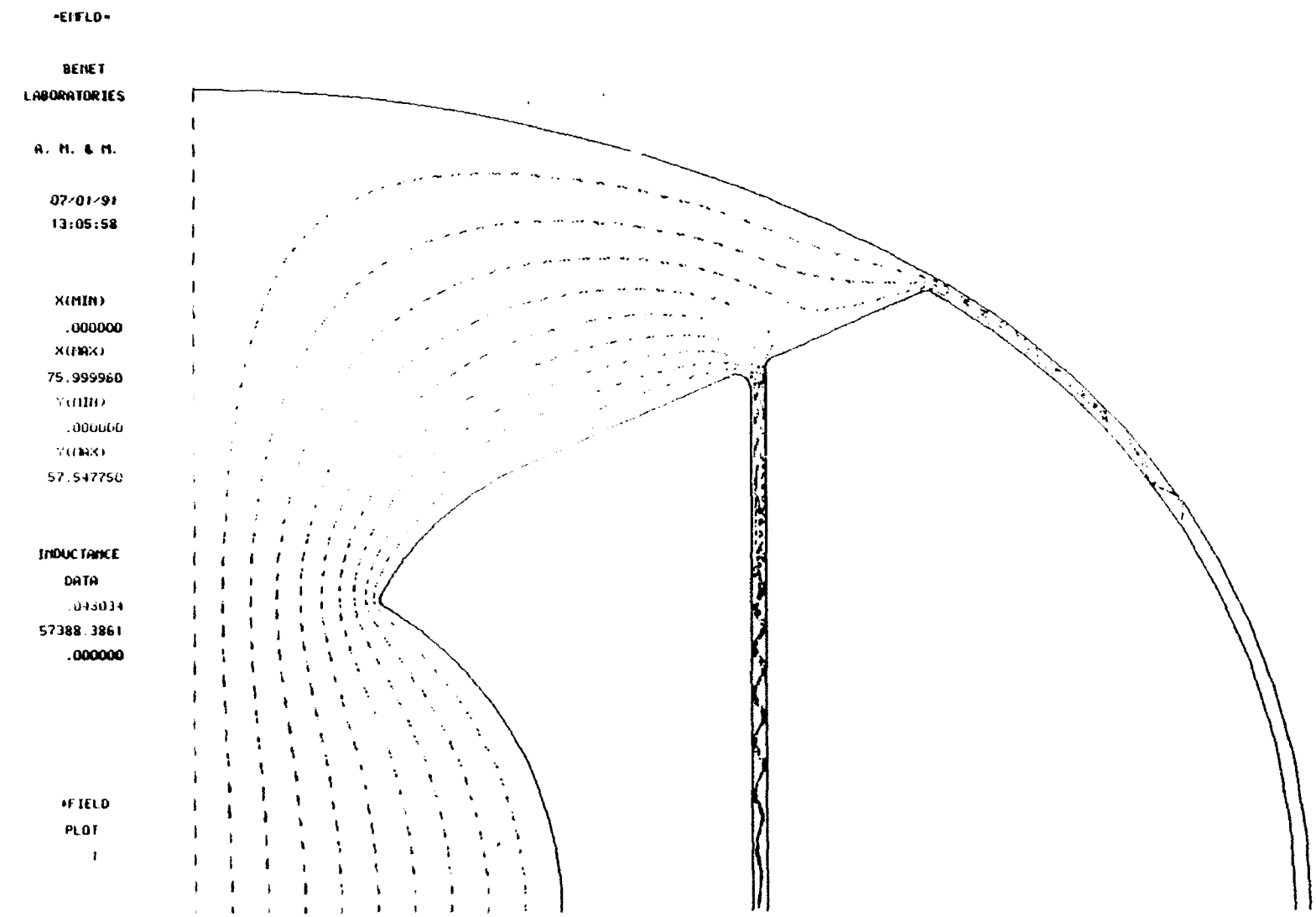


Figure 17. "*FIELD" plot of B-fields.

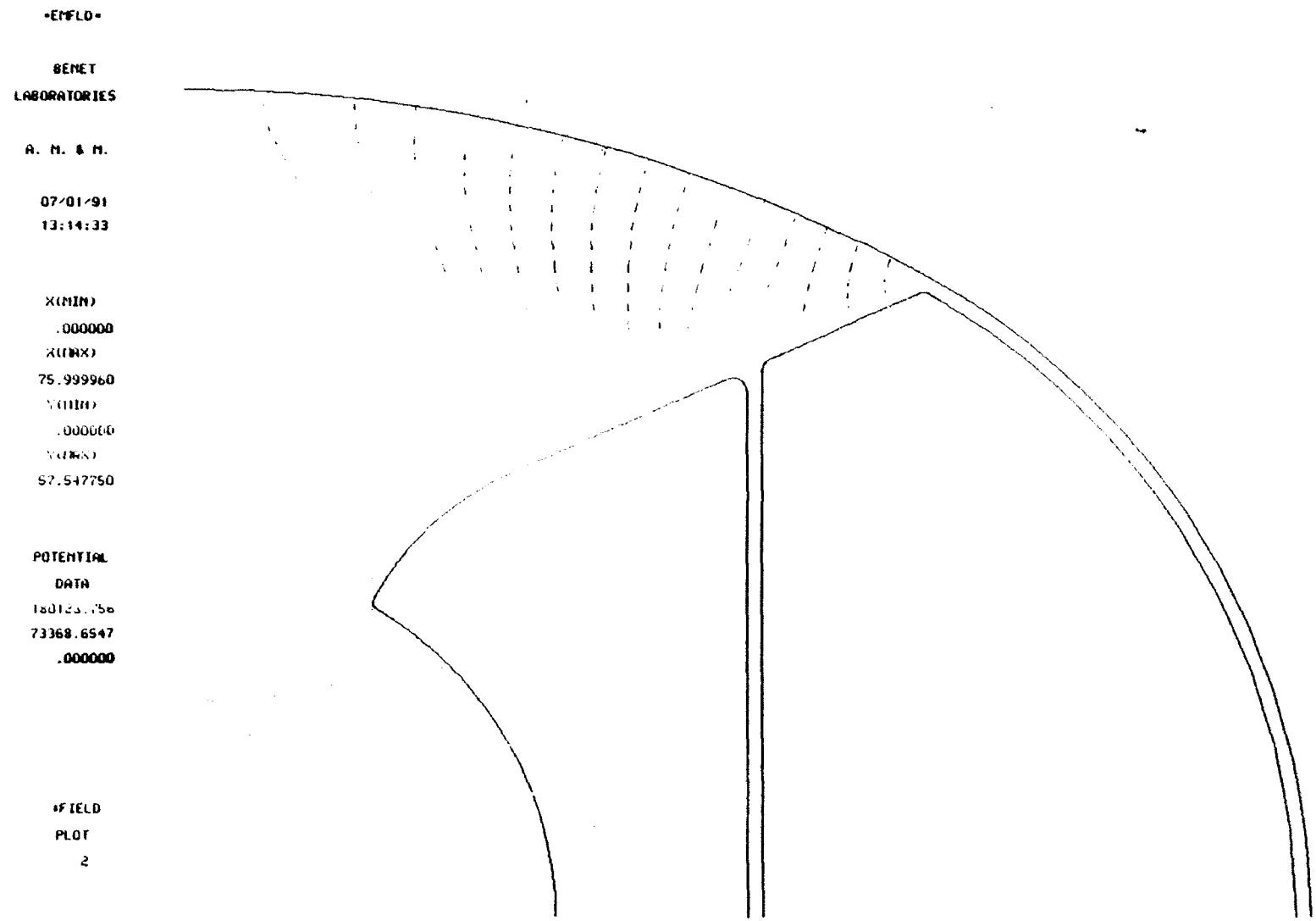


Figure 18. "*FIELD" plot of E-fields.

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