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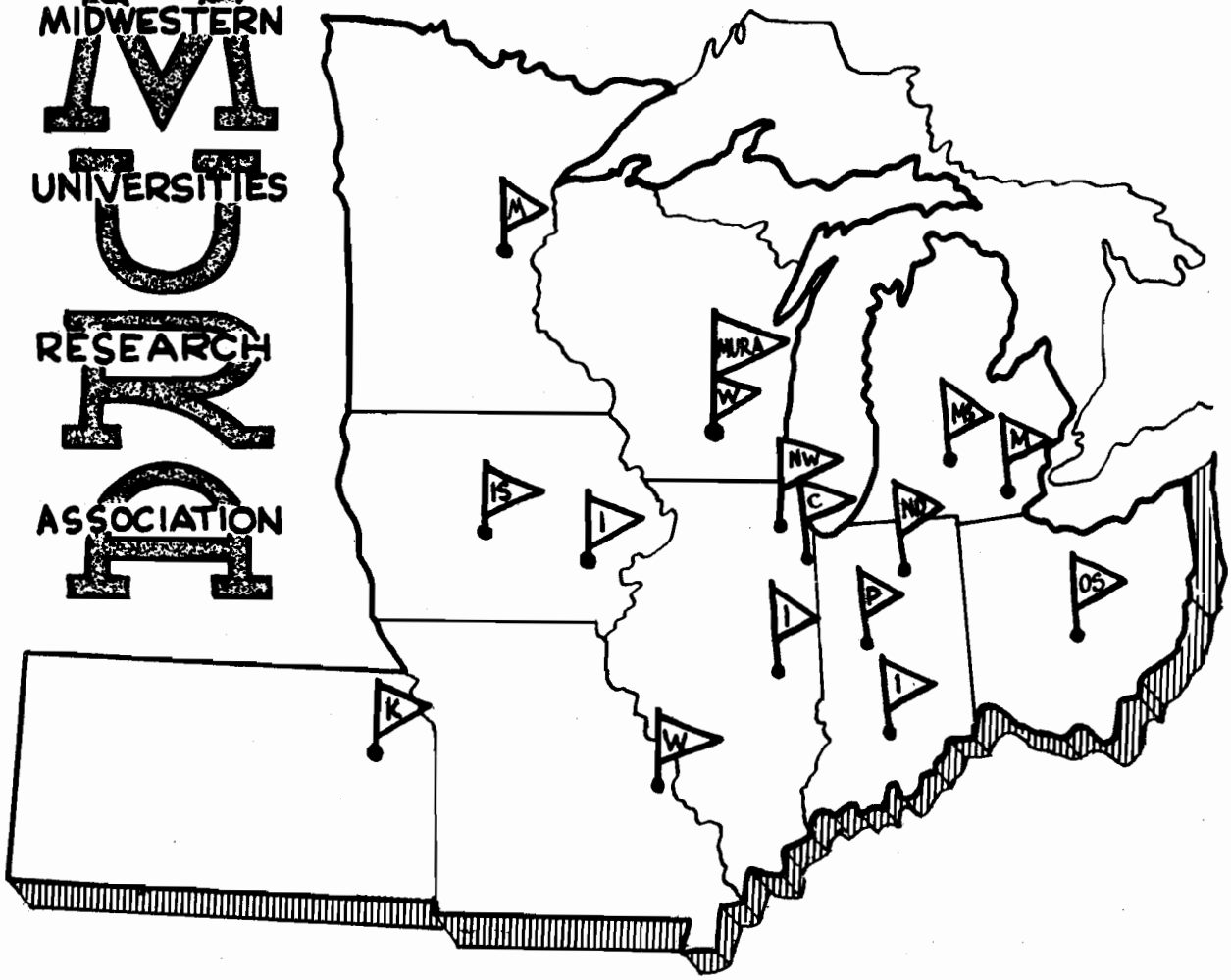

REPORT FOROCYL PROGRAM
(Program 13)
(Including FORMERGE (Program 50)
February-March, 1957

NUMBER 221
Internal
(IBM Program)

FOROCYL PROGRAM

(Program 13)

(Including FORMERGE (Program 50))

The following notes concerning the IBM FOROCYL program constitute an interim description of the means whereby the program is used. Details concerning the means whereby the programmin g was accomplished are not included.

Questions concerning programming and the mechanics of processing agenda, as well as subtile questions concerning use of the program, should be referred to Dr. J. N. Snyder, to whom we are indebted for bringing FOROCYL into operation.

FOROCYL PROGRAM (Program 13)

1. Object:

The FOROCYL program is a greatly expanded and augmented version of the ILLIAC SCAPOCYL program and is designed to solve the magnetostatic potential problem for a scaling accelerator in such a way as to permit subsequent orbit studies. The FOROCYL program differs from the SCAPOCYL in the following significant respects:

1. The scaled potential may be negative.
2. The unit-cell need not be square, but may be rectangular with a height-to-width ratio $r = \ell/h \leq 1$.
3. The program generates magnetic field components for storage on a grid, in contrast to the ILLIAC program in which the quantity Ω/η was stored (as half-words).
4. A FOURIER analysis of the scaled field-component $-h_z$ is provided at two levels in the mesh (at $j=o$ and $j = j_{FOURIER}$).

A provision is made for the introduction of prescribed current-values through a supplementary term in the basic algorism.

2. The Basic Equations:

The differential equation which is solved for the scaled magnetostatic potential $\Omega \equiv (1+x)^{-K'} V$ is [cf. MURA-LJL-8, Revised, 21 Feb. 1956]:

$$\Omega_{\xi\xi} + \left(1 + \frac{4\pi^2\eta^2}{(\frac{1}{w})^2 + N^2}\right)\Omega_{\eta\eta} - \frac{4\pi\frac{1}{w}}{(\frac{1}{w})^2 + N^2}\eta\,\Omega_{\xi\eta}$$
$$+ \frac{4\pi k'\frac{1}{w}}{(\frac{1}{w})^2 + N^2}\Omega_{\xi} - \frac{4\pi^2(2k'-1)}{(\frac{1}{w})^2 + N^2}\eta\,\Omega_{\eta} + \frac{4\pi^2 k'^2}{(\frac{1}{w})^2 + N^2}\Omega = 0,$$

where

$$k' = k+1, \quad \xi = \frac{1}{2\pi}\left[\frac{\ln(1+x)}{w} - N\theta\right], \quad \eta = \frac{\sqrt{(\frac{1}{w})^2 + N^2}}{2\pi}\,\frac{y}{1+x}.$$

The solution is obtained by relaxation, subject to the following boundary conditions: (i) Ω is an odd function of η (taken as zero on the median plane $\eta = 0$), (ii) prescribed boundary values (BV) shall be satisfied at mesh points along an upper bounding surface, and (iii) Ω is to be periodic in the internal $\Delta\xi = 1$. The algorisms employed are listed in MURA-205 (Int.) and the means of introducing current-values (CC) are discussed in MURA-211 (Int.).

3. Operation.

The coordinates of a mesh point are $\xi = ih = i/a$, $\eta = j\ell = j(rh) = j\, r/a$, with i & j integers. The symbol b is used to denote one plus various particular values of j to which reference is made on the agenda, i.e. the total number of rows (including j=0) in question. The program normally commences with a "Laplace phase", on a mesh of over-all dimensions characterized by a_M, b_M, in which a simple 4-point Laplace algorism is employed to give approximate values of Ω in the body of the mesh. The Laplace phase is followed by a "Main phase", again on a mesh of dimensions a_M, b_M The "Final phase" is carried out on a mesh of dimensions a_F, b_F and permits the use of the "cut-off" or "collapse" features of the program. With the "cut-off" provision, values of Ω obtained in the Main phase for the row $b = b_F$ become fixed boundary values for the Final phase; with the "collapse" feature mesh-cells with linear dimensions half as great may be employed in the Final phase, with interpolation employed to give the additional new boundary values required on the row $b = b_F$ (note that in this latter case b_F must be odd). Current values (CC) should not be present at points covered by the Final pass.

A sufficient degree of convergence to terminate each phase of the program is judged to be attained when the "residual" (change of the value of Ω in successive iterations) becomes as small as a specified ϵ at a particular point in the mesh ("check-point" method) or when the sum of the residuals throughout the mesh becomes as small as a specified ϵ ("residual method").

Upon completion of the iterations of the Final phase, the values of Ω are available and normalized field-components are computed. Fourier analyses of $-h_z$, for $j = j_{Fourier}$ and for $j = 0$, are also provided.

4. Permissible Dimensions:

The mesh dimensions in each phase should be such that a(b-1) + 2 x (Number of current values) $\leq$ 7600. For preparation of the field-cards, carrying the values of the three field components for each point of the mesh, $3ab_{\text{Print \& Punch Fields}}$ should not exceed 7311. For field print-outs which are trustworthy throughout and for correct Fourier analysis, one should, however, specify the relevant values of b to conform to the condition $3ab \leq 7200$ (i.e., $ab \leq 2400$).

5. Agenda:

The standard FOROCYL Agenda Form (copy attached) appears to require little explanation.

I.D. No.:	An integer identifying the run;
a_M, b_M:	Define mesh dimensions for Laplace and Main phase (note $b = j + 1$);
a_F, b_F:	Define mesh dimensions for Final phase;
b_{PRP}:	Print-outs of potentials are made up through $j = b_{PRP} - 1$;

b_{PRPUF}: Print-outs and punched cards are made for normalized field components up through $j = b_{PRPUF} - 1$;

i_L, j_L: Locate the check-point for testing convergence of Laplace phase;

i_M, j_M: Locate the check-point for testing convergence of Main phase;

i_F, j_F: Locate the check-point for testing convergence o. Final phase (Presumably if the check-point method is used, the check-points should be located within that part of mesh in question where the potentials are subject to appreciable modification by the iteration process);

$j_{Fourier}$: Defines the row on which $-h_z$ is subjected to Fourier analysis (in addition to $j = o$);

L, M, & N Marks: Permit by-passing of one or more phases of the program if -1000000 is entered in the proper box or boxes;

$\frac{1}{w} \times 10^{-4}$, $k' \times 10^{-4}$, $N \times 10^{-4}$: Represent scaled values of the machine-parameters $\frac{1}{w}$, $k' \equiv k + 1$, & N;

ϵ_L, ϵ_M, ϵ_F: Specify the quantities against which the residuals are tested to determine convergence of the Laplace, Main, & Final phases, respectively (normally ϵ_L would be comparatively large, since the Laplace operation gives only an approximate solution);

r: Denotes the ratio ℓ/h of the η- and ξ - dimensions of the unit cell ($r \leq 1$, and if $r = 1$ the value 0 or no value at all should be entered) -- values of r significantly less than .5 may lead to undesirably slow convergence, and exceedingly small values may give rise to "division hang-ups" during the course of computation;

B/A: Specifies a constant which will permit non-linear interpolation of boundary values, to provide within the mesh starting values for the iterative process

$$\left(\Omega_{interp.} = \Omega_{Boundary} \frac{j + (B/A) j^3}{j_B + (B/A) j_B^3} \right.$$

with $|B/A| < 1$ and taken equal to zero if no entry is made).

Boundary values and current values are entered on a separate sheet or sheets (copy attached). On these sheets N denotes the number of consecutive points for which the potential value is the same, so that the potential value need be entered only once for the group, followed by the i, j coordinates of the N points. The symbol I indicates that the boundary value in question will be interpolated down to the median-plane to provide starting values for the iteration. Current values, even if identical, must be entered individually. *A check in the BV or CC box indicates respectively whether a boundary value or a current value is specified. Because of the interpolation feature it is well to enter the boundary values by starting at the upper left-hand corner of the mesh and going across from left to right. Because of the periodic nature of the problem, values associated with the right-hand boundary of the mesh (which are perforce identical to those on the left hand boundary) are not entered -- thus in practice the coordinate index i takes on values o, 1, ...a-1 with i = a not being used since this corresponds to i = o. The values which are entered may be positive, negative, or zero, but must be less than .5 in absolute value (as must the resulting potentials elsewhere within the mesh).

6. Modifications:

In some problems it may be possible to hasten convergence by initially loading the mesh with the potential obtained previously in a similar problem, of the same mesh size, provided that the boundaries of the new problem do not lie outside those of the old problem. If this procedure is to be employed, the agendum should be marked at the top as follows:

MAKE INITIAL TOTAL MESH LOAD WITH FOROCYL Ω DECK #$\boxed{}$, specifying the I. D. No. of the run to be employed for this purpose. The boundary values for the new problem should then not be subjected to interpolation (omit the symbol I) and one would normally mark the Laplace phase as complete (L Mark = -1000000).

As a second elaboration on the normal procedure, it may prove of convenient flexibility in approximate trajectory studies of an orientation character to generate field components from a given solution of the potential problem, using modified values of the machine parameters k', $\frac{1}{w}$, & N. These new field-components, and the new parameters, would be used in the subsequent trajectory computations. For this purpose one marks the agendum at the top as follows: CHANGE k', $\frac{1}{w}$, & N on FOROCYL Ω DECK # $\boxed{}$.

The remainder of the agendum is filled out so as to be identical with that for the earlier problem, save for a new I. D. number and the modified values of the scaled machine parameters.

*Do not, however, enter a 1 to denote the presence of a single entry (see example on back of FOROCYL agenda sheets).

7. Permissible Range of Values for Parameters:

The machine parameters should generally lie within ranges similar to those suggested in MURA-LJL-8 (Revised), viz:

$$|k'| < 512 \qquad \frac{1}{2} < \frac{N}{2\pi} < 1024 \qquad \text{(or } N=0 \text{ is permissible)},$$

$$\frac{\sqrt{\left(\frac{1}{w}\right)^2 + N^2}}{2\pi} < 1024 \qquad \text{(but normally greater than } \frac{4}{2\pi}\text{)},$$

$$|\Omega| < \frac{1}{2}, \qquad \frac{\pi^2 \eta^2}{\left(\frac{1}{w}\right)^2 + N^2} < \frac{1}{2}, \qquad \frac{\pi^2}{\left(\frac{1}{w}\right)^2 + N^2} < 1.$$

Stand d Format for Output:

Integer (I) or Fraction (F) Designation								
I		0		Program No. (13)	Problem No.			
I		0		a_M	b_M	a_F	b_F	b_{prp}
F		0		$(1/w) \times 10^{-4}$	$k' \times 10^{-4}$	$N \times 10^{-4}$		
F		0		ϵ_L	ϵ_m	ϵ_f	r (0 means r=1)	B/A
I		0		Laplace Itern's	Main Itern's	Final Itern's	These are preceded by a minus sign if the phase in question is completed	
F		1000		$\langle \Omega_\eta \rangle_0 \times 10^{-3}$				
F		(aj+i)		Ω (aj+i)	Ω(aj+i+1)	Ω (aj+i+2)	Ω(aj+i+3)	Ω(aj+i+4)
I		Prog.#13		Problem No.				
I		a_M		b_M	a_F	b_F	b_{prp}	
I		$a_{for\ Fields}$		b_{prpuf}				
I		. . .		Laplace Itern's	Main Itern's	Final Itern's		
F		. . .		$(1/w) \times 10^{-4}$	$k' \times 10^{-4}$	$N \times 10^{-4}$		
F		. . .		ϵ_L	ϵ_m	ϵ_f	r	B/A
F		. . .		h	ℓ			
F		. . .		$2^{-7} \langle \Omega_\eta \rangle_0$				
F		$j_{Fourier}$		$10^{-2} \langle -h_z \rangle$ ←	at $j=j_{Fourier}$			
F		1 1 1 1 1		{Dec. Pt. Locator}	{Dec. Pt. Locator}	{Dec. Pt. Locator} ←	A number close to unity	
F		$[10^3 j_{Fourier} + \text{Harmonic}]$		Sine comp.	cos comp.	cumulative f		
F		$10^{-2} j_{Fourier}$		$(1/10)\ f_{rms}$				
F								
F								
F			Similar Fourier Analysis of $-h_z$ for j = o					
F								
F		1 1 1 1 1		{Dec. Pt. Locator}	{Dec. Pt. Locator}	{Dec. Pt. Locator} ←	A number close to unity.	
F		$[10^3 j+i]$		h_θ	h_r	h_z		

FOROCYL AGENDUM (PROGRAM 13)

PARA-METER	ADDRESS	VALUE	REMARKS	
I. D. No	8117			Integers
a_M	8118			
b_M	8119			
a_F	8120			
b_F	8121		if mesh collapsed, must be odd	
b_{PRP}	8122			
b_{PRPUF}	8123			
i_L	8124			
j_L	8125			
i_M	8126			
j_M	8127			
i_F	8128			
j_F	8129			
$j_{FOURIER}$	8130			
L Mark	8145			
M Mark	8146			
F Mark	8147			
$\frac{1}{\mu} \times 10^{-4}$	8135			Fractions
$k' \times 10^{-4}$	8136			
$N \times 10^{-4}$	8137			
ϵ_L	8138			
ϵ_M	8139			
ϵ_F	8140			
r	8141			
B/A	8142			

Sense Switch Settings

Check Point Method	SS2 Up	
Residual Method	SS2 Down	
Collapse Mesh (Cutoff if Up)	SS3 Down	
Punch Fields	SS4 Down	
Print Fields	SS5 Down	
Punch and Print Potentials	SS6 Down	

NOTE:

1. To omit any value, merely leave its line blank.
2. Please enter potentials and currents and their co-ordinates on standard data sheets. (See sample copy on reverse.) NO comments should appear on these sheets!
3. To mark Laplace, Main, or Final done, enter the value -1000000 in the proper box. Main cannot be omitted if Final is to be done.
4. Be sure to indicate positions of sense switches 2, 3, 4, 5, and 6 by a check in the appropriate box.
5. DOES THIS AGENDUM EMPLOY DATA CARDS FROM OTHER AGENDA? If so, check box vividly and attach a separate sheet describing changes in detail. ☐

SAMPLE FOROCYL DATA SHEET

	ID NUMBER 00					
N	VALUE	BV	CC	i	j	I
1	.04	✓				
				0	16	I
1	.049	✓				
				1	16	I
72	0	✓				
				0	1	
				1	1	
				2	1	
				⋮		
				71	1	
	00923765		✓			
				43	2	
	00923765		✓			
				44	3	
	00745621		✓			
				21	5	

FOROCYL DATA SHEET PAGE _____

ID NUMBER							ID NUMBER						
N	VALUE	BV	CC	i	j	I	N	VALUE	BV	CC	i	j	I

To be attached to the write-up of FOROCYL (PROGRAM 13)

The main phase of FOROCYL can be modified so that the new potential computed by the algorism described in the write-up is first multiplied by the quantity $(1 + \alpha)$ before being restored to the mesh.

In order to use this option the quantity $\left(\frac{1 + \alpha}{2}\right)$ must be entered as a fraction in location 8143 and the agenda must be marked "USE INCREASE Ω OVERWRITE."

In general, the use of this option will interfere with the standard convergence test.