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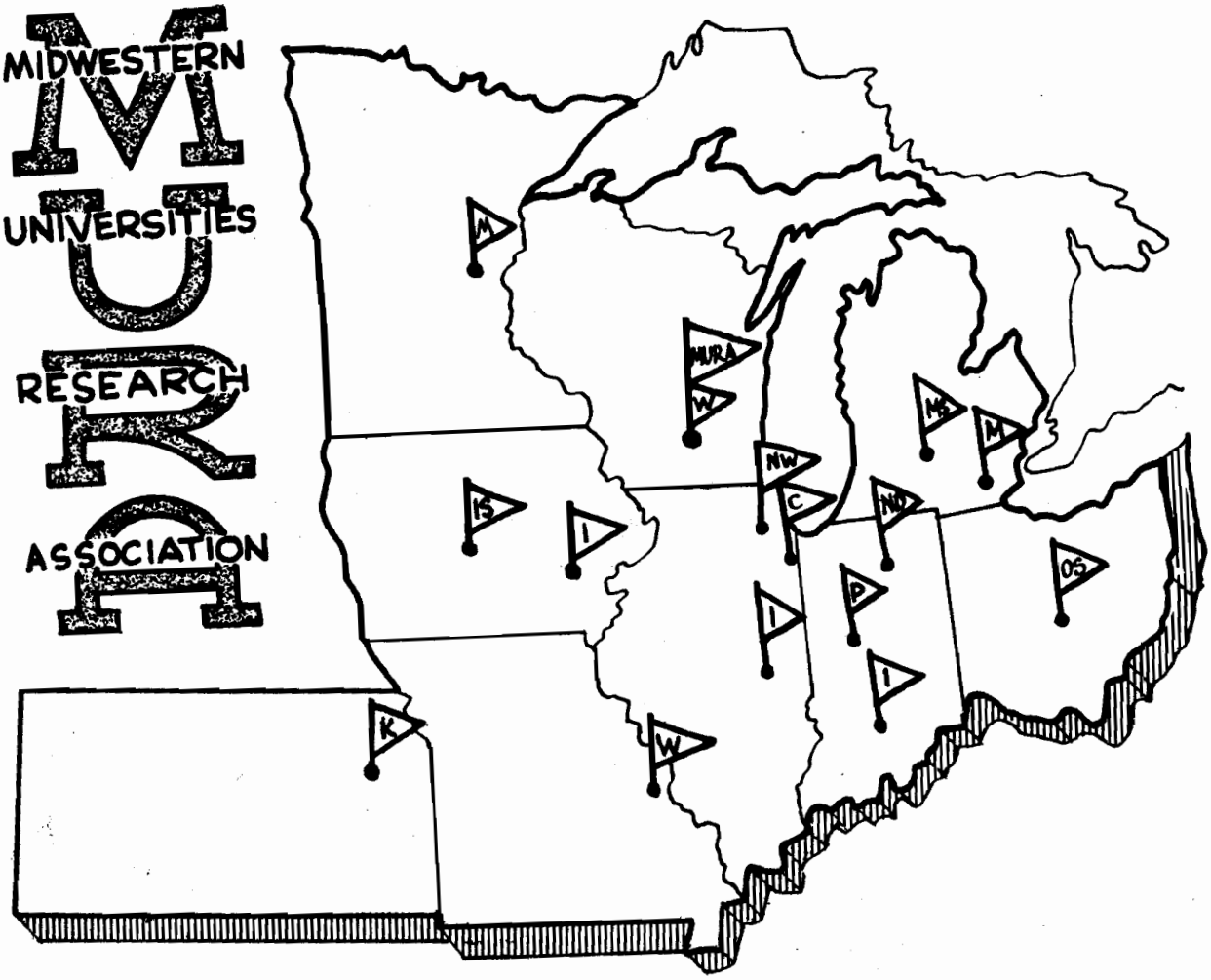

REPORT FORMESH PROGRAM
(Program 26)
February-March, 1957

NUMBER 222
Internal
(IBM Program)

FORMESH PROGRAM

(Program 26)

The following notes concerning the IBM FORMESH program constitute an interim description of the means whereby the program is used. Details concerning the means whereby the programming was accomplished are <u>not</u> 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 FORMESH into operation.

FORMESH PROGRAM (Program #26)

1. Purpose:

The FORMESH program is for the purpose of solving the differential equations for the trajectory of a particle in an FFAG accelerator, employing fields stored on a two-dimensional mesh. The stored field components would normally be provided by a run made with the FOROCYL program (quod vide), and a two-dimensional mesh suffices by virtue of the assumed scaling property of the accelerator (cf. MURA-LJL-8, Revised, dtd. 21 February 1956).

The present program differs from that used with the ILLIAC in that (i) scaled field-components, rather than Ω/η are now stored, and (ii) the dynamics problem is now formulated directly in terms of the variables x, y, & θ rather than by use of the less-familiar quantities S, T. & Θ. The variables x, y, θ are interpretable in terms of cylindrical coordinates r, z, ϕ ($\hat{e}_z \times \hat{e}_r = \hat{e}_\phi$) as $x = \frac{r-r_1}{r_1}$, $y = z/r_1$, $\theta = \phi - \frac{1}{\omega N} \ln (r_1/r_0)$, with the reference radius such that $e\langle -H_z|_{\substack{r=r_1 \\ z=0}} \rangle_{Av.} r_1 = p$.

2. The Equations which are solved:

The equations solved are those cited in MURA-LJL-8, Rev., p. 9:

$$dx/d\theta = \frac{(1+x)p_x}{\sqrt{1-p_x^2-p_y^2}}$$

$$dy/d\theta = \frac{(1+x)p_y}{\sqrt{1-p_x^2-p_y^2}}$$

$$dp_x/d\theta = \sqrt{1-p_x^2-p_y^2} + (1+x)\left[h_z - \frac{p_y}{\sqrt{1-p_x^2-p_y^2}} h_\theta\right]$$

$$dp_y/d\theta = (1+x)\left[\frac{p_x}{\sqrt{1-p_x^2-p_y^2}} h_\theta - h_r\right].$$

The normalized field-components are stored on a net in ξ, η space, where $\xi \equiv \frac{1}{2\pi}\left[\frac{\ln(1+x)}{\omega} - N\theta\right]$, $\eta \equiv \frac{1}{2\pi}\sqrt{\left(\frac{1}{\omega}\right)^2 + N^2}$ $\left(\frac{1}{1+x}\right)$

The field-values, h_r, h_z, & h_θ, which are required at each stage of the integration process are obtained from the stored values by interpolation. At present linear interpolation is used, save that within the first mesh above the median plane quadratic interpolation in η is used for the even function h_z.

3. The agenda:

The standard form for a FORMESH agendum (sample attached) requires little explanation. The identification number of the FOROCYL program from which the fields are obtained is specified in the box provided at the top of the sheet.

I.D.:	An integer denoting the run number;
N_e:	The number of Runge-Kutta steps to be made for completion of the problem;
N_p:	The number of R-K steps per print-out;
n_{RK}:	The number of R-K steps per sector [i.e., in the interval $\Delta\theta = 2\pi/N$]; *
m:	When N = 0 the R-K interval h must be specified by the aid of the integer m, where m is the largest integer (not greater than 8) such that $2^m h < 1$;
$(c_p)_o$:	The initial setting of the print counter;
p_{xo}, p_{yo}, x_o, y_o, $\left(\frac{N\theta}{2\pi}\right)_o$	Initial values of the variables (if a systematic series of related runs is involved, staple together the main and subsequent agenda sheets which describe the runs to be made);

x_{max}: Overflow limit for $|x|$ ($\leq .5$);

$\frac{1}{64} p_{x_{max}} = \frac{1}{64} p_{y_{max}}$: <u>Scaled</u> overflow limit for the conjugate momenta (it is advisable to specify this quantity sufficiently low that no division hang-ups result from the denominator $\sqrt{1 - p_x^2 - p_y^2}$ and probably $\frac{1}{64} p_{max}$ should not exceed .009 or .01 in virtually all cases);

$2^m h$: When N = 0, this quantity is used to express the R-K interval h (scaled up by 2^m).

The overflow limit for $|y|$ is normally given by the height of the mesh; at address 7626, however, an entry b_{phony} (an integer $\leq b_{PRPUF}$) may be made, such that an overflow in y is considered to have taken place if $|\eta| \geq (b_{phony} - 1)\, \ell$.

*A necessary inequality, which may raise the permissible lower limit for N if η_{RK} is unfortunately chosen (when $N \neq 0$), is $\frac{2\pi}{N} \frac{2^M}{\eta_{RK}} < 1$, where M is defined by $\frac{1}{2} \leq \frac{2^M}{\eta_{RK}} < 1$.

4. Optional Embellishments:

The "Search" feature may be elected, to terminate a series of runs after the first run which does not overflow in N_e steps, by checking the appropriate box.

If desired, so-called invariants may be computed and printed at $N\theta = 0$ (mod. 2π) and, using seperately-specified coefficients, elsewhere.

The "invariants" are given as the square root of quadratic forms

$$K_x \equiv \sqrt{\xi_x (x - x_f)^2 + \eta_x (x - x_f)(p_x - p_{x_f}) + \zeta_x (p_x - p_{x_f})^2}$$

cg. MURA-206 : $$K_y \equiv \sqrt{\xi_y (y - y_f)^2 + \eta_y (y - y_f)(p_y - p_{y_f}) + \zeta_y (p_y - p_y)^2}$$

To obtain these quantities the following fractional (decimal) data are specified on a FORMESH INVARIANTS agendum sheet attached to the standard agendum:

$\xi_x/10$
$\xi_y/10$
$\eta_x/10$
$\eta_y/10$
$\zeta_x/10$
$\zeta_y/10$
x_f y_f p_{x_f} p_{y_f}

for use at $N\theta = 0$ (mod, 2π), followed by a second set of such quantities (designated by primes) for use at other values of θ.

5. Format of Output:

Integer or Fraction Designation						
I	0	Program 26	Program 26	Program 26	Program 26	Program 26
I	00013	1D of Forocyl Mesh				
I	0	a	b			
F	0	h	ℓ			
F	0	10^{-4} (1/w)	10^{-4} k'	10^{-4} N		
The foregoing information appears only at the start of a series of FORMESH runs with the same FOROCYL deck.						
F	I.D.No.					
F	Print No.	p_x	p_y	x	y	$N\theta/2\pi$(mod.1)
F	Overflow Designation (if overflow occurs)*					

* 1: $|x| > x_{max}$

2: $|y| > y_{max}$

3: $|p_x| > p_{max}$

4: $|p_y| > p_{max}$

5: $p_x^2 + p_y^2 > 1.$

x and y Invariants, if called for, appear in the p_x and p_y columns, respectively, above the line which gives the values from which they are computed. The invariants are not, however, computed for the initial conditions.

FORMESH AGENDUM (PROGRAMME 26)

EMPLOYS FIELDS FROM FOROCYL NO.		or FORMERGE NO.	

Parameter	Address	Value	Remarks	
I. D.	7597			Integers
N_e	7598			
N_p	7599			
n_{RK}	7600			
m	7687		Needed only if $N \equiv 0$	
$(C_p)_o$	7588		(0)	
b_{PHONY}	7626			
p_{x_o}	7591			Fractions
p_{y_o}	7592			
x_o	7593			
y_o	7594			
$(N\theta/2\pi)_o$	7580		(0)	
x_{max}	7595		(1/2)	
$p_{x_{max}} = p_{y_{max}}$	7596		(1×2^{-6}) (SCALE BY 2^{-6})	
$2^m h$	7624		Needed only if $N \equiv 0$	
HUMAN ID	7601		Not for MUMBLEBUMPS	

"SEARCH" (Stop after first run that is stable through N_e steps) SS6 Up	
Is this the first of a series of runs?	
Is this a subsequent run in a series, referring to previous agenda?	

NOTES:

1. To omit any of the above parameters, simply leave its line blank.
2. The values given above in the remarks column are those which are entered if nothing is specified for them. Consequently, parameters having those values need not be entered by the data card. However, if some other value is desired, merely indicate it in its place.
3. A parameter once changed remains so in a series of runs, except that $(C_p)_o$ and $(N\theta/2\pi)_o$ if set different from 0 must be so reset on each such run.
4. To submit a series of problems which differ only slightly, indicate "series" in the above box, and fill out one of these sheets for each separate problem. In this case it is not necessary to enter values other than those which differ from the preceding problem. Please staple the whole series securely together to form one entity.
5. If a series forms a "search" in the sense that the series is to be stopped after the first run which is stable through N_e steps, please check the box above, otherwise write nothing.
6. A box is provided for the mesh number.

Notes on use of O/W to permit change of $\frac{1}{w}$, k' and N in computing fields from Forocyl potentials:

Construct new agendum as follows:

1. Mark both L & F done $\left\{\begin{array}{l}\text{L mark} = -1000000 \\ \text{F mark} = -1000000\end{array}\right]$

2. Set a_m, b_m equal to the values of a, b for the old run in the phase in which the old problem was operating when it was terminated. [Thus a_m, b_m are as on the old agendum unless the old problem had entered the final phase (whether it made no iterations, some iterations, or completed the final phase) in which case a_m, b_m are set equal to the old values of a_F, b_F. If F had been marked done, however, the old values of a_m, b_m are used.]

3. Use a new I. D. number.

4. Enter the new values of $\frac{1}{w}$, k', & N (scaled by 10^{-4}).

5. Other entries bearing subscripts L or F may be omitted, but it is considered best to keep i_M, j_M, ϵ_M as before and to set $\sigma_{PRP} = \sigma_M$. σ_{PRPUF} may be set as desired, provided it is compatible with the values of Ω which are available and with the number of field-components which can be obtained. Similarly $j_{FOURIER}$ may be set as desired to analyze the fields on any level at which they will be available.

The Snyder story, as told to

L. J. Laslett

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			
$\frac{1}{w} \times 10^{-4}$	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. ☐

CHANGE k' 1/w & N ON FOROCYL Ω DECK NUMBER [ ]

FOROCYL AGENDUM (PROGRAM 13)

PARAMETER	ADDRESS	VALUE	REMARKS	
I. D. No	8117	Enter new I.D. No		Integers
a_M	8118	set equal to a, b for the old run in the phase in which it was operating when terminated		
b_M	8119			
a_F	8120	NOT NEEDED		
b_F	8121	NOT NEEDED	if mesh collapsed, must be odd	
b_{PRP}	8122	NEW b_{PRP}		
b_{PRPUF}	8123	As desired, consistent with limitations		
i_L	8124	NOT NEEDED		
j_L	8125	NOT NEEDED		
i_M	8126	OLD VALUE		
j_M	8127	OLD VALUE		
i_F	8128	NOT NEEDED		
j_F	8129	NOT NEEDED		
$j_{FOURIER}$	8130	As desired, consistent with limitations		
L Mark	8145	−1000000		
M Mark	8146	OMIT		
F Mark	8147	−1000000		
$\frac{1}{w} \times 10^{-4}$	8135	set in the new values		Fractions
$k' \times 10^{-4}$	8136			
$N \times 10^{-4}$	8137			
ϵ_L	8138	NOT NEEDED		
ϵ_M	8139	OLD VALUE		
ϵ_F	8140	NOT NEEDED		
r	8141	OLD VALUE		
B/A	8142	NOT NEEDED		

Sense Switch Settings

Check Point Method	SS2 Up	CHECK
Residual Method	SS2 Down	
Collapse Mesh (Cutoff if Up)	SS3 Down	DON'T CHECK
Punch Fields	SS4 Down	as desired
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. [ ] CHECK VIVIDLY

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	

October 22, 1958

MEMO: To Computer Users

RE: FORMESH P-JUMPS

FROM: Robert Morse

This program represents a slight addition to the standard FORMESH program in that it allows the user to effect discontinuous changes in the value of p_x at arbitrary points during the course of a run.

The program will accept from 1 to 100 integers N_i which represent the number of Runge-Kutta steps between two successive insertions of a change in p_x. It will also accept from 1 to 100 fractions Δp_{x_i}, which represent the changes in p_x (positive or negative) which it is desired to produce. The change in momentum will be entered <u>after</u> a printing step, assuming that one has been scheduled for the particular iteration in question.

Whether or not the full quota of 100 N_i, Δp_{x_i} pairs is used, it is necessary to inform the program of the number used by inserting $N_{i+1} = 0$. If this is done, all following values of N, and all values of Δp_x from $\Delta p_{x_{i+1}}$ onward, will be ignored. Even if all 100 pairs are used, it is still necessary to enter $N_{101} = 0$.

All values of N and Δp_x, including zero values, are held from run to run, unless changed by the user.

This program requires a smaller mesh than FORMESH. In particular,

$$3\,ab \leq 7162$$

Agendum preparation: Use a standard FORMESH agendum sheet. Vividly inscribe on the top: "USE P-JUMPS OVERWRITE." Write "(over)" on the bottom and put the new data on the reverse side. The values for N should be written under the heading "Add to integers," and should have the addresses 7286, 7287, ... The values for Δp_x should have the heading "Add to fractions," and should be entered with addresses 7186, 7187, ...