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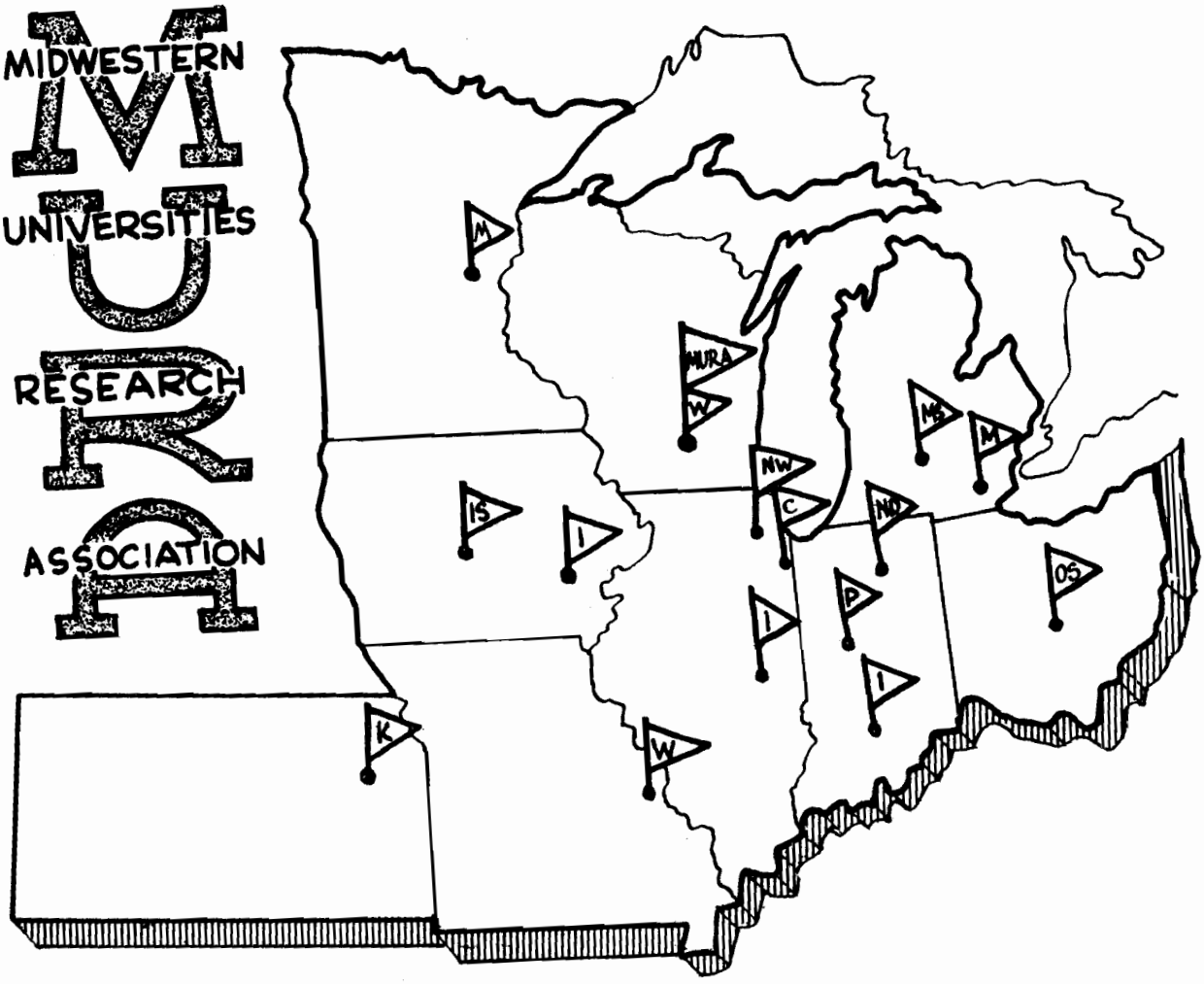

REPORT SPIRIT
(Program 245)
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SPIRIT
(Program 245)
Elizabeth Z. Chapman

SPIRIT is a program for the IBM 704[1] to solve the equations of motion describing the betatron oscillations of particles in a fixed field alternating gradient accelerator. These equations are copied below for convenience.

$$\frac{dx}{d\theta} = \frac{(a + x)\, p_x}{\sqrt{P^2 - p_x^2 - p_y^2}}$$

$$\frac{dy}{d\theta} = \frac{(a + x)\, p_y}{\sqrt{P^2 - p_x^2 - p_y^2}}$$

$$\frac{dp_x}{d\theta} = \sqrt{P^2 - p_x^2 - p_y^2} + \lambda (a + x) \left[\frac{B_y}{B_o} - \frac{p_y}{\sqrt{P^2 - p_x^2 - p_y^2}} \frac{B_\theta}{B_o} \right] \quad (1)$$

$$\frac{dp_y}{d\theta} = \lambda (a + x) \left[\frac{p_x}{\sqrt{P^2 - p_x^2 - p_y^2}} \frac{B_\theta}{B_o} - \frac{B_x}{B_o} \right]$$

1. 8192 words of core storage, 1 drum unit (for the overwrite feature) and 1 tape unit for the resumption procedure.

This program was suggested by a memorandum from Phil Morton to Elizabeth Z. Chapman dated April 16, 1959.

EQUATIONS

One specifies the magnetic field components, B_x, B_y, and B_θ by specifying B_y on the median plane in the form:

$$\left(\frac{B_y}{B_o}\right)_{y=0} = -(a+x)^k \left[\sum_{m=0}^{\infty} (g_m \cos m u \phi + f_m \sin m u \phi)\right]\left[\sum_{n=0}^{\infty} (a_n \cos n q N'\theta + b_n \sin n q N'\theta)\right] \tag{2}$$

where $\phi = N'\theta - \frac{1}{uw} \ln (a+x)$

The fields written in the same form used by Powell[2] are:

$$\frac{B_x}{B_o} = (a+x)^k \sum_{i=1}^{\infty} \sum_{\substack{m=0 \\ n=-\infty}}^{\infty} (\alpha_{i,m,n}\, c_{m,n} + \beta_{i,m,n}\, s_{m,n}) \frac{1}{(2i-1)!} \left(\frac{y}{a+x}\right)^{2i-1}$$

$$\frac{B_y}{B_o} = -(a+x)^k \sum_{i=0}^{\infty} \sum_{\substack{m=0 \\ n=-\infty}}^{\infty} (\mu_{i,m,n}\, c_{m,n} + \nu_{i,m,n}\, s_{m,n}) \frac{1}{(2i)!} \left(\frac{y}{a+x}\right)^{2i} \tag{3}$$

$$\frac{B_\theta}{B_o} = (a+x)^k \sum_{i=1}^{\infty} \sum_{\substack{m=0 \\ n=-\infty}}^{\infty} (\gamma_{i,m,n}\, c_{m,n} + \delta_{i,m,n}\, s_{m,n}) \frac{1}{(2i-1)!} \left(\frac{y}{a+x}\right)^{2i-1}$$

$$\begin{aligned} \text{where } c_{m,n} &= \cos(m u \phi + n q N'\theta) \\ s_{m,n} &= \sin(m u \phi + n q N'\theta) \\ \phi &= N'\theta - \frac{1}{uw} \ln (a+x) \end{aligned} \tag{4}$$

These expressions for B_x, B_y, and B_θ are truncated by specifying i_{max}, m_{max}

2. J. L. Powell, MURA Report No. 80, August 16, 1956.

and n_{max}. All terms in the series with $i > i_{max}$ are neglected.

The user of this program specifies the g_m, f_m $(m = 0, 1, 2, \ldots, m_{max} \leq 8)$, a_n, b_n $(n = 0, \pm 1, \pm 2, \ldots, \pm n_{max} \leq 11)$, k, u, q, N', $\frac{1}{w}$. The SPIRIT program then computes the $\gamma_{i,m,n}$, $\delta_{i,m,n}$, $\alpha_{i,m,n}$, $\beta_{i,m,n}$, $\mu_{i,m,n}$ and $\nu_{i,m,n}$ from the following recursion relations:

$$\gamma_{i+1,m,n} = -(mu + nq)\, N' \nu_{i,m,n}$$
$$\delta_{i+1,m,n} = (mu + nq)\, N' \mu_{i,m,n} \tag{5}$$

$$\alpha_{i+1,m,n} = \frac{m}{w} \nu_{i,m,n} - (k - 2i)\, \mu_{i,m,n}$$
$$\beta_{i+1,m,n} = -\frac{m}{w} \mu_{i,m,n} - (k - 2i)\, \nu_{i,m,n} \tag{6}$$

$$\mu_{i+1,m,n} = \left[-(k-2i)^2 + \frac{m^2}{w^2} + (mu + nq)^2 N'^2\right] \mu_{i,m,n} + \left[2\,\frac{m}{w}\,(k-2i)\right] \nu_{i,m,n}$$
$$\nu_{i+1,m,n} = \left[-(k-2i)^2 + \frac{m^2}{w^2} + (mu + nq)^2 N'^2\right] \nu_{i,m,n} - \left[2\,\frac{m}{w}\,(k-2i)\right] \mu_{i,m,n} \tag{7}$$

where

$$\mu_{o,m,n\ (n \neq 0)} = \frac{1}{2}\left[g_m a_n - (\mathrm{sgn}\, n)\, f_m b_n\right]$$
$$\nu_{o,m,n\ (n \neq 0)} = \frac{1}{2}\left[f_m a_n + (\mathrm{sgn}\, n)\, g_m b_n\right] \tag{8}$$
$$\mu_{o,m,o} = g_m a_o$$
$$\nu_{o,m,o} = f_m a_o$$

and

$$\alpha_{o,m,n} = \beta_{o,m,n} = \gamma_{o,m,n} = \delta_{o,m,n} = 0.$$

The section of the program which does this computation is later erased. Therefore, it is impossible to submit series agenda in which g_m, f_m, a_n, b_n, k, $\frac{1}{w}$, u, q, N' or n_{RK} change. At each integration step the program computes the fields from equations (3) which occur in the equations of motion.

OUTPUT

All input parameters are printed at the start of every run. The initial print format is shown on page 5.

Every N_P integration steps, one line is printed. p_x, p_y, x, y, $\frac{N\theta}{2\pi}$ is printed in columns one through five respectively, with an index at the left of each line which counts the lines starting with the first line numbered zero. The SPIRIT program operates in the floating point mode; therefore all numbers other than integers will be printed in floating point form. A floating point number is printed as an 8 digit decimal fraction and a signed two digit exponent. The decimal point is understood to be between the first and second decimal digits, counting from left to right. If the decimal fraction is positive the sign is omitted and if the fraction is negative the sign is printed. If the floating point number is identically zero, then an eleven digit zero is printed. For example, .03124 is printed as 31240000- 2 and 0 as 00000000000.

INITIAL PRINT FORMAT

	Line Label	Col. 1	Col. 2	Col. 3	Col. 4	Col. 5
I*	00000	Program #	Human ID	Run ID		
I	00001	N_P	N_e			
I	00002	i_{max}	m_{max}	n_{max}		
I	00003	$(C_P)_o$	$(C_e)_o$	N_{plot}		
	00004	N'	n_{RK}			
	00005	$1/w$	k	u	q	
	00006	p_{x_o}	p_{y_o}	x_o	y_o	$\left(\frac{N\theta}{2\pi}\right)_o$
	00007	$p_{x_{max}} = p_{y_{max}}$	x_{max}	y_{max}		
	00008	P	a	λ		
	Space					
	0000m#	f_m	g_m			
	Space					
	1000n**	a_n	b_n			

* I indicates a line of integers. All other lines contain floating point numbers.

\# $m = 0, 1, 2, \ldots, m_{max}$. Any line which would contain two numbers identically zero is not printed. The omission is indicated as a line space. Successive lines of zeroes are indicated by only a single line space, rather than a separate line space for each line omitted.

** $n = 0, 1, 2, \ldots, n_{max}$.

When a problem comes to the end ($C_e = N_e$), the word END is printed below the last line of the output at the right side of the page.

If $N_{plot} = 1$ the program plots x vs. p_x at the end of the run. For $N_{plot} = 2$, y vs. p_y is plotted.

When p_x, p_y, x or y exceed their bounds, as set by $p_{x_{max}} = p_{y_{max}}$, x_{max} and y_{max}, computations on a run (problem) are stopped and an identifying symbol is printed in the line numbering column before proceeding to the next run. These symbols are:

00001	p_x overflow,
00002	p_y overflow,
00003	x overflow,
00004	y overflow.

If at some time during the computations $\sqrt{P^2 - p_x^2 - p_y^2}$ should become negative or zero, the program prints the line

SQUARE ROOT P2 - PX2 - PY2 NEGATIVE

and proceeds to the next run.

INPUT

A standard agendum form is included on pages 8 and 9. Two types of numbers appear on it: fixed point integers (first ten lines) and floating point numbers. Integers are written in the usual fashion; leading zeroes may be omitted, and $2^{35}-1$ is the largest integer allowed. The value to be entered as a floating point number must first be expressed in the form

$$\text{Value} = n \times 10^{exp}$$

where $1 \leq |n| < 10$, or zero and n may contain from 1 to 9 (inclusive) decimal digits and $|\exp| \leq 37$. All quantities are assumed positive unless designated negative by - . All quantities not specified are set equal to zero except for $p_{x_{max}} = p_{y_{max}} = 1$, $x_{max} = 1/2$, $y_{max} = 1/2$, $P = 1$, $\lambda = 1$ and $a = 1$.

The series and search features are included in this program. These are described in ILL TEMPERED FIVE, MURA Report No. 457.

Notes on preparing the data deck and the starting procedure are identical to those included in ILL TEMPERED FIVE, MURA Report No. 457.

SPIRIT AGENDUM

(Program 245)

Parameter	Address	Value		Remarks	
Human ID	2624				FIXED POINT INTEGERS
Run ID	2625				
N_p	2626			Number of RK steps between prints of p_x, p_y, x, y, $N'\theta/2\pi$.	
N_e	2627			Number of RK steps to end of problem.	
i_{max}	2628			Last term in power series for B_x, B_y, B_θ $0 < i_{max} \leq 4$.	
m_{max}	2629			Highest spiral harmonic, $0 \leq m_{max} \leq 8$.	
n_{max}	2630			Highest angular harmonic, $0 \leq n_{max} \leq 11$.	
$(C_p)_o$	2965			Initial reading of the print counter.	
$(C_e)_o$	2966			Initial reading of the end counter.	
N_{plot}	2967			0 for no plot; 1 for x, p_x; 2 for y, p_y.	
		n	exp		
N'	2631			Number of sectors.	FLOATING POINT NUMBERS
K	2632			Number of RK steps per sector.	
$K = 1/w$	2633				
k	2634				
u	2635				
q	2636				
p_{x_o}	2637				
p_{y_o}	2638				
x_o	2639			Initial Coordinate values.	
y_o	2640				
$(N'\theta/2\pi)_o$	2641				
$p_{x_{max}} = p_{y_{max}}$	2642			(1) momentum upper bound.	
x_{max}	2643			(1/2) position upper bound.	
y_{max}	2644			(1/2) position upper bound.	
P	2645			(1)	
a	2646			(1)	
λ	2647			(1)	

OVERWRITE	SENSE SWITCH 5 UP	
SEARCH FEATURE	SENSE SWITCH 6 UP	

SPIRIT AGENDUM (Program 245)

Fourier coefficients of the median plane field

$$\left(\frac{B_y}{B_o}\right)_{y=0} = -(a+x)^k \left[\sum_m (g_m \cos m u \Phi + f_m \sin m u \Phi)\right]\left[\sum_n (a_n \cos n q N' \theta + b_n \sin n q N' \theta)\right]$$

Parameter	Address	Value n	Value exp	Parameter	Address	Value n	Value exp
g_8	2614			f_8	2604		
g_7	2615			f_7	2605		
g_6	2616			f_6	2606		
g_5	2617			f_5	2607		
g_4	2618			f_4	2608		
g_3	2619			f_3	2609		
g_2	2620			f_2	2610		
g_1	2621			f_1	2611		
g_o	2622						
a_{11}	2592			b_{11}	2580		
a_{10}	2593			b_{10}	2581		
a_9	2594			b_9	2582		
a_8	2595			b_8	2583		
a_7	2596			b_7	2584		
a_6	2597			b_6	2585		
a_5	2598			b_5	2586		
a_4	2599			b_4	2587		
a_3	2600			b_3	2588		
a_2	2601			b_2	2589		
a_1	2602			b_1	2590		
a_o	2603						
OVERWRITE							
ϵ_x	2648			(10^{-6})			
ρ_x	2649			(10^{-4})			
ρ_y	2650			(10^{-4})			
E	2651			(1)			

FLOATING POINT NUMBERS

NOTE: Enter N_{FP} as N_p, N_{EFP} as N_e on the preceding page

SENSE SWITCH SETTINGS

SS1 (Tested once per integration step)

UP Stop with location counter = 06064_8

storage register = 042000000001_8

SS2
DOWN: For each time START is pressed one integration cycle will be completed. To resume normal operations, put SS1 down.

SS2
UP: Press START and a dump of the entire core memory onto logical tape 1 will be produced followed by a normal stop in location 03373_8. To resume, see tape resumption procedure.

DOWN Continuous integration.

SS2 (Tested once per integration step)

UP Stop with location counter = 06070_8

storage register = 042000000002_8

Press START and if:

SS1
UP: See SS1 up, SS2 up above.

SS1
DOWN: Computations on the current run are stopped and END is printed.

SS3
UP: A plot will be printed if N_{plot} = 1 or 2 and if more than 5 points have been saved.

SS3
DOWN: No plot.

SS6
UP: Stop with location counter = 03637_8, storage register = 042000077777_8 signalling the end of the problem. If START is pressed now, computations will continue with the next run of the series.

SS6
DOWN: Computations will continue with the next run of the series.

DOWN Continuous integration

SS3 (Tested only if SS2 up and SS1 down)

UP See SS2 up, SS1 down, SS3 up above.

DOWN Continuous integration

SS4 Not used.

SS5 (Tested once at the beginning of a series)

UP OVERWRITE put into operation.

DOWN Normal operation.

SS6 (Tested whenever a run is completed in any of the following ways.)

1. $C_e = N_e$
2. SS2 has been put up.
3. An overflow has occurred (p_x, p_y, x, or y have exceeded their bounds).

UP Case 1 and 2, normal search stop at location 03637_8 with storage register = 042000077777_8 will signal the end of the problem. If START is pressed now, computations will continue with the next run of the series. Case 3, computation is continued with the next run of the series without a stop.

DOWN Normal operation.

PROGRAM STOPS

Nineteen program stops are listed on pages 13 and 14. Stops 1, 2, 3, 4 are normal stops. The remaining stops are abnormal and indicate a data error,

prohibited intermediate values, or a computer error.

There are a number of stops which are not listed. These are chiefly divide check stops which could occur because of prohibited values for certain quantities or could be the result of a computer error. If the computer should stop at one of these abnormal stops (listed or unlisted), it is important that it be noted by the operator -- the complete console configuration should be recorded and the problem removed from the computer.

SPIRIT
Program 245
PROGRAM STOPS

Stop No.	Location Counter (Octal)	Storage Register (Octal)	Reason For Stop
1.	03373	000000077777	NORMAL stop, end of a series of runs (or end of a tape dump).
2.	03637	042000077777	NORMAL stop, end of search (SS6 up)
3.	06064	042000000001	SS1 up, end of one integration cycle
4.	06070	042000000002	SS2 up
5.	00027	000000000005	Check sum error on the card just read by MU LBL3. Press START to ignore check sum error and continue loading cards.
6.	03362	000000003362	STOPINHERE card missing or out of order. (Operator: Check the order of the cards in the data deck. Rearrange the data deck or add the missing card. Reload the program deck and the data deck).
7.	03366	000000003366	STOPFLOPHERE card missing. (Operator: See instructions for stop No. 6).
8.	04017	000000004017	Cosine error return, $\lvert u\,\phi \rvert > 2^{36}$. *
9.	04024	000000004024	Sine error return, $\lvert u\phi \rvert > 2^{36}$. *
10.	04031	000000004031	Cosine error return, $\lvert q\,N'\theta \rvert > 2^{36}$. *
11.	04036	000000004036	Sine error return, $\lvert q\,N'\theta \rvert > 2^{36}$. *
12.	04464	000000004446	Tape check on, press START to write and check again.
13.	04472	000000004503	Tape check on, press START to try loading the tape again.
14.	04563	000000004563	Logarithm error return, $(a + x) \leqslant 0$. *

Stop No.	Location Counter (Octal)	Storage Register (Octal)	Reason For Stop
15.	04574	000000004574	Exponential error return, $\lvert (k + 1) \ln (a + x) \rvert > 87.3$ *
		OVERWRITE STOPS	
16.	01632	000000001621	Check sum error while reading from drum, press START to try again.
17.	02031	000000002031	Square root error return, $\sqrt{P^2 - p_x^2}$ negative. *
18.	07036	000000007020	Check sum error while writing on drum, press START to try again.
			* Operator: Note stop number on the output, remove the problem and return to the user.
19.	02206	000000002206	Sine error return, $\lvert \sigma \rvert > 2^{36}$. *

TAPE RESUMPTION

If it is desired to interrupt the computation at any time with the possibility of resuming later, set a tape unit to logical tape 1 and put sense switches 1 and 2 up. Almost immediately the computer comes to one of the following two stops depending on which sense switch is tested first.

a. SS1 tested first.
   Storage register = 042000000001_8
   Location counter = 06064_8

b. SS2 tested first.
   Storage register = 042000000002_8
   Location counter = 06070_8

Pressing START causes the other sense switch to be tested and if it is also up the entire core memory is written on logical tape 1. The normal program stop (location counter = 03373_8, storage register = 000000077777_8) then occurs.

At the time of resumption, the data cards for the remaining runs of the series (not including the current run) must be readied in the card reader. Also the resumption tape must be loaded on logical tape 1. Then press LOAD TAPE. The first line of print will contain the following information: program number, human ID and run ID. Computation is then continued in the normal manner.

APPENDIX

OVERWRITE

SPIRIT possesses an overwrite which is put in operation by placing sense switch 5 up at the beginning of a series of runs. This overwrite is a generalization of a fixed point search and is identical to Cyclotron Overwrite 2 of ILL TEMPERED FIVE, MURA Program #220. For a complete description, see Appendix II of ILL TEMPERED FIVE, MURA Report #457.

The agendum for the overwrite is included at the bottom of the second page of the standard agendum (page 14).