MSUCP-10

MISTIC EQUILIBRIUM ORBIT CODE

T.I. Arnette

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Department of Physics
East Lansing, Michigan

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CONTENTS

I. GENERAL DESCRIPTION

A code has been written for the MISTIC computer[1] which locates and determines the properties of equilibrium orbits in cyclotron-type magnetic fields. The equilibrium orbit for a given particle and energy is, by definition, that orbit which closes smoothly on itself after one revolution and has the same periodicity as the magnetic field.

For a given energy band, the code computes and outputs in tabular form, as a function of the kinetic energy, the mean radius of the equilibrium orbit, the percentage difference between the particle frequency and the isochronous frequency, the radius and radial momentum at $\theta=0$, and the small amplitude focusing frequencies ν_r and ν_z.

II. METHOD

Because the MISTIC has only a 1024-word memory at present with no auxiliary storage, the code is divided into three parts. Part I loads the field data into memory. Part II, using equations 1-6 (see page 2), searches for equilibrium orbits at given energy increments and, after locating the orbits, stores their $\theta=0$ radius and radial momentum values. Finally, Part III, using the stored r, p_r values as initial conditions, integrates equations 1-12 through one period and outputs results.

(1) "MISTIC" is a fast automatic digital computer with 1024 word cathode ray tube memory, patterned after the University of Illinois computer, the "ILLIAC". A 16,000 word magnetic core memory for the MISTIC is under construction.

The equations integrated by the code are:

(1) $dr/d\theta = (r/Q)p_r$

(2) $dp_r/d\theta = Q - rB(r,\theta)$

(3) $dx_1/d\theta = (p_r/Q)x_1 + (p^2 r/Q^3)p_{x_1}$

(4) $dp_{x_1}/d\theta = -(p_r/Q)p_{x_1} - x_1 \frac{\partial}{\partial r}[rB(r,\theta)]$

(5) $dx_2/d\theta = (p_r/Q)x_2 + (p^2 r/Q^3)p_{x_2}$

(6) $dp_{x_2}/d\theta = -(p_r/Q)p_{x_2} - x_2 \frac{\partial}{\partial r}[rB(r,\theta)]$

(7) $dz_1/d\theta = (r/Q)p_{z_1}$

(8) $dp_{z_1}/d\theta = [r\frac{\partial}{\partial r}B(r,\theta) - (p_r/Q)\frac{\partial}{\partial \theta}B(r,\theta)]z_1$

(9) $dz_2/d\theta = (r/Q)p_{z_2}$

(10) $dp_{z_2}/d\theta = [r\frac{\partial}{\partial r}B(r,\theta) - (p_r/Q)\frac{\partial}{\partial \theta}B(r,\theta)]z_2$

(11) $d\langle r\rangle/d\theta = (N/2\pi)r$

(12) $d\phi/d\theta = (N/2\pi)[(\gamma r/Q) - 1]$

Where:

$r(\theta)$ and $p_r(\theta)$ = radius and radial component of momentum, respectively, as a function of θ.

p	= magnitude of particle momentum = $[(K/E_o)^2 + 2(K/E_o)]^{1/2}$.
Q	= $(p^2 - p_r^2)^{1/2}$.
$x_1(\theta)$ and $p_{x_1}(\theta)$	= radial and radial momentum displacement from $r(\theta)$ and $p_r(\theta)$ of a disturbed orbit with $x_1(0) = \delta$, $p_{x_1}(0) = 0$.
$x_2(\theta)$ and $p_{x_2}(\theta)$	= radial and radial momentum displacement with $x_2(0) = 0$, $p_{x_2}(0) = \delta$.
$z_1(\theta)$ and $p_{z_1}(\theta)$	= axial and axial momentum displacement from reference orbit with $z_1(0) = \delta$, $p_{z_1}(0) = 0$.
$z_2(\theta)$ and $p_{z_2}(\theta)$	= axial and axial momentum displacement from reference orbit with $z_2(0) = 0$, $p_{z_2}(0) = \delta$.
$\langle r \rangle$	= mean radius of reference orbit from $\theta = 0$.
γ	= total relativistic energy = $(K/E_o + 1)$.
ϕ	= percentage angular difference between the particle azimuth and the phase of a sinusoidially time varying signal.

The units employed are the same as in the earlier General Orbit Code for MISTIC.[2] Lengths are in cyclotron units (1 cyc. unit = c/ω_{rf}) and magnetic fields in units of $\omega_{rf} m_o/q$ where ω_{rf} is the frequency of the electron voltage,

(2) M.M. Gordon and H.G. Blosser, Mistic General Orbit Code, MSUCP-7 (1961) unpublished.

and m_o and q are the rest mass and charge of the accelerated particle. γ is computed by the code from the input values of kinetic and rest energies.

The equilibrium orbit is located by a rapidly convergent iteration procedure described in detail in an earlier report.(3)

The Runge-Kutta fourth-order integration method as adapted by Gill is used to integrate the equations.

Whenever interpolation is required, as in the calculation of the magnetic fields, the 4-point central LaGrangian interpolation scheme is used. The derivative of the LaGrangian interpolation equation is used when interpolating for radial derivatives. (Since the field, as described below, is stored as a Fourier series in θ, azimuthal derivatives are computed by direct summing of the derivative series.)

III. INPUT DATA

As in the General Orbit Code, the median plan magnetic field is input as tables of functions designated $B_o(r)$, $H_i(r)$, $G_i(r)$, $h_i(r)$, and $g_i(r)$-each of these functions being specified by giving its numerical value at a set of uniformly spaced r values (all of which are integral multiples of some Δr). In terms of these functions the magnetic field is internally computed from the formula

$$B(r,\theta) = B_o(r) + \sum_{i=1}^{H} [H_i(r)\cos iN\theta + G_i(r)\sin iN\theta] + \sum_{i=1}^{h} [h_i(r)\cos i\theta + g_i(r)\sin i\theta] \qquad (13)$$

(3) M.M. Gordon and T.A. Welton, Computation Methods for AVF Cyclotron Design Studies, ORNL-2765, Sept. 1959.

Since the field data are expressed the same as in the General Orbit Program the same data tape and data loading routine is used here as in the earlier code. With respect to the θ given in eq. 13, orbits are tracked in the negative θ direction by the routine.

IV. PARAMETERS

There are two sets of parameters which must be furnished the code. The first set pertaining to the field data, is used by Part I of the code only, and must precede the field data. The parameters are read by the DOI in the following order and format:

00 16K

00 F 00 $\underline{\lambda/2}$ J	λ = multiplicative scaling factor for H_i, G_i, h_i, and g_i (does not change B_o).
00 F 00 $\underline{2^{-12}/\Delta r}$ J	Δr = radial spacing of field data in cyclotron units.
00 F 00 $\underline{a}$ F	a = number of r values for which data are to be stored.[4]
00 F 00 $\underline{H}$ F	H = number of main field harmonics to be stored.
00 F 00 $\underline{h}$ F	h = number of imperfection field harmonics to be stored.

[4] As dicussed in Section VI, a, H, and h must be such that $a(2[H + h] + 1) \leq 380$.

00	dF	00		F	d = number of digits/number on input tape.
00	F	00	b	F	b = number of r values for which data are on tape.
00	F	00	α	F	α = number of r entries to skip before starting to store data.
26 55N					transfer directive.

The second set of parameters describes the field data to the main program, (the parameters for the field loading code have been overwritten) and also sets up the initial energy value, the increment in energy, and the number of tabular values wanted. These parameters are also read in by the DOI and thus must also be in DOI format. A number of the parameters are rarely changed and the usual values are written into the main program. These quantities need to be included on the parameter tape only when values different from those preset by the program are wanted. In the following description preset values of the various parameters are given in parenthesis after the description; if no parenthesis is given the parameter must be set by the parameter tape on all runs.

Main Program Parameter List

Absolute location	Parameter	
41	00 F 00 a F	a = no. of radius values for which field data is stored (a = 48)
42	00 F 00 $2^{-12}/\Delta r$ J	Δr = radial spacing of field data in cyc. units ($2^{-12}/\Delta r$ = .030169109810)
43	00 F 00 β F	$\beta\Delta r$ = smallest r for which field data is stored in memory (β = 0)
44	00 F 00 H F	H = no. of main field harmonics (H = 3)

Absolute location	Parameter	
45	00 F 00 $\underline{h}$ F	h = no. of imperfections field harmonics
46	00 F 00 $\underline{N}$ F	N = no. of sectors in main field (3)
47	00 F 00 $\underline{K}$ J	K = initial kinetic energy[5] (K = .028)
48	00 F 00 $\underline{\Delta K}$ J	ΔK = kinetic energy increment[5] (ΔK = .002)
49	00 F 00 $\underline{2^2\zeta}$ J	$2^2\zeta = 8\pi/kN'$, ($2^2\zeta$ = .5235987756)
50	00 F 00 $\underline{E_o}$ J	E_o = rest mass[5] (E_o=.93823)
51	80 F 00 $\underline{k}$ F	k = no. of Runge-Kutta steps/orbit period (k = 16)
52	00 F 00 $\underline{\delta}$ J	δ = initial values for some Runge-Kutta variables (δ = .001)
53	00 F 00 $\underline{\epsilon}$ J	ϵ = closure tolerance on E.O. on next to last pass thru search routine $\|r_f - r_i\| + \|p_{r_f} - p_{r_i}\| < \epsilon$ (ϵ = .001)
70	00 F 00 $\underline{N'/2\pi}$ J	N' = no. of orbit periods/revolution (N' = 3)
81	00 F 00 $\underline{n}$ F	n = no. of energy values for which orbits to be found. $n \leq 24$.
	26980N	transfer directive
	$\underline{\text{xxxxxxxxxx}}$	10 decimal identification digits (digits can be zero but there must be 10 characters)

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(5) K, ΔK, and E_o must be in same units - any unit is acceptable - 10^9ev is usually employed as unit.

V. OPERATION

The program is run by the following sequence of steps.
(1) Bootstrap "Load Field Program" tape for loading fields.
(2) Black switch field parameters and field data tape. This program stops on a black switch stop after reading and placing the average field and the main field harmonics. Another black switch start will read and place imperfection field harmonic data.
(3) Bootstrap, being certain not to clear memory, sexadecimal "E.O. Program Tape I".
(4) Black switch main program parameter tape. This part of program runs from 30-45 seconds per energy value, and stops. The normal stop is location 972($3NN_{16}$). See "Code Stops" section for interpretation of other stops.
(5) Black switch sexadecimal "E.O. Program Tape II." There is a short interlude at beginning of this tape which prints headings for output, resets some addresses, reads in the rest of the tape and then proceeds with Part III.

VI. CODE LIMITATIONS

There are several limitations in the program, most of which are space limitations.
(1) The number of energy values for which equilibrium orbit data are to be calculated cannot exceed 24 for any one run.
(2) The number of locations for storing field information cannot exceed 380. If a wider range of field values is needed, this program will have to be run twice with the appropriate parameters to Part I, so that it will select the correct band of radius values for field data storage.
(3) As mentioned above the minimum radius value for which field data is stored must be an integer multiple (any integer

$\geq$ - 1 is acceptable) of Δr, the radial increment for field data; i.e. $r_{min.} = \beta \Delta r$ where $\beta = (-1, 0, 1, 2, ...)$.
(4) Since field data must be inserted between Part I and Part II, and a parameter tape between Part II and Part III, each part of the program is on separate tapes. However, it is possible, if desirable, to make a sexadecimal tape of Parts I and II together. This sexadecimal tape would replace "program tape" in step 1 of operation and delete steps 2 and 3, thus reducing the amount of tape handling.

VII. CODE STOPS

In the orbit search part of the program if the code has found all of the desired orbits it stops in location 506 ($1LK_{16}$), after which restarting with the black switch will read in Part III of the program and continue the computation. Similarly if the code tries unsuccessfully p times (p is an integer presently set at 5 and stored in location 969) to find a closed orbit it stops in location 972 ($3NN_{16}$) after which restarting with the black switch will read in Part III as above. Another black switch stop occurs in location 364 ($16N_{16}$) if the code needs field values for larger radii than are stored. As in the previous cases, a restart with the black switch reads in Part III and continues the computations with the values already stored.

In addition to the above stops a number of others may occur in Part II signifying various difficulties. These include (1) r too small-left of 362 ($16K_{16}$), (2) $\sqrt{p^2-p_r^2}$ imaginary-right of 86 (056_{16}) and (3) $Q^3 \leq 1/4 p^2 r$ - left of 260 (104_{16}). None of these stops is restartable with the black switch but one can of course always proceed to Part III by means of a bootstrap load (without memory clear) of the Part III program.

VIII. OUTPUT

For each orbit the following information is output:

1. The energy in the same units as input.
2. The average radius of the orbit in units of c/ω_{rf}.
3. The fractional difference between particle rotation time and unit time, unit time being the r-f period.
4. The $\theta=0$ orbit radius in units of c/ω_{rf}.
5. The $\theta=0$ radial momentum of the particle in m_oc units.
6. $\nu_r/10$ where ν_r is the radial focusing frequency in units of the orbital frequency (normaly ν_r is output as 8 digits - if ν_r is imaginary, 1/2 cos σ_r is output under "NuR" heading but only 7 digits are punched).
7. $\nu_z/10$ - same as 6. except axial frequency.

IX. FIXED POINT OVERWRITE

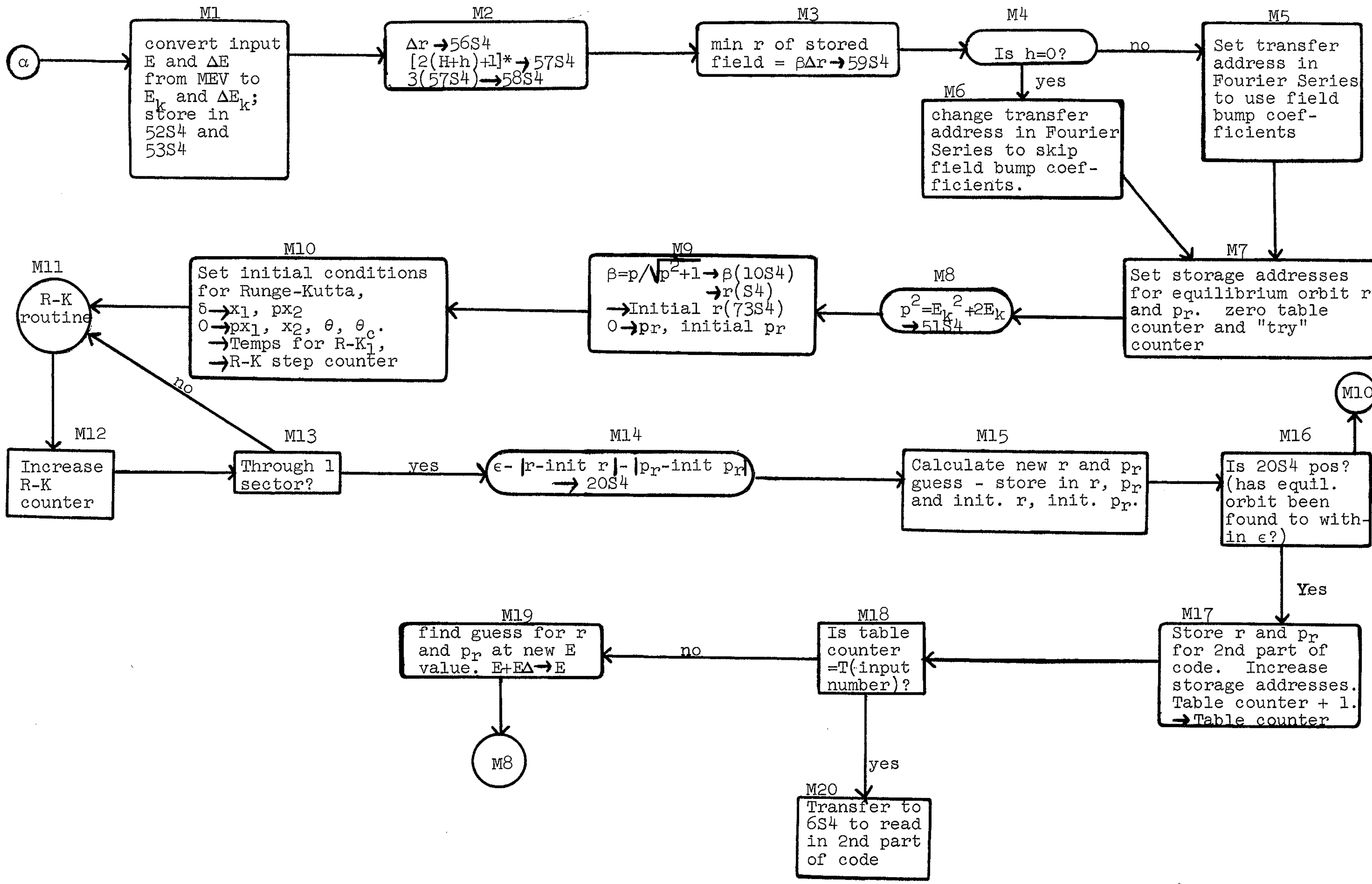
There is an overwrite tape available for use with the program which allows the location of stable and unstable fixed points instead of equilibrium orbits. When searching for equilibrium orbits, the programs uses $r = [1 - \gamma^{-2}]^{1/2}$ and $p_r = 0$ as initial guesses for the orbit location at the first energy value, and at following energies progressive extrapolated guesses are made as described by Gordon.[3] For fixed points this procedure is ineffective and hence r, p_r guesses of the orbit location at the first three energy values must be furnished to the code, after which it proceeds as before to extrapolate new guesses from orbits already found. Also since the fixed point orbits have only once per revolution symmetry, the code must go through an entire revolution regardless of the periodicity of the magnetic field. Parameters must therefore be set for an N' = 1 run; that is, "k" in decimal location 51 must be the number of r-k steps per revolution and "N'/2π" in decimal location 70 must be set to 1/2π. The extra parameters required for the overwrite tape are:

525 = guess for r at initial energy
526 = guess for pr at initial energy
527 = guess for r at second energy
528 = guess for pr at second energy
529 = guess for r at third energy
530 = guess for pr at third energy

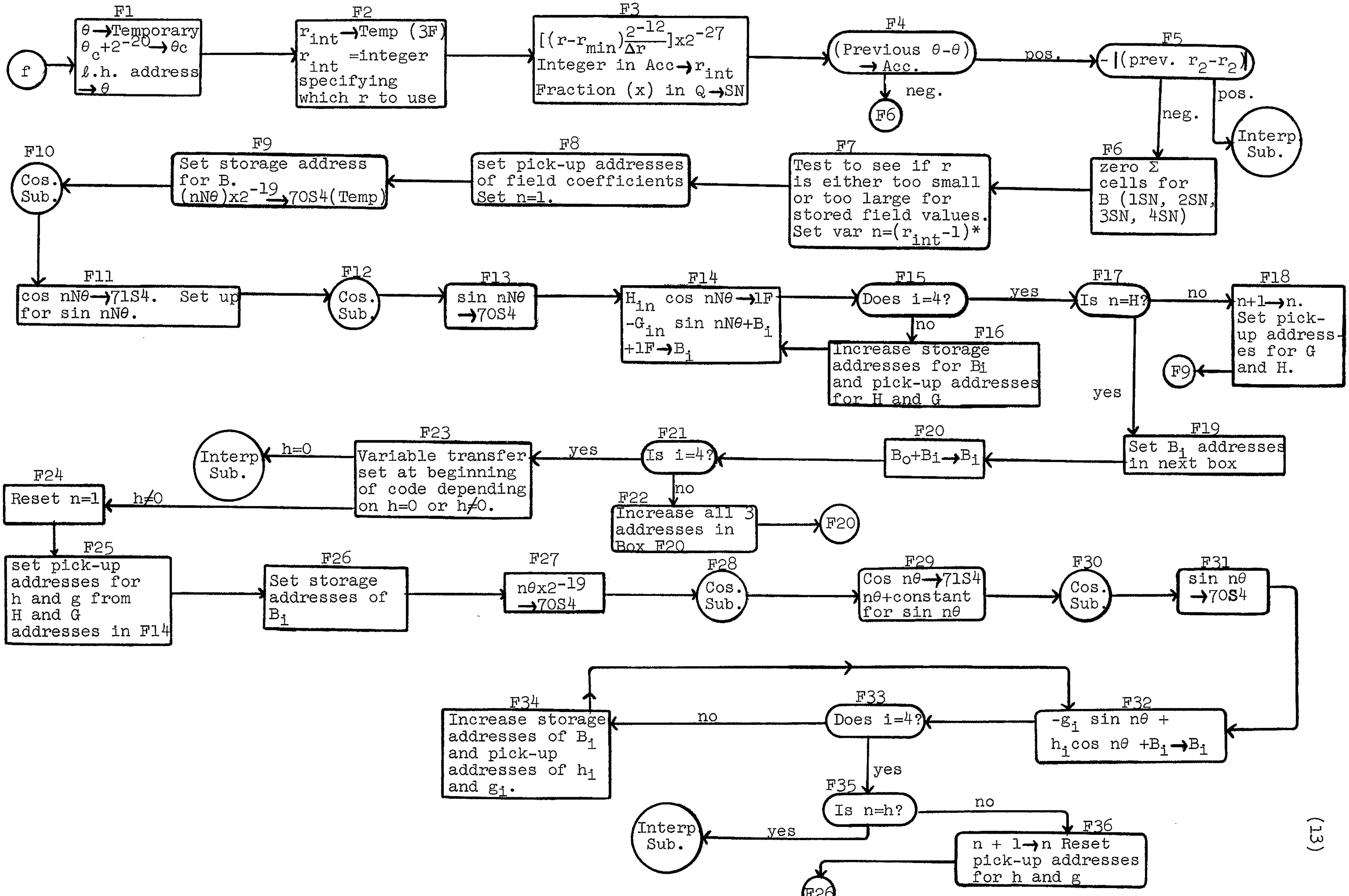
X. FLOW CHARTS AND PROGRAM

Equilibrium Orbit Code - Part II

S5 - MAIN ROUTINE



Fourier Series Routine (Part II)



Interpolation - Part II

I 1

Calculate interpol. coeff.

$A_1/2 = -1/12(x^3 - 3x^2 + 2x)$

$A_2/2 = 1/4(x^3 - 2x^2 - x + 2)$

$A_3/2 = -1/4(x^3 - x^2 - 2x)$

$A_4/2 = 1/12(x^3 - x)$

Where x = fraction part of

$$\frac{r - r_o}{\Delta r}$$

→

I 2

$B/4 = A_1B_1 + A_2B_2 + A_3B_3 + A_4B_4$

→ 62S4

→

I 3

Calculate interp. coeff. for $\frac{\partial B}{\partial r}$

$A'_1/2 = (-\frac{1}{2}x^2 + x - 1/3)/2$

$A'_2/2 = (\frac{3}{2}x^2 - 2x - 1/2)/2$

$A'_3/2 = (-\frac{3}{2}x^2 + x + 1)/2$

$A'_4/2 = (\frac{1}{2}x^2 - 1/6)/2$

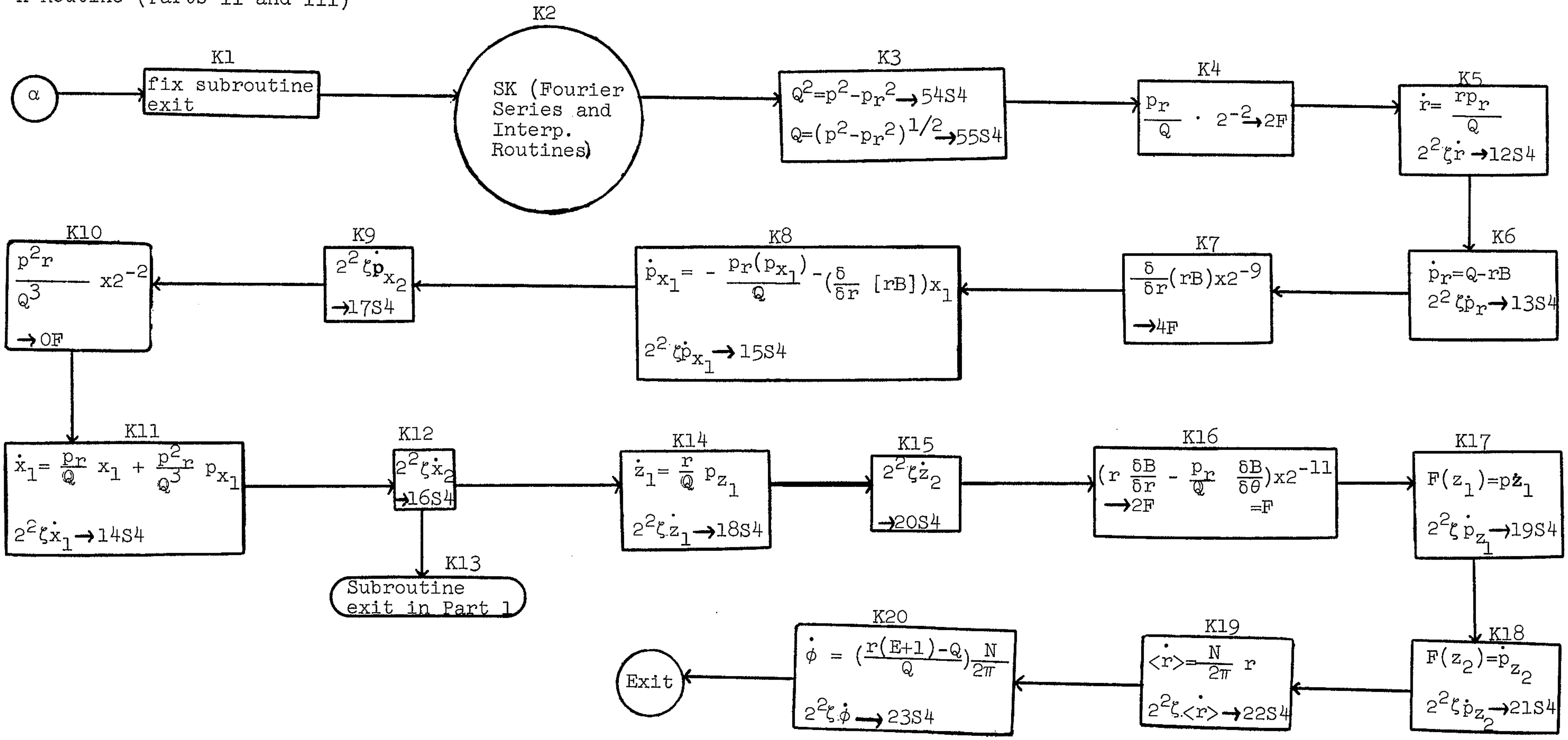
→

I 4

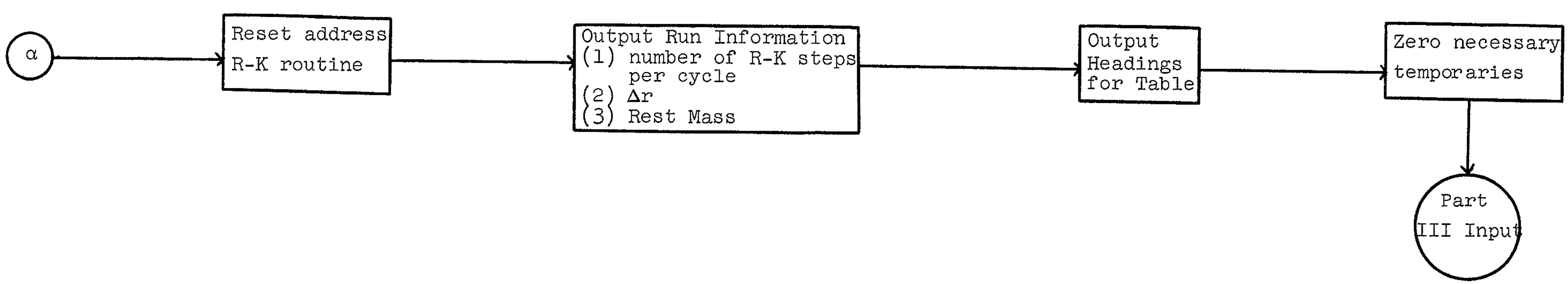
$$\frac{\partial B}{\partial r} x\ 2^{-9} = \frac{A'_1B'_1 + A'_2B'_2 + A'_3B'_3 + A'_4B'_4}{\Delta r \cdot 2^9}$$

→ 63S4

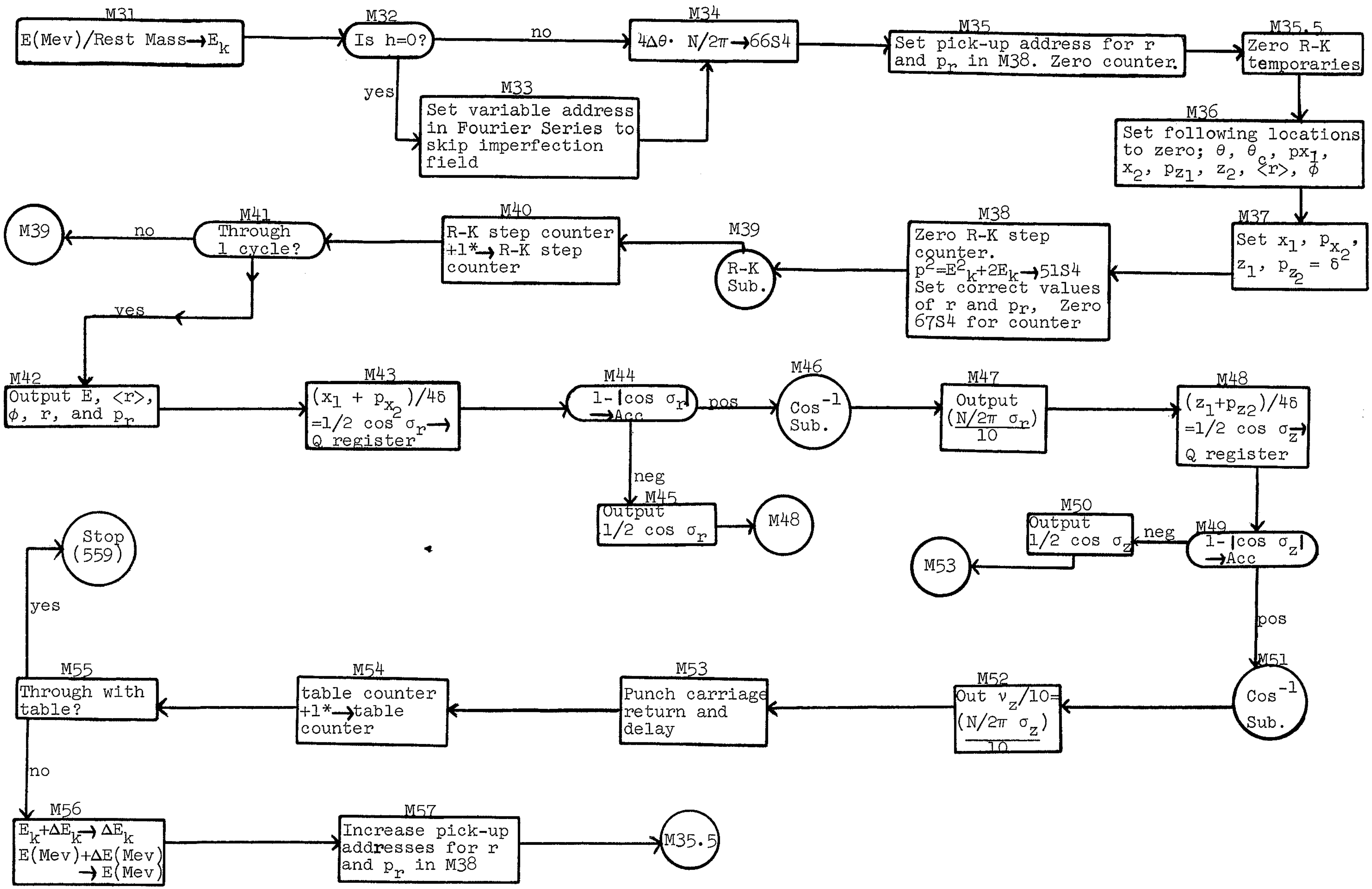
K-Routine (Parts II and III)



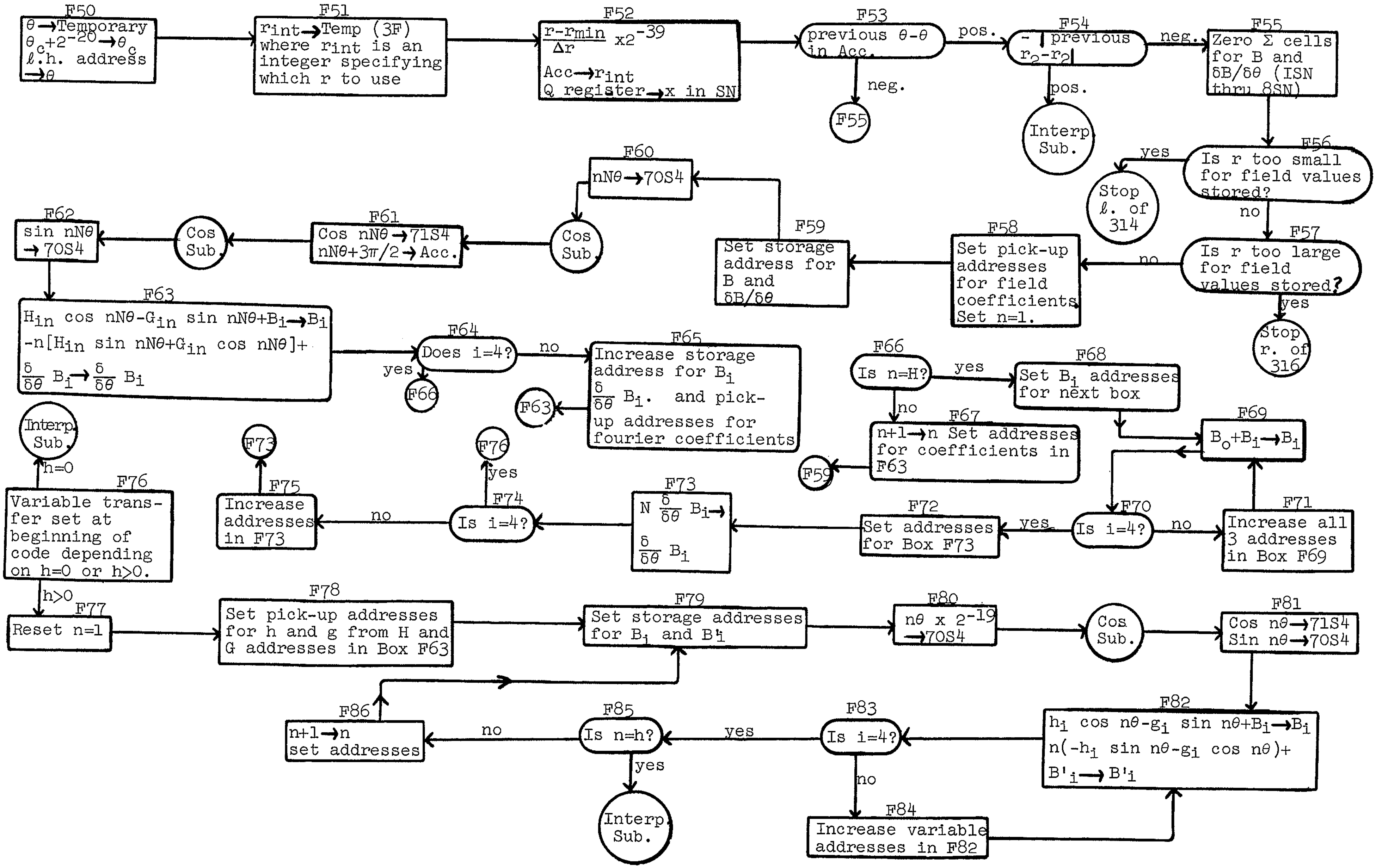
Interlude Between Parts II and III (on Part III tape)



S5-Main Routine-for Part III



B (Fourier Series) Routine-Part III



Interpolation - Part III

I 10

Calculate interpol. coeff.

$A_1/2 = -1/12(x^3 - 3x^2 + 2x)$

$A_2/2 = 1/4(x^3 - 2x^2 - x + 2)$

$A_3/2 = -1/4(x^3 - x^2 - 2x)$

$A_4/2 = 1/12(x^3 - x)$

Where x = fraction part of $\frac{r - r_o}{\Delta r}$

→ **I 11**

$B/4 = A_1B_1 + A_2B_2 + A_3B_3 + A_4B_4$

$\longrightarrow$ 62S4

→ **I 12**

$\frac{\partial B}{\partial \theta} \times 2^{-9} = A_1B'_1 + A_2B'_2 + A_3B'_3 + A_4B'_4 \longrightarrow$ 64S4

where $B' = \frac{\partial B}{\partial \theta}$

→ **I 13**

Calculate interp. coeff. for $\frac{\partial B}{\partial r}$

$A'_1/2 = (-\frac{1}{2}x^2 + x - 1/3)/2$

$A'_2/2 = (\frac{3}{2}x^2 - 2x - 1/2)/2$

$A'_3/2 = (-\frac{3}{2}x^2 + x + 1)/2$

$A'_4/2 = (\frac{1}{2}x^2 - 1/6)/2$

→ **I 14**

$\frac{\partial B}{\partial r} \times 2^{-9} = \frac{A'_1B'_1 + A'_2B'_2 + A'_3B'_3 + A'_4B'_4}{\Delta r \cdot 2^9}$

$\longrightarrow$ 63S4

S-BOX SETTINGS

Part II (E-O SEARCH)

004K

S4	00F 005F	Parameters, Temporaries, Constants
S5	00F 00435F	Main Routine
S6	00F 00F	
S7	00F 0082F	Square Root (R1)
S8	00F 0091F	Runge-Kutta (F1)
S9	00F 00225F	K-Routine
SK	00F 00345F	Fourier Series
SS	00F 00560F	Field Storage
SN	00F 00273F	Interpolation
SJ	00F 00132F	Cosine Routine and Tables
SF	00F 00F	
SL	00F 00175F	r and p_r Storage

Part III

S4	00F 005F	Parameters, Temporaries, Constants
S5	00F 00495F	Main Routine
S6	00F 00980F	Output (P2)
S7	00F 0082F	Square Root (R1)
S8	00F 0091F	Runge-Kutta (F1)
S9	00F 00225F	K-Routine
SK	00F 00295F	Fourier Series
SS	00F 00560F	Field Storage
SN	00F 00421F	Interpolation
SJ	00F 00132F	Cosine Routine and Tables
SF	00F 00940F	ν Routine
SL	00F 00175F	r and p_r Storage

S4

CONSTANTS, PARAMETERS AND STORAGE
PARTS II AND III

Abs. Addr.	Rel. Addr.		Comments	
5	0	Order Pairs are for	r	
6	1	Part II of Code only	p_r	
7	2	where corresponding	x_1	
8	3	variable is not used	p_{x_1}	
9	4		x_2	
10	5		p_{x_2}	
11	6	80 40F 40 F	z_1	
12	7	26 F S5 F	p_{z_1}	
13	8	40 70S4 22 67SK	z_2	
14	9		p_{z_2}	
15	10	β (Part II)	$\langle r \rangle$	
16	11		ϕ	
17	12		$\zeta\dot{r}$	
18	13		$\zeta\dot{p}_r$	
19	14		$\zeta\dot{x}_1$	
20	15		$\zeta\dot{p}_{x_1}$	
21	16		$\zeta\dot{x}_2$	
22	17		$\zeta\dot{p}_{x_2}$	
23	18	40 71S4 50 F	$\zeta\dot{z}_1$	
24	19	71 47S4 26 63S5	$\zeta\dot{p}_{z_1}$	
25	20	Storage (Part II)	$\zeta\dot{z}_2$	
26	21	L5 20S4 36 66S5	$\zeta\dot{p}_{z_2}$	
27	22	26 971F 00 F	$\zeta\langle\dot{r}\rangle$	
28	23		$\zeta\dot{\phi}$	
29	24		1	
30	25		2	
31	26		3	Temporaries for Runge-Kutta (1–6)
32	27		4	
33	28		5	
34	29		6	

Abs. Addr.	Rel. Addr.	Order Pairs	Comments	
35	30	40 111S5 L5 51S4	7	Temporaries for Runge-Kutta
36	31	22 513F 00 F	8	
37	32		9	
38	33		10	
39	34	Table Counter Part II	11	
40	35		12	
41	36		No. of r values	Field Data Input
42	37		$2^{-12}/\Delta r$	
43	38		β^*	
44	39		H^*	
45	40		h^*	
46	41		N^*	
47	42		E in MEV	
48	43		ΔE in MEV	
49	44		$2^2\zeta=2\pi/kN \cdot 2^2$	
50	45		E_o (Rest Mass)	
51	46		(No. of R-K steps sector)-1	
52	47		δ=Initial values of R-K variable	
53	48	00 F 00 0010 0000 0000J	ϵ=goodness of fit of Equilibrium Orbit	
54	49		2^{-20}	
55	50		zero	
56	51		$p^2=E_k{}^2 + 2E_k$	
57	52		E_k	
58	53		ΔE_k	
59	54		$Q^2=p^2-p_r{}^2$	
60	55		$Q(p^2-p_r{}^2)^{1/2}$	
61	56		Δr	
62	57		2(H+h)+1	Integers
63	58		3[2(H+h)+1]	
64	59		r min	

Abs. Addr.	Rel. Addr.	Order Pairs	Comments
65	60		θ
66	61		θ_c
67	62		$B \times 2^{-2}$
68	63		$\partial B/\partial r \times 2^{-9}$
69	64		$\partial B/\partial \theta \times 2^{-9}$
70	65		$N/2\pi$
71	66		$2^2\zeta\ N/2\pi$
72	67		r int.
73	68		var. int.
74	69		n
75	70		Temp 1
76	71		Temp 2
77	72	00 72F 00 F	$3\pi/2$
78	73		Init R Part 1 } counter
79	74		Init P_r } in Part 2
80	75		R-K step counter
81	76		No. of E values wanted

S5

MAIN ROUTINE

PART II

Abs. Addr.	Rel. Addr.	Order Pairs				Box Nos.		Comments
435	0	L5	42S4	50	50S4	M1		
436	1	66	45S4	S5	5SN			
437	2	40	52S4	L5	43S4			
438	3	50	50S4	66	45S4			E and ΔE converted to units of m_oc^2
439	4	S5	F	40	53S4			
440	5	50	50S4	19	11F	M2		
441	6	66	37S4	S5	SL			
442	7	40	56S4	L5	39S4			$\Delta r \rightarrow$ 56S4
443	8	L4	40S4	50	50S4			
444	9	00	1F	K4	SS			
445	10	40	57S4	00	1F			2(H+h)+1 → 57S4
446	11	L4	57S4	40	58S4			3[2(H+h)+1] → 58S4
447	12	50	38S4	75	56S4	M3		
448	13	00	39F	40	59S4			r min → 59S4
449	14	26	15L	40	59S4			
450	15	L3	40S4	32	17L	M4		Is h=0?
451	16	F5	16L	42	60SK	M5		
452	17	22	18L	L5	1L		M6	
453	18	42	60SK	L5	6L		M7	
454	19	42	66L	F5	66L			
455	20	42	67L	41	34S4			Zero table counter and "try" counter
456	21	41	970F	50	52S4		M8	
457	22	7J	52S4	L4	52S4			
458	23	L4	52S4	40	51S4			$p^2 \rightarrow$ 51S4
459	24	10	1F	40	1F	M9		

Abs. Addr.	Rel. Addr.	Order Pairs				Box Nos.		Comments
460	25	LJ	1F	40	1F			
461	26	L5	51S4	10	1F			
462	27	66	1F	S5	F			
463	28	NO	F	50	28L			
464	29	26	S7	40	10S4			$\beta \rightarrow$ 10S4
465	30	40	S4	40	73S4			$\rightarrow r$, Initial r
466	31	41	1S4	40	74S4			$0 \rightarrow p_r$, Initial p_r
467	32	L5	47S4	40	2S4	M10		Set initial conditions for R-K
468	33	40	5S4	41	3S4			
469	34	40	4S4	40	60S4			
470	35	40	61S4	40	24S4			Set temporaries for R-K
471	36	40	25S4	40	26S4			
472	37	40	27S4	40	28S4			
473	38	40	29S4	40	75S4			R-K counter = 0
474	39	00	2F	50	39L	M11		Enter R-K
475	40	26	S8	F5	75S4		M12	
476	41	40	75S4	LO	46S4		M13	
477	42	36	39L	L5	S4		M14	
478	43	LO	73S4	40	F			r-int $r \rightarrow 0$
479	44	L5	1S4	LO	74S4			
480	45	40	1F	L5	48S4			p_r-int $p_r \rightarrow 1$
481	46	L2	F	L2	1F		M15	
482	47	40	20S4	50	1F			$\epsilon - \lvert\epsilon_r\rvert - \lvert\epsilon_{p_r}\rvert \rightarrow$ 20S4
483	48	75	4S4	10	1F			
484	49	40	2F	50	3S4			$\frac{\Delta p_r x_2}{2}$
485	50	75	4S4	10	1F			
486	51	40	3F	L5	5S4			$\frac{p x_2 - \delta}{2} \rightarrow$ 70S4
487	52	LO	47S4	10	1F			
488	53	40	70S4	50	70S4			
489	54	75	F	LO	2F			

Abs. Addr.	Rel. Addr.	Order Pairs				Box Nos.	Comments
490	55	40	2F	50	70S4		
491	56	75	2S4	26	339F		
492	57	L0	3F	40	3F		
493	58	50	2F	71	47S4		
494	59	66	3F	S5	F		
495	60	40	3F	L4	73S4		
496	61	40	73S4	40	S4		
497	62	71	2S4	22	341F		
498	63	L4	71S4	66	4S4		
499	64	S5	F	L4	74S4		
500	65	40	74S4	26	344F		
501	66	L5	S4	40	[F]	M17	Get better guesses and store in 175 ff.
502	67	L5	1S4	40	[F]		
503	68	F5	67L	42	66L		Set new storage addresses
504	69	F5	66L	42	67L		
505	70	F5	34S4	40	34S4		
506	71	L0	76S4	34	6S4	M18 M20	Read in Hex Tape 2
507	72	L5	110L	40	109L	M19	Get initial guess for new p value
508	73	L5	111L	40	110L		
509	74	L5	114L	40	113L		
510	75	L5	115L	40	114L		
511	76	L5	S4	L0	10S4		
512	77	66	10S4	S5	F		
513	78	26	30S4	50	78L		
514	79	26	S7	L5	1S4		
515	80	66	2F	S5	F		
516	81	26	976F	26	[82L]		
517	82	L5	111L	40	112L		
518	83	L5	115L	40	116L		
519	84	L5	85L	42	81L		

Abs. Addr.	Rel. Addr.	Order Pairs				Box Nos.	Comments
520	85	26	102L	26	86L		
521	86	L5	111L	00	1F		
522	87	L0	110L	40	112L		
523	88	L5	115L	00	1F		
524	89	L0	114L	40	116L		
525	90	L5	91L	42	81L		
526	91	26	102L	26	92L		
527	92	L5	111L	00	1F		
528	93	L4	111L	40	F		
529	94	L1	110L	00	1F		
530	95	L0	110L	L4	F		
531	96	L4	109L	40	112L		
532	97	L5	115L	00	1F		
533	98	L4	115L	40	F		
534	99	L1	114L	00	1F		
535	100	L0	114L	L4	F		
536	101	L4	113L	40	116L		
537	102	26	-107L	75	10S4		
538	103	L4	10S4	40	S4		
539	104	40	73S4	26	982F		
540	105	75	116L	40	1S4		
541	106	40	74S4	26	32L		
542	107	L4	52S4	L4	53S4		
543	108	40	52S4	22	973F		
544	109						ρ_{-3}
545	110						ρ_{-2}
546	111						ρ_{-1}
547	112						ρ
548	113						ρ'_{-3}
549	114						ρ'_{-2}

Abs. Addr.	Rel. Addr.	Order Pairs				Box Nos.	Comments
550	115						ρ'-1
551	116						ρ'
969	0	00	F	00	5F		
970	1		Counter				
971	2	F5	970F	40	970F		
972	3	L0	969F	34	6S4		
973	4	26	32S5	L5	975F		
974	5	40	30S5	26	21S5		
975	6	50	112S5	22	102S5		
976	7	S5	F	40	115S5		
977	8	22	81S5	00	F		
978	9						
979	10						
980	11	80	40F	82	40F		Beginning of Program
981	12	92	971F	26	435F		
982	13	L5	51S4	50	982F		
983	14	26	S7	40	1F		
984	15	50	1F	26	105S5		

S9

K-Routine

Abs. Addr.	Rel. Addr.	Order Pairs				Box Nos.		Comments
225	0	K5	F	42	69L	K1		Fix exit
226	1	26	SK	50	1S4	K2	K3	Transfer to Fourier Series Routine
227	2	71	1S4	L4	51S4			
228	3	40	54S4	50	3L			$Q^2 \rightarrow 54S4 = p^2 - p_r^2$
229	4	26	S7	40	55S4			$Q = (p^2 - p_r^2)^{1/2} \rightarrow 55S4$
230	5	L5	1S4	10	2F	K4		
231	6	50	50S4	66	55S4			
232	7	S5	F	40	2F			$\frac{p_r}{4Q} \rightarrow 2$
233	8	75	S4	40	F	K5		$\frac{rp_r}{4Q} \rightarrow 0$
234	9	50	F	75	44S4			
235	10	00	2F	40	12S4			$2^2 \zeta \dot{r} \rightarrow 12S4$
236	11	50	S4	71	62S4	K6		
237	12	40	F	L5	55S4			$\frac{rB}{4} \rightarrow 0$
238	13	10	2F	L4	F			
239	14	40	F	50	F			$\frac{(Q-rB)}{4} \rightarrow 0$
240	15	75	44S4	00	2F			
241	16	40	13S4	50	2F		K7	$2^2 \zeta \dot{p}_r \rightarrow 13S4$
242	17	79	3S4	40	1F			
243	18	50	S4	75	63S4			
244	19	40	3F	L5	62S4			$r \frac{\delta B}{\delta r} \times 2^{-9} \rightarrow 3$
245	20	10	7F	L4	3F			
246	21	40	4F	50	4F		K8	$\frac{\delta}{\delta r}[rB] \rightarrow 4 \times 2^{-9}$
247	22	71	2S4	00	7F			
248	23	L4	1F	40	F			
249	24	50	F	75	44S4			
250	25	00	2F	40	15S4			$2^2 \zeta \dot{p}_{x_1} \rightarrow 15S4$
251	26	50	2F	79	5S4	K9		
252	27	40	1F	50	4F			
253	28	71	4S4	00	7F			
254	29	L4	1F	40	F			$(\frac{-p_r}{Q} \cdot p_{x_2})$

Abs. Addr.	Rel. Addr.	Order Pairs				Box Nos.	Comments
255	30	50	F	75	44S4		
256	31	00	2F	40	17S4		$2^2\zeta\dot{p}_{x_2} \to 17S4$
257	32	50	54S4	75	55S4	K10	
258	33	40	F	50	51S4		$Q^3 \to 0$
259	34	75	S4	10	2F		
260	35	66	F	S5	F		
261	36	40	F	50	F	K11	$\frac{p^2r}{Q^3} \cdot 2^{-2} \to 0$
262	37	75	3S4	40	14S4		$(p_{x_1} \frac{p^2r}{Q^3}) \cdot 2^{-2} \to 14S4$
263	38	50	2F	75	2S4		
264	39	L4	14S4	40	14S4		
265	40	50	14S4	75	44S4		
266	41	00	2F	40	14S4		$2^2\zeta\dot{x}_1 \to 14S4$
267	42	50	F	75	5S4	K12	
268	43	40	16S4	50	2F		
269	44	75	4S4	L4	16S4		
270	45	40	16S4	50	16S4		
271	46	75	44S4	00	2F		
272	47	40	16S4	50	S4	* K14	$2^2\zeta\dot{x}_2 \to 16S4$
273	48	75	44S4	40	F		$2^2\zeta r \to 0$
274	49	50	F	75	7S4		
275	50	66	55S4	S5	F		$2^2\zeta \frac{rp_{z_1}}{Q}$
276	51	40	18S4	50	F	K15	$2^2\zeta\dot{z}_1 \to 18S4$
277	52	75	9S4	66	55S4		
278	53	S5	F	40	20S4		$2^2\zeta\dot{z}_2 \to 20S4$
279	54	50	2F	71	64S4	K16	

* For K-routine in Part II Rel. Addr. 47 is:
47 ; 40 16S4 22 [F]

Abs. Addr.	Rel. Addr.	Order Pairs				Box Nos.		Comments
280	55	40	2F	L5	3F			$\frac{-p_r}{Q}\frac{\delta B}{\delta\theta}\cdot 2^{-11}\rightarrow 2$
281	56	10	2F	L4	2F			
282	57	40	2F	50	2F		K17	$[r\frac{\delta B}{\delta r} - \frac{p_r}{Q}\frac{\delta B}{\delta\theta}]\cdot 2^{-11}\rightarrow 2$
283	58	75	44S4	40	2F			" " $\cdot(\zeta)\rightarrow 2$
284	59	50	2F	75	6S4			
285	60	00	11F	40	19S4			$2^2\zeta\dot{p}_{z_1}\rightarrow$ 19S4
286	61	50	2F	75	8S4	K18		
287	62	00	11F	40	21S4			$2^2\zeta\dot{p}_{z_2}\rightarrow$ 21S4
288	63	50	66S4	75	S4	K19		
289	64	40	22S4	50	S4		K20	$2^2\zeta\langle\dot{r}\rangle\rightarrow$ 22S4
290	65	75	52S4	L4	S4			
291	66	L0	55S4	10	2F			
292	67	66	55S4	75	66S4			
293	68	00	2F	40	23S4			$2^2\zeta\dot{\phi}\rightarrow$ 23S4
294	69	NO	F	22	[F]			

SN

Interpolation

Part II

Abs. Addr.	Rel. Addr.	Order Pairs				Box Nos.	Comments
273	0	00	F	00	F		x } Storage
274	1	00	F	00	F		B_1 } Storage
275	2	00	F	00	F		B_2 } Storage
276	3	00	F	00	F		B_3 } Storage
277	4	00	F	00	F		B_4 } Storage
278	5	50	L	75	L	I1	
279	6	40	F	50	F		$x^2 \rightarrow 0$
280	7	75	L	40	1F		$x^3 \rightarrow 1$
281	8	L0	L	10	1F		
282	9	40	2F	50	2F		$(x^3-x)\cdot 2^{-1} \rightarrow 2$
283	10	75	55L	40	61L		$A_4/2 \rightarrow 1/6(x^3-x)\cdot 2^{-1} \rightarrow 61L$
284	11	L5	L	26	62L		
285	12	L4	65L	L0	2F		
286	13	10	1F	40	60L		$A_3/2 \rightarrow 60L$
287	14	L5	2F	L0	F		
288	15	L4	57L	10	1F		
289	16	40	59L	L5	1F		$A_2/2 \rightarrow 59L$
290	17	L0	F	L0	F		
291	18	L4	L	L0	F		
292	19	L4	L	10	1F		
293	20	40	2F	50	2F		
294	21	71	55L	40	58L		$A_1/2 \rightarrow 58L$
295	22	50	1L	75	58L	I2	
296	23	40	70S4	50	2L		
297	24	75	59L	L4	70S4		

Abs. Addr.	Rel. Addr.	Order Pairs				Box Nos.	Comments
298	25	40	70S4	50	3L		
299	26	75	60L	40	71S4		
300	27	50	4L	75	61L		
301	28	L4	71S4	L4	70S4		
302	29	00	1F	40	62S4		B x $2^{-2} \rightarrow 62S4$
303	30	L1	F	10	1F	I3	
304	31	L4	L	10	1F		
305	32	L0	55L	40	58L		
306	33	L5	F	10	2F		
307	34	40	2F	00	1F		
308	35	L4	2F	40	2F		
309	36	L0	L	40	1F		
310	37	L1	56L	10	1F		
311	38	L4	1F	40	59L		
312	39	L5	L	10	1F		
313	40	L4	56L	L0	2F		
314	41	40	60L	L5	F		
315	42	10	1F	L0	55L		
316	43	10	1F	40	61L		
317	44	50	1L	75	58L	I4	
318	45	40	70S4	50	2L		
319	46	75	59L	40	71S4		
320	47	50	3L	75	60L		
321	48	L4	71S4	10	1F		
322	49	40	71S4	50	4L		
323	50	75	61L	L4	70S4		
324	51	10	1F	L4	71S4		
325	52	40	71S4	50	71S4		
326	53	75	37S4	00	7F		
327	54	40	63S4	22	1S9		

Abs. Addr.	Rel. Addr.	Order Pairs				Box Nos.	Comments
328	55	00	F	00	1666 6666 6666J		
329	56	40	F	00	F		
330	57	40	F	00	4999 9999 9900J		
331	58						Storage for interpolating coefficients
332	59						
333	60						
334	61						
335	62	10	1F	40	65L		Storage
336	63	L5	F	10	1F		
337	64	26	12L	00	F		
338	65	00	F	00	F		
339	66	40	71S4	50	70S4		
340	67	71	47S4	L4	71S4		
341	68	26	57S5	40	71S4		
342	69	50	3F	75	47S4		
343	70	L4	71S4	26	18S4		
344	71	40	1S4	26	26F		

SK

Fourier Series

Part III

Abs. Addr.	Rel. Addr.	Order Pairs				Box Nos.	Comments
295	0	L5	60S4	40	2F	F50	existing $\theta \rightarrow 2F$
296	1	L5	61S4	L4	49S4		
297	2	40	61S4	46	60S4		
298	3	L5	67S4	40	3F	F51	$r_2 \rightarrow 3F$
299	4	L5	S4	L0	59S4	F52	
300	5	40	F	50	F		
301	6	75	37S4	10	27F		
302	7	40	67S4	S5	SS		new $r_2 \rightarrow 67S4$
303	8	40	SN	L5	2F	F53	x=fraction for interpolation→ OSN
304	9	L0	60S4	32	10L		
305	10	26	13L	L5	3F	F54	
306	11	L0	67S4	40	F		
307	12	L3	F	36	9SN		skip remainder of routine if r_2 and θ unchanged
308	13	41	1SN	40	2SN	F55	zero storage locations
309	14	40	3SN	40	4SN		
310	15	40	5SN	40	6SN		
311	16	40	7SN	40	8SN		
312	17	L5	67S4	F0	50S4	F56	Test to see if r in range of table
313	18	40	68S4	32	19L		
314	19	00	F	L5	36S4	F57	r too small stop
315	20	F0	67S4	F0	50S4		
316	21	36	22L	00	F		
317	22	50	68S4	75	57S4	F58	Setting pick-up addresses
318	23	L5	7L	S4	5SN		
319	24	42	67L	F4	50S4		

Abs. Addr.	Rel. Addr.	Order Pairs				Box Nos.		Comments
320	25	42	40L	42	44L			
321	26	F4	50S4	42	41L			
322	27	42	45L	F5	50S4			
323	28	40	69S4	L5	34L		F25	set n=1
324	29	42	42L	42	43L			
325	30	00	1F	00	1F			
326	31	L5	38L	46	49L			
327	32	10	20F	42	49L			
328	33	50	69S4	75	60S4	F60		$Nn\theta$
329	34	75	41S4	S5	1SN			
330	35	40	70S4	50	35L			$nN\theta \rightarrow$ 70S4
331	36	26	SJ	40	71S4		F61	cos $nN\theta \rightarrow$ 71S4
332	37	L5	70S4	L4	72S4			
333	38	NO	5SN	50	38L			
334	39	26	SJ	40	70S4	F62		sin $nN\theta \rightarrow$ 70S4
335	40	50	71S4	75	[F]	F63		
336	41	40	1F	50	[F]			
337	42	71	70S4	L4	[F]			
338	43	L4	1F	40	[F]			
339	44	50	70S4	71	[F]			
340	45	40	2F	50	[F]			
341	46	71	71S4	L4	2F			
342	47	40	2F	50	2F			
343	48	75	69S4	00	31F			
344	49	L4	[F]	40	[F]			
345	50	L5	49L	L0	123L	F64		
346	51	36	59L	L5	49L		F65	Increase storage addresses
347	52	L4	30L	42	49L			
348	53	46	49L	F5	42L			
349	54	42	42L	42	43L			

Abs. Addr.	Rel. Addr.	Order Pairs				Box Nos.		Comments
350	55	L5	40L	L4	57S4			Increase pick-up addresses
351	56	42	40L	42	44L			
352	57	F4	50S4	42	41L			
353	58	42	45L	26	40L			
354	59	L5	69S4	L0	39S4	F66		Harmonic for 4 fields and 4 deriv.
355	60	32	65L	F5	69S4		F67	Is n=H
356	61	40	69S4	F5	45L			no, increase n and reset pick-up addresses
357	62	L0	58S4	42	44L			
358	63	42	40L	F4	50S4			
359	64	42	41L	42	45L			
360	65	22	28L	L5	34L		F68	
361	66	42	68L	00	20F			
362	67	46	68L	L5	[F]		F69	
363	68	L4	[F]	40	[F]			
364	69	L5	68L	L0	124L	F70		
365	70	32	74L	L5	68L		F71	
366	71	L4	30L	42	68L			
367	72	46	68L	L5	67L			
368	73	L4	57S4	42	67L			
369	74	22	67L	L5	38L		F72	
370	75	46	76L	46	78L			
371	76	50	[F]	75	41S4	F73		
372	77	00	40F	N0	F			
373	78	40	[F]	L5	76L		F74	$\frac{\partial}{\partial\theta} B_i(r,\theta) x 2^{-9} \rightarrow B_i$
374	79	L0	125L	32	82L			
375	80	L5	76L	L4	30L	F75		
376	81	46	76L	46	78L			
377	82	26	76L	26	[83L]		F76	Variable transfer
378	83	F5	50S4	40	69S4	F77		n=1 again
379	84	F5	45L	L0	58S4	F78		set pick-up addresses

Abs. Addr.	Rel. Addr.	Order Pairs				Box Nos.		Comments
380	85	42	97L	42	101L			
381	86	F4	50S4	42	98L			
382	87	42	102L	L5	34L		F79	set storage addresses
383	88	42	99L	42	100L			
384	89	L5	38L	46	106L			
385	90	L5	23L	42	106L			
386	91	50	69S4	75	60S4	F80		
387	92	26	223F	50	92L			$n\theta \rightarrow$ 70S4
388	93	26	SJ	40	71S4	F81		cos $n\theta \rightarrow$ 71S4
389	94	L5	70S4	L4	72S4			
390	95	NO	F	50	95L			
391	96	26	SJ	40	70S4			
392	97	50	71S4	75	[F]	F82		
393	98	40	1F	50	[F]			
394	99	71	70S4	L4	[F]			
395	100	L4	1F	40	[F]			
396	101	50	70S4	71	[F]			
397	102	40	1F	50	[F]			
398	103	71	71S4	L4	1F			
399	104	40	1F	50	1F			
400	105	75	69S4	00	30F			
401	106	L4	[F]	40	[F]			
402	107	L5	106L	L0	123L	F83		
403	108	36	116L	L5	106L		F84	
404	109	L4	30L	42	106L			
405	110	46	106L	F5	99L			
406	111	42	99L	42	100L			
407	112	L5	97L	L4	57S4			
408	113	42	97L	42	101L			
409	114	F5	97L	42	98L			

Abs. Addr	Rel. Addr.	Order Pairs				Box Nos.		Comments
410	115	42	102L	26	97L			
411	116	L5	69S4	LO	40S4	F85		
412	117	36	9SN	F5	69S4		F86	
413	118	40	69S4	F5	102L			
414	119	LO	58S4	42	97L			
415	120	42	101L	F4	50S4			
416	121	42	98L	42	102L			
417	122	22	87L	26	9SN	}		Test words
418	123	L4	8SN	40	8SN			
419	124	L4	4SN	40	4SN			
420	125	50	8SN	75	41S4			

SK

Fourier Series

Part II

Abs. Addr.	Rel. Addr.	Order Pairs				Box Nos.		Comments
345	0	L5	60S4	40	2F	F1		existing $\theta \rightarrow 2F$
346	1	L5	61S4	L4	49S4			
347	2	40	61S4	46	60S4			increase θ_c-partially
348	3	L5	67S4	40	3F	F2		substitute $\theta - r_2 \rightarrow 3F$
349	4	L5	S4	L0	59S4	F3		
350	5	40	F	50	F			calculate new r_2
351	6	75	37S4	10	27F			
352	7	40	67S4	S5	SS		F4	x=fraction for inter-
353	8	40	SN	L5	2F			polation→0SN
354	9	L0	60S4	32	10L			
355	10	26	13L	L5	3F		F5	
356	11	L0	67S4	40	F			
357	12	L3	F	36	5SN			
358	13	41	1SN	40	2SN	F6		zero storage locations
359	14	40	3SN	40	4SN			for Σcells
360	15	L5	67S4	F0	50S4	F7		Test to see if r in
361	16	40	68S4	32	17L			range of table
362	17	00	F	L5	36S4			r too small stop
363	18	F0	67S4	F0	50S4			
364	19	36	20L	24	11F			r too large stop
365	20	50	68S4	75	57S4	F8		
366	21	L5	7L	S4	1SN			
367	22	42	53L	F4	50S4			
368	23	42	36L	F4	50S4			
369	24	42	37L	F5	50S4			

Abs. Addr.	Rel. Addr.	Order Pairs				Box Nos.		Comments
370	25	40	69S4	L5	21L		F9	Set n=1
371	26	42	38L	42	39L			
372	27	50	69S4	75	60S4			
373	28	75	41S4	S5	F			
374	29	40	70S4	22	31SK			
375	30	00	1F	00	1F			
376	31	NO	F	50	31L	F10		
377	32	26	SJ	40	71S4		F11	
378	33	L5	70S4	L4	72S4			
379	34	NO	F	50	34L			
380	35	26	SJ	40	70S4	F12	F13	sin nNθ→70S4
381	36	50	71S4	75	[F]			
382	37	40	1F	50	[F]			
383	38	71	70S4	L4	[F]			
384	39	L4	1F	40	[F]			
385	40	L5	39L	L0	88L	F15		
386	41	36	46L	F5	39L		F16	Increase storage
387	42	42	39L	42	38L			addresses
388	43	L5	36L	L4	57S4			Increase pick-up
389	44	42	36L	F4	50S4			addresses
390	45	42	37L	26	36L			
391	46	L5	69S4	L0	39S4	F17		
392	47	32	51L	F5	69S4		F18	
393	48	40	69S4	F5	37L			
394	49	L0	58S4	42	36L			
395	50	F5	36L	42	37L			
396	51	22	25L	L5	21L		F19	
397	52	42	54L	00	20F			
398	53	46	54L	L5	[F]		F20	
399	54	L4	[F]	40	[F]			

Abs. Addr.	Rel. Addr.	Order Pairs				Box Nos.		Comments
400	55	L5	54L	L0	89L	F21		
401	56	32	60L	L5	54L		F22	
402	57	L4	30L	42	54L			
403	58	46	54L	L5	53L			
404	59	L4	57S4	42	53L			
405	60	22	53L	26	[61L]		F23	Variable transfer
406	61	F5	50S4	40	69S4	F24		n=1 again
407	62	F5	37L	L0	58S4	F25		set pick-up addresses
408	63	42	72L	F4	50S4			
409	64	42	73L	L5	21L		F26	
410	65	42	74L	42	75L			
411	66	50	69S4	75	60S4	F27		
412	67	22	7S4	50	67L		F28	$n\theta \rightarrow$ 70S4
413	68	26	SJ	40	71S4		F29	cos $n\theta \rightarrow$ 71S4
414	69	L5	70S4	L4	72S4			
415	70	NO	F	50	70L		F30	
416	71	26	SJ	40	70S4		F31	
417	72	50	71S4	75	[F]		F32	
418	73	40	1F	50	[F]			
419	74	71	70S4	L4	[F]			
420	75	L4	1F	40	[F]			
421	76	L5	75L	L0	88L	F33		
422	77	36	82L	F5	74L		F34	
423	78	40	74L	42	75L			
424	79	L5	72L	L4	57S4			
425	80	42	72L	F5	72L			
426	81	42	73L	26	72L			
427	82	L5	69S4	L0	40S4	F35		
428	83	36	5SN	F5	69S4		F36	increase n
429	84	40	69S4	F5	73L			

Abs. Addr.	Rel. Addr.	Order Pairs				Box Nos.	Comments
430	85	L0	58S4	42	72L		Increase pick-up addresses
431	86	F5	72L	42	73L		
432	87	22	64L	00	F		
433	88	L4	1F	40	4SN		
434	89	L4	4SN	40	4SN		

S8

Runge-Kutta Integration Subroutine

Abs. Addr.	Rel. Addr.	Order Pairs				Comments
91	0	L5	5F	L4	6F	(c+n) 2^{-37}
92	1	00	20F	46	13L	
93	2	L5	13L	40	37L	
94	3	L5	3F	42	14L	$a2^{-39}$
95	4	00	20F	46	14L	
96	5	L5	14L	40	38L	
97	6	L5	5F	L0	4F	(c-b) 2^{-39}
98	7	42	40L	00	20F	(c-b) 2^{-19}
99	8	46	40L	L5	4F	$b2^{-39}$
100	9	L0	3F	42	39L	(b-a) 2^{-39}
101	10	00	20F	46	39L	(b-a) 2^{-19}
102	11	50	12L	26	999F	
103	12	00	F	00	L	
104	13	64	F	00	33L	
105	14	80	F	00	F	
106	15	00	F	26	L	
107	16	26	1N			
91	0	S5	F	46	8L	Set shift addresses
92	1	46	11L	L4	3L	=m
93	2	42	22L	22	21L	Set link address
94	3	L5	F	40	1F	
95	4	L5	F	40	F	
96	5	L0	F	L0	1F	$(k_{i,j} - B_j q_{ij})$
97	6	40	3F	50	F	
98	7	7J	3F	L4	3F	$(k_{ij} - B_j q_{ij})(A_j + 1)2^{-m}$
99	8	10	F	40	3F	
100	9	L4	F	40	F	Step y_i

Abs. Addr.	Rel. Addr.	Order Pairs				Comments
101	10	L5	3F	50	2F	Form $r_{i,j+1}$
102	11	00	F	40	3F	
103	12	50	F	7J	F	$C_j k_{ij} - k_{ij}$
104	13	L0	F	L4	1F	
105	14	L4	3F	L4	3F	$q_{ij} + 3r_{i,j+1}$
106	15	L4	3F	40	F	
107	16	L5	9L	L4	13L	
108	17	42	9L	46	9L	Increase all addresses depending on i by 1 until i = n
109	18	L4	39L	46	4L	
110	19	L4	40L	42	15L	
111	20	46	3L	L0	37L	
112	21	36	3L	L5	L	Increase j from 0 to 3 and then leave by link
113	22	42	21L	32	F	
114	23	46	5L	10	10F	Adjust addresses which depend on j
115	24	L4	18L	42	6L	
116	25	46	12L	50	25L	Call in auxiliary subroutine
117	26	26	S7	41	2F	Clear 2F so that it can be used as zero
118	27	L5	38L	26	17L	Start new i cycle.
119	28	40	F	00	F	C_0, C_3
120	29	NO	F	00	F	A_0
121	30	40	F	00	2071 0678 1186 J	$1/\sqrt{2}C_1$, A_2
122	31	80	F	00	2928 9321 8814 J	$-1/\sqrt{2}\ A_1$, C_2
123	32	80	F	00	1666 6666 6667 J	$-5/6\ A_3$
124	33	LJ	1025F	06	1058L	Expressed in units of 2^{-9}, 2^{-19}, 2^{-29}, 2^{-39}. Addresses used to set addresses to refer to the constants A_j, C_j and make the address in 5L, 1 or 2 according as B_j 2 or 1, and to stop the address in 21, dependent on j, and to stop when positive.
125	34	LJ	3074F	06	3107L	
126	35	LF	2F	06	2084L	
127	36	LJ	1025F	07	37L	

Abs. Addr.	Rel. Addr.		Order Pairs			Comments
128	37	64	F	00	33L	3 end constants by interlude
129	38	80	F	00	F	
130	39	00	F	00	F	
131	40	00	F	00	F	

S6

Output Subroutine

Abs. Addr.	Rel. Addr.	Order Pairs				
980	0	40	F	L1	16L
981	1	S4	L	46	1L
982	2	42	14L	36	6L
983	3	L5	F	36	5L
984	4	92	706F	22	5L
985	5	92	642F	00	2F
986	6	JO	8L	7J	17L
987	7	42	8L	22	8L
988	8	00	63F	19	F
989	9	L6	F	10	39F
990	10	75	15L	00	36F
991	11	82	4F	10	40F
992	12	L5	1L	LO	16L
993	13	46	1L	36	10L
994	14	92	965F	22	F
995	15	00	F	00	10F
996	16	S4	1F	00	1023F
997	17	00	1F	K9	100F

S7

Square Root Subroutine

82	0	40	1F	K5	F
83	1	42	8L	51	1F
84	2	10	1F	SJ	F
85	3	40	2F	50	F
86	4	L5	1F	66	2F
87	5	S5	F	LO	2F
88	6	10	1F	36	8L
89	7	L4	2F	26	3L
90	8	L5	2F	22	F

SJ

Cosine Subroutine and Tables

Abs. Addr.	Rel. Addr.	Order Pairs			
132	0	40	14L	K5	F
133	1	42	15L	42	16L
134	2	L5	14L	LO	17L
135	3	32	2L	40	14L
136	4	L4	17L	40	F
137	5	L4	14L	10	1F
138	6	40	1F	36	8F
139	7	L5	F	22	8L
140	8	L1	14L	40	F
141	9	80	2F	LO	17L
142	10	32	12L	L5	15L
143	11	L4	F	40	14L
144	12	26	14L	L5	16L
145	13	L6	1F	40	14L
146	14	00	F	00	F
147	15	L5	18L	22	F
148	16	L1	18L	22	F
149	17	00	96F	00	F
150	18	7L	4095F	LL	4095F
151	19	7L	2973F	75	2220F
152	20	7F	3706F	K4	2996F
153	21	7J	2213F	L3	4064F
154	22	7S	2615F	51	3364F
155	23	79	848F	1K	2278F
156	24	76	1050F	L3	3276F
157	25	72	3275F	9J	2760F
158	26	6F	3486F	SK	1354F
159	27	6K	1753F	8K	1084F
160	28	65	2249F	K2	3422F
161	29	60	964F	96	3169F

Abs. Addr.	Rel. Addr.	Order Pairs				
162	30	5K	2087F	99	2558F
163	31	54	1623F	19	1102F
164	32	4J	3774F	4L	3670F
165	33	47	462F	NF	1722F
166	34	40	F	00	F
167	35	38	2510F	K7	498F
168	36	30	4028F	54	3422F
169	37	29	590F	JK	2958F
170	38	21	527F	S8	808F
171	39	18	3979F	83	3178F
172	40	10	2897F	50	3948F
173	41	08	1522F	13	1678F
174	42	00	F	00	F

INTERLUDE BETWEEN PARTS II AND III

Abs. Addr.	Rel. Addr.	Order Pairs			
494	0	L5	128F	42	112F
495	1	L5	28S8	00	1F
496	2	L4	46S4	00	32F
497	3	82	8F	92	963F
498	4	92	259F	92	771F
499	5	92	194F	92	451F
500	6	92	963F	92	258F
501	7	92	642F	92	971F
502	8	92	707F	L5	56S4
503	9	50	10F	50	9L
504	10	26	S6	92	967F
505	11	L5	45S4	NO	F
506	12	50	7F	50	12L
507	13	26	S6	92	139F
508	14	92	519F	92	971F
509	15	92	259F	92	194F
510	16	92	987F	92	258F
511	17	92	963F	92	387F
512	18	92	323F	92	987F
513	19	92	2F	92	771F
514	20	92	387F	92	706F
515	21	92	194F	92	987F
516	22	92	258F	92	999F
517	23	92	2F	92	258F
518	24	92	987F	92	770F
519	25	92	450F	92	963F
520	26	92	258F	92	987F
521	27	92	770F	92	450F
522	28	92	963F	92	899F
523	29	92	135F	92	519F

Abs. Addr.	Rel. Addr.	Order Pairs			
524	30	92	707F	41	72F
525	31	41	73F	41	74F
526	32	26	999F	00	F

26495 N

S5

Main Routine

Part III

Abs. Addr.	Rel. Addr.	Order Pairs				Box Nos.	Comments
495	0	L5	42S4	50	50S4	M31	
496	1	66	45S4	S5	SL		E(Mev) converted to E_k
497	2	40	52S4	L3	40S4	M32	
498	3	36	4L	26	5L		
499	4	L5	60L	42	82SK	M33	set variable transfer depending on h=0
500	5	50	65S4	75	44S4	M34	
501	6	40	66S4	L5	1L	M35	$2^2\zeta \frac{N}{2\pi} \rightarrow$ 66S4
502	7	42	23L	F5	23L		
503	8	42	24L	41	73S4		zero counter
504	9	L5	60L	46	10L		
505	10	41	[F]	L5	10L		
506	11	L0	59L	36	14L		
507	12	L5	10L	L4	30SK		
508	13	46	10L	26	10L		
509	14	41	60S4	40	61S4	M36	$\theta=\theta_c=0$
510	15	40	3S4	40	4S4		set I.C. for R-K
511	16	40	7S4	40	8S4		
512	17	40	10S4	40	11S4		
513	18	L5	47S4	40	2S4	M37	
514	19	40	5S4	40	6S4		
515	20	40	9S4	41	75S4	M38	
516	21	50	52S4	75	52S4		
517	22	L4	52S4	L4	52S4		
518	23	40	51S4	L5	[F]		$p^2=E_k^2 + 2E_k$
519	24	40	S4	L5	[F]		

Abs. Addr.	Rel. Addr.	Order Pairs				Box Nos.		Comments
520	25	40	1S4	NO	9SN			
521	26	00	2F	50	26L	M39		
522	27	26	S8	F5	75S4		M40	
523	28	40	75S4	L0	46S4			
524	29	36	26L	L5	42S4	M41	M42	E out
525	30	50	5F	50	30L			
526	31	26	S6	L5	10S4			<r> out
527	32	50	8F	50	32L			
528	33	26	S6	L5	11S4			ϕ out
529	34	50	8F	50	34L			
530	35	26	S6	L5	S4			r out
531	36	50	8F	50	36L			
532	37	26	S6	L5	1S4			p_r out
533	38	50	8F	50	38L			

00 534K (Altered)

534	0	26	S6	L5	2S4		M43	$x_1+p_{x_2}$
535	1	L4	5S4	10	2F			
536	2	66	47S4	SS	F		M44	
537	3	36	6L	S5	F			
538	4	50	7F	50	4L	M45		
539	5	26	S6	22	12L			Output 1/2 cos σ_r
540	6	S5	F	00	1F			
541	7	40	4F	NO	F			
542	8	50	4F	50	8L			
543	9	26	10SF	40	4F	M46		
544	10	50	4F	75	65S4	M47		
545	11	50	8F	50	11L			
546	12	26	S6	L5	6S4		M48	Output $\frac{\nu_r}{10}$
547	13	L4	9S4	10	2F			
548	14	66	47S4	SS	F		M49	

Abs. Addr.	Rel. Addr.	Order Pairs				Box Nos.	Comments
549	15	36	18L	S5	F		
550	16	50	7F	50	16L	M50	
551	17	26	S6	22	1SF		Output 1/2 cos σ_z
552	18	S5	F	00	1F	M51	
553	19	40	4F	26	22L		
554	20	41	35S4	L5	10S5		Test Word used
555	21	00	24S4	00	9SN		for setting
556	22	50	4F	50	22L		
557	23	26	10SF	40	4F		
558	24	50	4F	75	65S4	M52	
559	25	26	SF	00	F		End of program

SF

Continuation of S5 and $\cos^{-1}$ Routine

Part III

Abs. Addr.	Rel. Addr.	Order Pairs				Box Nos.	Comments
940	0	50	8F	50	L		
941	1	26	S6	92	519F	M53	
942	2	92	139F	F5	73S4	M54	
943	3	40	73S4	L0	76S4	M55	
944	4	32	64S5	L5	52S4	M56	
945	5	L4	53S4	40	52S4		
946	6	L5	42S4	L4	43S4		
947	7	40	42S4	F5	24S5		
948	8	42	23S5	F5	23S5	M57	
949	9	42	24S5	26	9S5		
		00	950K				
950	0	K5	F	42	18L		Inverse cosine routine
951	1	46	2L	50	28L		
952	2	L5	[F]	40	F		
953	3	32	6L	L5	18L		
954	4	42	21L	L5	22L		
955	5	42	18L	L7	F		
956	6	40	F	75	F		
957	7	L4	27L	40	1F		
958	8	50	1F	75	F		
959	9	L4	26L	40	1F		
960	10	50	1F	75	F		
961	11	L4	25L	40	1F		
962	12	50	1F	75	F		
963	13	L4	24L	40	3F		
964	14	L1	F	10	2F		

Abs. Addr.	Rel. Addr.	Order Pairs				Box Nos.		Comments
965	15	L4	29L	50	15L			
966	16	26	S7	40	F			
967	17	50	F	75	3F			
968	18	00	1F	22	[F]			
969	19	00	F	40	F			
970	20	L5	23L	L0	F			
971	21	NO	F	22	[F]			
972	22	00	F	00	19L			
973	23	00	F	00	3141	5926	5360	J
974	24	00	F	00	1570	7878	6000	J
975	25	NO	F	00	4785	8754	7000	J
976	26	00	F	00	0084	6664	9000	J
977	27	NO	F	00	4964	2433	7000	J
978	28	00	F	00	0008	6488	4000	J
979	29	20	F	00	F			

SN

Interpolation
Part III

Abs. Addr.	Rel. Addr.	Order Pairs				Box Nos.	Comments
421	0	00	F	00	F		
422	1	00	F	00	F		
423	2	00	F	00	F		
424	3	00	F	00	F		
425	4	00	F	00	F		
426	5	00	F	00	F		
427	6	00	F	00	F		
428	7	00	F	00	F		
429	8	00	F	00	F		
430	9	L5	L	10	1F		$x/2 \to 4$
431	10	40	4F	50	L		$x^2/2 \to 0$
432	11	75	4F	40	F		
433	12	50	F	75	L		$x^3/2 \to 1$
434	13	40	1F	LO	4F		
435	14	40	2F	50	2F		$\frac{(x^3-x)}{2} \to 4$
436	15	75	67L	40	73L		$1/6(x^3-x)\cdot 2^{-1} \to 73L$
437	16	L5	4F	L4	F		
438	17	LO	2F	10	1F		$1/2(x+x^2-x^3+x)$
439	18	40	72L	L5	2F		$A_3 \to 72L$
440	19	L4	69L	10	1F		
441	20	LO	F	40	71L		$A_2 \to 71L$
442	21	L5	1F	LO	F		
443	22	LO	F	L4	L		
444	23	LO	F	40	2F		
445	24	50	2F	71	67L		

Abs. Addr.	Rel. Addr.	Order Pairs				Box Nos.	Comments
446	25	40	70L	50	1L		$A_1 \rightarrow 70L$
447	26	75	70L	40	70S4		
448	27	50	2L	75	71L		
449	28	L4	70S4	40	70S4		
450	29	50	3L	75	72L		
451	30	40	71S4	50	4L		
452	31	75	73L	L4	71S4		
453	32	L4	70S4	00	1F		
454	33	40	62S4	50	5L		$Bx2^{-2} \rightarrow 62S4$
455	34	75	70L	40	70S4		
456	35	50	6L	75	71L		
457	36	40	71S4	50	7L		
458	37	75	72L	L4	70S4		
459	38	40	70S4	50	8L		
460	39	75	73L	L4	71S4		
461	40	L4	70S4	00	1F		
462	41	40	64S4	L1	F		$\frac{\delta B}{\delta \theta} \rightarrow 64S4$
463	42	L4	L	10	1F		
464	43	L0	67L	40	70L		
465	44	L5	F	10	1F		
466	45	L4	F	40	2F		
467	46	L0	L	40	1F		
468	47	L1	68L	10	1F		
469	48	L4	1F	40	71L		
470	49	L5	4F	L4	68L		
471	50	L0	2F	40	72L		
472	51	L5	F	L0	67L		
473	52	10	1F	40	73L		
474	53	50	1L	75	70L		
475	54	40	70S4	50	2L		

Abs. Addr.	Rel. Addr.	Order Pairs				Box Nos.	Comments
476	55	75	71L	40	71S4		
477	56	50	3L	75	72L		
478	57	L4	71S4	10	1F		
479	58	40	71S4	50	4L		
480	59	75	73L	L4	70S4		
481	60	10	1F	L4	71S4		
482	61	40	71S4	50	71S4		
483	62	75	37S4	00	7F		
484	63	40	63S4	22	1S9		$\frac{\delta B}{\delta r} \rightarrow 63S4$
485	64	00	F	00	F		
486	65	00	F	00	F		
487	66	00	F	00	F		
488	67	00	F	00	1666 6666 6666J		
489	68	40	F	00	F		
490	69	40	F	00	4999 9999 9900J		
491	70						Storage for interpolating coefficients (491–494)
492	71						
493	72						
494	73						

FIXED POINT OVERWRITE TAPE
for PART II

Abs. Addr.	Rel. Addr.	Order Pairs				Box Nos.	Comments
507	0	L5	527F	40	525F		
508	1	L5	528F	40	526F		
509	2	L5	4L	40	L		
510	3	26	107S5	NO	F		
511	4	26	5L	26	9L		
512	5	L5	529F	40	525F		
513	6	L5	530F	40	526F		
514	7	L5	4L	00	20F		
515	8	46	L	26	107S5		
516	9	L5	66S5	LO	26L		
517	10	42	12L	LO	26L		
518	11	42	13L	LO	26L		
519	12	42	15L	L5	F		
520	13	NO	F	LO	F		
521	14	40	S4	00	1F		
522	15	L4	S4	L4	F		
523	16	40	S4	40	73S4		
524	17	F5	12L	26	27L		
531	0	L5	526F	40	1S4		
532	1	40	74S4	26	32S5		
533	2	00	F	00	2F		
534	3	42	5L	F5	520F		
535	4	42	6L	F5	522F		
536	5	42	8L	L5	F		
537	6	NO	F	LO	F		
538	7	40	1S4	00	1F		
539	8	L4	1S4	L4	F		
540	9	40	1S4	40	74S4		
541	10	26	549F	L5	52S4		

Abs. Addr.	Rel. Addr.	Order Pairs				Box Nos.	Comments
549	0	L5	2L	40	30S5		
550	1	26	107S5	NO	F		
551	2	26	32S5	NO	F		
465	0	L5	525F	40	S4		
466	1	40	73S4	26	96S5		
543	0	40	52S4	26	456F		

24999N (Transfer directive)