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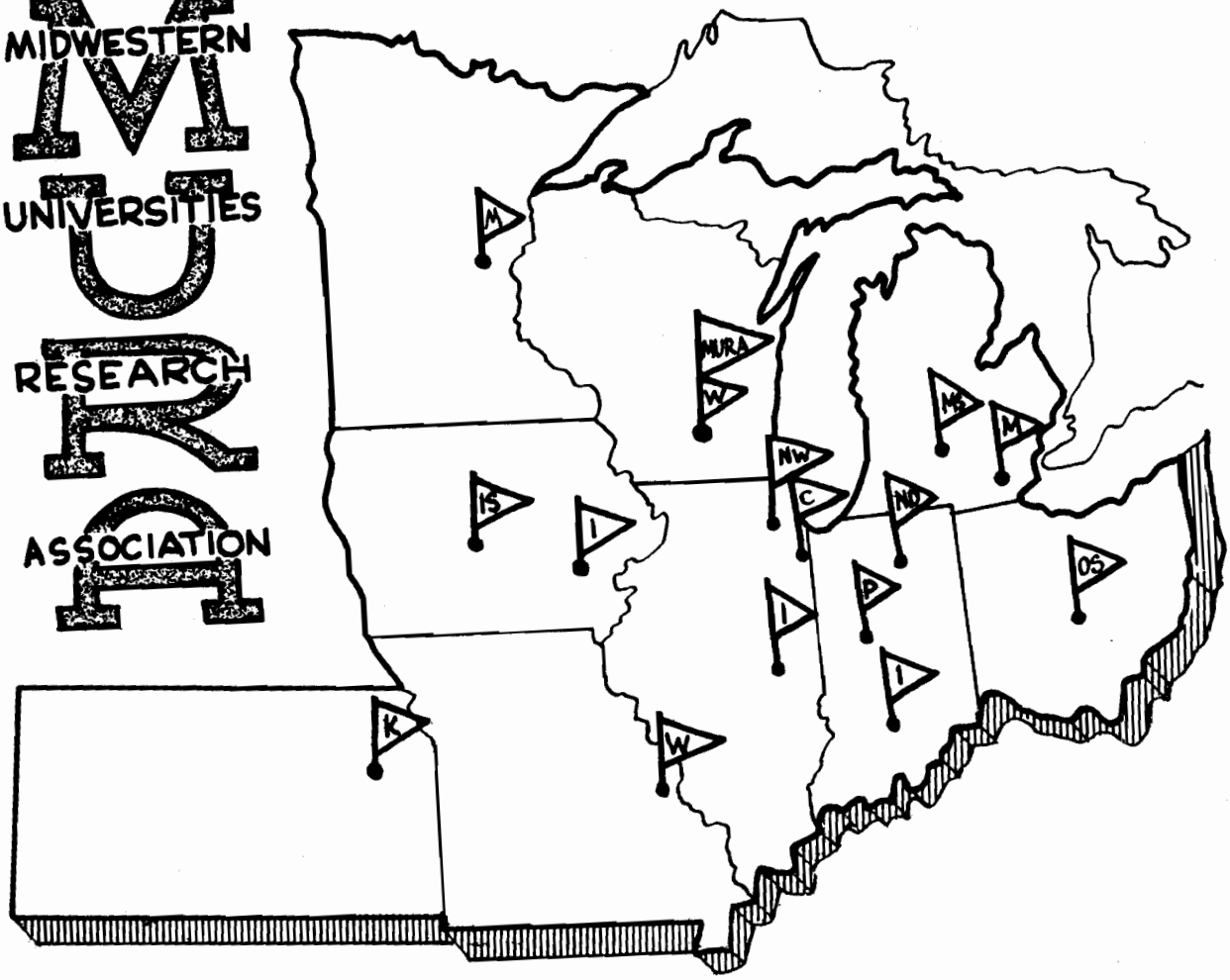

REPORT ILL TEMPERED FIVE

(Program 175)

May, 1958

NUMBER 411

Internal

(IBM Program)

MURA-411

ILL TEMPERED FIVE

(Program 175)

Elizabeth Z. Chapman

ILL TEMPERED FIVE is a program for the IBM 704 to solve the equations of motion describing the betatron oscillations of particles in a fixed field alternating gradient accelerator. These equations are shown below.

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

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

$$\frac{d\, p_x}{d\theta} = \sqrt{P^2 - p_x^2 - p_y^2} + \lambda(a + x)\left[\frac{B_y}{B_0} - \frac{p_y}{\sqrt{P^2 - p_x^2 - p_y^2}}\,\frac{B_\theta}{B_0}\right]$$

$$\frac{d\, p_y}{d\theta} = \lambda(a + x)\left[\frac{p_x}{\sqrt{P^2 - p_x^2 - p_y^2}}\,\frac{B_\theta}{B_0} - \frac{B_x}{B_0}\right]$$

Magnetic fields are to be entered in dimensionless units.

The method of obtaining the three magnetic field components, B_x, B_y and B_θ is described by F. T. Cole in MURA-377.

The highest harmonic accepted by the program is the 15th. Any number of hamonics up to and including the 15th is permitted.

The series expressions for B_x, B_y and B_θ are truncated by specifying i_{max}. All terms in the series with $i > i_{max}$ are neglected in the field computation.

The program will compute zero, one or two invariants as requested by the user on the invariants agendum (page 6). The equations and parameters are the same as those used in WELL TEMPERED FIVE.

Pages 3, 4 and 5 comprise a standard agendum which must be filled out and submitted by the user. Except for P, a and λ which are constants in the equations of motion, the parameters and their use are identical with those in WELL TEMPERED FIVE. In case the user has forgotten these, see L. D. Fosdick, MURA-226 for a detailed discussion.

A series of problems or a search is accomplished in the same manner as in WELL TEMPERED FIVE.

The initial print format is shown on page 7. The printed output is identical in format to that of WELL TEMPERED FIVE.

If a WELL TEMPERED FIVE problem (i.e., $j = 0$) is run with ILL TEMPERED FIVE, results will differ in round-off, because a different print subroutine is used. There are further slight differences in problems with y different from zero because the calculations are done in a slightly different way.

The printing time is about 0.680 sec. per line and the average computation time per Runge-Kutta step is 0.6 sec.

Page 8 is a list of possible program stops.

NOTE:

1. If $k \neq 0$, a must be 1; if $k = 0$, a may be set different from 1.

2. m_{max} <u>must</u> be set equal to the number of the highest <u>non-zero</u> harmonic.

Parameter	Address	Value		Remarks	
ID	3710				FIXED POINT INTEGERS
N_p	3694			The number of RK steps between prints of p_x, p_y, x, y, $N\theta/2\pi$.	
N_e	3695			The number of RK steps to end of problem.	
$(C_p)_o$	3961			Counter counts RK steps modulo N_p: print p_x, etc. when C_p = zero.	
$(C_e)_o$	3962			Counter counts RK steps; problem ends when $C_e = N_e$.	
i_{max}	3696			Last term in power series for H_x, H_y, H_z: $0 < i_{max} \leq 12$.	
m_{max}	3697			Highest harmonic, $0 \leq m_{max} \leq 15$.	
j_{max}	3698			Last term in power series for μ_{im}, ν_{im}, α_{im}, β_{im}, k, K, $0 \leq j_{max} \leq 4$.	
		n	exp		
N	3692				FLOATING POINT NUMBERS
n_{RK}	3693			The number of RK steps per sector.	
p_{x_o}	3760				
p_{y_o}	3761				
x_o	3762			Initial coordinate values.	
y_o	3763				
$(N\theta/2\pi)_o$	3764				
$p_{x\,max} = p_{y\,max}$	1924			(1) momentum upper bound.	
x_{max}	1925			(1/2) position upper bound.	
y_{max}	1926			(1/2) position upper bound.	
P	1927			(1) P in $\sqrt{P^2 - p_x^2 - p_y^2}$	
a	1919			(1) a in (a + x)	
λ	1969			(1)	

SEARCH FEATURE	SENSE SWITCH 6 UP	

NOTE:

1. If this is one run of a series, only those values differing from those of the preceding run need be specified, EXCEPT for PRINT COUNTER and END COUNTER, which are set equal to zero unless specified otherwise in the agendum.

2. If this run does not belong to a series, then all quantities not specified are set equal to zero, EXCEPT for $p_{x\,max} = p_{y\,max}$, x_{max}, and y_{max} which have the values given in parentheses in the remarks column when not specified in the agendum.

Fourier coefficients of the median plane field

$$B_y = -(a + x)^k \sum_m \left\{ \mu_{o,m} \cos m \Phi + \nu_{o,m} \sin m \Phi \right\} \text{ where } \mu_{o,m} = \sum_j \mu_{o,m,j} x^j, \ \nu_{o,m} = \sum_j \nu_{o,m,j} x^j$$

Parameter	Address	Value n	Value exp	Parameter	Address	Value n	Value exp
$\mu_{0,15,0}$	3794			$\nu_{0,15,0}$	3874		
$\mu_{0,14,0}$	3799			$\nu_{0,14,0}$	3879		
$\mu_{0,13,0}$	3804			$\nu_{0,13,0}$	3884		
$\mu_{0,12,0}$	3809			$\nu_{0,12,0}$	3889		
$\mu_{0,11,0}$	3814			$\nu_{0,11,0}$	3894		
$\mu_{0,10,0}$	3819			$\nu_{0,10,0}$	3899		
$\mu_{0,9,0}$	3824			$\nu_{0,9,0}$	3904		
$\mu_{0,8,0}$	3829			$\nu_{0,8,0}$	3909		
$\mu_{0,7,0}$	3834			$\nu_{0,7,0}$	3914		
$\mu_{0,6,0}$	3839			$\nu_{0,6,0}$	3919		
$\mu_{0,5,0}$	3844			$\nu_{0,5,0}$	3924		
$\mu_{0,4,0}$	3849			$\nu_{0,4,0}$	3929		
$\mu_{0,3,0}$	3854			$\nu_{0,3,0}$	3934		
$\mu_{0,2,0}$	3859			$\nu_{0,2,0}$	3939		
$\mu_{0,1,0}$	3864			$\nu_{0,1,0}$	3944		
$\mu_{0,0,0}$	3869			$\nu_{0,0,0}$	3949		
$\mu_{0,15,1}$	3793			$\nu_{0,15,1}$	3873		
$\mu_{0,14,1}$	3798			$\nu_{0,14,1}$	3878		
$\mu_{0,13,1}$	3803			$\nu_{0,13,1}$	3883		
$\mu_{0,12,1}$	3808			$\nu_{0,12,1}$	3888		
$\mu_{0,11,1}$	3813			$\nu_{0,11,1}$	3893		
$\mu_{0,10,1}$	3818			$\nu_{0,10,1}$	3898		
$\mu_{0,9,1}$	3823			$\nu_{0,9,1}$	3903		
$\mu_{0,8,1}$	3828			$\nu_{0,8,1}$	3908		
$\mu_{0,7,1}$	3833			$\nu_{0,7,1}$	3913		
$\mu_{0,6,1}$	3838			$\nu_{0,6,1}$	3918		
$\mu_{0,5,1}$	3843			$\nu_{0,5,1}$	3923		
$\mu_{0,4,1}$	3848			$\nu_{0,4,1}$	3928		
$\mu_{0,3,1}$	3853			$\nu_{0,3,1}$	3933		
$\mu_{0,2,1}$	3858			$\nu_{0,2,1}$	3938		
$\mu_{0,1,1}$	3863			$\nu_{0,1,1}$	3943		
$\mu_{0,0,1}$	3868			$\nu_{0,0,1}$	3948		
$\mu_{0,15,2}$	3792			$\nu_{0,15,2}$	3872		
$\mu_{0,14,2}$	3797			$\nu_{0,14,2}$	3877		
$\mu_{0,13,2}$	3802			$\nu_{0,13,2}$	3882		
$\mu_{0,12,2}$	3807			$\nu_{0,12,2}$	3887		
$\mu_{0,11,2}$	3812			$\nu_{0,11,2}$	3892		
$\mu_{0,10,2}$	3817			$\nu_{0,10,2}$	3897		
$\mu_{0,9,2}$	3822			$\nu_{0,9,2}$	3902		
$\mu_{0,8,2}$	3827			$\nu_{0,8,2}$	3907		
$\mu_{0,7,2}$	3832			$\nu_{0,7,2}$	3912		
$\mu_{0,6,2}$	3837			$\nu_{0,6,2}$	3917		
$\mu_{0,5,2}$	3842			$\nu_{0,5,2}$	3922		
$\mu_{0,4,2}$	3847			$\nu_{0,4,2}$	3927		
$\mu_{0,3,2}$	3852			$\nu_{0,3,2}$	3932		

FLOATING POINT NUMBERS

Parameter	Address	Value n	Value exp	Parameter	Address	Value n	Value exp	
$\mu_{0,2,2}$	3857			$\nu_{0,2,2}$	3937			FLOATING POINT NUMBERS
$\mu_{0,1,2}$	3862			$\nu_{0,1,2}$	3942			
$\mu_{0,0,2}$	3867			$\nu_{0,0,2}$	3947			
$\mu_{0,15,3}$	3791			$\nu_{0,15,3}$	3871			
$\mu_{0,14,3}$	3796			$\nu_{0,14,3}$	3876			
$\mu_{0,13,3}$	3801			$\nu_{0,13,3}$	3881			
$\mu_{0,12,3}$	3806			$\nu_{0,12,3}$	3886			
$\mu_{0,11,3}$	3811			$\nu_{0,11,3}$	3891			
$\mu_{0,10,3}$	3816			$\nu_{0,10,3}$	3896			
$\mu_{0,9,3}$	3821			$\nu_{0,9,3}$	3901			
$\mu_{0,8,3}$	3826			$\nu_{0,8,3}$	3906			
$\mu_{0,7,3}$	3831			$\nu_{0,7,3}$	3911			
$\mu_{0,6,3}$	3836			$\nu_{0,6,3}$	3916			
$\mu_{0,5,3}$	3841			$\nu_{0,5,3}$	3921			
$\mu_{0,4,3}$	3846			$\nu_{0,4,3}$	3926			
$\mu_{0,3,3}$	3851			$\nu_{0,3,3}$	3931			
$\mu_{0,2,3}$	3856			$\nu_{0,2,3}$	3936			
$\mu_{0,1,3}$	3861			$\nu_{0,1,3}$	3941			
$\mu_{0,0,3}$	3866			$\nu_{0,0,3}$	3946			
$\mu_{0,15,4}$	3790			$\nu_{0,15,4}$	3870			
$\mu_{0,14,4}$	3795			$\nu_{0,14,4}$	3875			
$\mu_{0,13,4}$	3800			$\nu_{0,13,4}$	3880			
$\mu_{0,12,4}$	3805			$\nu_{0,12,4}$	3885			
$\mu_{0,11,4}$	3810			$\nu_{0,11,4}$	3890			
$\mu_{0,10,4}$	3815			$\nu_{0,10,4}$	3895			
$\mu_{0,9,4}$	3820			$\nu_{0,9,4}$	3900			
$\mu_{0,8,4}$	3825			$\nu_{0,8,4}$	3905			
$\mu_{0,7,4}$	3830			$\nu_{0,7,4}$	3910			
$\mu_{0,6,4}$	3835			$\nu_{0,6,4}$	3915			
$\mu_{0,5,4}$	3840			$\nu_{0,5,4}$	3920			
$\mu_{0,4,4}$	3845			$\nu_{0,4,4}$	3925			
$\mu_{0,3,4}$	3850			$\nu_{0,3,4}$	3930			
$\mu_{0,2,4}$	3855			$\nu_{0,2,4}$	3935			
$\mu_{0,1,4}$	3860			$\nu_{0,1,4}$	3940			
$\mu_{0,0,4}$	3865			$\nu_{0,0,4}$	3945			

$k = \sum_j k_j x^j$ $\qquad$ $K = \sum_j K_j x^j$ $\qquad$ where $K = \frac{1}{w}$

k_0	3720			K_0	3715			
k_1	3719			K_1	3714			
k_2	3718			K_2	3713			
k_3	3717			K_3	3712			
k_4	3716			K_4	3711			

ILL TEMPERED FIVE

Invariants Agendum

(Programme 175)

To be attached by staples to the front of a series of ILL TEMPERED FIVE runs which are to employ the invariants feature.

Parameter	Address	Value		Remarks	
N_I	3745			The number of invariants: 1 or 2	INTEGERS
N_{I_p}	3746			The number of RK steps between prints of 1st invariant	
N'_{I_p}	3747			The number of RK steps between prints of 2nd invariant	
$(C_I)_o$	3965			Counter counts RK steps modulo N_{I_p}; print K_x, K_y when C_I = zero	
$(C'_I)_o$	3966			Counter counts RK steps modulo N'_{I_p}; print K'_x, K'_y when C'_I = zero	
		n	exp		
ξ_x	3725				FLOATING POINT NUMBERS
η_x	3726			Parameters for K_x	
ζ_x	3727			$K_x = \sqrt{\xi_x(x-x_f)^2 + \eta_x(x-x_f)(p_x - p_{xf}) + \zeta_x(p_x - p_{xf})^2}$	
x_f	3728				
p_{xf}	3729				
ξ_y	3730			Parameters for K_y	
η_y	3731			$K_y = \sqrt{\xi_y(y-y_f)^2 + \eta_y(y-y_f)(p_y - p_{yf}) + \zeta_y(p_x - p_{xf})^2}$	
ζ_y	3732				
y_f	3733				
p_{yf}	3734				
ξ'_x	3735				
η'_x	3736			Parameters for K'_x	
ζ'_x	3737			$K'_x = \sqrt{\xi'_x(x-x'_f)^2 + \eta'_x(x-x'_f)(p_x - p'_{xf}) + \zeta'_x(p_x - p'_{xf})^2}$	
x'_f	3738				
p'_{xf}	3739				
ξ'_y	3740				
η'_y	3741			Parameters for K'_y	
ζ'_y	3742			$K'_y = \sqrt{\xi'_y(y-y'_f)^2 + \eta'_y(y-y'_f)(p_y - p'_{yf}) + \zeta'_y(p_y - p'_{yf})^2}$	
y'_f	3743				
p'_{yf}	3744				

Initial Print Format

	Col. 1	Col. 2	Col. 3	Col. 4	Col. 5
0	Program #	Run #			
1	N	n_{RK}	a		
2	N_p	N_e			
3	N_I	N_{I_p}	N'_{I_p}		
4	ξ_x	η_x	ζ_x	x_f	P_{xf}
5	ξ_y	η_y	ζ_y	y_f	P_{yf}
6	ξ'_x	η'_x	ζ'_x	x'_f	P'_{xf}
7	ξ'_y	η'_y	ζ'_y	y'_f	P'_{yf}
8	i_{max}	m_{max}	j_{max}		
9	$(C_p)_o$	$(C_e)_o$	$(C_I)_o$	$(C'_I)_o$	
10	$p_{x\,max} = p_{y\,max}$	x_{max}	y_{max}	P	λ
11	p_{xo}	p_{yo}	x_o	y_o	$(N\theta/2\pi)_o$
12	k_4	k_3	k_2	k_1	k_0
13	K_4	K_3	K_2	K_1	K_0
14	$\mu_{0,15,4}$	$\mu_{0,15,3}$	$\mu_{0,15,2}$	$\mu_{0,15,1}$	$\mu_{0,15,0}$
15	$\mu_{0,14,4}$	$\mu_{0,14,3}$	$\mu_{0,14,2}$	$\mu_{0,14,1}$	$\mu_{0,14,0}$
16	$\mu_{0,13,4}$	$\mu_{0,13,3}$	$\mu_{0,13,2}$	$\mu_{0,13,1}$	$\mu_{0,13,0}$
17	$\mu_{0,12,4}$	$\mu_{0,12,3}$	$\mu_{0,12,2}$	$\mu_{0,12,1}$	$\mu_{0,12,0}$
18	$\mu_{0,11,4}$	$\mu_{0,11,3}$	$\mu_{0,11,2}$	$\mu_{0,11,1}$	$\mu_{0,11,0}$
19	$\mu_{0,10,4}$	$\mu_{0,10,3}$	$\mu_{0,10,2}$	$\mu_{0,10,1}$	$\mu_{0,10,0}$
20	$\mu_{0,9,4}$	$\mu_{0,9,3}$	$\mu_{0,9,2}$	$\mu_{0,9,1}$	$\mu_{0,9,0}$
21	$\mu_{0,8,4}$	$\mu_{0,8,3}$	$\mu_{0,8,2}$	$\mu_{0,8,1}$	$\mu_{0,8,0}$
22	$\mu_{0,7,4}$	$\mu_{0,7,3}$	$\mu_{0,7,2}$	$\mu_{0,7,1}$	$\mu_{0,7,0}$
23	$\mu_{0,6,4}$	$\mu_{0,6,3}$	$\mu_{0,6,2}$	$\mu_{0,6,1}$	$\mu_{0,6,0}$
24	$\mu_{0,5,4}$	$\mu_{0,5,3}$	$\mu_{0,5,2}$	$\mu_{0,5,1}$	$\mu_{0,5,0}$
25	$\mu_{0,4,4}$	$\mu_{0,4,3}$	$\mu_{0,4,2}$	$\mu_{0,4,1}$	$\mu_{0,4,0}$
26	$\mu_{0,3,4}$	$\mu_{0,3,3}$	$\mu_{0,3,2}$	$\mu_{0,3,1}$	$\mu_{0,3,0}$
27	$\mu_{0,2,4}$	$\mu_{0,2,3}$	$\mu_{0,2,2}$	$\mu_{0,2,1}$	$\mu_{0,2,0}$
28	$\mu_{0,1,4}$	$\mu_{0,1,3}$	$\mu_{0,1,2}$	$\mu_{0,1,1}$	$\mu_{0,1,0}$
29	$\mu_{0,0,4}$	$\mu_{0,0,3}$	$\mu_{0,0,2}$	$\mu_{0,0,1}$	$\mu_{0,0,0}$
30	$\nu_{0,15,4}$	$\nu_{0,15,3}$	$\nu_{0,15,2}$	$\nu_{0,15,1}$	$\nu_{0,15,0}$
31	$\nu_{0,14,4}$	$\nu_{0,14,3}$	$\nu_{0,14,2}$	$\nu_{0,14,1}$	$\nu_{0,14,0}$
32	$\nu_{0,13,4}$	$\nu_{0,13,3}$	$\nu_{0,13,2}$	$\nu_{0,13,1}$	$\nu_{0,13,0}$
33	$\nu_{0,12,4}$	$\nu_{0,12,3}$	$\nu_{0,12,2}$	$\nu_{0,12,1}$	$\nu_{0,12,0}$
34	$\nu_{0,11,4}$	$\nu_{0,11,3}$	$\nu_{0,11,2}$	$\nu_{0,11,1}$	$\nu_{0,11,0}$
35	$\nu_{0,10,4}$	$\nu_{0,10,3}$	$\nu_{0,10,2}$	$\nu_{0,10,1}$	$\nu_{0,10,0}$
36	$\nu_{0,9,4}$	$\nu_{0,9,3}$	$\nu_{0,9,2}$	$\nu_{0,9,1}$	$\nu_{0,9,0}$
37	$\nu_{0,8,4}$	$\nu_{0,8,3}$	$\nu_{0,8,2}$	$\nu_{0,8,1}$	$\nu_{0,8,0}$
38	$\nu_{0,7,4}$	$\nu_{0,7,3}$	$\nu_{0,7,2}$	$\nu_{0,7,1}$	$\nu_{0,7,0}$
39	$\nu_{0,6,4}$	$\nu_{0,6,3}$	$\nu_{0,6,2}$	$\nu_{0,6,1}$	$\nu_{0,6,0}$
40	$\nu_{0,5,4}$	$\nu_{0,5,3}$	$\nu_{0,5,2}$	$\nu_{0,5,1}$	$\nu_{0,5,0}$
41	$\nu_{0,4,4}$	$\nu_{0,4,3}$	$\nu_{0,4,2}$	$\nu_{0,4,1}$	$\nu_{0,4,0}$
42	$\nu_{0,3,4}$	$\nu_{0,3,3}$	$\nu_{0,3,2}$	$\nu_{0,3,1}$	$\nu_{0,3,0}$
43	$\nu_{0,2,4}$	$\nu_{0,2,3}$	$\nu_{0,2,2}$	$\nu_{0,2,1}$	$\nu_{0,2,0}$
44	$\nu_{0,1,4}$	$\nu_{0,1,3}$	$\nu_{0,1,2}$	$\nu_{0,1,1}$	$\nu_{0,1,0}$
45	$\nu_{0,0,4}$	$\nu_{0,0,3}$	$\nu_{0,0,2}$	$\nu_{0,0,1}$	$\nu_{0,0,0}$

ILL TEMPERED FIVE (Program 175)

Program Stops

STOP NO.	INSTRUCTION	LOCATION (OCTAL)	REASON FOR STOP
1.	HTR 1 000000000001	02403	Square Root Error Return
2.	HTR 1 000000000001	02431	Square Root Error Return
3.	HTR 1 000000000001	02562	Square Root Error Return ($\sqrt{P^2 - p_x^2 - p_y^2}$ negative)
4.	HTR 2 000000000002	02572	Logarithm Error Return
5.	HTR 3 000000000003	02607	Exponential Error Return
6.	HPR 63 042000000077	05703	$i_{max} = 0$ or > 12
7.	HPR 63 042000000077	05710	$m_{max} > 15$
8.	HPR 63 042000000077	05715	$j_{max} > 4$
9.	HPR 4095 042000007777	05674	$\mu_{o,\ m,\ j} \equiv \nu_{o,\ m,\ j} \equiv 0$ for all m, j
10.	HPR 7 042000000007	02030	SS1 UP, end of integration cycle
11.	HPR 1 042000000001	02767	SS6 UP, end of search
12.	HTR 1001 000000001751	02106	STOPINHERE card is missing
13.	HTR 1001 000000001751	02113	STOPFLOPHERE card is missing
14.	HTR 32767 000000077777	02122	OSTOPIT card just read, end of series
15.	HPR 32256 042000077000	06320	$\lvert\mu'_{i,\ m,\ j}\rvert$ or $\lvert\nu'_{i,\ m,\ j}\rvert > 2^{125}$
16.	HPR 32263 042000077007	03122	$\lvert\mu'_{i,\ m}\rvert, \lvert\nu'_{i,\ m}\rvert, \lvert\alpha'_{i,\ m}\rvert$ or $\lvert\beta'_{i,\ m}\rvert > 2^{125}$
17.	HPR 511 042000000777	02500	$\left(\frac{y}{a+x}\right), \left(\frac{y}{a+x}\right)^2$ Overflow stop