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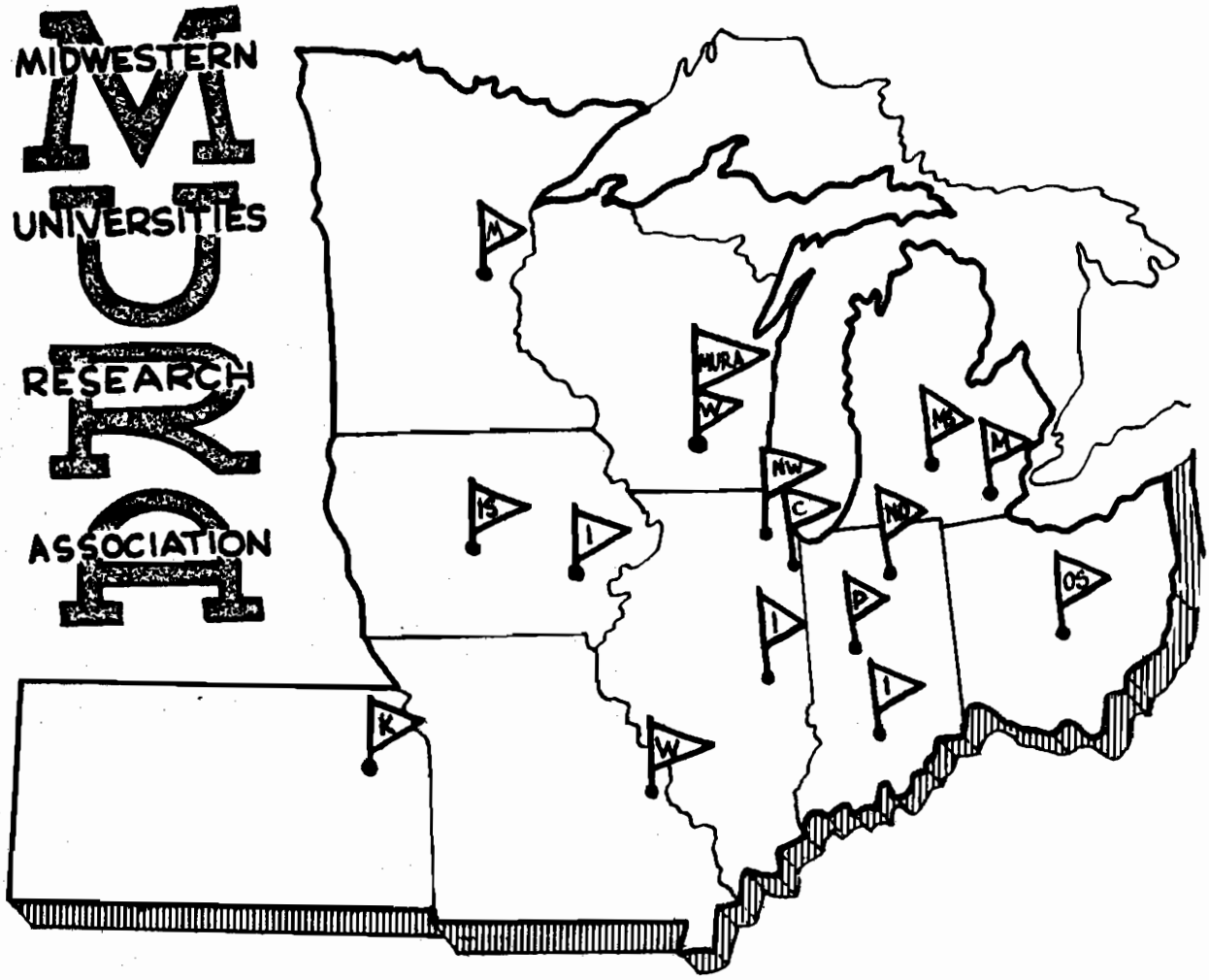


REPORT

UNICYL
(Program Library)
August 1961

NUMBER 617

Computer Program
(Internal)

DISCLAIMER
Although this program has been carefully tested by its contributor, no guarantee is made of its correct functioning under all conditions, and no responsibility is taken by him in case of possible failure.

UNICYL
(Program F47)
G. A. Westlund

UNICYL calculates magnetic field potentials via relaxation on a three-dimensional mesh. At present it is composed of four separate programs, namely F47L, F47, F47C, and F47Y. Other programs are expected to be added to the list to handle various types of output.

F47L

F47L is the load program. It produces a tape to be used by F47 during the actual relaxation. This tape contains the boundary and current values in up to 100 records of 7,000 words each. Each record contains information for one K plane (see diagram in Figure 1). The first 2,500 words contain current values in air, permeability (μ) values in iron (plus pole only), and current values for each J plane in iron. The remaining 4,500 words (maximum) contain potentials across the entire K plane.

Because of core space limitations, the maximum number of I, J, K planes in the mesh is restricted to 99, 45, 100. The maximum number of planes permitted within coil regions is 99, 25, 100.

Figure 1 shows a distorted perspective view of the problem region. The heavy lines denote iron-air boundaries. The dotted lines indicate hidden iron-air boundaries and problem limits (in air).

Figure 2 defines the I, J, K boundary parameters. Note that the origin for the three coordinate axes is (1, 1, 1) rather than (0, 0, 0). The median plane becomes the plane J = 1. If $K_3 = K_4$, it is assumed that the slot shown does not exist. Similarly, if $K_1 = K_2$, or $K_5 = K_6$, the corresponding lip does not exist.

Figure 3 defines the copper-air boundary parameters. If $C_{K1} = C_{K2}$, or $C_{K3} = C_{K4}$, it is assumed that the current winding is replaced by a two-dimensional sheet from C_{I1} to C_{I4}.

F47L can operate in one of two modes. Either a blank tape is to be loaded with iron boundaries and one or more coils, or a previously loaded tape is to be updated with additional coils. If sense switch one is up, an original load is assumed. The tape to be prepared is mounted on tape drive 4. The program deck (F47L) is loaded via the card reader, followed by load parameters. These parameters, with their corresponding loading addresses, are listed on page 2. These load parameters are followed by an "end data" card, then one or more groups of coil parameters, each terminated by an "end data" card. Coil parameters are listed on page 3.

If sense switch 1 is down, an updating load is assumed. The reading of load parameters is bypassed, and only coil parameters are processed. The tape to be prepared is mounted on tape drive 4, and the original tape that was previously loaded is mounted on tape drive 3.

All parameters should be entered on the standard MURA-FORTRAN agendum sheets.

NOTE: The last group of coil parameters should be terminated by only one "end data" card.

LOAD PARAMETERS

Address	Parameter	Address	Parameter
1	Load ID No.	62	K_3
2	μ	63	K_4
3		64	K_5
.	(Halving)		
.	( )		
.	(Parameters)	65	K_6
.			
.			
45		66	K_7
51	I_1	67	$h = \Delta \xi$
52	I_2	68	$\ell = \Delta \eta$
53	I_3	69	$p = \Delta \theta_{max}$
54	I_4	70	M
55	J_1	71	N
56	J_2	72	$\kappa = \frac{1}{w}$
57	J_3	73	k
58	J_4	("PUNICYL" ONLY) → 46	PRE-PRE ID FOR SMALLER K
59	J_5	47	PRE-PRE ID FOR LARGER K
60	K_1	48	ZERO POLE BEVEL
61	K_2	50	PLUS POLE BEVEL

The load ID number can be any positive integer less than 32,768. μ is the finite permeability. The "halving parameters" are entered in pairs to denote interval spacing between K planes. The first number of each pair gives the interval size to be used up to the value of K given by the second number. Interval sizes can be 1.0, 0.5, or 0.25. They are entered at the odd addresses from 3 to 49 (as many as are required). The even addresses receive values of K where the interval size changes (The first plane is assumed to be at K = 1). The last even address used must receive a value equal to K_7. Only doubling or halving is permitted at any interval size change (a change from 1 to 1/4 or vice versa is not permitted). The interval size must remain constant for at least two intervals between consecutive values at even addresses. I_1, I_2, I_3, and I_4 must be integers, with $I_1 \geq 4$, $I_4 \leq 99$. J_1, J_2, J_3, J_4, and J_5 must be integers, with $J_5 \leq 45$. K_1 through K_6 can be fractional if processing with finite permeability is not desired. Otherwise K_1 through K_6 must be coincident with K planes described by the halving parameters. K_7 must be a multiple of 1/4, and equal the last entered halving parameter. $K_7 \leq 100$. h, ℓ, and p are the distances between planes in the I, J, K directions (for interval sizes = 1.0).

NOTE: The plane $K = K_7$ has multiplicative periodicity with an imaginary plane just before the plane K = 1.

COIL PARAMETERS

Address	Parameter
1	Coil ID No.
2	C_{I1}
3	C_{I2}
4	C_{I3}
5	C_{I4}
6	C_{J1}
7	C_{J2}
8	C_{K1}
9	C_{K2}
10	C_{K3}
11	C_{K4}
12	V_o

The coil ID number can be any positive integer less than 32,768. C_{I1} - C_{I4} and C_{K1} - C_{K4} may be fractional, but C_{J1} and C_{J2} must be integers (see Fig. 3). is the current through the coil windings.

The following restrictions must be met: $C_{J1} \geq (J_1 + 2)$, $C_{J1} \geq J_2$.

A maximum of 50 coils can be specified during a load operation. The parameters of one coil are separated from those of the next coil by an "end data" card.

<u>NOTE</u>: The parameters of the last entered coil must be terminated by <u>only one</u> "end data" card.

Current values for each coil are added to the mesh via the following formulae:

$CV = \mathcal{E} + X + Y + Z$, where

$$\mathcal{E} = \left(\frac{2\pi^2 \ell^2}{(\frac{1}{w})^2 + N^2}\right)\left(\frac{V_0(J-1)}{C_{J2}-C_{J1}}\right)\left(\frac{C_{I4} - I + \frac{1}{w}/2\pi h}{C_{I4}-C_{I3}}\right) \quad \text{in region I} \tag{c1}$$

$$\mathcal{E} = \left(\frac{2\pi^2 \ell^2}{(\frac{1}{w})^2 + N^2}\right)\left(\frac{V_0(J-1)}{C_{J2}-C_{J1}}\right)\left(\frac{K - C_{K1}}{C_{K2}-C_{K1}}\right) \quad \text{in region II} \tag{c2}$$

$$\mathcal{E} = \left(\frac{2\pi^2 \ell^2}{(\frac{1}{w})^2 + N^2}\right)\left(\frac{V_0(J-1)}{C_{J2}-C_{J1}}\right)\left(\frac{I - C_{I1} - \frac{1}{w}/2\pi h}{C_{I2}-C_{I1}}\right) \quad \text{in region III} \tag{c3}$$

$$\mathcal{E} = \left(\frac{2\pi^2 \ell^2}{(\frac{1}{w})^2 + N^2}\right)\left(\frac{V_0(J-1)}{C_{J2}-C_{J1}}\right)\left(\frac{C_{K4} - K}{C_{K4}-C_{K3}}\right) \quad \text{in region IV} \tag{c4}$$

$$C_{J1} < J < C_{J2}$$

$$X = \frac{N_1(A(C_{I4} - I) - B) - N_{++0} D}{C_{I4} - C_{I3}} \quad \text{in region I} \tag{c5}$$

$$X = \frac{N_1 A (K - C_{K1})}{C_{K2} - C_{K1}} \quad \text{in region II} \tag{c6}$$

$$X = \frac{N_1(A(I - C_{I1}) + B) + N_{++0} D}{C_{I2} - C_{I1}} \quad \text{in region III} \tag{c7}$$

$$X = \frac{N_1 A (C_{K4} - K)}{C_{K4} - C_{K3}} \quad \text{in region IV} \tag{c8}$$

$$J = C_{J1}, \quad J = C_{J2}$$

$X = 0$ if $J \neq C_{J1}$ or C_{J2}

where $\mathcal{D}_0 = (\frac{1}{w})^2 + N^2$, $N_{++0} = -\frac{\pi \ell^2 (J-1)}{2\pi w \mathcal{D}_0 h}$, $D = \frac{2V_0}{C_{J2} - C_{J1}}$,

on plane C_{J1}: $N_1 = N_{0+0} = \frac{1}{2}\left(1 + \frac{4\pi^2}{\mathcal{D}_0}\left([J-1]\ell\right)^2\right) + \frac{\pi^2\ell^2}{\mathcal{D}_0}(J-1)$

$$A = \frac{V_0}{C_{J2} - C_{J1}}$$

$$B = \frac{\frac{1}{w}\ell^2 V_0 (C_{J1} - 1)}{4\pi(C_{J2} - C_{J1})\left(\frac{\mathcal{D}_0}{4\pi^2} + \ell^2(C_{J1} - 1)^2\right)h}$$

on plane C_{J2}: $N_1 = N_{0-0} = \frac{1}{2}\left(1 + \frac{4\pi^2}{\mathcal{D}_0}\left([J-1]\ell\right)^2\right) - \frac{\pi^2\ell^2}{\mathcal{D}_0}(J-1)$

$$A = \frac{-V_0}{C_{J2} - C_{J1}}$$

$$B = \frac{\frac{1}{w}\ell^2 V_0 (C_{J2} - 1)}{4\pi(C_{J2} - C_{J1})\left(\frac{\mathcal{D}_0}{4\pi^2} + \ell^2(C_{J2} - 1)^2\right)h}$$

$$Y = \frac{N_{0+0} V_0}{C_{J2} - C_{J1}} - \frac{\pi^2\ell^2(J-1)V_0}{\mathcal{D}_0(C_{J2} - C_{J1})} \quad \text{at } J = C_{J1} \tag{c9}$$

$$Y = \frac{-N_{0+0} V_0}{C_{J2} - C_{J1}} - \frac{\pi^2\ell^2(J-1)V_0}{\mathcal{D}_0(C_{J2} - C_{J1})} \quad \text{at } J = C_{J2} \tag{c10}$$

$$Z = \frac{2\pi^2\ell^2(J-1)V_0}{\mathcal{D}_0(C_{J2} - C_{J1})} \quad \text{for } C_{J1} < J < C_{J2} \tag{c11}$$

in air, where $C_{I2} \leq I \leq C_{I3}$, and $C_{K2} \leq K \leq C_{K3}$

Potentials are added to the mesh for each coil via the following formulae:

$V = V_0$ in iron where $C_{I2} \leq I \leq C_{I3}$ and $J_1 \leq J \leq C_{J1}$ and $C_{K2} \leq K \leq C_{K3}$ (includes points in a lip at $K_1 \leq K \leq C_{K3}$ if $C_{K2} \leq K_2$, or at $C_{K2} \leq K \leq K_6$ if $C_{K3} \leq K_5$) (V1)

$V = V_0\left(\frac{C_{J2} - J}{C_{J2} - C_{J1}}\right)$ at all points where $C_{I2} \leq I \leq C_{I3}$ and $C_{J1} \leq J < C_{J2}$ and $C_{K2} \leq K \leq C_{K3}$ (V2)

$$V = V_0\left(\frac{C_{J2} - J}{C_{J2} - C_{J1}}\right)\left(\frac{C_{I4} - I}{C_{I4} - C_{I3}}\right) \quad \text{in region I} \qquad \text{(V3)}$$

$$V = V_0\left(\frac{C_{J2} - J}{C_{J2} - C_{J1}}\right)\left(\frac{K - C_{K1}}{C_{K2} - C_{K1}}\right) \quad \text{in region II} \qquad \text{(V4)}$$

$$V = V_0\left(\frac{C_{J2} - J}{C_{J2} - C_{J1}}\right)\left(\frac{I - C_{I1}}{C_{I2} - C_{I1}}\right) \quad \text{in region III} \qquad \text{(V5)}$$

$$V = V_0\left(\frac{C_{J2} - J}{C_{J2} - C_{J1}}\right)\left(\frac{C_{K4} - K}{C_{K4} - C_{K3}}\right) \quad \text{in region IV} \qquad \text{(V6)}$$

at $C_{J1} \leq J < C_{J2}$

$$V = V_0\left(\frac{J-1}{J_1 - 1}\right) \quad \text{at } 1 < J < J_1 \text{ for all points in air above the flue gole where } C_{I2} \leq I \leq C_{I3} \text{ and } C_{K2} \leq K \leq C_{K3} \qquad \text{(V7)}$$

$$V = V_0\left(\frac{J-1}{C_{J1} - 1}\right) \quad \text{at } 1 < J < C_{J1} \text{ for all points in air } \underline{\text{not}} \text{ above the flue gole where } C_{I2} \leq I \leq C_{I3} \text{ and } C_{K2} \leq K \leq C_{K3} \qquad \text{(V8)}$$

$$V = V_0\left(\frac{J-1}{C_{J1} - 1}\right)\left(\frac{C_{I4} - I}{C_{I4} - C_{I3}}\right) \quad \text{above region I} \qquad \text{(V9)}$$

$$V = V_0\left(\frac{J-1}{C_{J1} - 1}\right)\left(\frac{K - C_{K1}}{C_{K2} - C_{K1}}\right) \quad \text{above region II} \qquad \text{(V10)}$$

$$V = V_0\left(\frac{J-1}{C_{J1} - 1}\right)\left(\frac{I - C_{I1}}{C_{I2} - C_{I1}}\right) \quad \text{above region III} \qquad \text{(V11)}$$

$$V = V_0\left(\frac{J-1}{C_{J1} - 1}\right)\left(\frac{C_{K4} - K}{C_{K4} - C_{K3}}\right) \quad \text{above region IV} \qquad \text{(V12)}$$

at points in air for $1 < J < C_{J1}$ except above an iron lip ($K_1 \leq K \leq K_6$)

NOTE: Regions I and III include the points that fall on their diagonal boundaries, while regions II and IV do not (see Figure 3).
None of the regions include points that fall on their inner boundaries (C_{I1}, C_{K2}, C_{I2}, and C_{K3}).

Permeability (μ) is loaded in iron at $I_2 \leq I \leq I_3$, $J_1 \leq J \leq J_4$, $K_1 \leq K \leq K_3$ or $K_4 \leq K \leq K_6$, only if μ has not been loaded during a prior load.

Special terms are added to the mesh (in the zero pole at $C_{K2} \leq K \leq C_{K3}$ and $K_2 \leq K \leq K_3$, or $C_{K2} \leq K \leq C_{K3}$ and $K_4 \leq K \leq K_5$) as follows:

$$\Delta_+ = \frac{V_0}{C_{J2} - C_{J1}} \quad \text{for planes } C_{J1} \leq J \leq (C_{J2} - 1) \quad \text{at } I = 3$$

$$\Delta_- = \frac{-V_0}{C_{J2} - C_{J1}} \quad \text{for planes } (C_{J1} + 1) \leq J \leq C_{J2} \quad \text{at } I = 4$$

F47

F47 is the relaxation program. It uses a tape produced by F47L (see F47L for description of tape). This tape is mounted on tape drive 1. A total of 5 tapes is used by F47. Erasable tapes are mounted on drives 2, 3, 4 and 5.

After every even numbered iteration, tape 1 contains the updated potentials for that iteration, and may be used as a starting tape for F47 if the program should be interrupted before the next even iteration is complete.

The program deck (F47) is loaded via the card reader, followed by relaxation parameters, followed by an "end data" card. All parameters should be entered on the standard MURA-FORTRAN agendum sheets.

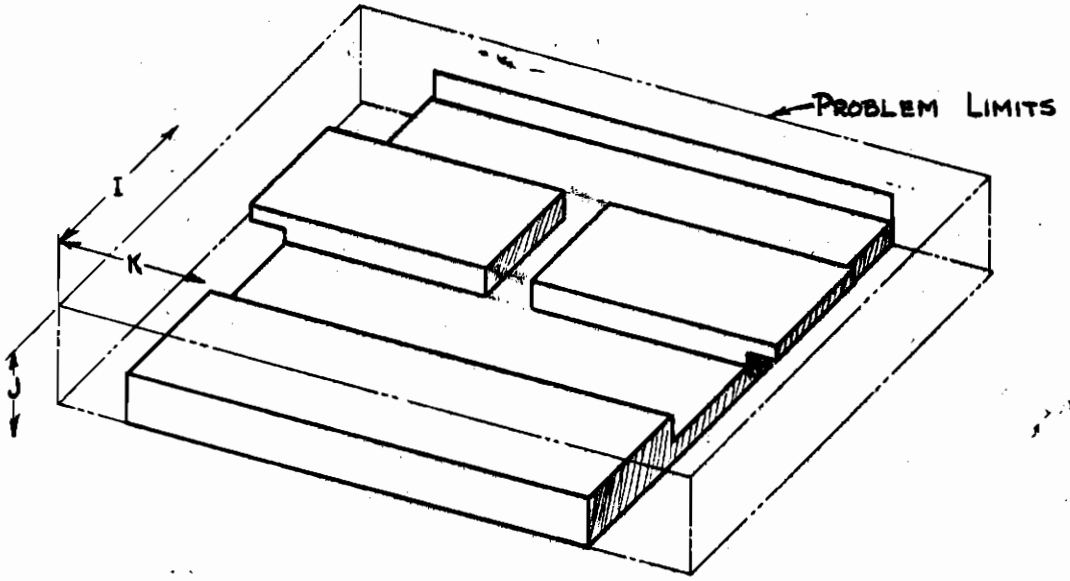
RELAXATION PARAMETERS

ADDRESS	PARAMETER
1	Relaxation ID No.
2	N_E
3	α
4	I_α
5	ϵ_α
6	ϵ_{RES}
7	A_μ
8	B_μ
9	r_o
10	i

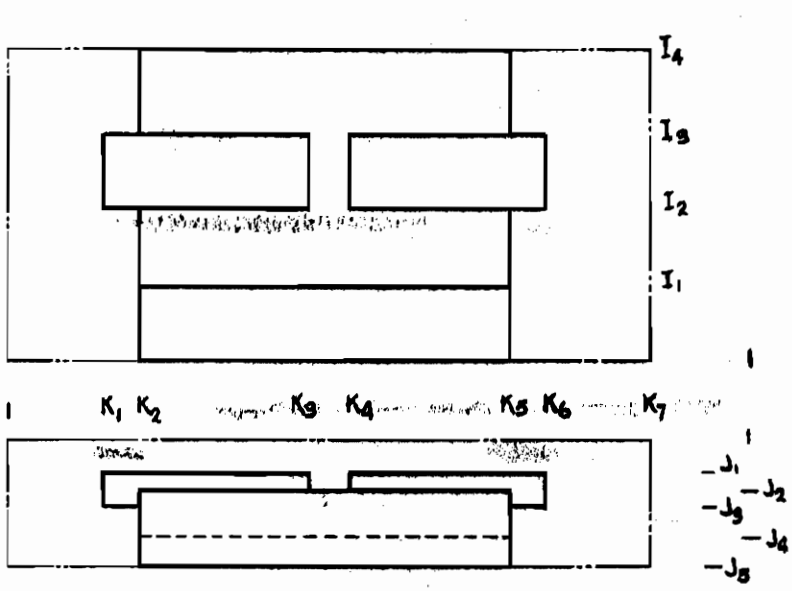
The relaxation ID number can be any positive integer less than 32,768. N_E is the total number of iterations to the end of the run. If $I_\alpha = 0$, α will be changed once if $\left|\sqrt{R_i/R_{i-1}} - \sqrt{R_{i-1}/R_{i-2}}\right| \leq \epsilon_\alpha$ where R_i is the sum of the residuals during iteration i. If $R_i \leq \epsilon_{RES}$, the run is terminated at the end of the i th iteration.

SENSE SWITCHES

1	UP =	Initial load by F47L
	DN =	Additional coil load by F47L
2	UP =	Residuals for every K-plane are printed on line at each iteration. Values of lambda are plotted at a normal stop.
	DN =	Total residual only is printed at each iteration. Values of lambda are not plotted.
3	-	Not used
4	UP =	Potentials on a K-plane are printed after it is processed.
	UP =	No potentials are printed.
5	UP =	Relaxation with finite permeability (for future use only - not completely built in at present)
	DN =	Normal relaxation
6	UP =	Interrupt F47 after the next even numbered iteration
	DN =	Continue to N_E iterations or residual convergence.


PROBLEM LIMITS
I
K
J

A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I2
I1
J2
J5
J1
J3
J4
J2
K1 K2
K3 K4
K5 K6
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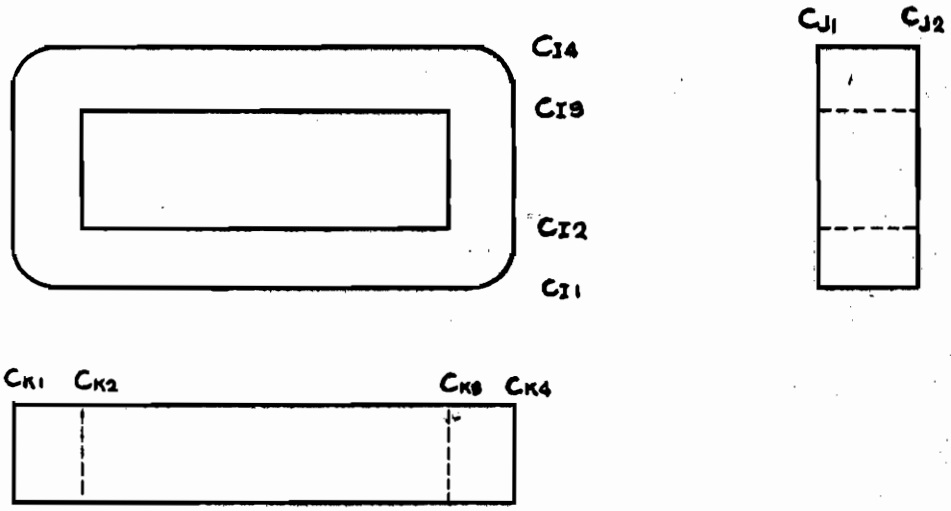
J2
J3
J4
J5

B


CI4
CI3
CI2
CI1
CJ1
CJ2
CK1 CK2
CK3 CK4

C