JAERI-M
7119

LOOM-P : A FINITE ELEMENT MESH GENERATION PROGRAM WITH ON-LINE GRAPHIC DISPLAY

June 1977

Takeharu ISE and Toshio YAMAZAKI*

日 本 原 子 力 研 究 所
Japan Atomic Energy Research Institute

LOOM-P: a Finite Element Mesh Generation Program with On-Line Graphic Display

Takeharu ISE and Toshio YAMAZAKI*

Division of Reactor Engineering, Tokai, JAERI

(Received May 23, 1977)

A description of the two-dimensional mesh generation program, LOOM-P, is given in detail. The program is developed newly to produce a mesh network for a reactor core geometry with the help of an automatic mesh generation routine built in it, under the control of the refresh-type graphic display. It is therefore similar to the edit program of the self-organizing mesh generator, QMESH-RENUM.

Additional techniques are incorporated to improve the pattern of mesh elements by means of on-line conversational mode. The obtained mesh network is edited out as input data to the three-dimensional neutron diffusion theory code, FEM-BABEL.

* Sumitomo Heavy Industries, Ltd.

LOOM－P：有限要素メッシュ自動作成プログラム

日本原子力研究所東海研究所原子炉工学部
伊勢　武治・山崎　俊雄*)

（1977年5月23日受理）

2次元平面に対する有限要素メッシュを自動的に作成するプログラムを開発した。LOOM－Pは自動メッシュ作成プログラムQMESH－RENUMの出力用プログラムに相当するもので，内蔵の自動メッシュ作成ルーチンと共に，原子炉炉心の有限要素メッシュ・ネットワークを作成する。更に，良い形状をした有限要素メッシュを得る為に，幾つかの機能が備えられている。これらは皆，グラフィック・ディスプレイ上で会話的に行われ，最後に，3次元中性子拡散計算コード・FEM－BABEL用のメッシュ・ネットワークを出力する。

*)　住友重機械工業株式会社

Contents

目　　次

1. Introduction

Recently, the finite element method[1] has widely been used for solving reactor physics problems as well as structure and hydrodynamics problems. Many computation programs have been developed for it but there still exists the difficulty to prepare an appropriate pattern of finite element meshes. Although several automatic mesh generating programs have been published so far[2∿10], there are few programs which are available. Among these, QMESH program [8∿10] seems the best mesh generator in view of techniques to produce improved shaped mesh elements, like the mesh smoothing and the mesh restructuring without user's interaction. In addition, the QMESH contains the bandwidth minimizing program, RENUM, as a companion program.

As the program is, however, made for general purposes, it produces quadrilateral mesh elements only. Therefore, we have developed an on-line atuomatic mesh generating program, LOOM-P, in order to produce also triangular mesh elements as an edit program to the QMESH-RENUM. The present program combines a mesh network produced by the automatic mesh generating routine built in it with a mesh network edited out of the QMESH-RENUM and then produces a complete network for a given body. Finally, the program rearranges the mesh data as the input data to the three-dimensional neutron diffusion theory code, FEM-BABEL[14], which has been already developed by us.

The LOOM-P is designed to feed the input data and to control the program on the CRT (direct viewing Cathod Ray Tube) display of the refresh-type graphical displaying apparatus, FACOM 6233A[12,13].

It is recommended that users unfamiliar to the graphic display should read all the following chapters but users familiar to the graphic display might skip the chapter 3.

2. Characteristics of the Program

Most power reactors have the azimuthal symmetry of one eight sector with a central angle of 45° shown in Fig. 1. Accordingly, we aimed at producing a mesh network to deal with the one eight sector. The sector, we call it as a body, can be devided into A-region of the inner fuel assemblies and Q-region of the outer fuel assemblies, the reflector and the reactor shroud, as shown in Fig. 2.

As the A-region has the regularity, the mesh generation is easily carried out through the automatic mesh generating routine built in the LOOM-P. In the other hand, the Q-region has a complex geometry, consisting of

1. Introduction

Recently, the finite element method[1] has widely been used for solving reactor physics problems as well as structure and hydrodynamics problems. Many computation programs have been developed for it but there still exists the difficulty to prepare an appropriate pattern of finite element meshes. Although several automatic mesh generating programs have been published so far[2∿10], there are few programs which are available. Among these, QMESH program [8∿10] seems the best mesh generator in view of techniques to produce improved shaped mesh elements, like the mesh smoothing and the mesh restructuring without user's interaction. In addition, the QMESH contains the bandwidth minimizing program, RENUM, as a companion program.

As the program is, however, made for general purposes, it produces quadrilateral mesh elements only. Therefore, we have developed an on-line atuomatic mesh generating program, LOOM-P, in order to produce also triangular mesh elements as an edit program to the QMESH-RENUM. The present program combines a mesh network produced by the automatic mesh generating routine built in it with a mesh network edited out of the QMESH-RENUM and then produces a complete network for a given body. Finally, the program rearranges the mesh data as the input data to the three-dimensional neutron diffusion theory code, FEM-BABEL[14], which has been already developed by us.

The LOOM-P is designed to feed the input data and to control the program on the CRT (direct viewing Cathod Ray Tube) display of the refresh-type graphical displaying apparatus, FACOM 6233A[12,13].

It is recommended that users unfamiliar to the graphic display should read all the following chapters but users familiar to the graphic display might skip the chapter 3.

2. Characteristics of the Program

Most power reactors have the azimuthal symmetry of one eight sector with a central angle of 45° shown in Fig. 1. Accordingly, we aimed at producing a mesh network to deal with the one eight sector. The sector, we call it as a body, can be devided into A-region of the inner fuel assemblies and Q-region of the outer fuel assemblies, the reflector and the reactor shroud, as shown in Fig. 2.

As the A-region has the regularity, the mesh generation is easily carried out through the automatic mesh generating routine built in the LOOM-P. In the other hand, the Q-region has a complex geometry, consisting of

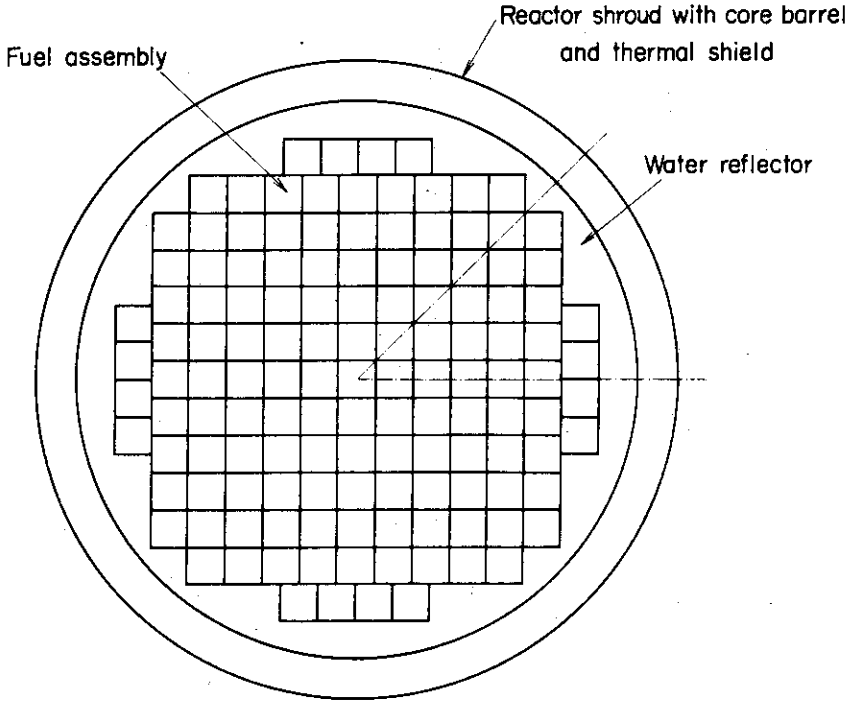

Fig. 1 Top view of a 1420 MW pressurized water cooled power reactor

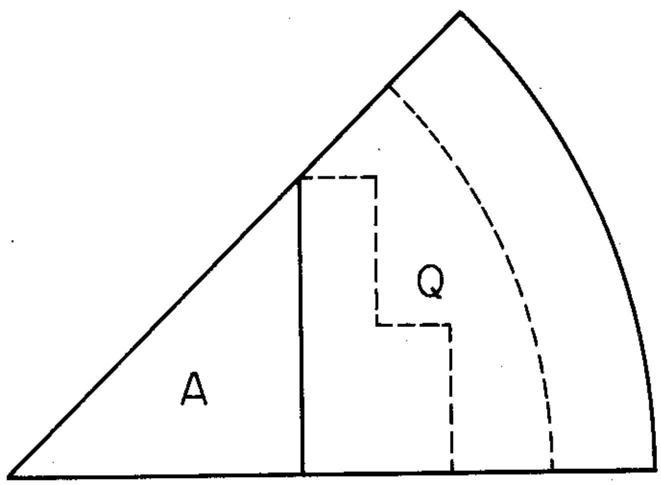

Fig. 2 One eighth core geometry for mesh generation

the regular fuel part, the water reflector part and the annular shroud part. The mesh generation is therefore carried out through another automatic mesh generation program, QMESH (mesh generation) and RENUM (renumbering the generated mesh network)[8,9,10].

Moreover, the following techniques are incorporated into the program; As there may exist local parts in A-region where the neutron flux changes drastically due to the strong absorber, it will need to have finer mesh elements locally. In that case users can devide any (rectangular) mesh element into two triangular meshes by picking it with the light-sensitive pen on the CRT display. For Q-region, one can use for regular part the same technique as mentioned above for A-region and moreover one can improve the mesh element shape by moving a node with the light pen "tracking" and/or by dividing automatically quadrilateral elements into triangular meshes.

The program finally combines A-region with Q-region to complete the mesh network for a given geometry and then produce the input data to the FEM-BABEL[14], on file unit 10 for nodes list, coordinates list and elements list (NAUTO=3 in No.18 in 1$), and on file unit 1 instead of punching out for region numbers list (10$) and boundary nodes list (15$). The printer edits the number of node points, the number of finite elements, the number of bandwidth, the number of regions and the number of boundary node points. In addition, it edits the lists of boundary node points, internal node points, their x- and y-coordinates, finite elements, and region numbers in a table.

2.1 Mesh Generation of A-Region

According to keying-in "NX", the number of divisions in the x-side and "XL", the length of the x-side (in cm), on the character key board of the graphic display apparatus, the mesh network is generated accordingly to a rule illustrated in Fig. 3. The key-in can be repeated until the key-in NX = "0".

When one picks the mark ◇ within a mesh element, the mesh element is devided into two triangular elements and then the element numbers are renumbered by adding one to the previous numbers, as shown in Fig. 4. The element deviding ends when picked "END" in the menu on the display.

The material region number is registered in the program as "1" for A-region.

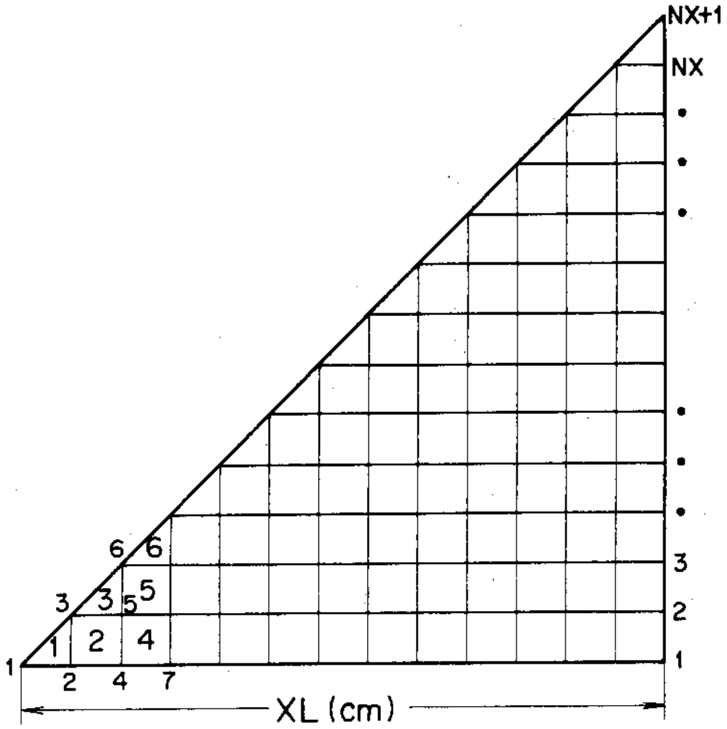

Fig. 3 Mesh network for A-region

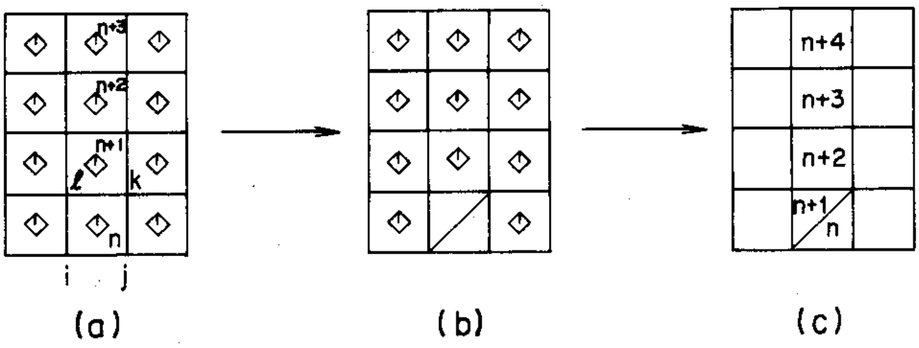

Fig. 4 Element deviding; (a) pick ◇ in the n-th element, (b) after picked, (c) renumbered

2.2 Mesh Generation of Q-Region

The Q-region is composed of Q1-subregion of rectangular mesh elements and Q2-subregion of quadrilateral mesh elements, as shown in Fig. 5.

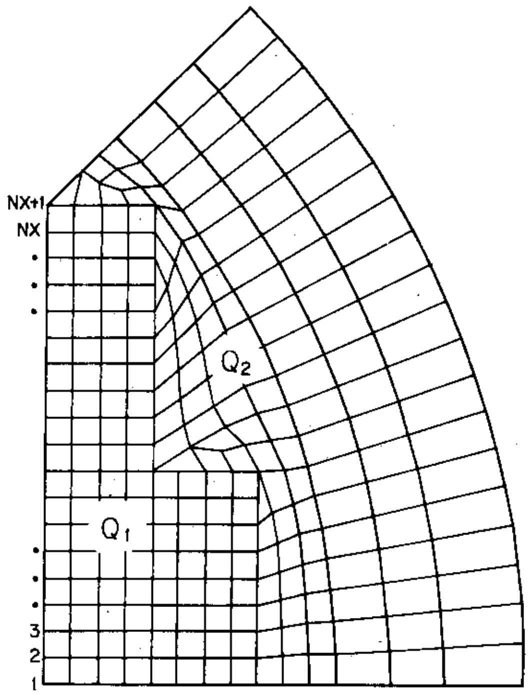

Fig. 5 Mesh network for Q-region

Although the mesh network of Q-region appears laborious to be generated, it can be produced by using sophiscatedly the self-organized mesh generator QMESH-RENUM. It is noted that the nodes are numbered from bottom to top as illustrated in Fig. 5 and the list of nodes on the leftest side must coincide with that on the rightest side of A-region.

Some additional notes are described about the QMESH-RENUM; One should use the JAERI version[11], which is a little modified to input with 12A4 format for COMMEN card. The meaning of the material number in REGION card is extented as follows. One should input negative integers for the sub-regions to which "element deviding" is applied and positive integers for the subregions to which "node moving" is applied. In Fig. 5, Q1-subregion has been specified as the region to be "element devided" and Q2-subregion as the region to be "node moved". The description of "element deviding" has already given in the chapter 2.1.

The "node moving" is carried out by moving a node picked by the light pen as shown in Fig. 6. This function is used in order to improve the mesh network when user does not satisfy the present mesh elements. The

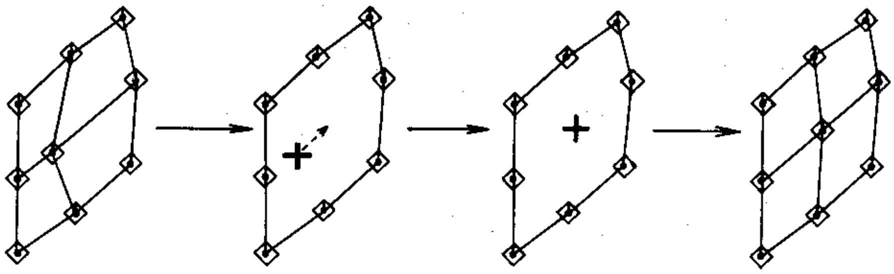

Fig. 6 Node moving; (a) pick a node ◇ ,
(b) the symbol + appears, (c) more + to the desired position, (d) the resulting mesh network

node moving can be repeated until user picks "END" in the menu. After finished these operations, "Automatic deviding" begins.

The "automatic deviding" is performed according to the following rule. The lengths of two diagonals are compared with each other and then the shorter diagonal is taken up as shown in Fig. 7. In other words, on the segments $\bar{P}$ and $\bar{Q}$ as

$$\bar{P} = \sqrt{(x_i - x_k)^2 + (y_i - y_k)^2}$$

$$\bar{Q} = \sqrt{(x_j - x_\ell)^2 + (y_j - y_\ell)^2}$$

then $\bar{L} = \min(\bar{P}, \bar{Q})$ is the diagonal to devide the quadrilateral into two triangular mesh elements.

Soon after automatic devidings, the node numbers are newly renumbered according to the rule shown in Fig. 7.

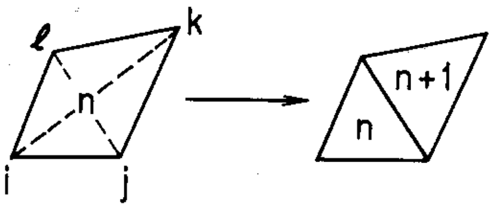

Fig. 7 Automatic deviding

The input data to the QMESH-RENUM for a sample problem are shown in Fig. 8.1, the corresponding inputted geometry in Fig. 8.2, and the generated mesh network in Fig. 8.3. It is noted that the subegions having negative material numbers are R_4, R_8 and R_9 shown in Fig. 8.2.

As the material region number "1" has already been assigned for A-

```
....*....1....*....2....*....3....*....4....*....5....*....6....*....7....*....8

*NO          M123.                                                      /P*RZONE2
                                                                       T,1/TIME  20
                                                                       C,4/CORE 256
                                                                       W,1/PAGE  80
                                                                       P,0/PCH    0
                                                                         ./
                                                                       C35/
*GJOB     2111223,T.ISL,446.12,SHINER                                    /00331
*HLIEDRUN   J1223,@MESH,RBSPC=100,FBTRK=300,DIRCT=100,SPCE2=100,NAME=1
*DISKTN  F08,J1223,P*RZONE2
*DISKTN  F55,J1223,P*RZONE
*DATA
COMMEN       SAMPLE DATA PWR 1420M* 1/8 CORE, ZONE  2                   P*R1420M
POINT            1=     13.0       0.0               1                   *
POINT            2=     14.5       0.0               1                   1/8 LOIS
POINT            3=   10.253    10.253               1                   3,C-REGN
POINT            4=      9.0       9.0               1
POINT            5=     11.0       9.0               1
POINT            6=     11.0       4.0               1
POINT            7=     13.0       4.0               1
POINT            8=      0.0       0.0
POINT            9=   13.697    4.1374
POINT           10=  11.4425     8.906
POINT           11=      9.0       0.0               1
POINT           12=     15.5       0.0               1
POINT           13=     16.5       0.0               1
POINT           14=     18.0       0.0               1
POINT           15=    10.96     10.96               1
POINT           16=   11.667    11.667               1
POINT           17=   12.728    12.728               1
POINT           18=     11.0       0.0               1
POINT           19=      9.0       4.0               1
LINE             1=  1    2         3        1.0     1
LINE   CIRC      2=  2    9    8    7        1.0     1
LINE             3=  3    4         4        1.0     1
LINE             4=  4    5         4        1.0     1
LINE             5=  5    6        10        1.0     1
LINE             6=  6    7         4        1.0     1
LINE             7=  7    1         8        1.0     1
LINE   CIRC      8=  9   10    8    9        1.0     1
LINE   CIRC      9= 10    3    8    3        1.0     1
LINE            10=  5   10         1
LINE            11=  7    9         2
LINE            12= 11   18         4                1
LINE            13= 19   11         8        1.0     1
LINE   CIRC     14= 12   15    8   19        1.0     1
LINE   CIRC     15= 13   16    8   19        1.0     1
LINE   CIRC     16= 14   17    6   19        1.0     1
LINE            17=  2   12         1        1.0     1
LINE            18= 12   13         1        1.0     1
LINE            19= 13   14         1        1.0     1
LINE            20=  3   15         1        1.0     1
LINE            21= 15   16         1        1.0     1
LINE            22= 16   17         1        1.0     1
LINE            23=  6   18         8
LINE            24= 18    1         4                1
LINE            25=  6   19         4
LINE            26=  4   19        10                1
REGION    2      1=  -1   -2  -11   -7
REGION    2      2=  -8  -10   -5   -6  -11
REGION    2      3=  -9   -3   -4  -10
REGION   -6      4= -23  -25  -13  -12
REGION    3      5= -17  -14  -20   -9   -8   -2
REGION    4      6= -18  -15  -21  -14
REGION    5      7= -19  -16  -22  -15
REGION   -6      8= -24   -7   -6  -23
REGION   -6      9=  -5   -4  -26  -25
SCHEME             JJJ R(SR)LB
SCHEME           4 LB
SCHEME           6 LB
SCHEME           9 LB
END
*HLIEDRUN   RFNAME=J0051,@PLOT,GRFD=ON,COMLIB=CALL,NAME=2               @PLOT
*DISKTO  F01,J1223,P*RZONE
*GCOM35
*DATA
REGION
     2REGION=1                                                          EXAMP8
     2REGION=2                                                          EXAMP8
     2REGION=3                                                          EXAMP8
     2REGION=4                                                          EXAMP8
     2REGION=5                                                          EXAMP8
     2REGION=6                                                          EXAMP8
     2REGION=7                                                          EXAMP8
     2REGION=8                                                          EXAMP8
     2REGION=9                                                          EXAMP8
     81420M* 1/8 CORE ZONE2
*HLIEDRUN   J1223,RENUM,NAME=3                                          RENUM
*DISKTO  F08,J1223,P*RZONE2                                             @MESH
*DISKTN  F09,J1223,PWRZON                                               TO FEM
*DISK  F10
*DATA
P-L-P          11   13   19   26    4
DUMP
END
*JEND
```

Fig. 8.1 Input cards set up for a sample problem

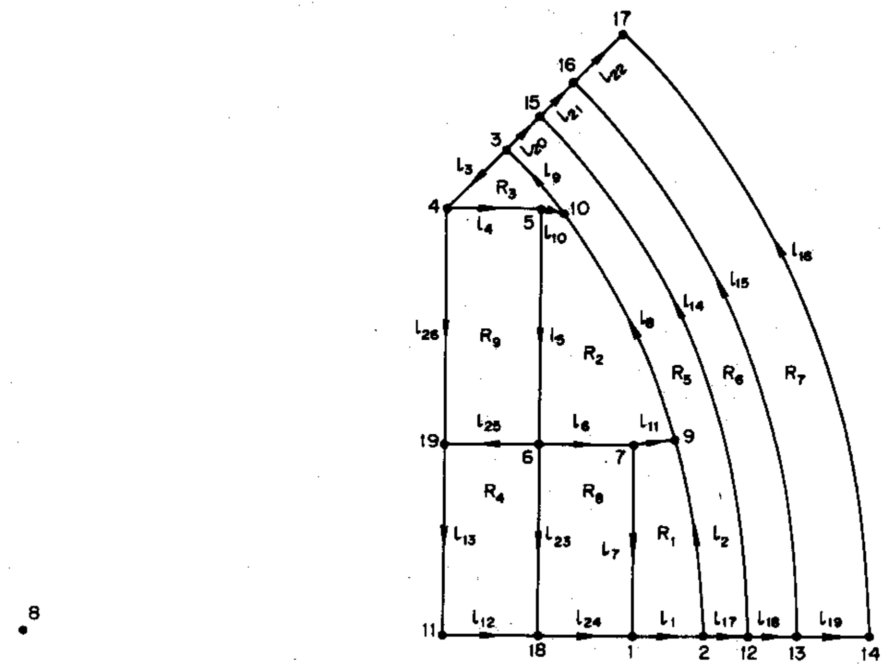

Fig. 8.2 Input geometry to the QMESH-RENUM for a sample problem

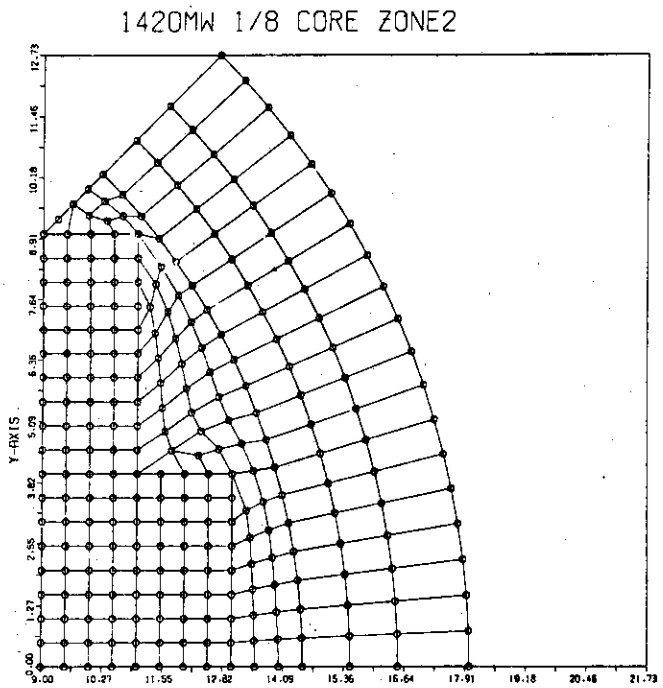

Fig. 8.3 The generated mesh network for a sample problem given in Fig. 8.1

region, the numbers greater than or equal to 2 must be applied to the material regions in Q-region.

2.3 Creation of the Body

The program combines the mesh network of A-region with that of Q-region to make the complete network of the body. Then, the renumberings of node numbers and element numbers are carried out through the body accordingly to Cuthill and Mckee rule[15].

On the CRT, the mesh networks of each subregion: A-region, Q1-subregion, Q2=subregion, ...are displayed according to the order of their mesh generations. Users can take a hard-copy (COM) of the mesh network of the subregion by picking a dish in the menu as shown in Table 1. Ascertaining the dish is winking, pick the button "HARDCOPY". After the hard copy has finished, pick the button "NOCOPY". This completes "hard copy" stage.

Table 1 "MENU" message

No. assigned in the program	MENU
1	ELEMENT
2	POINT
3	REGION
4	END

All these picking operations are performed under the command:

PLEASE PICK THE MENU

or

PLEASE PICK THE PGS COPY-MENU

By picking "END" in the menu, the stage changes to the next one. These stages are displayed as "final plot", which is title-figured on the upper right side in the CRT.

After finished all the operations on the graphic display, the program edits the input data to the FEM-BABEL[14]. The list of nodes with boundary flags, which were inputted in LINE and POINT cards in the QMESH, is punched out as the nodes with zero flux boundary conditions (input data 15$). In addition, the list of the absolute material region numbers, inputted in the REGION cards, is punched out as the finite elements with the corresponding region numbers (input data 10$).

Furthermore, all the input data for meshes (as input data of NAUTO =3 in No. 28 in 1$: input from the external tape), that is, node numbers, the coordinates, and the node numbers composing finite elements, are edited on file unit 10 (refer the chapter 3.3, too).

3. How to Use the Program

The section 3.1 may especially be of use, should users meet an error message in the program. The succeeding sections should be read in advance before using the program.

3.1 Descriptions of the Flow Charts and the Subprograms

The flow charts are shown from Fig. 9.1 to 9.10. The descriptions for subroutines not shown in the flow charts are described in the following.

1	INIT	data-setting and initialization for the display,
2	PAGIN	eliminate the paging of plotters or displays,
3	LOMTI	display the title "*LOOM-P*" on upper right side,
4	CHSIZE	select a size out of four character sizes (1<2<3<4),
5	SCALXY	set the minimum and maximum in x- and y-axes,
6	SCALN	optinum sealing in x- and y-axes,
7	BGDRW	display the title and scaling,
8	ICHSZ	count significant figures of floating data,
9	ELCENT	compute the barycentric coordinate of a mesh element,
10	MESHPL	display the mesh network,
11	TABSET	make the flag-table of triangular and quadrilateral elements,
12	FREAD	read data on key-board with free format,
13	MESS1	display the command to users,
14	AMESH	generate the mesh network for A-region,
15	APLOT	display the mesh network for A-region,
16	MENU	display the menu on lower right side,
17	PICKM	check the number (dish) pick out of the menu,
18	ELPLOT	display node numbers or element numbers,
19	RPLOT	display region numbers,
20	READQN	read the file unit 9 from RENUM,
21	YORN	key-in "Y"(yes) or "N"(no) and check input data,
22	ADDLI	draw the line used for dividing an element
23	ADDEL	extend and rewrite the element-table,
24	STARS	display the mark ◇ on the centroid of a mesh element

in No. 28 in 1$: input from the external tape), that is, node numbers, the coordinates, and the node numbers composing finite elements, are edited on file unit 10 (refer the chapter 3.3, too).

3. How to Use the Program

The section 3.1 may especially be of use, should users meet an error message in the program. The succeeding sections should be read in advance before using the program.

3.1 Descriptions of the Flow Charts and the Subprograms

The flow charts are shown from Fig. 9.1 to 9.10. The descriptions for subroutines not shown in the flow charts are described in the following.

1	INIT	data-setting and initialization for the display,
2	PAGIN	eliminate the paging of plotters or displays,
3	LOMTI	display the title "*LOOM-P*" on upper right side,
4	CHSIZE	select a size out of four character sizes (1<2<3<4),
5	SCALXY	set the minimum and maximum in x- and y-axes,
6	SCALN	optinum sealing in x- and y-axes,
7	BGDRW	display the title and scaling,
8	ICHSZ	count significant figures of floating data,
9	ELCENT	compute the barycentric coordinate of a mesh element,
10	MESHPL	display the mesh network,
11	TABSET	make the flag-table of triangular and quadrilateral elements,
12	FREAD	read data on key-board with free format,
13	MESS1	display the command to users,
14	AMESH	generate the mesh network for A-region,
15	APLOT	display the mesh network for A-region,
16	MENU	display the menu on lower right side,
17	PICKM	check the number (dish) pick out of the menu,
18	ELPLOT	display node numbers or element numbers,
19	RPLOT	display region numbers,
20	READQN	read the file unit 9 from RENUM,
21	YORN	key-in "Y"(yes) or "N"(no) and check input data,
22	ADDLI	draw the line used for dividing an element
23	ADDEL	extend and rewrite the element-table,
24	STARS	display the mark ◇ on the centroid of a mesh element

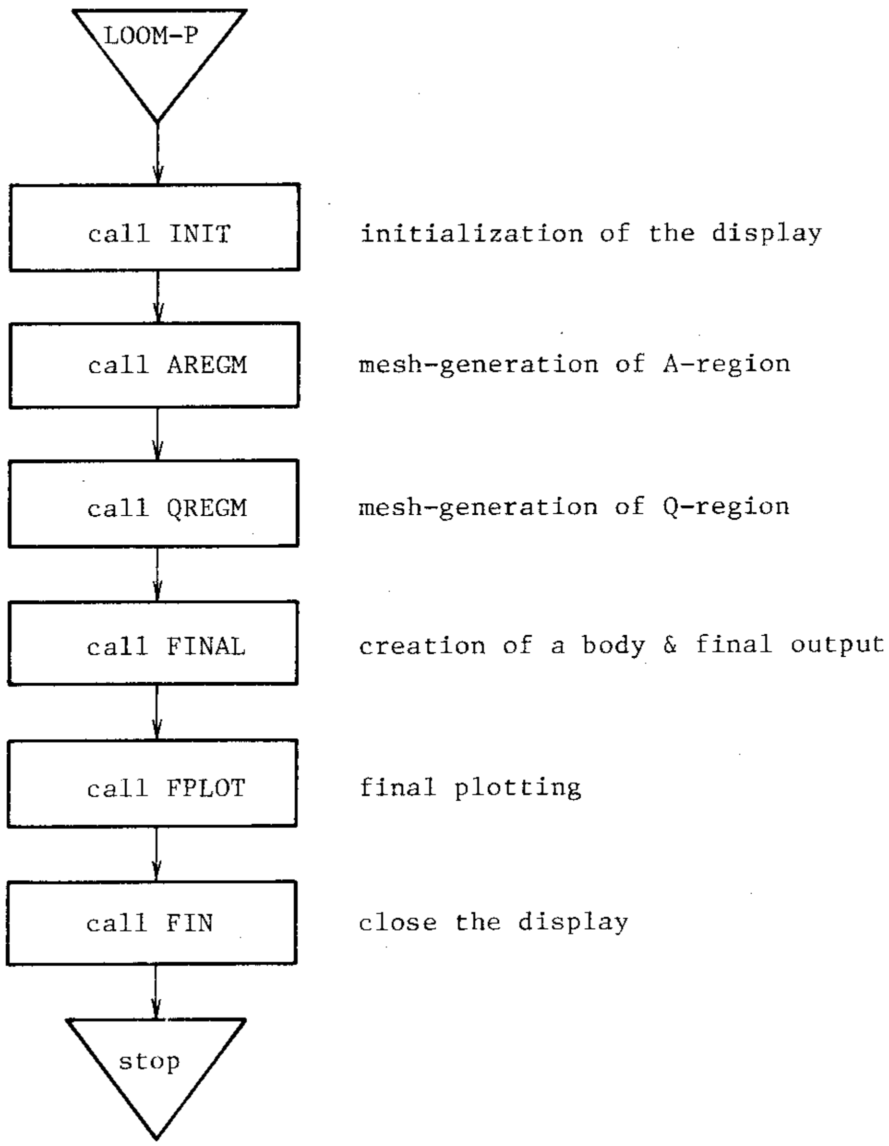

Fig. 9.1 Flow chart of main program

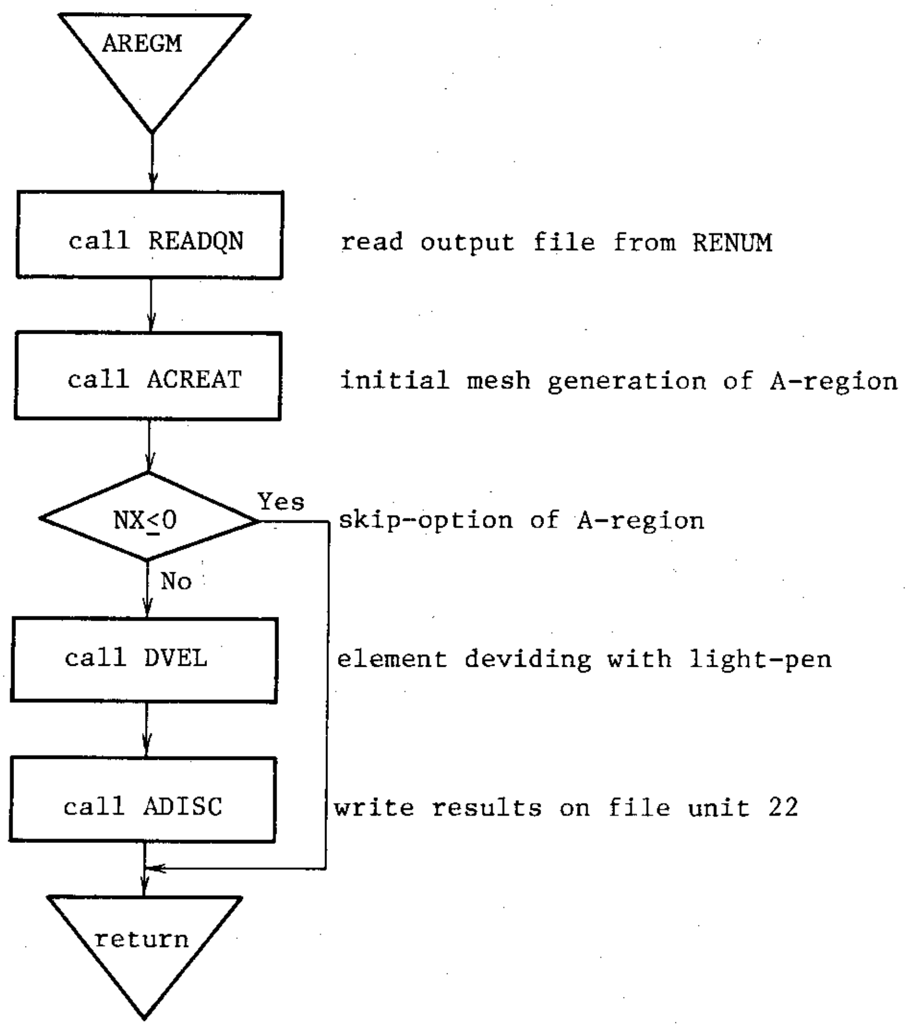

Fig. 9.2 Flow chart of subprogram AREGM

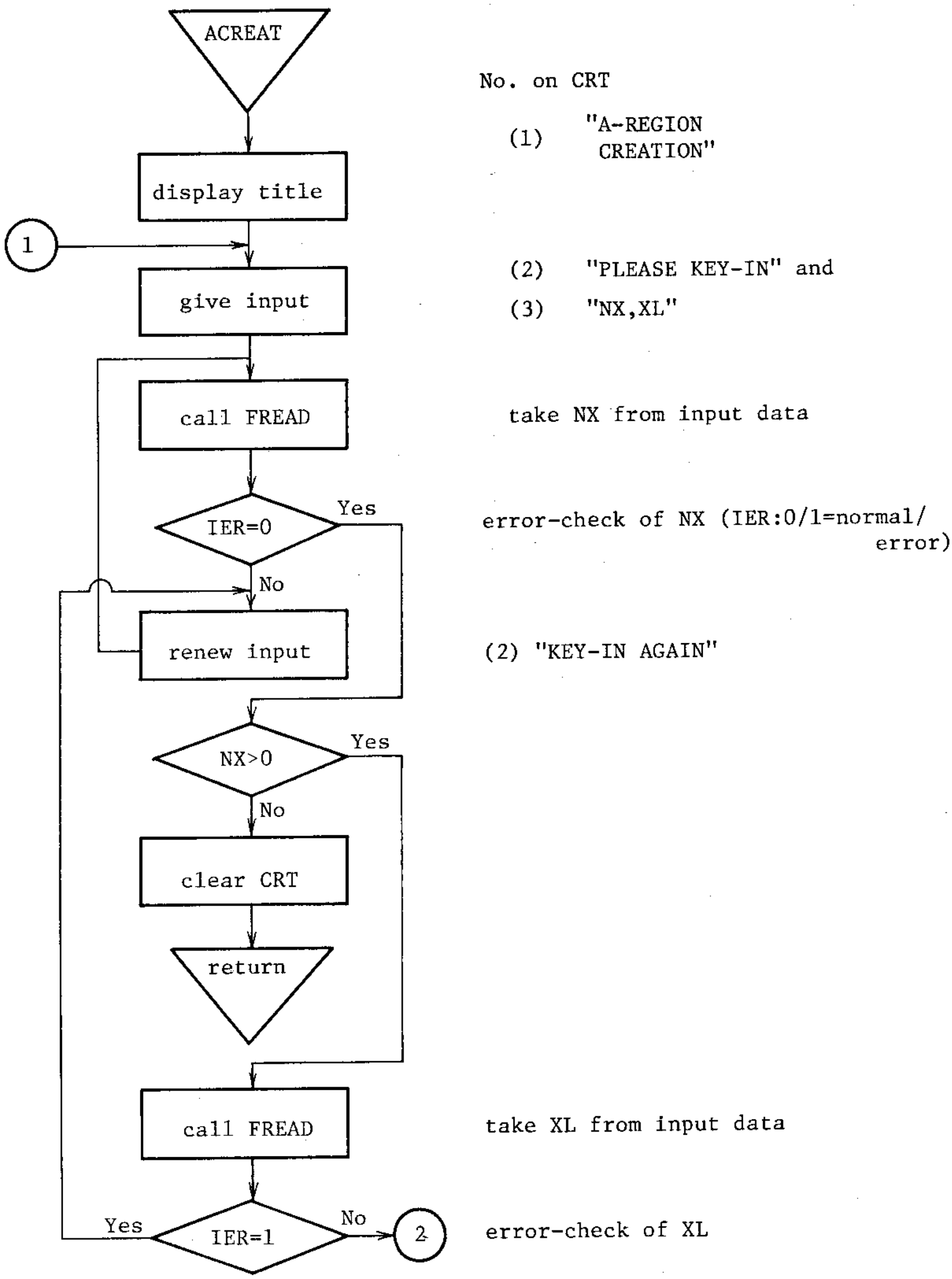

Fig. 9.3 Flow chart of subprogram ACREAT

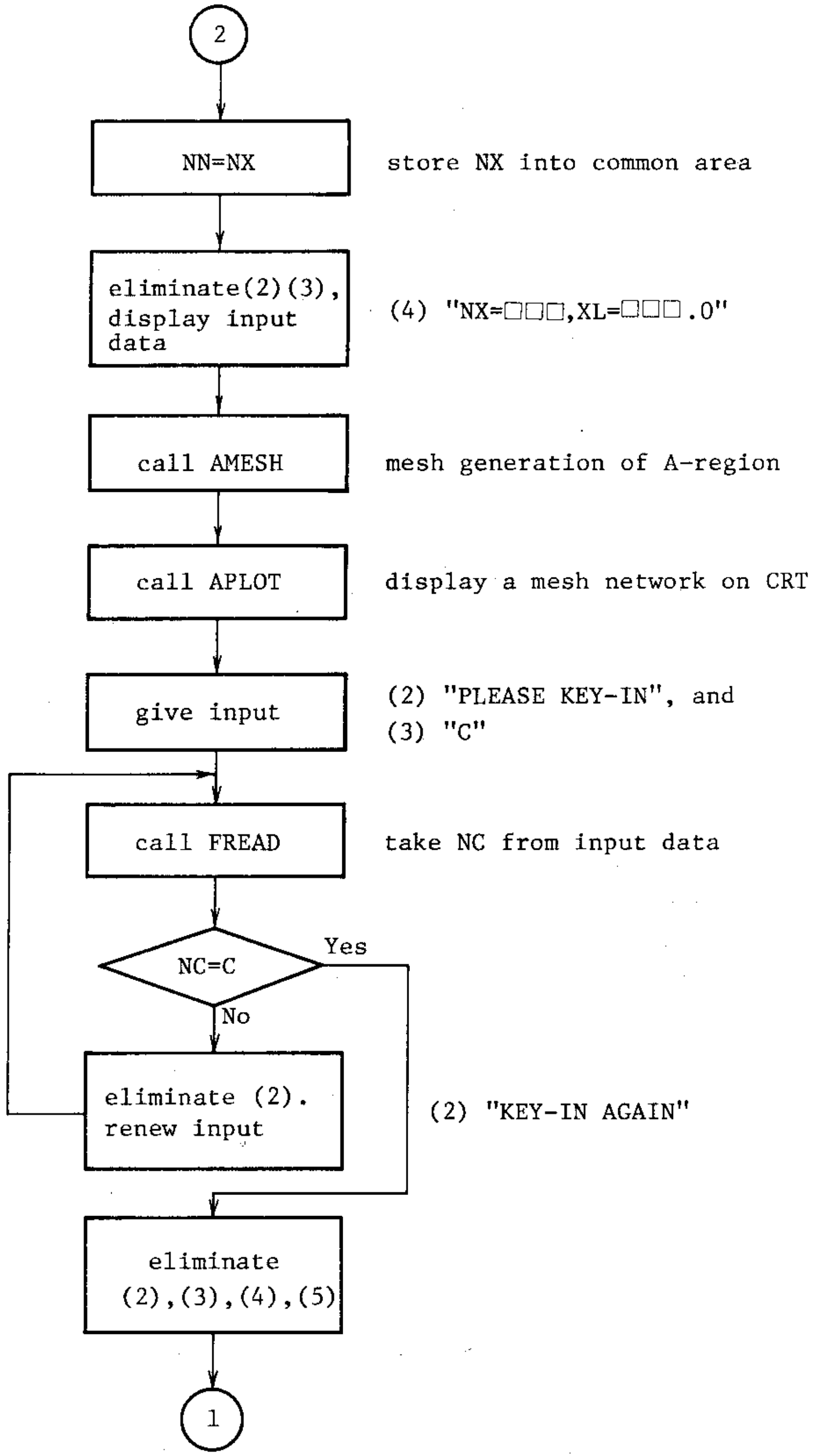

Fig. 9.3 (continued)

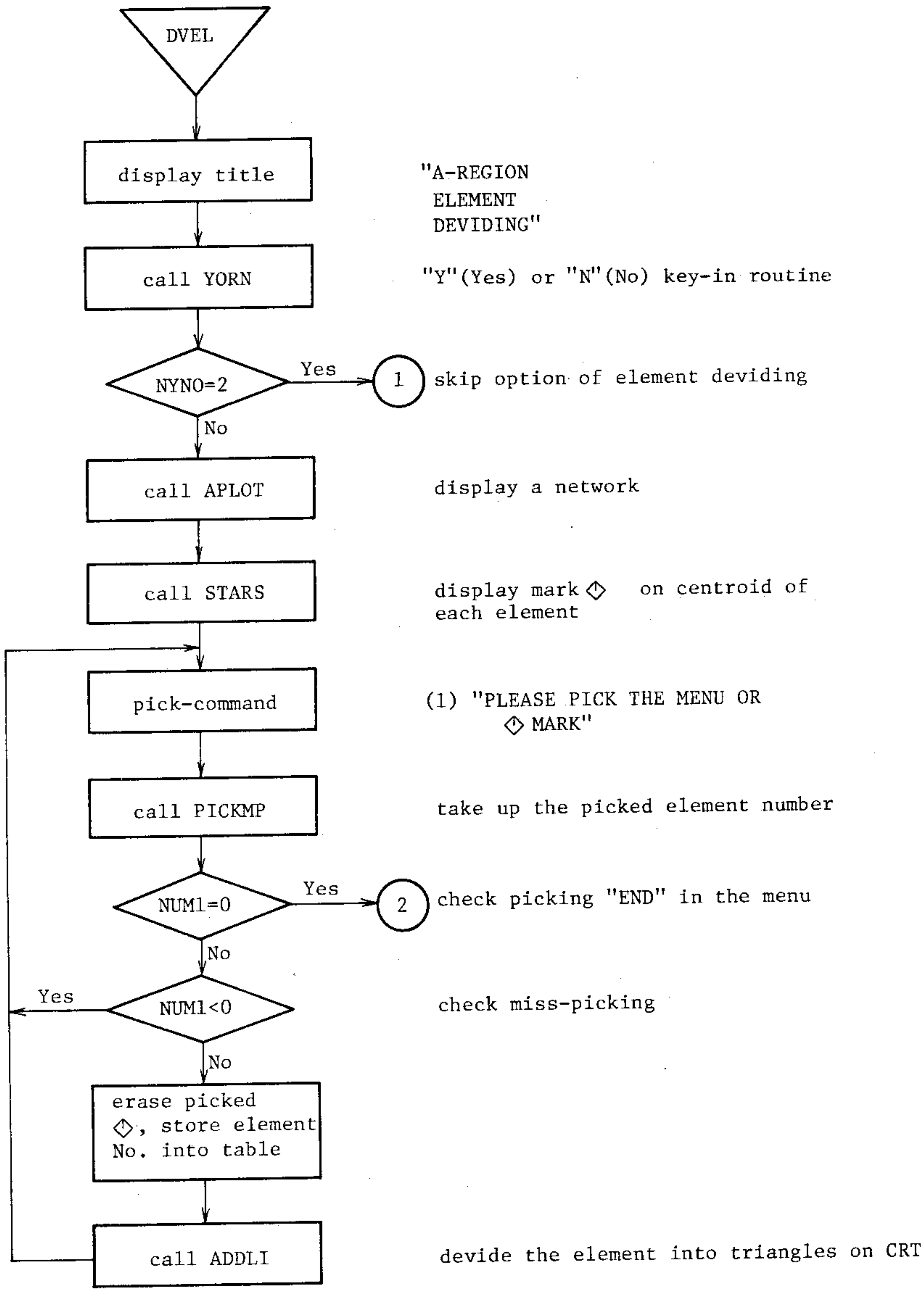

Fig. 9.4 Flow chart of subprogram DVEL

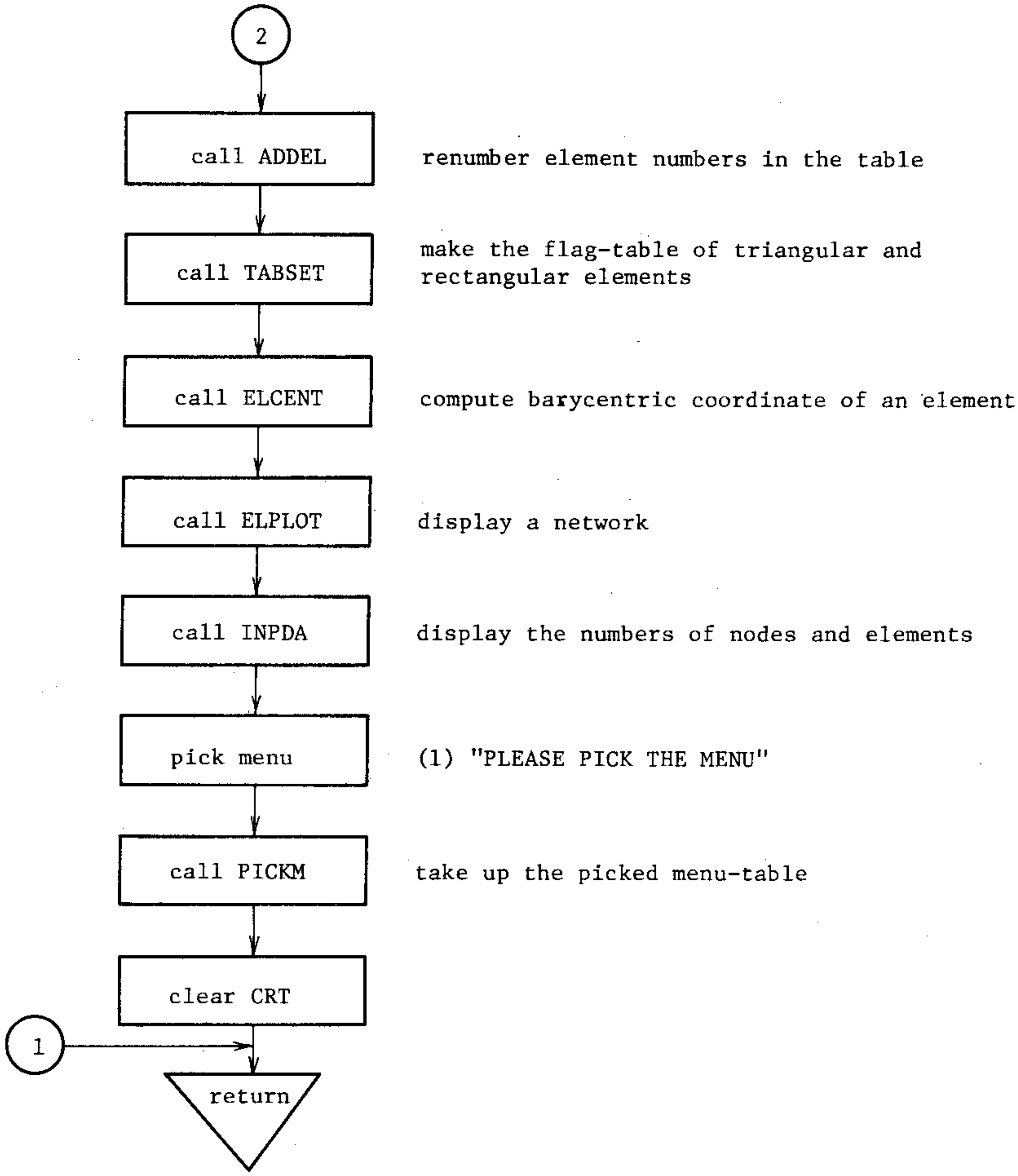

Fig. 9.4 (continued)

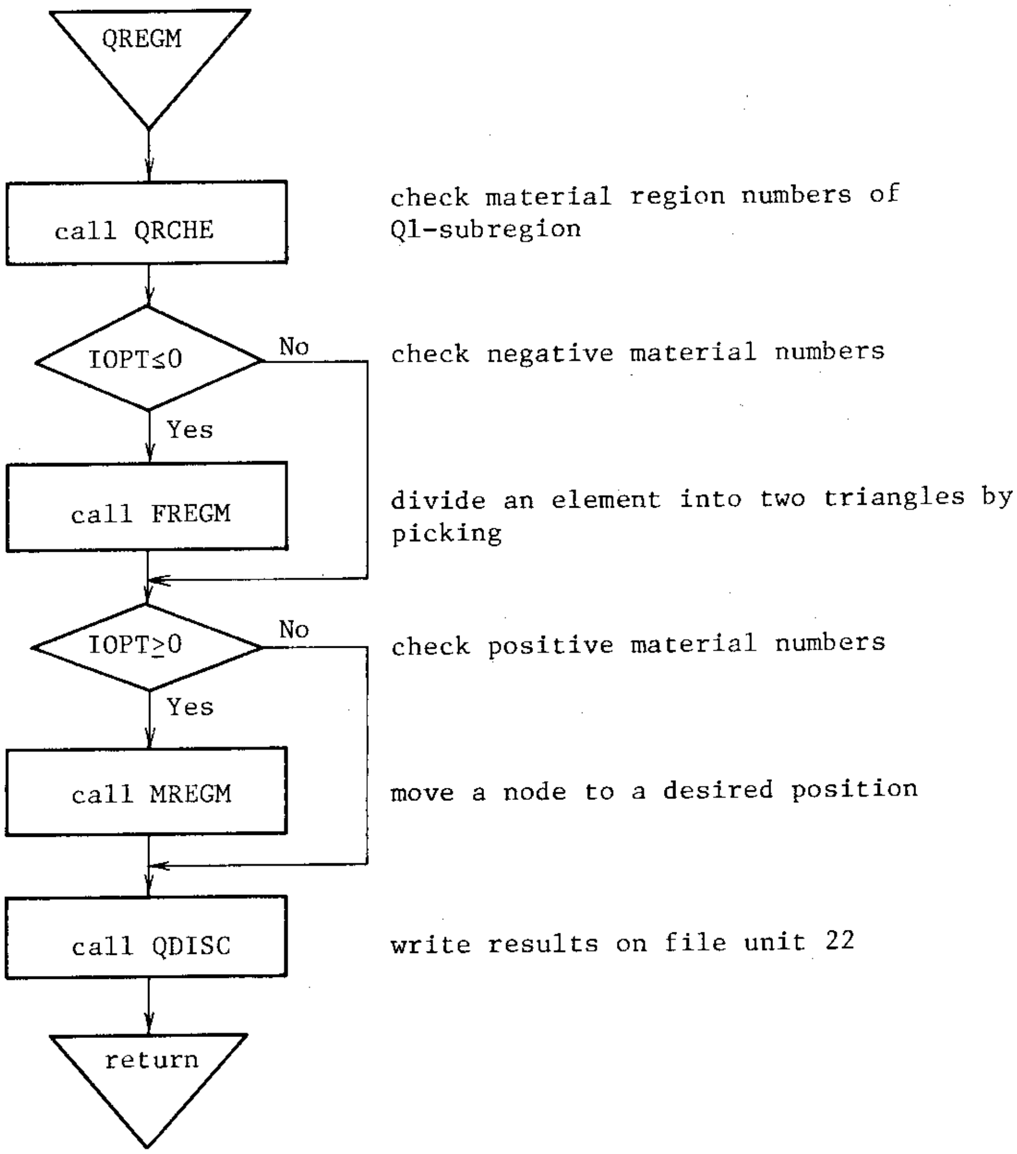

Fig. 9.5 Flow chart of subprogram QREGM

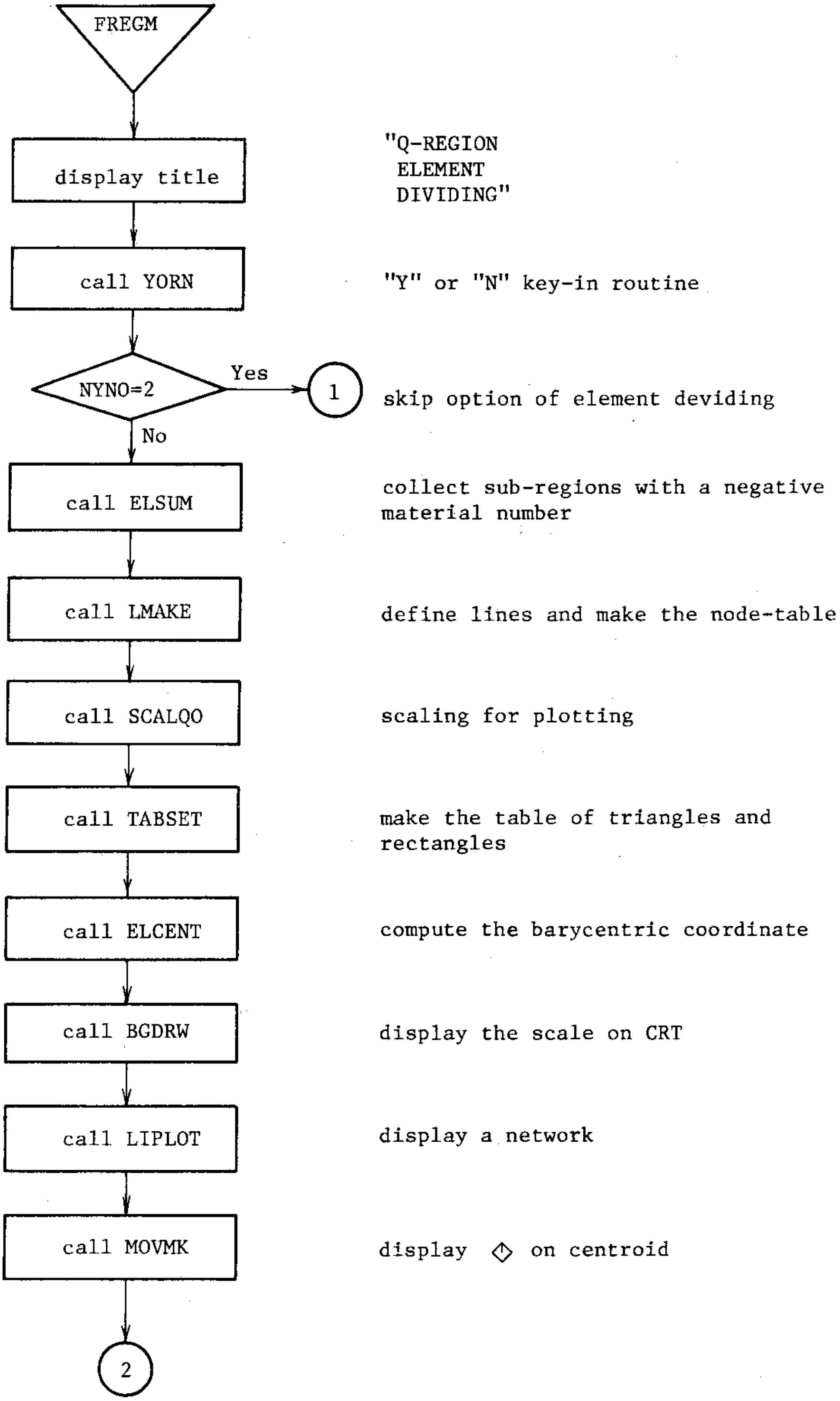

Fig. 9.6 Flow chart of subprogram FREGM

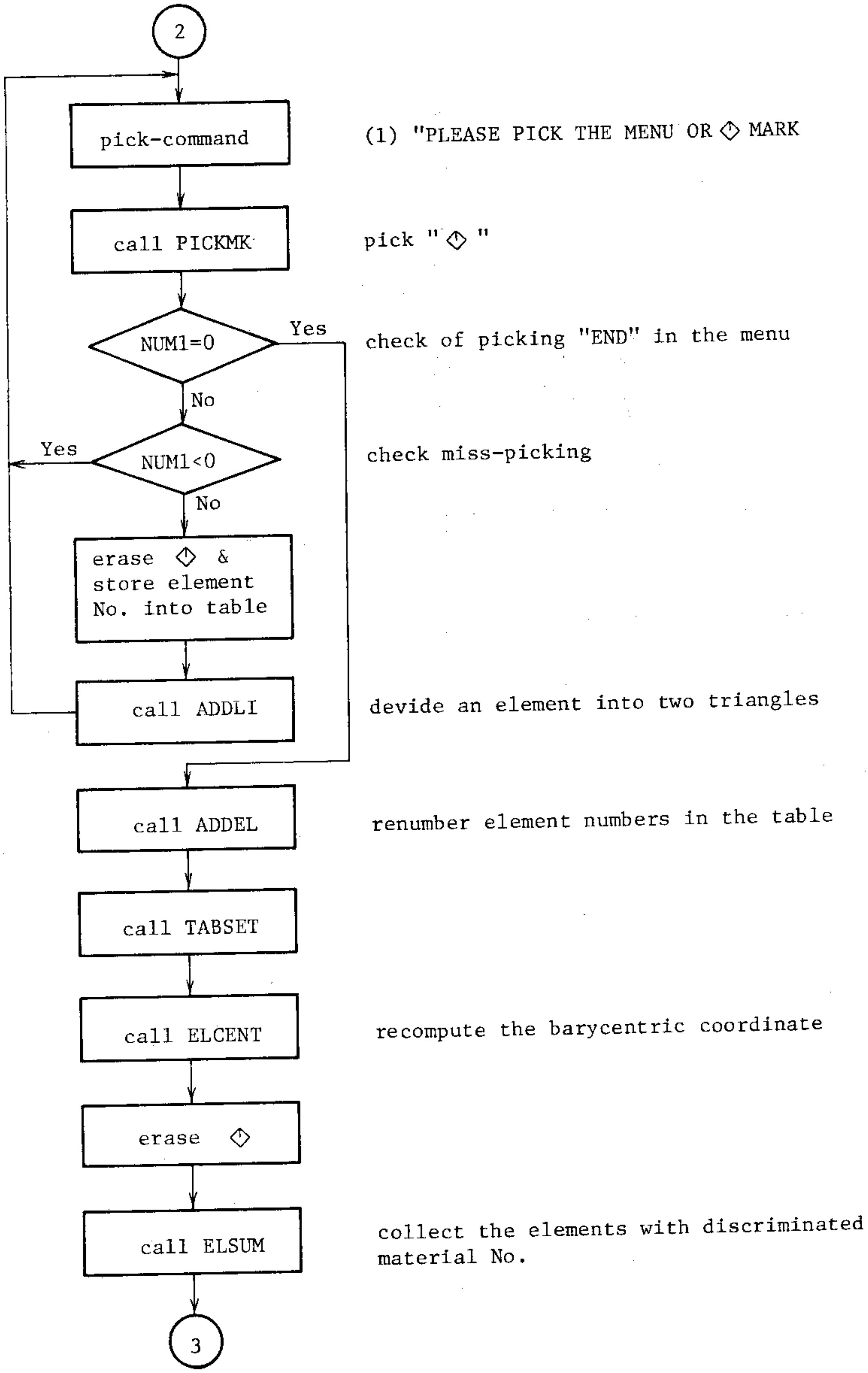

Fig. 9.6 (continued)

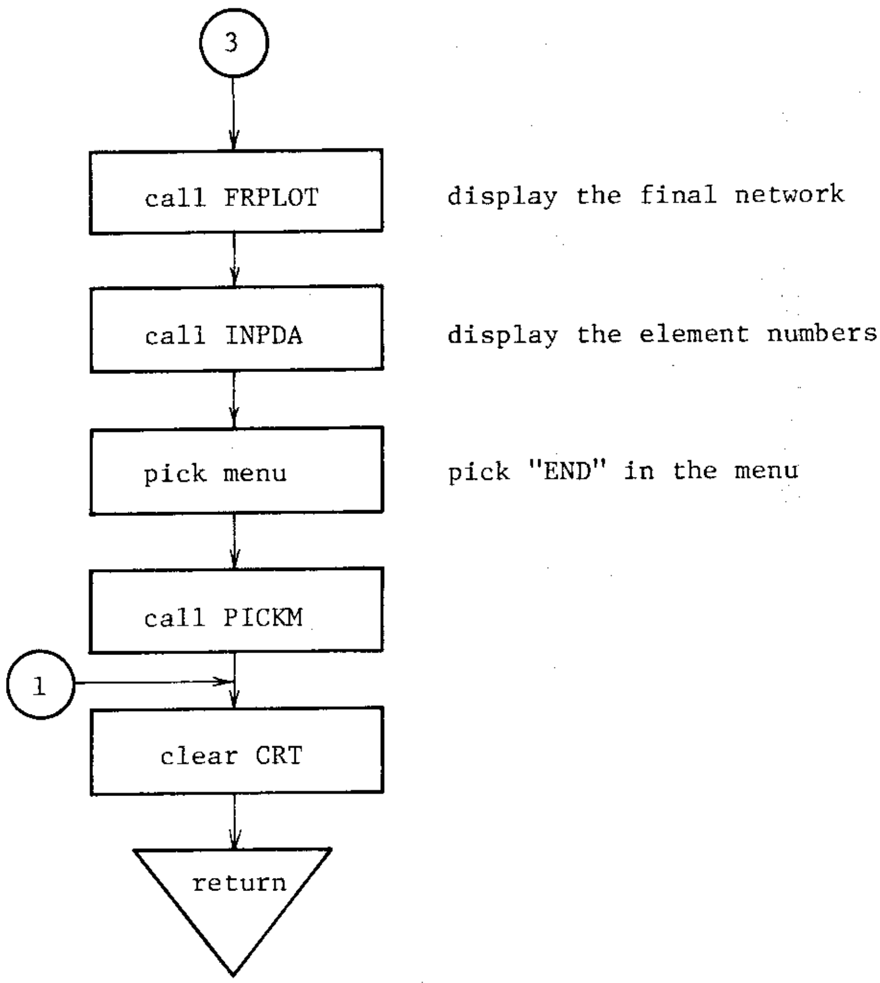

Fig. 9.6 (continued)

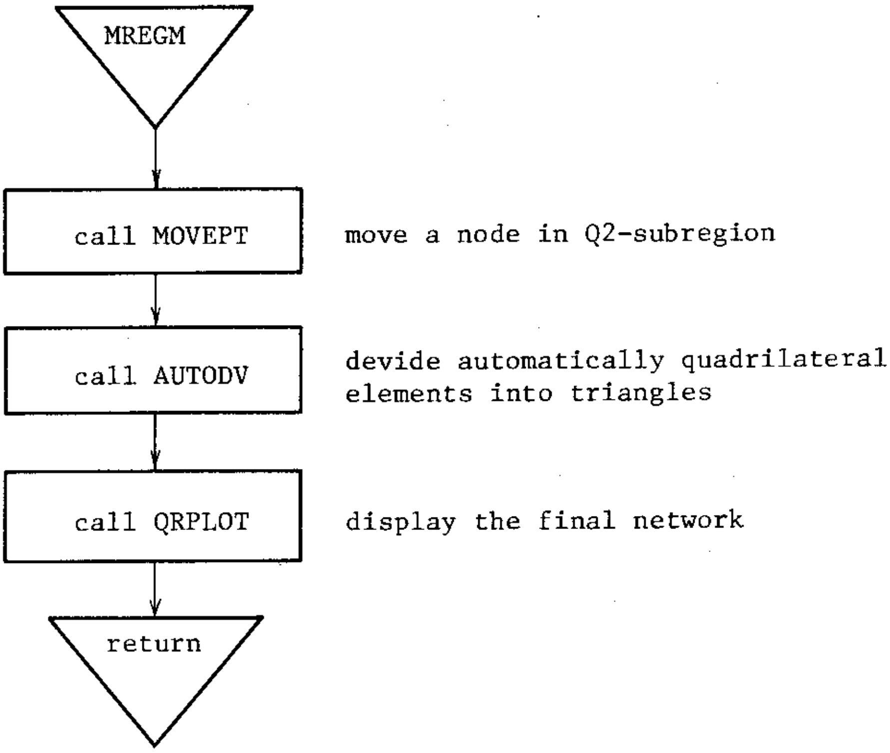

Fig. 9.7 Flow chart of subprogram MREGM

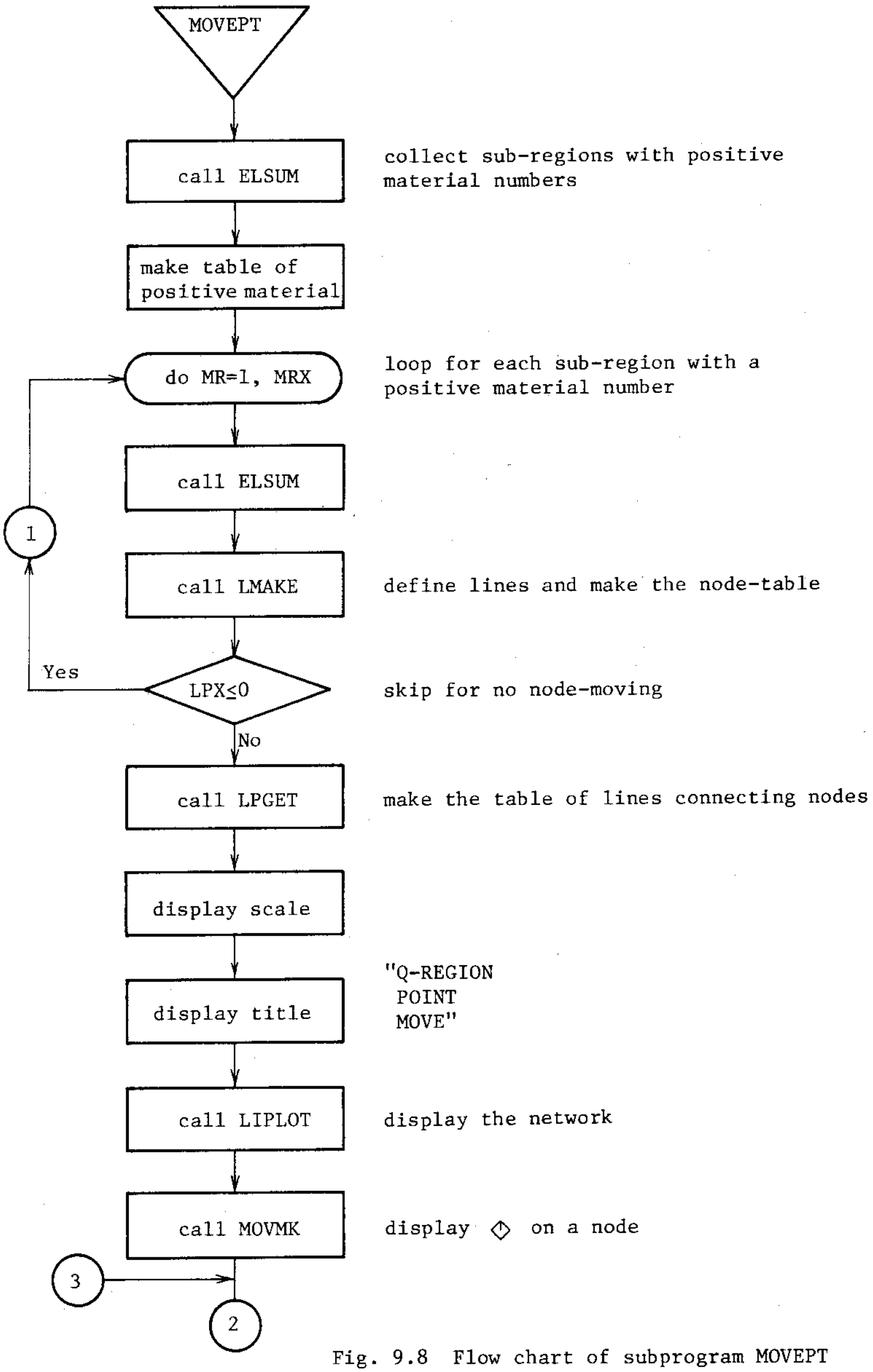

Fig. 9.8 Flow chart of subprogram MOVEPT

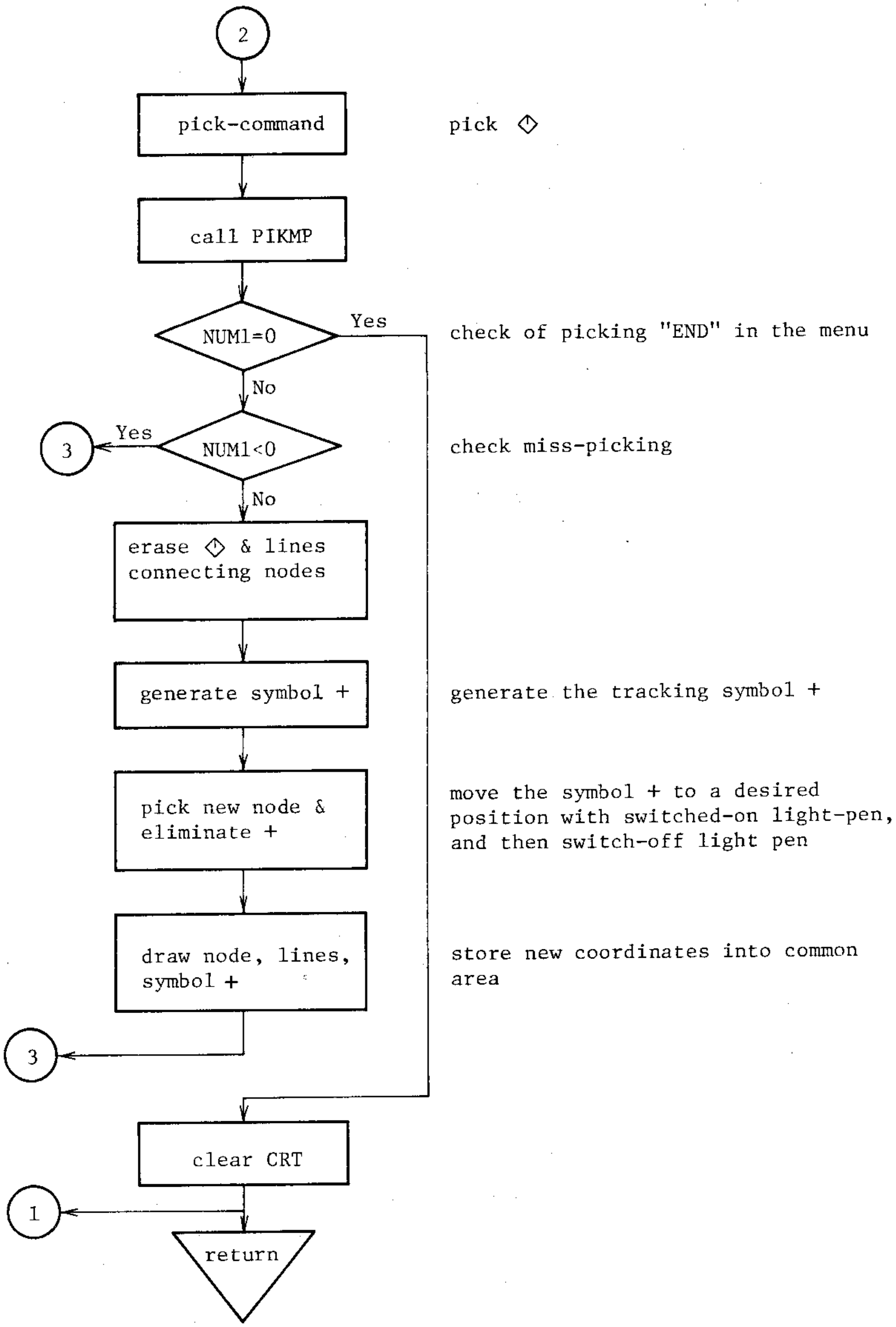

Fig. 9.8 (continued)

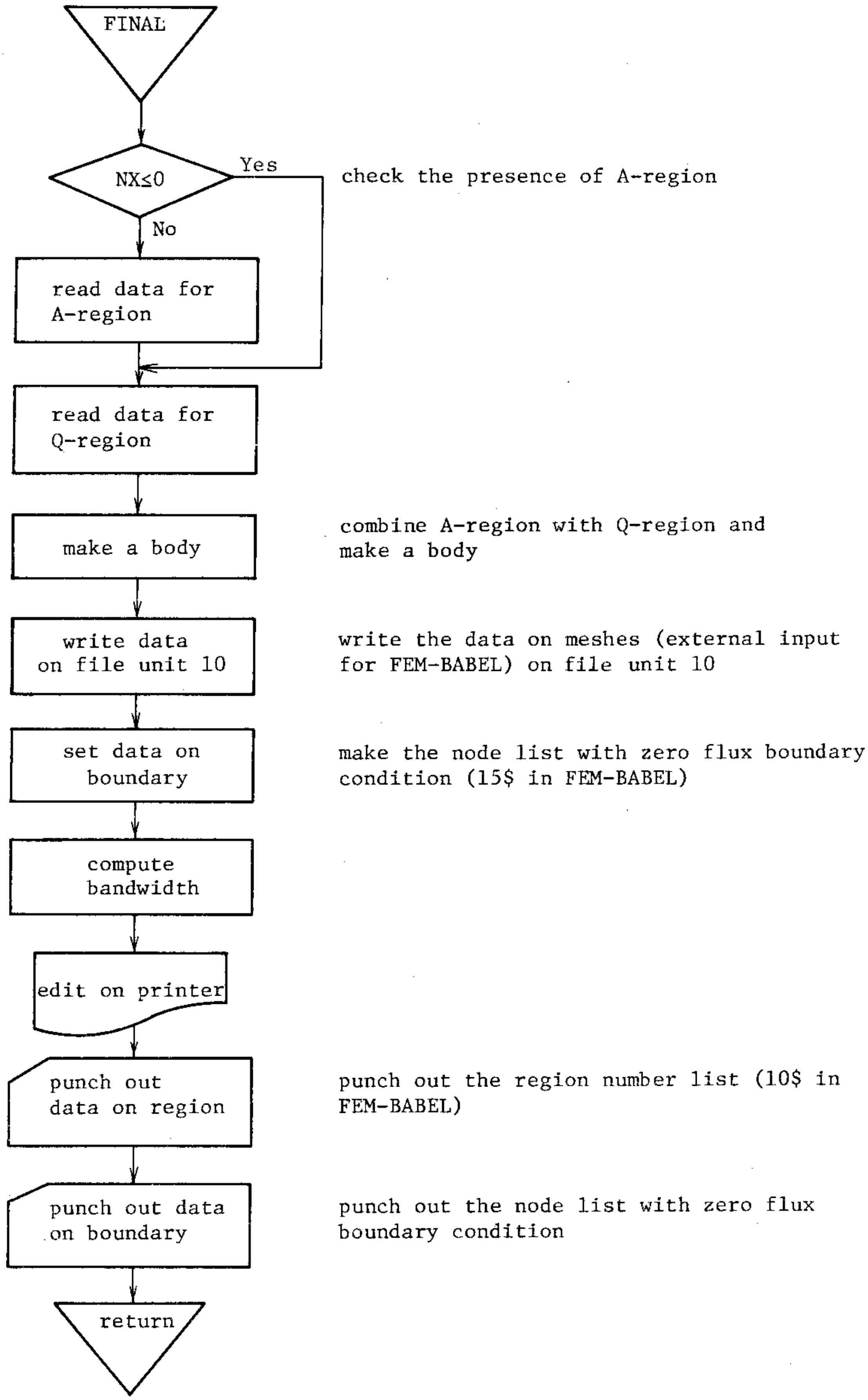

Fig. 9.9 Flow chart of subprogram FINAL

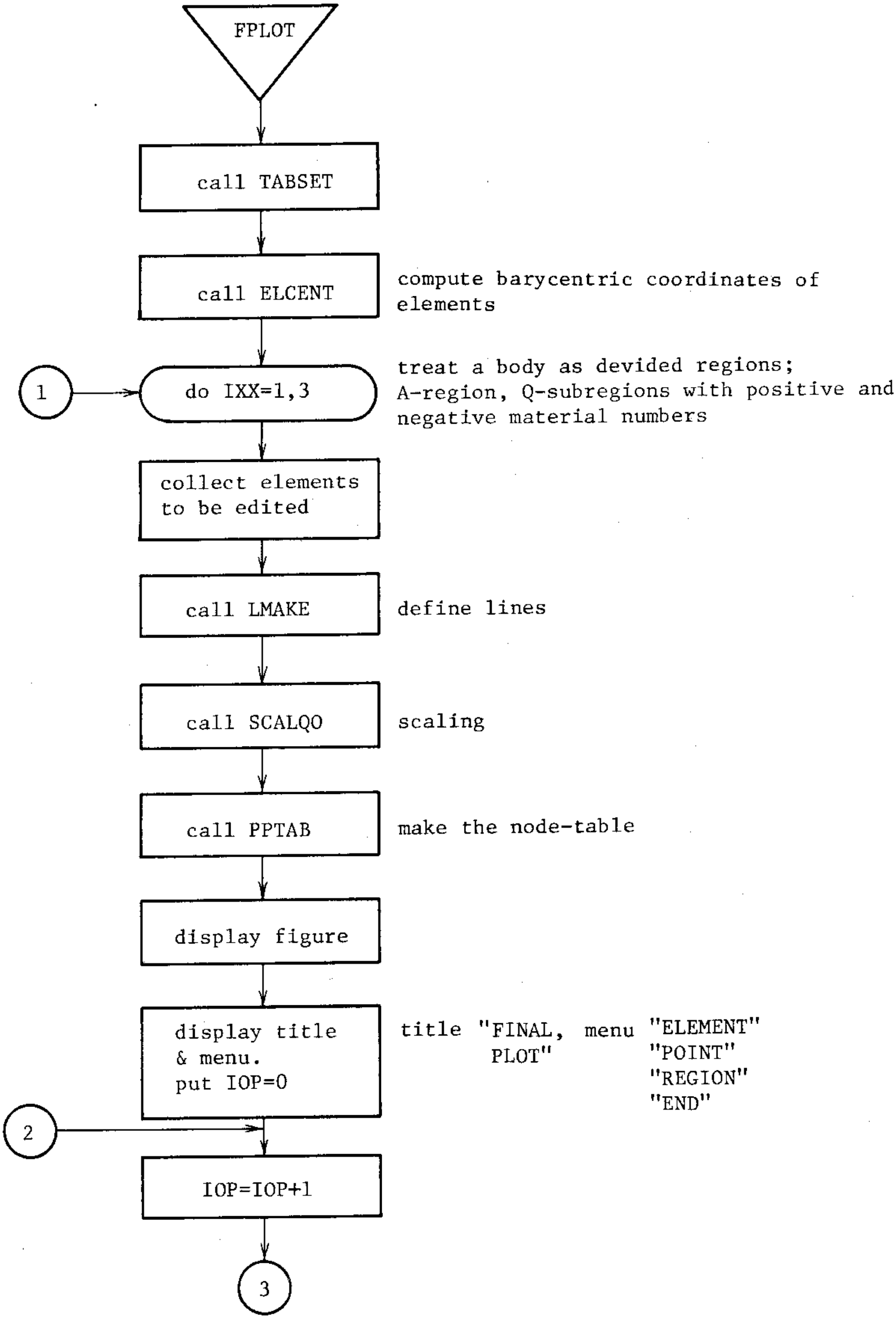

Fig. 9.10 Flow chart of subprogram FPLOT

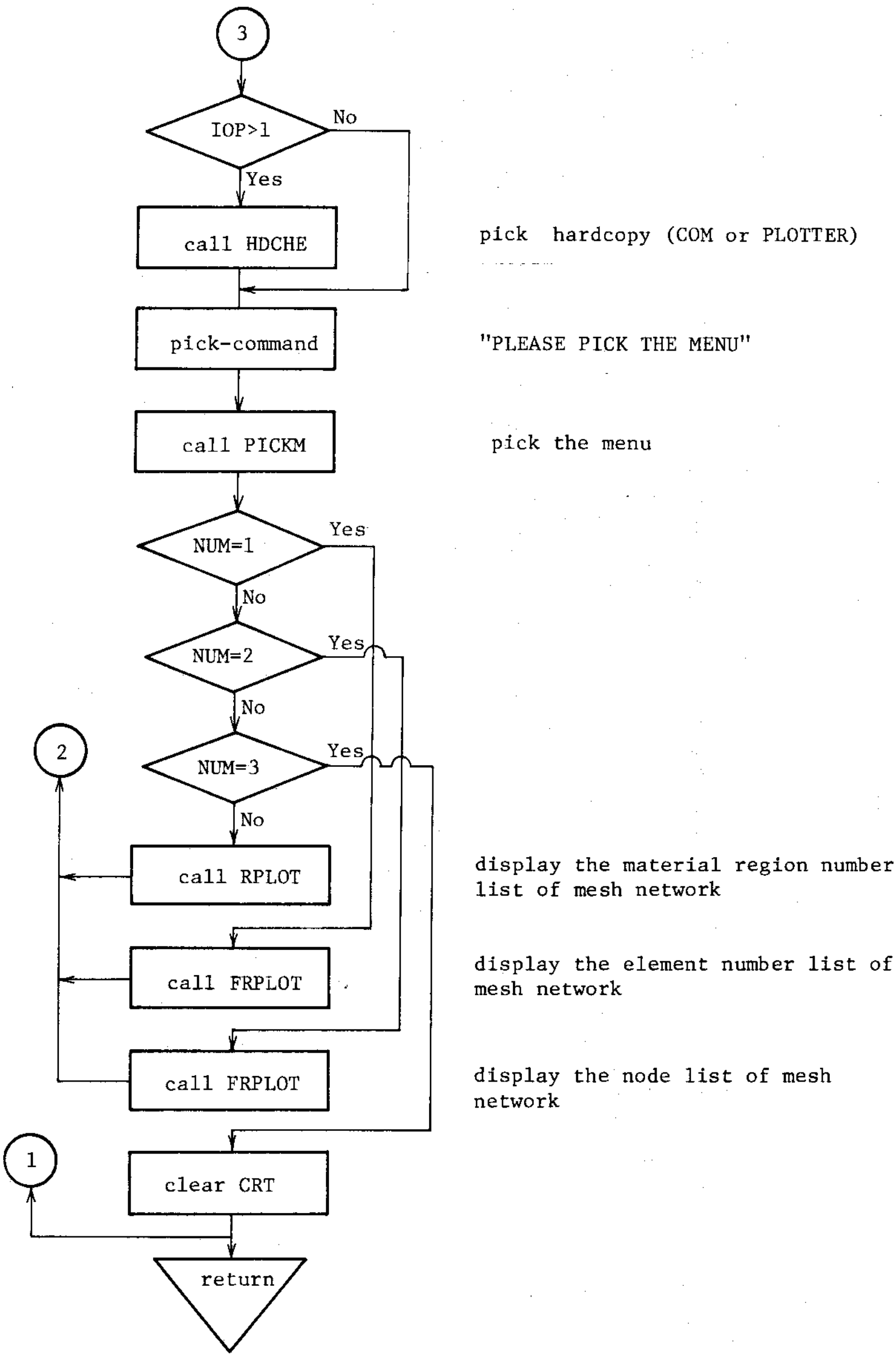

Fig. 9.10 (continued)

25	ADISC	write the data of meshes in A-region on assigned file unit,
26	ELSUM	collect the elements with discriminated material flag and make the table,
27	LMAKE	make the line-table and the node-table,
28	LPGET	make the list of lines connecting nodes (≤ 6),
29	SCALQO	scaling for displaying,
30	LIPLOT	make the mesh network having no-named lines,
31	NOVMK	display the mark ◇ on the centroid of an element or on a node,
32	PICKMP	pick up the mark ◇ or a dish in the menu,
33	QRCHE	check either positive or negative sign of the material number,
34	FRPLOT	display the pointed element or node,
35	AUTODV	automatic deviding,
36	CUTEL	compare the lengths of two diagonals with each other in a quadrilateral element,
37	QRPLOT	display the element-map for Q-region,
38	QDISC	write the data of meshes in Q-region on file unit 22,
39	INPDA	display the numbers of nodes and elements on upper right side
40	PPTAB	make the node-table composing an element,
41	FIN	close the displaying,
42	XAV	transform a given x-value to the length in CRT,
43	YAV	transform a given y-value to the length in CRT,
44	GDINIT	display the named line,
45	GDSEND	transmit the image to CRT,
46	DERASE	erase the named line on CRT,
47	DECOMEN	permit the comment with key-in and continue waiting a command,
48	GDCOPY	permit transmitting the figure on CRT to the graphic COM and continue waiting a command,
49	CHE	edit the final mesh network to the printer.

3.2 Limitations to the Program

It is noted that there are three kinds of limitations for using the LOOM-P: the first is due to the QMESH-RENUM, the second due to the dimension in the LOOM-P, and the third due to the buffer size of the graphic display FACOM 6233A.

Tables 2 and 3 show the limitations to the QMESH-RENUM and the LOOM-P, respectively. The limitations to the FACOM 6233A are the GDOA (editing area in core storage) of 3600 words, and the buffer size of 8000 words due

Table 2 Limitations to the QMESH-RENUM

Number of mesh elements	2000
Number of nodes	2100
Number of boundary nodes	300

Table 3 Limitations to the LOOM-P

	A-region	Q-region	a body
Number of mesh elements	1000	1000	1500
Number of nodes	1000	1000	1500
Number of boundary nodes		500	500

to the hard ware. Accordingly, the numbers of mesh elements and nodes, which can be displayed on CRT a time, are about 630 and about 660, respectively.

3.3 Input-Output File Units

The LOOM-P needs the file unit 9 (the output from the RENUM) as input and the file unit 10 (the input to the FEM-BABEL) as output. The file unit 22 is needed as scratch. The file unit 1 is required instead of the unit 7 for editing in card image for the FEM-BABEL, under the present operating system of JAERI's computer (punching-out is not permitted under the command of the display).

Table 4 shows the formats in the files 9 and 10, the contents of which are as follows;

Table 4 Contents in the file unit 9 and 10

Record number	File unit 9	File unit 10
1	(COMMEN(I),I=1,12)	NNN,KKK
2	KKK,NNN,NFF,MAXDIF	(X(I),Y(I),I=1,NNN), ((NELNO(I,J),I=1,4),J=1,KKK)
3	(X(N),Y(N),N=1,NNN)	(MAT(J),J=1,KKK)
4	((NELNO(I,J),I=1,4), MAT(J),J=1,KKK)	
5	(IFLAG(I),I=1,NFF)	

COMMEN	any comment written in the format 12A4,
KKK	the number of elements,
NNN	the number of nodes,
NFF	the number of boundary nodes,
MAXDIF	the maximum difference of node numbers per element (:bandwidth in the coefficient matrix of the system equation),
X,Y	coordinates of x and y (or r and z),
NELNO	the element-table composed of nodes per element,
MAT	the list of material numbers assigned to elements,
IFLAG	the list of boundary nodes.

3.4 Graphic Display Apparatus and Key-Ins with Free-Format

Figure 10 shows FACOM 6233A graphic display apparatus. After having inputted the data on the character key board, one must pat the END key. One can correct all the input data by the CANCEL key or partially the data by patting the ← or the → key. One can get the blank character by patting the space key.

In the LOOM-P, one picks the mark " ◇ " and the tracking symbol " + " with the light-pen. By drawing the switched-on pen near the " ◇ ", he will find out the " ◇ " winking. Then put the pen-switch off, the computer can catch the information of the " ◇ ". This is called "picking" the mark " ◇ ".

When one picks and moves the symbol " + " with the switched-on pen, the symbol " + " follows the movement of the pen. Then put the pen-switch off, the computer can store the coordinates where the pen was switched off. This is called "tracking".

On the CRT shown in Fig. 10, the #1 is the title given through the RENUM. The #2 is the title describing the contents of the figure given in the LOOM-P. The #3 is the message or the command to users. The #4 is the displaying area of input data keyed in and the #5 the menu to be picked with light-pen. During the time when the following message is #6, the computer cannot catch any information.

GSP NO JOB WA ROLL OUT TYU
(Your job is now rolled out.)

The above message is, however, out soon when user sends some information to the computer. The #7 is for the error message. User can kill his job by picking "KILL" shown in #7.

Users can take a hardcopy by pushing the key "PRINT" on the accompany-

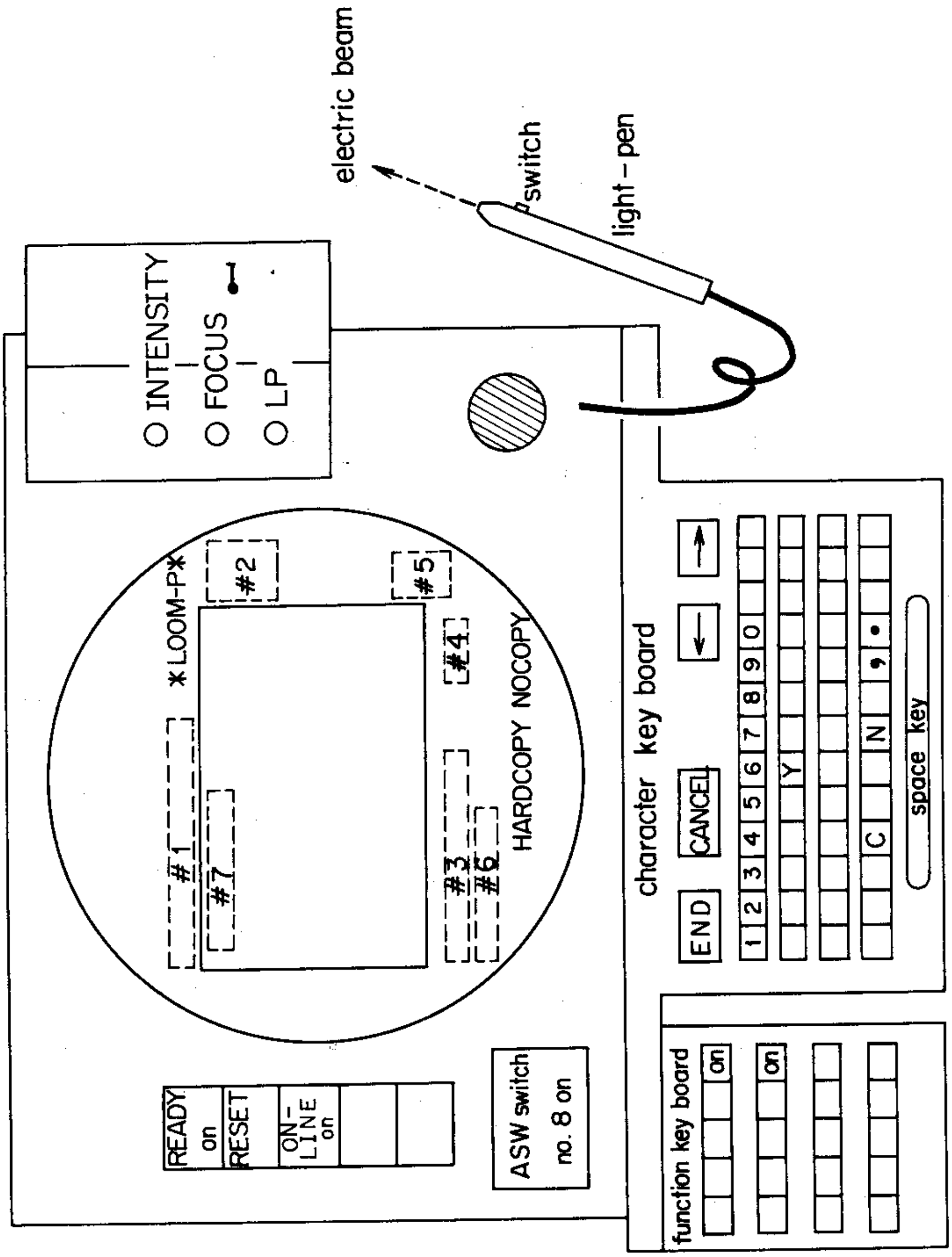

Fig. 10 Graphic display apparatus and console for key-ins

ing hardcopy apparatus FACOM 6541B. However, one must wait thirty seconds or so to get a sheet of figure.

It is easy and convenient to input with free format when one uses the character key board. After one has fed the data by key-in, he must pat "END" key to make the carriage return. One must pat the " , " key or "blank" key (: "space" key) when pausing between the data. In addition, one must pat "END" key when no input data to be fed.

Integer data are defined by "0, 1, ..., 9" only. One must not use "+" or "-". Blank data are registered in as "0". Floating point data are defined by "0, 1, ..., 9" and "."(dot), that is, in the F-format. Blank data are registered in as "0.0". The hollerith datum is defined by one English letter character and the blank datum is registered in as "C".

Although the program has the function to redo the key-in when mistook it, user can use the "CANCEL", or "←" or "→" key on the key board (see also the first part of this section).

4. Sample Problem and the Operation of Graphic Display

Before using the graphic display, one must prepare the input data (the file unit 9 from the RENUM) for the Q-region as a result of the QMESH-RENUM calculation. After the preparation of the input cards as shown Fig. 11.1, one can use the graphic display.

First, ascertaining the first lamp (READY) on, the third lamp (ON-LINE) on, and the No.8 of ASW switches (for hardcopy of COM) on, on the left side of the CRT, one should input the job cards in the card reader. When the job goes up to the execution step, one finds the following message on the console display with buzzing:

GRAPHIC START

GRAPHIC START

and the No.8 and No.16 lamps on the function key board light on. Then user must stand by the message from the program in front of the graphic display.

We take up the one eightth geometry of a 1420 MW PWR as an example. The operational scheme of the graphic display are summarized in Table 5. Soon after the job ended, the printer edits the results of the LOOM-P. Moreover, one can punch the data out of the file unit 1 made in the LOOM-P, by using a program as shown in Fig. 11.2 (see chapter 3.4, too).

ing hardcopy apparatus FACOM 6541B. However, one must wait thirty seconds or so to get a sheet of figure.

It is easy and convenient to input with free format when one uses the character key board. After one has fed the data by key-in, he must pat "END" key to make the carriage return. One must pat the " , " key or "blank" key (: "space" key) when pausing between the data. In addition, one must pat "END" key when no input data to be fed.

Integer data are defined by "0, 1, ..., 9" only. One must not use "+" or "-". Blank data are registered in as "0". Floating point data are defined by "0, 1, ..., 9" and "."(dot), that is, in the F-format. Blank data are registered in as "0.0". The hollerith datum is defined by one English letter character and the blank datum is registered in as "C".

Although the program has the function to redo the key-in when mistook it, user can use the "CANCEL", or "←" or "→" key on the key board (see also the first part of this section).

4. Sample Problem and the Operation of Graphic Display

Before using the graphic display, one must prepare the input data (the file unit 9 from the RENUM) for the Q-region as a result of the QMESH-RENUM calculation. After the preparation of the input cards as shown Fig. 11.1, one can use the graphic display.

First, ascertaining the first lamp (READY) on, the third lamp (ON-LINE) on, and the No.8 of ASW switches (for hardcopy of COM) on, on the left side of the CRT, one should input the job cards in the card reader. When the job goes up to the execution step, one finds the following message on the console display with buzzing:

GRAPHIC START

GRAPHIC START

and the No.8 and No.16 lamps on the function key board light on. Then user must stand by the message from the program in front of the graphic display.

We take up the one eighth geometry of a 1420 MW PWR as an example. The operational scheme of the graphic display are summarized in Table 5. Soon after the job ended, the printer edits the results of the LOOM-P. Moreover, one can punch the data out of the file unit 1 made in the LOOM-P, by using a program as shown in Fig. 11.2 (see chapter 3.4, too).

Table 5 Full operations of the graphic display for a sample problem

No.	Operations	Reference figure	Comments
1		Fig. 12.1	start network creation of A-region
2	key-in "18,9.0" "END"	Fig. 12.2	give NX and XL
3	key-in "C" "END"		
4	key-in "0" "END"		give NX=0 to next stage
5	key-in "Y" "END"		answer yes or no for element-deviding
6	pick "◇"	Fig.12.3 & Fig.4	devide a mesh element
7	repeat No.6		
8	pick "END"		get element map
9	pick "END"		to next Q-region stage
10	key-in "Y" "END"		answer yes or no for element-deviding of Q1-subregion
11	pick "◇"	Fig.12.4 & Fig.4	devide a mesh element
12	repeat No.11		
13	pick "END"		get element map
14	pick "END"		to next Q2-subregion stage
15	pick "◇"	Fig.12.5 & Fig.6	
16	move "+"		move a node (learn the trick to pick ◇ !)
17	repeat No.15 and 16		
18	pick "END"		get element map
19	key-in "C" "END"	Fig. 12.6	to next final plot stage
20	pick "ELEMENT"		selection of dishes for A-region
21	pick "HARDCOPY"	Fig.12.7 (element-map)	if necessary, COM-copy of the dish
22	pick "NOCOPY"		recover to program
23	repeat No.20∿22		if no more COM-copy, pick "NOCOPY" to go to next stage
	for node point map	Fig. 12.8 (node-map)	
	or region map	Fig. 12.9 (region-map)	
24	pick "END"		to next Q1-subregion stage
	repeat No.20∿23		
25	pick "END"		to next Q2-subregion stage
	repeat No.20∿23		
26	pick "END"		job closed to get figure out of CRT

```
....*....1....*....2....*....3....*....4....*....5....*....6....*....7....*....8

¥NO        J666.                                                              /
                                                                          T.2/TIME  1M
                                                                          C.2/CORE 128
                                                                          W.0/PAGE  40
                                                                          P.0/PCH    0.
                                                                            ./
                                                                          GDP/
                                                                          C35/
¥GJOB     2111223.T.ISE.446.12,SHINER                                        /00331
*DLIEDRUN    RFNAME=J1223.LOOMPJD.GRFD=ON.PGSLIB=CALL.GDSP=ON.GDBG=ON      LOOMP
*DISKTN   F01.J1223.PUNCH
*DISK     F08,TRK=4,INC=0                                                   GRAPHICS
*DISKTO   F09.J1223.PWRZON                                                  FR.PENUM
*DISKTN   F10.J1223.OUTBAB
*DISK     F22                                                               SCRATCH
*GCOM35
*DATA
¥JEND
```

Fig. 11.1 Set up the job control cards for the LOOM-P when using the graphic display

```
....*....1....*....2....*....3....*....4....*....5....*....6....*....7....*....8

¥NO        K666.                                                    /
                                                              T.0/TIME 10S
                                                              C.1/CORE  64
                                                              W.0/PAGE  40
                                                              P.2/PCH  200
                                                                 /00331
¥GJOB    2111223.T.ISE.446.12.SHINER
*HFORT
C     PROGRAM-PUNCH FILE UNIT 1 FOR FEM-BABEL, FROM LOOP-P
C     REFER EDIT ABOUT VALUES OF NELEM AND NBCON
C     PUNCH WHEN NPUNCH=7
C
      DIMENSION MATRE(1500),NBCP(500)
      READ (5,1000) NELEM,NBCON,NPUNCH
      REWIND 1
      READ (1,1600)
      WRITE(NPUNCH,1600)
      READ (1,2100) (MATRE(I),I=1,NELEM)
      WRITE(NPUNCH,2100) (MATRE(I),I=1,NELEM)
      READ (1,2200)
      WRITE(NPUNCH,2200)
C
      IF(NBCON.LE.0) GO TO 800
      READ (1,2000)
      WRITE(NPUNCH,2000)
      READ (1,2100) (NBCP(J),J=1,NBCON)
      WRITE(NPUNCH,2100) (NBCP(J),J=1,NBCON)
      READ (1,2200)
      WRITE(NPUNCH,2200)
  800 CONTINUE
 1000 FORMAT(3I6)
 1600 FORMAT(3H10*)
 2000 FORMAT(3H15*)
 2100 FORMAT(6I12)
 2200 FORMAT(3H  T)
      STOP
      END
*HLIEDRUN
*DISKTO  F01.J1223.PUNCH
*PUNCH
*DATA
   526   137     7
¥JEND
```

Fig. 11.2 Set up of a program obtaining punched data out of the file unit 1

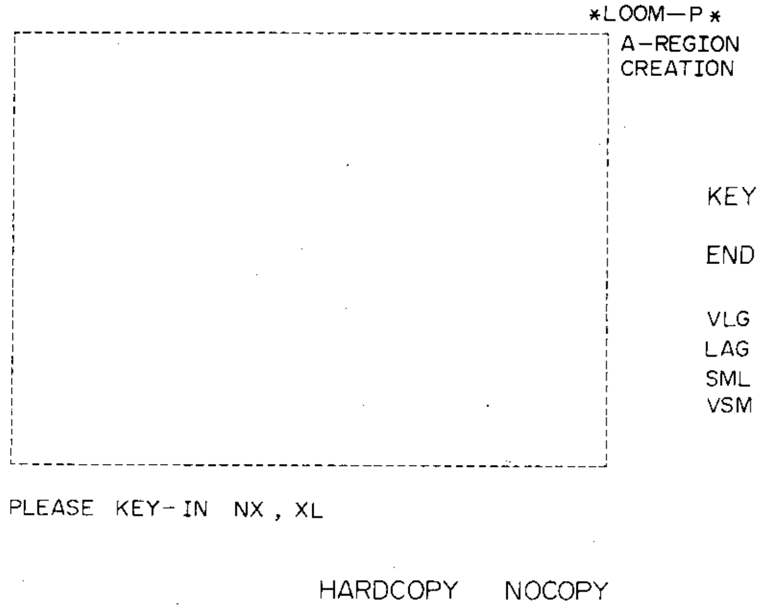

Fig. 12.1 The first figure on CRT for the mesh network creation of A-region

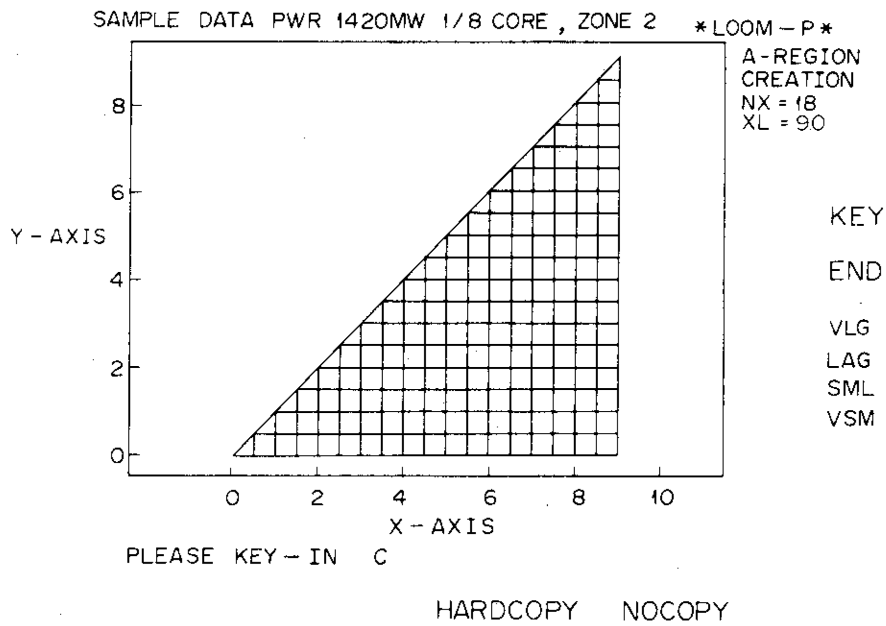

Fig. 12.2 The figure obtained after key-in of "18,9.0"

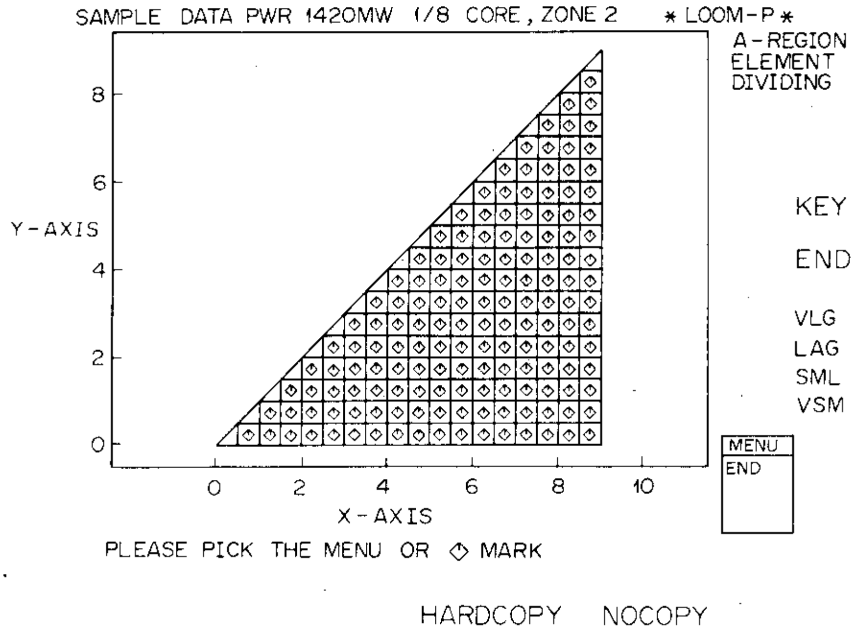

Fig. 12.3 The figure before element-deviding for A-region

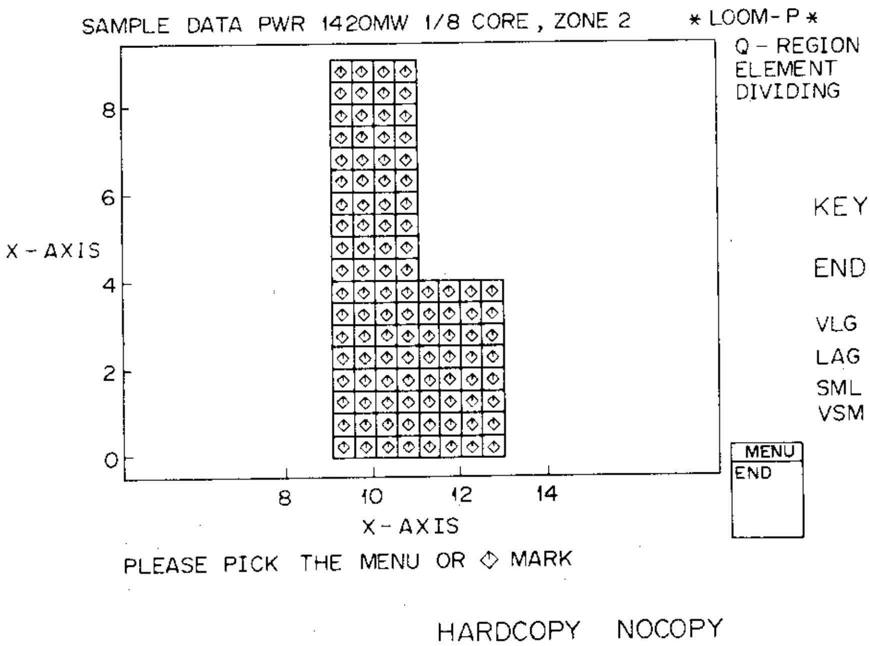

Fig. 12.4 The figure before element-deviding for Q1-subregion

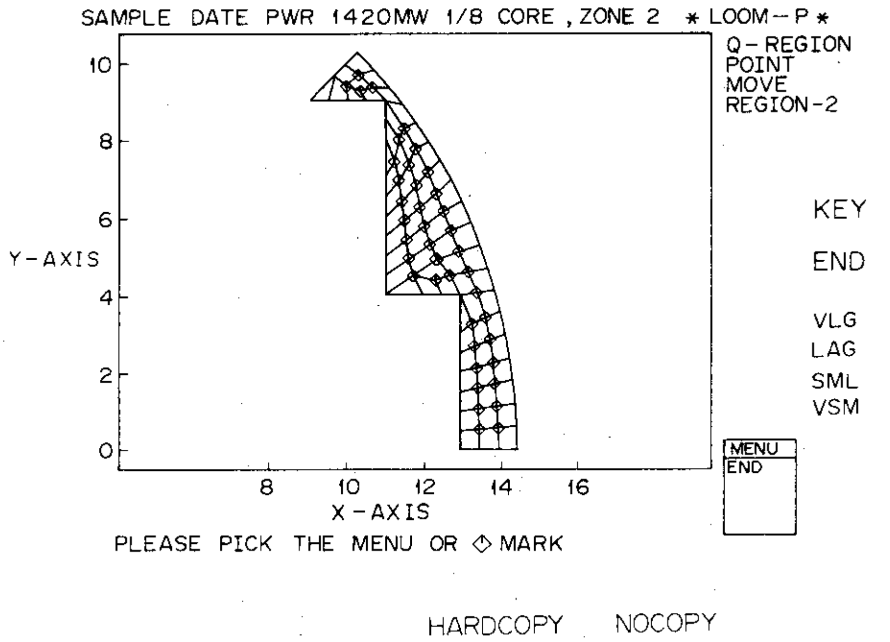

Fig. 12.5 The figure before node-moving for Q2-subregion

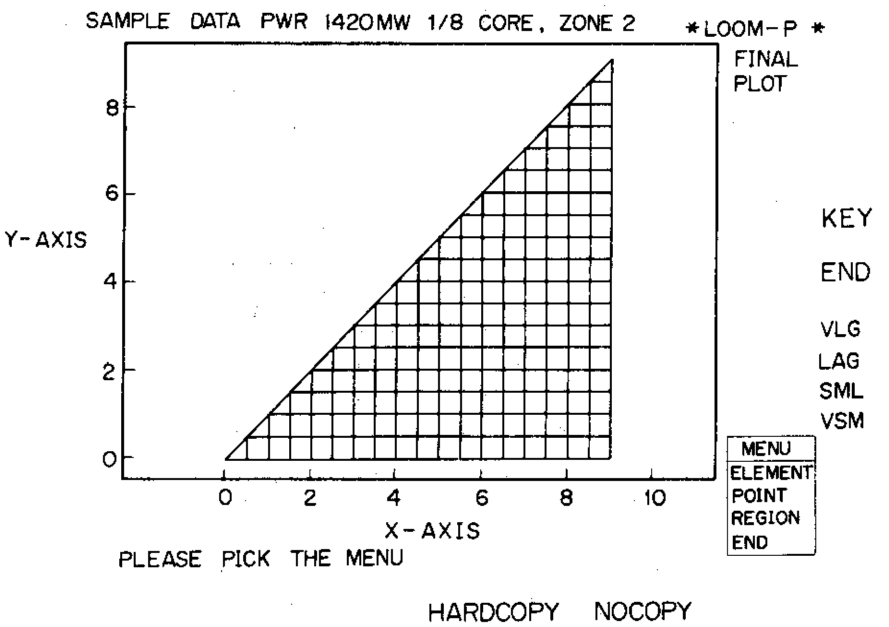

Fig. 12.6 The first figure of the final plottings

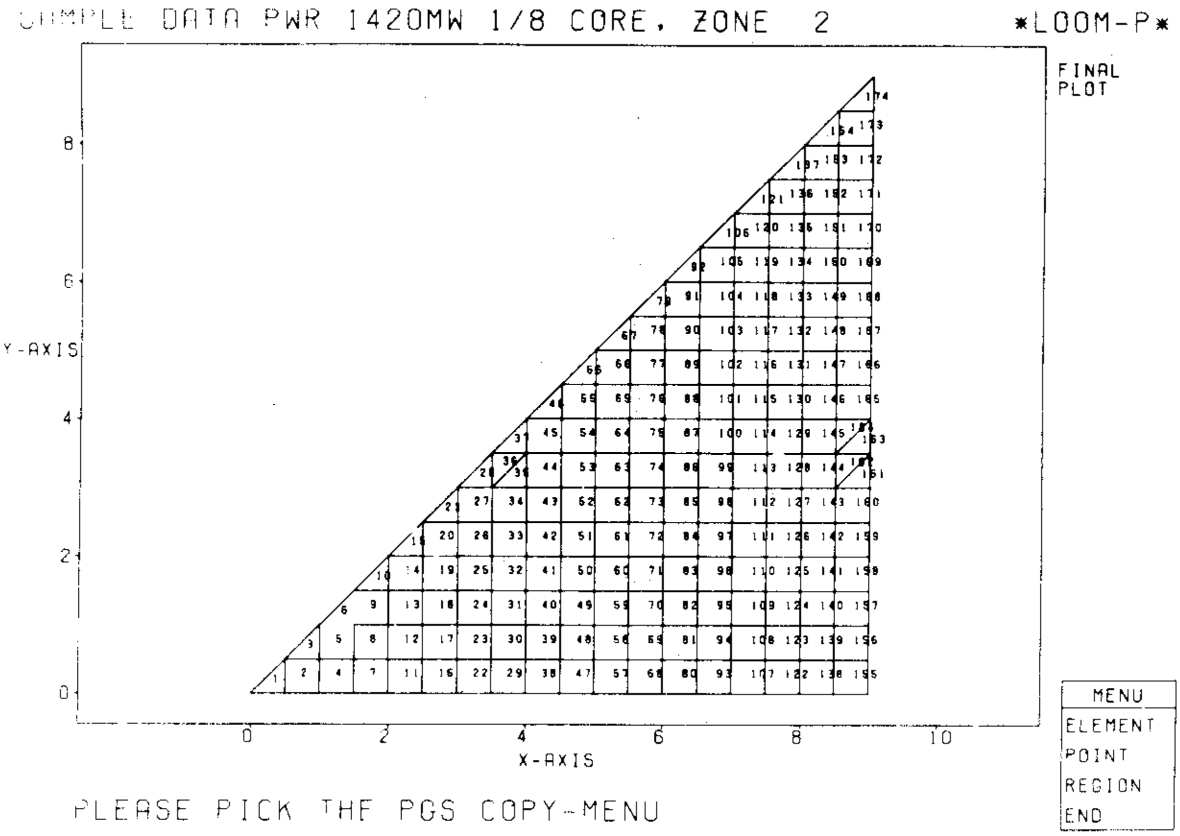

Fig. 12.7 Element map for A-region obtained from COM-copy

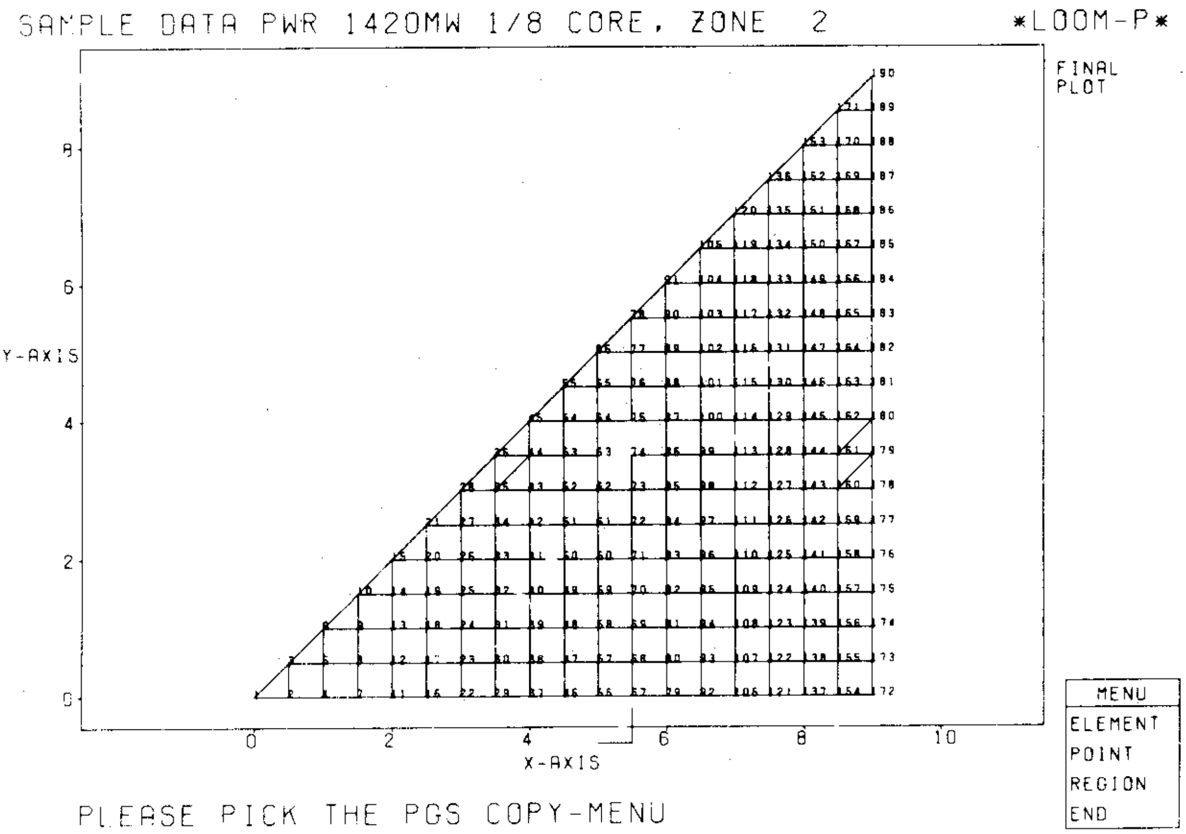

Fig. 12.8 Node map for A-region obtained from COM-copy

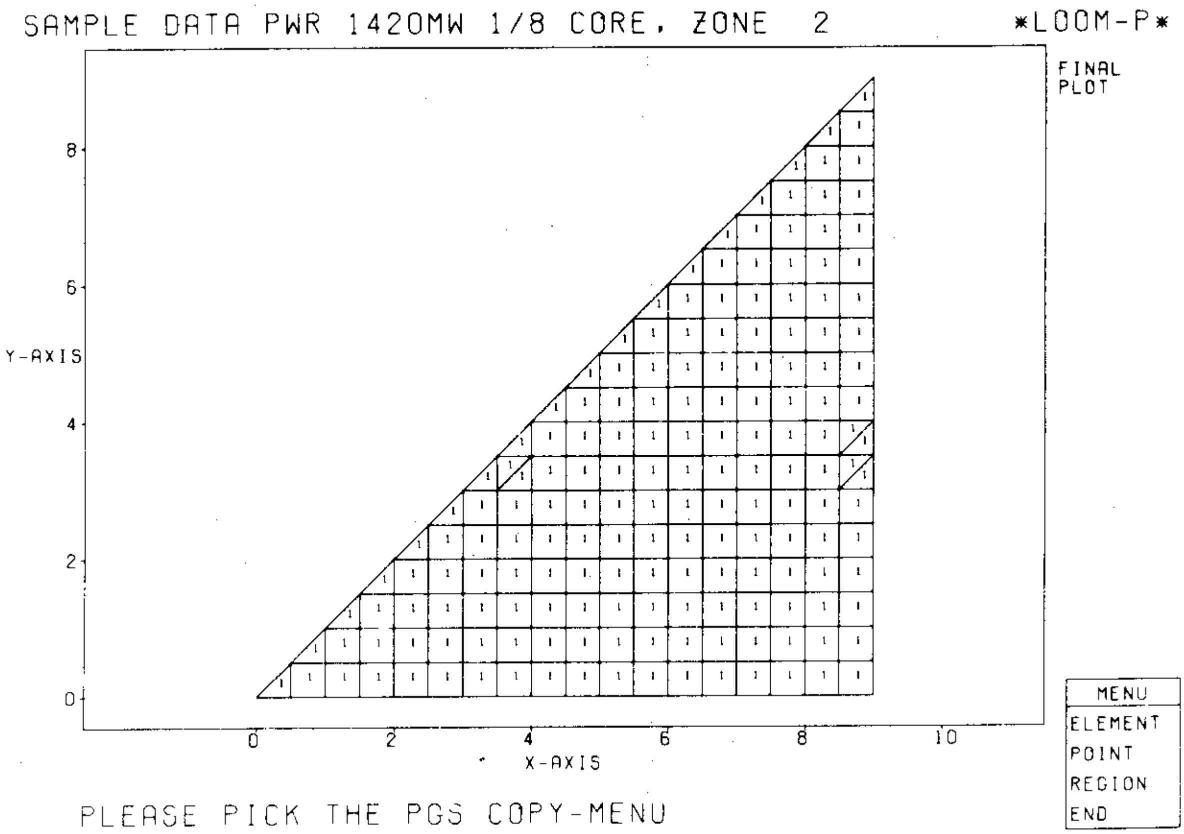

Fig. 12.9 Region map for A-region obtained from COM-copy

5. Conclusions

Users of the finite element codes suffer from the laborious preparation of input data on finite element meshes. It is difficult to produce automatically the good shaped meshes, in the sense of smoothly graded meshes, for any shaped region. Fortunately, it has been found the QMESH just fits to solve such a problem, though the program it two-dimensional.

The LOOM-P may be regarded just as an application of the QMESH. It is easy to modify the LOOM-P for use of other geometries, though it has been programed for a special purpose.

As the on-line type graphic display has severe limitations to the data storage, the partitioned viewing technique is adopted in the LOOM-P. It will be more useful to modify the LOOM-P so as to use a Tektronix keyboard graphics terminal, because the terminal does not have limitations to the data storage. In addition, one doesn't need probably some techniques used in the LOOM-P as being unfit for the terminal.

Acknowledgements

The LOOM-P has been programed by Mr. Atsuhiro Kubo of the Century Research Center Co.. Authors are indebted to Mr. Yasuhiro Nakamura of the computing center, JAERI for much helpful advice on the graphic display. They also wish to express many thanks to the study group of the finite element methods for their encouragements and discussions during this work: to Dr. Takumi Asaoka, Dr. Yasuaki Nakahara, Mr. Toichiro Fujimura of our laboratory, and Mr. Tadahiro Ohnishi of Hitachi Ltd..

This work was partially sponsered by Sumitomo Heavy Industries, Ltd..

5. Conclusions

Users of the finite element codes suffer from the laborious preparation of input data on finite element meshes. It is difficult to produce automatically the good shaped meshes, in the sense of smoothly graded meshes, for any shaped region. Fortunately, it has been found the QMESH just fits to solve such a problem, though the program it two-dimensional.

The LOOM-P may be regarded just as an application of the QMESH. It is easy to modify the LOOM-P for use of other geometries, though it has been programed for a special purpose.

As the on-line type graphic display has severe limitations to the data storage, the partitioned viewing technique is adopted in the LOOM-P. It will be more useful to modify the LOOM-P so as to use a Tektronix keyboard graphics terminal, because the terminal does not have limitations to the data storage. In addition, one doesn't need probably some techniques used in the LOOM-P as being unfit for the terminal.

Acknowledgements

The LOOM-P has been programed by Mr. Atsuhiro Kubo of the Century Research Center Co.. Authors are indebted to Mr. Yasuhiro Nakamura of the computing center, JAERI for much helpful advice on the graphic display. They also wish to express many thanks to the study group of the finite element methods for their encouragements and discussions during this work: to Dr. Takumi Asaoka, Dr. Yasuaki Nakahara, Mr. Toichiro Fujimura of our laboratory, and Mr. Tadahiro Ohnishi of Hitachi Ltd..

This work was partially sponsered by Sumitomo Heavy Industries, Ltd..

References

1) Zienkiewicz O. C., "The Finite Element Method in Engineering Science," McGraw-Hill Pub. Co. Ltd. (1971).
2) Lobitz D. W., "A mesh-generation code and contour-plotting routine," SC-TM-71-0557 (1972).
3) Burzer M. J., "ZONE-a finite element mesh generator," UCID-17139 (1976).
4) Grabrielson V. K., "Mesh generation for two-dimensional regions using a DVST (Direct View Storage Tube) graphics terminal," SAND-76-8231 (1976).
5) Windt P. D. and Reynen J., "EURCYL, a computer program to generate finite element meshes for cylinder-cylinder interactions," EUR 5030e (1973).
6) Cook W. A., "Three-dimensional mesh generator for finite element computer codes," LA-UR-74-1693 (1974).
7) Hutula D. N. and Zeiler S. M., "MESH3D: a three-dimensional finite element mesh generator program for eight-node isoparametric elements," WAPD-TM-1079 (1973).
8) Jones R. E., "QMESH: a self-organizing mesh generation program," SLA-73-1088 (1974).
9) Jones R. E., "Users manual for QMESH, a self-organizing mesh generation program," SLA-74-0239 (1974).
10) Jones R. E., "The QMESH mesh generation package," SAND-75-5884 (1976).
11) Ise T. and Tsutsui T., "Automatic mesh generation with QMESH program," JAERI-M7078 (1977, in Japanese).
12) Nakamura Y. and Onuma Y., "Graphic display and the programming," JAERI-M 6619 (1976, in Japanese).
13) Nakamura Y. and Onuma Y., "Graphic programming by the simplified GSP," JAERI-M 6711 (1976, in Japanese).
14) Ise T. et al. (in preparation).
15) Cuthill E. and Mckee J., "Reducing the bandwidth of sparse symmetric matrices," Proc. 24th National Conference ACM, ACM(1969) P157∿172.