NASA TECHNICAL NOTE

NASA TN D-5072

c. 1

NASA TN D-5072

DESCRIPTION AND EVALUATION OF DIGITAL-COMPUTER DESIGN-ANALYSIS PROGRAM FOR HOMOPOLAR INDUCTOR ALTERNATORS

by David S. Repas and Gary Bollenbacher

Lewis Research Center
Cleveland, Ohio

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION • WASHINGTON, D. C. • MARCH 1969

DESCRIPTION AND EVALUATION OF DIGITAL-COMPUTER DESIGN-ANALYSIS PROGRAM FOR HOMOPOLAR INDUCTOR ALTERNATORS

By David S. Repas and Gary Bollenbacher

Lewis Research Center
Cleveland, Ohio

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

For sale by the Clearinghouse for Federal Scientific and Technical Information
Springfield, Virginia 22151 – CFSTI price $3.00

ABSTRACT

A digital computer program for analyzing the electromagnetic design of homopolar inductor alternators is presented. The program, which is written in FORTRAN IV programming language, is described in general terms. The calculational methods are either outlined briefly or appropriate references are cited. Instructions for using the program are given and typical program input and output for a 15-kVA alternator are shown. Calculated results for this and two (nearly identical) 80-kVA alternators are compared with experimental data. In general, considering the many assumptions and approximations which are made in the calculational methods, it is felt that reasonable agreement has been obtained between the test data and calculated results.

CONTENTS

Page

SUMMARY 1

INTRODUCTION 1

COMPUTER PROGRAM DESCRIPTION 2
  General Description 2
  Description of Alternator to Which Program is Applicable 3
  Method of Calculation 4
    Magnetic calculations 4
    Efficiency and loss calculations 9
    Reactances 11
    Skew factor calculation 13

HOW TO USE COMPUTER PROGRAM 14
  Input Data Requirements 14
  Preparation of Material Decks 15
  Preparation of Alternator Design Deck 17
  Typical Computer Program Output 19

EVALUATION OF COMPUTER PROGRAM 27
  Description of Alternators Used for Program Evaluation 27
    Brayton cycle alternator 27
    SNAP-8 alternators 28
  Comparison of Experimental and Calculated Results 28
    Open-circuit saturation curves 28
    Field currents under load 29
    Losses and efficiency 29
    Reactances 33

CONCLUDING REMARKS 33

APPENDIXES -
  A - COMPLETE FORTRAN LISTING AND FLOW CHARTS OF HOMOPOLAR INDUCTOR ALTERNATOR COMPUTER PROGRAM 35
  B - DEFINITION OF FORTRAN VARIABLES 71
  C - DEFINITION OF INPUT VARIABLES FOR EACH NAMELIST NAME 82

REFERENCES 90

DESCRIPTION AND EVALUATION OF DIGITAL-COMPUTER DESIGN-ANALYSIS PROGRAM FOR HOMOPOLAR INDUCTOR ALTERNATORS

by David S. Repas and Gary Bollenbacher

Lewis Research Center

SUMMARY

A digital computer program for analyzing the electromagnetic design of homopolar inductor alternators is presented. The program, which is written in FORTRAN IV programming language, is described in general terms.

The method of calculation is either outlined briefly or appropriate references are cited. The items that are calculated by the program include the open-circuit saturation curve, the field-current requirement at various loads, losses, efficiency, and reactances. Instructions for using the program are given, and typical program input and output for a 15-kilovolt-ampere alternator are shown. Calculated results for this and two (nearly identical) 80-kilovolt-ampere alternators are compared with experimental data. The comparison shows that the maximum difference between calculated and experimental data is 7 percent for field currents and 0.7 percent for efficiency at rated load.

An alphabetical list of major FORTRAN symbols, the complete program listing including flow charts, and a list of input variables with definitions are given in the appendixes.

INTRODUCTION

The application of the digital computer to the design of alternators has found wide acceptance within the electric machinery industry. However, specific computer programs that have been written remain for the most part proprietary.

In 1964 work sponsored by the NASA resulted in a report (ref. 1) that contained eight design manuals and eight digital computer programs for analysis of most major types of alternators. The programs are written in the FORTRAN II programming language for use on an IBM-1620 computer equipped with an on-line card reader and a typewriter console for input and output.

These programs suffer from two shortcomings. The first is the limitations imposed by the equipment for which it was written. The second and more serious shortcoming is that, for most of the programs, accuracy had never been thoroughly verified by comparing calculated results with experimental data. Both shortcomings were remedied for one of the eight computer programs. The homopolar inductor program was chosen because of the interest in this alternator for use in space-power systems and because of the ready availability of experimental data for three different homopolar inductor alternators.

Elimination of the shortcomings required numerous program modifications. These modifications included converting the program to the FORTRAN IV programming language for use on an IBM-7094 computer and rewriting the input and output statements to utilize high-speed peripheral equipment. The required input data to the program were substantially reduced, and checks for obvious errors in the input data were added. The output was clarified to the point of being self-explanatory.

More significant were the modifications found necessary when results of computer calculations were compared with experimental data for the 15-kilovolt-ampere Brayton cycle alternator (refs. 2 and 3) and for the two 80-kilovolt-ampere SNAP-8 alternators (refs. 4 and 5). All three of these alternators are rated at 120/208 volts, 400 hertz, and 12 000 rpm. To obtain satisfactory agreement between experimental and calculated results, modifications were made in the magnetic, reactance, and efficiency calculations.

As shown in this report, the final version of the homopolar inductor alternator computer program gives calculated results that agree favorably with experimental data for all three alternators. The program may be used both for analyzing the electrical design of specific alternators and for parametric studies of alternators for auxiliary power generating systems.

COMPUTER PROGRAM DESCRIPTION

General Description

The homopolar inductor alternator computer program is an analysis program. This means that the program accepts as input a complete electromagnetic alternator design; from this, it calculates losses and efficiency, the open-circuit saturation curve, field-current requirement at various loads, several reactances, and weights of electromagnetic components. The results of the calculations, together with the input, are then printed out to provide a complete, self-explanatory record.

The program may be used with any computer system that accepts FORTRAN IV. For program execution, approximately 13 000 storage locations are needed. At the Lewis Research Center, the program has been used on the 7044-7094 Mod II direct couple system using a FORTRAN IV, version 13 compiler. For this system, typical pre-execution and execution times for the program are 1.0 and 0.04 minute, respectively.

The computer program consists of a main program and three subroutines. The subroutines were necessary because one long program would have been too large to compile with the available core storage locations.

Description of Alternator to Which Program is Applicable

The basic alternator configuration for which the computer program was written, with each major electromagnetic component identified, is illustrated in figure 1. As shown, the alternator consists of two laminated stators separated by a toroidal field coil. Surrounding both stators and the field coil is the yoke. The armature winding passes through both stators and under the field winding.

The rotor is constructed with saliences or poles on each end; all north poles are at one end and all south poles at the other. As in a conventional salient-pole alternator, the centerlines for the north and south poles are 180 electrical degrees apart.

A number of assumptions, in addition to those implicit in the geometric configura-

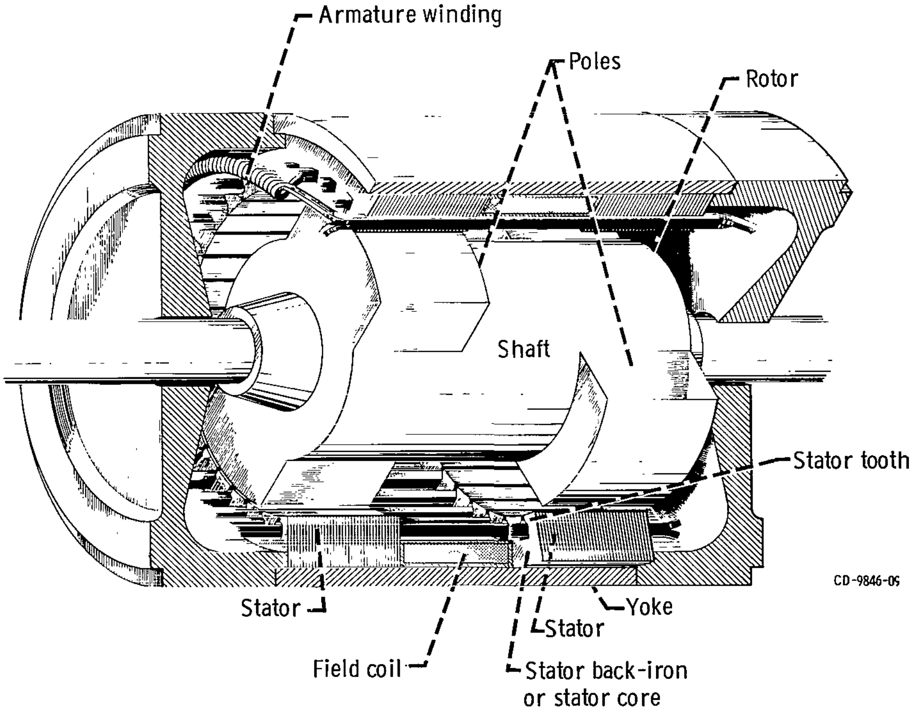


Figure 1. - Cutaway view of homopolar inductor alternator.

tion, are made regarding the alternator. These assumptions are

(1) Shaft, poles, and pole head are made of same magnetic material

(2) Alternator armature winding is three-phase Y-connected

(3) Both stators are made of the same material

(4) Distance between stators is the same as the field coil width

(5) Field coil is confined to the toroidal space bordered by a stator on each side, the yoke on the outside, and the armature winding on the inside

(6) Alternator has only one field winding.

In contrast to the restrictions imposed on the alternator by the preceding assumptions, there are several options that are available to the program user. These options, which increase the applicability of the program, are

(1) Armature conductors may be round or rectangular

(2) Field conductors may be round or rectangular

(3) Armature conductors may consist of any number of strands

(4) Yoke, rotor, and stator may each be made of a different magnetic material

(5) Damper windings may or may not be present

(6) If damper windings are present, the damper bars may be either round or rectangular

(7) Five different slot configurations may be used

(8) Three different yoke geometries may be used.

Method of Calculation

This section of the report will outline in general terms the method of calculation used in the computer program. However, due to the length of the program and the large number of equations involved, specific equations will not, except in a few instances, be given. Instead, references for the major design analysis equations are given. Reference 1 is particularly applicable.

More detailed information and specific equations may be found in the program listing in appendix A. To assist in locating specific information in the listing, COMMENT cards are used freely to identify the major calculations. Of further value is appendix B, which is an alphabetcal listing of the major FORTRAN variables including definitions and units, and the flow charts for the main program and two of the three subroutines included in appendix A.

Magnetic calculations. - A cross-sectional view of a homopolar inductor alternator is given in figure 2. For clarity, a two-pole alternator is shown. The main flux path in the alternator is shown by the solid arrows, and the leakage flux paths are indicated by the broken arrows. An additional leakage flux φ_m from the rotor to the stator between

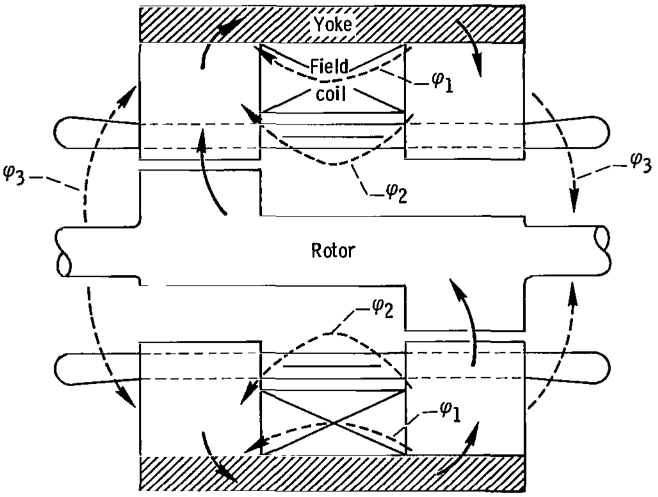


Figure 2. - Homopolar-inductor-alternator basic configuration and flux paths. Leakage flux across field coil, φ_1; leakage flux from stator to stator, φ_2; leakage flux from stator to rotor end extension, φ_3.

the rotor poles is also present. This path is shown in figure 3, which is a developed end view of the alternator.

The main flux flows from a rotor north pole, across the air gap and then radially through the stator teeth and stator back iron. It then goes axially through the yoke to the other stator stack where the flux path is completed through the stator laminations, air gap, and rotor.

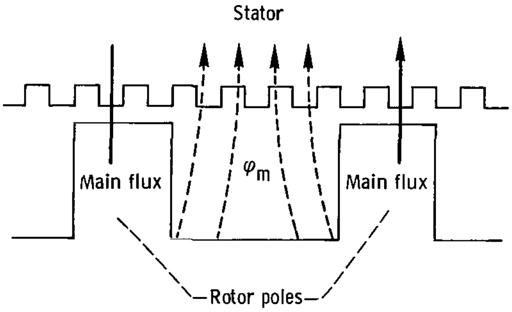


Figure 3. - Homopolar-inductor-alternator end view showing leakage flux between poles. Leakage flux between poles from rotor to stator, φ_m.

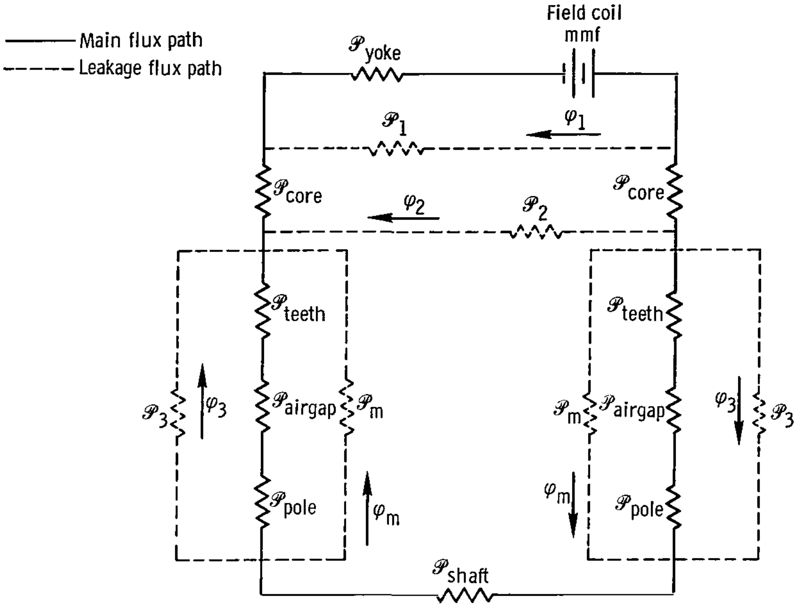


Figure 4. - Equivalent magnetic circuit for homopolar inductor alternator at no-load.

An equivalent magnetic circuit for the homopolar inductor alternator is given in figure 4. The various leakage fluxes and permeances which are considered in this program are shown. In this report, the laminated stator back iron is referred to as the stator core. The rotor shaft is the cylindrical part of the rotor and excludes the poles (fig. 1).

Some of the more important equations and assumptions used to determine field currents for various load conditions will be described in this section of the report. The complete equations for the magnetics calculations can be found in the FORTRAN program listing for subroutine MAGNET which is included in appendix A.

The method of calculation used to determine the field current at no-load will be described first. The flux distribution in the air gap at no-load is shown in figure 5. In the

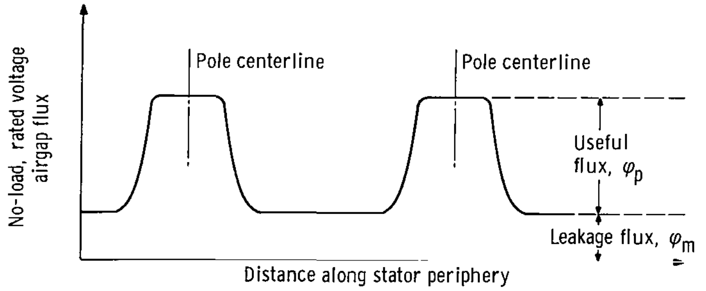


Figure 5. - No-load rated-voltage airgap flux distribution for homopolar inductor alternator.

following discussion, the useful flux in the air gap and poles is taken to be the flux that is present, excluding the leakage flux between the poles from the rotor to the stator φ_m.

In determining the useful flux in the air gap and poles, a hypothetical total flux φ_t is first calculated. This hypothetical total flux is assumed to have a constant flux density over the entire pole pitch; that is, the shape of the field form is assumed to be rectangular (ref. 6).

From the equation for the induced voltage in the armature winding of a synchronous machine, φ_t is calculated. This calculation takes into account the fact that the winding is pitched and distributed and that the actual flux wave is not a true sinusoid. The flux density in the air gap B_g due to the useful flux is

$$B_g = \frac{\varphi_t}{\pi l d}$$

where

l length of one stator stack

d inside diameter of the stator laminations

The air gap magnetomotive-force drop F_g from B_g is then

$$F_g = B_g \frac{g_e}{\mu_o}$$

where

g_e effective length of the air gap

μ_o permeability of air

The useful flux per pole φ_p is

$$\varphi_p = \frac{\varphi_t}{P} C_P$$

where

P number of poles

C_P ratio of the average to the maximum value of the field form (ref. 7)

From φ_p, the flux densities and magnetomotive-force drops, due to the useful flux in both the poles and stator teeth, are determined. The effect of φ_m, the leakage flux between poles from the rotor to the stator, on the air gap, pole, and teeth flux densities and magnetomotive-force drops must now be included.

It is assumed that this leakage flux density is constant around the stator periphery (fig. 5). Also, φ_m is the product of the sum of the air gap plus pole plus teeth magnetomotive-force drops and the permeance of the leakage path. The effect of φ_m is to increase the flux densities and, thus, the magnetomotive-force drops in the air gap, poles, and teeth. Since the magnitude of φ_m and these magnetomotive-force drops are interrelated, an iteration process is involved in determining φ_m.

Once the preceeding part of the magnetics calculations is completed, the rest of the procedure is fairly straightforward. A flow chart that gives the order of the entire magnetics calculations is given in appendix A. The magnetomotive-force drops in the magnetic parts of the alternator are determined in the program from the material magnetization curves. These curves are an input to this program.

The magnetics calculations are also made for several alternator loads at the load power factor specified in the program input. Rated terminal voltage for the alternator is assumed for these calculations. For load conditions, some modifications to the no-load calculation method must be made. As shown in reference 1, the air-gap magnetomotive force under load F_{gl} will increase from the no-load rated-voltage value. Neglecting the effect of φ_m,

$$F_{gl} = e_d \cdot F_g$$

where

$$e_d = WX_d \sin \psi + \cos(\psi - \theta)$$

$$\psi = \tan^{-1} \frac{\sin \theta + WX_q}{\cos \theta}$$

and

W load at which F_{gl} is to be calculated, per unit

X_d direct-axis synchronous reactance, per unit

θ $\cos^{-1}$ (power factor)

X_q quadrature-axis synchronous reactance, per unit

Also, from reference 1, the flux per pole under load will increase from the no-load, rated-voltage value. Again, neglecting φ_m, the flux per pole under load φ_{pl} is

$$\varphi_{pl} = g_x \cdot \varphi_p$$

where

$$g_x = e_d - 0.93\, WX_{ad} \sin \varphi$$

where X_{ad} is the direct-axis armature reaction reactance. Now, φ_m is a function of the air gap, pole, and teeth magnetomotive-force drops and of the demagnetizing magnetomotive-force due to the armature current.

Using these modifications, the magnetic characteristics of the alternator for load conditions can now be determined. The procedure is essentially the same as presented for the no-load case.

Efficiency and loss calculations. - Individual losses and efficiency are calculated at several loads of increasing magnitude, continuing until the alternator saturates or until calculations have been completed for five loads. While the first load at which loss calculations are made must always be zero per unit, the program user has the option of specifying any or all of the remaining four loads. These loads are designated by G within the program (G is in per unit).

Rated voltage and power factor, as defined by the program input data, are assumed throughout the loss and efficiency calculations. The individual losses, that are calculated by the program, along with the method of calculation or references, are listed below.

Field conductor losses and armature conductor losses: These losses are given by the expression I^2R where I is the dc or rms current in the winding, as appropriate, and R is the dc winding resistance corrected for the winding temperature. Correcting the winding resistance for temperature involves several assumptions:

(1) The average no-load winding temperature T_{NL} is known or can be estimated.

(2) The average rated-load winding temperature T_{RL} is known or can be estimated.

(3) The average winding temperature is a parabolic function of the current in the winding.

With these assumptions, the winding temperature T_G at any load G is

$$T_G = \frac{T_{RL} - T_{NL}}{\left(I_{RL} - I_{NL}\right)^2} \left(I_G - I_{NL}\right)^2 + T_{NL}$$

where

I_{RL} current at rated load

I_{NL} current at no-load, equal to zero for armature winding

I_G current in winding at load G

For the armature winding I_{NL} is, of course, zero. (If in the program, 1.0 per unit load (G = 1.0) is not one of the loads for which losses are calculated, then the above equation is only approximately applied to the field temperature calculations.)

Eddy losses: References 1 and 8 present discussions of armature conductor eddy losses.

Pole-face losses: For no-load pole-face-loss calculations, see references 1 and 9; for pole-face-loss calculations at any other load see reference 10 (eq. 22).

Damper losses: No-load damper losses are calculated as shown in reference 11 using the "cold" damper-bar temperature; for damper bar loss calculations under load (ref. 10, eq. 22), the "hot" damper bar temperature is used regardless of the magnitude of the load. The cold and hot damper-bar temperatures are inputs to the program.

Stator core loss and stator tooth loss: The respective equations used to calculate these losses are

$$\text{Stator core loss} = k(\text{Stator core weight})(WL)\left(\frac{\text{Stator core flux density}}{BK}\right)^2$$

$$\text{Stator tooth loss} = k(\text{Stator tooth weight})(WL)\left(\frac{\text{Stator tooth flux density}}{BK}\right)^2$$

where

k empirical constant equal to 3.0. (This constant is variously stated in the literature to range from 1.5 to 3.0. The 3.0 value was chosen in this program because it provided the closest agreement between experimental and calculated values.)

WL core loss at flux density BK and at rated alternator frequency, W/lb

BK flux density at which WL is measured

and where weights are given in pounds.

Windage loss: If an accurate value for windage loss is known, it may be read into the program for use in the efficiency calculation. If the windage loss is not read into the program, it will be assumed to be zero. The program user may also elect to have the program calculate an approximate value for windage loss. In that case, the equation used (ref. 1) is

$$W = 2.52\times 10^{-6}(d^{2.5}n^{1.5}l)$$

where

W windage loss, W

d rotor diameter, in.

n rotor speed, rpm

l pole length, in.

This equation assumes that the gas surrounding the rotor is air at standard pressure and temperature. For gases other than air at standard pressure and temperature, windage losses may be calculated by the method given in reference 12.

Miscellaneous load losses: These losses are assumed to be 1 percent of the kilovolt-ampere output of the alternator at load point G.

Efficiency: At each load efficiency is calculated from

$$\text{Efficiency} = \frac{\text{Alternator power output}}{\text{Alternator power output} + \sum \text{Losses}} \times 100$$

where both alternator power output and losses are expressed in watts.

Reactances. - In the program, the following reactances are calculated:

(1) Armature winding leakage X_{al}

(2) Direct-axis armature reaction X_{ad}

(3) Quadrature-axis armature reaction X_{aq}

(4) Direct-axis synchronous X_d

(5) Quadrature-axis synchronous X_q

(6) Field leakage X_f

(7) Direct-axis transient X'_d

The armature winding leakage reactance is the sum of the slot leakage and end winding leakage reactances. The slot leakage reactance is determined from formulas given in reference 7, but the end winding reactance is calculated using the method of reference 13. Both the direct and quadrature-axis armature reaction reactances are determined from the method given in reference 7. The synchronous reactances are determined in the usual manner; that is, $X_d = X_{ad} + X_{al}$ and $X_q = X_{aq} + X_{al}$.

The field leakage reactance is determined from the permeances of the alternator leakage paths. These paths are shown in figures 2 to 4. The field leakage permeance $\mathscr{P}_f$ is

$$\mathscr{P}_f = \mathscr{P}_1 + \mathscr{P}_2 + \frac{1}{2}\mathscr{P}_3 + \frac{P}{4} \cdot \mathscr{P}_m$$

where

$\mathscr{P}_1$	permeance of leakage path across field coil
$\mathscr{P}_2$	permeance of leakage path from stator to stator
$\mathscr{P}_3$	permeance of leakage path from stator to rotor and extension
P	number of poles
$\mathscr{P}_m$	permeance of leakage path between poles

The field leakage inductance L_f is then

$$L_f = N_f^2 \cdot \mathscr{P}_f$$

where

N_f number of field turns

The field leakage reactance referred to the field winding X_{ff} is

$$X_{ff} = 2\pi f \cdot L_f$$

where

f rated output frequency of alternator

The field leakage reactance referred to the armature is then

$$X_f = \frac{3}{2} X_{ff} \cdot \left(\frac{N_A}{N_f}\right)^2$$

where

$$N_A = \frac{N_s \cdot N_c \cdot k_p \cdot k_d}{2 \cdot M \cdot C}$$

where

N_A	effective armature winding turns
N_s	number of slots
N_c	conductors per slot
k_p	pitch factor
k_d	distribution factor
M	number of phases
C	number of parallel circuits

The direct-axis transient reactance is calculated by the usual method

$$X'_d = X_{al} + \frac{X_f \cdot X_{ad}}{X_f + X_{ad}}$$

Skew factor calculation. - The usual skew factor formula for conventional alternators having only one stator stack does not apply to a homopolar inductor alternator. A new equation, which takes into account the stator stack separation, had to be derived for use in this computer program:

$$\text{Skew factor} = \frac{2T_p}{\pi s_o}\left[\sin \frac{s_o\pi}{2T_p}\right]\left[\cos \left(\frac{s_o\pi}{2T_p}\right)\left(1 + \frac{b}{l_o}\right)\right]$$

where

T_p	pole pitch
s_o	stator slot skew measured at the stator bore (for one stator stack)
b	distance between two stator stacks
l_o	length of one stator stack

The preceding equation reduces to the usual formula when the stator separation is zero ($b = 0$) providing that it is recognized that setting $b = 0$ gives a stator stack of length $2l_o$ and a total slot skew of $2s_o$.

HOW TO USE COMPUTER PROGRAM

Input Data Requirements

To use this computer program for the analysis of a homopolar inductor alternator the complete electromagnetic design of the alternator must be known. This includes physical dimensions, armature and field winding parameters and the magnetic characteristics of the materials to be used in the stator, rotor, and yoke. The design information must then be transferred onto data cards for use with the program. A typical set of data cards is shown in figure 6. It consists of three material decks. The material decks must be in the order shown in the figure, that is, stator material, rotor material, and yoke material. There must be exactly three material decks in each data deck even if two or all three materials are identical.

If more than one alternator design deck is included in the data deck, the program will treat each design deck independently. Each will result in a separate alternator analysis complete with an individual output record. However, the same material decks will be assumed to apply to each alternator design deck.

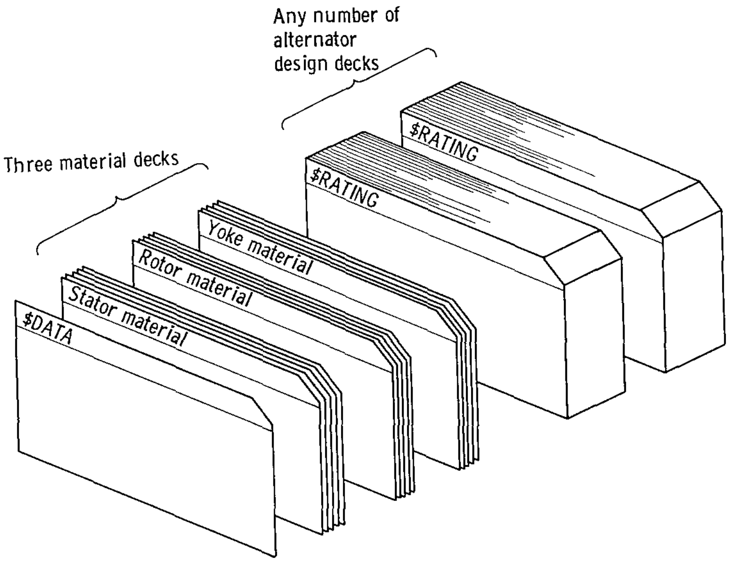


Figure 6. - Typical data deck makeup.

Preparation of Material Decks

A material deck consists of five cards. The first card contains the material name. This serves two functions: it identifies the material deck, and it is read by the computer and stored for later printout on the output record. The remaining four cards contain information about the magnetization curve of the material specified on the first card. This information allows the approximate reconstruction of the magnetization curve during program execution. Table I summarizes the information pertaining to each data card of a material deck.

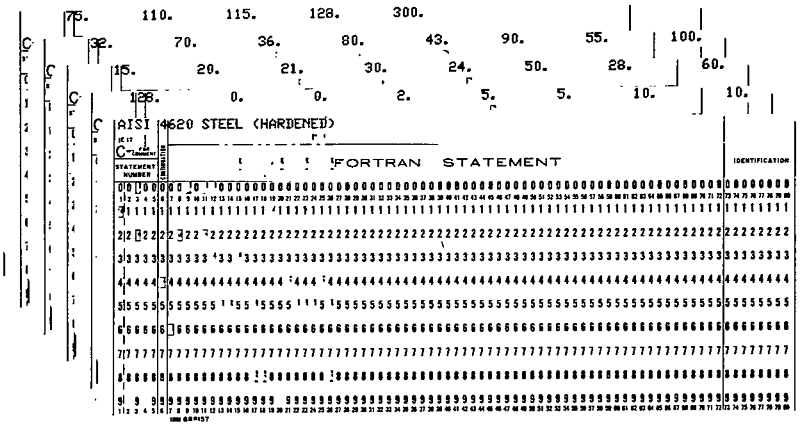
TABLE I. - FORMAT AND TYPE OF DATA REQUIRED ON MATERIAL DECK DATA CARDS

Card	Format	*Information contained on card*
1	6A6	Material name
2 - 5	8F10. 1	Coordinates from material magnetization curve

To illustrate preparation of a material deck, AISI 4620 steel (hardened) will be used as an example. The first card of this material deck will appear as shown in figure 7. The material name should start in column 1 and may extend up to column 36.

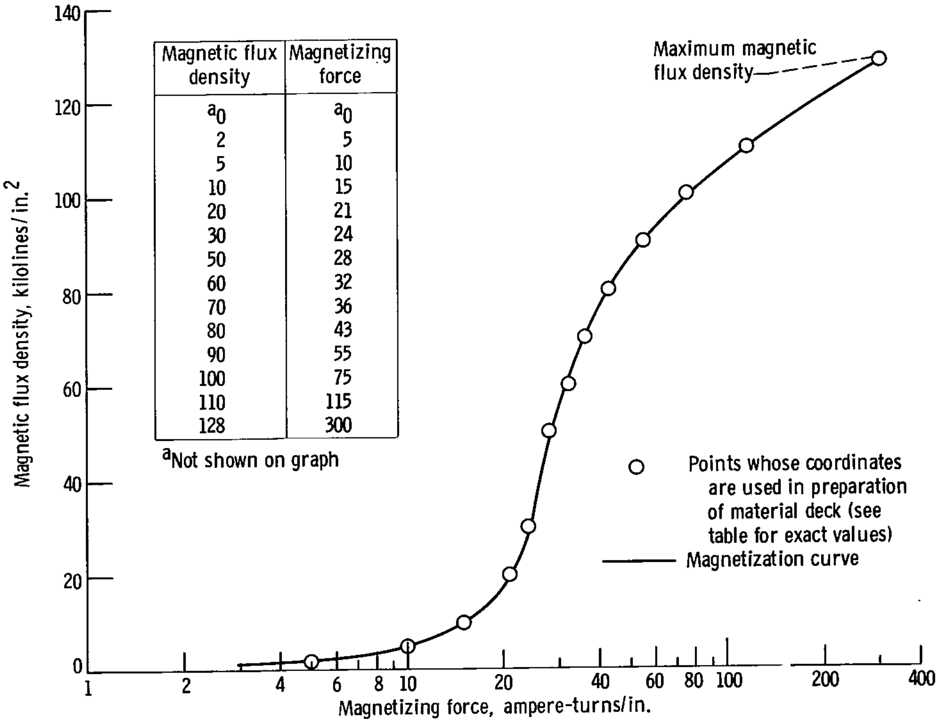
To prepare the remaining four cards of the material deck, the magnetization curve of the material is needed. The magnetization curve for AISI 4620 steel (hardened) is shown in figure 8. The units must be kilolines per square inch for the magnetic flux density and ampere-turns per inch for the magnetizing force. Fourteen points on the curve must then be chosen. In the figure, 13 points are indicated by data symbols; the 14th point is the origin. These points are listed in the table insert. Careful attention must be paid to the sequence in which the numbers are punched onto data cards. The first number must be the maximum flux density of the points chosen. In the example, this value is 128 kilolines per square inch. This is followed in ascending order, by alternate values of magnetic flux density and magnetizing force. Again, in the example, with reference to the table insert, the values appear in the following sequence on the data cards: 128, 0, 0, 2, 5, 5, 10, . . . 110, 115, 128, 300. The complete material deck for AISI 4620 steel (hardened) is shown in figure 7.

During program execution, the original magnetization curve is approximately recon-



```
75.     110.    115.    128.    300.
32.     70.     36.     80.     43.     90.     55.     100.
15.     20.     21.     30.     24.     50.     28.     60.
128.    0.      0.      2.      5.      5.      10.     10.
AISI 4620 STEEL (HARDENED)
```

Figure 7. - Material deck for AISI 4620 steel (hardened).



Magnetic flux density	Magnetizing force
$^a0$	$^a0$
2	5
5	10
10	15
20	21
30	24
50	28
60	32
70	36
80	43
90	55
100	75
110	115
128	300

[a]Not shown on graph

Figure 8. - Average magnetization curve for AISI 4620 steel (hardened).

structed by interpolation between points. The interpolation assumes a straight line on semi-log paper between data points.

Preparation of Alternator Design Deck

The alternator design deck contains all the dimensions, the geometric configuration (in numerical code), and the winding parameters needed for an electromagnetic analysis of the alternator design. Unlike the material decks, which are read according to a FORMAT statement, the alternator design decks are read with a READ statement referencing a NAMELIST name. For each NAMELIST name one or more data cards are required to numerically define the variables included in that NAMELIST name. In all there are 11 NAMELIST names. Each name is suggestive of the type of variables included in its list. Table II lists the NAMELIST names in the order in which they must appear in the alternator design deck and indicates the type of information conveyed by the variables belonging to that NAMELIST name. Detailed information about each NAMELIST name is provided in appendix C.

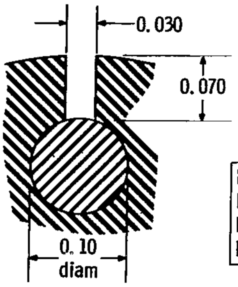
Preparation of an alternator design deck will now be illustrated with the construction of a typical data card for the NAMELIST name DAMPER. The data that will be used is

TABLE II. - SUMMARY OF NAMELIST NAMES USED IN ALTERNATOR DESIGN DECK[a]

NAMELIST name[b]	Type of information included
RATING	Rated kVA, power factor, voltage, rpm, etc.
STATOR	All stator dimensions but not including slot dimensions
SLOTS	Specifies type of slot and slot dimensions
WINDNG	Fully describes armature winding
AIRGAP	Gives air gap dimensions
CONST	Gives various constants needed for internal calculations
ROTOR	Gives pole and pole head dimensions but not including damper winding
DAMPER	All variables concerning damper windings
SHAFT	All shaft dimensions
YOKE	Yoke dimensions and type of yoke
FIELD	Includes all field coil parameters

[a] For detailed information, see appendix C (table VII).

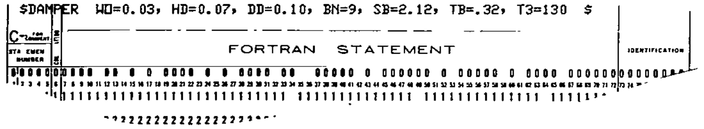
[b] Presented in the order in which they must appear in the alternator design deck.



Damper bar length	2.12
Damper bar pitch	0.32
Number of damper bars per pole	9
Damper bar material	Copper

(a) Damper bar and damper bar slot design for Brayton-cycle alternator. (All dimensions are in inches.)

BN	9
WO	0.030
HD	0.070
DD	0.100
H	Not read in when damper bars are round
B	Not read in when damper bars are round
SB	2.120
TB	0.320
T33	20° C is acceptable since true temperature is (by assumption) unknown
T3	130
RE	Not read in since 0.694 is sufficiently accurate
ALPHAE	Not read in since 3.93×10^{-3} is sufficiently accurate



```
 $DAMPER  WO=0.03, HD=0.07, DD=0.10, BN=9, SB=2.12, TB=.32, T3=130  $
```

(b) Numerical values of DAMPER variables and appearance of data card. (See table VII(h) for definitions of FORTRAN symbols.)

Figure 9. - Preparation of data card for NAMELIST name DAMPER.

for the 400-hertz, 15-kilovolt-ampere, 120/208-volt Brayton cycle alternator (refs. 2 and 3). Figure 9(a) gives all pertinent design data for the Brayton cycle alternator damper circuit. Figure 9(b) shows how the design data are related to the variables of NAMELIST name DAMPER (table VII(h), appendix C) and how these data are transferred to the data card DAMPER.

Data cards for the remaining NAMELIST names are prepared in a similar manner. To illustrate the result, a complete data deck listing for the Brayton cycle alternator follows.

```
$DATA
SILICON STEEL (.007 IN. LAMINATION)
 129.      0.        0.        3.3       .4        12.9      .8        23.9
 1.2       36.1      1.6       45.1      2.        61.3      3.        68.4
 4.        77.5      6.1       80.       8.1       93.5      60.6      103.2
 181.8     109.8     303.      129.      707.
AISI 4620 STEEL (HARDENED)
    128.        0.        0.        2.        5.       5.       10.        10.
     15.       20.       21.       30.       24.      50.       28.        60.
     32.       70.       36.       80.       43.      90.       55.       100.
     75.      110.      115.      128.      300.
INGOT IRON
    125.        0.        0.        2.         1.5       6.      1.8        8.5
     2.      30.5       2.6     48.          3.3      62.5     4.2       75.5
     5.7      59.       9.2     97.         14.     104.5     26.       114.
     98.     121.      210.    125.        300.
 $RATING  VA=15, EE=208, F=400, IPX=4, PF=0.8, G=0,.5,1.,1.5,2.  $
 $STATOR  DI=5.28, DU=8.68, CL=2.00, LTS=.007, WL=8.6, BK=77.4, SF=0.90  $
 $SLOTS  ZZ=2, BO=.065, BS=.171, HO=.04, HX=.482, HS=.62, HT=.035, HY=0.127,
     IQQ=48  $
 $WINDNG  RF=1, SC=8, YY=8, C=2, DW=.140, SN=2, SN1=2, DW1=.0250, CE=.12,
     SD=.0290, T1=114.5, T11=93.5  $
 $AIRGAP  GC=.040  $
 $CONST  $
 $ROTOR  PL=1.88, HP=0.85, HP1=1.0, PE=.700, BP=2.37, LTR1=0.014  $
 $DAMPER  WO=0.03, HD=0.07, DD=0.10, BN=9, SB=2.12, TB=.32, T3=130  $
 $SHAFT  DSH=3.53, DISH1=1.00, ALH=2.28  $
 $YOKE  TYPY=1, TY=.44  $
 $FIELD  PCOIL=6.56, DCOIL=8.18, PT=515, RD=.0571, T2=113, T22=100.5  $
```

Typical Computer Program Output

In this section, the output, which resulted from the input data shown in the preceeding section, is presented. This output is typical, although the actual program output format will vary somewhat, depending, for example, on the type of slot or yoke configuration specified in the input data.

```
    **HOMOPCLAR INDUCTOR ALTERNATOR**

ALTERNATCR RATING

         ALTERNATCR KVA                   15.0
         LINE-LINE VCLTAGE               208.
         LINE-NEUT. VOLTAGE              120.
         PHASE CURRENT                    41.64
         POWER FACTCR                      0.80
         PHASES                            3
         FREQUENCY                       400.
         POLES                             4
         RPM                           12C00.0
```

```
STATOR SLOTS

    TYPE-PARTIALLY CLOSED
                                                                   -BO-
                                                        ----------*    *----------
                                                         HO       *    *
                                                        ----------*    *
         BO                      0.065 INCHES                    *      *
         BS                      0.171                   HT     *        *
         HO                      0.040                         *          *
         HX                      0.482                   -----*            *
         HT                      0.035                        *            *
         HW                      0.052                   HW   *            *
         HS                      0.620                   -----*  ********  *  HS
                                                              *  *      *  *
         NO. OF SLOTS               48                        *  *      *  *
                                                              *  ********  *
         SLOT PITCH              0.346 INCHES            HX   *            *
                                                              *  ********  *
         SLOT PITCH                                           *  *      *  *
           AT 1/3 DIST.          0.373 INCHES                 *  *      *  *
                                                         -----*  ********  *
                                                              *            *
                                                              **************-----
                                                              1            1
                                                              1-----BS-----1
                                                              1            1


AIR GAP

         MINIMUM AIR GAP             0.040 INCHES
         MAXIMUM AIR GAP             0.040
         EFFECTIVE AIR GAP           0.043

         CARTER COEFFICIENT
               STATOR                1.057
                ROTOR                1.014

ARMATURE WINDING (Y-CONNECTED, FORM WOUND)

         STRAND DIMENSIONS                         0.1400 X 0.0250 INCHES
         UNINSULATED STRAND HEIGHT (RADIAL)        0.0250
         DISTANCE BTWN CL OF STRANDS (RADIAL)      0.0290

         STRANDS/CONDUCTOR IN RADIAL DIR.          2.
         TOTAL STRANDS/CONDUCTOR                   2.
         CONDUCTOR AREA                            0.0070 SQ-IN.
         CURRENT DENSITY AT FULL LOAD           2973.99   AMP/SQ-IN.

         COIL EXTENSION BEYOND CORE                0.120  INCHES
         MEAN LENGTH OF 1/2 TURN                  12.030
         END TURN LENGTH                           5.750
         STATOR SLOT SKEW (PER STATOR)             0.

         RESISTIVITY AT 20 DEG. C                  0.6940 MICRO OHM INCHES
         STATOR RESISTANCE AT   25. DEG. C         0.0389 OHMS

         NO. OF EFFECTIVE SERIES TURNS            26.54
         SLOTS SPANNED                             8.
         SLOTS PER POLE PER PHASE                  4.00
         CONDUCTORS/SLOT                           8.
         NO. OF PARALLEL CIRCUITS                  2.
         PHASE BELT ANGLE                         60.     DEGREES

         SKEW FACTOR                               1.000
         DISTRIBUTION FACTOR                       0.958
         PITCH FACTOR                              0.866
```

```
FIELD WINDING

         CONDUCTOR DIAMETER                          0.0571 INCHES
         CONDUCTOR AREA                              0.0026 SQ-IN.

         NO. OF TURNS                              515.
         MEAN LENGTH OF TURN                        23.154  INCHES

         RESISTIVITY AT 20 DEG. C                    0.6940 MICRO OHM INCHES
         FIELD RESISTANCE AT  25. DEG. C             3.2951 OHMS

         COIL INSIDE DIAMETER                        6.560  INCHES
         COIL OUTSIDE DIAMETER                       8.180
         COIL WIDTH                                  2.280


STATOR

         STATOR INSIDE DIAMETER                    5.28  INCHES
         STATOR OUTSIDE DIAMETER                   8.68
         OVERALL CORE LENGTH (ONE STACK)           2.00
         EFFECTIVE CORE LENGTH                     1.80
         DEPTH BELOW SLOT                          1.08

         STACKING FACTOR                           0.90

         NO. OF COOLING DUCTS                      0.
         WIDTH OF DUCTS                            0.    INCHES

         CORE LOSS AT  77.4 KILOLINES/SQ.IN.       8.6   WATTS/LB.
         LAMINATION THICKNESS                      0.007 IN.


ROTOR

         POLE BODY WIDTH                      2.370 INCHES
                   AXIAL LENGTH               1.880
                   STACKING FACTOR            1.000

         POLE HEAD WIDTH                      2.717 INCHES
                   AXIAL LENGTH               1.880
                   STACKING FACTOR            0.911
                   LAMINATION THICKNESS       0.014 INCHES

         POLE EMBRACE                         0.700
         POLE HEIGHT                          0.850 INCHES
         POLE HEIGHT (EFF.)                   1.000
         ROTOR DIAMETER                       5.200
         PERIPHERAL SPEED                 16349.    FEET/MIN.
         SPEC. TANGENTIAL FORCE               1.076 LBS/SQ.IN.
```

```
SHAFT

         DIAMETER (UNDER FIELD COIL)        3.530 INCHES
         INSIDE DIAMETER (OF HOLLOW SHAFT)  0.
         DIAMETER (UNDER END TURNS)         1.000
         LENGTH (BTW. POLES)                2.280

DAMPER BARS (ROUND)

         DAMPER BAR DIAMETER              0.100 INCHES
         SLOT OPENING WIDTH               0.030
         SLOT OPENING HEIGHT              0.070
         DAMPER BAR LENGTH                2.120
         DAMPER BAR PITCH                 0.320

         NO. OF DAMPER BARS/POLE           9

         RESISTIVITY AT 20 DEG. C         0.694 MICRO-OHM INCHES

YOKE (TYPE 1)


                                                  1
                                                  1
                                                  1
                                                  1
           *********************************  -------
           *                               *
          *            YOKE               *   TY = 0.44 IN.
         *                              **
         ******************************* ------------
             *        *       *        *          1
             * STATOR * FIELD * STATOR *          1
             *        * COIL  *        *          1
             *        *       *        *          1
             *        *********        *
             *        *       *        *
             **********       **********


        INSIDE YOKE DIAMETER    8.680 INCHES
        STATOR SEPARATION       2.280 INCHES

WEIGHTS

        STATOR COND.           10.380 POUNDS
        FIELD COND.             9.802
        STATOR IRON            33.092
        ROTOR                  21.966
        YOKE                   22.405

        TOTAL
         (ELECTROMAGNETIC)     97.645
```

```
CONSTANTS

        C1, FUNDAMENTAL/MAX. OF FIELD FLUX   1.128
        CP, POLE CONSTANT                    0.711
        CM, DEMAGNETIZATION FACTOR           0.844
        CQ, CROSS MAGNETIZATION FACTOR       0.502
        D1, POLE FACE LOSS FACTOR            1.170


PERMEANCES (LINES/AMPERE TURN)

        AIR GAP                            196.370 PER INCH OF CORE LENGTH
        WINDING LEAKAGE - STATOR SLOT        5.078
                          STATOR END         9.949

        LEAKAGE
           PM, FROM ROTOR TO STATOR
            (BTWN. ROTOR TEETH)             32.571
           P5, ACROSS FIELD COIL            17.543
           P6, FROM STATOR TO STATOR        27.910
           P7, STATOR TO SHAFT END           6.951


REACTANCES

        AMPERE CONDUCTORS/INCH             417.343
        REACTANCE FACTOR                     0.586

        STATOR WINDING LEAKAGE              11.782 PERCENT
        ARM. REACTION (DIRECT)             109.504
        ARM. REACTION (QUAD.)               57.821
        SYNCHRONOUS (DIRECT)               121.286
        SYNCHRONOUS (QUAD.)                 69.603
        FIELD LEAKAGE                       75.040
        TRANSIENT                           56.309

        FIELD SELF INDUCTANCE                1.379 HENRIES


        OPEN CIRCUIT TIME CONSTANT
              (FIELD ONLY)                 0.41859 SECONDS


        SHORT CIRCUIT AMPERE-TURNS        1394.682
        SHORT CIRCUIT RATIO                  1.043

STATOR MATERIAL - SILICON STEEL (.007 IN. LAMINATION)


ROTOR MATERIAL -- AISI 4620 STEEL (HARDENED)


YOKE MATERIAL --- INGOT IRON
```

```
MAGNETIZATION CHARACTERISTICS
    (NO LOAD, RATED VOLTAGE)

         TOTAL USEFUL FLUX    1418.98 KILOLINES
         USEFUL FLUX/POLE      252.19

         FLUX DENSITIES
            AIRGAP (INCL. PML)  42.77 KL/SQ-IN
            POLE                59.12
            TOOTH               86.38
            CORE                42.56
            SHAFT (UNDER FLD.)  58.56
            YOKE (OVER FLD.)    50.65

         AMPERE-TURNS
            AIRGAP             600.99 PER STATOR
            POLE                27.02
            TOOTH               13.06
            CORE                 2.03
            SHAFT (UNDER POLE)  42.14

            SHAFT (UNDER FLD.)  71.94
            YOKE                12.49

            TOTAL             1454.92
```

ALTERNATOR LOAD CHARACTERISTICS (RATED VOLTAGE, 0.80 POWER FACTOR)

PERCENT LOAD	0.	50.	100.	150.	200.
LEAKAGE FLUX (PML)	20.88	41.09	64.08	89.31	115.20
AIR-GAP AMPERE TURNS	600.99	877.98	1208.45	1563.37	1929.39
FLUX DENSITIES (KL/SQ-IN)					
POLE	59.12	64.33	69.79	75.99	82.74
TEETH	86.38	93.99	101.97	111.02	120.89
SHAFT (UNDER FLD.)	58.56	67.64	77.59	88.72	100.50
CORE	42.56	46.91	51.66	57.10	63.00
YOKE (OVER FLD.)	50.65	59.96	70.59	82.68	95.54
TOTAL AMPERE TURNS	1454.92	2084.03	2893.04	3875.65	4913.03
FIELD CURRENT (AMPS)	2.83	4.05	5.62	7.53	9.54
CURRENT DENS. (FIELD)	1103.24	1580.28	2193.73	2938.83	3725.45
FIELD VOLTS	12.02	17.34	24.79	35.40	49.34
TEMPERATURES (DEG.C)					
FIELD	100.50	102.89	113.00	135.92	172.78
ARMATURE	93.50	98.75	114.50	140.75	177.50
RESISTANCES (OHMS)					
FIELD	4.25	4.28	4.41	4.70	5.17
ARMATURE	0.0492	0.0500	0.0523	0.0563	0.0618
EDDY FACTOR	1.02	1.02	1.01	1.01	1.01
ALTERNATOR LOSSES (WATTS)					
FIELD	33.95	70.16	139.25	266.39	470.69
WINDAGE	0.	0.	0.	0.	0.
STATOR TOOTH	98.26	116.32	136.92	162.31	192.43
STATOR CORE	102.55	124.61	151.12	184.60	224.76
POLE FACE	84.97	90.18	105.79	131.81	168.23
DAMPER	0.22	0.28	0.32	0.40	0.52
STATOR COPPER	0.	64.98	272.19	658.51	1285.34
EDDY	0.	0.34	1.30	2.71	4.39
MISC. LOAD	0.	75.00	150.00	225.00	300.00
TOTAL	319.96	541.86	956.90	1631.73	2646.36
ALTERNATOR OUTPUT (KVA)	0.	7.50	15.00	22.50	30.00
ALTERNATOR OUTPUT (KW)	0.	6.00	12.00	18.00	24.00
ALTERNATOR INPUT (KW)	0.32	6.54	12.96	19.63	26.65
PERCENT LOSSES	100.00	8.28	7.39	8.31	9.93
PERCENT EFFICIENCY	0.00	91.72	92.61	91.69	90.07

```
                                        NO-LOAD SATURATION DATA
                                        -----------------------

VOLTAGE
  PERCENT              80.00      90.00     100.00     110.00     120.00     130.00     140.00     145.00      a0.      a0.

  LINE-NEUTRAL         96.07     108.08     120.09     132.10     144.11     156.12     168.12     174.13       0.       0.
  LINE-LINE           166.40     187.20     208.00     228.80     249.60     270.40     291.20     301.60       0.       0.

FIELD CURRENT           2.27       2.53       2.83       3.22       3.81       4.50       5.31       5.79       0.       0.

FLUX DENS.(KL/SQ-IN)
  POLE                 47.27      53.18      59.12      65.16      71.39      77.71      84.09      87.38       0.       0.
  TOOTH                69.07      77.70      86.38      95.21     104.30     113.54     122.87     127.67       0.       0.
  SHAFT                46.78      52.62      58.56      64.76      71.49      78.48      85.65      89.51       0.       0.
  CORE                 34.03      38.27      42.56      46.97      51.63      56.42      61.31      63.88       0.       0.
  YOKE                 40.47      45.49      50.65      56.20      62.50      69.20      76.19      80.08       0.       0.

AMPERE-TURNS
  AIRGAP              480.53     540.58     600.99     662.39     725.72     790.03     855.02     888.51       0.       0.
  POLE                 23.42      24.96      27.02      29.06      31.53      35.29      40.66      44.09       0.       0.
  TOOTH                 2.56       3.88      13.06      45.87     123.72     223.49     337.56     417.45       0.       0.
  CORE                  1.65       1.82       2.03       2.27       2.55       2.87       3.25       3.60       0.       0.
  SHAFT               139.98     147.13     156.22     166.48     178.87     195.56     219.19     234.29       0.       0.
  YOKE                 10.78      11.55      12.49      13.70      15.21      17.81      40.35      42.12       0.       0.

  TOTAL              1167.10    1301.17    1454.92    1659.37    1961.14    2316.75    2732.51    2983.74       0.       0.
```

[a] All zeros in a column indicate that some section of the alternator has saturated. Examination of the previous column will generally identify which part of the magnetic circuit saturated.

EVALUATION OF COMPUTER PROGRAM

Agreement between results of the computer calculations and experimental data was determined for three homopolar inductor alternators. These three alternators were the 400-hertz Brayton cycle alternator and both the preprototype and prototype SNAP-8 machines. A more detailed description of these alternators is given in the following section of the report. Test data for the Brayton cycle alternator were obtained from reference 3. For the SNAP-8 alternators, test data were taken from references 4 and 5.

Description of Alternators Used for Program Evaluation

Brayton cycle alternator. - The Brayton cycle alternator is rated 12 kilowatts at 0.8 power factor (lagging), 120/208 volts, 400 hertz, and 12 000 rpm. It is designed to be cooled with oil which has a temperature of 93° C.

The stator laminations are 0.007-inch electrical sheet steel and the yoke is made of ingot iron. Both the armature and field winding conductors are copper. The armature conductors are stranded and laid flat in the slot to minimize eddy-current losses.

The rotor is made from AISI 4620 steel and has laminated pole tips of 0.014-inch electrical sheet steel. The laminated pole tips are electron-beam welded to the rotor and were used to minimize pole-face losses. In addition, zirconium copper damper bars were installed in the pole tips to equalize the terminal voltage during unbalanced loading

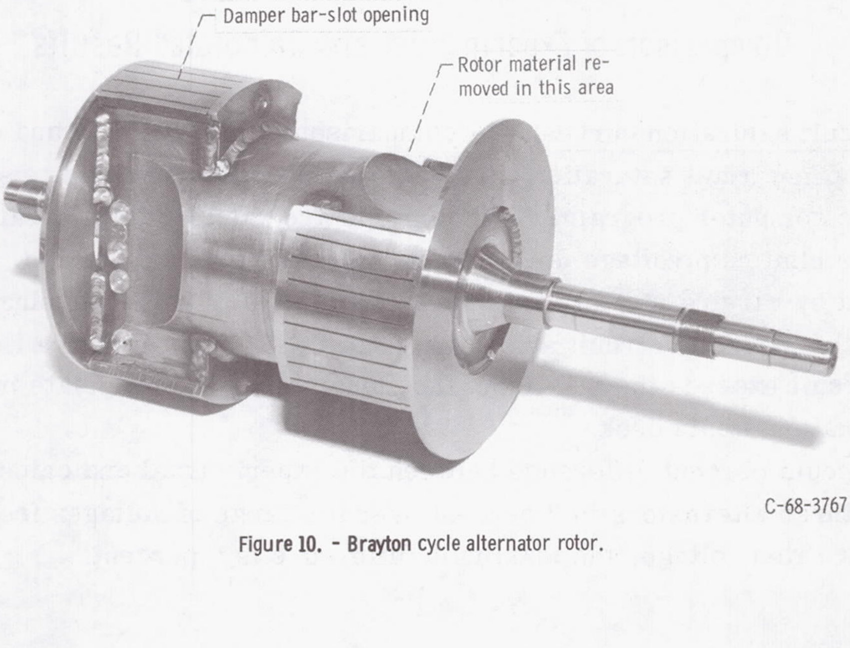


Figure 10. - Brayton cycle alternator rotor.

conditions. A photograph of the rotor is shown in figure 10. Note that some of the rotor material between the poles has been removed to reduce the leakage flux between poles from the rotor to the stator. Complete details of the alternator design are given in the sample output (pp. 19 to 26).

SNAP-8 alternators. - The two SNAP-8 alternators are rated 60 kilowatts at 0.75-power factor (lagging), 120/208 volts, 400 hertz, and 12 000 rpm. They are designed to be cooled with a polyphenyl ether oil, which has a temperature of 99° C

A comparison of the magnetic materials used in the preprototype and prototype SNAP-8 alternators is shown in the following table:

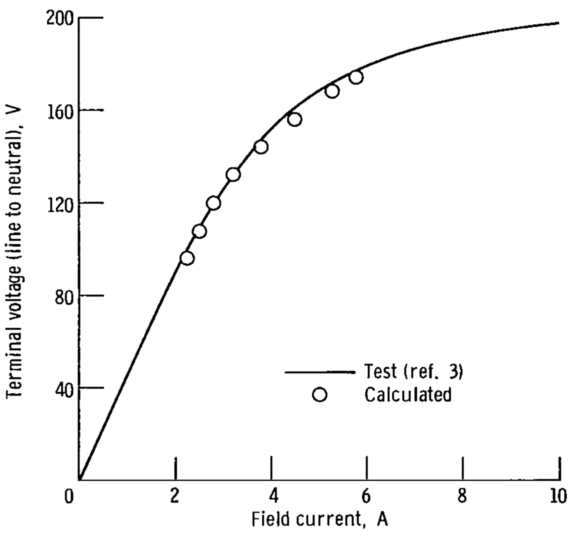
	Preprototype	Prototype
Stator laminations (0.014 in.)	AISI M-19	AISI M-19
Rotor	AISI 4130	AISI 4620
Yoke	Ingot iron	AISI 1020

The prototype alternator has a thicker yoke than the preprototype and also has some of the rotor material between the poles removed as in the Brayton cycle alternator. In addition, the prototype alternator had circumferential grooves machined in the pole face surfaces in an attempt to reduce pole-face losses. Test results indicated that there was no major difference in pole-face loss between the prototype and preprototype alternators.

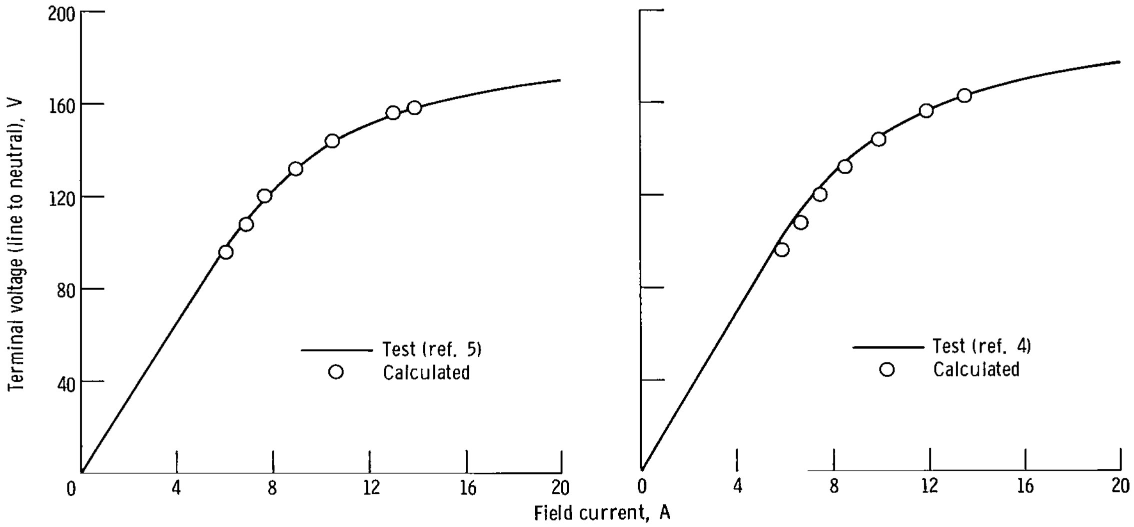
Comparison of Experimental and Calculated Results

Open-circuit saturation curves. - A comparison of the test data and calculated results for the open-circuit saturation curves of the three alternators are shown in figure 11. In the computer program, field currents are calculated for a range of terminal voltages. The minimum voltage is 80 percent of rated terminal voltage. The voltage is then increased by varying steps (maximum of 10 percent of rated terminal voltage) until some part of the magnetic circuit saturates. Saturation occurs when a flux density in a part of the circuit exceeds the maximum flux density of the appropriate material as specified in the material data deck.

The maximum percent difference between the experimental and calculated field currents for the three alternators is 7 percent over the range of voltages from minimum to maximum. At rated voltage, the maximum difference is 4 percent.



(a) 400-Hertz Brayton cycle alternator.



(b) SNAP-8 alternator (preprototype).

(c) SNAP-8 alternator (prototype).

Figure 11. - Alternator open-circuit saturation curve.

Field currents under load. - In table III, field currents are compared at rated voltage and power factor for various alternator loads. At rated load conditions, the maximum percent difference between the test and calculated field currents for any of the alternators if 5 percent.

Losses and efficiency. - Before discussing losses and efficiency, the test and calculated values for the field and armature winding resistances will be compared. This is of interest because, in determining copper losses, it is important that the winding resist-

TABLE III. - COMPARISON OF EXPERIMENTAL AND CALCULATED FIELD CURRENTS AT RATED VOLTAGE AND POWER FACTOR

Alternator	Load (a)	Field current, A		Percent difference
		Test[b]	Calculated	
Brayton cycle (400 Hz)	7.5 kVA at 0.8 power factor	[c]4.1	4.1	0
	15.0 kVA at 0.8 power factor	5.7	5.6	1.9
	22.5 kVA at 0.8 power factor	7.7	7.5	2.6
	30.0 kVA at 0.8 power factor	9.8	9.5	3.1
SNAP-8 (preprototype)	60 kVA at 0.75 power factor	[d]23.1	23.8	3.0
SNAP-8 (prototype)	60 kVA at 0.75 power factor	[d]19.1	18.1	5.4

[a] All power factors are lagging.

[b] For separate excitation.

[c] Test values from ref. 3.

[d] Test values from ref. 4.

ances be computed accurately from the conductor size and physical dimensions of the coil.

A comparison of test and calculated winding resistances for the three alternators at 25° C is given in table IV. All the corresponding test and calculated resistances agree to within 5 percent except for the calculated SNAP-8 preprototype armature resistance which is low by 10 percent.

The reason for this larger error is probably as follows. When the cross-sectional

TABLE IV. - CALCULATED AND EXPERIMENTAL WINDING RESISTANCE AT 25° C

Alternator	Winding	Resistance, ohms		Percent difference
		Test	Calculated	
Brayton cycle (400 Hz)	Armature	[a]0.0382	0.0389	1.8
	Field	3.27	3.30	.9
SNAP-8 (preprototype)	Armature	[b]0.0063	0.0057	10.0
	Field	1.46	1.53	4.7
SNAP-8 (prototype)	Armature	[b]0.0057	0.0056	1.8
	Field	1.48	1.53	3.3

[a] Test values from ref. 2.

[b] Test values from ref. 4.

area of a rectangular conductor is determined in the program, the radius of the rounded corner is calculated per ASTM B48-55. The armature conductor of the SNAP-8 preprototype alternator appears to have a larger corner radius than that used in the program. Hence, the computed conductor cross-sectional area is greater than the actual value. This results in a lower calculated than actual value for this particular resistance.

Test and calculated values of the losses and electromagnetic efficiency at rated load and power factor for each of the three alternators is given in table V. For the test data, the method of separation of losses as given in reference 14 was used. For comparison of loss data, the following experimental losses are used: field and armature conductor losses and open-circuit core, and stray load losses. Since these are not the losses spe-

TABLE V. - COMPARISON OF EXPERIMENTAL AND CALCULATED LOSSES AND EFFICIENCY AT RATED LOAD

Alternator	Load (a)	Loss or efficiency being compared	Test data	Calculated data	Percent difference
Brayton cycle (400 Hz)	15 kVA at 0.8 power factor	Armature conductor, W	[c]277	272	1.8
		Field conductor, W	135	139	2.9
		Open-circuit core, W	320	286	11.2
		Additional load,[b] W	270	260	3.8
		Total loss, W	1002	957	4.6
		Efficiency, percent	92.3	92.6	.3
SNAP-8 (preprototype)	60 kVA at 0.75 power factor	Armature conductor, W	[d]1470	1344	9.0
		Field conductor, W	1210	1337	10.0
		Open-circuit core, W	1250	1335	6.6
		Additional load,[b] W	2500	1995	22.4
		Total loss, W	6430	6011	6.7
		Efficiency, percent	90.3	90.9	.7
SNAP-8 (prototype)	60 kVA at 0.75 power factor	Armature conductor, W	[e]1320	1323	0.2
		Field conductor, W	800	744	7.2
		Open circuit core, W	1250	1314	5.0
		Additional load,[b] W	2000	1883	6.0
		Total loss, W	5370	5264	2.0
		Efficiency, percent	91.8	91.9	.1

[a] All power factors lagging.

[b] Stray load loss for test data. Total of stator copper eddy, miscellaneous load and additional pole face, damper, and stator tooth and core due to load for calculated data.

[c] Test values from ref. 3.

[d] Test values from ref. 5.

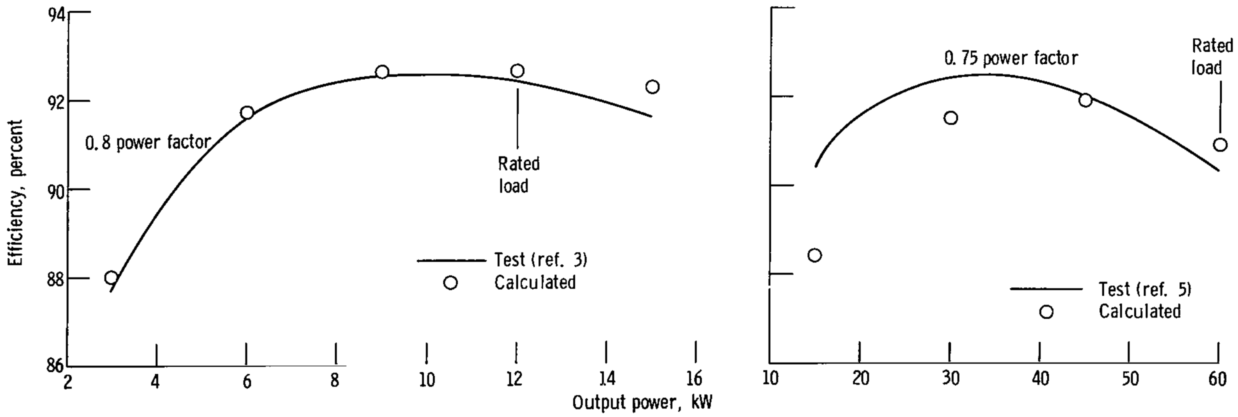
[e] Test values from ref. 4.

cifically calculated in the program, to make a comparison with the test data, some of the computed losses had to be added together. A table that shows the calculated losses corresponding to the experimental values of the open-circuit core and stray load losses follows.

Experimental loss	Corresponding calculated losses that are added together
Open-circuit core	No-load pole face No-load stator tooth No-load stator core No-load damper
Stray load	Armature conductor eddy Miscellaneous load Additional pole factor, stator tooth, stator core, and damper due to load

The maximum difference between the test and calculated values of electromagnetic efficiency for any one of the three alternators was 0.7 percent. Agreement between the test and calculated data for the specific losses was not as good, ranging up to a maximum difference of 22 percent. Conductor losses can be in error due both to inaccuracies in the resistance computation and in the estimated operating temperature of the windings. The accuracy of the pole-face, tooth, and core loss calculations, all of which are highly empirical, affect the comparisons for the open-circuit core losses and for the additional losses due to load.

Experimental and calculated values of electromagnetic efficiencies for the Brayton



(a) 400-Hertz Brayton cycle alternator.

(b) SNAP-8 alternator (preprototype).

Figure 12. - Electromagnetic efficiency.

cycle alternator over a range of loads from 25 to 125 percent of rated load are given in figure 12(a). Figure 12(b) shows a similar comparison for the SNAP-8 preprototype alternator up to rated load. Maximum difference in data for the Brayton cycle alternator is 0.8 percent. For the SNAP-8 alternator, the maximum difference in test and calculated efficiencies is 2 percent which occurs at 25 percent of rated load. From 50 percent to rated load, the maximum difference is 1.0 percent. The difference at lower loads is not due to a large error in any one particular calculated loss. Rather, it is caused by an accumulation of small errors in several of the computed losses.

Reactances. - A limited evaluation of the accuracy of the alternator reactance calculations was made. The direct-axis synchronous, and direct-axis transient reactances of the alternators were the only ones for which both experimental and calculated values were available. A comparison for these reactances is given in table VI. Except for the test data of the transient reactances, all values of reactances are for unsaturated conditions.

TABLE VI. - EXPERIMENTAL AND CALCULATED ALTERNATOR REACTANCES

Alternator	Reactance	Test value, per unit	Calculated value, per unit	Percent difference
Brayton cycle (400 Hz)	Direct-axis synchronous	[a]1.19	1.21	1.7
	Direct-axis transient	.475	.563	17.0
SNAP-8 (preprototype)	Direct-axis synchronous	[b]1.40	1.57	11.4
SNAP-8 (prototype)	Direct-axis synchronous	[c]1.52	1.56	2.6
	Direct-axis transient	.60	.656	8.9

[a] Test values from ref. 3.
[b] Test values from ref. 5.
[c] Test values from ref. 4.

The maximum difference between the experimental and calculated data for the direct-axis synchronous reactance is 11 percent. This is for the SNAP-8 preprototype alternator. For the other two alternators, agreement is much better, being within 3 percent. For the direct-axis transient reactance, the calculated values exceed the corresponding test values by as much as 17 percent. This is probably due mainly to neglecting the effects of saturation on the calculated value.

CONCLUDING REMARKS

This report presents a digital computer program which calculates the electrical performance characteristics of a homopolar inductor alternator from design data. A comparison was made between the test results and calculated data for the 400-hertz Brayton cycle and SNAP-8 alternators. The following observations were made.

1. For the open-circuit saturation curves, the maximum difference between the test and calculated values of field currents was 7 percent.
2. At rated load and power factor, the test and calculated field currents agreed to within 5 percent.
3. The calculated efficiencies of the alternators at rated load and power factor were in agreement with the test results by a maximum difference of 0.7 percent.
4. For a range of alternator loads from 25 to 125 percent of rated load, test and calculated efficiencies agreed to within 2 percent.

The program accuracy, as summarized above, is sufficient to allow using the program in practical applications such as parametric system studies and for specific alternator designs.

Lewis Research Center,
National Aeronautics and Space Administration,
Cleveland, Ohio, October 28, 1968,
120-27-03-42-22.

APPENDIX A

COMPLETE FORTRAN LISTING AND FLOW CHARTS OF HOMOPOLAR INDUCTOR ALTERNATOR COMPUTER PROGRAM

The complete FORTRAN listings of the main program and the three subroutines, which together constitute the homopolar inductor alternator computer program, are contained herein. The main program is INDCT, and the three subroutines are, in the order given, SINDUC, MAGNET, and OUTPUT. Each program listing, except that for OUTPUT, is followed by its flow chart. The organization of OUTPUT is self-evident since it consist largely of WRITE and FORMAT statements.

INDCT

```
      INDCT

      COMMON A,AA,AB,AC,ACR,AG,AI,ALH,ALPHAE,ALPHAR,ALPHAS,ALY,ALYC,ALYR
     1,AP,AS,ASH,ATH,AY,AYC,AYR,B,B1,B2,B3,BCLL,BCCIL,BG,BK,BN,BO,BP,BPL
     2,BS,BSHL,BTLL,BV,BYCLL,C,C1,CC,CCR,CE,CF,CK,CL,CM,CP,CQ,CW,D,D1,DC
     3CIL,DD,DF,CI,DISH,CISH1,CR,DSH,DU,DW,DW1,DYC,EC,EDD,EE,EL,EP,EW,F,
     4FCL,FE,FFLL,FGL,FGML,FH,FK1,FPL,FQ,FS,FSHL,FSHLP,FTL,FYCL,FYL,FYRL
     5,G,GA,GC,GE,GP,GXX,H,HC,HD,HM,HO,HP,HP1,HS,HT,HV,HW,HX,HY,IBN,IPN,
     6IPX,IQQ,IZZ,JA,KSAT,LTR,LTR1,LTS,P5,P6,P7,PBA,PC,PCCIL,PE,PF,PHL,P
     7HW,PI,PL,PM,PML,PN,PT,PX,QN,CQ,RC,RD,RE,RF,RG1,RK,RK1,RPM,RR,RS,RT
     8,RY,S,SB,SC,SD,SF,SH,SI,SIGMA,SK,SN,SN1,SS,STATET,T1,T11,T2,T22,T3
     9,T33,TB,TC,TF,TG,TS,TST,TT,TY,TYE,TYPY,TYR,VA,VR,WC,WF,WI,WL,WO WR
     $CTCR,WTCTAL,WYOKE,XA,XB,XD,XF,XL,XQ,XR,XU,YY,Z,ZG,ZZ,ZZZ
C
      INTEGER TYPY,ZZ
C
      DIMENSION QVLN(10), QVLL(10), QFCUR(10), QAGAT(10), QTAT(10), QPAT
     1(10), QCAT(10), QTHAT(10), QSAT(10), QYAT(10), QPD(10), QCD(10), Q
     2THD(10), QSD(10), QYD(10), QPERV(10), AI(90), GX(5), YA(5), ED(5),
     3 FGX(5), PR(5), FI(5), PS(5), G(5), DL(5), PP(5), EX(5), ST(5), WA
     4(5), STRAY(5), FFL(5), BSHLL(5), BCL(5), BTL(5), BPLL(5), BYCL(5),
     5 FGLL\5), PMLL(5), P(5), E(5), PZ(5), SP(5), WQL(5), CDD(5), EF(5)
     6, AKVA(5), EZ(10), TTA(10), TTB(10), RRA(10), RRB(10), SMAT(6), RM
     7AT(6), YMAT(6)
C
      READ (5,1) SMAT
      READ (5,2) (AI(I),I=1,29)
      READ (5,1) RMAT
      READ (5,2) (AI(I),I=31,59)
      READ (5,1) YMAT
      READ (5,2) (AI(I),I=61,89)
1     FORMAT (6A6)
2     FORMAT (8F10.1)
3     CALL SINDUC
      CALL OUTPUT
C
C     COMPUTE TOOTH WIDTH AT 1/3 DISTANCE FROM NARROWEST SECTION
C
      IF (ZZ-3) 4,5,6
4     SM=TT-BS
      GO TO 8
5     SM=(3.1416*(CI+2.*HS)/CQ)-B3
      GO TO 8
6     IF (ZZ-4) 5,7,4
7     SM=TT-.94*BS
8     CONTINUE
C
```

```
C     AREAS AND LENGTHS FOR MAGNETIC CALCULATIONS
C
      AP=BP*PL*RK
      ACR=(DU-2.*HC)*3.1416*PE*SS/PX
      FATI=FGML
      ATH=QQ*SS*SM*PE/PX
      ASH=(DSH**2-DISH**2)*.7854
      AY=TY*(DU+TY)*3.1416
      IF (TYPY-2) 10,11,9
 9    ALY=1.334*CL
      GO TO 12
 10   AYR=0
      AYC=0
      ALY=BCOIL+.667*CL
      ALYR=0
      ALYC=0
      GO TO 13
 11   ALY=.667*CL
 12   AYC=3.1416*(DYC+TYE)*TYE
      AYR=TYR*(DU+2.*TY)*3.1416
      ALYC=BCOIL
      ALYR=DYC-DL
 13   CONTINUE
C
C     NO-LOAD, RATED VOLTAGE MAGNETIZATION CHARACTERISTICS
C
      ZZZ=PX*GE/(.00319*GA*PE)
      KSAT=10
      GXX=1.
      ECC=1.
      FH=BG*GE/0.00319
      FGML=0.
      CALL MAGNET
      J=1
      FGLL(J)=FGL
      PMLL(J)=PML
      BPLL(J)=BPL
      BTL(J)=BTLL
      BSHLL(J)=BSHL
      BCL(J)=BCLL
      BYCL(J)=BYCLL
      FFL(J)=FFLL
C
C     SHORT CIRCUIT RATIO AND SHORT CIRCUIT AMPERE-TURNS CALCS
C
      FSC=XA*FH*0.02
      SCR=FFLL/FSC
      WRITE (6,14) FSC,SCR
 14   FORMAT (1HL,9X,27H SHORT CIRCUIT AMPERE-TURNS,F16.3/10X,20H SHORT
     1CIRCUIT RATIO,F23.3)
      WRITE (6,15) SMAT
 15   FORMAT (1HL,18H STATOR MATERIAL -,1H ,6A6)
      WRITE (6,16) RMAT
 16   FORMAT (1HL,18H ROTOR MATERIAL --,1H ,6A6)
      WRITE (6,17) YMAT
 17   FORMAT (1HL,18H YOKE MATERIAL ---,1H ,6A6)
```

```
      FYOKE=FYL+FYCL+FYRL
      WRITE (6,18) TG,FQ,BG,BPL,BTLL,BCLL,BSHL,BYCLL,FGL,FPL,FTL,FCL,FSH
     1LP,FSHL,FYCKE,FFLL
18    FORMAT (1H1,30H MAGNETIZATION CHARACTERISTICS/5X,25H (NO LOAD, RAT
     1ED VOLTAGE)//10X,18H TCTAL USEFUL FLUX,F12.2,10H KILOLINES/10X,17H
     2 USEFUL FLLX/POLE,F13.2//10X,15H FLUX DENSITIES/13X,19H AIRGAP (IN
     3CL. PML),F8.2,9H KL/SC-IN/13X,5H POLE,F22.2/13X,6H TOOTH,F21.2/13X
     4,5H CORE,F22.2/13X,19H SHAFT (UNDER FLD.),F8.2/13X,17H YCKE (OVER
     5FLD.),F10.2//10X,13H AMPERE-TURNS/13X,7H AIRGAP,F20.2,11H PER STAT
     6OR/13X,5H POLE,F22.2/13X,6H TCOTH,F21.2/13X,5H CORE,F22.2/13X,19H
     7SHAFT (UNDER PCLE),F8.2//13X19H SHAFT (UNDER FLD.),F8.2/13X,5H YOK
     8E,F22.2//13X,6H TOTAL,F21.2)
      IF (KSAT.EC.0) GO TO 19
      GC TO 20
19    WRITE (6,76)
      GO TO 3
C
C     HCT AND CCLC CAMPER BAR LOSS CALCULATIONS
C
20    IF (BN) 21,21,22
21    WD=C.0
      WU=0.0
      GC TO 44
22    AA=WO/GE
      VT=C
      IF (AA) 23,26,23
23    IF (AA-C.65) 24,26,25
24    VT=ALOG(10.*AA)*(-0.242)+0.59
      GO TO 26
25    VT=0.327-(AA*0.266)
26    CCNTINUE
      FS1=2.0*QN*PN*F
      FS2=2.0*FS1
      M=0
      RM=RE*(1.0+ALPHAE*(T33-2C.))
      GC TO 28
27    RM=RE*(1.0+ALPHAE*(T3-20.))
28    AA=(FS1/RM)**0.5*CC*0.32
      AB=(FS2/RM)**0.5*DD*0.32
      IF (AA-2.5) 29,29,30
29    V1=1.0-0.15*AA+0.3*AA*AA
      GC TO 31
30    V1=AA
31    IF (AB-2.5) 32,32,33
32    V2=1.0-C.15*AB+C.3*AB*AB
      GC TO 34
33    V2=AB
34    IF (H.EQ.O.) GO TC 35
      IF (H.EQ.B) GO TC 35
      VC=H/(3.0*B*V1)
      GO TO 36
35    VC=C.75/V1
36    VS=HD/WO+VT+VC
      VG=TB/(CC*GC)
      Q1=1.0-(1.0/(((BO*0.5/GC)**2.0+1.0)**0.5))
      QZ=BO/TS
```

```
      Q2=1.05*SIN(CZ*2.844)
      IF (QZ-0.37) 37,37,38
37    C3=0.46
      GC TO 39
38    Q3=0.23*SIN(10.46*QZ-2.1)+0.23
39    C4=SIN(6.283*TB/TS-1.571)+1.C
      C5=SIN(12.566*TB/TS-1.571)+1.0
      IF (H) 41,40,41
40    AB=C.785*DD*CD
      GC TO 42
41    AB=H*B
42    W2=PX*BN*SB*RM*1.246/(AB*1000.)
      W3=(Q2/(2.0*VS+(VG/Q4)))**2.0*V1
      W5=(Q3/(2.C*VS+(VG/Q5)))**2.C*V2
      WD=(TS*BG*C1*CC)**2.0*W2*(W3+W5)
      M=M+1
      IF (M-1) 44,43,44
43    WU=WD
      GC TO 27
44    CONTINUE
C
C     PCLE-FACE LCSS CALCULATICN
C
      GT=BO/GC
      AA=1.75/(GT**1.35)+0.8
      GF=AA*PI*SC/(C*FH)
      D2=BG**2.5*0.C00061
      D3=(0.0167*CQ*RPM)**1.65*0.0C0015147
      IF (TS-0.9) 45,45,46
45    D4=TS**1.285*0.81
      GC TO 49
46    IF (TS-2.0) 47,47,48
47    D4=TS**1.145*0.79
      GC TO 49
48    D4=TS**0.79*0.92
49    D7=BO/GC
      IF (D7-1.7) 50,50,51
50    D5=D7**2.31*C.3
      GO TO 56
51    IF (D7-3.C) 52,52,53
52    D5=D7**2.0*0.35
      GC TO 56
53    IF (D7-5.0) 54,54,55
54    D5=D7**1.4*0.625
      GC TO 56
55    D5=D7**C.965*1.38
56    D6=10.0**(0.932*C1-1.6C6)
      WN=D1*D2*D3*D4*D5*D6*GA
C
C     CALCULATE NC-LOAC,RATEC VOLTAGE TOOTH AND CCRE LOSS
C
      WT=(SM)*QC*SS*HS*0.849*(BTL(1)/BK)**2.0*WL
      WC=(DU-HC)*2.67*HC*SS*(BCL(1)/BK)**2.0*WL
```

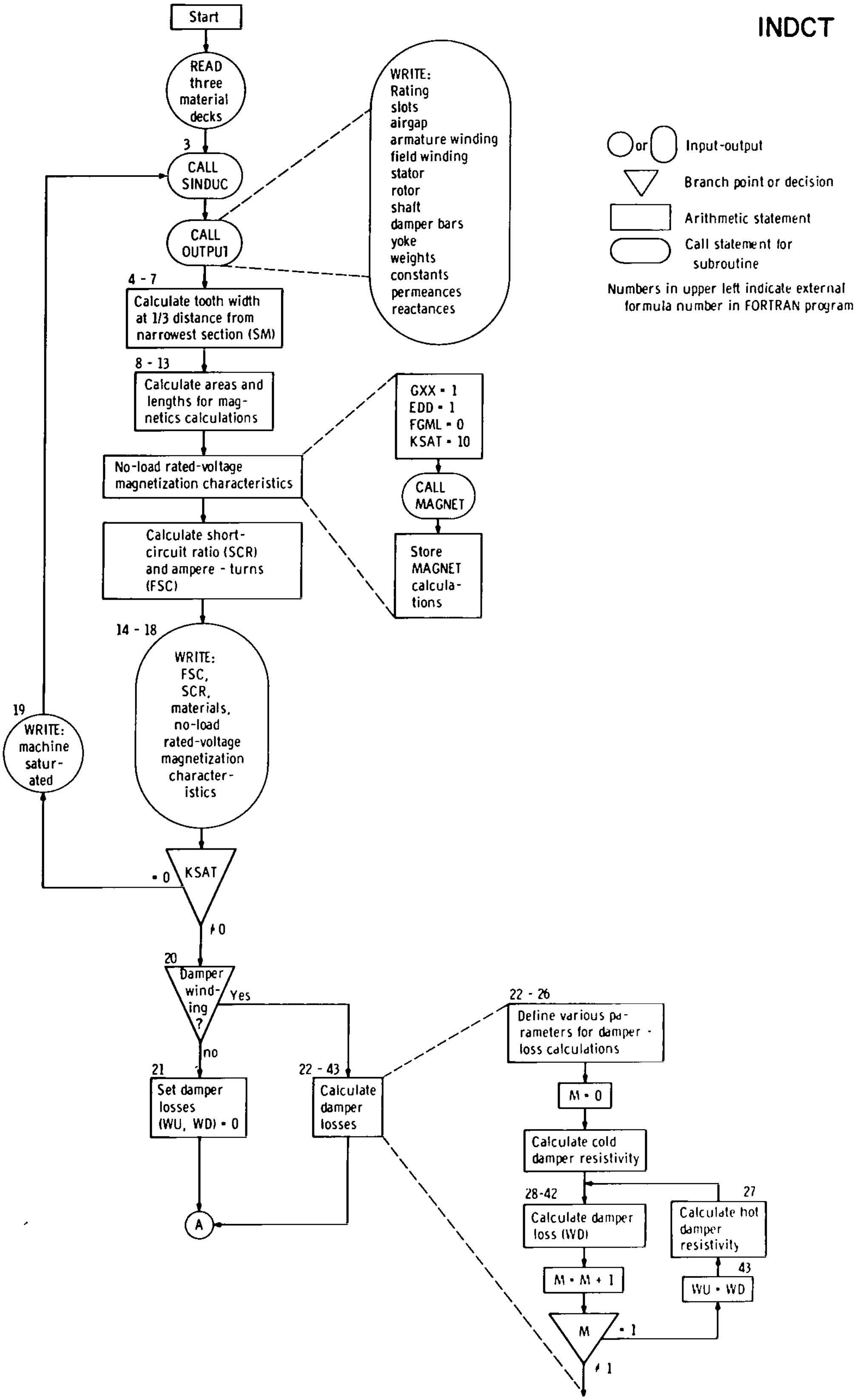
```
C
C     ARRANGING LOAD POINTS IN ORDER
C
      DO 58 J=1,4
      IA=5-J
      DO 58 I=1,IA
      IF (G(I).GT.G(I+1)) GO TO 57
      GO TO 58
57    POL=G(I)
      G(I)=G(I+1)
      G(I+1)=POL
58    CONTINUE
      G(1)=0.
      MM=5
      DO 59 I=2,5
      IF (G(I).GE.1.0.AND.G(I-1).LT.0.999) MM=I
      YA(I)=100./G(I)
59    CONTINUE
C
C     CALCULATE GENERATOR LOAD CHARACTERISTICS
C
      AN=ARCOS(PF)
      DO 60 J=2,5
      AA=ATAN((XB/YA(J)+SIN(AN))/PF)
      BB=AA-AN
      ED(J)=XA*SIN(AA)/YA(J)+COS(BB)
      FGX(J)=FATI*100./YA(J)
      GX(J)=((ED(J)-(0.93*XD*SIN(AA)/YA(J))))*CK
      TTB(J)=0.
      TTA(J)=0.
      RRA(J)=0.
      RRB(J)=0.
      EZ(J)=0.
      STRAY(J)=0
      PMLL(J)=0
      FFL(J)=0
      BSHLL(J)=0
      BCL(J)=0
      BTL(J)=0
      BPLL(J)=0
      BYCL(J)=0
      FI(J)=0
      CCD(J)=0
      EF(J)=0
      PR(J)=0
      ST(J)=0
      WCL(J)=0
      FP(J)=0
      DL(J)=0
      PS(J)=0
      EX(J)=0
      SP(J)=0
      AKVA(J)=0
      WA(J)=0
      P(J)=0
      PZ(J)=0
      E(J)=0
60    FGLL(J)=0
      J=2
```

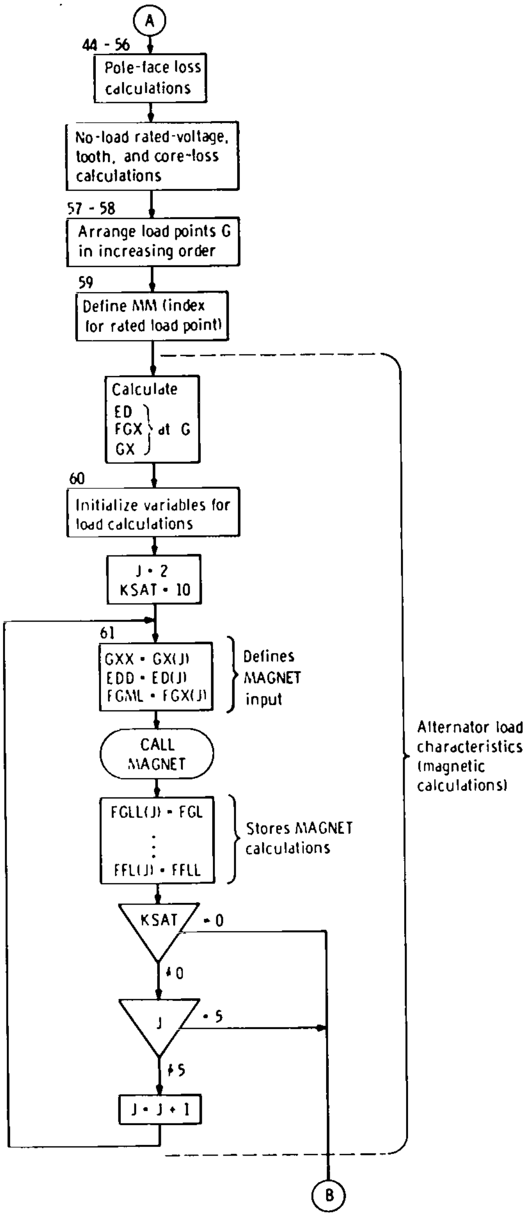
```
      KSAT=10
   61 GXX=GX(J)
      ECD=ED(J)
      FGML=FGX(J)
      CALL MAGNET
      FGLL(J)=FGL
      PMLL(J)=PML
      BPLL(J)=BPL
      BTL(J)=BTLL
      BSHLL(J)=BSHL
      BCL(J)=BCLL
      BYCL(J)=BYCLL
      FFL(J)=FFLL
      IF (KSAT.EQ.0) GO TO 62
      IF (J.EQ.5) GO TO 62
      J=J+1
      GO TO 61
   62 JA=J
      IF (KSAT.EQ.0) JA=JA-1
      FI(MM)=FFL(MM)/PT
      WW=WU
      VV=3.*PI*EP*PF
      M=1
   63 CONTINUE
C
C     EDDY FACTOR CALCULATIONS
C
      UA=G(M)
      TTA(M)=(T1-T11)*UA*UA+T11
      RB=(1.0E-6)*RS*(1.0+ALPHAS*(TTA(M)-20.))
      IF (SH) 64,64,65
   64 EZ(M)=1.
      GO TO 66
   65 AA=0.584+(SN*SN-1.0)*0.0625*(SD*CL/(SH*HM/2.))**2
      AB=(SH*SC*F*AC/(BS*RB*1000000.0))**2.0
      ET=AA*AB*0.00335+1.0
      EB=ET-0.00168*AB
      EZ(M)=(ET+EB)*0.5
C
C     LOSSES AND EFFICIENCY UNDER LOAD
C
   66 FI(M)=FFL(M)/PT
      CDD(M)=FI(M)/AS
      TTB(M)=((T2-T22)/(FI(MM)-FI(1))**2)*(FI(M)-FI(1))**2+T22
      RRB(M)=(1.0E-6)*RR*(1.0+ALPHAR*(TTB(M)-20.))*ZG
      PR(M)=FI(M)*FI(M)*RRB(M)
      EF(M)=FI(M)*RRB(M)
      RRA(M)=RB*RY
      PS(M)=(3.*(PI*UA)**2)*RRA(M)
      WQL(M)=WQ*(BCL(M)/BCL(1))**2
      ST(M)=WT*(BTL(M)/BTL(1))**2
      WA(M)=VV*UA/1000.
      AKVA(M)=WA(M)/PF
      STRAY(M)=AKVA(M)*10.0
      GM=(GF*UA)**2.0+1.0
      DL(M)=GM*WW
```

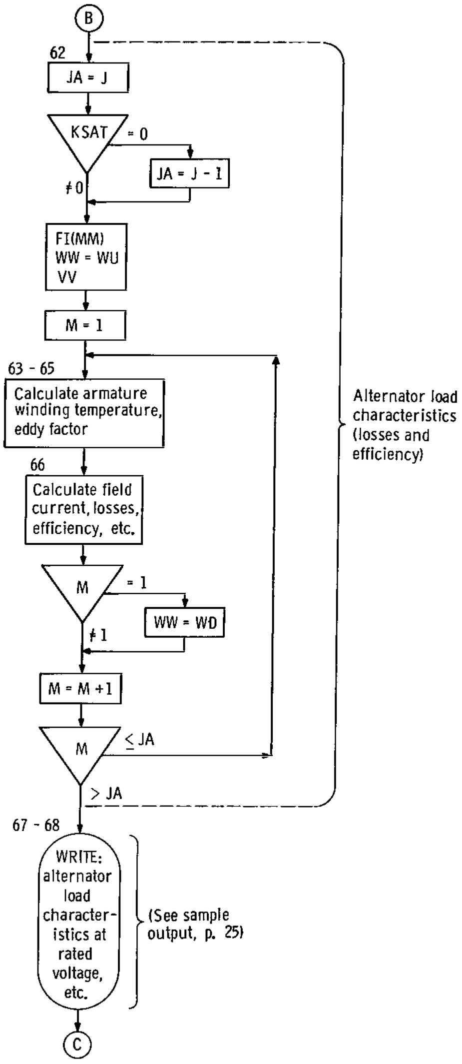
```
      PP(M)=GM*WN                                                       A 326
      EX(M)=(EZ(M)-1.0)*PS(M)*2.0*CL/HM                                 A 327
      SP(M)=PP(M)+DL(M)+PR(M)+PS(M)+EX(M)+ST(M)+WF+WQL(M)+STRAY(M)      A 328
      P(M)=(SP(M)/1000.)+WA(M)                                          A 329
      PZ(M)=(SP(M)/P(M))*.1                                             A 330
      E(M)=100.0-PZ(M)                                                  A 331
      IF (M.EQ.1) WW=WD                                                 A 332
      M=M+1                                                             A 333
      IF (M.LE.JA) GO TO 63                                             A 334
      WRITE (6,67) PF,(G(I),I=1,5),(PMLL(I),I=1,5),(FGLL(I),I=1,5),(BPLL A 335
     1(I),I=1,5),(BTL(I),I=1,5),(BSHLL(I),I=1,5),(BCL(I),I=1,5),(BYCL(I) A 336
     2,I=1,5),(FFL(I),I=1,5),(FI(I),I=1,5),(CDD(I),I=1,5),(EF(I),I=1,5) A 337
67    FORMAT (1H1,26X47HALTERNATOR LOAD CHARACTERISTICS (RATED VOLTAGE,F A 338
     15.2,14H POWER FACTOR)/27X66H-------------------------------------- A 339
     2----------------------------////7X12HPERCENT LOAD,11X,2PF17.0,4F19 A 340
     3.0//7X18HLEAKAGE FLUX (PML),5X,0P5F19.2/7X20HAIR-GAP AMPERE TURNS, A 341
     43X5F19.2//7X25HFLUX DENSITIES (KL/SQ-IN)/10X4HPOLE,16X5F19.2/10X5H A 342
     5TEETH15X5F19.2/10X18HSHAFT (UNDER FLD.)2X5F19.2/10X4HCORE16X5F19.2 A 343
     6/10X16HYOKE (OVER FLD.)4X5F19.2//7X18HTOTAL AMPERE TURNS5X5F19.2/7 A 344
     7X20HFIELD CURRENT (AMPS)3X5F19.2/7X21HCURRENT DENS. (FIELD)2X5F19. A 345
     82/7X11HFIELD VOLTS12X5F19.2)                                      A 346
      WRITE (6,68) (TTB(I),I=1,5),(TTA(I),I=1,5),(RRB(I),I=1,5),(RRA(I), A 347
     1I=1,5),(EZ(I),I=1,5),(PR(I),I=1,5),WF,WF,WF,WF,WF,(ST(I),I=1,5),(W A 348
     2QL(I),I=1,5),(PP(I),I=1,5),(DL(I),I=1,5),(PS(I),I=1,5),(EX(I),I=1, A 349
     35),(STRAY(I),I=1,5),(SP(I),I=1,5),(AKVA(I),I=1,5),(WA(I),I=1,5),(P A 350
     4(I),I=1,5),(PZ(I),I=1,5),(E(I),I=1,5)                             A 351
68    FORMAT (1HK,6X20HTEMPERATURES (DEG.C)/10X5HFIELD15X5F19.2/10X8HARM A 352
     1ATURE12X5F19.2//7X18HRESISTANCES (OHMS)/10X5HFIELD15X5F19.2/10X8HA A 353
     2RMATURE12X5F19.4//7X11HEDDY FACTOR12X5F19.2//7X25HALTERNATOR LOSSE A 354
     3S (WATTS)/10X5HFIELD15X5F19.2/10X7HWINDAGE13X5F19.2/10X12HSTATOR T A 355
     4OOTH8X5F19.2/10X11HSTATOR CORE9X5F19.2/10X9HPOLE FACE11X5F19.2/10X A 356
     56HDAMPER14X5F19.2/10X13HSTATOR COPPER7X5F19.2/10X4HEDDY16X5F19.2/1 A 357
     60X10HMISC. LOAD10X5F19.2/10X5HTOTAL15X5F19.2//7X23HALTERNATOR OUTP A 358
     7UT (KVA)5F19.2/7X22HALTERNATOR OUTPUT (KW)1X5F19.2/7X21HALTERNATOR A 359
     8 INPUT (KW)2X5F19.2/7X14HPERCENT LOSSES9X5F19.2/7X18HPERCENT EFFIC A 360
     9IENCY5X5F19.2)                                                    A 361
C                                                                       A 362
C      CALCULATE NO-LOAD SATURATION DATA                                 A 363
C                                                                       A 364
      DO 69 J=1,10                                                      A 365
      QPERV(J)=0                                                        A 366
      QVLL(J)=0                                                         A 367
      QVLN(J)=0                                                         A 368
      QFCUR(J)=0                                                        A 369
      QTAT(J)=0                                                         A 370
      QAGAT(J)=0                                                        A 371
      QPAT(J)=0                                                         A 372
      QCAT(J)=0                                                         A 373
      QTHAT(J)=0                                                        A 374
      QSAT(J)=0                                                         A 375
      QYAT(J)=0                                                         A 376
      QPD(J)=0                                                          A 377
      QCD(J)=0                                                          A 378
      QTHD(J)=0                                                         A 379
      QSD(J)=0                                                          A 380
69    QYD(J)=0                                                          A 381
```

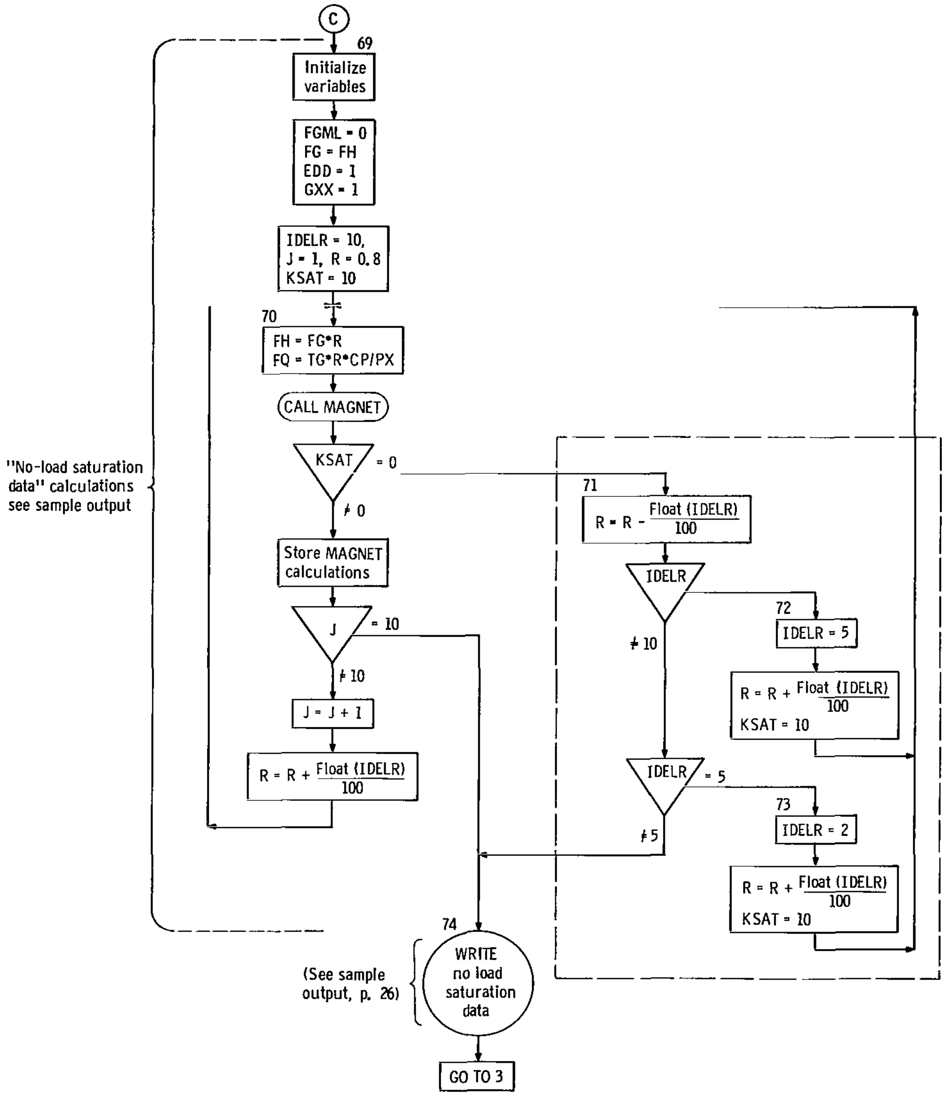
```
      FGML=0.
      FG=FH
      EDD=1.
      GXX=1.
      IDELR=10
      R=.8
      J=1
      KSAT=10
 70   FH=FG*R
      FQ=TG*R*CP/PX
      CALL MAGNET
      IF (KSAT.EQ.0) GO TO 71
      QPERV(J)=100.*R
      QVLL(J)=EE*R
      QVLN(J)=QVLL(J)/SQRT(3.)
      QFCUR(J)=FFLL/PT
      QTAT(J)=FFLL
      QAGAT(J)=FGL
      QPAT(J)=FPL
      QCAT(J)=FCL
      QTHAT(J)=FTL
      QSAT(J)=FSHL+2.*FSHLP
      QYAT(J)=FYL+FYCL+FYRL
      QPD(J)=BPL
      QCD(J)=BCLL
      QTHD(J)=BTLL
      QSD(J)=BSHL
      QYD(J)=BYCLL
      IF (J.EQ.10) GO TO 74
      J=J+1
      R=R+FLOAT(IDELR)/100.
      GO TO 70
 71   R=R-FLOAT(IDELR)/100.
      IF (IDELR.EQ.10) GO TO 72
      IF (IDELR.EQ.5) GO TO 73
      GO TO 74
 72   IDELR=5
      R=R+FLOAT(IDELR)/100.
      KSAT=10
      GO TO 70
 73   IDELR=2
      R=R+FLOAT(IDELR)/100.
      KSAT=10
      GO TO 70
 74   WRITE (6,75) (QPERV(K),K=1,10),(QVLN(K),K=1,10),(QVLL(K),K=1,10),(
     1QFCUR(K),K=1,10),(QPD(K),K=1,10),(QTHD(K),K=1,10),(QSD(K),K=1,10),
     2(QCD(K),K=1,10),(QYD(K),K=1,10),(QAGAT(K),K=1,10),(QPAT(K),K=1,10)
     3,(QTHAT(K),K=1,10),(QCAT(K),K=1,10),(QSAT(K),K=1,10),(QYAT(K),K=1,
     410),(QTAT(K),K=1,10)
 75   FORMAT (1H1,50X23HNO-LOAD SATURATION DATA/51X23H------------------
     1-----//2X7HVOLTAGE/5X7HPERCENT6X10F11.2//5X12HLINE-NEUTRAL1X10F11.
     22/5X9HLINE-LINE4X10F11.2//2X13HFIELD CURRENT3X10F11.2//2X20HFLUX D
     3ENS.(KL/SQ-IN)/5X4HPOLE9X10F11.2/5X5HTOOTH8X10F11.2/5X5HSHAFT8X10F
     411.2/5X4HCORE9X10F11.2/5X4HYOKE9X10F11.2//2X12HAMPERE-TURNS/5X6HAI
     5RGAP7X10F11.2/5X4HPOLE9X10F11.2/5X5HTOOTH8X10F11.2/5X4HCORE9X10F11
     6.2/5X5HSHAFT8X10F11.2/5X4HYOKE9X10F11.2//5X5HTOTAL8X10F11.2)
      GO TO 3
 76   FORMAT (1HL10X,17HMACHINE SATURATED)
      END
```

INDCT


Start
READ three material decks
3
CALL SINDUC
CALL OUTPUT
WRITE: Rating slots airgap armature winding field winding stator rotor shaft damper bars yoke weights constants permeances reactances
4 - 7
Calculate tooth width at 1/3 distance from narrowest section (SM)
8 - 13
Calculate areas and lengths for magnetics calculations
No-load rated-voltage magnetization characteristics
GXX = 1
EDD = 1
FGML = 0
KSAT = 10
CALL MAGNET
Store MAGNET calculations
Calculate short-circuit ratio (SCR) and ampere - turns (FSC)
14 - 18
WRITE: FSC, SCR, materials, no-load rated-voltage magnetization characteristics
19
WRITE: machine saturated
KSAT
= 0
≠ 0
20
Damper winding ?
Yes
no
21
Set damper losses (WU, WD) = 0
22 - 43
Calculate damper losses
A
22 - 26
Define various parameters for damper - loss calculations
M = 0
Calculate cold damper resistivity
28-42
Calculate damper loss (WD)
27
Calculate hot damper resistivity
M = M + 1
43
WU = WD
M
= 1
≠ 1
or
Input-output
Branch point or decision
Arithmetic statement
Call statement for subroutine
Numbers in upper left indicate external formula number in FORTRAN program


A
44 - 56
Pole-face loss calculations
No-load rated-voltage, tooth, and core-loss calculations
57 - 58
Arrange load points G in increasing order
59
Define MM (index for rated load point)
Calculate
ED
FGX
GX
at G
60
Initialize variables for load calculations
J = 2
KSAT = 10
61
GXX = GX(J)
EDD = ED(J)
FGML = FGX(J)
Defines MAGNET input
CALL MAGNET
FGLL(J) = FGL
FFL(J) = FFLL
Stores MAGNET calculations
KSAT
= 0
≠ 0
J
= 5
≠ 5
J = J + 1
Alternator load characteristics (magnetic calculations)
B


B
62
JA = J
KSAT
= 0
JA = J - 1
≠ 0
FI(MM)
WW = WU
VV
M = 1
63 - 65
Calculate armature winding temperature, eddy factor
66
Calculate field current, losses, efficiency, etc.
M
= 1
WW = WD
≠ 1
M = M + 1
M
≤ JA
> JA
Alternator load characteristics (losses and efficiency)
67 - 68
WRITE: alternator load characteristics at rated voltage, etc.
(See sample output, p. 25)
C


C
69
Initialize variables
FGML = 0
FG = FH
EDD = 1
GXX = 1
IDELR = 10,
J = 1, R = 0.8
KSAT = 10
70
FH = FG*R
FQ = TG*R*CP/PX
CALL MAGNET
KSAT
= 0
≠ 0
Store MAGNET calculations
J
= 10
≠ 10
J = J + 1
R = R + Float (IDELR)/100
"No-load saturation data" calculations see sample output
71
R = R - Float (IDELR)/100
IDELR
≠ 10
72
IDELR = 5
R = R + Float (IDELR)/100
KSAT = 10
IDELR
= 5
≠ 5
73
IDELR = 2
R = R + Float (IDELR)/100
KSAT = 10
74
WRITE no load saturation data
(See sample output, p. 26)
GO TO 3

```
      SUBROUTINE SINDUC
      COMMON A,AA,AB,AC,ACR,AG,AI,ALH,ALPHAE,ALPHAR,ALPHAS,ALY,ALYC,ALYR
     1,AP,AS,ASH,ATH,AY,AYC,AYR,B,B1,B2,B3,BCLL,BCOIL,BG,BK,BN,BO,BP,BPL
     2,BS,BSHL,BTLL,BV,BYCLL,C,C1,CC,CCR,CE,CF,CK,CL,CM,CP,CQ,CW,D,D1,DC
     3OIL,DD,DF,DI,DISH,DISH1,DR,DSH,DU,DW,DW1,DYC,EC,EDO,EE,EL,EP,EW,F,
     4FCL,FE,FFLL,FGL,FGML,FH,FK1,FPL,FQ,FS,FSHL,FSHLP,FTL,FYCL,FYL,FYRL
     5,G,GA,GC,GE,GP,GXX,H,HC,HD,HM,HO,HP,HP1,HS,HT,HV,HW,HX,HY,IBN,IPN,
     6IPX,IQQ,IZZ,JA,KSAT,LTR,LTR1,LTS,P5,P6,P7,PBA,PC,PCOIL,PE,PF,PHL,P
     7HW,PI,PL,PM,PML,PN,PT,PX,QN,CQ,RC,RD,RE,RF,RG1,RK,RK1,RPM,RR,RS,RT
     8,RY,S,SB,SC,SD,SF,SH,SI,SIGMA,SK,SN,SN1,SS,STATET,T1,T11,T2,T22,T3
     9,T33,TB,TC,TF,TG,TS,TST,TT,TY,TYE,TYPY,TYR,VA,VR,WC,WF,WI,WL,WO,WR
     $OTOR,WTOTAL,WYOKE,XA,XB,XD,XF,XL,XQ,XR,XU,YY,Z,ZG,ZZ,ZZZ
C
      INTEGER TYPY,ZZ
C
      REAL LT,LTS,LTR,LTR1
C
      DIMENSION DA(8), DX(6), DY(8), DZ(8), AI(90), G(5)
C
      NAMELIST /RATING/ VA,EE,EP,F,RPM,IPX,PF,G/STATOR/DI,DU,CL,HV,BV,SF
     1,LTS,WL,BK/SLOTS/ZZ,BC,B3,BS,HO,HX,HY,HS,HT,IQQ/WINDNG/RF,SC,YY,C,
     2DW,SN,SN1,DW1,CE,SD,PBA,SK,T1,RS,ALPHAS,T11,TST/AIRGAP/GC,GP/CONST
     3/C1,CP,EL,CM,CQ,WF/ROTOR/RK,PL,HP,HP1,PE,BP,WROTOR,LTR,LTR1,RK1,PH
     4W,PHL,D1/DAMPER/WO,HD,DD,H,B,BN,SB,TB,T33,RE,ALPHAE,T3/SHAFT/DSH,D
     5ISH,DISH1,ALH/YOKE/TYPY,TY,TYE,TYR,DYC/FIELD/PCOIL,DCOIL,PT,RD,RT,
     6T2,BCOIL,TF,T22,RR,ALPHAR
C
      DATA DA,DX,DY,DZ/0.05,0.072,0.125,0.165,0.225,0.438,0.688,1.5,0.00
     10124,0.00021,0.00021,0.00084,2*0.00189,2*0.000124,2*0.00084,0.0018
     29,0.00335,0.00754,0.0302,3*0.000124,2*0.00335,0.00754,0.0134,0.030
     32/
C
      C1=0
      RS=0.694
      RR=0.694
      RE=0.694
      ALPHAS=0.00393
      ALPHAR=0.00393
      ALPHAE=0.00393
      T33=20.
      TF=25.
      TST=25.
      GP=0.
      RK1=0.
      PE=0.
      PHW=0.
      PL=0.
      PHL=0.
      LTR1=0.
      D1=0.
```

```
      PBA=60.
      SN=1.0
      DYC=0.
      SH=0.
      DW1=0
      DD=0.
      CW=0
      CP=0
      EL=0
      CM=0
      G(1)=0.
      G(2)=0.75
      G(3)=1.00
      G(4)=1.25
      G(5)=1.50
      CQ=0
      PM=0
      P5=0
      P6=0
      P7=0
      WC=0.
      WF=0
      TY=0
      TYE=0
      TYR=0
      DYC=0
      EP=0.
      EE=0.
      IPN=3
      PN=3.
      IPX=0
      F=0.
      RPM=0.
      BP=0.
      SF=0.
      RK=0.
      LTS=0.
      LTR=0.
      WROTOR=0.
      HV=0.
      BV=0.
      BCOIL=0.
      H=0.
      SK=0
      WRITE (6,1)
1     FORMAT (1H143X33H**HOMOPOLAR INDUCTOR ALTERNATOR**)
      READ (5,RATING)
      READ (5,STATOR)
      READ (5,SLOTS)
      READ (5,WINDNG)
      READ (5,AIRGAP)
      READ (5,CONST)
      READ (5,ROTOR)
      READ (5,DAMPER)
      READ (5,SHAFT)
      READ (5,YOKE)
      READ (5,FIELD)
```

```
      IF (EP.EQ.0.) EP=EE/1.732051
      IF (EE.EQ.0.) EE=EP*1.732051
      IF (GP.EQ.0.) GP=GC
      IF (DW1.NE.0.) SH=DW1
      IF (IPX.EQ.0.AND.RPM.NE.0.) IPX=(F*120.)/RPM
      PX=IPX
      IF (RPM.EQ.0..AND.PX.NE.0.) RPM=(F*120.)/PX
      IF (F.EQ.0.) F=PX*RPM/120.
      HW=HY-HC-HT
      QQ=IQQ
      IF (ZZ.NE.3) GO TO 2
      B1=(HO+HT-HS)*(6.283185/QQ)+B3
      B2=B1+(6.283185*HW/QQ)
      BS=(B2+B3)/2.
2     CONTINUE
      PI=(VA*1000.)/(EE*SQRT(3.))
      CK=1.
      IF (PF.GE.0.95) CK=1.10
      IF (ZZ.EQ.1.OR.ZZ.EQ.5) BO=BS
      IZZ=ZZ
      CB=.25
      IF (DU.GE.8.) CB=0.5
      IF (BCOIL.EQ.0.) BCOIL=ALH
      FE=3.1416*(PCOIL+DCOIL)/2.
      DR=DI-2.*GC
      IF (PE.EQ.0.) PE=(PX/3.1415927)*(ARSIN(PHW/DR))
      IF (PHW.EQ.0.) PHW=DR*SIN(3.1415927*PE/PX)
      IF (BP.EQ.0.) BP=PHW
      IF (PL.EQ.0.) PL=PHL
      IF (PHL.EQ.0.) PHL=PL
      HC=(DU-DI-2.0*HS)*0.5
      IF (DYC.EQ.0.) DYC=DU
      ZY=0.7*HS
      DO 3 I=1,5
3     IF (G(I).GT.9.) G(I)=G(I)/100.
      QN=QQ/(PX*PN)
      CS=YY/(PN*QN)
C
C     CHECK FOR ERROR CONDITIONS
C
      IF (CS.GT.1.0.OR.CS.LT.0.5) WRITE (6,5) CS
      IF (EP*EE.EQ.0..OR.ABS(EE/EP-1.732051).GT.0.01) WRITE (6,6)
      IF (PX*F*RPM.EQ.0..OR.ABS(F-PX*RPM/120.).GT.0.1) WRITE (6,7)
      IF (HC.LT.ZY) WRITE (6,8) HC,HS
      IF (DSH.GE.DR) WRITE (6,9)
      IF (DCOIL.GT.DYC) WRITE (6,10)
      IF (PCOIL.LT.DI+2.*HS) WRITE (6,11)
      IF (TYPY.GT.1.AND.TYE*TYR.LT.1.0E-10) WRITE (6,12)
      IF (RT.LT.1.0E-10) GO TO 4
      IF ((((DCOIL-PCOIL)*BCOIL)/(RT*RD)).LE.2.*PT) WRITE (6,13)
      GO TO 14
4     IF ((DCOIL-PCOIL)*BCOIL/RD**2.LE.1.7146*PT) WRITE (6,13)
5     FORMAT (5X,27H CS (PER UNIT POLE PITCH) =,F7.3/10X,31H CS MUST BE
     1BETWEEN 0.5 AND 1.0)
6     FORMAT (1H ,38H EITHER PHASE OR LINE VOLTAGE IS WRONG)
```

```
7     FORMAT (1H ,44H FREQUENCY, RPM, OR NO. OF POLES IS IN ERROR)
8     FORMAT (1H /5X54HDEPTH BELOW SLOT IS LESS THAN 70 PERCENT OF SLOT
     1DEPTH/10X,4HDBS=F8.4/10X,4H SD=F8.4)
9     FORMAT (1H ,46H SHAFT DIAMETER IS GREATER THAN ROTOR DIAMETER)
10    FORMAT (1H ,34H FIELD COIL O.D. EXCEEDS YOKE I.D.)
11    FORMAT (1H ,29H FIELD COIL I.D. IS TOO SMALL)
12    FORMAT (1H ,49H TYE AND TYR MUST BE READ IN FOR TYPE 2 OR 3 YOKE)
13    FORMAT (1H ,81H FIELD COIL DIMENSIONS ARE TOO SMALL FOR THE SPECIF
     1IED NO. OF TURNS AND WIRE SIZE)
C
C     DETERMINE ROTOR AND STATOR STACKING FACTORS
C
14    M=1
      STFK=SF
      LT=LTS
      GO TO 17
15    M=2
      STFK=RK
      LT=LTR
      GO TO 17
16    M=3
      STFK=RK1
      LT=LTR1
17    IF (STFK.NE.0.) GO TO (19,20,21),M
      IF (LT.EQ.0.) GO TO 18
      STFK=1.0-(12.5E-4/LT)
      GO TO (19,20,21),M
18    STFK=1.0
      GO TO (19,20,21),M
19    SF=STFK
      GO TO 15
20    RK=STFK
      GO TO 16
21    RK1=STFK
C
C     CALCULATE POLE FACE LOSS FACTOR
C
      M=0
      IF (D1.NE.0.) GO TO 29
      IF (LTR1.NE.0.) GO TO 22
      M=1
      IF (RK1.GT.0.9999) GO TO 28
      LTR1=(12.5E-4)/(1.0-RK1)
22    IF (LTR1-0.045) 23,23,24
23    D1=1.17
      GO TO 29
24    IF (LTR1-0.094) 25,25,26
25    D1=1.75
      GO TO 29
26    IF (LTR1-0.17) 27,27,28
27    D1=3.5
      GO TO 29
28    D1=7.0
29    IF (M.EQ.1) LTR1=0.
      IBN=BN+.1
      SS=SF*(CL-MV*BV)
```

```
      SIGMA=(54.E3/DI**2)*(PF/SS)*(VA/RPM)
      VR=0.262*DR*RPM
      TS=3.142*DI/QQ
      IF (ZZ-4) 30,31,30
30    TT=(.667*HS+DI)*3.142/QQ
      GO TO 32
31    TT=(DI+2.0*HO+1.333*BS)*3.1416/QQ
C
C     CALCULATE CARTER COEFFICIENTS
C
32    IF (ZZ.GT.1.AND.ZZ.LT.5) GO TO 33
      CC=(5.0*GC+BS)*TS/((5.0*GC+BS)*TS-BS*BS)
      GO TO 34
33    CC=(4.44*GC+0.75*BO)*TS
      CC=CC/(QC-BO*BO)
34    IF (IBN.EQ.0) GO TO 35
      QC=(4.44*GC+0.75*WO)*TB
      CCR=QC/(QC-WO**2)
      GO TO 36
35    CCR=1.
36    TP=3.142*DI/PX
C
C     PITCH FACTOR AND SKEW FACTOR CALCULATIONS
C
      CF=SIN(YY*1.571/(PN*QN))
      IF (SK) 37,37,38
37    FS=1.0
      GO TO 39
38    FS=(SK/TP)*1.5707
      FS=(1./FS)*(SIN(FS))*(COS(FS*(1.+BCOIL/CL)))
C
C     CHECK IF WINDING HAS INTEGRAL NO. OF SLOTS PER POLE PER PHASE
C
39    D=1.0
      IF (PBA.GT.61.0) D=2.0
      IZY=IPX*IPN
      IDM=0
40    IDM=IDM+IZY
      IF (IQQ-IDM) 42,41,40
C
C     CALCULATE DISTRIBUTION FACTOR FOR INTEGRAL SLOT WINDING
C
41    DF=SIN(1.571*D/PN)/(QN*D*SIN(1.571/(PN*QN)))
      GO TO 46
C
C     CALCULATE DISTRIBUTION FACTOR FOR FRACTIONAL SLOT WINDING
C
42    IIQQ=IQQ
      I=2
43    IF ((IZY/I)*I.EQ.IZY.AND.(IIQQ/I)*I.EQ.IIQQ) GO TO 44
      IF (I.GT.IZY) GO TO 45
      I=I+1
      GO TO 43
44    IZY=IZY/I
      IIQQ=IIQQ/I
      GO TO 43
```

```
45      FNQ=IIQQ
        CF=SIN(1.571*C/PN)/(FNQ*C*SIN(1.571/(FNQ*PN)))
46      EC=QQ*SC*CF*FS/C
C
C       COMPUTE ARMATURE CONDUCTOR AREA
C
        IF (DW1) 47,47,48
47      AC=0.785*DW*DW*SN1
        GO TO 60
48      ZY=0.0
        DT=AMIN1(DW,DW1)
        DG=AMAX1(DW,DW1)
49      IF (DT-.05) 52,52,50
50      JA=0
51      JA=JA+1
        IF (DT-DA(JA)) 53,53,51
52      D=0
        IF (ZY) 59,59,72
53      IF (DG-0.188) 54,54,55
54      CY=DX(JA-1)
        CZ=DX(JA)
        GO TO 58
55      IF (DG-0.75) 56,56,57
56      CY=DY(JA-1)
        CZ=DY(JA)
        GO TO 58
57      CY=DZ(JA-1)
        CZ=DZ(JA)
58      D=CY+(CZ-CY)*(DT-DA(JA-1))/(DA(JA)-DA(JA-1))
        IF (ZY) 59,59,72
59      AC=(DT*DG-D)*SN1
C
C       CALCULATE END EXTENSION LENGTH
C
60      IF (EL) 61,61,69
61      IF (RF) 62,62,68
62      IF (PX-2.0) 63,63,64
63      U=1.3
        GO TO 67
64      IF (PX-4.0) 65,65,66
65      U=1.5
        GO TO 67
66      U=1.7
67      EL=3.1416*U*YY*(DI+HS)/QQ+0.5
        GO TO 69
68      EL=2.0*CE+(3.1416*(0.5*HX+DB))+(YY*TS*TS/(SQRT(TS*TS-BS*BS)))
69      HM=2.*CL+EL+BCOIL
C
C       CALCULATE STATOR RESISTANCE
C
        A=PI*SC*CF/(C*TS)
        RY=SC*QQ*HM/(PN*AC*C*C)
        RG1=(1.E-6)*RS*(1.0+ALPHAS*(TST-20.))*RY
        S=PI/(C*AC)
C
C       COMPUTE FIELD CONDUCTOR AREA
```

```
C
      IF (RT) 70,70,71
70    AS=.7854*RD*RD
      GO TO 73
71    ZY=1.0
      DT=AMIN1(RT,RD)
      DG=AMAX1(RT,RD)
      GO TO 49
72    AS=DT*DG-C
C
C     COMPUTE FIELD RESISTANCE
C
73    ZG=PT*FE/AS
      FK1=(1.E-6)*RR*(1.0+ALPHAR*(TF-20.))*ZG
C
C     NO LOAD MAGNETIC CALCULATIONS
C
      GA=3.142*DI*(CL-HV*BV)
      GE=CC*GC*CCR
      AG=6.38*DI/(PX*GE)
      IF (C1) 75,74,75
74    C1=(.649*ALOG(PE)+1.359)*((GC/GP)**0.352)
75    CW=0.707*EE*C1*CF/(EP*PN)
      TG=6000000.0*EE/(CW*EC*RPM)
      BG=TG/GA
      IF (CP) 76,76,77
76    CP=(GC/GP)**.41*PE*(ALOG(GC/TP)*.0378+1.191)
77    FQ=TG*CP/PX
C
C     DETERMINE DEMAGNETIZING AMPERE TURNS (FULL LOAD)
C
      IF (CM) 78,78,79
78    AA=SIN(3.142*PE)
      AB=SIN(1.571*PE)*4.0
      CM=(3.142*PE+AA)/AB
79    CONTINUE
      FGML=.45*EC*PI*CM*CF/PX
C
C     PERMEANCE CALCULATIONS
C
      IF (CQ) 80,80,81
80    AB=3.1416*PE
      CQ=(4.*PE+1.)/5.-SIN(AB)/3.1416
81    XR=.0707*A*CF/(C1*BG)
      FACTOR=YY/(PN*CN)
      IF (PBA.LT.61.) GO TO 82
      FF=.05*(24.*FACTOR-1.)
      IF (FACTOR.GE.0.667) FF=.75
      IF (ZZ.EQ.5) FF=1.
      GO TO 83
82    FF=.25*(6.*FACTOR-1.)
      IF (FACTOR.GE.0.667) FF=.25*(3.*FACTOR+1.)
      IF (ZZ.EQ.5) FF=1.
83    CX=FF/(CF*CF*DF*DF)
      Z=CX*20.0/(PN*CN)
      BT=3.142*DI/CQ-BO
```

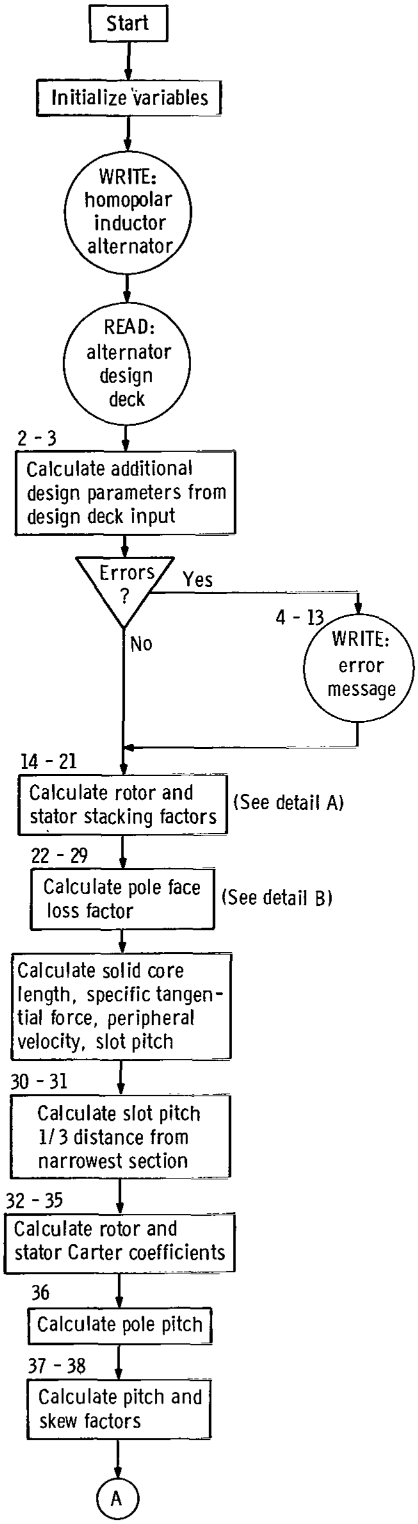
```
      ZA=BT*BT/(16.0*TS*GC)
      ZB=0.35*BT/TS
      ZC=HO/BC
      ZD=HX*.333/BS
      ZE=HY/BS
      IF (ZZ-2) 84,85,86
84    PC=Z*(ZE+ZD+ZA+ZB)
      GO TO 90
85    PC=Z*(ZC+(2.0*HT/(BO+BS))+(HW/BS)+ZD+ZA+ZB)
      GO TO 90
86    IF (ZZ-4) 87,88,89
87    PC=Z*(ZC+(2.0*HT/(BO+B1))+(2.0*HW/(B1+B2))+(HX/(3.*B2))+ZA+ZB)
      GO TO 90
88    PC=Z*(ZC+0.62)
      GO TO 90
89    PC=Z*(ZE+ZD+(0.5*GC/TS)+(0.25*TS/GC)+0.6)
90    EK=EL/(10.0**(0.103*YY*TS+0.402))
      IF (DI-8.0) 91,91,92
91    EK=SQRT(EK)
92    ZF=.612*ALOG(10.0*CS)
      EW=6.28*EK*ZF*(TP**(0.62-(.228*ALOG(ZF))))/(CL*DF*DF)
      PM=3.19*3.1416*DR*CL*(2.0-PE)/(PX*(HP1+GC))
      P5=1.675*(DCOIL-PCOIL)*(DCOIL+PCOIL)/BCOIL
      P6=2.5*(PCOIL-DI)*(PCOIL+DI)/BCOIL
      P6=P6+1.67*(DI-DSH)*(DI+DSH)/BCOIL
      P7=2.5*(DI+DISH1)*(DU-DI)/(DU-DISH1)
      RL=(P5+P6+P7/2.+PM*PX/4.)
      STATET=CQ*SC*DF*CF/(2.*PN*C)
C
C     STATOR WINDING LEAKAGE AND ARMATURE REACTION REACTANCES
C
      XL=XR*(2.*PC+EW)
      XD=XR*AG*C1*CM
      XQ=XR*CQ*AG
C
C     FIELD LEAKAGE REACTANCE, SELF INDUCTANCE AND TIME CONSTANT
C
      XF=3.0E-06*3.1416*F*(STATET**2)*RL*PI/EP
      SI=PT*PT*(PX*3.1416*CP*AG*CL/8.+RL)*1.E-08
      TC=SI/FK1
C
C     SYNCHRONOUS AND TRANSIENT REACTANCES CALCULATIONS
C
      XA=XL+XD
      XB=XL+XQ
      XU=XL+(XF*XD)/(XF+XD)
C
C     COMPUTE FRICTION AND WINDAGE
C
      IF (WF-1.0) 94,93,94
93    WF=DR**2.5*(RPM**1.5)*PL*0.00000252
C
C     WEIGHT CALCULATIONS
C
94    IF (ZZ-3) 95,96,95
95    WI=((DU+DI)*(DU-DI)*3.1416)/4.
```

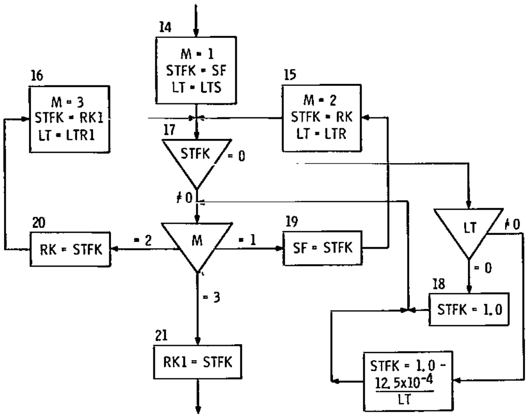
```
      IF (ZZ.NE.4) WI=WI-QQ*(BS*HS-((HO+0.5*HT)*(BS-BO)))
      IF (ZZ.EQ.4) WI=WI-QQ*(BS*BS*3.1416/4.+HO*BO)
      GO TO 97
96    WI=(DU-HC)*3.1416*HC
      WI=WI+HS*((DI+2.*HS)*3.1416-QQ*BS)
      WI=WI+QQ*((HO+0.5*HT)*(BS-BO))
97    WI=WI*0.566*SS
C
      RC=0.321*PT*FE*AS
C
      WC=.321*SC*QQ*AC*HM
C
      IF (TYPY.EQ.1) GO TO 98
      WYOKE=.283*((3.1416*(DYC+TYE)*TYE*(BCOIL+2.*TYR))+(3.1416*((DU+TY+
     1DYC)/2.)*2.*TYR*(DYC-(DU+TY))/2.))
      IF (TYPY.EQ.2) WYOKE=WYOKE+3.1416*0.283*(DU+TY)*TY*(2.*CL)
      IF (TYPY.EQ.3) WYOKE=WYOKE+3.1416*0.283*2.*CL*(0.333*((0.5*DU+TY)*
     1*2+(0.5*(DU+TY))**2+(0.5*(DU+TY))*(0.5*DU+TY))-0.25*DU*DU)
      GO TO 99
98    WYOKE=.283*3.1416*(DU+TY)*TY*(2.*CL+BCOIL)
C
99    IF (WROTOR.NE.0.) GO TO 100
      WSHAFT=.283*3.1416*(DSH**2-DISH**2)/4.*(ALH+2.*PL)
      THETA=2.*3.1416*PE/PX
      ATIP=DR**2*(THETA-SIN(THETA))/8.
      ABCDY=DR*SIN(THETA/2.)*(DR*COS(THETA/2.)/2.-DSH/2.)
      BETA=ARSIN((DR*SIN(THETA/2.)/2.)/(DSH/2.))*2.
      ABASE=DSH**2*(SIN(BETA/2.)-SIN(BETA)/4.-BETA/4.)/2.
      WPOLE=.283*PL*(ATIP+ABCDY+ABASE)
      WROTOR=WSHAFT+PX*WPOLE
100   WTOTAL=WC+WI+RC+WYOKE+WROTOR
      RETURN
      END
```

SINDUC

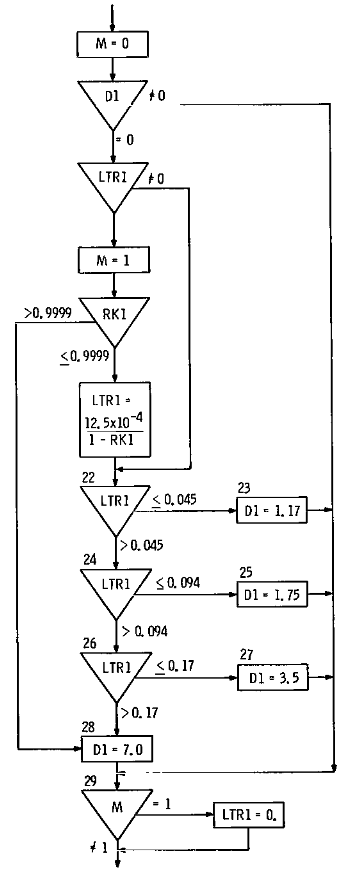
○ or ⬯	Input/Output
▽	Branch point or decision
▭	Arithmetic statement
⬭	Call statement for subroutine

Numbers at upper left indicate external formula numbers in FORTRAN program

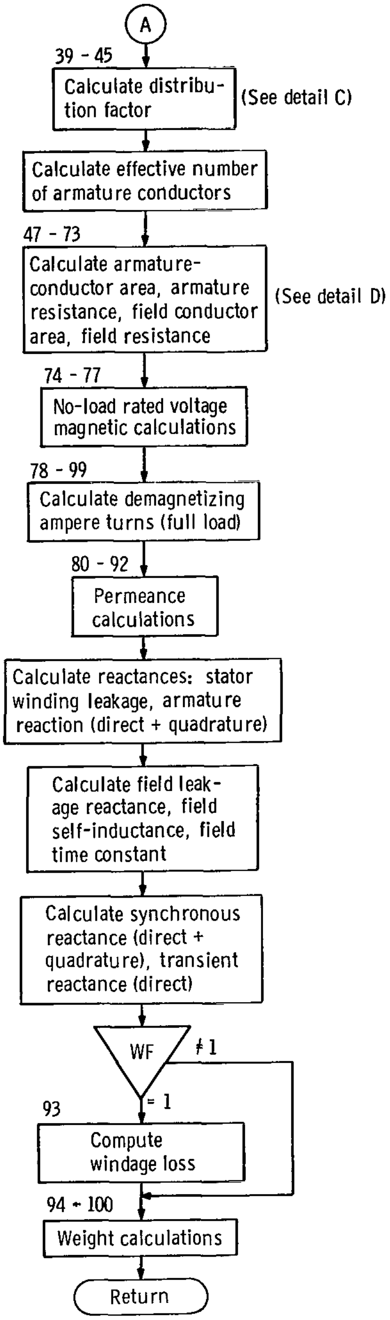


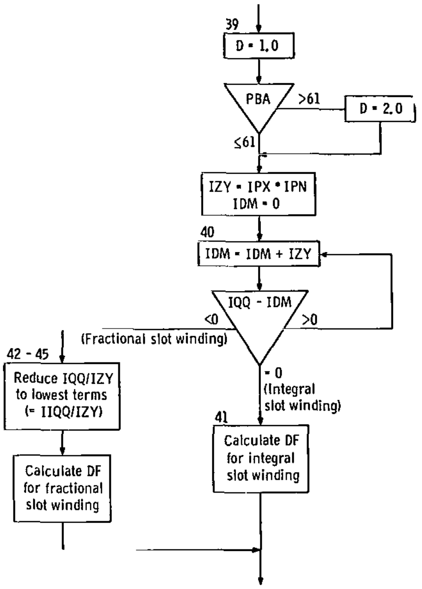


Detail A

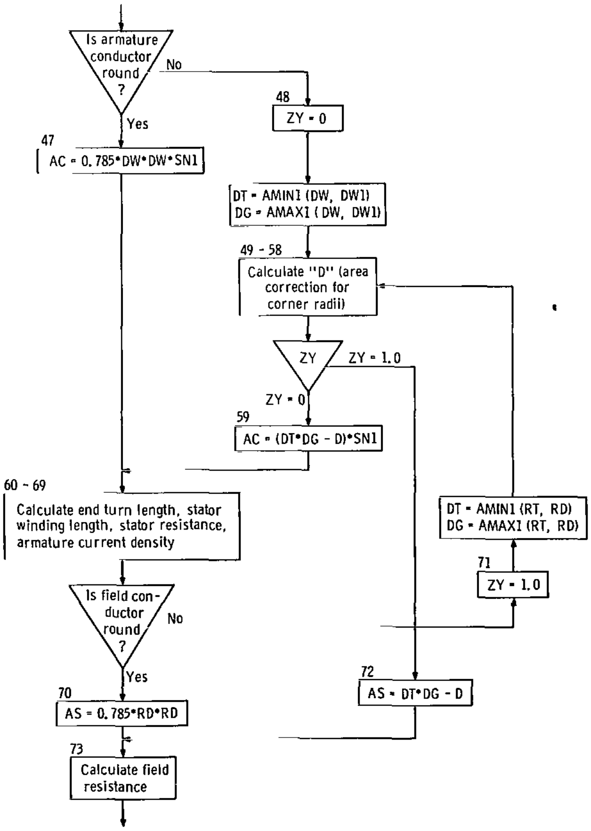


Detail B


A
39 - 45
Calculate distribution factor
(See detail C)
Calculate effective number of armature conductors
47 - 73
Calculate armature-conductor area, armature resistance, field conductor area, field resistance
(See detail D)
74 - 77
No-load rated voltage magnetic calculations
78 - 99
Calculate demagnetizing ampere turns (full load)
80 - 92
Permeance calculations
Calculate reactances: stator winding leakage, armature reaction (direct + quadrature)
Calculate field leakage reactance, field self-inductance, field time constant
Calculate synchronous reactance (direct + quadrature), transient reactance (direct)
WF
≠ 1
= 1
93
Compute windage loss
94 - 100
Weight calculations
Return


39
D = 1.0
PBA
>61
D = 2.0
≤61
IZY = IPX * IPN
IDM = 0
40
IDM = IDM + IZY
IQQ - IDM
<0
>0
(Fractional slot winding)
42 - 45
Reduce IQQ/IZY to lowest terms (= IIQQ/IZY)
Calculate DF for fractional slot winding
= 0
(Integral slot winding)
41
Calculate DF for integral slot winding

Detail C

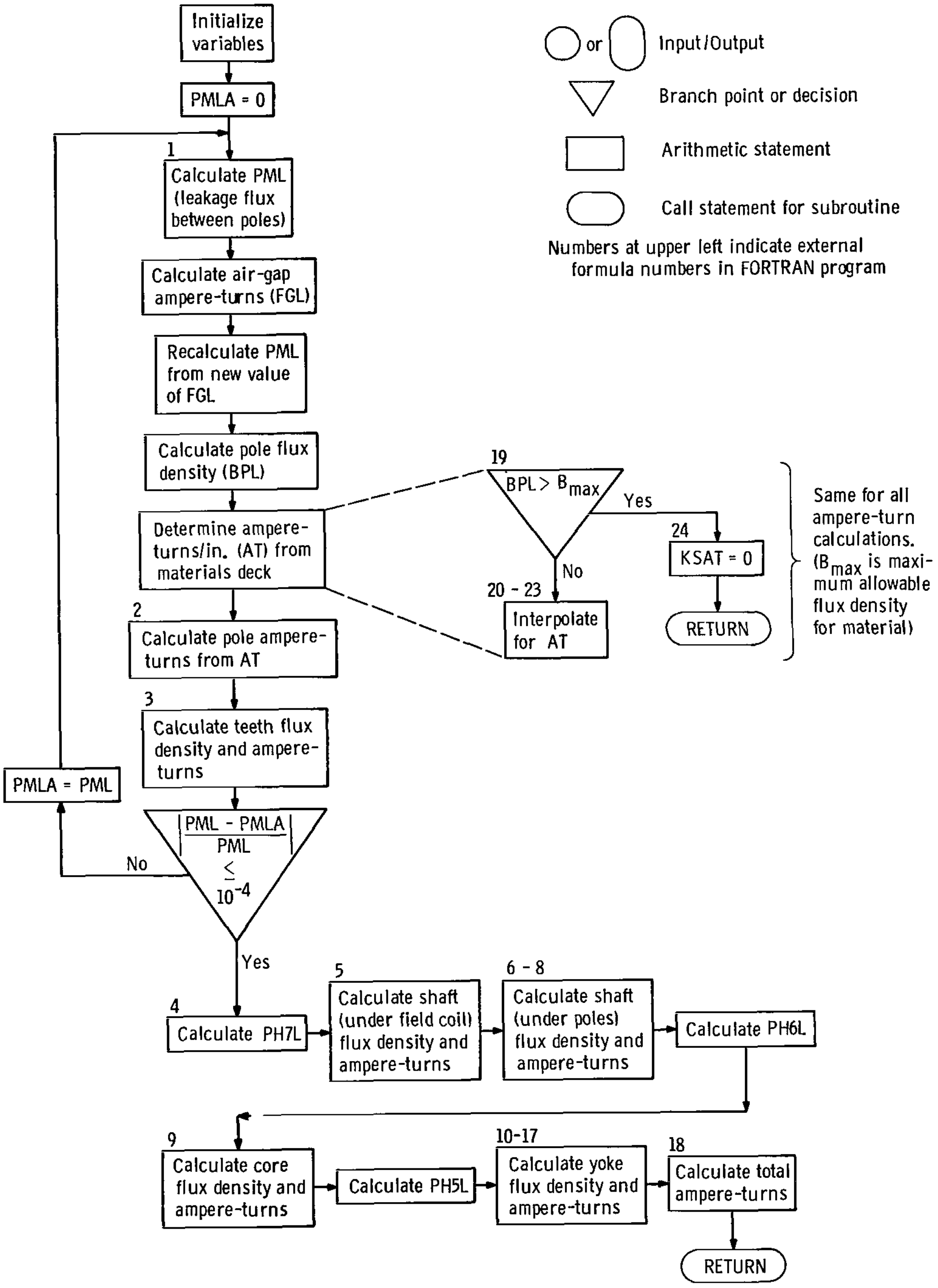

Is armature conductor round ?
No
Yes
47
AC = 0.785*DW*DW*SN1
48
ZY = 0
DT = AMIN1 (DW, DW1)
DG = AMAX1 (DW, DW1)
49 - 58
Calculate "D" (area correction for corner radii)
ZY
ZY = 1.0
ZY = 0
59
AC = (DT*DG - D)*SN1
60 - 69
Calculate end turn length, stator winding length, stator resistance, armature current density
DT = AMIN1 (RT, RD)
DG = AMAX1 (RT, RD)
71
ZY = 1.0
Is field conductor round ?
No
Yes
70
AS = 0.785*RD*RD
72
AS = DT*DG - D
73
Calculate field resistance

```
      SUBROUTINE MAGNET
      COMMON A,AA,AB,AC,ACR,AG,AI,ALH,ALPHAE,ALPHAR,ALPHAS,ALY,ALYC,ALYR
     1,AP,AS,ASH,ATH,AY,AYC,AYR,B,B1,B2,B3,BCLL,BCOIL,BG,BK,BN,BO,BP,BPL
     2,BS,BSHL,BTLL,BV,BYCLL,C,C1,CC,CCR,CE,CF,CK,CL,CM,CP,CQ,CW,D,D1,DC
     3OIL,DD,DF,DI,DISH,DISH1,DR,DSH,DU,DW,DW1,DYC,EC,EDD,EE,EL,EP,EW,F,
     4FCL,FE,FFLL,FGL,FGML,FH,FK1,FPL,FQ,FS,FSHL,FSHLP,FTL,FYCL,FYL,FYRL
     5,G,GA,GC,GE,GP,GXX,H,HC,HD,HM,HO,HP,HP1,HS,HT,HV,HW,HX,HY,IBN,IPN,
     6IPX,IQQ,IZZ,JA,KSAT,LTR,LTR1,LTS,P5,P6,P7,PBA,PC,PCOIL,PE,PF,PHL,P
     7HW,PI,PL,PM,PML,PN,PT,PX,QN,CQ,RC,RD,RE,RF,RG1,RK,RK1,RPM,RR,RS,RT
     8,RY,S,SB,SC,SD,SF,SH,SI,SIGMA,SK,SN,SN1,SS,STATET,T1,T11,T2,T22,T3
     9,T33,TB,TC,TF,TG,TS,TST,TT,TY,TYE,TYPY,TYR,VA,VR,WC,WF,WI,WL,WO,WR
     $OTOR,WTOTAL,WYOKE,XA,XB,XD,XF,XL,XQ,XR,XU,YY,Z,ZG,ZZ,ZZZ
      INTEGER TYPY
      DIMENSION AI(90), G(5)
      BPL=0
      BTLL=0
      BSHL=0
      BCLL=0
      BYCLL=0
      FFLL=0
      FTL=0
      FPL=0
      PPL=GXX*FQ
      W=FH*EDD
      FGL=W
      PMLA=0
C
C     CALCULATE AIRGAP AMPERE-TURNS AND PML (LEAKAGE FLUX BTWN POLES)
C
1     PML=PM*(FGML+FTL+FPL+FGL)*.001
      PMLAG=PML*PE/(2.0-PE)
      FGL=W+PMLAG*ZZZ
      PML=PM*(FGML+FTL+FPL+FGL)*.001
      PMLAG=PML*PE/(2.0-PE)
C
C     FLUX DENSITY AND AMPERE-TURNS FOR POLE
C
      BPL=(PPL+PMLAG)/AP
      NA=31
      K=1
      X=BPL
      GO TO 19
2     FPL=AT*HP
C
C     FLUX DENSITY AND AMPERE-TURNS FOR TEETH
C
      BTLL=(PPL+PMLAG)/ATH
      X=BTLL
      NA=1
      K=2
```

```
      GO TO 19
3     FTL=AT*HS
C
C     CHECK IF PML HAS CONVERGED
C
      IF (ABS((PML-PMLA)/PML).LE.1.0E-04) GO TO 4
      PMLA=PML
      GO TO 1
C
C     FLUX DENSITY AND AMPERE-TURNS FOR SHAFT (UNDER FIELD COIL)
C
4     Z=FTL+FGL+FPL
      PH7L=P7*Z*.001
      PSHL=(PPL+PMLAG)*PX/2.0+PML*PX/2.0+PH7L
      BSHL=PSHL/ASH
      X=BSHL
      NA=31
      K=3
      GO TO 19
5     FSHL=AT*ALH
C
C     FLUX DENSITY AND AMPERE-TURNS FOR SHAFT (UNDER POLES)
C
      PDIFF=PSHL-PH7L
      X=(.250*PDIFF+PH7L)/ASH
      NA=31
      K=4
      GO TO 19
6     FSHLP=AT*PL/2.0
      X=(.625*PDIFF+PH7L)/ASH
      NA=31
      K=5
      GO TO 19
7     FSHLP=FSHLP+AT*PL/4.0
      X=(.875*PDIFF+PH7L)/ASH
      NA=31
      K=6
      GO TO 19
8     FSHLP=FSHLP+AT*PL/4.0
C
C     FLUX DENSITY AND AMPERE-TURNS FOR CORE
C
      Z=2.*Z+FSHL+FSHLP*2.
      PH6L=P6*Z*.001
      BCLL=(PPL+PMLAG+(PH7L+PH6L)/PX)/ACR
      X=BCLL
      NA=1
      K=7
      GO TO 19
9     FCL=AT*HC
C
C     FLUX DENSITY AND AMPERE-TURNS FOR YOKE
C
      Z=Z+2.*FCL
      PH5L=P5*Z*.001
      IF (TYPY-1) 11,10,11
```

```
10      PY=PSHL+PH6L+PH5L
        GO TO 12
11      PY=PSHL+PH6L
12      X=PY/AY
        NA=61
        K=8
        GO TO 19
13      FYL=AT*ALY
        IF (TYPY-1) 14,15,14
14      PY=PY+PH5L
        X=PY/AYC
        BYCLL=X
        NA=61
        K=9
        GO TO 19
15      FYCL=0
        FYRL=0
        BYCLL=X
        GO TO 18
16      FYCL=AT*ALYC
        X=PY/AYR
        NA=61
        K=10
        GO TO 19
17      FYRL=AT*ALYR
C
C       TOTAL AMPERE-TURNS
C
18      FFLL=2.*(FGL+FTL+FCL+FPL+FSHLP)+FSHL+FYL+FYCL+FYRL
        RETURN
C
C       INTERPOLATION PROCEDURE FOR MATERIAL CURVES
C
19      IF (AI(NA)-X) 24,20,20
20      NA=NA+3
21      IF (AI(NA)-X) 22,23,23
22      NA=NA+2
        GO TO 21
23      AA=AI(NA)
        BB1=AI(NA-2)
        DC=AI(NA+1)
        D=AI(NA-1)
        XX=(AA-BB1)/(.4343*(ALOG(DC)-ALOG(D+.0001)))
        Y=AA-XX*.4343*ALOG(DC)
        AT=EXP(2.306*(X-Y)/XX)
        GO TO (2,3,5,6,7,8,9,13,16,17),K
24      KSAT=0
        RETURN
        END
```

MAGNET


or
Input/Output
Branch point or decision
Arithmetic statement
Call statement for subroutine
Numbers at upper left indicate external formula numbers in FORTRAN program
Initialize variables
PMLA = 0
1
Calculate PML (leakage flux between poles)
Calculate air-gap ampere-turns (FGL)
Recalculate PML from new value of FGL
Calculate pole flux density (BPL)
Determine ampere-turns/in. (AT) from materials deck
19
BPL > B_{max}
Yes
24
KSAT = 0
RETURN
No
20 - 23
Interpolate for AT
Same for all ampere-turn calculations. (B_{max} is maximum allowable flux density for material)
2
Calculate pole ampere-turns from AT
3
Calculate teeth flux density and ampere-turns
PMLA = PML
$\left|\frac{PML - PMLA}{PML}\right| \leq 10^{-4}$
No
Yes
4
Calculate PH7L
5
Calculate shaft (under field coil) flux density and ampere-turns
6 - 8
Calculate shaft (under poles) flux density and ampere-turns
Calculate PH6L
9
Calculate core flux density and ampere-turns
Calculate PH5L
10-17
Calculate yoke flux density and ampere-turns
18
Calculate total ampere-turns
RETURN

```
      SUBROUTINE OUTPUT
      COMMON A,AA,AB,AC,ACR,AG,AI,ALH,ALPHAE,ALPHAR,ALPHAS,ALY,ALYC,ALYR
     1,AP,AS,ASH,ATH,AY,AYC,AYR,B,B1,B2,B3,BCLL,BCOIL,BG,BK,BN,BO,BP,BPL
     2,BS,BSHL,BTLL,BV,BYCLL,C,C1,CC,CCR,CE,CF,CK,CL,CM,CP,CQ,CW,D,D1,DC
     3OIL,DD,DF,DI,DISH,DISH1,DR,DSH,DU,DW,DW1,DYC,EC,EDD,EE,EL,EP,EW,F,
     4FCL,FE,FFLL,FGL,FGML,FH,FK1,FPL,FQ,FS,FSHL,FSHLP,FTL,FYCL,FYL,FYRL
     5,G,GA,GC,GE,GP,GXX,H,HC,HD,HM,HO,HP,HP1,HS,HT,HV,HW,HX,HY,IBN,IPN,
     6IPX,IQQ,IZZ,JA,KSAT,LTR,LTR1,LTS,P5,P6,P7,PBA,PC,PCOIL,PE,PF,PHL,P
     7HW,PI,PL,PM,PML,PN,PT,PX,QN,QQ,RC,RD,RE,RF,RG1,RK,RK1,RPM,RR,RS,RT
     8,RY,S,SB,SC,SD,SF,SH,SI,SIGMA,SK,SN,SN1,SS,STATET,T1,T11,T2,T22,T3
     9,T33,TB,TC,TF,TG,TS,TST,TT,TY,TYE,TYPY,TYR,VA,VR,WC,WF,WI,WL,WO,WR
     $OTOR,WTOTAL,WYCKE,XA,XB,XD,XF,XL,XQ,XR,XU,YY,Z,ZG,ZZ,ZZZ
C
      DIMENSION STAR(5), DASH(3), AI(90), G(5)
C
      INTEGER TYPY
C
      REAL LTS,LTR,LTR1
C
      DATA STAR(1)/30H******************************/,DASH(1)/18H-------
     1-----------/
C
C
      WRITE (6,1) VA,EE,EP,PI,PF,IPN,F,IPX,RPM
1     FORMAT (1HL,18H ALTERNATOR RATING//10X,15H ALTERNATOR KVA,F16.1/10
     1X,18H LINE-LINE VOLTAGE,F12.0/10X,19H LINE-NEUT. VOLTAGE,F11.0/10X
     2,14H PHASE CURRENT,F18.2/10X,13H POWER FACTOR,F19.2/10X,7H PHASES,
     3I22/10X,10H FREQUENCY,F20.0/10X,6H POLES,I23/10X,4H RPM,F27.1)
      IF (IZZ-2) 3,5,2
2     IF (IZZ-4) 7,9,11
3     WRITE (6,4) BS,HX,HY,HS,IQQ,TS,TT
4     FORMAT (1HL,13H STATOR SLOTS//5X10H TYPE-OPEN/54X,9H--------*,12X6
     1H*-----/62X1H*,12X1H*/55X2HHY,5X1H*,12X1H*/10X3H BS,F26.3,1X6HINCH
     2ES,16X,1H*,12X1H*/10X3H HX,F26.3,15X,9H--------*,2X8H********,2X1H
     3*/10X3H HY,F26.3,23X1H*,2X1H*,6X1H*,2X1H*/10X3H HS,F26.3,23X1H*,2X
     41H*,6X1H*,2X1H*/62X,1H*,2X8H********,2X1H*2X2HHS/55X2HHX,5X,1H*,12
     5X1H*/10X13H NO. OF SLOTSI16,23X,1H*,2X8H********,2X1H*/62X1H*,2X1H
     6*,6X1H*,2X1H*/10X11H SLOT PITCH,F18.3,1X6HINCHES,16X1H*,2X1H*,6X1H
     7*,2X1H*/54X9H--------*,2X8H********,2X1H*/10X11H SLOT PITCH,41X1H*
     8,12X1H*/10X15H   AT 1/3 DIST.,F14.3,1X6HINCHES,16X19H*************
     9*-----/62X1H1,12X1H1/62X14H1-----BS-----1/62X1H1,12X1H1)
      GO TO 13
5     WRITE (6,6) BO,BS,HO,HX,HT,HW,HS,IQQ,TS,TT
6     FORMAT (1HL,13H STATOR SLOTS//5X22H TYPE-PARTIALLY CLOSED/67X4H-BO
     1-/57X10H---------*,4X10H*---------/58X2HHO,6X1H*,4X1H*/57X10H-----
     2----*,4X1H*/10X3H BO,F26.3,1X6HINCHES,19X1H*,6X1H*/10X3H BS,F26.3,
     319X2HHT,4X1H*,8X1H*/10X3H HO,F26.3,24X1H*,10X1H*/10X3H HX,F26.3,18
     4X6H-----*,12X1H*/10X3H HT,F26.3,23X1H*,12X1H*/10X3H HW,F26.3,19X2H
     5HW,2X1H*,12X1H*/10X3H HS,F26.3,18X6H-----*2X8H********,2X1H*,2X2HH
     6S/62X1H*,2X1H*,6X1H*,2X1H*/10X13H NO. OF SLOTSI16,23X1H*,2X1H*,6X1
```

```
     7H*,2X1H*/62X1H*,2X8H********,2X1H*/10X11H SLOT PITCH,F18.3,1X6HINC
     8HES,12X2HHX,2X1H*,12X1H*/62X1H*,2X8H********,2X1H*/10X11H SLOT PIT
     9CH,41X1H*,2X1H*,6X1H*,2X1H*/10X15H   AT 1/3 DIST.,F14.3,1X6HINCHES
     $,16X1H*2X1H*6X1H*2X1H*/57X6H-----*,2X8H********,2X1H*/62X1H*,12X1H
     $*/62X19H**************-----/62X1H1,12X1H1/62X14H1-----BS-----1/62X
     $1H1,12X1H1)
      GO TO 13
7     WRITE (6,8) B0,B1,B2,B3,BS,H0,HX,HT,HW,HS,IQQ,TS,TT
8     FORMAT (1H1,13H STATOR SLOTS//5X25HTYPE-CONSTANT TOOTH WIDTH/61X1H
     11,14X1H1/61X16H1------B1------1/10X3H B0,F26.3,1X6HINCHES,15X1H1,1
     24X1H1/10X3H B1,F26.3,22X1H1,5X4H-B0-,5X1H1/10X3H B2,F26.3,11X17H--
     3---------1----*,4X17H*----1-----------/10X3H B3,F26.3,22X1H1,4X1H*
     4,4X1H*,4X1H1,8X2HH0/10X15H BS = (B2+B3)/2,F14.3,22X1H1,4X1H*,4X17H
     5*----1-----------/10X3H H0,F26.3,22X1H1,2X1H*,8X1H*,2X1H1,8X2HHT/1
     60X3H HX,F26.3,22X1H*,14X,12H*-----------/10X3H HT,F26.3,12X2HHS,7X
     71H*,16X1H*,7X2HHW/10X3H HW,F26.3,20X1H*,3X12H************,3X10H*--
     8-------/10X3H HS,F26.3,19X2H*1,3X1H*,10X1H*,3X2H1*/57X1H*,1X1H1,3X
     91H*,10X1H*,3X1H1,1X1H*,4X2HHX/10X13H NO. OF SLOTS,I16,17X1H*,2X1H1
     $,3X12H************,3X1H1,2X1H*,6H------/55X1H*,3X1H1,18X1H1,3X1H*/
     $10X11H SLOT PITCH,F18.3,1X6HINCHES,4X34H----**********************
     $********/54X1H1,4X1H1,18X1H1,4X1H1/10X11H SLOT PITCH,33X1H1,4X20H1
     $--------B2--------1,4X1H1/10X15H   AT 1/3 DIST.,F14.3,1X6HINCHES,8
     $X1H1,4X1H1,18X1H1,4X1H1/54X30H1-------------B3-------------1/54X1H
     $1,28X1H1)
      GO TO 13
9     WRITE (6,10) B0,H0,BS,HS,IQQ,TS,TT
10    FORMAT (1H1,13H STATOR SLOTS//5X,11H TYPE-ROUND//10X,13H SLOT OPEN
     1ING,F16.3,1X6HINCHES/10X,19H SLOT OPENING DEPTH,F10.3/10X,14H SLOT
     2 DIAMETER,F15.3/10X11H SLOT DEPTH,F18.3//10X,13H NO. OF SLOTS,I16/
     3/10X,11H SLOT PITCH,F18.3,1X6HINCHES//10X,11H SLOT PITCH/10X,15H
     4 AT 1/3 DIST.,F14.3,1X6HINCHES)
      GO TO 13
11    WRITE (6,12) BS,HX,HY,HS,IQQ,TS,TT
12    FORMAT (1H1,13H STATOR SLOTS//5X25H TYPE-OPEN (1 COND./SLOT)/57X,6
     1H-----*12X6H*-----/62X,1H*,12X1H*/58X5HHY  *,12X1H*/62X1H*,12X1H*/
     210X,3H BS,F26.3,1X6HINCHES,11X,6H-----*,2X8H********,2X1H*/10X,3H
     3HX,F26.3,23X,1H*,2X1H*,6X1H*,2X1H*/10X,3H HY,F26.3,23X,1H*,2X1H*,6
     4X1H*,2X1H*/10X,3H HS,F26.3,23X,1H*,2X1H*,6X1H*,2X1H*,2X2HHS/58X2HH
     5X,2X1H*,2X1H*,6X1H*,2X1H*/10X,13H NO. OF SLOTS,I16,23X1H*,2X1H*,6X
     61H*,2X1H*/62X1H*,2X1H*,6X1H*,2X1H*/10X,11H SLOT PITCH,F18.3,1X6HIN
     7CHES,16X1H*,2X1H*,6X1H*,2X1H*/57X6H-----*,2X8H********,2X1H*/10X11
     8H SLOT PITCH,41X1H*,12X1H*/10X15H   AT 1/3 DIST.,F14.3,1X6HINCHES,
     916X19H**************-----/62X1H1,12X1H1/62X14H1-----BS-----1/62X1H
     $1,12X1H1)
13    CONTINUE
      WRITE (6,14) GC,GP,GE
14    FORMAT (1H1,8H AIR GAP//10X,16H MINIMUM AIR GAP,F17.3,1X6HINCHES/1
     10X,16H MAXIMUM AIR GAP,F17.3/10X,18H EFFECTIVE AIR GAP,F15.3//)
      IF (IBN.EQ.0) GO TO 16
      WRITE (6,15) CC,CCR
15    FORMAT (1H ,10X,18HCARTER COEFFICIENT/17X,6HSTATOR,F20.3/18X5HROTO
     1R,F20.3)
      GO TO 18
16    WRITE (6,17) CC
17    FORMAT (1H ,10X,18HCARTER COEFFICIENT,F14.3)
18    IF (RF.LT..5) WRITE (6,19)
```

```
      IF (RF.GE..5) WRITE (6,20)                                          D 107
19    FORMAT (1H1,45H ARMATURE WINDING (Y-CONNECTED, RANDOM WOUND)//)     D 108
20    FORMAT (1H1,43H ARMATURE WINDING (Y-CONNECTED, FORM WOUND)//)       D 109
      IF (DW1.EQ.0.) WRITE (6,21) DW                                      D 110
21    FORMAT (1H ,9X,16H STRAND DIAMETER,F32.4,1X6HINCHES)                D 111
      IF (DW1.GT.0.) WRITE (6,22) DW,DW1,SH                               D 112
22    FORMAT (1H ,9X,18H STRAND DIMENSIONS,F30.4,2H X,1XF6.4,1X6HINCHES/  D 113
     110X,35H UNINSULATED STRAND HEIGHT (RADIAL),F13.4)                   D 114
      WRITE (6,23) SD,SN,SN1,AC,S,CE,HM,EL,SK,RS,TST,RG1,STATET,YY,QN     D 115
23    FORMAT (1H ,10X36HDISTANCE BTWN CL OF STRANDS (RADIAL),F11.4//10X,  D 116
     133H STRANDS/CONDUCTOR IN RADIAL DIR.,F11.0/10X,24H TOTAL STRANDS/C  D 117
     2ONDUCTOR,F20.0/10X,15H CONDUCTOR AREA,F33.4,1X6HSQ-IN./10X,29H CUR  D 118
     3RENT DENSITY AT FULL LOAD,F17.2,3X10HAMP/SQ-IN.//10X,27H COIL EXTE  D 119
     4NSION BEYOND CORE,F20.3,2X6HINCHES/10X,24H MEAN LENGTH OF 1/2 TURN  D 120
     5,F23.3/10X,16H END TURN LENGTH,F31.3/10X,30H STATOR SLOT SKEW (PER  D 121
     6 STATOR),F17.3//10X,25H RESISTIVITY AT 20 DEG. C,F23.4,1X16HMICRO   D 122
     7OHM INCHES/10X,21H STATOR RESISTANCE AT,F6.0,7H DEG. C,F14.4,1X4HO  D 123
     8HMS//10X,30H NO. OF EFFECTIVE SERIES TURNS,F16.2/10X,14H SLOTS SPA  D 124
     9NNED,F30.0/10X,25H SLOTS PER POLE PER PHASE,F21.2)                  D 125
      WRITE (6,24) SC,C,PBA,FS,DF,CF                                      D 126
24    FORMAT (1H ,9X,16H CONDUCTORS/SLOT,F28.0/10X,25H NO. OF PARALLEL C  D 127
     1IRCUITS,F19.0/10X,17H PHASE BELT ANGLE,F27.0,5X7HDEGREES//10X,12H   D 128
     2SKEW FACTOR,F35.3/10X,20H DISTRIBUTION FACTOR,F27.3/10X,13H PITCH   D 129
     3FACTOR,F34.3)                                                       D 130
      IF (RT.EQ.0.) WRITE (6,25) RC                                       D 131
      IF (RT.GT.0.) WRITE (6,26) RC,RT                                    D 132
25    FORMAT (1HL,14H FIELD WINDING//10X19H CONDUCTOR DIAMETER,F29.4,1X6  D 133
     1HINCHES/)                                                           D 134
26    FORMAT (1HL,14H FIELD WINDING//10X,21H CONDUCTOR DIMENSIONS,F27.4,  D 135
     12H X,1XF6.4,1X6HINCHES/)                                            D 136
      WRITE (6,27) AS,PT,FE,RR,TF,FK1,PCOIL,DCOIL,BCOIL                   D 137
27    FORMAT (1H ,9X15H CONDUCTOR AREA,F33.4,1X6HSQ-IN.//10X13H NO. OF T  D 138
     1URNS,F31.0/10X20H MEAN LENGTH OF TURN,F27.3,2X6HINCHES//10X25H RES  D 139
     2ISTIVITY AT 20 DEG. C,F23.4,1X16HMICRO OHM INCHES/10X20H FIELD RES  D 140
     3ISTANCE AT,F5.0,7H DEG. C,F16.4,1X4HOHMS//10X21H COIL INSIDE DIAME  D 141
     4TER,F26.3,2X6HINCHES/10X22H COIL OUTSIDE DIAMETER,F25.3/10X11H COI  D 142
     5L WIDTH,F36.3)                                                      D 143
      WRITE (6,28) DI,DO,CL,SS,HC,SF,HV,BV,BK,WL                          D 144
28    FORMAT (1H1,7H STATOR//10X,23H STATOR INSIDE DIAMETER,F21.2,1X6HIN  D 145
     1CHES/10X,24H STATOR OUTSIDE DIAMETER,F20.2/10X,32H OVERALL CORE LE  D 146
     2NGTH (ONE STACK),F12.2/10X,22H EFFECTIVE CORE LENGTH,F22.2/10X,17H  D 147
     3 DEPTH BELOW SLOT,F27.2//10X,16H STACKING FACTOR,F28.2//10X,21H NO  D 148
     4. OF COOLING DUCTS,F21.0/10X,15H WIDTH OF DUCTS,F29.2,1X6HINCHES//  D 149
     510X,13H CORE LOSS AT,F6.1,17H KILOLINES/SQ.IN.,F7.1,2X9HWATTS/LB.)  D 150
      IF (LTS.NE.0.) WRITE (6,29) LTS                                     D 151
29    FORMAT (10X,21H LAMINATION THICKNESS,F24.3,4H IN.)                  D 152
      WRITE (6,30) BP,PL,RK                                               D 153
30    FORMAT (1HL,6H ROTOR//10X,16H POLE BODY WIDTH,F24.3,7H INCHES/20X,  D 154
     113H AXIAL LENGTH,F17.3/20X,16H STACKING FACTOR,F14.3)               D 155
      IF (LTR.NE.0.) WRITE (6,31) LTR                                     D 156
31    FORMAT (1H ,19X,21H LAMINATION THICKNESS,F9.3,7H INCHES)            D 157
      WRITE (6,32) PHW,PHL,RK1                                            D 158
32    FORMAT (1HK,9X,16H POLE HEAD WIDTH,F24.3,7H INCHES/20X,13H AXIAL L  D 159
     1ENGTH,F17.3/20X,16H STACKING FACTOR,F14.3)                          D 160
      IF (LTR1.NE.0.) WRITE (6,31) LTR1                                   D 161
      WRITE (6,33) PE,HP,HP1,DR,VR,SIGMA                                  D 162
```

```
33    FORMAT (1HK,9X,13H POLE EMBRACE,F27.3/10X,12H POLE HEIGHT,F28.3,1X
     16HINCHES/10X,19H POLE HEIGHT (EFF.),F21.3/10X,15H ROTOR DIAMETER,F
     225.3/10X,17H PERIPHERAL SPEED,F20.0,3X,10H FEET/MIN./10X,23H SPEC.
     3 TANGENTIAL FORCE,F17.3,11H LBS/SQ.IN.)
      WRITE (6,34) DSH,DISH,DISH1,ALH
34    FORMAT (1HL,6H SHAFT//10X,28H DIAMETER (UNDER FIELD COIL),F13.3,7H
     1 INCHES/10X,34H INSIDE DIAMETER (OF HOLLOW SHAFT),F7.3/10X,27H DIA
     2METER (UNDER END TURNS),F14.3/10X,20H LENGTH (BTW. POLES),F21.3)
      IF (IBN.EQ.0) WRITE (6,35)
35    FORMAT (1HL,19H DAMPER BARS (NONE))
      IF (DD.EQ.0..AND.IBN.NE.0) WRITE (6,36) H,B
36    FORMAT (1HL,26H DAMPER BARS (RECTANGULAR)//10X,22H DAMPER BAR DIME
     1NSIONS,F17.3,2H X,1XF5.3,1X6HINCHES)
      IF (DD.NE.0..AND.IBN.NE.0) WRITE (6,37) DD
37    FORMAT (1HL,20H DAMPER BARS (ROUND)//10X,20H DAMPER BAR DIAMETER,F
     119.3,1X6HINCHES)
      IF (IBN.NE.0) WRITE (6,38) WC,HD,SB,TB,IBN,RE
38    FORMAT (1H ,9X,19H SLOT OPENING WIDTH,F20.3/10X,20H SLOT OPENING H
     1EIGHT,F19.3/10X,18H DAMPER BAR LENGTH,F21.3/10X,17H DAMPER BAR PIT
     2CH,F22.3//10X,24H NO. OF DAMPER BARS/POLE,I12//10X,25H RESISTIVITY
     3 AT 20 DEG. C,F14.3,17H MICRO-OHM INCHES)
      WRITE (6,39) TYPY
39    FORMAT (1H1,11H YOKE (TYPE,I2,1H))
      IF (TYPY-2) 40,43,48
40    WRITE (6,41) (STAR(I),I=1,5),DASH(1),TY,(STAR(2),I=1,5),(DASH(I),I
     1=1,2),STAR(1)
41    FORMAT (1HL/4(52X,1H1/),13X,5A6,5H***  ,A6,1H-/13X,1H*,31X,1H*/12X
     1,1H*,13X,4HYOKE,14X,1H*,3X,4HTY =,F5.2,4H IN./11X,1H*,30X,2H**/11X
     2,5A6,1H*,1X,2A6/15X,1H*,8X,1H*,7X,1H*,8X,1H*,10X,1H1/15X,27H* STAT
     3OR * FIELD * STATOR *,10X,1H1/15X,1H*,8X,9H* COIL  *,8X,1H*,10X,1H
     41/8X,2(7X,1H*,8X,1H*),10X,1H1/15X,1H*,8X,A6,3H***,8X,1H*/15X,1H*,8
     5X,1H*,7X,1H*,8X,1H*/8X,2(7X,10H**********)///)
      WRITE (6,42) DU,BCOIL
42    FORMAT (1HK,9X,20HINSIDE YOKE DIAMETER,3X,F7.3,7H INCHES/10X,17HST
     1ATOR SEPARATION,6X,F7.3,7H INCHES)
      GO TO 50
43    WRITE (6,44) (DASH(I),I=1,2),(STAR(I),I=1,4),DASH(1)
44    FORMAT (1HL,35X,5H1   1/32X,16H----1   1----TYR/2(12X,1H1,23X,1H1,
     13X,1H1/),12X,1H1,43X,1H1/10X,2A6,1H-,1X,2A6,5H*****,15X,1H1/24X,1H
     2*,15X,1H*,15X,1H1/11X,3HTYE,10X,1H*,5X,4HYOKE,6X,1H*,15X,1H1/2X,2(
     315X,A6,2H**),2X,A6,3H---)
45    WRITE (6,46) (DASH(I),I=1,2),(STAR(I),I=1,4),DASH(1),(STAR(I),I=1,
     13)
46    FORMAT (1H ,9X,2A6,5H-----,1X,A6,3H***,18X,2HTY/12X,1H1,15X,1H*,7X
     1,1H*/12X,1H1,5X,A6,5H*****,1X,5HFIELD,1X,2A6,2X,A6,3H---/12X,1H1,6
     2X,1H*,8X,1H*,1X,4HCOIL,2X,1H*,8X,1H*,10X,1H1/12X,2(7X,10H* STATOR
     3*),10X,1H1/19X,1H*,8X,A6,3H***,8X,1H*,10X,1H1/12X,2(7X,1H*8X,1H*),
     410X,1H1/12X,2(7X,1H*,8X,1H*)/12X,2(7X,A6,4H****)///)
      WRITE (6,47) TYR,TYE,TY,DYC,DU,BCOIL
47    FORMAT (1HL,9X,3HTYR,F30.3,7H INCHES/10X,3HTYE,F30.3/10X,2HTY,F31.
     13/10X,25HDYC, YOKE INSIDE DIAMETER/15X,16H(ABOVE FLD COIL),F12.3/1
     20X,27HDU, STATOR OUTSIDE DIAMETER,F6.3/10X,25HBCOIL, SPACE BTWN ST-
     3ATORS,F8.3)
      GO TO 50
48    WRITE (6,49) (DASH(I),I=1,2),(STAR(I),I=1,2),(DASH(I),I=1,2)
49    FORMAT (1H+,13X,14H(TAPERED ENDS)/1HL,35X,1H1,3X,1H1/32X,5H----1,3
```

```
     1X,9H1-----TYR/2(12X,1H1,23X,1H1,3X,1H1/),12X,1H1,43X,1H1/10X,1H-,2
     2A6,1X,2A6,5H*****,15X,1H1/24X,1H*,15X,1H*,15X,1H1/11X,3HTYE,8X,3H*
     3**,15X,3H***,2X,2A6,2H--/19X,3H***,8X,4HYOKE,9X,3H***/16X,3H***,27
     4X,3H***)
      GO TO 45
50    WRITE (6,51) WC,RC,WI,WROTOR,WYOKE,WTOTAL
51    FORMAT (1HL,8H WEIGHTS//10X13H STATOR COND.,F17.3,1X6HPOUNDS/10X12
     1H FIELD COND.,F18.3/10X12H STATOR IRON,F18.3/10X,6H ROTOR,F24.3/10
     2X,5H YOKE,F25.3//10X,6H TOTAL/11X18H (ELECTROMAGNETIC),F11.3)
      WRITE (6,52) C1,CP,CM,CQ,D1
52    FORMAT (1HL,10H CONSTANTS//10X,35H C1, FUNDAMENTAL/MAX. OF FIELD F
     1LUX,F8.3/10X,18H CP, POLE CONSTANT,F25.3/10X,27H CM, DEMAGNETIZATI
     2ON FACTOR,F16.3/10X,31H CQ, CROSS MAGNETIZATION FACTOR,F12.3/10X,2
     36H D1, POLE FACE LOSS FACTOR,F17.3)
      WRITE (6,53) AG,PC,EW,PM,P5,P6,P7
53    FORMAT (1H1,31H PERMEANCES (LINES/AMPERE TURN)//10X,8H AIR GAP,F35
     1.3,24H PER INCH OF CORE LENGTH/10X,30H WINDING LEAKAGE - STATOR SL
     2OT,F13.3/29X,10HSTATOR END,F14.3//10X,8H LEAKAGE/13X,25H PM, FROM
     3ROTOR TO STATOR/15X,19H(BTWN. ROTOR TEETH),F19.3/13X,22H P5, ACROS
     4S FIELD COIL,F18.3/13X,26H P6, FROM STATOR TO STATOR,F14.3/13X,24H
     5 P7, STATOR TO SHAFT END,F16.3)
      WRITE (6,54) A,XR,XL,XC,XQ,XA,XB,XF,XU,SI,TC
54    FORMAT (1HL,11H REACTANCES//10X23H AMPERE CONDUCTORS/INCH,F20.3/10
     1X17H REACTANCE FACTOR,F26.3//10X23H STATOR WINDING LEAKAGE,F20.3,1
     2X,7HPERCENT/10X23H ARM. REACTION (DIRECT),F20.3/10X22H ARM. REACTI
     3ON (QUAD.),F21.3/10X21H SYNCHRONOUS (DIRECT),F22.3/10X20H SYNCHRON
     4OUS (QUAD.),F23.3/10X14H FIELD LEAKAGE,F29.3/10X10H TRANSIENT,F33.
     53//10X22H FIELD SELF INDUCTANCE,F21.3,1X7HHENRIES///10X27H OPEN CI
     6RCUIT TIME CONSTANT/17X13H (FIELD ONLY),F23.5,1X7HSECONDS)
      RETURN
      END
```

APPENDIX B

DEFINITION OF FORTRAN VARIABLES

The following is an alphabetic listing of the major FORTRAN variables used in the program. The variables are defined and the units used in the program are given. The list includes approximately 75 percent of all FORTRAN variables appearing in the program.

A	ampere-conductors per inch of stator periphery, A/in.
AA	used for variety of calculations
AB	used for variety of calculations
ABASE	area used in rotor weight calculation, in.^{2}
ABODY	area used in rotor weight calculation, in.^{2}
AC	armature conductor area, in.^{2}
ACR	effective core area per pole, in.^{2}
AG	specific air gap permeance per inch of core length per pole, lines/(A-turn)(in.)
AI	points on material magnetization curve
AIRGAP	NAMELIST name
AKVA	generator output at load point G, kVA
ALH	shaft length (between poles), in.
ALPHAE	temperature coefficient of resistivity of damper winding at 20° C, $^\circ$C^{-1}
ALPHAR	temperature coefficient of resistivity of field winding at 20° C, $^\circ$C^{-1}
ALPHAS	temperature coefficient of resistivity of armature winding at 20° C, $^\circ$C^{-1}
ALY	yoke dimension used in magnetic calculation, in.
ALYC	yoke dimension used in magnetic calculation, in.
ALYR	yoke dimension used in magnetic calculation, in.
AN	power factor angle, rad
AP	pole body cross-sectional area (solid area), in.^{2}
AS	field conductor area, in.^{2}
ASH	shaft cross-sectional area, in.^{2}

ATH	tooth cross-sectional area, in.^{2}
ATIP	area used in rotor weight calculation, in.^{2}
AY	yoke area = TY*(DU+TY)*3.14, in.^{2}
AYC	yoke area = TYE*(DYC+TYE)*3.14, in.^{2}
AYR	yoke area = TYR*(DU+2.*TY)*3.14, in.^{2}
B	rectangular damper bar slot width, in.
B1	stator slot dimension (see table VII(c)), in.
B2	stator slot dimension (see table VII(c)), in.
B3	stator slot dimension (see table VII(c)), in.
BCL	core flux density at load point G, kilolines/in.^{2}
BCLL	core flux density, kilolines/in.^{2}
BCOIL	field coil width, in.
BETA	angle used in rotor weight calculations, rad
BG	airgap flux density (no-load, rated voltage), kilolines/in.^{2}
BK	flux density at which core loss WL is given, kilolines/in.^{2}
BN	number of damper bars per pole
BO	stator slot dimension (see table VII(c)), in.
BP	pole body width, in.
BPL	pole flux density, kilolines/in.^{2}
BPLL	pole flux density at load point G, kilolines/in.^{2}
BS	stator slot dimension (see table VII(c)), in.
BSHL	shaft flux density, kilolines/in.^{2}
BSHLL	shaft flux density at load point G, kilolines/in.^{2}
BTL	tooth flux density at load point G, kilolines/in.^{2}
BTLL	tooth flux density, kilolines/in.^{2}
BV	width of cooling duct, in.
BYCL	yoke flux density (over field coil) at load point G, kilolines/in.^{2}
BYCLL	yoke flux density, kilolines/in.^{2}
C	number of parallel armature winding circuits per phase

C1	ratio of fundamental maximum to actual maximum value of field form
CC	Carter coefficient (stator).
CCR	Carter coefficient (rotor)
CDD	current density in field at load point G, A/in.^{2}
CE	straight portion of coil extension (see table VII(d)), in.
CF	pitch factor
CK	power factor adjustment factor
CL	length of one stator stack (axial direction), in.
CM	demagnetizing factor (direct axis)
CONST	NAMELIST name
CP	ratio of average to maximum value of field form
CQ	cross magnetizing factor (quadrature axis)
CS	per unit pole pitch
CW	winding constant
CX	dummy variable used in slot leakage permeance calculation
D	used for distribution factor calculation
D	area correction for corner radii in rectangular conductor, in.^{2}
D	used in interpolation between points on magnetization curve
D1	pole face loss factor
DAMPER	NAMELIST name
DASH	used in subroutine OUTPUT to print yoke diagram
DB	diameter of bender pin for forming armature coils, in.
DCOIL	field coil outside diameter, in.
DD	damper bar diameter, in.
DF	distribution factor
DG	largest dimension of rectangular conductor (field and armature), in.
DI	bore (inside) diameter of stator, in.
DISH	inside shaft diameter for hollow shaft, in.
DISH1	external shaft diameter (external to two stator stacks), in.

DL	damper losses at load point G, W
DR	rotor diameter, in.
DSH	shaft diameter (under field coil), in.
DT	smallest dimension of rectangular conductor (field and armature), in.
DU	stator outside diameter, in.
DW	armature winding strand diameter or width (see table VII(d)), in.
DW1	armature winding strand thickness (uninsulated) (see table VII(d)), in.
DX	used in rectangular conductor area calculation, $in.^2$
DY	used in rectangular conductor area calculation, $in.^2$
DYC	yoke dimension (see table VII(j)), in.
DZ	used in rectangular conductor area calculation, $in.^2$
E	alternator efficiency at load point G, percent
EB	eddy factor (bottom)
EC	number of effective armature conductors
ED	excitation voltage at load point G, per unit
EDD	excitation voltage, per unit
EE	line-to-line design voltage, rms V
EF	field voltage at load point G, V
EL	end extension length of armature coil, in.
EP	line-to-neutral design voltage, rms V
ET	eddy factor (top)
EW	specific stator end winding leakage permeance per inch of core length, lines/(A-turn)(in.)
EX	eddy losses at load point G, W
EZ	eddy factor
F	frequency, Hz
FACTOR	dummy variable used in slot leakage permeance calculation
FCL	core ampere turns, A-turn
FE	mean length of one field coil turn, in.
FF	dummy variable used in slot leakage permeance calculation

FFL	total ampere turns at load point G, A-turn
FFLL	total ampere turns, A-turn
FGL	airgap ampere turns, A-turn
FGLL	airgap ampere turns at load point G, A-turn
FGML	demagnetization ampere turns at rated load, A-turn
FGX	demagnetizing ampere-turns at load point G, A-turn
FH	airgap ampere turns (N. L., rated volt., for useful flux), A-turn
FI	field current at load point G, A
FIELD	NAMELIST name
FK1	field winding resistance at temperature TF, ohm
FPL	pole ampere turns, A-turn
FQ	useful flux per pole (no-load, rated voltage), kilolines
FS	skew factor
FSC	short-circuit ampere turns, A-turn
FSHL	shaft (under field coil) ampere turns, A-turn
FSHLP	shaft (under pole) ampere turns, A-turn
FTL	tooth ampere turns, A-turn
FYCL	yoke ampere turns, A-turn
FYL	yoke ampere turns, A-turn
FYOKE	yoke ampere turns, A-turn
FYRL	yoke ampere turns, A-turn
G	load point at which load characteristics are calculated, per unit or percent
GA	airgap area, in.^{2}
GC	minimum air gap (air gap at center of pole) (see table VII(e)), in.
GE	effective airgap, in.
GF	constant used in load pole-face and damper loss calculations
GP	maximum airgap (see table VII(e)), in.
GT	ratio of slot opening width to minimum airgap
GX	useful flux per pole multiplying factor at load point G

GXX	flux per pole multiplying factor
H	rectangular damper bar thickness, in.
HC	stator depth below slot, in.
HD	damper bar slot opening height, in.
HM	armature conductor length (1/2 coil length), in.
HO	stator slot dimension (see table VII(c)), in.
HP	pole height (pole body + pole head) (see table VII(g)), in.
HP1	effective pole height, in.
HS	stator slot dimension (see table VII(c)), in.
HT	stator slot dimension (see table VII(c)), in.
HV	number of cooling ducts per stator stack
HW	stator slot dimension (see table VII(c)), in.
HX	stator slot dimension (see table VII(c)), in.
HY	stator slot dimension (see table VII(c)), in.
IBN	number of damper bars
IDELR	voltage by which R is incremented, percent
IPN	number of phases
IPX	number of poles
IQQ	number of stator slots
IZZ	stator slot type
KSAT	saturation indicator (if KSAT = 0, part of alternator is saturated)
LT	lamination thickness (used in stacking factor calculations), in.
LTR	pole body lamination thickness, in.
LTR1	pole head lamination thickness, in.
LTS	stator lamination thickness, in.
MAGNET	subroutine name
OUTPUT	subroutine name
P	generator input power at load point G, kW
P5	leakage permeance across field coil, lines/A-turn
P6	leakage permeance from stator to stator, lines/A-turn

P7	leakage permeance from stator to shaft end, lines/A-turn
PBA	phase belt angle, deg
PC	specific armature slot winding leakage permeance per inch of core length, lines/(A-turn)(in.)
PCOIL	field coil inside diameter, in.
PE	pole embrace
PF	design power factor
PH57	leakage flux across field coil, kiloline
PH67	leakage flux from stator to stator, kiloline
PH7L	leakage flux from stator to rotor end extension, kiloline
PHL	pole head length (axial direction), in.
PHW	pole head width, in.
PI	rated line current, A
PL	pole body length (axial direction) (see table VII(g)), in.
PM	leakage permeance from rotor to stator, lines/A-turn
PML	leakage flux from rotor to stator (see fig. 3), kiloline
PMLA	leakage flux from rotor to stator (dummy variable), kiloline
PMLL	leakage flux at load point G, kiloline
PP	pole face losses at load point G, W
PR	field losses at load point G, W
PS	armature conductor copper losses at load point G, W
PT	number of field turns
PX	number of poles
PZ	alternator losses at load point G, percent
QAGAT	airgap ampere-turns at voltage QPERV, A-turn
QCAT	core ampere-turns at voltage QPERV, A-turn
QCD	flux density in core at voltage QPERV, kiloline/in.^{2}
QFCUR	field currents at voltage QPERV, A
QN	slots per pole per phase
QPAT	pole ampere-turns at voltage QPERV, A-turn

QPD	flux density in pole at voltage QPERV, kiloline/in.^{2}
QPERV	voltage at which no-load saturation data are calculated, percent
QQ	number of slots
QSAT	shaft ampere-turns at voltage QPERV, A-turn
QSD	flux density in shaft at voltage QPERV, kiloline/in.^{2}
QTAT	total ampere-turns at voltage QPERV, A-turn
QTHAT	tooth ampere-turns at voltage QPERV, A-turn
QTHD	flux density in tooth at voltage QPERV, kiloline/in.^{2}
QVLL	line-to-line voltage at which no-load saturation data are calculated, rms V
QVLN	line-to-neutral voltage at which no-load saturation data are calculated, rms V
QYAT	yoke ampere-turns at voltage QPERV, A-turn
QYD	flux density in yoke (over field coil) at voltage QPERV, kiloline/in.^{2}
R	alternator voltage at which no-load saturation data are calculated, per unit
RATING	NAMELIST name
RC	field coil weight, lb
RD	field conductor diameter or width, in.
RE	damper bar resistivity at 20° C, (μohm)(in.)
RF	type of armature winding (random or form wound)
RG1	armature winding resistance at temperature TST, ohm
RK	pole body stacking factor
RK1	pole head stacking factor
RM	damper bar resistivity at temperature T3 and T33, (μohm)(in.)
ROTOR	NAMELIST name
RPM	rotor rotational speed, rpm
RR	field coil resistivity at 20° C, (μohm)(in.)
RRA	armature winding resistance at load point G, ohm
RRB	field winding resistance at load point G, ohm
RS	armature conductor resistivity at 20° C, (μohm)(in.)
RT	field conductor thickness, in.

S	armature conductor current density at rated load, A/in.^{2}
SB	damper bar length, in.
SC	number of conductors per stator slot
SCR	short circuit ratio
SD	distance between centerline of armature winding strands (in depth) (see table VII(d)), in.
SF	stacking factor (stator)
SH	uninsulated armature winding strand height, in.
SHAFT	NAMELIST name
SI	field self-inductance, H
SIGMA	specific tangential force on rotor, psi
SK	stator slot skew at stator inside diameter (for one stack), in.
SLOTS	NAMELIST name
SM	tooth width at 1/3 distance from narrowest section, in.
SN	strands per armature conductor in depth
SN1	total strands per armature conductor
SP	total losses at load point G, W
SS	solid stator stack length (one stack), in.
ST	stator tooth losses at load point G, W
STAR	used in subroutine OUTPUT to print yoke diagram
STATET	number of effective armature winding turns
STATOR	NAMELIST name
STFK	stacking factor for lamination thickness LT
STRAY	miscellaneous load losses at load point G, W
T1	rated-load armature temperature, $^{\circ}$C
T11	no-load armature winding temperature, $^{\circ}$C
T2	rated-load field winding temperature, $^{\circ}$C
T22	no-load field winding temperature, $^{\circ}$C
T3	hot damper bar temperature, $^{\circ}$C
T33	cold damper bar temperature, $^{\circ}$C

TB	damper bar pitch, in.
TC	open-circuit time constant (field only), sec
TF	field coil temperature at which FK1 is calculated, °C
TG	total useful flux, kiloline
THETA	angle used in rotor weight calculations, rad
TP	pole pitch, in.
TS	stator slot pitch at stator inside diameter, in.
TST	armature winding temperature at which RG1 is calculated, °C
TT	stator slot pitch at 1/3 distance from narrow section, in.
TTA	armature winding temperature at load point G, °C
TTB	field winding temperature at load point G, °C
TY	yoke dimension (see table VII(j)), in.
TYE	yoke dimension (see table VII(j)), in.
TYPY	type of yoke (see table VII(j)), in.
SINDUC	subroutine name
TYR	yoke dimension (see table VII(j)), in.
UA	=G(M), per unit
VA	kilovolt-ampere rating of alternator, kVA
VR	rotor peripheral velocity, ft/min
WA	generator output power at load point G, kW
WC	stator conductor weight, lb
WD	no-load damper loss at temperature T3, W
WF	windage loss, W
WI	stator iron weight, lb
WINDNG	NAMELIST name
WL	core loss at flux density BK, W/lb
WN	no-load pole face losses, W
WO	damper bar slot opening width, in.
WPOLE	weight of one pole, lb

WQ	no-load rated voltage core loss, W
WQL	stator core losses at load point G, W
WROTOR	rotor weight (=WSHAFT+PX*WPOLE), lb
WSHAFT	shaft weight (including portion under poles), lb
WT	no-load rated voltage tooth loss, W
WTOTAL	total electromagnetic weight, lb
WU	no-load damper loss at temperature T33, W
WYOKE	yoke weight, lb
XA	synchronous reactance (direct), percent
XB	synchronous reactance (quadrature), percent
XD	armature reaction reactance (direct), percent
XF	field leakage reactance, percent
XL	stator winding leakage reactance, percent
XQ	armature reaction reactance (quadrature), percent
XR	reactance factor
XU	transient reactance (direct axis), percent
YA	=100/G
YOKE	NAMELIST name
YY	slots spanned per coil (number of slots between coil sides + 1)
ZA	dummy variable used in slot leakage permeance calculation
ZB	dummy variable used in slot leakage permeance calculation
ZC	dummy variable used in slot leakage permeance calculation
ZD	dummy variable used in slot leakage permeance calculation
ZE	dummy variable used in slot leakage permeance calculation
ZZ	stator slot type (see table VII(c))
ZZZ	air gap reluctance over pole, A-turn/kiloline

APPENDIX C

DEFINITION OF INPUT VARIABLES FOR EACH NAMELIST NAME

This appendix defines all variables (FORTRAN symbols) that may be used as input to the homopolar inductor alternator computer program. Each variable is listed under the appropriate NAMELIST name. The NAMELIST names are arranged in the order in which the data cards must appear in the data deck. Units are given, where applicable, and each variable is classified as mandatory (M), conditional (C), or optional (O). A mandatory classification indicates that the variable must be read in. The conditional classification indicates that, for some alternator designs, the variable is required and that, for others, it may be omitted. Variables identified as optional are read in at the discretion of the user. In each case where an optional variable is omitted, an assumption regarding that variable is made internal to the program. This assumption is explained in the remarks column of the tables. The remarks column also gives other pertinent information.

TABLE VII. - DEFINITIONS OF INPUT VARIABLES

(a) NAMELIST name RATING

FORTRAN symbol	Definition	Classification (a)	Remarks
VA	Kilovolt-ampere rating of alternator, kVA	M	--
EE	Line-to-line design voltage, rms V	C	Either one must be read in, or both may be read in
EP	Line-to-neutral design voltage, rms V	C	
F	Frequency, Hz	C	Any two must be read in, or all three may be read in
RPM	Shaft rotational speed, rpm	C	
IPX	Number of poles	C	
PF	Design power factor	M	--
G	Load points at which load characteristics are calculated (see sample output, p. 25), percent or per unit	O	G is a subscripted variable (array size is 5); if not read in, program assumes values, 0, 0.75, 1.0, 1.25, and 1.50; any one or all (except 0) may be changed by reading in different values; program automatically arranges values in increasing order; any number > 9.0 is assumed to be in percent, ≤ 9.0 in per unit

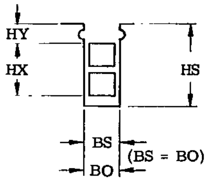
(b) NAMELIST name STATOR

FORTRAN symbol	Definition	Classification (a)	Remarks
DI	Bore diameter (i.d.), in.	M	------------------------------------
DU	Stator lamination outside diameter, in.	M	------------------------------------
CL	Length of one stator stack, in.	M	------------------------------------
HV	Number of cooling ducts	C	If there are no cooling ducts, these need not be read in
BV	Width of cooling duct, in.	C	
SF	Stacking factor (stator)	C	Either one or both may be read in, if neither is read in, program assumes that stator in not laminated (SF = 1.0)
LTS	Stator lamination thickness, in.	C	
WL	Core loss at flux density BK, W/lb	M	------------------------------------
BK	Flux density at which core loss WL is given	M	------------------------------------

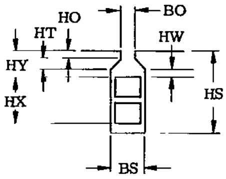
[a] M, mandatory; C, conditional; O, optional.

TABLE VII. - Continued.

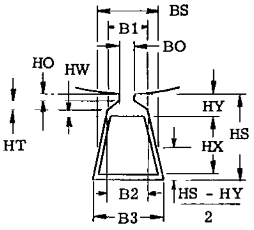
(c) NAMELIST name SLOTS



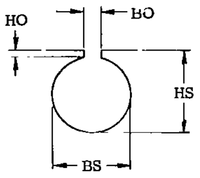
Types 1 and 5: Open slot, constant slot width. Type 5 slot is same as type 1, but it contains only one coil side.



Type 2: Partly closed slot, constant slot width.



Type 3: Partly closed slot, constant tooth width.



Type 4: Round slot.

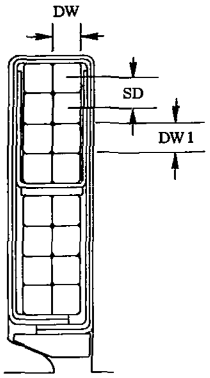
FORTRAN symbol (a)	Definition	Classification (b)	Remarks
ZZ	Slot type	M	See sketch
BO	Slot dimension, in.	C	
B3			
BS			
HO			
HX			
HY			
HS			
HT	↓	↓	↓
IQQ	Number of slots	M	----------

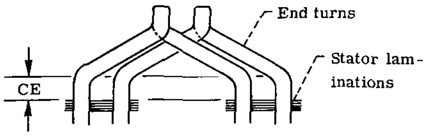
[a] Variables shown in the sketch but not defined in this table are not allowable input. These variables are shown for reference only.

[b] M, mandatory; C, conditional.

TABLE VII. - Continued.

(d) NAMELIST name WINDNG



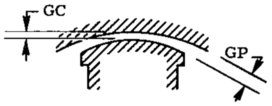


FORTRAN symbol	Definition	Classification (a)	Remarks
RF	Type of coil	M	RF = 1.0 for form wound coil; RF = 0 for random wound coil
SC	Number of conductors per slot	M	--
YY	Slots spanned per coil (number of slots between coil sides plus one)	M	--
C	Number of parallel circuits per phase	M	--
DW	Strand diameter or width, in.	M	See sketches
SN	Strands per conductor in depth (radial direction)	C	Read for rectangular wire only (in sketch, SN = 4)
SN1	Total strands per conductor	M	In sketch SN1 = 8
DW1	Uninsulated stator strand thickness (radial direction), in.	C	Read for rectangular wire only; see sketches
CE	Straight portion of coil extension, in.	M	See sketches
SD	Distance between centerline of strands in depth, in.	M	See sketches
PBA	Phase belt angle, deg	O	If not read in, program assumes PBA = 60°
SK	Stator slot skew at stator inside diameter (for one stack only), in.	O	If not read in, program assumes SK = 0
T1	Rated-load armature winding temperature, °C	M	Used for loss and efficiency calculations
RS	Armature conductor resistivity at 20° C, (μohm)(in.)	O	If not read in, program assumes copper resistivity (0.694)
ALPHAS	Armature conductor temperature coefficient of resistivity at 20° C, °C	O	If not read in, program assumes copper temperature coefficient (0.00393)
T11	No-load armature winding temperature, °C	M	Used for loss and efficiency calculations
TST	Armature winding temperature, °C	O	Program calculates and prints out armature resistance at this temperature; if not read in, program assumes TST = 25° C

[a] M, mandatory; C, conditional; O, optional.

TABLE VII. - Continued.

(e) NAMELIST name AIRGAP



FORTRAN symbol	Definition	Classification (a)	Remarks
GC	Minimum air gap (air gap at center of pole), in.	M	See sketch
GP	Maximum air gap, in.	C	Need not be read in if air gap is constant (i.e., if GP = GC); see sketch

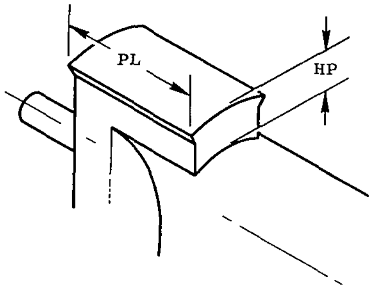
(f) NAMELIST name CONST

FORTRAN symbol	Definition	Classification (a)	Remarks
C1	Ratio of fundamental maximum to actual maximum value of field form (field form is air-gap flux density distribution due to field only)	O	Identical to those defined for conventional salient pole alternator (ref. 7); effect of leakage flux between poles in homopolar inductor alternator is accounted for separately (see section Magnetics Calculations): if not an input, values are calculated from formulas given in refs. 1 and 7
CP	Ratio of average to maximum value of field form	O	
CM	Demagnetizing factor (direct axis)	O	
CQ	Cross magnetizing factor (quadrature axis)	O	
EL	End turn length, in.	O	Read in if exact value is known; if not, program will calculate approximate value
WF	Windage losses, W	O	Read in actual value; if not read in, program neglects windage in efficiency calculations; to have program calculate approximate windage loss, set WF = 1.0

[a] M, mandatory; C, conditional; O, optional.

TABLE VII. - Continued.

(g) NAMELIST name ROTOR



FORTRAN symbol	Definition	Classification (a)	Remarks
RK	Stacking factor of pole body	C	One or both may be read in; if neither is read in program assumes that pole body is not laminated (RK = 1.0)
LTR	Lamination thickness of pole body, in.	C	
RK1	Pole head stacking factor	C	One or both may be read in; if neither is read in, program assumes solid pole head (RK1 = 1.0)
LTR1	Pole head lamination thickness, in	C	
PL	Pole body length (axial direction), in.	C	If PL = PHL, only one (either one) need be read in; see sketch
PHL	Pole head length (axial direction), in.	C	
PE	Pole embrace	C	One must be read in; both may be read in
PHW	Pole head width, in.	C	
BP	Pole body width, in.	C	If BP = PHW, BP need not be read in
HP	Pole height (pole body + pole head), in.	M	See sketch
HP1	Effective pole height, in.	M	If air gap between poles is uniform, HP1 = HP; if not, HP1 > HP; Unless a better value is known, assume that HP1 = 1.15 HP
WROTOR	Rotor weight, lb	O	If not read in, program will calculate approximate rotor weight
D1	Pole face loss factor	O	If not read in, D1 is calculated from value of LTR1 using the following: D1 = 1.17 for LTR1 ≤ 0.045; D1 = 1.75 for $0.045 < \text{LTR1} \leq 0.094$; D1 = 3.5 for $0.094 < \text{LTR1} \leq 0.17$; D1 = 7.0 for LTR1 > 0.17; of LTR1 is not read in, program calculates value of LTR1 based on RK1

[a]M, mandatory; C, conditional; O, optional.

TABLE VII. - Continued.

(h) NAMELIST name DAMPER

FORTRAN symbol	Definition	Classification (a)	Remarks
BN	Number of damper bars per pole	M	If BN = 0, none of following variables for DAMPER need be read in
WO	Damper bar slot opening width, in.	C	------------------------------------
HD	Damper bar slot opening height, in.	C	------------------------------------
DD	Damper bar diameter, in.	C	For round damper bars only
H	Rectangular damper bar thickness, in.	C	For rectangular damper bars only
B	Rectangular damper bar slot width, in.	C	
SB	Damper bar length, in.	C	------------------------------------
TB	Damper bar pitch, in.	C	------------------------------------
T33	Cold damper bar temperature, ^{o}C	O	If this is not read 20^{o} C will be assumed
T3	Hot damper bar temperature, ^{o}C	C	------------------------------------
RE	Damper bar resistivity at 20^{o} C, (μohm)(in.)	O	0.694 Will be assumed unless otherwise read in
ALPHAE	Temperature coefficient of resistivity at 20^{o} C, $^{o}C^{-1}$	O	0.00393 Will be assumed unless otherwise read in

^{a}M, mandatory; C, conditional; O, optional.

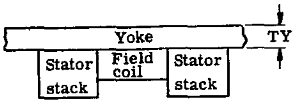
(i) NAMELIST name SHAFT

FORTRAN symbol	Definition	Classification (a)	Remarks
DSH	Shaft diameter (under field coil), in.	M	------------------------------------
DISH	Inside shaft diameter (for hollow shaft), in.	C	Read in only for hollow shaft
DISH1	External shaft diameter (external to two stator stacks), in.	M	------------------------------------
ALH	Shaft length between poles, in.	M	------------------------------------

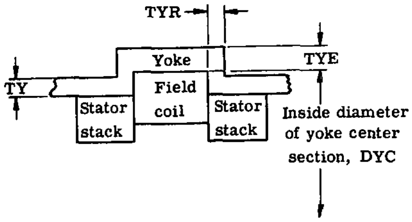
^{a}M, mandatory; C, conditional.

TABLE VII. - Continued.

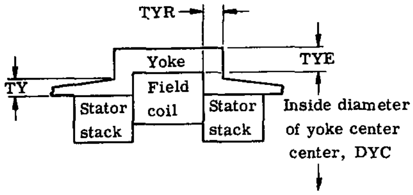
(j) NAMELIST name YOKE



Type 1.



Type 2.



Type 3: same as type 2 except that end section are tapered for constant flux density.

FORTRAN symbol	Definition	Classification (a)	Remarks
TYPY	Type of yoke	M	Three types of yokes are allowable; see sketches
TY	Yoke dimensions, in. (see sketches)	M	
TYE		C	Needed for types 2 and 3 yokes only.
TYR		C	
DYC		C	

[a] M, mandatory; C, conditional.

TABLE VII. - Concluded.

(k) NAMELIST name FIELD

FORTRAN symbol	Definition	Classification (a)	Remarks
PCOIL	Field coil inside diameter, in.	M	------------------------------------
DCOIL	Field coil outside diameter, in.	M	------------------------------------
PT	Number of field turns	M	------------------------------------
RD	Field conductor diameter or width, in.	M	------------------------------------
RT	Field conductor thickness, in.	C	Do not read in for round conductors
BCOIL	Field coil width, in.	C	Do not read in if BCOIL = ALH (see table VII(i)
T2	Rated-load field temperature, $^{\circ}C$	M	Used in loss and efficiency calculations
T22	No-load field temperature, $^{\circ}C$	M	
RR	Field-coil resistivity at 20° C, (μohm)(in.)	O	If not read in, 0.694 is assumed
ALPHAR	Temperature coefficient of resistivity at 20° C, $^{\circ}C^{-1}$	O	If not read in, 0.00393 is assumed
TF	Field-coil temperature, $^{\circ}C$	O	Program calculates and prints out field-coil resistance at this temperature; if not read in, program assumes TF = 25° C

[a] M, mandatory; C, conditional; O, optional.

REFERENCES

1. Ellis, J. N.; and Collins, F. A.: Brushless Rotating Electrical Generators for Space Auxiliary Power Systems. Vols. 1-5. Lear Siegler, Inc. (NASA CR-54320), Apr. 26, 1965.
2. Dryer, A. M.; Kirkpatrick, F. M.; Russel, E. F.; Wimsatt, J. M.; and Yeager, L. J.: Alternator and Voltage Regulator - Exciter Design and Development. Vol. I. General Electric Co., June 9, 1967.
3. Edkin, Richard A.; Valgora, Martin E.; and Perz, Dennis A.: Performance Characteristics of 15 kVA Homopolar Inductor Alternator for 400 Hz Brayton-Cycle Space-Power System. NASA TN D-4698, 1968.
4. Osborn, G. A.; Wimsatt, J. M.; Whipple, E. R.; Balke, R. L.; and Luddy, C. T.: Alternator Design and Development for the SNAP-8 Electrical Generating System. Rep. 30-12-15-65, General Electric Co., Dec. 15, 1965.
5. Repas, David S.; and Valgora, Martin E.: Voltage Distortion Effects of SNAP-8 Alternator Speed Controller and Alternator Performance Results. NASA TN D-4037, 1967.
6. Kuhlmann, John H.: Design of Electrical Apparatus. Third ed., John Wiley & Sons, Inc., 1950.
7. Kilgore, L. A.: Calculation of Synchronous Machine Constants - Reactances and Time Constants Affecting Transient Characteristics. AIEE Trans., vol. 50, 1931, pp. 1201-1214.
8. Gilman, R. E.: Eddy Current Losses in Armature Conductors. AIEE Trans., vol. 39, Pt. I, 1920, pp. 997-1047.
9. Spooner, T.; and Kinnard, I. F.: Surface Iron Losses with Reference to Laminated Materials. AIEE Trans., vol. 43, 1924, pp. 262-281.
10. Pollard, E. I.: Load Losses in Salient Pole Synchronous Machines. AIEE Trans., vol. 54, 1935, pp. 1332-1340.
11. Pollard, E. I.: Calculation of No-Load Damper Winding Losses in Synchronous Machines. AIEE Trans., vol. 51, 1932, pp. 477-481.
12. Vrancik, James E.: Prediction of Windage Power Loss in Alternators. NASA TN D-1686, 1968.
13. Barnes, E. C.: An Experimental Study of Machine End-Turn Leakage Reactances. AIEE Trans., Vol. 70, Pt. I, 1951, pp. 671-679.
14. Anon.: Test Procedures for Synchronous Machines. IEEE No. 115, Mar. 1965.

NASA-Langley, 1969 —— 3 E-4660

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
WASHINGTON, D. C. 20546

OFFICIAL BUSINESS

FIRST CLASS MAIL

POSTAGE AND FEES PAID
NATIONAL AERONAUTICS AND
SPACE ADMINISTRATION

POSTMASTER: If Undeliverable (Section 158 Postal Manual) Do Not Return

> *"The aeronautical and space activities of the United States shall be conducted so as to contribute . . . to the expansion of human knowledge of phenomena in the atmosphere and space. The Administration shall provide for the widest practicable and appropriate dissemination of information concerning its activities and the results thereof."*
>
> —NATIONAL AERONAUTICS AND SPACE ACT OF 1958

NASA SCIENTIFIC AND TECHNICAL PUBLICATIONS

TECHNICAL REPORTS: Scientific and technical information considered important, complete, and a lasting contribution to existing knowledge.

TECHNICAL NOTES: Information less broad in scope but nevertheless of importance as a contribution to existing knowledge.

TECHNICAL MEMORANDUMS: Information receiving limited distribution because of preliminary data, security classification, or other reasons.

CONTRACTOR REPORTS: Scientific and technical information generated under a NASA contract or grant and considered an important contribution to existing knowledge.

TECHNICAL TRANSLATIONS: Information published in a foreign language considered to merit NASA distribution in English.

SPECIAL PUBLICATIONS: Information derived from or of value to NASA activities. Publications include conference proceedings, monographs, data compilations, handbooks, sourcebooks, and special bibliographies.

TECHNOLOGY UTILIZATION PUBLICATIONS: Information on technology used by NASA that may be of particular interest in commercial and other non-aerospace applications. Publications include Tech Briefs, Technology Utilization Reports and Notes, and Technology Surveys.

Details on the availability of these publications may be obtained from:

SCIENTIFIC AND TECHNICAL INFORMATION DIVISION
NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
Washington, D.C. 20546