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DIGITAL-COMPUTER PROGRAM FOR DESIGN-ANALYSIS OF SALIENT, WOUND POLE ALTERNATORS

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16. Abstract

A digital computer program for analyzing the electromagnetic design of salient, wound pole alternators is presented. The program, which is written in FORTRAN IV, calculates the open-circuit saturation curve, the field-current requirements at rated voltage for various loads and losses, efficiency, reactances, time constants, and weights. The methods used to calculate some of these items are presented or appropriate references are cited. Instructions for using the program and typical program input and output for an alternator design are given, and an alphabetical list of most FORTRAN symbols and the complete program listing with flow charts are included.

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SUMMARY

A digital computer program for analyzing the electromagnetic design of salient, wound pole alternators is presented. The program, which is written in the FORTRAN IV programming language, calculates the open-circuit saturation curve, the field-current requirements at rated voltage for various loads and losses, efficiency, reactances, time constants, and weights. The methods used to calculate some of these items are presented or appropriate references are cited.

The program is useful for parametric studies and alternator design optimization. Instructions for using the program and typical program input and output for an alternator design are given in the appendixes. Also included are an alphabetical list of FORTRAN symbols and the complete program listing with flow charts.

INTRODUCTION

Dynamic energy conversion systems developed at the NASA Lewis Research Center for use in space have used solid rotor, brushless alternators. As a result, computer programs for analyzing the homopolar inductor and the outside-coil Lundell alternators were developed. These programs are described in references 1 and 2.

In recent months, researchers at Lewis have been studying the concept of an integrated engine generator for aircraft secondary power systems (ref. 3). For this application a salient, wound pole alternator was considered. The salient, wound pole alternator is inherently much lighter in weight than a solid-rotor alternator and usually has lower reactances resulting in better voltage regulation and transient performance.

Because of these considerations, it became necessary to develop a salient, wound pole computer program similar to the solid-rotor alternator programs. The fastest and easiest way to develop such a program was to modify the existing Lundell program. In addition, the material presented in reference 4 was used extensively, particularly in calculating reactances and time constants.

Most of the necessary modifications arise directly from the differences in the magnetic circuits of the salient, wound pole and Lundell alternators. Also the effect of rotor damper bars on alternator performance was included in the salient, wound pole program. While the resultant salient, wound pole alternator program differs from the Lundell computer program, there still remain many similarities. Both programs are written in FORTRAN IV programming language, most of the FORTRAN symbols used are the same, and the input requirements and output formats are similar.

This report describes the program in detail and gives some of the methods of calculation. Instructions for using the program, typical input and output, the program listing and flow charts, and a FORTRAN symbol list are included in the appendixes.

COMPUTER PROGRAM DESCRIPTION

General Description

The salient, wound pole alternator computer program is an analysis program. This means that the program accepts as input a complete electromagnetic alternator design; from this, it calculates the open-circuit saturation curve, the field-current requirements at rated voltage for various loads and losses, efficiency, several reactances and time constants, 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. An explanation of how to use the program, including a list of input variables with definitions, is given in appendix A. A typical program output is shown in appendix B.

The program is written in FORTRAN IV and requires approximately 14 200 storage locations for execution. At Lewis, the program has been used on the IBM 7044-7094 Mod II direct-couple system using a FORTRAN IV version 13 compiler. For this system typical pre-execution time is 1. 10 minutes and typical execution time is 0. 04 minute per alternator design.

Figure 1 shows a simplified flow chart of the complete program. As can be seen, the program consists of a main program SALENT and four subrountines SUBSAL, OUTPUT, MAGNET, and WINDGE. The subroutines are necessary, in part, because one program is too large to compile with the available core storage locations. FORTRAN listings and detailed flow charts are given in appendix C.

Communication between the main program and its subroutines is by means of COMMON except for subroutine WINDGE which uses an argument list.

Description of Alternator to Which Program is Applicable

The basic alternator for which the program was written is the salient, wound pole alternator. A cross-sectional view of this type of alternator showing the main flux path is given in figure 2. For clarity, a four-pole alternator is shown. In addition to the main flux, leakage fluxes between the rotor poles are present.

The main flux flows from a rotor north pole, across the air gap and then radially through the stator teeth into the stator back-iron or core. It then goes circumferentially through the stator core for a distance of one pole pitch, enters the teeth and continues radially across the air gap into a rotor south pole. From there the flux goes radially through the south pole, circumferentially through the rotor back-iron or core and then completes its path radially through a north pole.

A number of assumptions, in addition to those implicit in the geometric configuration, are made regarding the alternator:

(1) Rotor poles and core are made of the same material.

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

(3) The field coil cross-section is rectangular in shape.

(4) There is one field coil per pole.

(5) The eddy current loss in round conductors is assumed to be zero.

(6) The only leakage flux paths are between the rotor north and south poles.

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

(1) Armature conductors may be round or rectangular.

(2) Field conductors may be round or rectangular.

(3) Armature conductors may be stranded.

(4) Rotor and stator need not be made of the same magnetic material.

(5) Damper windings may or may not be present. If there is no damper winding, the rotor pole face is assumed to be smooth, that is, without slots.

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

(7) Five different stator slot configurations may be used.

METHOD OF CALCULATION

This section of the report outlines in general terms the method of calculation used in the computer program. However, because of the length of the program and the large number of equations involved, specific equations will not, except in a few instances, be given. These equations can be found in volume 2 of reference 4. In addition, detailed information and equations may be found in the program listings and flow charts in appendix C. To assist in locating information in the listing COMMENT, cards are used to identify the major calculations. Of further value is appendix D which is a FORTRAN symbol list.

Many variables, both in the report and in the computer program, are expressed in the per unit system. Per unit quantities are defined as follows:

1 per unit voltage = rated voltage

1 per unit current = rated current

1 per unit volt-amperes = rated volt-amperes

1 per unit impedance = (line-to-neutral rated voltage)/(rated current)

Some variables are given in percent; these are per unit values multiplied by 100. Equations given throughout this report will use the same FORTRAN symbols used in the program and as defined in appendix D. Where a FORTRAN symbol does not exist, an ordinary algebraic symbol will be used.

Leakage Permeance Calculations

The rotor leakage flux has a pronounced effect on the saturation curves and, to a lesser degree, on alternator efficiency and weight. Because the leakage paths (fig. 3) are through air (or some other gas exhibiting linear magnetic properties), they can be characterized by a permeance value. The permeance of a leakage path is defined as the ratio of flux through the path to the ampere-turn drop across the path.

As indicated in figure 3, four rotor leakage permeances are considered in the program. These are

(1) P1 - permeance between the inner pole head surfaces

(2) P2 - permeance between the pole head end surfaces

(3) P3 - permeance between the inner pole body surfaces

(4) P4 - permeance between the pole body end surfaces.

These permeances are calculated using the equations presented in reference 5 (pp. 73 to 75 and 273 and 274).

Magnetic Calculations

The purpose of the magnetic calculations is to compute the flux densities throughout the alternator, the ampere-turn drop across the various parts of the magnetic circuit, and the total field excitation. In the program the computations are divided into three categories:

(1) No-load rated-voltage magnetization characteristics

(2) Alternator load characteristics - This category comprises magnetic calculations at rated voltage for several loads at a fixed power factor. These calculations may then be repeated for up to five different power factors.

(3) No-load saturation data - This category gives up to 10 points on the open-circuit saturation curve starting at voltage VMIN.

The magnetic calculations are carried out, for the most part, in subroutine MAGNET, which is called by the main program SALENT as required (see fig. 1). However, before calling MAGNET for the first time, all areas and lengths needed by MAGNET are calculated in SALENT.

Just before each transfer to the subroutine, three additional quantities needed by MAGNET are calculated in SALENT. These quantities are the useful flux per pole in the air gap (PPL), the ampere-turn drop in the air gap (FGL1), and the demagnetizing ampere-turns due to armature current (FGXL). The quantities PPL, FGL1, and FGXL are functions of voltage, load, and load power factor.

At no load, PPL and FGL1 are proportional to the output voltage and, since the armature current is zero, the demagnetizing ampere-turns FGXL are zero. Expressed in equation form:

$$\mathrm{PPL} = (\mathrm{EDD})(\mathrm{FQ})$$

$$\mathrm{FGL1} = (\mathrm{EDD})(\mathrm{FH})$$

$$\mathrm{FGXL} = 0$$

where FQ is the useful flux per pole at no-load rated voltage (calculated in SALENT), FH is the air-gap ampere-turn drop per pole at no-load rated voltage (calculated in SALENT), and EDD is the constant of proportionality, here, equal to per unit alternator output voltage.

Under load (at rated voltage), the calculation of PPL, FGL1, and FGXL requires reference to the alternator phasor diagram shown in figure 4 (ref. 6, p. 238). Construction of the diagram starts with the terminal voltage and armature current phasors which, along with the angle between them, are determined by the particular load for which PPL, FGL1, and FGXL are to be calculated. The phasors representing resistance and reactance drops are then added to the diagram using values of armature resistance and synchronous reactance values previously calculated in SALENT. This locates the quadrature axis.

The angle between the quadrature axis and the current phasor is of interest for calculating FGXL. This angle, labeled XI and called the internal power factor angle, can be calculated from the geometry of the phasor diagram. The length $\overline{\mathrm{OP}}$ is also determined from the phasor diagram. The length $\overline{OP}$ is the quadrature axis air-gap voltage modified to account for flux wave form distortion under load (fig. 4). The quantities PPL, FGL1, and FGXL can now be determined from the following equations:

$$FGXL = FGML \cdot G \cdot \sin(XI)$$

For power factors <0.95

$$PPL = FQ \cdot (\text{length of } \overline{OP})$$

$$FGL1 = FH \cdot (\text{length of } \overline{OP})$$

for power factors >0.95

$$PPL = FQ \cdot (\text{length of } \overline{OP}) \cdot 1.10$$

$$FGL1 = FH \cdot (\text{length of } \overline{OP}) \cdot 1.10$$

where FGML is the demagnetizing ampere-turns at rated load and G is the volt-ampere output of the alternator (in per unit). The PPL, FGL1, and FGXL calculations are summarized in table I.

With PPL, FGL1, and FGXL known, the calculations are turned over to subroutine MAGNET. The approach taken in MAGNET is to represent the actual magnetic circuit of the alternator by an equivalent electrical circuit having lumped resistive elements. The resistors representing air gaps or leakage flux paths are assumed linear. Those that represent a part of the flux path through iron must be considered nonlinear. The equivalent circuit over one pole pitch for the salient, wound pole alternator is given in figure 5.

From the useful flux per pole (PPL) the flux densities and ampere-turn drops for the stator teeth (FTL) and stator core (FCL) are determined. These ampere-turn drops, together with the ampere-turn drop in the air-gap (FGL1) and the demagnetizing ampere-turns (FGXL), are used to determine the rotor leakage flux (PPRL). With the magnetomotive force (mmf) acting on each leakage flux path known, the leakage flux can be calculated from

$$\text{Leakage flux} = \text{mmf} \cdot \text{permeance}$$

The mmf across paths 1 and 2 (fig. 3) is

$$2 \cdot (FGL1 + FGXL + FTL + FCL) = 2 \cdot \text{mmf}_{tot}$$

For paths 3 and 4, the mmf is $2 \cdot \text{mmf}_{tot}$ at the pole head and zero at the pole base, the average value being equal to mmf_{tot}. The rotor leakage flux is added to the useful flux to obtain total flux. The total flux is used to compute the flux densities and ampere-turn drops for the rotor pole and rotor core. This completes the equivalent circuit analysis.

Efficiency and Loss Calculations

Individual losses and efficiency are calculated at rated voltage for 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, 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 the volt-ampere alternator output expressed in per unit or percent).

These calculations are first carried out for rated power factor. They are then repeated up to four times for any other power factor specified in the program input. The individual losses that are calculated by the program, along with the method of calculation or references, are presented in the following sections.

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

(1) The average no-load temperature is known or can be estimated.

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

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

The assumed variation in the armature winding temperature as a function of current is illustrated in figure 6(a). A similar curve for the field winding is shown in figure 6(b).

Armature conductor eddy loss (EX). - References 4 and 7 present a discussion of armature conductor eddy losses. In the program these losses are assumed to be zero for round conductors because round conductors are usually small. For rectangular conductors they are given by

$$EX = (EZ - 1)(PS)\frac{CL}{HM}$$

where EZ is the eddy factor, which is a function of conductor geometry, armature winding parameters, frequency, and armature conductor resistivity; PS is the armature conductor loss; CL is the length of armature conductor within the stator slot; and HM is the total armature conductor length.

Pole face losses (WN and PP). - The no-load pole-face loss (WN) (see refs. 4 and 8) is calculated from the equation

$$WN = (GA)(D1)(D2)(D3)(D4)(D5)(D6)$$

where GA is the main air gap area and D1 to D6 are empirical factors that are functions of, respectively, pole-face lamination thickness, air-gap flux density, slot frequency, slot pitch, slot opening to air-gap ratio, and pole embrace. As given in reference 4 the empirical curve that defines the factor D3 is limited to a maximum slot frequency of 5800 hertz. In the program, for all slot frequencies greater than 5800 hertz, values of D3 are obtained by extrapolation.

Under load (ref. 9, eq. (22)) the pole face loss (PP) is given by

$$PP = (GM)(WN) \qquad GM \geq 1$$

where GM is the function of alternator current, ratio of slot opening to air gap, number of conductors per slot, number of parallel circuits, and air-gap ampere-turns at no-load and rated voltage.

Damper losses (WW and DL). - The no-load damper bar loss (WW) is calculated as shown in reference 10 using the cold damper-bar temperature (T33). Under load (ref. 9, eq. (22)) the damper bar loss (DL) is given by

$$DL = (GM)(WW) \qquad GM \geq 1$$

For this calculation, the hot damper bar temperature (T3) is used regardless of the magnitude of the load.

Stator core loss (WQL and WQ) and stator tooth loss (ST and WT). - The respective equations used to calculate these losses are

$$\text{stator core loss} = 3(\text{stator core weight})(WL)\left(\frac{\text{stator tooth flux density}}{BK}\right)^2$$

$$\text{stator tooth loss} = 3(\text{stator tooth weight})(WL)\left(\frac{\text{stator tooth flux density}}{BK}\right)^2$$

where WL is the core loss at flux density BK and at rated alternator frequency and

BK is the flux density at which WL is measured. Both WL and BK are obtained from the data provided by the material manufacturer.

Miscellaneous load loss (WMIS). - In an alternator there are generally additional electromagnetic losses not accounted for by the losses enumerated so far. These losses, labeled miscellaneous load loss, are assumed to be 1 percent of the kilovolt-ampere output of the alternator at load point G.

Windage loss (WND). - The program user may elect to have the program calculate an approximate value of windage loss for the main air gap only. Disk losses due to the rotor ends are not included. The method used is derived from the results presented in references 11 and 12. The windage loss, assuming that the alternator rotor is cylindrical, is calculated first. In most cases this assumption is valid. The rotors of many aircraft salient-pole alternators are made nearly cylindrical by inserting metal pieces or coil wedges between the poles at the rotor outside diameter. To account for the effect of stator slots and the nonsmoothness of the rotor, the windage loss value is multiplied by 1.5. In calculating the windage loss, the user has the option of assuming either constant or variable pressure in the air gap cavity as a function of load.

Efficiency (E). - At each load efficiency is calculated from

$$\text{efficiency} = \frac{\text{alternator power output} \times 100}{(\text{alternator power output}) + (\text{losses})}$$

Reactances and Time Constants

In the program the following reactances are calculated:

(1) Armature winding leakage (XL)
(2) Direct-axis armature reaction (XD)
(3) Quadrature-axis armature reaction (XQ)
(4) Direct-axis synchronous (XA)
(5) Quadrature-axis synchronous (XB)
(6) Direct-axis transient (XU)
(7) Direct-axis subtransient (XX)
(8) Quadrature-axis subtransient (XY)
(9) Negative sequence (XN)
(10) Field leakage (XF)
(11) Direct-axis damper bar leakage (XDD)
(12) Quadrature-axis damper bar leakage (XDQ).

Also, the following time constants are determined:

(1) Open-circuit time constant (field only) (TC)
(2) Armature time constant (TA)

(3) Transient time constant (TTC).

The equations used to calculate both the reactances and time constants are given in reference 4. The majority of these equations were derived from the theory presented in reference 13.

CONCLUDING REMARKS

This report describes a digital computer program for the analysis of salient, wound pole alternators. The program accepts as input a complete electromagnetic design; from this, it calculates the open-circuit saturation curve, field-current requirements at rated voltage for various loads, losses, and efficiencies, several reactances and time constants, and weights of electromagnetic components.

The program is based on previous programs written for the Lundell and homopolar inductor alternators. Many of the calculation procedures used in this program are based on techniques developed for these two alternators. However, the method used in magnetic calculations for the salient, wound pole alternator had to be derived especially for this machine. This method, including leakage flux calculations, is described in detail in the report.

Lewis Research Center,
National Aeronautics and Space Administration,
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APPENDIX A

HOW TO USE COMPUTER PROGRAM

Input Data Requirements

To use this computer program for the analysis of salient, wound-pole alternators, 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 and rotor. The design information must then be transferred to data cards for use with the program. A typical set of data cards is shown in figure 7. It consists of two material decks followed by any number of alternator design decks. The material decks must be in the order shown in the figure, that is, stator material and rotor material. There must be exactly two material decks in each data deck even if both materials are identical. The last two cards of the alternator design deck (the air gap gas name and $WIND) are needed only if windage loss is to be calculated by the program.

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 two material decks will be assumed to apply to each alternator design deck.

Preparation of Material Decks

A material deck consists of five cards. The first card contains the material name. This serve 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 the coordinate values of 14 arbitrary data points located on the magnetization curve of the material specified on the first card.

During program execution, the original magnetization curve is approximately reconstructed by interpolation between points. The interpolation assumes a straight line on semilog paper between data points.

Table II lists those variables associated with the two material decks. It also states the FORMAT used on each card and gives a brief description of the data appearing on each data card.

To illustrate preparation of a material deck, SAE 4340 steel will be used as an example. The first card of this material deck will appear as shown in figure 8. 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 SAE 4340 steel is shown in figure 9. 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 off the graph. 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 allowable flux density for the material (B_{max}). During program execution, if a flux density exceeds B_{max}, the alternator is assumed to have saturated, and magnetic calculations will be terminated. In the example, this value is 122.5 kilolines per square inch. The maximum allowable flux density 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: 122.5, 0, 0.01, 6.45, 12, 12.9, 24, . . ., 116, 280, 122.5, 454. The complete material deck for SAE 4340 steel is shown in figure 8.

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 (except for the air-gap gas name card) 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 nine NAMELIST names. Each name is suggestive of the type of variables included in its list. Detailed information about each NAMELIST name is provided in table III, which lists all variables used with the alternator design deck. All variables belonging to the same NAMELIST name are grouped together. 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 from the program input. Variables identified as optional are read in at the discretion of the program user. In each case where an optional variable is omitted from the program input, an assumption regarding that variable is made within the program. The remarks column of the table supplies specific explanations in regard to all conditional or optional variables.

The air-gap gas name card uses an input format of 6A6, which is identical to that used for the stator and rotor material names (see table II). The gas name (FLUID) should start in column 1 and may extend up to column 36.

To further clarify the definition of some variables, figures 10 to 14 are given. These figures are referenced in table III where applicable.

Preparation of an alternator design deck will be illustrated with the construction of a typical data card for the NAMELIST name DAMPER. The data used are the same as that used to obtain the sample output presented in appendix B. Figure 15(a) gives all the pertinent design data. Figure 15(b) shows how the design data are related to the variables of NAMELIST name DAMPER 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 results, a complete data deck listing for the sample alternator design is shown in figure 16. The output that resulted from this data deck is presented in appendix B.

APPENDIX B

TYPICAL OUTPUT LISTING

The following is the output listing of the salient, wound pole computer program resulting from the input data shown in figure 16. While this output listing is typical, the output format may vary somewhat, depending for example, on the type of stator slot configuration used or on whether windage loss was computed by the program.

Note that on page 21 under "No-Load Saturation Data," the last column contains all zeros. In general, when one or more columns contain all zeros, it indicates that the flux density calculated for some section of the magnetic circuit was greater than the maximum flux density given on the appropriate material data deck; that is, the alternator has saturated thereby causing the calculations to be terminated. When this occurs a message is printed on the affected page of the output identifying which section of the alternator saturated.

```
              *** WOUND-POLE, SALIENT-POLE ALTERNATOR ***

ALTERNATOR RATING

          ALTERNATOR KVA              200.0
          LINE-LINE VOLTAGE           294.
          LINE-NEUT. VOLTAGE          170.
          PHASE CURRENT               392.16
          POWER FACTOR                  0.75
          PHASES                        3
          FREQUENCY                   500.
          POLES                        12
          RPM                        5000.0

STATOR SLOTS

     TYPE-PARTIALLY CLOSED

          BO                        0.070  INCHES
          BS                        0.142
          HO                        0.030
          HX                        0.345
          HT                        0.055
          HW                        0.015
          HS                        0.455

          NO. OF SLOTS                180

          SLOT PITCH                0.218  INCHES

          SLOT PITCH
            AT 1/3 DIST.            0.223  INCHES
```

```
          -BO-
---------*    *----------
 HO      *    *
---------*    *
        *      *
 HT    *        *
      *          *
-----*            *
     *            *
 HW  *            *
-----*  ********  *  HS
     *  *      *  *
     *  *      *  *
     *  ********  *
 HX  *            *
     *  ********  *
     *  *      *  *
     *  *      *  *
-----*  ********  *
     *            *
     **************-----
     1            1
     1-----BS-----1
     1            1
```

AIR GAP

MINIMUM AIR GAP	0.070	INCHES
MAXIMUM AIR GAP	0.070	
EFFECTIVE AIR GAP	0.076	
CARTER COEFFICIENT		
STATOR	1.066	
ROTOR	1.013	

ARMATURE WINDING (Y-CONNECTED, FORM WOUND)

STRAND DIMENSIONS	0.1120 X 0.1500	INCHES
DISTANCE BTWN CL OF STRANDS (RADIAL)	0.1600	
STRANDS/CONDUCTOR IN RADIAL DIR.	1.	
TOTAL STRANDS/CONDUCTOR	1.	
CONDUCTOR AREA	0.0166	SQ-IN.
CURRENT DENSITY AT FULL LOAD	7879.38	AMP/SQ-IN.
COIL EXTENSION BEYOND CORE	0.250	INCHES
MEAN LENGTH OF 1/2 TURN	10.177	
END TURN LENGTH	4.977	
END TURN EXTENSION	1.702	
STATOR SLOT SKEW	0.	
RESISTIVITY AT 20 DEG. C	0.6940	MICRO OHM INCHES
STATOR RESISTANCE AT 25. DEG. C	0.0058	OHMS
NO. OF EFFECTIVE SERIES TURNS	18.20	
TOTAL EFFECTIVE CONDUCTORS	114.13	
WINDING PITCH	0.8000	
SLOTS SPANNED	12.	
SLOTS PER POLE PER PHASE	5.00	
CONDUCTORS/SLOT	2.	
NO. OF PARALLEL CIRCUITS	3.	
PHASE BELT ANGLE	60.	DEGREES
SKEW FACTOR	1.000	
DISTRIBUTION FACTOR	0.957	
PITCH FACTOR	0.951	

FIELD WINDING

CONDUCTOR DIMENSIONS	0.1900 X 0.0250	INCHES
CONDUCTOR AREA	0.0047	SQ-IN.
NO. OF TURNS (PER POLE)	44.	
MEAN LENGTH OF TURN	15.233	INCHES
RESISTIVITY AT 20 DEG. C	0.6940	MICRO OHM INCHES
FIELD RESISTANCE AT 25. DEG. C (COILS IN SERIES)	1.1982	OHMS
COIL HEIGHT	0.750	
COIL WIDTH	0.420	

CONSTANTS

C1, FUNDAMENTAL/MAX. OF FIELD FLUX	1.096
CP, POLE CONSTANT	0.697
CM, DEMAGNETIZATICN FACTOR	0.855
CQ, CROSS MAGNETIZATION FACTOR	0.458
D1, POLE FACE LOSS FACTOR	1.170

STATOR

STATOR INSIDE DIAMETER	12.50	INCHES
STATOR OUTSIDE DIAMETER	14.50	
OVERALL CORE LENGTH	5.20	
EFFECTIVE CORE LENGTH	4.99	
DEPTH BELOW SLOT	0.55	
STACKING FACTOR	0.96	
NO. OF COOLING DUCTS	0.	
WIDTH OF DUCTS	0.	INCHES
CORE LOSS AT 77.4 KILOLINES/SQ.IN.	11.8	WATTS/LB.
LAMINATION THICKNESS	0.006	IN.

ROTOR

POLE BODY	WIDTH	1.300	INCHES
	AXIAL LENGTH	5.200	
	HEIGHT	0.750	
	STACKING FACTOR	1.000	
POLE HEAD	WIDTH	2.146	INCHES
	AXIAL LENGTH	5.200	
	HEIGHT	0.480	
	STACKING FACTOR	0.900	
	LAMINATION THICKNESS	0.006	INCHES

POLE EMBRACE	0.667	
ROTOR DIAMETER	12.360	
PERIPHERAL SPEED	16192.	FEET/MIN.
SPEC. TANGENTIAL FORCE	2.077	LBS/SQ.IN.
DIAMETER OF ROTOR CORE	9.900	INCHES
INSIDE DIAMETER (OF HOLLOW SHAFT)	8.200	

DAMPER BARS (ROUND)

DAMPER BAR DIAMETER	0.100 INCHES
SLOT OPENING WIDTH	0.030
SLOT OPENING HEIGHT	0.070
DAMPER BAR LENGTH	5.200
DAMPER BAR PITCH	0.213
NO. OF DAMPER BARS/POLE	9
RESISTIVITY AT 20 DEG. C	0.694 MICRO-OHM INCHES
TEMPERATURE (HOT)	150.00 DEG.C

WEIGHTS

STATOR COND.	19.511 POUNDS
FIELD COND.	12.264
STATOR IRON	44.539
ROTOR	67.545
TOTAL (ELECTROMAGNETIC)	143.859

PERMEANCES

WINDING LEAKAGE (PER INCH OF CORE LENGTH)	
STATOR SLOT	2.998 LINES/AMPERE TURN
STATOR END	3.456
DAMPER-DIRECT (PER INCH)	5.772
DAMPER-QUADRATURE	4.575
P1 POLE HEAD INNER	16.919
P2 POLE HEAD END	3.165
P3 POLE BODY INNER	16.167
P4 POLE BODY END	2.567
EFFECTIVE POLE LEAKAGE	58.900

REACTANCES

AMPERE CONDUCTORS/INCH	1139.604
REACTANCE FACTOR	1.985
STATOR WINDING LEAKAGE	12.813 PERCENT
ARM. REACTION (DIRECT)	163.503
ARM. REACTION (QUAD.)	79.912
SYNCHRONOUS (DIRECT)	176.316
SYNCHRONOUS (QUAD.)	92.725
FIELD LEAKAGE	28.997
TRANSIENT	41.810
DAMPER LEAKAGE (DIRECT)	11.459
DAMPER LEAKAGE (QUAD.)	9.083

SUBTRANSIENT (DIRECT)	24.272
SUBTRANSIENT (QUAD.)	21.896
NEGATIVE SEQUENCE	23.084
FIELD SELF INDUCTANCE	0.130 HENRIES
OPEN CIRCUIT TIME CONSTANT (FIELD ONLY, AT 25. DEG. C)	0.10855 SECONDS
TRANSIENT TIME CONSTANT	0.02574
ARMATURE TIME CONSTANT (WINDING AT 25. DEG. C)	0.01270
SHORT CIRCUIT AMPERE-TURNS	1479.691
SHORT CIRCUIT RATIO	0.642

WINDAGE AT RATED LOAD

FLUID PROPERTIES OF AIR

VISCOSITY	1.210E-05 LBS/SEC-FT
DENSITY	0.0549 LBS/CU.FT.
PRESSURE	15.00 LBS/SQ. IN
TEMPERATURE	150.00 DEG. C
MOLECULAR WEIGHT	29.90

REYNOLDS NUMBER 7139.84

WINDAGE LOSS 150.49 WATTS

STATOR MATERIAL - VANADIUM PERMENDUR

ROTOR MATERIAL -- SAE 4340 STEEL (ROOM TEMP)

MAGNETIZATION CHARACTERISTICS (NO LOAD, RATED VOLTAGE)

TG, TOTAL USEFUL FLUX	7234.08 KILOLINES
FQ, MAIN AIR-GAP FLUX/POLE	420.44
PPRL, LEAKAGE FLUX/POLE	50.26

FLUX DENSITIES (KILOLINES/SQ IN)	
MAIN AIR GAP	35.426
STATOR CORE	77.268
STATOR TEETH	103.345
ROTOR - POLE	69.630
CORE	53.247

AMPERE-TURNS/POLE	
MAIN AIR GAP	839.225
STATOR CORE	5.819
STATOR TEETH	1.999
ROTOR - POLE	54.565
CORE	49.028
TOTAL	950.636

ALTERNATOR LOAD CHARACTERISTICS (RATED VOLTAGE, 0.75 POWER FACTOR)

PERCENT KVA	0.	50.	100.	150.	200.
LEAKAGE FLUX/POLE (KL)	50.26	87.46	130.56	175.69	222.08
FLUX DENSITIES (KL/SQ-IN)					
STATOR - CORE	77.27	82.95	88.91	95.99	104.07
TEETH	103.35	110.94	118.92	128.39	139.19
ROTOR - POLE	69.63	79.71	90.88	103.26	116.62
CORE	53.25	60.95	69.50	78.96	89.18
AMPERE-TURNS/POLE					
MAIN AIR GAP	839.22	900.93	965.72	1042.58	1130.31
STATOR - CORE	5.82	6.05	6.30	6.99	8.08
TEETH	2.00	2.50	3.41	5.50	14.37
ROTOR - POLE	54.57	60.01	76.33	120.86	251.99
CORE	49.03	52.41	56.49	62.80	82.30
DEMAGNETIZING	0.	568.70	1234.05	1919.85	2607.52
TOTAL AMPERE TURNS	950.64	1590.59	2342.30	3158.57	4094.58
FIELD AMPERES (PER COIL)	21.61	36.15	53.23	71.79	93.06
CURRENT DENS. (FIELD)	4548.50	7610.49	11207.20	15112.77	19591.28
FIELD VOLTS (PER COIL)	2.78	5.15	8.90	14.71	24.37
TEMPERATURES (DEG.C)					
FIELD	100.00	135.49	200.00	297.98	446.13
ARMATURE	100.00	125.00	200.00	325.00	500.00
RESISTANCES (OHMS)					
FIELD (PER COIL)	0.13	0.14	0.17	0.20	0.26
ARMATURE	0.0075	0.0080	0.0097	0.0125	0.0164
ALTERNATOR LOSSES (WATTS)					
FIELD	721.01	2232.68	5686.00	12671.38	27219.13
WINDAGE	0.	101.86	150.49	195.49	241.81
STATOR TOOTH	595.06	685.78	787.97	918.38	1079.46
STATOR CORE	1192.10	1373.84	1578.55	1839.82	2162.50
POLE FACE	114.97	133.10	187.52	278.20	405.16
DAMPER	0.02	0.03	0.05	0.05	0.07
STATOR COPPER	0.	924.89	4471.48	12955.52	30236.58
EDDY	0.	168.58	557.90	974.81	1320.08
MISC. LOAD	0.	1000.00	2000.00	3000.00	4000.00
TOTAL	2623.14	6620.74	15419.92	32833.60	66664.71
ALTERNATOR OUTPUT (KVA)	0.	100.00	200.00	300.00	400.00
ALTERNATOR OUTPUT (KW)	0.	75.00	150.00	225.00	300.00
EFFICIENCY (PER CENT)					
ELECTRO-MAGNETIC	0.	92.00	90.76	87.33	81.87
OVER-ALL	0.	91.89	90.68	87.27	81.82

ALTERNATOR LOAD CHARACTERISTICS (RATED VOLTAGE, 1.00 POWER FACTOR)

PERCENT KVA	0.	50.	100.	150.	200.
LEAKAGE FLUX/POLE (KL)	50.26	70.37	105.19	147.71	192.90
FLUX DENSITIES (KL/SQ-IN)					
STATOR - CORE	77.27	82.25	78.22	77.94	81.54
TEETH	103.35	110.01	104.61	104.25	109.06
ROTOR - POLE	69.63	76.62	78.52	84.59	94.17
CORE	53.25	58.59	60.04	64.68	72.01
AMPERE-TURNS/POLE					
MAIN AIR GAP	839.22	893.37	849.53	846.54	885.59
STATOR - CORE	5.82	6.02	5.86	5.85	5.99
TEETH	2.00	2.42	2.07	2.05	2.35
ROTOR - POLE	54.57	57.87	58.94	64.39	84.36
CORE	49.03	51.53	52.07	53.85	57.91
DEMAGNETIZING	0.	286.40	921.84	1646.58	2373.94
TOTAL AMPERE TURNS	950.64	1297.60	1890.30	2619.26	3410.14
FIELD AMPERES (PER COIL)	21.61	29.49	42.96	59.53	77.50
CURRENT DENS. (FIELD)	4548.50	6208.62	9044.51	12532.32	16316.45
FIELD VOLTS (PER COIL)	2.78	3.99	6.49	10.64	16.96
TEMPERATURES (DEG.C)					
FIELD	100.00	117.02	158.25	229.98	334.04
ARMATURE	100.00	125.00	200.00	325.00	500.00
RESISTANCES (OHMS)					
FIELD (PER COIL)	0.13	0.14	0.15	0.18	0.22
ARMATURE	0.0075	0.0080	0.0097	0.0125	0.0164
ALTERNATOR LOSSES (WATTS)					
FIELD	721.01	1411.74	3347.40	7600.83	15770.54
WINDAGE	0.	101.86	150.49	195.49	241.81
STATOR TOOTH	595.06	674.32	609.76	605.49	662.64
STATOR CORE	1192.10	1350.89	1221.55	1212.99	1327.48
POLE FACE	114.97	133.10	187.52	278.20	405.16
DAMPER	0.02	0.02	0.03	0.05	0.07
STATOR COPPER	0.	924.89	4471.48	12955.52	30236.58
EDDY	0.	168.58	557.90	974.81	1320.08
MISC. LOAD	0.	1000.00	2000.00	3000.00	4000.00
TOTAL	2623.14	5765.38	12546.11	26823.32	53964.28
ALTERNATOR OUTPUT (KVA)	0.	100.00	200.00	300.00	400.00
ALTERNATOR OUTPUT (KW)	0.	100.00	200.00	300.00	400.00
EFFICIENCY (PER CENT)					
ELECTRO-MAGNETIC	0.	94.64	94.16	91.85	88.16
OVER-ALL	0.	94.55	94.10	91.79	88.11

NO-LOAD SATURATION DATA

VOLTAGE										
PERCENT	70.00	85.00	100.00	115.00	130.00	145.00	147.00	149.00	0.	0.
LINE-NEUTRAL	119.00	144.50	170.00	195.50	221.00	246.50	249.90	253.30	0.	0.
LINE-LINE	206.11	250.28	294.45	338.62	382.78	426.95	432.84	438.73	0.	0.
FIELD CURRENT	15.50	18.54	21.61	24.72	28.17	38.09	44.23	55.46	0.	0.
FLUX PER POLE	294.31	357.37	420.44	483.50	546.57	609.64	618.04	626.45	0.	0.
LEAKAGE FLUX	35.30	42.77	50.26	57.81	65.63	88.30	102.76	128.81	0.	0.
FLUX DENSITIES										
STATOR										
CORE	54.09	65.68	77.27	88.86	100.45	112.04	113.58	115.13	0.	0.
TEETH	72.34	87.84	103.35	118.85	134.35	149.85	151.92	153.98	0.	0.
ROTOR										
POLE	48.76	59.19	69.63	80.08	90.56	103.24	106.63	111.73	0.	0.
CORE	37.29	45.27	53.25	61.24	69.25	78.95	81.54	85.44	0.	0.
AMPERE-TURNS/POLE										
MAIN AIR-GAP	587.46	713.34	839.22	965.11	1090.99	1216.88	1233.66	1250.44	0.	0.
STATOR										
CORE	5.13	5.47	5.82	6.30	7.52	10.34	10.96	11.62	0.	0.
TEETH	1.43	1.58	2.00	3.40	8.44	263.48	490.96	914.87	0.	0.
ROTOR										
POLE	45.71	50.07	54.57	60.51	76.12	122.37	145.02	190.95	0.	0.
CORE	42.07	45.42	49.03	52.51	56.35	62.79	65.73	72.37	0.	0.
TOTAL	681.80	815.87	950.64	1087.83	1239.43	1675.85	1946.33	2440.26	0.	0.

*** STATOR TOOTH IS SATURATED ***

APPENDIX C

COMPLETE FORTRAN LISTINGS AND FLOW CHARTS OF SALIENT, WOUND POLE ALTERNATOR ANALYSIS PROGRAM

The complete FORTRAN listings of the main program and the four subroutines, which together constitute the salient, wound pole alternator analysis program, are contained herein. The main program is SALENT and the four subroutines are, in the order given, SUBSAL, OUTPUT, MAGNET, and WINDGE. Each program listing, is followed by its flow chart.

```
C      MAIN PROGRAM  SALENT
C      FOR USE WITH WOUND POLE, SALIENT POLE ALTERNATORS
C
       COMMON A,AA,AB,AC,ACORE,AI,ALPHAE,ALPHAR,ALPHAS,APOLE,APOLHD,ARCOR
      1E,AS,ATOOTH,B,B1,B2,B3,BCL,BCOIL,BG,BK,BN,BO,BPL,BRC,BS,BTL,BV,C,C
      21,CC,CCR,CE,CF,CL,CM,CQ,CP,D1,DCORE,DD,DF,DI,DISH,DR,DRCORE,DSH,DU
      3,DW,DW1,EC,EE,EL,ENDEXT,EP,EW,F,FCL,FE,FFL,FGL1,FGML,FGXL,FH,FK1,F
      4PL,FQ,FRC,FS,FTL,G,GA,GC,GE,GP,H,HC,HCOIL,HD,HM,HO,HS,HT,HV,HW,HX,
      5HY,IBN,IPN,IPX,IQQ,IWF,IZZ,KSAT,LTR,LTR1,LTS,P1,P2,P3,P4,PBA,PBH,P
      6BL,PBW,PC,PDD,PDQ,PE,PEFF,PF,PFC,PHH,PHL,PHW,PI,PN,PPL,PPRL,PT,PTC
      7H,PX,QN,CQ,RC,RD,RE,RF,RG1,RK,RK1,RPM,RR,RS,RT,RY,S,SB,SC,SD,SF,SH
      8,SI,SIGMA,SK,SN,SN1,SS,STATET,T1,T11,T2,T22,T3,T33,TA,TB,TC,TF,TG,
      9TS,TST,TT,TTC,VA,VMIN,VR,WC,WI,WL,WO,WROTOR,WTOTAL,XA,XB,XD,XDD,XD
      $Q,XF,XL,XN,XQ,XR,XU,XX,XY,YY,ZG,ZZ
C
       INTEGER ZZ
C
       REAL LTS,LTR,LTR1
C
       DIMENSION FQLL(10), QPERV(10), QVLL(10), QVLN(10), FGLL1(10), BPLL
      1(10), FFLL(10), BCLL(10), BTLL(10), FPLL(10), FTLL(10), FCLL(10),
      2FI(10), BRCORL(10), FRCORL(10), PPRLL(10), FDMLL(5), TTB(5), TTA(5
      3), RRA(5), RRB(5), EZ(5), WMIS(5), CDD(5), EF(5), PR(5), ST(5), WQ
      4L(5), PP(5), PS(5), EX(5), SP(5), AKVA(5), WA(5), E1(5), E(5), DL(
      55), WND(5), AI(60), G(5), RMAT(6), SMAT(6), PFC(5), CMPNT(16)
C
C
       DATA CMPNT(1)/24H            *** ROTOR POLE/,CMPNT(5)/24H          *
      1** ROTOR CORE/,CMPNT(9)/24H          *** STATOR TOOTH/,CMPNT(13)/24H
      2          *** STATOR CORE/
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)
```

```
1     FORMAT (6A6)
2     FORMAT (8F10.1)
3     CALL SUBSAL
      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*(DI+2.*HS)/QQ)-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
      ATOOTH=QQ*SS*SM*PE/PX
      ACORE=SS*((DU-(DI+2.*HS))/2.)
      CCORE=((2.*(DI+2.*HS)+DU)/3.)*3.1416/(2.0*PX)
      APOLE=PBL*PBW*RK
      APOLHD=0.25*RK1*(PHL+PBL)*(PHW+PBW)
      ARCORE=PBL*((DSH-DISH)/2.0)*RK
      DRCORE=((2.0*DSH+DISH)/3.0)*3.14159/(2.0*PX)
C
C     INITIALIZE SUBSCRIPTED VARIABLES USED IN LOAD CHARACT. CALCS
C
      DO 9 J=1,230
9     FGLL1(J)=0.
C
C     ------------------------------------------------------------------
C     NO-LOAD, RATED VOLTAGE MAGNETIZATION CHARACTERISTICS
C     ------------------------------------------------------------------
C
      FGXL=0.
      PPL=FQ
      FGL1=FH
      CALL MAGNET
      J=1
      FPLL(J)=FPL
      FTLL(J)=FTL
      FCLL(J)=FCL
      FRCORL(J)=FRC
      FFLL(J)=FFL
      FGLL1(J)=FGL1
      FDMLL(J)=FGXL
      BPLL(J)=BPL
      BTLL(J)=BTL
      BCLL(J)=BCL
      BRCORL(J)=BRC
      PPRLL(J)=PPRL
C
C     SHORT CIRCUIT RATIO AND SHORT CIRCUIT AMPERE-TURNS CALCS
C
      FSC=XA*FH*0.01
      SCR=FFL/FSC
      WRITE (6,10) FSC,SCR
```

```
10     FORMAT (1HK,9X,27H SHCRT CIRCUIT AMPERE-TURNS,F16.3/10X,20H SHORT
      1CIRCUIT RATIO,F23.3)
C
C      WINDAGE LOSS AT RATED LOAD
C
       IF (IWF.NE.1) GO TO 11
       KWIND=1
       CALL WINDGE (G,RPM,DR,CL,KWIND,GC,M,WFTTL)
C
11     WRITE (6,12) SMAT
12     FORMAT (1H1,18H STATOR MATERIAL -,1H ,6A6)
       WRITE (6,13) RMAT
13     FORMAT (1HK,18H ROTOR MATERIAL --,1H ,6A6)
       WRITE (6,14) TG,FQ,PPRL
14     FORMAT (1HL,30H MAGNETIZATION CHARACTERISTICS,25H (NO LOAD, RATED
      1VOLTAGE)//10X,22H TG, TOTAL USEFUL FLUX,F20.2,10H KILOLINES/10X,27
      2H FQ, MAIN AIR-GAP FLUX/POLE,F15.2/10X,24H PPRL, LEAKAGE FLUX/POLE
      3,F18.2//10X,33H FLUX DENSITIES (KILOLINES/SQ IN))
       WRITE (6,15) BG,BCL,BTL,BPL,BRC
15     FORMAT (13X,13H MAIN AIR GAP,F27.3/13X,12H STATOR CORE,F28.3/13X,1
      13H STATOR TEETH,F27.3/13X,13H ROTOR - POLE,F27.3/21X5H CORE,F27.3)
       WRITE (6,16)
16     FORMAT (1HK,9X,18H AMPERE-TURNS/POLE)
       WRITE (6,15) FGL1,FCL,FTL,FPL,FRC
       WRITE (6,17) FFL
17     FORMAT (1H ,12X,6H TOTAL,F34.3///)
       IF (KSAT.EQ.10) GO TO 19
       J=4*KSAT
       I=J-3
       WRITE (6,18) (CMPNT(K),K=I,J)
18     FORMAT (1HK,20X,4A6,40H SATURATED AT NO-LOAD, RATED VOLTAGE ***)
       GO TO 3
C
C      NO-LOAD POLE-FACE LOSS CALCULATION
C
19     GT=BO/GC
       AA=1.75/(GT**1.35)+0.8
       GF=AA*PI*SC/(C*FH)
       D2=BG**2.5*0.000061
       D3=(0.0167*QQ*RPM)**1.65*1.5147E-5
       IF (TS-0.9) 20,20,21
20     D4=TS**1.285*0.81
       GO TO 24
21     IF (TS-1.5) 22,22,23
22     D4=TS**1.145*0.79
       GO TO 24
23     D4=TS**0.79*0.92
24     IF (GT-1.7) 25,25,26
25     D5=GT**2.31*0.3
       GO TO 31
26     IF (GT-3.0) 27,27,28
27     D5=GT**2.0*0.35
       GO TO 31
28     IF (GT-5.0) 29,29,30
29     D5=GT**1.4*0.676
       GO TO 31
30     D5=GT**0.965*1.38
31     D6=10.0**(0.932*C1-1.606)
       WN=D1*D2*D3*D4*D5*D6*GA
```

```
C
C     HOT AND COLD DAMPER BAR LOSS CALCULATIONS
C
      IF (BN) 32,32,33
32    WD=0.0
      WU=0.0
      GO TO 55
33    AA=WO/GE
      VT=0
      IF (AA) 34,37,34
34    IF (AA-0.65) 35,37,36
35    VT=ALOG(10.*AA)*(-0.242)+0.59
      GO TO 37
36    VT=0.327-(AA*0.266)
37    CONTINUE
      FS1=2.0*QN*PN*F
      FS2=2.0*FS1
      M=0
      RM=RE*(1.0+ALPHAE*(T33-20.))
      GO TO 39
38    RM=RE*(1.0+ALPHAE*(T3-20.))
39    BARD=DD
      IF (DD.EQ.0.) BARD=SQRT(4.0*H*B/3.1416)
      AA=(FS1/RM)**0.5*BARD*0.32
      AB=(FS2/RM)**0.5*BARD*0.32
      IF (AA-2.5) 40,40,41
40    V1=1.0-0.15*AA+0.3*AA*AA
      GO TO 42
41    V1=AA
42    IF (AB-2.5) 43,43,44
43    V2=1.0-0.15*AB+0.3*AB*AB
      GO TO 45
44    V2=AB
45    IF (H.EQ.0.) GO TO 46
      IF (H.EQ.B) GO TO 46
      VC=H/(3.0*B*V1)
      GO TO 47
46    VC=0.75/V1
47    VS=HD/WO+VT+VC
      VG=TB/GE
      Q1=1.0-(1.0/(((BO*0.5/GC)**2.0+1.0)**0.5))
      QZ=BO/TS
      Q2=1.05*SIN(QZ*2.844)
      IF (QZ-0.37) 48,48,49
48    Q3=0.46
      GO TO 50
49    Q3=0.23*SIN(10.46*QZ-2.1)+0.23
50    Q4=SIN(6.283*TB/TS-1.571)+1.0
      Q5=SIN(12.566*TB/TS-1.571)+1.0
      IF (H) 52,51,52
51    AB=0.785*DD*DD
      GO TO 53
52    AB=H*B
53    W2=PX*BN*SB*RM*1.246/(AB*1000.)
      W3=(Q2/(2.0*VS+(VG/Q4)))**2.0*V1
      W5=(Q3/(2.0*VS+(VG/Q5)))**2.0*V2
      WD=(TS*BG*Q1*CC)**2.0*W2*(W3+W5)
      M=M+1
      IF (M-1) 55,54,55
```

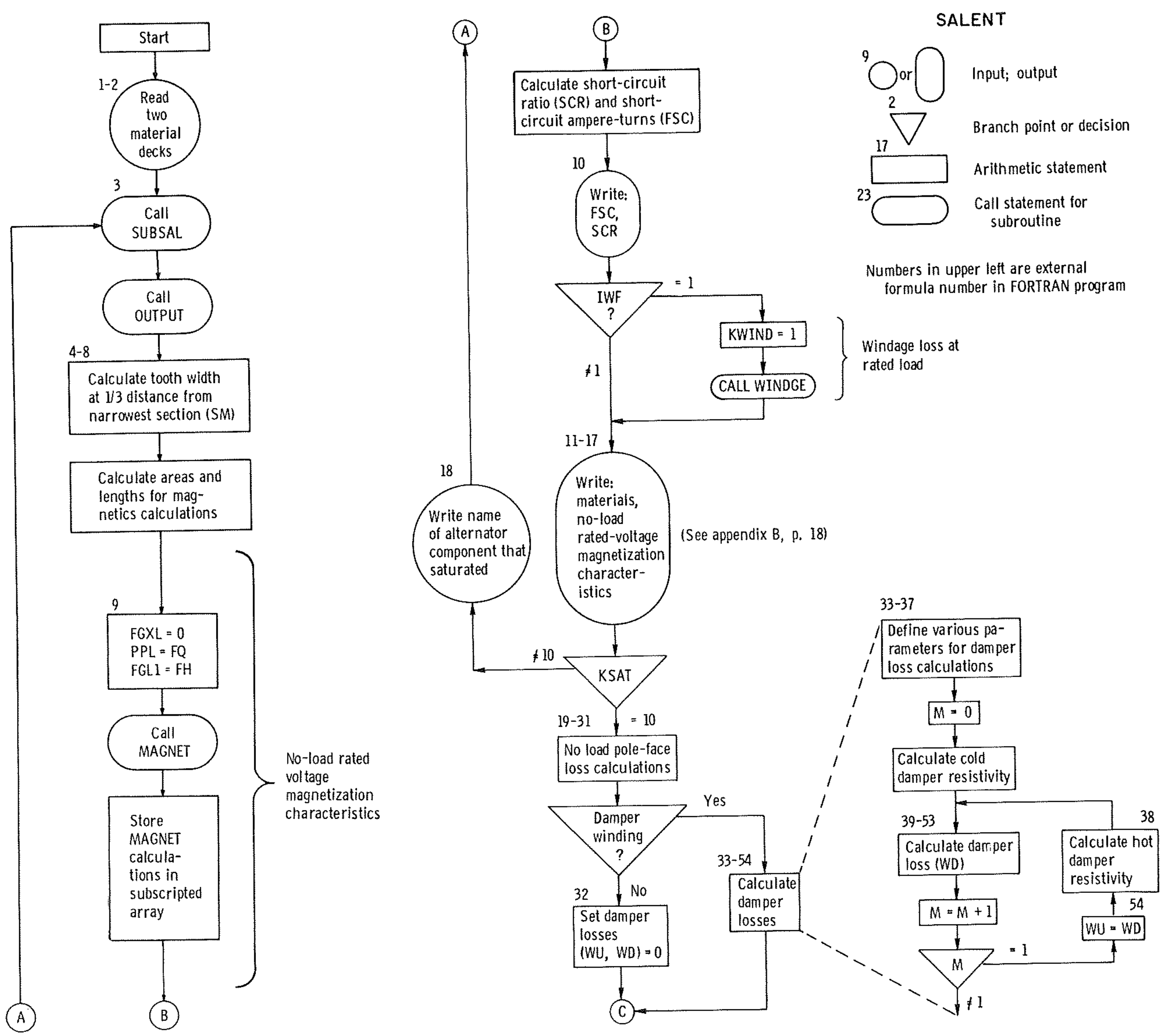
```
54    WU=WD
      GO TO 38
55    CONTINUE
C
C     CALCULATE NO-LOAD,RATED VOLTAGE TOOTH AND CORE LOSS
C
      WT=(SM)*QQ*SS*HS*0.849*(BTLL(1)/BK)**2.0*WL
      WQ=(DU-HC)*2.67*HC*SS*(BCLL(1)/BK)**2.0*WL
C
C     ARRANGING LOAD POINTS IN INCREASING ORDER
C
      DO 57 J=1,4
      IA=5-J
      DO 57 I=1,IA
      IF (G(I).GT.G(I+1)) GO TO 56
      GO TO 57
56    POL=G(I)
      G(I)=G(I+1)
      G(I+1)=POL
57    CONTINUE
      G(1)=0.
C
      MM=5
      DO 58 I=2,5
58    IF (G(I).GE.1.0.AND.G(I-1).LT.0.999) MM=I
C
C     DEFINE NPF
C
      DO 59 I=1,5
59    IF (PFC(I).LT.0.001) GO TO 60
      I=I+1
60    NPF=I-1
C
C     ------------------------------------------------------------------
C     CALCULATE ALTERNATOR LOAD CHARACTERISTICS
C     ------------------------------------------------------------------
C
      I=0
61    I=I+1
      PF=PFC(I)
      CK=1.0
      IF (PF.GE.0.95) CK=1.10
      AN=ARCOS(PF)
      EZ(1)=1.0
      K=0
      IA=10
      J=0
      JA=5
C
C     ARMATURE TEMPERATURE AND RESISTANCE CALCULATION
C
62    J=J+1
      TTA(J)=(T1-T11)*G(J)*G(J)+T11
      RB=(1.0E-6)*RS*(1.0+ALPHAS*(TTA(J)-20.))
      RRA(J)=RB*RY
      IF (J.EQ.1) GO TO 62
C
C     EDDY FACTOR CALCULATICNS
```

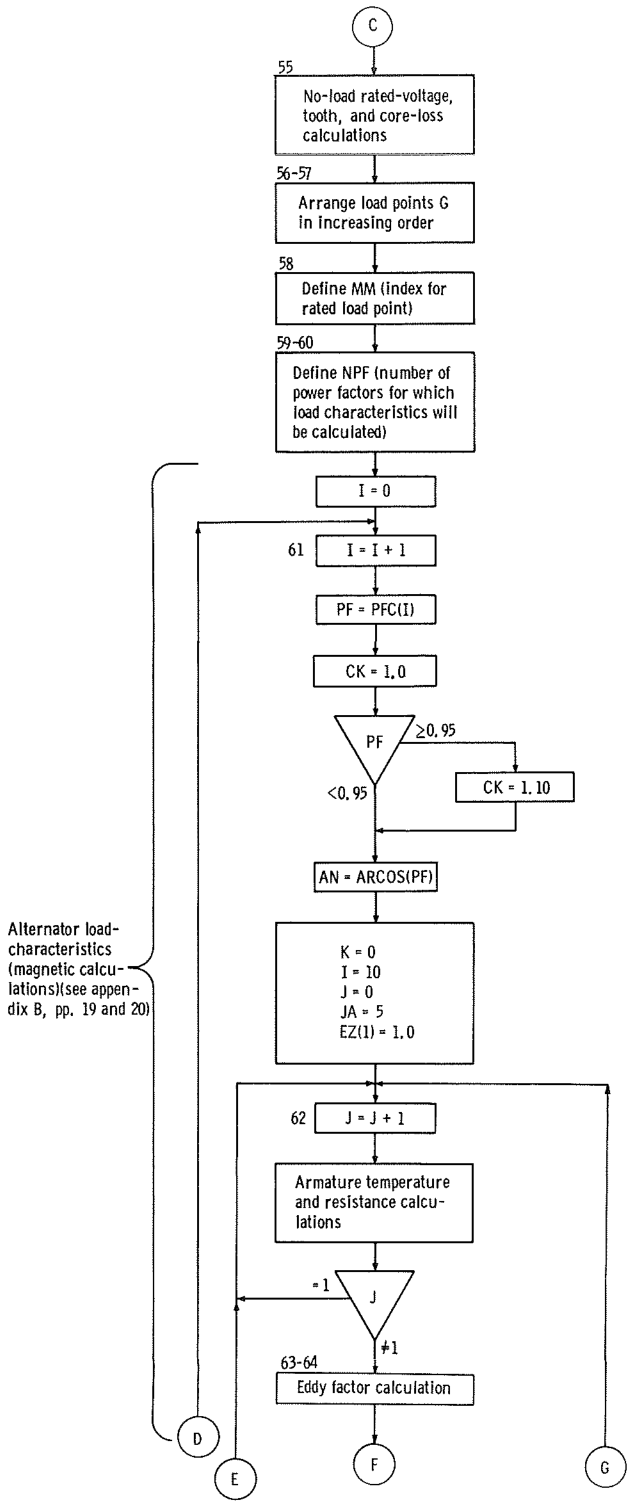
```
C
      IF (SH) 63,63,64
63    EZ(J)=1.
      GO TO 65
64    AA=0.584+(SN*SN-1.0)*0.0625*(SD*CL/(SH*HM/2.))**2
      AB=(SH*SC*F*AC/(BS*RB*1.0E6))**2.0
      ET=AA*AB*0.00335+1.0
      EB=ET-0.00168*AB
      EZ(J)=(ET+EB)*0.5
C
65    XI=ATAN((((XB*G(J))/100.)+SIN(AN))/(PF+RRA(J)*(PI/EP)*G(J)))
      BB=XI-AN
      EDD=COS(BB)+(RRA(J)*(PI/EP)*G(J)*COS(XI))+XA*SIN(XI)*G(J)*0.01
      GXX=(EDD-0.93*XD*SIN(XI)*G(J)*0.01)*CK
      FGXL=FGML*G(J)*SIN(XI)
      PPL=FQ*GXX
      FGL1=FH*GXX
      CALL MAGNET
      FPLL(J)=FPL
      FTLL(J)=FTL
      FCLL(J)=FCL
      FRCORL(J)=FRC
      FFLL(J)=FFL
      FDMLL(J)=FGXL
      BPLL(J)=BPL
      BTLL(J)=BTL
      BCLL(J)=BCL
      BRCORL(J)=BRC
      FGLL1(J)=FGL1
      PPRLL(J)=PPRL
      IF (KSAT.NE.10) GO TO 66
      IF (K.NE.0) GO TO 67
      IF (J.LT.5) GO TO 62
      GO TO 71
66    IA=KSAT
      IF ((G(J)-G(J-1)).LE.0.140) GO TO 68
      G(J)=G(J)-0.10
      J=J-1
      K=K+1
      GO TO 62
67    IF (J.EQ.5) GO TO 71
      J=J+1
68    JA=J-1
69    M=220+J
      DO 70 K=J,M,5
70    FGLL1(K)=0.
      J=J+1
      IF (J.LT.6) GO TO 69
      IF (MM.GT.JA) MM=JA
71    IF (I.EQ.1) FIMM=FFLL(MM)/PT
      VV=3.*PI*EP*PF
C
C     LOSSES AND EFFICIENCY UNDER LOAD
C
      M=0
      KWIND=0
      WW=WU
72    M=M+1
      UA=G(M)
```

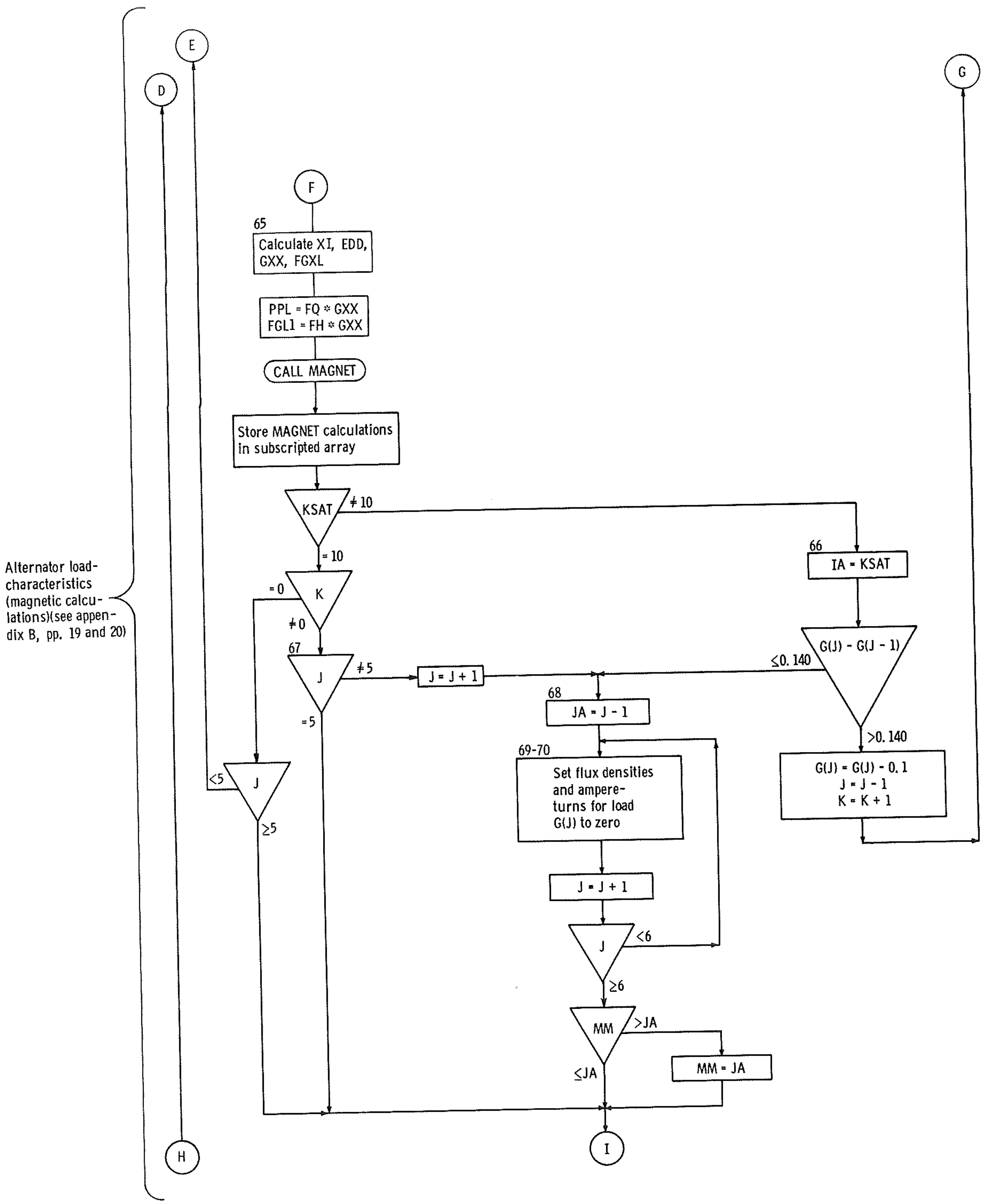
```
      FI(M)=FFLL(M)/PT
      CDD(M)=FI(M)/AS
      IF (MM.NE.1) GO TO 73
      TTB(M)=T22
      GO TO 74
   73 TTB(M)=(((T2-T22)*FI(M)**2)+(T22*FIMM**2-T2*FI(1)**2))/(FIMM**2-FI
     1(1)**2)
   74 RRB(M)=(1.0E-6)*RR*(1.0+ALPHAR*(TTB(M)-20.))*ZG
      PR(M)=FI(M)*FI(M)*RRB(M)
      RRB(M)=RRB(M)/PX
      EF(M)=FI(M)*RRB(M)
      PS(M)=(3.*(PI*UA)**2)*RRA(M)
      WQL(M)=WQ*(BCLL(M)/BCLL(1))**2
      ST(M)=WT*(BTLL(M)/BTLL(1))**2
      WA(M)=VV*UA/1000.
      IF (IWF.NE.1) GO TO 75
      IF (M.EQ.1) GO TO 75
      CALL WINDGE (G,RPM,DR,CL,KWIND,GC,M,WFTTL)
      WND(M)=WFTTL
   75 AKVA(M)=WA(M)/PF
      WMIS(M)=AKVA(M)*10.0
      GM=(GF*UA)**2+1.0
      PP(M)=GM*WN
      DL(M)=GM*WW
      EX(M)=(EZ(M)-1.0)*PS(M)*(CL/HM)
      SP(M)=PP(M)+PR(M)+PS(M)+EX(M)+ST(M)+WQL(M)+WMIS(M)+WND(M)
      E(M)=(WA(M)/(WA(M)+(SP(M)-WND(M))/1000.))*100.
      E1(M)=(WA(M)/(WA(M)+SP(M)/1000.))*100.
      IF (M.EQ.1) WW=WD
      IF (M.LT.JA) GO TO 72
      WRITE (6,76) PF,(G(I),I=1,5),(PPRLL(I),I=1,5)
      IF (KSAT.EQ.10) G(JA)=G(JA)+FLOAT(K)*0.10
      IF (KSAT.NE.10) G(JA+1)=G(JA+1)+FLOAT(K)*0.10
      WRITE (6,77) (BCLL(I),I=1,5),(BTLL(I),I=1,5),(BPLL(I),I=1,5),(BRCO
     1RL(I),I=1,5)
      WRITE (6,78) (FGLL1(I),I=1,5)
      WRITE (6,77) (FCLL(I),I=1,5),(FTLL(I),I=1,5),(FPLL(I),I=1,5),(FRCO
     1RL(I),I=1,5)
      WRITE (6,79) (FDMLL(I),I=1,5),(FFLL(I),I=1,5),(FI(I),I=1,5),(CDD(I
     1),I=1,5),(EF(I),I=1,5)
   76 FORMAT (1H1,26X47HALTERNATOR LOAD CHARACTERISTICS (RATED VOLTAGE,F
     15.2,14H POWER FACTOR)/27X,11(6H------),//7X11HPERCENT KVA,12X,2PF1
     27.0,4F19.0//7X22HLEAKAGE FLUX/POLE (KL),1X0PF19.2,4F19.2//7X25HFLU
     3X DENSITIES (KL/SQ-IN))
   77 FORMAT (10X13HSTATOR - CORE,7X5F19.2/19X5HTEETH6X5F19.2/10X,12HROT
     1OR - POLE,8X,5F19.2/18X,4HCORE,8X,5F19.2)
   78 FORMAT (1H /7X,17HAMPERE-TURNS/POLE/10X,12HMAIN AIR GAP,8X,5F19.2)
   79 FORMAT (1H ,9X13HDEMAGNETIZING7X5F19.2/7X18HTOTAL AMPERE TURNS5X5F
     119.2//7X24HFIELD AMPERES (PER COIL),F18.2,4F19.2/7X21HCURRENT DENS
     2. (FIELD)2X5F19.2/7X22HFIELD VOLTS (PER COIL),1X5F19.2)
      WRITE (6,80) (TTB(I),I=1,5),(TTA(I),I=1,5),(RRB(I),I=1,5),(RRA(I),
     1I=1,5),(PR(I),I=1,5),(WND(I),I=1,5),(ST(I),I=1,5),(WQL(I),I=1,5),(
     2PP(I),I=1,5),(DL(I),I=1,5),(PS(I),I=1,5),(EX(I),I=1,5),(WMIS(I),I=
     31,5),(SP(I),I=1,5),(AKVA(I),I=1,5),(WA(I),I=1,5),(E(I),I=1,5)
   80 FORMAT (1HK,6X20HTEMPERATURES (DEG.C)/10X5HFIELD15X5F19.2/10X8HARM
     1ATURE12X5F19.2/7X18HRESISTANCES (OHMS)/10X16HFIELD (PER COIL)4X,5F
     219.2/10X8HARMATURE12X5F19.4//7X25HALTERNATOR LOSSES (WATTS)/10X5HF
     3IELD15X5F19.2/10X7HWINDAGE13X5F19.2/10X12HSTATOR TOOTH8X5F19.2/10X
```

```
     411HSTATOR CORE9X5F19.2/10X9HPOLE FACE11X5F19.2/10X6HDAMPER,14X5F19
     5.2/10X13HSTATOR COPPER7X5F19.2/10X4HEDDY16X5F19.2/10X10HMISC. LOAD
     610X5F19.2/10X5HTOTAL15X5F19.2//7X23HALTERNATOR OUTPUT (KVA)5F19.2/
     77X22HALTERNATOR OUTPUT (KW)1X5F19.2//7X,21HEFFICIENCY (PER CENT)/1
     80X,16HELECTRO-MAGNETIC,4X,5F19.2)
      IF (IWF.EQ.1) WRITE (6,81) (E1(I),I=1,5)
81    FORMAT (10X,8HOVER-ALL,12X,5F19.2)
      KSAT=IA
      IF (KSAT.EQ.10) GO TO 83
      J=4*KSAT
      M=J-3
      WRITE (6,82) (CMPNT(K),K=M,J)
82    FORMAT (1HK,20X,4A6,13H IS SATURATED,4H ***)
83    IF (I.GE.NPF) GO TO 84
      GO TO 61
C
C     INITIALIZE VARIABLES  USED IN NO-LOAD MAGNETIC CALCS
C
84    CONTINUE
      DO 85 J=1,160
85    FQLL(J)=0.
C
C     ------------------------------------------------------------------
C     CALCULATE NO-LOAD SATURATION DATA
C     ------------------------------------------------------------------
C
      FGXL=0.
      IDELR=15
      EDD=VMIN
      J=1
86    PPL=FQ*EDD
      FGL1=FH*EDD
      CALL MAGNET
      IF (KSAT.NE.10) GO TO 87
      FQLL(J)=PPL
      CPERV(J)=100.*EDD
      QVLL(J)=EE*EDD
      QVLN(J)=QVLL(J)/SQRT(3.)
      FI(J)=FFL/PT
      FPLL(J)=FPL
      FTLL(J)=FTL
      FCLL(J)=FCL
      FRCORL(J)=FRC
      FFLL(J)=FFL
      BPLL(J)=BPL
      BTLL(J)=BTL
      BCLL(J)=BCL
      BRCORL(J)=BRC
      FGLL1(J)=FGL1
      FPRLL(J)=PPRL
      IF (J.EQ.10) GO TO 90
      J=J+1
      EDD=EDD+FLOAT(IDELR)/100.
      GO TO 86
87    EDD=EDD-FLOAT(IDELR)/100.
      IF (IDELR.GT.5) GO TO 88
```

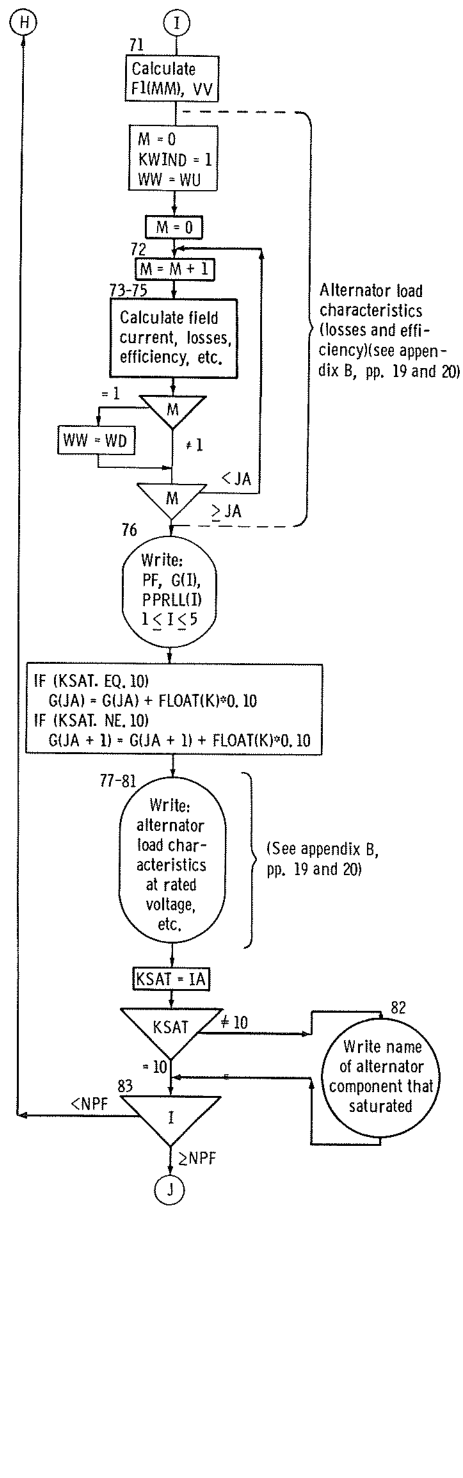
```
      IF (IDELR.GT.2) GO TO 89
      GO TO 90
88    IDELR=(IDELR/6)*5
      EDD=EDD+FLOAT(IDELR)/100.
      GO TO 86
89    IDELR=(IDELR/3)*2
      EDD=EDD+FLOAT(IDELR)/100.
      GO TO 86
90    WRITE (6,91) (QPERV(K),K=1,10),(QVLN(K),K=1,10),(QVLL(K),K=1,10),(
     1FI(K),K=1,10),(FQLL(K),K=1,10),(PPRLL(K),K=1,10)
91    FORMAT (1H1,50X23HNO-LOAD SATURATION DATA/51X23H------------------
     1-----//2X7HVOLTAGE/5X7HPERCENT6X10F11.2//5X12HLINE-NEUTRAL1X10F11.
     22/5X9HLINE-LINE4X10F11.2//2X13HFIELD CURRENT3X10F11.2//2X,13HFLUX
     3PER POLE,3X,10F11.2/2X,12HLEAKAGE FLUX,4X10F11.2//2X,14HFLUX DENSI
     4TIES)
      WRITE (6,92) (BCLL(K),K=1,10),(BTLL(K),K=1,10),(BPLL(K),K=1,10),(B
     1RCORL(K),K=1,10)
92    FORMAT (1H ,4X6HSTATOR/7X,4HCORE,7X,10F11.2/7X,5HTEETH,6X,10F11.2/
     15X,5HROTOR/7X,4HPOLE,7X,10F11.2/7X,4HCORE,7X,10F11.2)
      WRITE (6,93)
93    FORMAT (1HK,1X,17HAMPERE-TURNS/POLE)
      WRITE (6,94) (FGLL1(K),K=1,10)
94    FORMAT (1H ,4X,12HMAIN AIR-GAP,F12.2,9F11.2)
      WRITE (6,92) (FCLL(K),K=1,10),(FTLL(K),K=1,10),(FPLL(K),K=1,10),(F
     1RCORL(K),K=1,10)
      WRITE (6,95) (FFLL(K),K=1,10)
95    FORMAT (1HK,4X,5HTOTAL,8X,10F11.2)
      IF (KSAT.EQ.10) GO TO 3
      J=4*KSAT
      I=J-3
      WRITE (6,82) (CMPNT(K),K=I,J)
      GO TO 3
      END
```


SALENT
Start
1-2
Read two material decks
3
Call SUBSAL
Call OUTPUT
4-8
Calculate tooth width at 1/3 distance from narrowest section (SM)
Calculate areas and lengths for magnetics calculations
9
FGXL = 0
PPL = FQ
FGL1 = FH
Call MAGNET
Store MAGNET calculations in subscripted array
No-load rated voltage magnetization characteristics
A
B
Calculate short-circuit ratio (SCR) and short-circuit ampere-turns (FSC)
10
Write: FSC, SCR
IWF ?
= 1
≠ 1
KWIND = 1
CALL WINDGE
Windage loss at rated load
11-17
Write: materials, no-load rated-voltage magnetization characteristics
(See appendix B, p. 18)
18
Write name of alternator component that saturated
KSAT
≠ 10
= 10
19-31
No load pole-face loss calculations
Damper winding ?
Yes
No
32
Set damper losses (WU, WD) = 0
33-54
Calculate damper losses
C
33-37
Define various parameters for damper loss calculations
M = 0
Calculate cold damper resistivity
39-53
Calculate damper loss (WD)
38
Calculate hot damper resistivity
54
WU = WD
M = M + 1
M
= 1
≠ 1
9
or
Input; output
2
Branch point or decision
17
Arithmetic statement
23
Call statement for subroutine
Numbers in upper left are external formula number in FORTRAN program

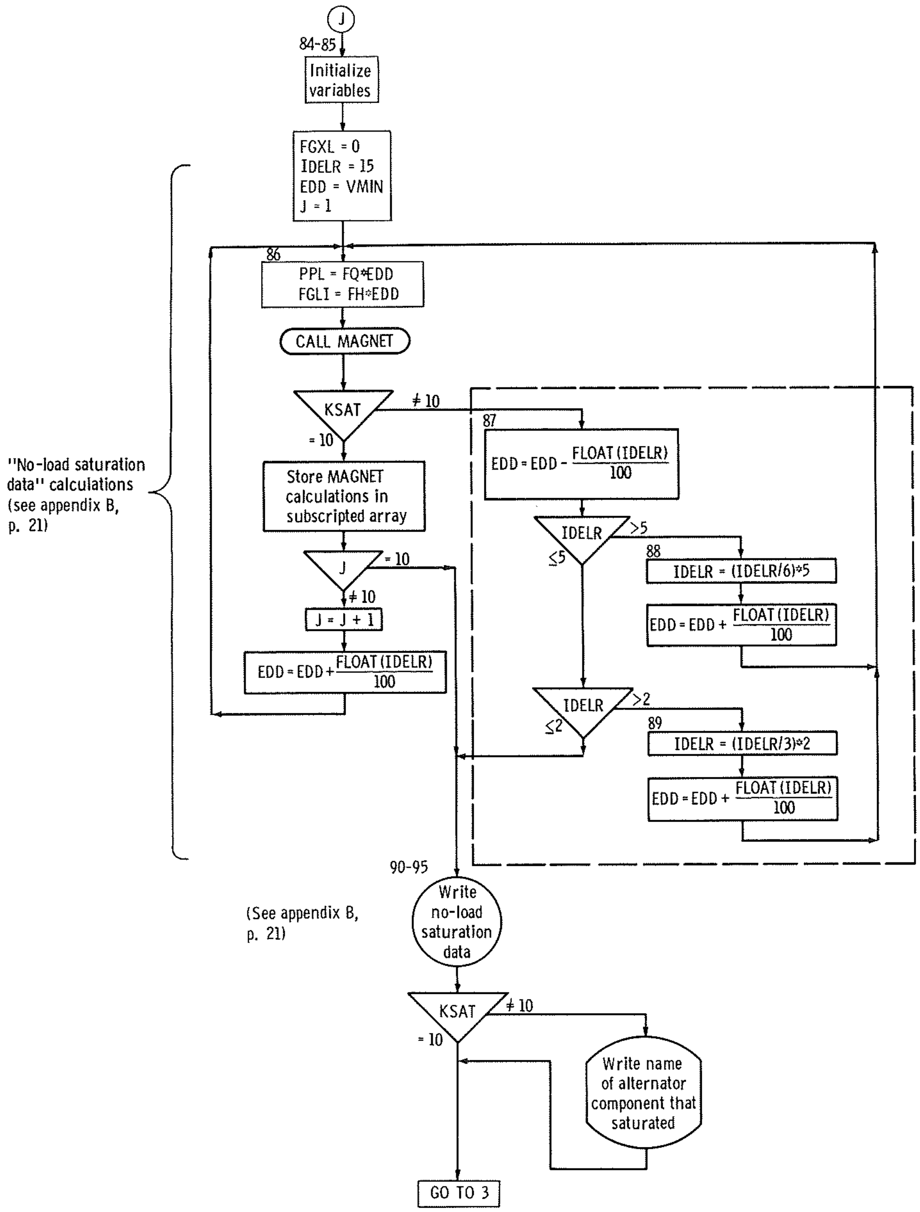

C
55
No-load rated-voltage, tooth, and core-loss calculations
56-57
Arrange load points G in increasing order
58
Define MM (index for rated load point)
59-60
Define NPF (number of power factors for which load characteristics will be calculated)
I = 0
61
I = I + 1
PF = PFC(I)
CK = 1.0
PF
≥0.95
<0.95
CK = 1.10
AN = ARCOS(PF)
K = 0
I = 10
J = 0
JA = 5
EZ(1) = 1.0
62
J = J + 1
Armature temperature and resistance calculations
J
= 1
≠1
63-64
Eddy factor calculation
Alternator load-characteristics (magnetic calculations)(see appendix B, pp. 19 and 20)
D
E
F
G



E
D
G
F
65
Calculate XI, EDD, GXX, FGXL
PPL = FQ * GXX
FGL1 = FH * GXX
CALL MAGNET
Store MAGNET calculations in subscripted array
KSAT
≠ 10
= 10
66
IA = KSAT
Alternator load-characteristics (magnetic calculations)(see appendix B, pp. 19 and 20)
= 0
K
≠ 0
67
J
≠ 5
J = J + 1
G(J) - G(J - 1)
≤0. 140
= 5
68
JA = J - 1
>0. 140
69-70
Set flux densities and ampere-turns for load G(J) to zero
G(J) = G(J) - 0. 1
J = J - 1
K = K + 1
<5
J
≥5
J = J + 1
J
<6
≥6
MM
>JA
MM = JA
≤JA
H
I



H
I
71
Calculate F1(MM), VV
M = 0
KWIND = 1
WW = WU
M = 0
72
M = M + 1
73-75
Calculate field current, losses, efficiency, etc.
= 1
M
WW = WD
≠ 1
< JA
M
≥ JA
Alternator load characteristics (losses and efficiency)(see appendix B, pp. 19 and 20)
76
Write: PF, G(I), PPRLL(I) 1 ≤ I ≤ 5
IF (KSAT. EQ. 10)
G(JA) = G(JA) + FLOAT(K)*0. 10
IF (KSAT. NE. 10)
G(JA + 1) = G(JA + 1) + FLOAT(K)*0. 10
77-81
Write: alternator load characteristics at rated voltage, etc.
(See appendix B, pp. 19 and 20)
KSAT = IA
KSAT
≠ 10
82
Write name of alternator component that saturated
= 10
83
<NPF
I
≥NPF
J



J
84-85
Initialize variables
FGXL = 0
IDELR = 15
EDD = VMIN
J = 1
86
PPL = FQ*EDD
FGLI = FH*EDD
CALL MAGNET
KSAT
≠ 10
= 10
87
EDD = EDD - FLOAT (IDELR) / 100
"No-load saturation data" calculations (see appendix B, p. 21)
Store MAGNET calculations in subscripted array
IDELR
>5
≤5
88
IDELR = (IDELR/6)*5
EDD = EDD + FLOAT (IDELR) / 100
J
= 10
≠ 10
J = J + 1
EDD = EDD + FLOAT (IDELR) / 100
IDELR
>2
≤2
89
IDELR = (IDELR/3)*2
EDD = EDD + FLOAT (IDELR) / 100
90-95
(See appendix B, p. 21)
Write no-load saturation data
KSAT
≠ 10
= 10
Write name of alternator component that saturated
GO TO 3

```
      SUBROUTINE SUBSAL
      COMMON A,AA,AB,AC,ACORE,AI,ALPHAE,ALPHAR,ALPHAS,APOLE,APOLHD,ARCOR
     1E,AS,ATOOTH,B,B1,B2,B3,BCL,BCOIL,BG,BK,BN,BO,BPL,BRC,BS,BTL,BV,C,C
     21,CC,CCR,CE,CF,CL,CM,CQ,CP,D1,DCORE,DD,DF,DI,DISH,DR,DRCORE,DSH,DU
     3,DW,DW1,EC,EE,EL,ENDEXT,EP,EW,F,FCL,FE,FFL,FGL1,FGML,FGXL,FH,FK1,F
     4PL,FQ,FRC,FS,FTL,G,GA,GC,GE,GP,H,HC,HCOIL,HD,HM,HO,HS,HT,HV,HW,HX,
     5HY,IBN,IPN,IPX,IQQ,IWF,IZZ,KSAT,LTR,LTR1,LTS,P1,P2,P3,P4,PBA,PBH,P
     6BL,PBW,PC,PDD,PDQ,PE,PEFF,PF,PFC,PHH,PHL,PHW,PI,PN,PPL,PPRL,PT,PTC
     7H,PX,QN,QQ,RC,RD,RE,RF,RG1,RK,RK1,RPM,RR,RS,RT,RY,S,SB,SC,SD,SF,SH
     8,SI,SIGMA,SK,SN,SN1,SS,STATET,T1,T11,T2,T22,T3,T33,TA,TB,TC,TF,TG,
     9TS,TST,TT,TTC,VA,VMIN,VR,WC,WI,WL,WO,WROTOR,WTOTAL,XA,XB,XD,XDD,XD
     $Q,XF,XL,XN,XQ,XR,XU,XX,XY,YY,ZG,ZZ
C
      INTEGER ZZ
C
      REAL LT,LTS,LTR,LTR1
C
      DIMENSION DA(8), DX(6), DY(8), DZ(8), G(5), PFC(5), AI(60)
C
      NAMELIST /RATING/ VA,EE,EP,F,RPM,IPX,PFC,G,VMIN/STATOR/DI,DU,CL,HV
     1,BV,SF,LTS,WL,BK/SLOTS/ZZ,BO,B3,BS,HO,HX,HY,HS,HT,IQQ/WINDNG/RF,SC
     2,BX,SEP,PTCH,EL,YY,C,DW,SN,SN1,DW1,CE,SD,PBA,SK,T1,RS,ALPHAS,T11,T
     3ST/AIRGAP/GC,GP,IWF/ROTOR/C1,CP,CM,CQ,D1,RK,LTR,RK1,LTR1,PHL,PE,PH
     4W,WROTOR,PHH,DISH,DSH,PBL,PBH,PBW/FIELD/HCOIL,PT,RD,RT,T2,BCOIL,TF
     5,T22,RR,ALPHAR,FE/DAMPER/BN,WO,HD,DD,H,B,SB,TB,T33,RE,ALPHAE,T3
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
      WRITE (6,1)
1     FORMAT (1H1,14X,43H*** WOUND-POLE, SALIENT-POLE ALTERNATOR ***)
      DO 2 I=1,5
2     PFC(I)=0.
      ALPHAE=0.00393
      ALPHAR=0.00393
      ALPHAS=0.00393
      B=0.
      BCOIL=0.
      BV=0.
      BX=0.
      C1=0
      CM=0
      CP=0
      CQ=0
      CW=0
      D1=0.
      DD=0.
      DISH=0.
      DSH=0.
      DW1=0
      EE=0.
      EL=0
      ENDEXT=0.
      EP=0.
      F=0.
```

```
G(1)=0.
G(2)=0.75
G(3)=1.00
G(4)=1.25
G(5)=1.50
GP=0.
H=0.
HCOIL=0.
HV=0.
IPN=3
IPX=0
IWF=0
LTR=0.
LTR1=0.
LTS=0.
PBA=60.
PBL=0
PBW=0
PE=0.
PHL=0.
PHW=0.
PN=3.
PTCH=0.
RE=0.694
RK=0.
RK1=0.
RPM=0.
RR=0.694
RS=0.694
RT=0.
SB=0.
SEP=0.01
SF=0.
SK=0
SN=1.0
T3=0.
T33=20.
TB=0.
TF=25.
TST=25.
VMIN=0.7
WO=0.
WROTOR=0.
XF=0.
YY=0.
READ (5,RATING)
READ (5,STATOR)
READ (5,SLOTS)
READ (5,AIRGAP)
READ (5,ROTOR)
READ (5,FIELD)
READ (5,DAMPER)
PF=PFC(1)
IF (EP.EQ.0.) EP=EE/1.732051
IF (EE.EQ.0.) EE=EP*1.732051
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-HO-HT
      CQ=IQQ
      IF (ZZ.NE.3) GO TO 3
      B1=(HO+HT-HS)*(6.283185/CQ)+B3
      B2=B1+(6.283185*HW/QQ)
      BS=(B2+B3)/2.
      IF (BX.EQ.0.) BX=BS-.015
3     CONTINUE
      IF (BX.EQ.0.) BX=BS-.015
      PI=(VA*1000.)/(EE*SQRT(3.))
      IF (ZZ.EQ.1.OR.ZZ.EQ.5) BO=BS
      IZZ=ZZ
      DB=.25
      IF (YY.EQ.0.) YY=FLOAT(IFIX((QQ/PX)*PTCH+0.45))
      IF (PTCH.EQ.0.) PTCH=YY*PX/QQ
      IF (DU.GE.8.) DB=0.5
      DR=DI-2.*GC
      IF (DSH.EQ.0.) DSH=DR-2.0*(PHH+PBH)
      IF (HCOIL.EQ.0.) HCOIL=PBH
      IF (GP.EQ.0.) GP=GC
      IF (PE.EQ.0.) PE=(PX/3.1415927)*(ARSIN(PHW/DR))
      IF (PHW.EQ.0.) PHW=DR*SIN(3.1415927*PE/PX)
      IF (PBL.EQ.0.) PBL=PHL
      IF (PHL.EQ.0.) PHL=PBL
      FE=2.0*PBL+2.0*(PBW-0.25)+3.14159*(0.45+BCOIL)
      HC=(DU-DI-2.0*HS)*0.5
      ZY=0.7*HS
      DO 4 I=1,5
4     IF (G(I).GT.9.) G(I)=G(I)/100.
      QN=QQ/(PX*PN)
      CS=YY/(PN*QN)
      IF (BN.EQ.0.) GO TO 5
      IF (SB.EQ.0.) SB=PHL
      IF (T3.EQ.0.) T3=T1
      IF (DD.NE.0.) XX=DD
      IF (H.NE.0.) XX=H
      IF (TB.EQ.0.) TB=3.1415927*(DR-2.0*WO-XX)*PE/(PX*(BN+1.0))
C
C     CHECK FOR ERROR CONDITIONS
C
5     IF (ABS(PTCH-YY*PX/QQ).GT.0.0001) GO TO 6
      GO TO 7
6     WRITE (6,9) PTCH
      PTCH=YY*PX/QQ
7     IF (CS.GT.1.0.OR.CS.LT.0.5) WRITE (6,10) CS
      IF (EP*EE.EQ.0..OR.ABS(EE/EP-1.732051).GT.0.01) WRITE (6,11)
      IF (PX*F*RPM.EQ.0..OR.ABS(F-PX*RPM/120.).GT.0.1) WRITE (6,12)
      IF (HC.LT.ZY) WRITE (6,13) HC,HS
      IF (((3.14159*DSH/PX)-PBW).LT.2.0*BCOIL) WRITE (6,14)
      IF (RT.LT.1.0E-10) GO TO 8
      IF (((HCOIL*BCOIL)/(RT*RD)).LE.PT) WRITE (6,15)
      GO TO 16
8     IF (HCOIL*BCOIL/RD**2.LE.0.8573*PT) WRITE (6,15)
9     FORMAT (1H ,F5.3,30H WINDING PITCH IS NOT POSSIBLE)
10    FORMAT (5X,27H CS (PER UNIT POLE PITCH) =,F7.3/10X,31H CS MUST BE
     1BETWEEN 0.5 AND 1.0)
11    FORMAT (1H ,38H EITHER PHASE OR LINE VOLTAGE IS WRONG)
12    FORMAT (1H ,44H FREQUENCY, RPM, OR NO. OF POLES IS IN ERROR)
```

```
13    FORMAT (1H /5X54HDEPTH BELOW SLOT IS LESS THAN 70 PERCENT OF SLOT
     1DEPTH/10X,4HDBS=F8.4/10X,4H SD=F8.4)
14    FORMAT (1H ,57H FIELD COIL IS WIDER THAN AVAILABLE SPACE AT BASE O
     1F POLE)
15    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
16    M=1
      STFK=SF
      LT=LTS
      GO TO 19
17    M=2
      STFK=RK
      LT=LTR
      GO TO 19
18    M=3
      STFK=RK1
      LT=LTR1
19    IF (STFK.NE.0.) GO TO (21,22,23),M
      IF (LT.EQ.0.) GO TO 20
      STFK=1.0-(12.5E-4/LT)
      GO TO (21,22,23),M
20    STFK=1.0
      GO TO (21,22,23),M
21    SF=STFK
      GO TO 17
22    RK=STFK
      GO TO 18
23    RK1=STFK
C
C     CALCULATE POLE FACE LOSS FACTOR
C
      M=0
      IF (D1.NE.0.) GO TO 31
      IF (LTR1.NE.0.) GO TO 24
      M=1
      IF (RK1.GT.0.9999) GO TO 30
      LTR1=(12.5E-4)/(1.0-RK1)
24    IF (LTR1-0.045) 25,25,26
25    D1=1.17
      GO TO 31
26    IF (LTR1-0.094) 27,27,28
27    D1=1.75
      GO TO 31
28    IF (LTR1-0.17) 29,29,30
29    D1=3.5
      GO TO 31
30    D1=7.0
31    IF (M.EQ.1) LTR1=0.
      IBN=BN+.1
C
C
      SS=SF*(CL-HV*BV)
      SIGMA=(54.E3/DI**2)*(PF/SS)*(VA/RPM)
      VR=0.262*DR*RPM
      TP=3.14159*DR/PX
```

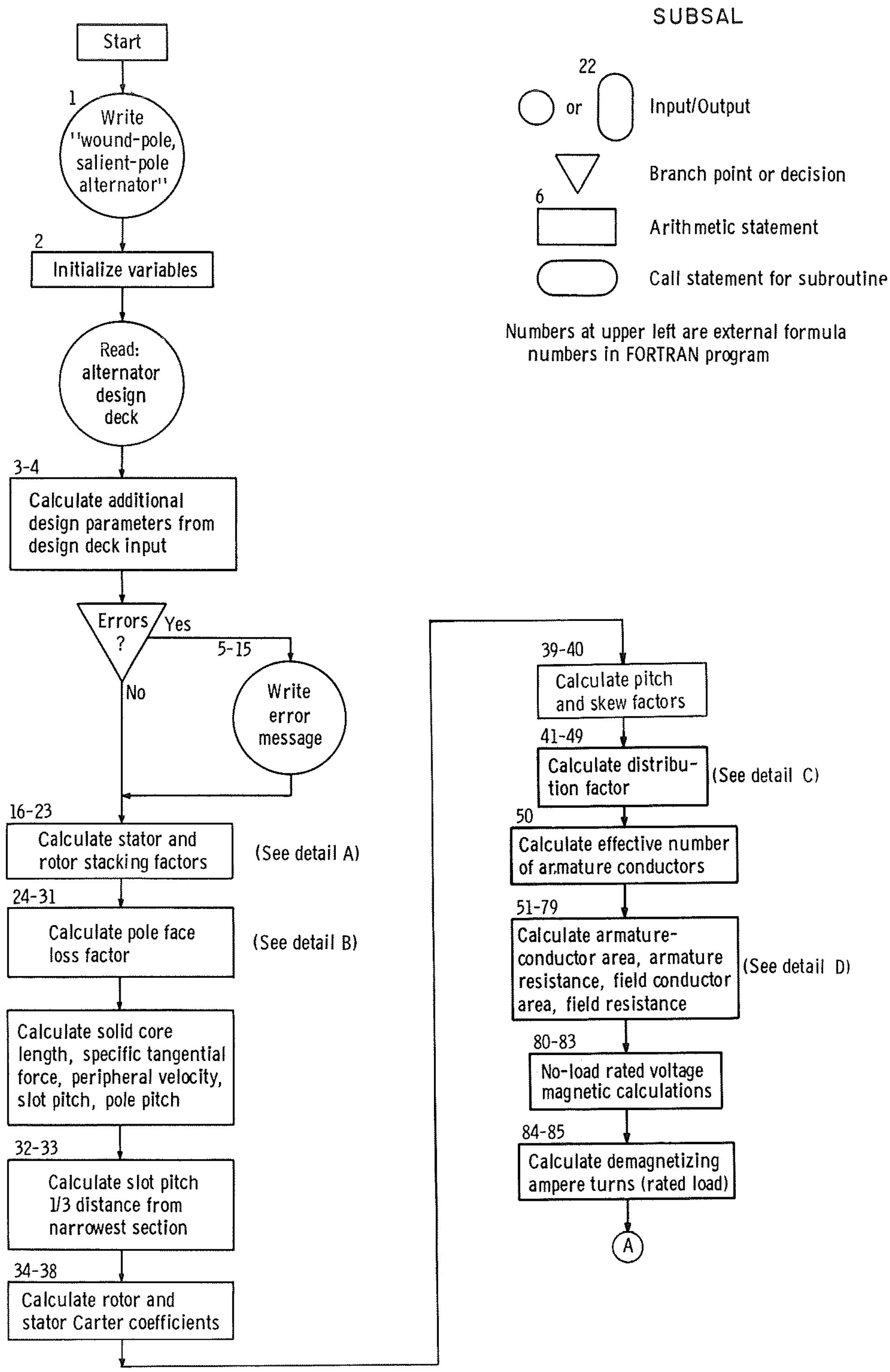
```
      TS=3.142*DI/QQ
      IF (ZZ-4) 32,33,32
32    TT=(.667*HS+DI)*3.142/CQ
      GO TO 34
33    TT=(DI+2.0*HO+1.333*BS)*3.1416/QQ
C
C     CALCULATE CARTER COEFFICIENTS
C
34    IF (ZZ.GT.1.AND.ZZ.LT.5) GO TO 35
      CC=(5.0*GC+BS)*TS/((5.0*GC+BS)*TS-BS*BS)
      GO TO 36
35    QC=(4.44*GC+0.75*BO)*TS
      CC=QC/(QC-BO*BO)
36    IF (IBN.EQ.0) GO TO 37
      QC=(4.44*GC+0.75*WO)*TB
      CCR=QC/(QC-WO**2)
      GO TO 38
37    CCR=1.
38    CONTINUE
C
C     PITCH FACTOR AND SKEW FACTOR CALCULATIONS
C
      CF=SIN(YY*1.571/(PN*QN))
      IF (SK) 39,39,40
39    FS=1.0
      GO TO 41
40    FS=(SK/TP)*1.5707
      FS=(1./FS)*(SIN(FS))
C
C     CHECK IF WINDING HAS INTEGRAL NO. OF SLOTS PER POLE PER PHASE
C
41    D=1.0
      IF (PBA.GT.61.0) D=2.0
      IC=IFIX(C+0.001)
      IZY=IPX*IPN
      IDM=0
42    IDM=IDM+IZY
      IF (IQQ-IDM) 44,43,42
C
C     CALCULATE DISTRIBUTION FACTOR FOR INTEGRAL SLOT WINDING
C
43    DF=SIN(1.571*D/PN)/(QN*D*SIN(1.571/(PN*QN)))
      IF ((IPX/IC)*IC.NE.IPX) WRITE (6,48) IC
      GO TO 50
C
C     CALCULATE DISTRIBUTION FACTOR FOR FRACTIONAL SLOT WINDING
C
44    IIQQ=IQQ
      I=2
45    IF ((IZY/I)*I.EQ.IZY.AND.(IIQQ/I)*I.EQ.IIQQ) GO TO 46
      IF (I.GT.IZY) GO TO 47
      I=I+1
      GO TO 45
46    IZY=IZY/I
      IIQQ=IIQQ/I
      GO TO 45
47    FNQ=IIQQ
      DF=SIN(1.571*D/PN)/(FNQ*D*SIN(1.571/(FNQ*PN)))
      IF ((IZY/3)*3.EQ.IZY) WRITE (6,49)
```

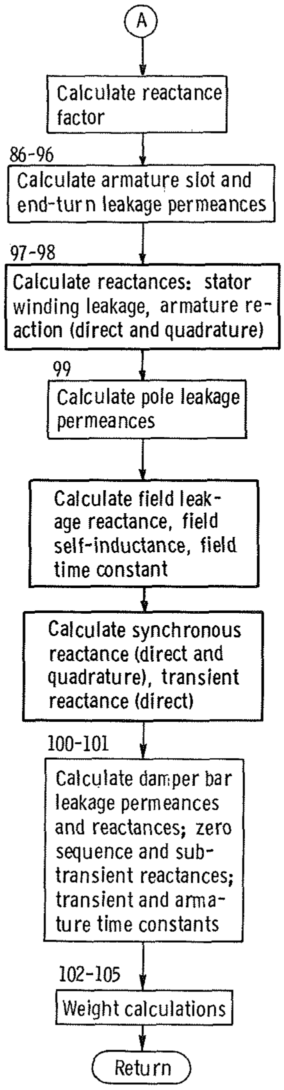
```
      IF ((IPX/IZY)*IZY.NE.IPX) WRITE (6,49)
      IZY=IPX/IZY
      IF ((IZY/IC)*IC.NE.IZY) WRITE (6,48) IC
48    FORMAT (1H ,I2,35H PARALLEL CIRCUITS ARE NOT POSSIBLE)
49    FORMAT (2H ,41H IMPROPER FRACTIONAL-SLOT WINDING IS USED)
50    EC=QQ*SC*CF*FS/C
C
C     COMPUTE ARMATURE CONDUCTOR AREA
C
      IF (DW1) 51,51,52
51    AC=0.785*DW*DW*SN1
      GO TO 64
52    ZY=0.0
      DT=AMIN1(DW,DW1)
      DG=AMAX1(DW,DW1)
53    IF (DT-.05) 56,56,54
54    JA=0
55    JA=JA+1
      IF (DT-DA(JA)) 57,57,55
56    D=0
      IF (ZY) 63,63,78
57    IF (DG-0.188) 58,58,59
58    CY=DX(JA-1)
      CZ=DX(JA)
      GO TO 62
59    IF (DG-0.75) 60,60,61
60    CY=DY(JA-1)
      CZ=DY(JA)
      GO TO 62
61    CY=DZ(JA-1)
      CZ=DZ(JA)
62    D=CY+(CZ-CY)*(DT-DA(JA-1))/(DA(JA)-DA(JA-1))
      IF (ZY) 63,63,78
63    AC=(DT*DG-D)*SN1
C
C     CALCULATE END EXTENSION LENGTH
C
64    IF (EL) 65,65,75
65    IF (RF) 66,66,72
66    IF (PX-2.0) 67,67,68
67    U=1.3
      GO TO 71
68    IF (PX-4.0) 69,69,70
69    U=1.5
      GO TO 71
70    U=1.7
71    EL=3.1416*U*YY*(DI+HS)/QQ+0.5
      GO TO 75
72    IF (ZZ.EQ.4) GO TO 73
      U=DI+2.*HY+HX
      GO TO 74
73    U=DI+HS
74    UU=3.1416*U/QQ
      SALPHA=(BX+SEP)/UU
      ALPHA=ARSIN(SALPHA)
      CALPHA=COS(ALPHA)
      STRLEN=3.1416*U*YY/(QQ*CALPHA)
      EL=2.0*CE+STRLEN+1.5708*(0.5*HX+DB)
      ENDEXT=STRLEN*SALPHA/2.0+CE+(HX+DB)/2.0
```

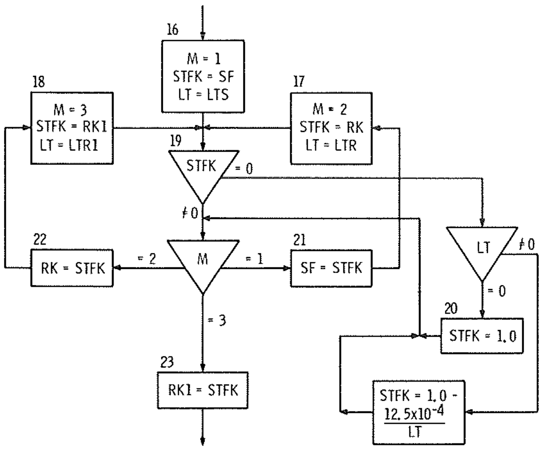
```
75    HM=CL+EL
C
C     CALCULATE STATOR RESISTANCE
C
      A=PI*SC*CF/(C*TS)
      RY=SC*QQ*HM/(PN*AC*C*C)
      RG1=(1.E-6)*RS*(1.0+ALPHAS*(TST-20.))*RY
      S=PI/(C*AC)
C
C     COMPUTE FIELD CONDUCTCR AREA
C
      IF (RT) 76,76,77
76    AS=.7854*RD*RD
      GO TO 79
77    ZY=1.0
      DT=AMIN1(RT,RD)
      DG=AMAX1(RT,RD)
      GO TO 53
78    AS=DT*DG-D
C
C     COMPUTE FIELD RESISTANCE
C
79    ZG=(PT*FE/AS)*PX
      FK1=(1.E-6)*RR*(1.0+ALPHAR*(TF-20.))*ZG
C
C     NO LOAD MAGNETIC CALCULATIONS
C
      GA=3.1416*DI*(CL-HV*BV)
      GE=CC*GC*CCR
      AG=6.38*DI/(PX*GE)
      IF (C1) 81,80,81
80    C1=(.649*ALOG(PE)+1.359)*((GC/GP)**0.352)
81    CW=(0.707/1.732)*C1*DF
      TG=EE/(CW*EC*RPM)*6.0E6
      BG=TG/GA
      FH=BG*GE/0.00319
      IF (CP) 82,82,83
82    CP=PE*(ALOG(GC/TP)*.0378+1.191)*((GC/GP)**0.41)
83    FQ=TG*CP/PX
C
C     DETERMINE DEMAGNETIZING AMPERE TURNS (RATED LOAD)
C
      IF (CM) 84,84,85
84    AA=SIN(3.142*PE)
      AB=SIN(1.571*PE)*4.0
      CM=(3.142*PE+AA)/AB
85    CONTINUE
      FGML=.45*EC*PI*CM*DF/PX
C
C     REACTANCE FACTOR CALCULATION
C
      XR=.0707*A*DF/(C1*BG)
C
C     SPECIFIC ARMATURE SLOT AND END-TURN LEAKAGE PERMEANCES
C
      FACTOR=YY/(PN*QN)
      IF (PBA.LT.61.) GO TO 86
      FF=.05*(24.*FACTOR-1.)
      IF (FACTOR.GE.0.667) FF=.75
```

```
      IF (ZZ.EQ.5) FF=1.
      GO TO 87
86    FF=.25*(6.*FACTOR-1.)
      IF (FACTOR.GE.0.667) FF=.25*(3.*FACTOR+1.)
      IF (ZZ.EQ.5) FF=1.
87    CX=FF/(CF*CF*DF*DF)
      Z=CX*20.0/(PN*QN)
      BT=3.142*DI/QQ-BO
      ZA=BT*BT/(16.0*TS*GC)
      ZB=0.35*BT/TS
      ZC=HO/BO
      ZD=HX*.333/BS
      ZE=HY/BS
      IF (ZZ-2) 88,89,90
88    PC=Z*(ZE+ZD+ZA+ZB)
      GO TO 94
89    PC=Z*(ZC+(2.0*HT/(BO+BS))+(HW/BS)+ZD+ZA+ZB)
      GO TO 94
90    IF (ZZ-4) 91,92,93
91    PC=Z*(ZC+(2.0*HT/(BO+B1))+(2.0*HW/(B1+B2))+(HX/(3.*B2))+ZA+ZB)
      GO TO 94
92    PC=Z*(ZC+0.62)
      GO TO 94
93    PC=Z*(ZE+ZD+(0.5*GC/TS)+(0.25*TS/GC)+0.6)
94    EK=EL/(10.0**(0.103*YY*TS+0.402))
      IF (DI-8.0) 95,95,96
95    EK=SQRT(EK)
96    ZF=.612*ALOG(10.0*CS)
      EW=6.28*EK*ZF*(TP**(0.62-(.228*ALOG(ZF))))/((CL-HV*BV)*DF*DF)
C
C     STATOR WINDING LEAKAGE AND ARMATURE REACTION REACTANCES
C
      IF (CQ) 97,97,98
97    AB=3.1416*PE
      CQ=(4.*PE+1.)/5.-SIN(AB)/3.1416
98    XL=XR*(PC+EW)
      XD=(0.45*EC*PI*CM*DF*100.)/(FH*PX)
      XQ=((CQ)/(CM*C1))*XD
C
C     POLE LEAKAGE PERMEANCES
C
      AA=TP*(1.0-PE)
      XXX=PHH+GC
      P1=6.38*PHL*XXX/AA
      P2=4.06*XXX*ALOG(1.0+3.14159*PHW/(2.0*AA))
      P3=0.
      P4=0.
      DO 99 I=1,4
      XXX=(DR-2.0*PHH)-FLOAT(2*I-1)*PBH/4.0
      XXX=3.14159*XXX/PX-PBW
      P3=P3+0.4*PBL*PBH*(8.0-FLOAT(2*I-1))/XXX
99    P4=P4+0.254*PBH*(8.0-FLOAT(2*I-1))*ALOG(1.0+3.14159*PBW/(2.0*XXX))
      PEFF=2.0*(P1+P2)+P3+P4
C
C     FIELD LEAKAGE REACTANCE, SELF INDUCTANCE AND TIME CONSTANT
C
      STATET=QQ*SC*DF*CF/(2.*PN*C)
      XF=XD*(1.0-(C1/CM)/(2.0*CP+(4.0*PEFF/CL)/(3.14159*AG)))
      SI=(PT**2)*PX*PBL*((CP*AG*3.14159)/2.0+PEFF/CL)*1.0E-08
      TC=SI/FK1
```

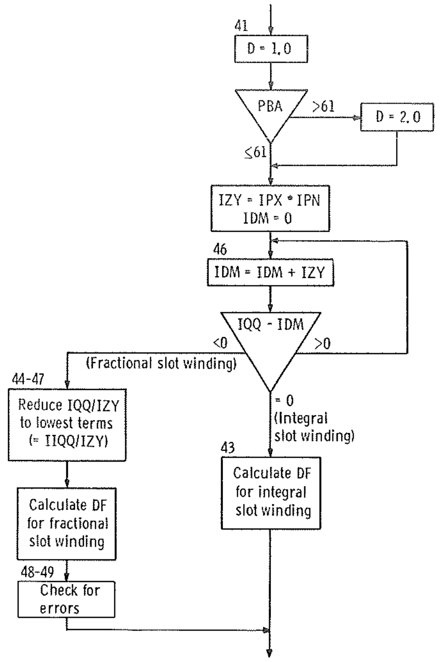
```
C
C     SYNCHRONOUS AND TRANSIENT REACTANCES CALCULATIONS
C
      XA=XL+XD
      XB=XL+XQ
      XU=XL+XF
C
C     DAMPER BAR AND SUBTRANSIENT REACTANCES, ETC.
C
      IF (IBN.EQ.0) GO TO 1C0
      AA=.62
      IF (DD.EQ.0.) AA=H/(3.*B)
      BD=(HD/WO+AA+0.5)*6.38
      BE=6.38*(PHW-(BN-1.0)*TB)/(3.0*GE)
      PDD=(BD+BE)*(PEFF/CL)*COS((BN-1.0)*TB*1.5708/TP)/(BD+BE+(PEFF/CL))
      XDD=XR*PDD
      XX=XL+XDD
      PDQ=(HD/WO+AA+0.5+GC/TP)*20.*TB/TP
      XDQ=XR*PDQ
      XY=XL+XDQ
      GO TO 101
100   XDD=0.
      XDQ=0.
      XX=XU
      XY=XB
101   XN=(XX+XY)/2.0
      TA=XN/(628.3*F*RG1)
      TTC=XU*TC/XA
C
C     WEIGHT CALCULATIONS
C
      IF (ZZ-3) 102,103,102
102   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 104
103   WI=(DU-HC)*3.1416*HC
      WI=WI+HS*((DI+2.*HS)*3.1416-QQ*B3)
      WI=WI+QQ*((HO+0.5*HT)*(BS-BO))
104   WI=WI*0.283*SS
C
      RC=(.321*PT*FE*AS)*PX
C
      WC=.321*SC*QQ*AC*HM
C
      IF (WROTOR.NE.0.) GO TO 105
      WRCORE=.283*3.1416*(DSH**2-DISH**2)/4.*PBL
      THETA=2.*3.1416*PE/PX
      ATIP=DR**2*(THETA-SIN(THETA))/8.
      APHEAD=PHW*(PHH-DR*(1.0-COS(THETA/2.)))
      APBODY=PBH*PBW
      BETA=ARSIN(PBW/DSH)
      ABASE=DSH*PBW*(1.0-COS(BETA))-DSH**2*(2.0*BETA-SIN(2.0*BETA))/8.
      WPOLE=0.283*(PHL*(ATIP+APHEAD)+PBL*(APBODY+ABASE))
      WROTOR=WRCORE+PX*WPOLE
105   WTOTAL=WC+WI+RC+WROTOR
      RETURN
      END
```


SUBSAL
22
or
Input/Output
Branch point or decision
6
Arithmetic statement
Call statement for subroutine
Numbers at upper left are external formula numbers in FORTRAN program
Start
1
Write "wound-pole, salient-pole alternator"
2
Initialize variables
Read: alternator design deck
3-4
Calculate additional design parameters from design deck input
Errors ?
Yes
5-15
Write error message
No
16-23
Calculate stator and rotor stacking factors
(See detail A)
24-31
Calculate pole face loss factor
(See detail B)
Calculate solid core length, specific tangential force, peripheral velocity, slot pitch, pole pitch
32-33
Calculate slot pitch 1/3 distance from narrowest section
34-38
Calculate rotor and stator Carter coefficients
39-40
Calculate pitch and skew factors
41-49
Calculate distribution factor
(See detail C)
50
Calculate effective number of armature conductors
51-79
Calculate armature-conductor area, armature resistance, field conductor area, field resistance
(See detail D)
80-83
No-load rated voltage magnetic calculations
84-85
Calculate demagnetizing ampere turns (rated load)
A

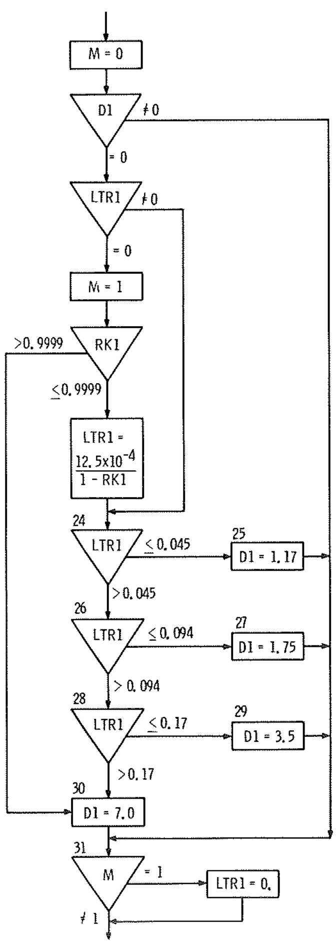

A
Calculate reactance factor
86-96
Calculate armature slot and end-turn leakage permeances
97-98
Calculate reactances: stator winding leakage, armature reaction (direct and quadrature)
99
Calculate pole leakage permeances
Calculate field leakage reactance, field self-inductance, field time constant
Calculate synchronous reactance (direct and quadrature), transient reactance (direct)
100-101
Calculate damper bar leakage permeances and reactances; zero sequence and subtransient reactances; transient and armature time constants
102-105
Weight calculations
Return



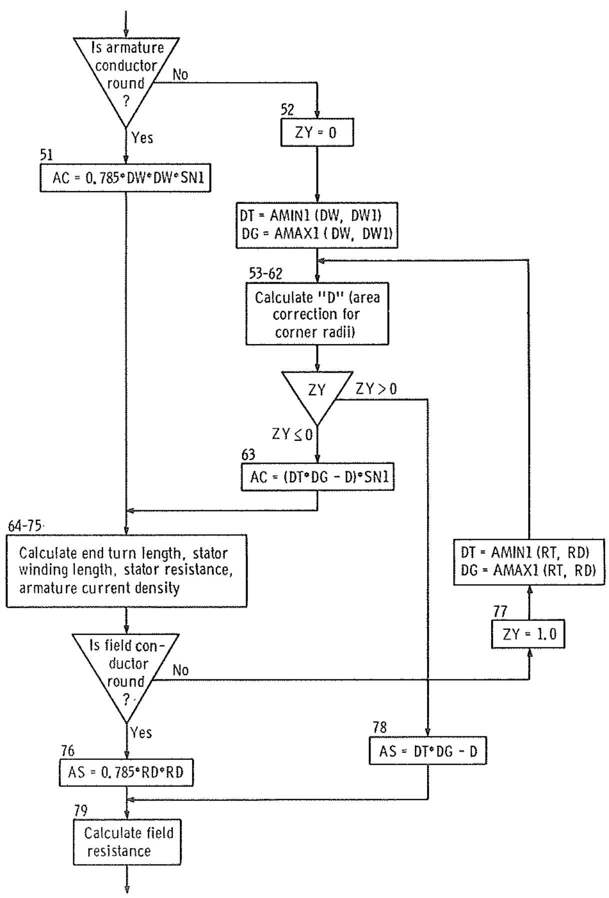
Detail A



Detail C



Detail B



Detail D

```
      SUBROUTINE OUTPUT
C
      COMMON A,AA,AB,AC,ACORE,AI,ALPHAE,ALPHAR,ALPHAS,APOLE,APOLHD,ARCOR
     1E,AS,ATOOTH,B,B1,B2,B3,BCL,BCOIL,BG,BK,BN,BO,BPL,BRC,BS,BTL,BV,C,C
     21,CC,CCR,CE,CF,CL,CM,CQ,CP,D1,DCORE,DD,DF,DI,DISH,DR,DRCORE,DSH,DU
     3,DW,DW1,EC,EE,EL,ENDEXT,EP,EW,F,FCL,FE,FFL,FGL1,FGML,FGXL,FH,FK1,F
     4PL,FQ,FRC,FS,FTL,G,GA,GC,GE,GP,H,HC,HCOIL,HD,HM,HO,HS,HT,HV,HW,HX,
     5HY,IBN,IPN,IPX,IQQ,IWF,IZZ,KSAT,LTR,LTR1,LTS,P1,P2,P3,P4,PBA,PBH,P
     6BL,PBW,PC,PDD,PDQ,PE,PEFF,PF,PFC,PHH,PHL,PHW,PI,PN,PPL,PPRL,PT,PTC
     7H,PX,QN,QQ,RC,RD,RE,RF,RG1,RK,RK1,RPM,RR,RS,RT,RY,S,SB,SC,SD,SF,SH
     8,SI,SIGMA,SK,SN,SN1,SS,STATET,T1,T11,T2,T22,T3,T33,TA,TB,TC,TF,TG,
     9TS,TST,TT,TTC,VA,VMIN,VR,WC,WI,WL,WO,WROTOR,WTOTAL,XA,XB,XD,XDD,XD
     $Q,XF,XL,XN,XQ,XR,XU,XX,XY,YY,ZG,ZZ
C
      DIMENSION G(5), PFC(5), AI(60)
C
      INTEGER ZZ
C
      REAL LTS,LTR,LTR1
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) BO,B1,B2,B3,BS,HO,HX,HT,HW,HS,IQQ,TS,TT
```

```
8      FORMAT (1HL,13H STATOR SLOTS//5X25HTYPE-CONSTANT TOOTH WIDTH/61X1H
      11,14X1H1/61X16H1------B1------1/10X3H BO,F26.3,1X6HINCHES,15X1H1,1
      24X1H1/10X3H B1,F26.3,22X1H1,5X4H-BO-,5X1H1/10X3H B2,F26.3,11X17H--
      3---------1----*,4X17H*----1-----------/10X3H B3,F26.3,22X1H1,4X1H*
      4,4X1H*,4X1H1,8X2HHO/10X15H BS = (B2+B3)/2,F14.3,22X1H1,4X1H*,4X17H
      5*----1-----------/10X3H HO,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) BO,HO,BS,HS,IQQ,TS,TT
10     FORMAT (1HL,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 (1HL,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
C
       WRITE (6,14) GC,GP,GE
14     FORMAT (1HL,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,F20.3/17X5HROTO
      1R,F21.3)
       GO TO 18
16     WRITE (6,17) CC
17     FORMAT (1H ,10X,18HCARTER COEFFICIENT,F14.3)
18     CONTINUE
       IF (RF.LT..5) WRITE (6,19)
       IF (RF.GE..5) WRITE (6,20)
19     FORMAT (1H1,45H ARMATURE WINDING (Y-CONNECTED, RANDOM WOUND)//)
20     FORMAT (1H1,43H ARMATURE WINDING (Y-CONNECTED, FORM WOUND)//)
       IF (DW1.EQ.0.) WRITE (6,21) DW
21     FORMAT (1H ,9X,16H STRAND DIAMETER,F32.4,1X6HINCHES)
       IF (DW1.GT.0.) WRITE (6,22) DW,DW1
22     FORMAT (1H ,9X,18H STRAND DIMENSIONS,F30.4,2H X,1X,F6.4,1X,6HINCHE
      1S)
```

```
      WRITE (6,23) SD,SN,SN1,AC,S,CE,HM,EL,ENDEXT,SK,RS,TST,RG1,STATET,E
     1C,PTCH,YY,QN
23    FORMAT (1H ,10X36HDISTANCE BTWN CL OF STRANDS (RADIAL),F11.4//10X,
     133H STRANDS/CONDUCTOR IN RADIAL DIR.,F11.0/10X,24H TOTAL STRANDS/C
     2CNDUCTOR,F20.0/10X,15H CONDUCTOR AREA,F33.4,1X6HSQ-IN./10X,29H CUR
     3RENT DENSITY AT FULL LOAD,F17.2,3X10HAMP/SQ-IN.//10X,27H COIL EXTE
     4NSION BEYOND CORE,F20.3,2X6HINCHES/10X,24H MEAN LENGTH OF 1/2 TURN
     5,F23.3/10X,16H END TURN LENGTH,F31.3/10X19H END TURN EXTENSION,F28
     6.3/10X,17H STATOR SLOT SKEW,F30.3//10X,25H RESISTIVITY AT 20 DEG.
     7C,F23.4,1X16HMICRO OHM INCHES/10X,21H STATOR RESISTANCE AT,F6.0,7H
     8 DEG. C,F14.4,1X4HOHMS//10X,30H NO. OF EFFECTIVE SERIES TURNS,F16.
     92/10X,27H TOTAL EFFECTIVE CONDUCTORS,F19.2/10X,14H WINDING PITCH,F
     $34.4/10X,14H SLOTS SPANNED,F30.0/10X,25H SLOTS PER POLE PER PHASE,
     $F21.2)
      WRITE (6,24) SC,C,PBA,FS,DF,CF
24    FORMAT (1H ,9X,16H CONDUCTORS/SLOT,F28.0/10X,25H NO. OF PARALLEL C
     1IRCUITS,F19.0/10X,17H PHASE BELT ANGLE,F27.0,5X7HDEGREES//10X,12H
     2SKEW FACTOR,F35.3/10X,20H DISTRIBUTION FACTOR,F27.3/10X,13H PITCH
     3FACTOR,F34.3)
      IF (RT.EQ.0.) WRITE (6,25) RD
      IF (RT.GT.0.) WRITE (6,26) RD,RT
25    FORMAT (1HL,14H FIELD WINDING//10X19H CONDUCTOR DIAMETER,F29.4,1X6
     1HINCHES/)
26    FORMAT (1HL,14H FIELD WINDING//10X,21H CONDUCTOR DIMENSIONS,F27.4,
     12H X,1XF6.4,1X6HINCHES/)
      WRITE (6,27) AS,PT,FE,RR,TF,FK1
27    FORMAT (1H ,9X15H CONDUCTOR AREA,F33.4,1X6HSQ-IN.//10X,24H NO. OF
     1TURNS (PER POLE),F20.0/10X20H MEAN LENGTH OF TURN,F27.3,2X6HINCHES
     2//10X25H RESISTIVITY AT 20 DEG. C,F23.4,1X16HMICRO OHM INCHES/10X2
     30H FIELD RESISTANCE AT,F5.0,7H DEG. C,F16.4,1X4HOHMS/17X18H (COILS
     4 IN SERIES))
      WRITE (6,28) HCOIL,BCOIL
28    FORMAT (10X12H COIL HEIGHT,F35.3/10X11H COIL WIDTH,F36.3)
      WRITE (6,29) C1,CP,CM,CQ,D1
29    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
     2CN FACTOR,F16.3/10X,31H CQ, CROSS MAGNETIZATION FACTOR,F12.3/10X,2
     36H D1, POLE FACE LOSS FACTOR,F17.3)
      WRITE (6,30) DI,DU,CL,SS,HC,SF,HV,BV,BK,WL
30    FORMAT (1H1,7H STATOR//10X,23H STATOR INSIDE DIAMETER,F21.2,1X6HIN
     1CHES/10X,24H STATOR OUTSIDE DIAMETER,F20.2/10X,20H OVERALL CORE LE
     2NGTH,F24.2/10X,22H EFFECTIVE CORE LENGTH,F22.2/10X,17H DEPTH BELOW
     3 SLOT,F27.2//10X,16H STACKING FACTOR,F28.2//10X,21H NO. OF COOLING
     4 DUCTS,F21.0/10X,15H WIDTH OF DUCTS,F29.2,1X6HINCHES//10X,13H CORE
     5 LOSS AT,F6.1,17H KILOLINES/SQ.IN.,F7.1,2X9HWATTS/LB.)
      IF (LTS.NE.0.) WRITE (6,31) LTS
31    FORMAT (10X,21H LAMINATION THICKNESS,F24.3,4H IN.)
      WRITE (6,32) PBW,PBL,PBH,RK
32    FORMAT (1HL,6H ROTOR//10X,16H POLE BODY WIDTH,F24.3,7H INCHES/20X,
     113H AXIAL LENGTH,F17.3/20X,7H HEIGHT,F23.3/20X,16H STACKING FACTOR
     2,F14.3)
      IF (LTR.NE.0.) WRITE (6,33) LTR
33    FORMAT (1H ,19X,21H LAMINATION THICKNESS,F9.3,7H INCHES)
      WRITE (6,34) PHW,PHL,PHH,RK1
34    FORMAT (1HK,9X,16H POLE HEAD WIDTH,F24.3,7H INCHES/20X,13H AXIAL L
     1ENGTH,F17.3/20X,7H HEIGHT,F23.3/20X,16H STACKING FACTOR,F14.3)
      IF (LTR1.NE.0.) WRITE (6,33) LTR1
      WRITE (6,35) PE,DR,VR,SIGMA
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35    FORMAT (1HK,9X,13H POLE EMBRACE,F27.3/10X,15H ROTOR DIAMETER,F25.3
     1/10X,17H PERIPHERAL SPEED,F20.0,3X,10H FEET/MIN./10X,23H SPEC. TAN
     2GENTIAL FORCE,F17.3,11H LBS/SQ.IN.)
      WRITE (6,36) DSH,DISH
36    FORMAT (1HK,9X,23H DIAMETER OF ROTOR CORE,F18.3,7H INCHES/10X,34H
     1INSIDE DIAMETER (OF HOLLOW SHAFT),F7.3)
      IF (IBN.EQ.0) WRITE (6,37)
37    FORMAT (1HL,19H DAMPER BARS (NONE))
      IF (DD.EQ.0..AND.IBN.NE.0) WRITE (6,38) H,B
38    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 (6,39) DD
39    FORMAT (1HL,20H DAMPER BARS (ROUND)//10X,20H DAMPER BAR DIAMETER,F
     119.3,1X6HINCHES)
      IF (IBN.NE.0) WRITE (6,40) WO,HD,SB,TB,IBN,RE,T3
40    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//10X,18H TEMPERATURE (HOT
     4),F20.2,2X5HDEG.C)
      WRITE (6,41) WC,RC,WI,WROTOR,WTOTAL
41    FORMAT (1H1,8H WEIGHTS//10X13H STATOR COND.,F17.3,1X6HPOUNDS/10X12
     1H FIELD COND.,F18.3/10X12H STATOR IRON,F18.3/10X,6H ROTOR,F24.3//1
     20X,6H TOTAL/11X18H (ELECTROMAGNETIC),F11.3)
      WRITE (6,42) PC,EW
42    FORMAT (1HL,11H PERMEANCES//10X,16H WINDING LEAKAGE/10X,26H (PER I
     1NCH OF CORE LENGTH)/12X,12H STATOR SLOT,F26.3,18H LINES/AMPERE TUR
     2N,/13X,10HSTATOR END,F27.3)
      IF (IBN.NE.0) WRITE (6,43) PDD,PDQ
43    FORMAT (1HK,9X25H DAMPER-DIRECT (PER INCH),F15.3/10X,18H DAMPER-QU
     1ADRATURE,F22.3)
      WRITE (6,44) P1,P2,P3,P4,PEFF
44    FORMAT (1HL,9X19H P1 POLE HEAD INNER,F21.3/10X17H P2 POLE HEAD END
     1,F23.3/10X19H P3 POLE BODY INNER,F21.3/10X17H P4 POLE BODY END,F23
     2.3/10X23H EFFECTIVE POLE LEAKAGE,F17.3)
      WRITE (6,45) A,XR,XL,XD,XQ,XA,XB,XF,XU
45    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)
      IF (IBN.NE.0) WRITE (6,46) XDD,XDQ
46    FORMAT (1H ,9X24H DAMPER LEAKAGE (DIRECT),F19.3/10X,23H DAMPER LEA
     1KAGE (QUAD.),F20.3)
      WRITE (6,47) XX,XY,XN,SI,TF,TC,TTC,TST,TA
47    FORMAT (1H ,9X22H SUBTRANSIENT (DIRECT),F21.3/10X21H SUBTRANSIENT
     1(QUAD.),F22.3/10X18H NEGATIVE SEQUENCE,F25.3//10X22H FIELD SELF IN
     2DUCTANCE,F21.3,1X7HHENRIES//10X27H OPEN CIRCUIT TIME CONSTANT/13X,
     316H (FIELD ONLY, AT,F4.0,8H DEG. C),F14.5,1X7HSECONDS/10X24H TRANS
     4IENT TIME CONSTANT,F21.5/10X23H ARMATURE TIME CONSTANT/13X12H (WIN
     5DING AT,F4.0,8H DEG. C),F18.5)
      RETURN
      END
```
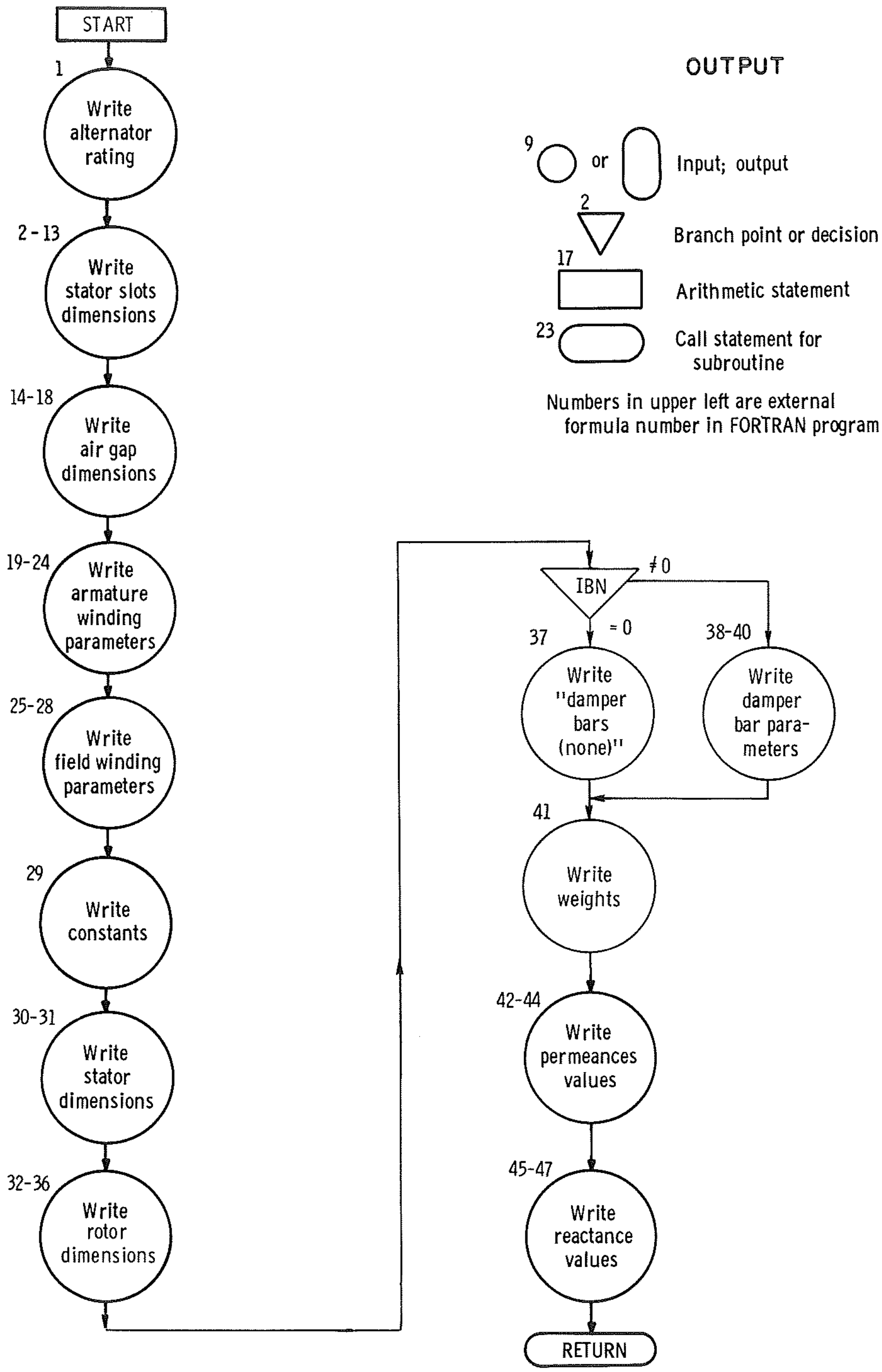
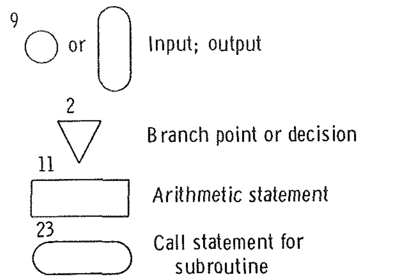
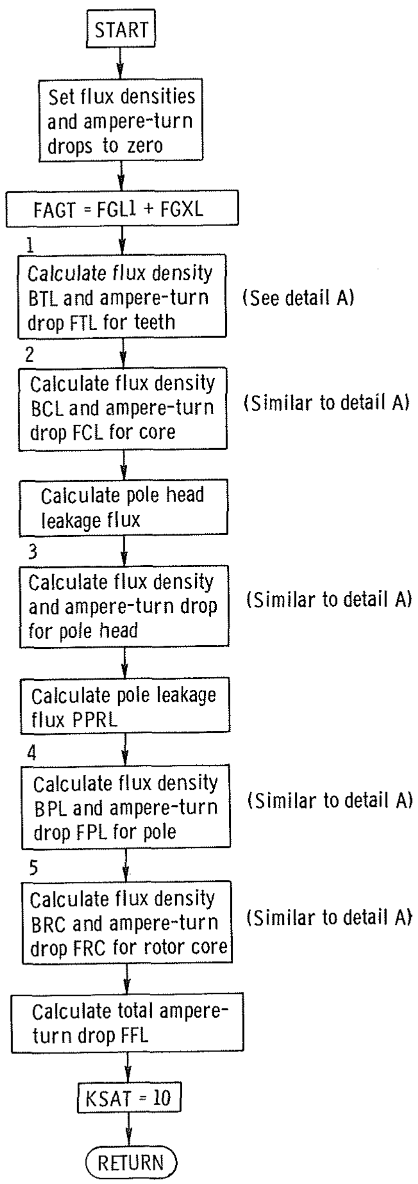


OUTPUT
9 or Input; output
2 Branch point or decision
17 Arithmetic statement
23 Call statement for subroutine
Numbers in upper left are external formula number in FORTRAN program
START
1 Write alternator rating
2 - 13 Write stator slots dimensions
14-18 Write air gap dimensions
19-24 Write armature winding parameters
25-28 Write field winding parameters
29 Write constants
30-31 Write stator dimensions
32-36 Write rotor dimensions
IBN
≠ 0
= 0
37 Write "damper bars (none)"
38-40 Write damper bar parameters
41 Write weights
42-44 Write permeances values
45-47 Write reactance values
RETURN

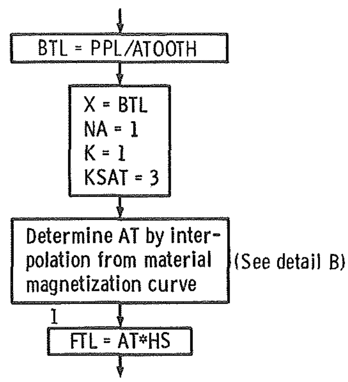
```
      SUBROUTINE MAGNET
C
      COMMON A,AA,AB,AC,ACORE,AI,ALPHAE,ALPHAR,ALPHAS,APOLE,APOLHD,ARCOR
     1E,AS,ATOOTH,B,B1,B2,B3,BCL,BCOIL,BG,BK,BN,BO,BPL,BRC,BS,BTL,BV,C,C
     21,CC,CCR,CE,CF,CL,CM,CQ,CP,D1,DCORE,DD,DF,DI,DISH,DR,DRCORE,DSH,DU
     3,DW,DW1,EC,EE,EL,ENDEXT,EP,EW,F,FCL,FE,FFL,FGL1,FGML,FGXL,FH,FK1,F
     4PL,FQ,FRC,FS,FTL,G,GA,GC,GE,GP,H,HC,HCOIL,HD,HM,HO,HS,HT,HV,HW,HX,
     5HY,IBN,IPN,IPX,IQQ,IWF,IZZ,KSAT,LTR,LTR1,LTS,P1,P2,P3,P4,PBA,PBH,P
     6BL,PBW,PC,PDD,PDQ,PE,PEFF,PF,PFC,PHH,PHL,PHW,PI,PN,PPL,PPRL,PT,PTC
     7H,PX,QN,QQ,RC,RD,RE,RF,RG1,RK,RK1,RPM,RR,RS,RT,RY,S,SB,SC,SD,SF,SH
     8,SI,SIGMA,SK,SN,SN1,SS,STATET,T1,T11,T2,T22,T3,T33,TA,TB,TC,TF,TG,
     9TS,TST,TT,TTC,VA,VMIN,VR,WC,WI,WL,WO,WROTOR,WTOTAL,XA,XB,XD,XDD,XD
     $Q,XF,XL,XN,XQ,XR,XU,XX,XY,YY,ZG,ZZ
C
      DIMENSION G(5), PFC(5), AI(60)
C
      INTEGER ZZ
C
      REAL LTS,LTR,LTR1
C
      BPL=0.
      BTL=0.
      BCL=0.
      BRC=0.
      FFL=0.
      FPL=0.
      FCL=0.
      FTL=0.
      FRC=0.
      PPRL=0.
      FAGT=FGL1+FGXL
C
C     FLUX DENSITY AND AMPERE-TURNS FOR TEETH
C
      BTL=PPL/ATOOTH
      X=BTL
      NA=1
      K=1
      KSAT=3
      GO TO 6
1     FTL=AT*HS
C
C     FLUX DENSITY AND AMPERE-TURNS FOR CORE
C
      BCL=PPL/(2.0*ACORE)
      X=BCL
      NA=1
      KSAT=4
      K=2
      GO TO 6
```

```
2       FCL=AT*DCORE
C
C       POLE HEAD LEAKAGE FLUX
C
        PPRL=(FAGT+FTL+FCL)*(2.0*(P1+P2))*0.001
C
C       FLUX DENSITY AND AMPERE-TURNS FOR ROTOR POLE HEAD
C
        BPL=(PPL+PPRL)/APOLHD
        X=BPL
        NA=31
        KSAT=1
        K=3
        GO TO 6
3       FPL=AT*PHH
C
C       FLUX DENSITY AND AMPERE-TURNS FOR ROTOR POLE BODY
C
        XXX=FAGT+FTL+FCL+FPL
        PPRL=PPRL+XXX*(P3+P4)*.001
        X=(PPL+PPRL)/APOLE
        BPL=AMAX1(BPL,X)
        KSAT=1
        K=5
        NA=31
        GO TO 6
4       FPL=FPL+AT*PBH
C
C       FLUX DENSITY AND AMPERE-TURNS FOR ROTOR CORE
C
        BRC=(PPL+PPRL)/(2.0*ARCORE)
        X=BRC
        NA=31
        KSAT=2
        K=4
        GO TO 6
5       FRC=AT*DRCORE
C
C       TOTAL AMPERE-TURNS
C
        FFL=FAGT+FTL+FCL+FPL+FRC
        KSAT=10
        RETURN
C
C       INTERPOLATION PROCEDURE FOR MATERIAL CURVES
C
6       IF (AI(NA).LT.X) GO TO 10
        NA=NA+3
7       IF (AI(NA)-X) 8,9,9
8       NA=NA+2
        GO TO 7
9       XX=(AI(NA)-AI(NA-2))/(ALOG(AI(NA+1)/(AI(NA-1)+0.0001)))
        Y=AI(NA)-XX*ALOG(AI(NA+1))
        AT=EXP((X-Y)/XX)
        GO TO (1,2,3,5,4),K
10      RETURN
        END
```

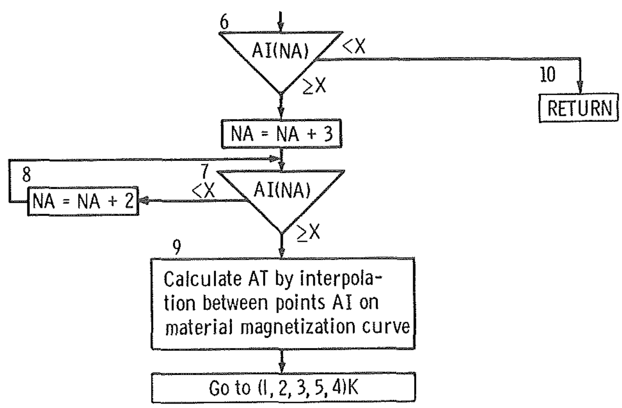


Numbers in upper left are external formula number in FORTRAN program



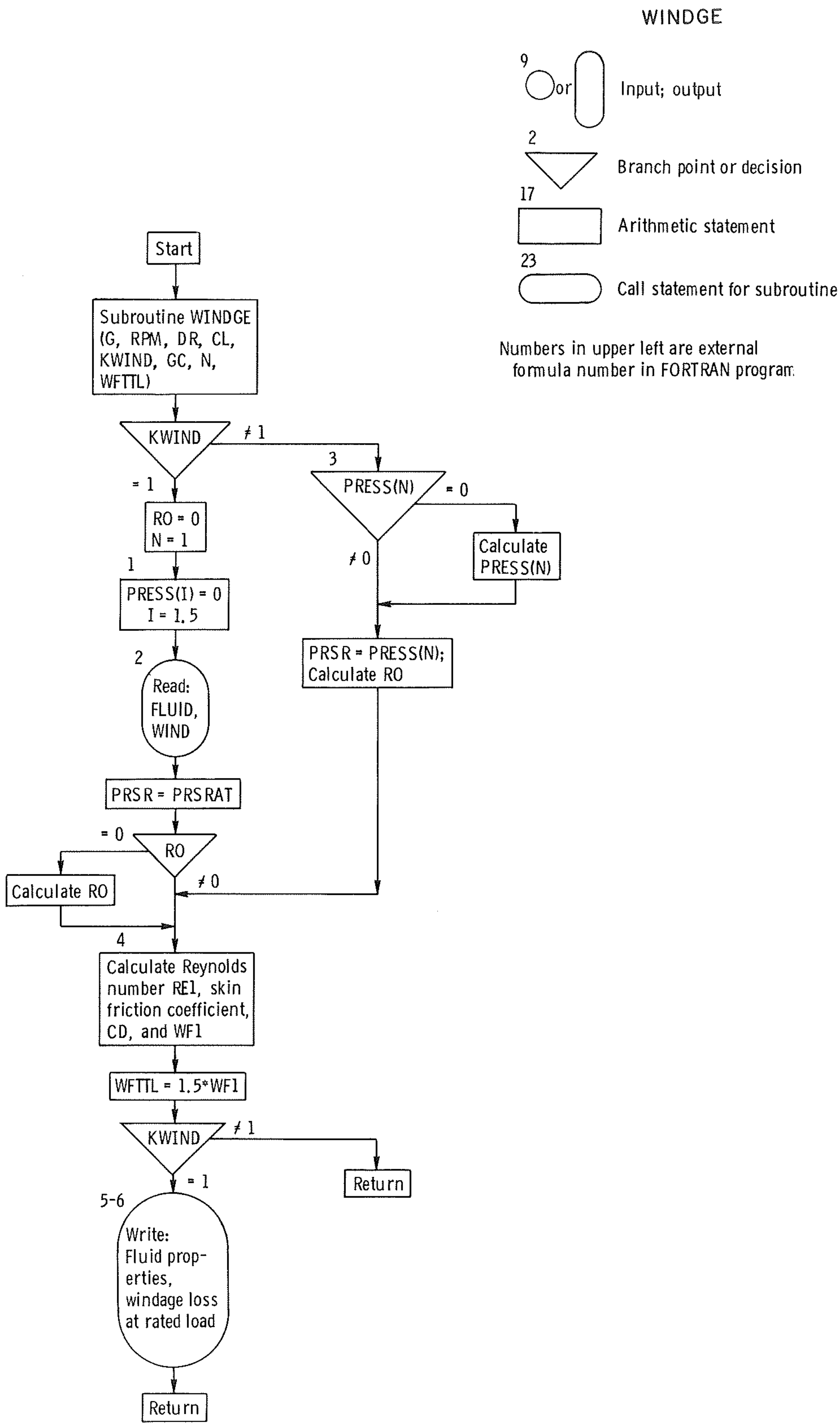


Detail A



Detail B

```
      SUBROUTINE WINDGE (G,RPM,DR,CL,KWIND,GC,N,WFTTL)
      DIMENSION G(5), PRESS(5), FLUID(6)
      REAL M
      NAMELIST /WIND/ VIS,PRESS,PRSRAT,M,TEMP,RO
      IF (KWIND.NE.1) GO TO 3
      RO=0
      N=1
      DO 1 I=1,5
1     PRESS(I)=0.
      READ (5,2) FLUID
2     FORMAT (6A6)
      READ (5,WIND)
      PRSR=PRSRAT
      IF (RO.EQ.0.) RO=(PRSR*M*5.18E-02)/(TEMP+273.0)
      GO TO 4
3     IF (PRESS(N).EQ.0.) PRESS(N)=PRSRAT*G(N)
      PRSR=PRESS(N)
      RO=(PRSR*M*5.18E-02)/(TEMP+273.0)
C
C     MAIN AIR GAP
C
4     RE1=3.14159*(DR/2.0)*GC*RPM*RO/(30.*144.*VIS)
      A=ALOG(RE1)
      IF (RE1.LT.7000.) CD=10.59346-1.78872*A+.08205*A**2
      IF (RE1.GE.7000.) CD=15.45399-2.81449*A+.135502*A**2
      CD=EXP(CD)*1.0E-03
      IF (RE1.GT.32000.) CD=2.25E-03
      WF1=(6.107E-10)*CD*RO*(RPM**3)*((DR/2.0)**4)*CL
      WFTTL=1.5*WF1
      IF (KWIND.NE.1) RETURN
C
      WRITE (6,5) FLUID,VIS,RO,PRSRAT,TEMP,M
5     FORMAT (1H1,22H WINDAGE AT RATED LOAD//10X20H FLUID PROPERTIES OF,
     11X6A6//13X,10H VISCOSITY,1PE25.3,11H LBS/SEC-FT/13X8H DENSITYOPF24
     2.4,11H LBS/CU.FT./13X,9H PRESSURE,0PF21.2,11H LBS/SQ. IN/13X,12H T
     3EMPERATURE,F18.2,7H DEG. C/13X,17H MOLECULAR WEIGHT,F13.2)
      WRITE (6,6) RE1,WFTTL
6     FORMAT (1HK,9X,16H REYNOLDS NUMBER,F17.2//10X13H WINDAGE LOSS,F20.
     12,1X5HWATTS)
      RETURN
      END
```



WINDGE
9
or
Input; output
2
Branch point or decision
17
Arithmetic statement
23
Call statement for subroutine
Numbers in upper left are external formula number in FORTRAN program
Start
Subroutine WINDGE (G, RPM, DR, CL, KWIND, GC, N, WFTTL)
KWIND
≠ 1
= 1
RO = 0
N = 1
1
PRESS(I) = 0
I = 1, 5
2
Read: FLUID, WIND
PRSR = PRSRAT
= 0
RO
≠ 0
Calculate RO
3
PRESS(N)
= 0
Calculate PRESS(N)
≠ 0
PRSR = PRESS(N); Calculate RO
4
Calculate Reynolds number RE1, skin friction coefficient, CD, and WF1
WFTTL = 1.5*WF1
KWIND
≠ 1
= 1
Return
5-6
Write: Fluid properties, windage loss at rated load
Return

APPENDIX D

DEFINITION OF FORTRAN VARIABLES

The following is an alphabetic list of the FORTRAN variables used in the program. Each variable is defined, and the units used in the program for each variable are given. Variables that are subscripted (dimensional) or that are permissible program input are identified by a + or *, respectively. In addition to some of the previous figures included in the report, figures 17 and 18 are used in the definitions of the FORTRAN variables.

	A	ampere conductors per inch of stator periphery, A/in.
	A	dummy variable used in subroutine WINDGE
	AA	dummy variable used for variety of calculations
	AB	dummy variable used for variety of calculations
	ABASE	area used in pole weight calculations, $in.^2$
	AC	armature conductor area, $in.^2$
	ACORE	stator core cross-sectional area used in magnetic calculations, $in.^2$
	AG	specific air gap permeance per pole, lines/(A-turn)(in.)
*+	AI	coordinates of points on material magnetization curves (see figs. 9 and 17)
	AIRGAP	NAMELIST name
+	AKVA	alternator output at load G, kVA
	ALPHA	angle used in end-turn length calculations (see fig. 18), rad
*	ALPHAE	temperature coefficient of RE, per ^{o}C
*	ALPHAR	temperature coefficient of RR, per ^{o}C
*	ALPHAS	temperature coefficient of RS, per ^{o}C
	AN	power factor angle (see fig. 4), rad
	APBODY	area used in pole weight calculations, $in.^2$
	APHEAD	area used in pole weight calculations, $in.^2$
	APOLE	pole area used in magnetic calculations, $in.^2$
	APOLHD	pole head area used in magnetic calculations, $in.^2$
	ARCORE	rotor core cross-sectional area used in magnetic calculations, $in.^2$

	AS	field conductor area, $in.^2$
	AT	ampere-turns per inch at flux density X for magnetic materials (see fig. 17), A-turn/in.
	ATIP	area used in pole weight calculations, $in.^2$
	ATOOTH	tooth area used in magnetic calculations, $in.^2$
*	B	rectangular damper bar width, in.
	B1	stator slot dimension (see fig. 10), in.
	B2	stator slot dimension (see fig. 10), in.
*	B3	stator slot dimension (see fig. 10), in.
	BARD	damper bar equivalent diameter used in loss calculations, in.
	BB	displacement angle (see fig. 4), rad
	BCL	stator core flux density, $kilolines/in.^2$
+	BCLL	stator core flux density, $kilolines/in.^2$
*	BCOIL	field coil width (see fig. 14), in.
	BD	used in damper bar leakage permeance calculations
	BE	used in damper bar leakage permeance calculations
	BETA	angle used in pole weight calculations, rad
	BG	main air-gap flux density (no-load rated voltage), $kilolines/in.^2$
*	BK	flux density at which core loss WL is specified, $kilolines/in.^2$
*	BN	number of damper bars per pole
*	BO	stator slot dimension (see fig. 10), in.
	BPL	pole flux density, $kilolines/in.^2$
+	BPLL	pole flux density, $kilolines/in.^2$
	BRC	rotor core flux density, $kilolines/in.^2$
+	BRCORL	rotor core flux density, $kilolines/in.^2$
*	BS	stator slot dimension (see fig. 10), in.
	BT	dummy variable used in slot and end turn leakage permeance calculations
	BTL	tooth flux density, $kilolines/in.^2$
+	BTLL	tooth flux density, $kilolines/in.^2$

*	BV	width of cooling ducts, in.
*	BX	thickness of armature coil at end-turn (see fig. 11), in.
*	C	number of parallel armature circuits per phase
*	C1	ratio of fundamental maximum to actual maximum value of field form
	CALPHA	cosine of alpha
	CC	Carter coefficient for stator slots
	CCR	Carter coefficient for rotor slots
	CD	skin friction coefficient of gas in alternator air gap
+	CDD	current density in field winding, $A/in.^2$
*	CE	armature coil extension (see fig. 11), in.
	CF	pitch factor
	CK	power-factor adjustment factor
*	CL	length of stator stack (axial direction), in.
*	CM	demagnetizing factor (direct axis)
+	CMPNT	array of names used in saturation message printout
*	CP	ratio of average to maximum value of field form
*	CQ	cross-magnetizing factor (quadrature axis)
	CS	armature winding pitch, per unit
	CW	winding constant
	CX	used in armature conductor slot leakage permeance calculations
	CY	used to calculate area correction D, $in.^2$
	CZ	used to calculate area correction D, $in.^2$
	D	used in distribution factor calculation
	D	area correction for corner radii in rectangular conductors, $in.^2$
*	D1	pole face loss factor
	D2	factor used in pole-face loss calculation
	D3	factor used in pole-face loss calculation
	D4	factor used in pole-face loss calculation
	D5	factor used in pole-face loss calculation
	D6	factor used in pole-face loss calculation

+	DA	used to calculate area correction D, $in.^2$
	DAMPER	NAMELIST name
	DB	diameter of bender pin for forming armature coils, in.
	DCORE	stator core length used in magnetic calculations, in.
*	DD	damper bar diameter, in.
	DF	distribution factor
	DG	maximum dimension of rectangular conductor, in.
*	DI	stator inside diameter, in.
*	DISH	rotor inside diameter (for rotor with center hole) (see fig. 14), in.
+	DL	damper bar loss, W
	DR	rotor diameter at main air gap, in.
	DRCORE	rotor core length used in magnetic calculations, in.
*	DSH	outside diameter of rotor core (see fig. 14), in.
	DT	minimum dimension of rectangular conductors, in.
*	DU	stator outside diameter, in.
*	DW	armature conductor strand diameter or width (see fig. 11), in.
*	DW1	armature conductor strand height (uninsulated) (see fig. 11), in.
+	DX	used in rectangular conductor area calculation, $in.^2$
+	DY	used in rectangular conductor area calculation, $in.^2$
+	DZ	used in rectangular conductor area calculation, $in.^2$
+	E	alternator electromagnetic efficiency, percent
+	E1	alternator overall efficiency, percent
	EB	eddy factor (bottom)
	EC	number of effective armature conductors
	EDD	excitation voltage, per unit
*	EE	line-to-line rated alternator voltage, V rms
+	EF	field voltage per coil, V dc
	EK	leakage reactance factor for armature winding end-turns
*	EL	length of end-turn for armature coil, in.

	ENDEXT	horizontal extension of armature coil end-turn beyond stator core (see fig. 18), in.
*	EP	line-to-neutral rated alternator voltage, V rms
	ET	eddy factor (top)
	EW	specific armature conductor end-turn leakage permeance, lines/(A-turn)(in.)
+	EX	eddy loss, W
+	EZ	eddy factor (average)
*	F	frequency, Hz
	FACTOR	used in armature conductor slot leakage permeance calculations
	FAGT	FGL1 + FGXL, A-turn
	FCL	stator core ampere turns, A-turn
+	FCLL	stator core ampere turns, A-turn
+	FDMLL	direct-axis demagnetizing ampere turns per pole at load G, A-turn
*	FE	mean length of one field coil turn, in.
	FF	used in armature conductor slot leakage permeance calculations
	FFL	total ampere turns, A-turn
+	FFLL	total ampere turns, A-turn
	FGL1	main air gap ampere turns, A-turn
+	FGLL1	main air gap ampere turns, A-turn
	FGML	maximum demagnetizing ampere turns per pole at rated load, A-turn
	FGXL	direct-axis demagnetizing ampere turns per pole at load G, A-turn
	FH	air-gap ampere turns per pole (no-load rated voltage), A-turn
+	FI	field current per coil, A
	FIELD	NAMELIST name
	FIMM	field current at rated load, A
	FK1	field winding resistance at temperature TF, ohm
*+	FLUID	name of gas in alternator air gap
	FNQ	used in distribution factor calculation
	FPL	pole ampere turns, A-turn

+	FPLL	pole ampere turns, A-turn
	FQ	flux per pole (no-load rated voltage), kilolines
+	FQLL	flux per pole at no-load voltage QPERV, kilolines
	FRC	rotor core ampere turns, A-turn
+	FRCORL	rotor core ampere turns, A-turn
	FS	skew factor
	FS1	factor used in damper bar loss calculations
	FS2	factor used in damper bar loss calculations
	FSC	short-circuit ampere turns for rated armature current, A-turn
	FTL	tooth ampere turns, A-turn
+	FTLL	tooth ampere turns, A-turn
*+	G	volt-ampere alternator output at which load characteristics are calculated, per unit or percent
	GA	main air-gap area, $in.^2$
*	GC	minimum air gap (air gap at center of pole) (see fig. 12), in.
	GE	effective main air-gap, in.
	GF	constant used in load pole-face loss calculation
	GM	factor used in load pole-face and damper loss calculations
*	GP	maximum air gap (see fig. 12), in.
	GT	ratio of stator slot opening width to main air-gap
	GXX	flux per pole multiplying factor (see fig. 4)
*	H	rectangular damper bar height, in.
	HC	stator depth below slot, in.
*	HCOIL	field coil height (see fig. 14), in.
*	HD	damper bar slot opening height, in.
	HM	armature conductor length (= 1/2 coil length), in.
*	HO	stator slot dimension (see fig. 10), in.
*	HS	stator slot dimension (see fig. 10), in.
*	HT	stator slot dimension (see fig. 10), in.
*	HV	number of stator cooling ducts

	HW	stator slot dimension (see fig. 10), in.
*	HX	stator slot dimension (see fig. 10), in.
*	HY	stator slot dimension (see fig. 10), in.
	I	used as index
	IA	used as index
	IBN	number of damper bars
	IC	number of parallel armature circuits per phase
	IDELR	increment by which QPERV is increased, percent
	IDM	(integer) × (number of poles) × (number of phases)
	IIQQ	used to calculate distribution factor for fractional slot winding
	IPN	number of phases
*	IPX	number of poles
*	IQQ	number of stator slots
*	IWF	index to specify if windage loss is to be calculated (see table III under NAMELIST name AIRGAP)
	IZY	(number of poles) × (number of phases)
	IZZ	type of stator slot (see fig. 10)
	J	used as index
	JA	number of load calculations made before alternator saturates
	K	used as index
	KSAT	saturation indicator (if KSAT = 10 alternator is saturated)
	KWIND	index used in conjunction with subroutine OUTPUT
	LT	dummy variable used in determination of stacking factors
*	LTR	rotor pole body lamination thickness, in.
*	LTR1	rotor pole head lamination thickness, in.
*	LTS	stator lamination thickness, in.
*	M	molecular weight of gas in alternator air gap
	M	used as index
	MAGNET	subroutine name
	MM	subscript of load point G such that G(MM) = 1.0

	N	used as index
	NA	used as index
	NPF	number of power factors for which load calculations are made
	OUTPUT	subroutine name
	P1	leakage permeance between inner pole head surfaces (see fig. 3), lines/A-turn
	P2	leakage permeance between pole head end surfaces (see fig. 3), lines/A-turn
	P3	leakage permeance between inner pole body surfaces (see fig. 3), lines/A-turn
	P4	leakage permeance between pole body end surfaces (see fig. 3), lines/A-turn
*	PBA	phase belt angle, deg
*	PBH	pole body height (see fig. 13), in.
*	PBL	pole body length (see fig. 13), in.
*	PBW	pole body width (see fig. 13), in.
	PC	specific armature conductor slot leakage permeance, lines/(A-turn)(in.)
	PDD	specific permeance of damper bars in direct axis, lines/(A-turn)(in.)
	PDQ	specific permeance of damper bars in quadrature axis, lines/(A-turn)(in.)
*	PE	pole embrace
	PEFF	effective pole leakage permeance = 2(P1 + P2) + P3 + P4, lines/A-turn
	PF	design power factor
	PF	power factor at which load characteristics are calculated
*+	PFC	power factors at which load characteristics are calculated
*	PHH	pole head height (see fig. 13), in.
*	PHL	pole head length (see fig. 13), in.
*	PHW	pole head width (see fig. 13), in.
	PI	rated line current, A
	PN	number of phases
	POL	dummy variable

+	PP	pole-face losses under load, W
	PPL	flux per pole in main air gap, stator core, and teeth, kilolines
	PPRL	leakage flux per pole, kilolines
+	PPRLL	leakage flux per pole, kilolines
+	PR	field copper loss, W
*+	PRESS	array of gas pressures in alternator air gap corresponding to load points G, $lb/in.^2$
	PRSR	gas pressure in alternator air gap, $lb/in.^2$
*	PRSRAT	gas pressure in alternator air gap at rated load VA, $lb/in.^2$
+	PS	armature copper loss, W
*	PT	number of field coil turns per pole
*	PTCH	stator winding pitch, per unit
	PX	number of poles
	Q1	used in damper bar loss calculations
	Q2	used in damper bar loss calculations
	Q3	used in damper bar loss calculations
	Q4	used in damper bar loss calculations
	Q5	used in damper bar loss calculations
	QC	used in Carter coefficient calculation
	QN	slots per pole per phase
+	QPERV	voltage points on no-load saturation curve, percent
	QQ	number of stator slots
+	QVLL	line-to-line voltage on no-load saturation curve, V rms
+	QVLN	line-to-neutral voltage on no-load saturation curve, V rms
	QZ	used in damper bar loss calculations
	RATING	NAMELIST name
	RB	resistivity of stator conductor at temperature TTA, μohm-in.
	RC	field coil weight (total of all coils), lb
*	RD	field conductor diameter or width, in.
*	RE	damper bar resistivity at 20° C, μohm-in.

	RE1	Reynolds number of gas in alternator air gap
*	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 temperatures T3 and T33, μohm-in.
*+	RMAT	rotor material name
*	RO	density of gas in alternator air gap at rated load VA, lb/ft^3
	ROTOR	NAMELIST name
*	RPM	rotor speed, rpm
*	RR	field coil resistivity at 20° C, μohm-in.
+	RRA	armature winding resistance, ohm
+	RRB	field coil resistance, ohm
*	RS	armature conductor resistivity at 20° C, μohm in.
*	RT	field conductor thickness, in.
	RY	RRA/RB, $\mu in.^{-1}$
	S	armature winding current density at rated load, $A/in.^2$
	SALENT	main program name
	SALPHA	sine of alpha
*	SB	damper bar length, in.
*	SC	number of armature conductors per stator slot
	SCR	short circuit ratio
*	SD	distance between centerlines of armature winding strands in depth (see fig. 11), in.
*	SEP	clearance between armature winding end-turns (see fig. 11), in.
*	SF	stator stacking factor
	SH	armature conductor strand height (uninsulated), in.
	SI	field self-inductance, H
	SIGMA	specific tangential force on rotor, $lb/in.^2$
*	SK	stator slot skew at stator inside diameter, in.

	SLOTS	NAMELIST name
	SM	tooth width at 1/3 distance from narrowest section, in.
*+	SMAT	stator material name
*	SN	strands per armature conductor in depth
*	SN1	total strands per armature conductor
+	SP	total losses, W
	SS	solid stator stack length, in.
+	ST	stator tooth loss, W
	STATET	number of effective armature winding turns
	STATOR	NAMELIST name
	STFK	stacking factor (dummy variable)
	STRLEN	length of straight part of armature winding end-turn (see fig. 18), in.
*	T1	armature winding temperature at rated load, $^{\circ}C$
*	T11	armature winding temperature at no-load, $^{\circ}C$
*	T2	field winding temperature at rated load, $^{\circ}C$
*	T22	field winding temperature at no-load, $^{\circ}C$
*	T3	hot damper bar temperature, $^{\circ}C$
*	T33	cold damper bar temperature, $^{\circ}C$
	TA	armature time constant, sec
*	TB	damper bar pitch, in.
	TC	open-circuit time constant (field only), sec
*	TEMP	temperature of gas in alternator air gap, $^{\circ}C$
*	TF	field coil temperature at which FK1 and TC are calculated, $^{\circ}C$
	TG	total air-gap flux at no-load, rated voltage, kilolines
	THETA	angle used in pole weight calculations, rad
	TP	pole pitch, in.
	TS	stator slot pitch at stator inside diameter, in.
*	TST	armature winding temperature at which RG1 and TA are calculated, $^{\circ}C$
	TT	stator slot pitch at 1/3 distance from narrowest section, in.

+	TTA	armature winding temperature, ^{o}C
+	TTB	field winding temperature, ^{o}C
	TTC	transient time constant, sec
	U	used to calculate end-turn length
	UA	= G(M), per unit
	UU	used to calculate end-turn length
	V1	used in damper bar loss calculations
	V2	used in damper bar loss calculations
*	VA	rating of alternator, kVA
	VC	used in damper bar loss calculations
	VG	used in damper bar loss calculations
*	VIS	viscosity of gas in alternator air gap, lb/sec-ft
*	VMIN	minimum voltage at which no-load saturation curve is calculated, per unit
	VR	rotor peripheral velocity at main air-gap, ft/min
	VS	used in damper bar loss calculations
	VT	used in damper bar loss calculations
	VV	rating of alternator, W
	W2	used in damper bar loss calculations
	W3	used in damper bar loss calculations
	W5	used in damper bar loss calculations
+	WA	alternator output power, kW
	WC	armature winding weight (copper only), lb
	WD	no-load damper loss at temperature T3, W
	WF1	windage loss in alternator air gap neglecting stator slots, W
	WFTTL	windage loss in alternator air gap including stator slots, W
	WI	stator iron weight, lb
	WIND	NAMELIST name
	WINDGE	subroutine name
	WINDNG	NAMELIST name

*	WL	core loss at flux density BK, W/lb
+	WMIS	miscellaneous load losses, W
	WN	no-load pole-face loss, W
+	WND	windage loss, W
*	WO	damper bar slot opening width, in.
	WPOLE	weight of one rotor pole, lb
	WQ	no-load rated voltage core loss, W
+	WQL	core loss, W
	WRCORE	weight of rotor core, lb
*	WROTOR	rotor weight, lb
	WT	no-load rated-voltage tooth loss, W
	WTOTAL	total electromagnetic weight, lb
	WU	no-load damper loss at temperature T33, W
	WW	no-load damper loss (dummy variable), W
	X	flux density at which AT is found by interpolation (see fig. 17), kilolines/in.^{2}
	XA	synchronous reactance (direct), percent
	XB	synchronous reactance (quadrature), percent
	XD	armature reaction reactance (direct), percent
	XDD	damper leakage reactance (direct), percent
	XDQ	damper leakage reactance (quadrature), percent
	XF	field winding leakage reactance, percent
	XI	angle between line current phasor and direct-axis (internal power factor angle) (see fig. 4), rad
	XL	stator winding leakage reactance, percent
	XN	negative sequence reactance, percent
	XQ	armature reaction reactance (quadrature), percent
	XR	reactance factor
	XU	transient reactance (direct), percent
	XX	subtransient reactance (direct), percent

	XX	slope of magnetization curve at flux density X (see fig. 17)
	XXX	dummy variable used in variety of calculations
	XY	subtransient reactance (quadrature), percent
	Y	used in interpolation procedure of material curves
*	YY	slots spanned per armature coil (number of slots between coil sides +1)
	Z	used in armature conductor slot leakage permeance calculations
	ZA	used in armature conductor slot leakage permeance calculations
	ZB	used in armature conductor slot leakage permeance calculations
	ZC	used in armature conductor slot leakage permeance calculations
	ZD	used in armature conductor slot leakage permeance calculations
	ZE	used in armature conductor slot leakage permeance calculations
	ZF	used in armature conductor slot leakage permeance calculations
	ZG	(length of field winding conductor)/(field conductor area), in.^{-1}
	ZY	= 0.7HS, in.
	ZY	used as an index in armature and field conductor area calculations
*	ZZ	type of stator slot (see fig. 10)

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9. Pollard, E. I.: Load Losses in Salient Pole Synchronous Machines. AIEE Trans., vol. 54, 1935, pp. 1332-1340.
10. Pollard, E. I.: Calculation of No-Load Damper Winding Losses in Synchronous Machines. AIEE Trans., vol. 51, 1932, pp. 477-481.
11. Gorland, Sol H.; Kempke, Erwin E., Jr.; and Lumannick, Stacey: Experimental Windage Losses for Close Clearance Rotating Cylinders in the Turbulent Flow Regime. NASA TM X-52851, 1970.
12. Gorland, Sol H.; and Kempke, Erwin E., Jr.: Experimental Windage Losses for a Lundell Generator Operating in Air in the Turbulent-Flow Regime. NASA TM X-52905, 1970.
13. Kilgore, L. A.: Calculation of Synchronous Machine Constants - Reactances and Time Constants Affecting Transient Characteristics. AIEE Trans., vol. 50, 1931, pp. 1201-1214.

TABLE I. - SUMMARY OF CALCULATIONS FOR PPL, FGL1, AND FGXL

	No-load rated-voltage magnetization characteristics	Alternator load characteristic (rated voltage)	No-load saturation data
Flux per pole (PPL)	PPL = FQ	For power factor <0.95 PPL = FQ · (length of $\overline{OP}$[a]) For power factor ≥0.95 PPL = FQ · (length of $\overline{OP}$) · 1.10	PPL = EDD · FQ
Air-gap ampere-turns per pole (FGL1)	FGL1 = FH	For power factor <0.95 FGL1 = FH · (length of $\overline{OP}$[a]) For power factor ≥0.95 FGL1 = FH · (length of $\overline{OP}$) · 1.10	FGL1 = EDD · FH
Demagnetizing ampere-turns (direct axis) (FGXL)	FGXL = 0	FGXL = FGML · G · sin(XI)[a]	FGXL = 0

[a]$\overline{OP}$ and XI are obtained from vector diagram shown in fig. 4.

TABLE II. - DEFINITION OF INPUT VARIABLES USED WITH MATERIAL DECKS

Card	FORTRAN symbol	Format	Description of data
1	SMAT	6A6	Stator material name
2 - 5	AI(J), 1≤J≤29	8F10.1	AI(1) is the saturation flux density of the stator material; AI(2) to AI(29) are, alternately, values of flux density (kilolines/in.^{2}) and magnetizing force (A-turn/in.) for 14 points on the stator material magnetization curve; the 14 points are arranged in order of increasing flux density; note that AI(1) = AI(28)
6	RMAT	6A6	Rotor material name
7 - 10	AI(J), 31≤J≤59	8F10.1	AI(31) is the saturation flux density of the rotor material; AI(32) to AI(59) are, alternately, values of flux density (kilolines/in.^{2}) and magnetizing force (A-turn/in.) for 14 points on the material magnetization curve; the 14 points are arranged in order of increasing flux density; note that AI(31) = AI(58)

TABLE III. - DEFINITION OF INPUT VARIABLES USED WITH ALTERNATOR DESIGN DECK

NAMELIST name	FORTRAN symbol	Definition	Classification (a)	Remarks
RATING	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	
	G	Volt-ampere load at which load characteristics are calculated, 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. If, at some value of G, the alternator saturates, then G will be decreased in steps of 0.1 until saturation no longer occurs
	PFC	Power factors at which load characteristics are calculated	M	PFC is a subscripted variable (array size is 5); one or more values must be read in; the first value will be assumed to be the design power factor
	VMIN	Lowest voltage for which a point on the open-circuit saturation curve will be calculated, per unit	O	If not read in, VMIN = 0.70 will be assumed
STATOR	DI	Stator inside diameter, in.	M	--------------------------------------
	DU	Stator lamination outside diameter, in.	M	--------------------------------------
	CL	Length of 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 is 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, kilolines/in.^{2}	M	--------------------------------------
SLOTS	ZZ	Stator slot type	M	See fig. 10
	BO	Slot dimension (use with slot types 2, 3, and 4), in.	C	↓
	B3	Slot dimension (use with slot type 3), in.	↓	↓
	BS	Slot dimension (use with slot types 1, 2, 4, and 5), in.	↓	↓
	HO	Slot dimension (use with slot types 2, 3, and 4), in.	↓	↓
	HX	Slot dimension (use with slot types 1, 2, 3, and 5), in.	↓	↓
	HY	Slot dimension (use with slot types 1, 2, 3, and 5), in.	↓	↓
	HS	Slot dimension (use with slot types 1, 2, 3, 4, and 5), in.	M	↓
	HT	Slot dimension (use with slot types 2 and 3), in.	C	↓
	IQQ	Number of stator slots	M	--------------------------------------

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

TABLE III. - Continued. DEFINITION OF INPUT VARIABLES USED WITH ALTERNATOR DESIGN DECK

NAMELIST name	FORTRAN symbol	Definition	Classification (a)	Remarks
WINDNG	RF	Type of armature coil	M	RF = 1.0 for form wound coil; RF = 0 for random wound coil
	SC	Number of conductors per stator slot	M	In fig. 11, SC = 4
	YY	Slots spanned per coil (number of slots between coil sides plus one)	C	Either one must be read in, or both may be read in
	PTCH	Armature winding pitch, per unit	C	
	C	Number of parallel circuits per phase	M	-------------------------------------
	DW	Strand diameter or width, in.	M	See fig. 11
	SN	Strands per armature conductor in depth (radial direction)	C	Read for rectangular wire only (in fig. 11, SN = 2)
	SN1	Total strands per armature conductor	M	In fig. 11, SN = 4
	DW1	Uninsulated strand thickness (radial direction), in.	C	Read for rectangular wire only; see fig. 11
	CE	Armature coil extension, in.	M	See fig. 11
	SD	Distance between centerline of strands in depth, in.	M	See fig. 11
	PBA	Phase belt angle, deg	O	If not read in, program assumes PBA = 60°
	SK	Stator slot skew at stator inside diameter, in.	O	If not read in, program assumes SK = 0
	T1	Rated-load armature winding temperature, $^{\circ}C$	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, $(^{\circ}C)^{-1}$	O	If not read in, program assumes copper temperature coefficient (0.00393)
	T11	No-load armature winding temperature, $^{\circ}C$	M	Used for loss and efficiency calculations
	TST	Armature winding temperature, $^{\circ}C$	O	Program calculates and prints out armature resistance at this temperature; if not read in, program assumes TST = 25° C
	EL	Armature coil end turn length, in.	O	Read in if exact value is known; if not, program will calculate approximate value
	BX	Thickness of armature coil at end-turn, in.	O	See fig. 11; if not read in, program assumes BX = BS - 0.015
	SEP	Clearance between armature winding end turns, in.	O	See fig. 11; if not read in, program assumes SEP = 0.01
AIRGAP	GC	Minimum air gap (at center of pole), in.	M	See fig. 12
	GP	Maximum air gap, in.	C	Need not be read in if air gap is constant (i.e., if GP = GC); see fig. 12
	IWF	Index to specify if windage loss is to be calculated	O	To have program calculate approximate windage loss in main air gap, set IWF = 1 and add data cards for air-gap gas name and NAMELIST name WIND at end of design deck

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

TABLE III. - Continued. DEFINITION OF INPUT VARIABLES USED WITH ALTERNATOR DESIGN DECK

NAMELIST name	FORTRAN symbol	Definition	Classification (a)	Remarks
ROTOR	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	
	PBL	Pole body length (axial direction), in.	C	If PBL = PHL, only one (either one) need be read in; see fig. 13
	PHL	Pole head length (axial direction), in.	C	
	PE	Pole embrace	C	One must be read in; both may be read in; see fig. 13
	PHW	Pole head width, in.	C	
	PHH	Pole head height, in.	M	See fig. 13
	PBH	Pole body height, in.	M	See fig. 13
	PBW	Pole body width, in.	M	See fig. 13
	DISH	Inside rotor diameter (for hollow rotor), in.	C	Read in only for rotor with center hole (see fig. 14)
	DSH	Outside diameter of rotor core, in.	O	Program calculates value if not read in (see fig. 14)
	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 < LTR1 ≤ 0.094; D1 = 3.5 for 0.094 < LTR1 ≤ 0.17; D1 = 7.0 for LTR1 > 0.17; if LTR1 is not read in, program calculates value of LTR1 based on RK1
	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	Constants defined for conventional salient pole alternator (ref. 13) if not an input, values are calculated from formulas given in refs. 4 and 13
	CP	Ratio of average to maximum value of field form	O	
	CM	Demagnetizing factor (direct axis)	O	
	CQ	Cross magnetizing factor (quadrature axis)	O	
FIELD	HCOIL	Field coil height, in.	O	If not read in, program assumes HCOIL = PBH, see fig. 14
	PT	Number of field coil turns per pole	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.	M	See fig. 14
	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 and open-circuit time constant at this temperature; if not read in, program assumes TF = 25° C
	FE	Mean length of one turn, in.	O	Program calculates approximate value if not read in

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

TABLE III. - Concluded. DEFINITION OF INPUT VARIABLES USED WITH ALTERNATOR DESIGN DECK

NAMELIST name	FORTRAN symbol	Definition	Classification (a)	Remarks
DAMPER	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 height, in.	C	For rectangular damper bars only
	B	Rectangular damper bar width, in.	C	
	SB	Damper bar length, in.	C	If not read in, SB = PHL is assumed
	TB	Damper bar pitch, in.	C	If not read in, approximate value is calculated
	T33	Cold damper bar temperature, ^{o}C	O	If not read in, 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	If not read in, program assumes copper resistivity (0.694)
	ALPHAE	Temperature coefficient of resistivity at 20^{o} C, $^{o}C^{-1}$	O	If not read in, program assumes copper temperature coefficient (0.00393)
WIND[b]	VIS	Viscosity of gas in alternator air gap, lb/sec-ft	M	--------------------------------------
	M	Molecular weight of gas	M	--------------------------------------
	TEMP	Temperature of gas, ^{o}C	M	--------------------------------------
	PRSRAT	Pressure of gas at alternator rating VA, lb/in.^{2}	M	--------------------------------------
	PRESS	Array of gas pressures corresponding to alternator load points G, lb/in.^{2}	O	If not read in, program scales PRSRAT directly with load
	RO	Density of gas at alternator rating VA, lb/ft^{3}	O	If not read in, program calculates value

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

[b]This card is needed only if IWF of NAMELIST name AIRGAP is unity. It must be preceded by a card giving the gas name (see p. 13).

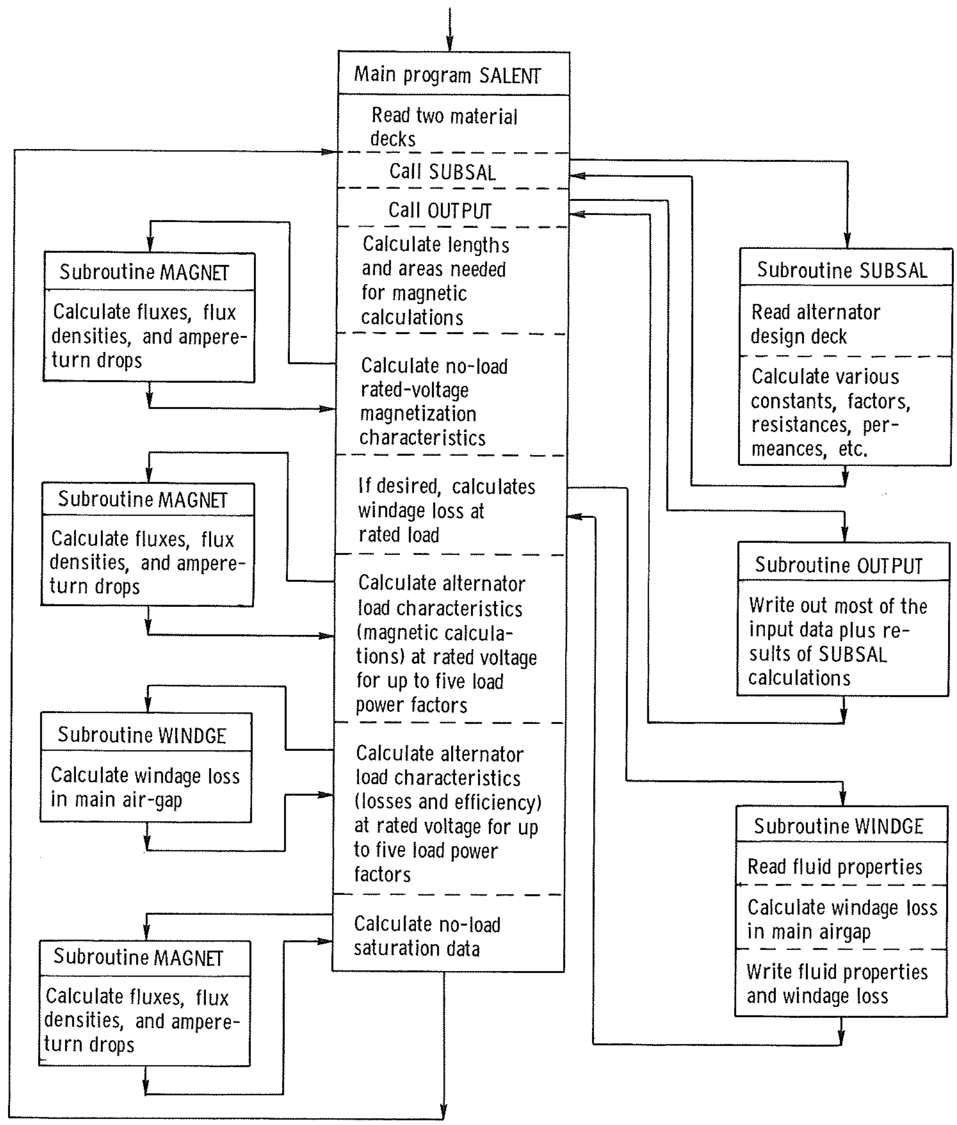


Figure 1. - Simplified flow chart of salient, wound pole alternator computer program.

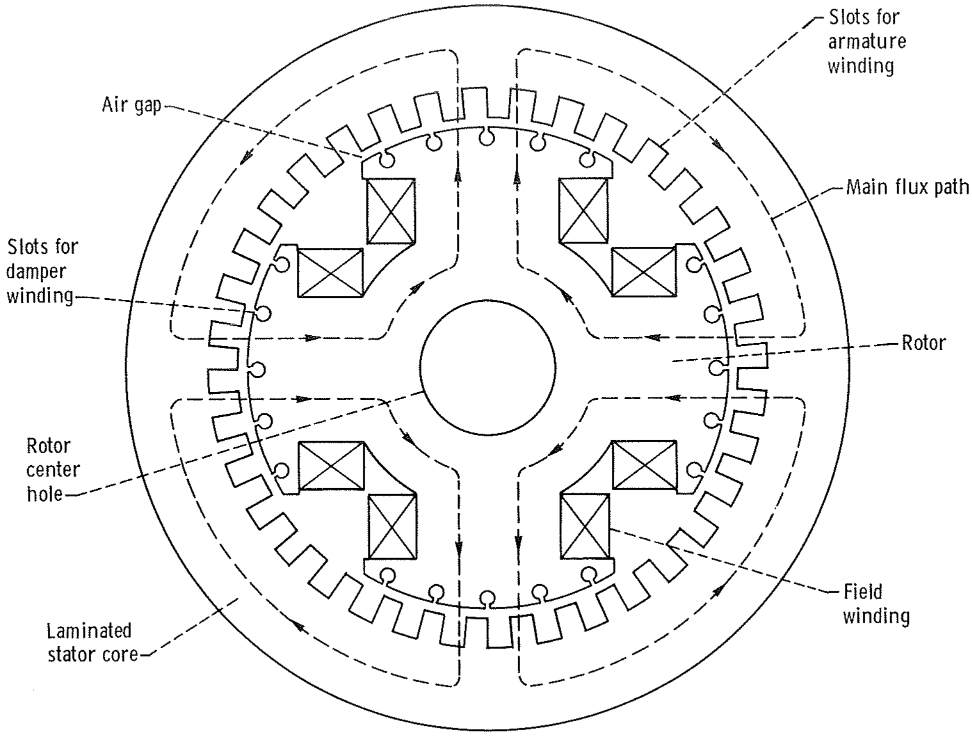


Figure 2. - Basic configuration of salient, wound pole alternator showing main flux path.

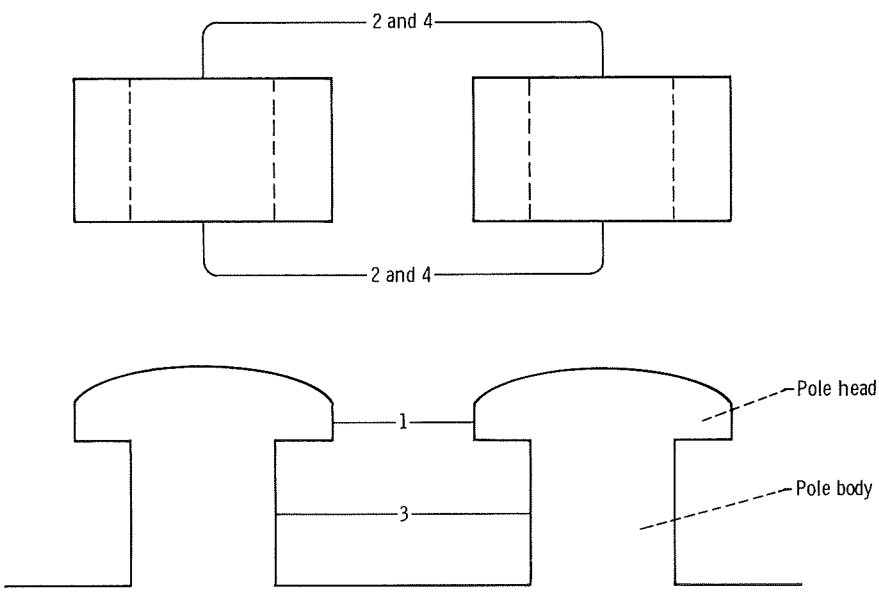


Figure 3. - View of salient, wound pole rotor showing flux leakage paths.

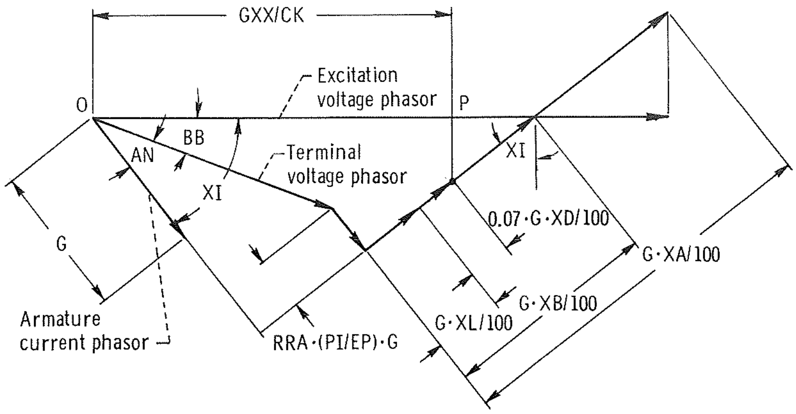


Figure 4. - Phasor diagram. This phasor diagram is in per unit system and is for rated voltage and volt-ampere load G at power factor cos (AN). Hence, the length of the terminal voltage phasor is one, and the length of the armature current phasor is G. Values of reactances XL, XB, and XA are in percent.

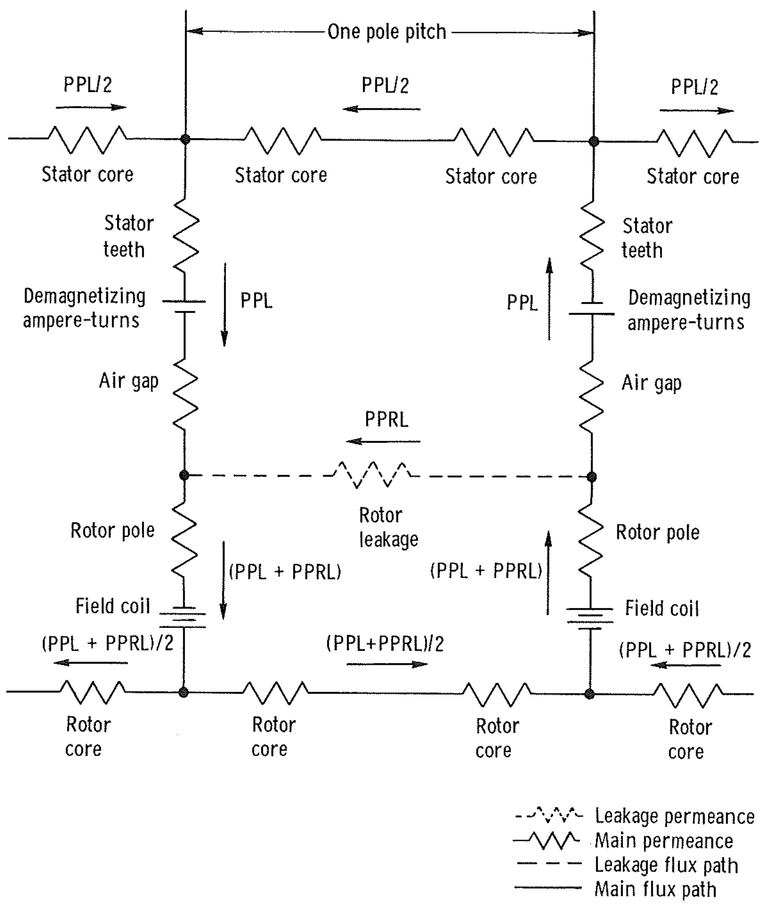


Figure 5. - Equivalent magnetic circuit of salient, wound pole alternator.

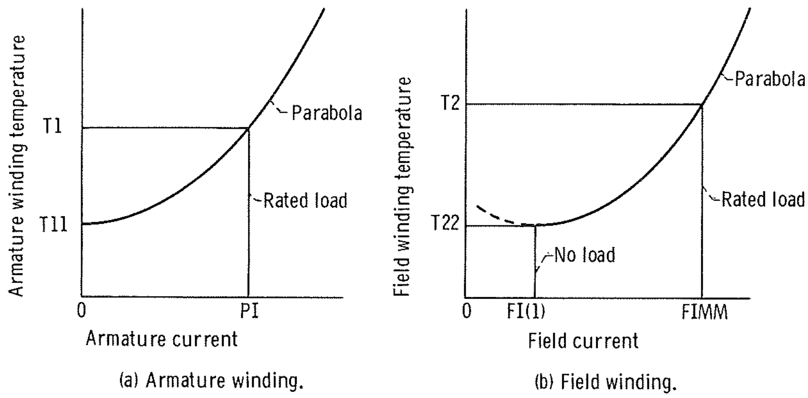


Figure 6. - Temperature variation as function of current.

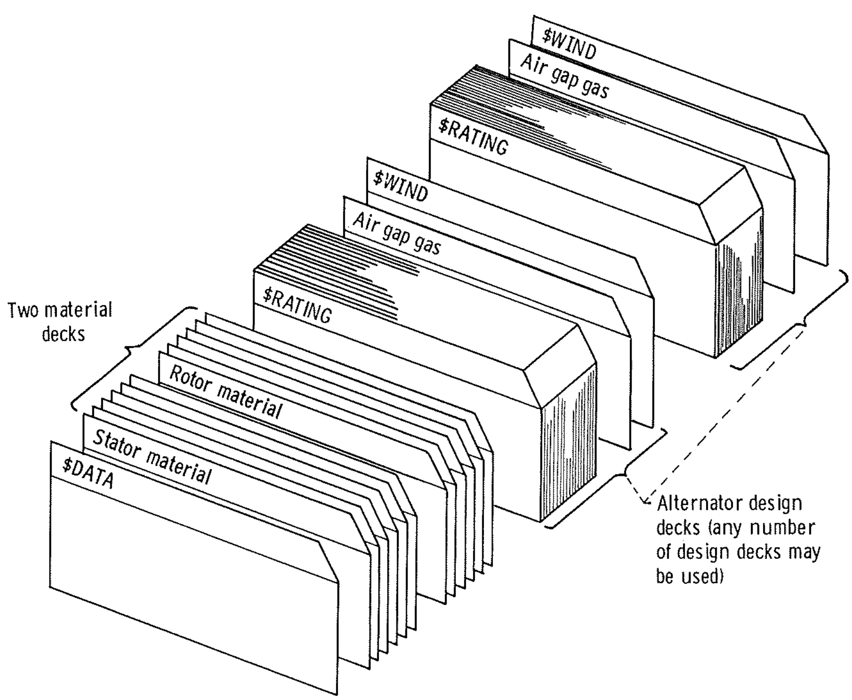


Figure 7. - Typical data deck makeup.

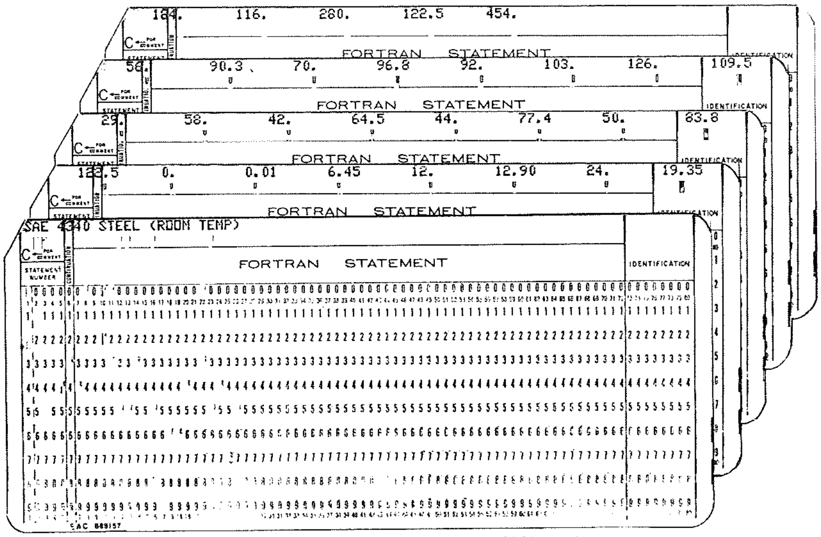
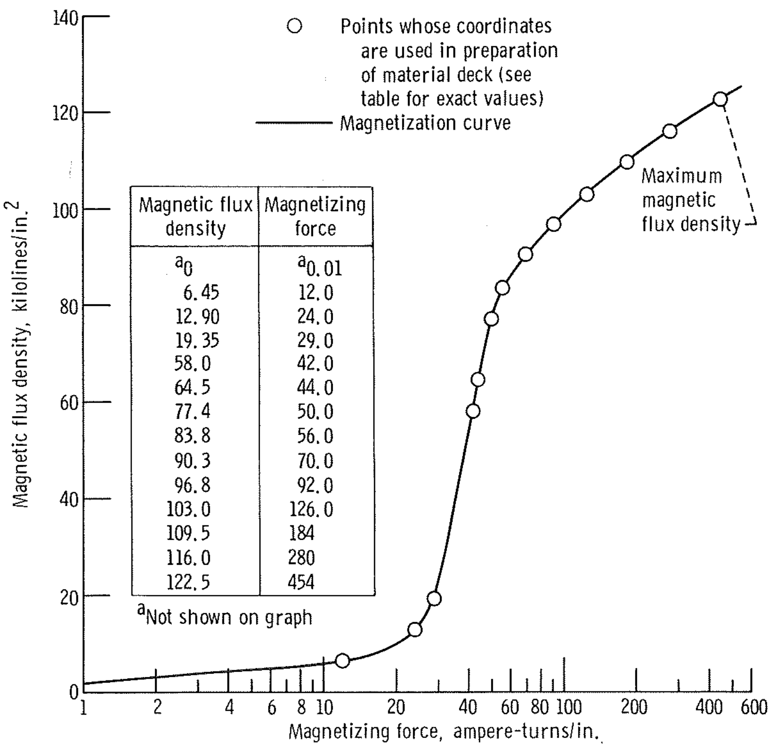


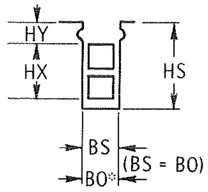
Figure 8. - Material deck for SAE 4340 steel.



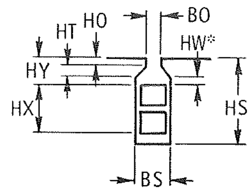
Magnetic flux density	Magnetizing force
[a]0	[a]0.01
6.45	12.0
12.90	24.0
19.35	29.0
58.0	42.0
64.5	44.0
77.4	50.0
83.8	56.0
90.3	70.0
96.8	92.0
103.0	126.0
109.5	184
116.0	280
122.5	454

[a]Not shown on graph

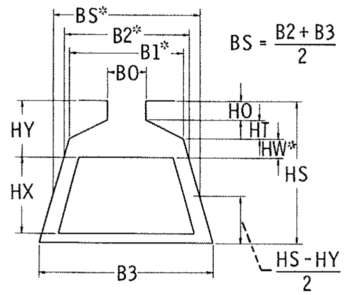
Figure 9. - Average magnetization curve for SAE 4340 steel.



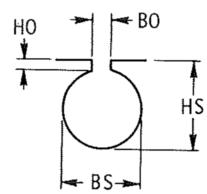
Types 1 and 5: Open slot, constant slot width. Type 5 slot is same as type 1, but it contains only one coil side.



Type 2: Partly closed slot, constant slot width.



Type 3: Partly closed slot, constant tooth width.



Type 4: Round slot.

Figure 10. - Stator slot dimensions. (Starred variables are not input; they are shown for reference only.)

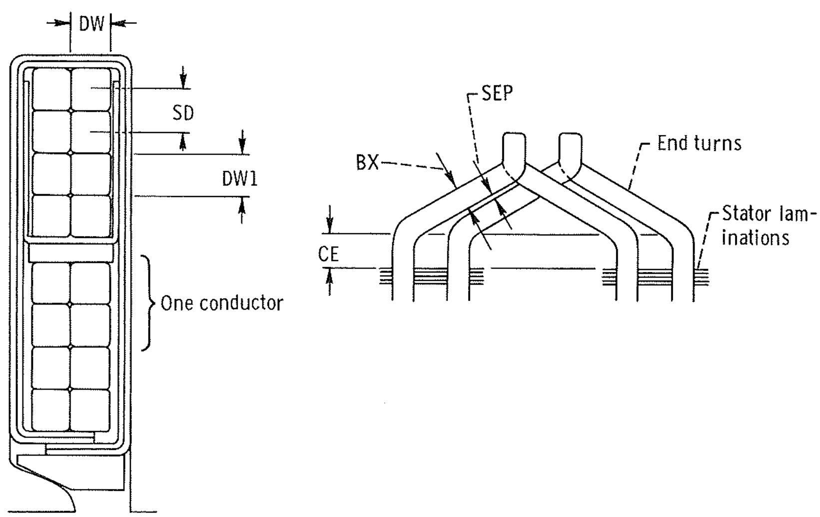


Figure 11. - Definition of variables used with NAMELIST name WINDNG.

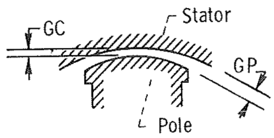


Figure 12. - Air gap dimensions.

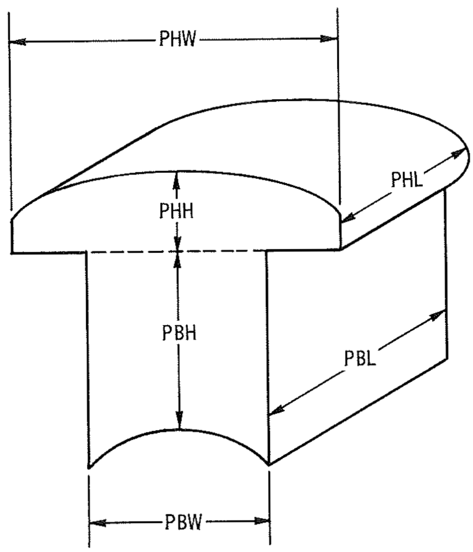


Figure 13. - Rotor pole dimensions.

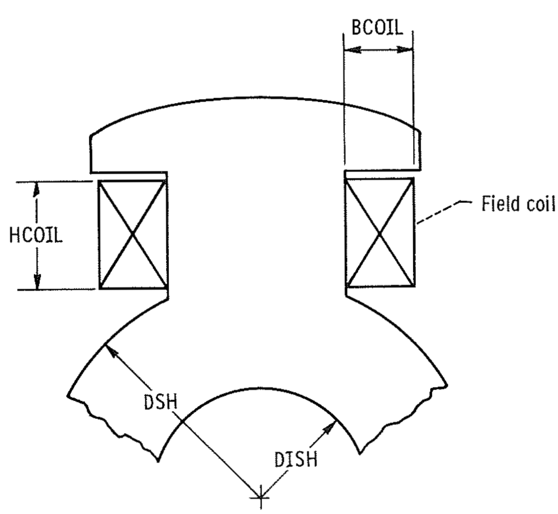
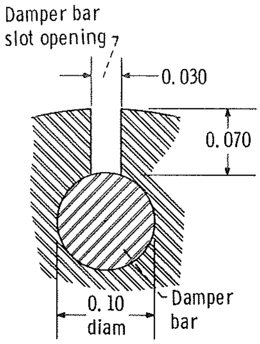


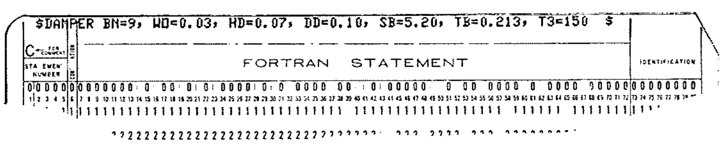
Figure 14. - Rotor and field dimensions.



Damper bar length	5.20
Damper bar pitch	0.213
Number of damper bars per pole	9
Damper bar material	Copper
Hot damper bar temperature, $^{\circ}C$	150
Cold damper bar temperature, $^{\circ}C$	20

(a) Damper bar design parameters.

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	5.20
TB	0.213
T33	Need not be read in; program automatically assumes 20^{0} C
T3	150
RE	Need not be read in; program automatically assumes value for copper
ALPHAE	Need not be read in; program automatically assumes value for copper



(b) Conversion of design parameters to FORTRAN symbols and data card $DAMPER.

Figure 15. - Preparation of data card for NAMELIST name DAMPER.

```
$DATA
VANADIUM PERMENDUR
   154.      12.9      1.92      38.7      2.62      77.4      3.23      90.3
   3.53      103.      4.35      109.7     5.25      116.      6.66      122.5
   8.68      129.      12.5      135.5     20.2      142.      44.4      145.3
   101.      148.3     363.      154.      2020.
SAE 4340 STEEL (ROOM TEMP)
   122.5     0.        0.01      6.45      12.       12.90      24.       19.35
   29.       58.       42.       64.5      44.       77.4      50.        83.8
   56.       90.3      70.       96.8      92.       103.      126.       109.5
   184.      116.      280.      122.5     454.
 $RATING VA=200, EP=170, F=500, IPX=12, G=0,.5,1.0,1.5,2.0, PFC=.75,1.0  $
 $STATOR DI=12.5, DU=14.5, CL=5.20, SF=0.96, LTS=.006, WL=11.8, BK=77.4  $
 $SLCTS ZZ=2, BO=0.07, BS=0.142, HO=0.03, HX=0.345, HY=0.10, HS=0.455, HT=0.055,
     IQQ=180  $
 $WINDNG RF=1, SC=2, C=3, SN=1, SN1=1, DW=0.112, DW1=0.150, CE=0.25, SD=0.160,
     T1=200, T11=100, PTCH=0.8  $
 $AIRGAP GC=0.07, IWF=1  $
 $ROTOR D1=1.17, PHL=5.20, PE=0.6667, DISH=8.2, DSH=9.9, PHH=0.46, PBH=0.75,
     PBW=1.30, RK1=0.90, LTR1=.006  $
 $FIELD BCOIL=0.42, PT=44, RD=0.19, RT=0.025, T2=200, T22=100  $
 $DAMPER BN=9, WO=0.03, HD=0.07, DD=0.10, SB=5.20, TB=0.213, T3=150  $
AIR
 $WIND M=29.9, VIS=1.21E-05, PRSRAT=15.0, TEMP=150  $
```

Figure 16. - Listing of data deck for sample alternator design.

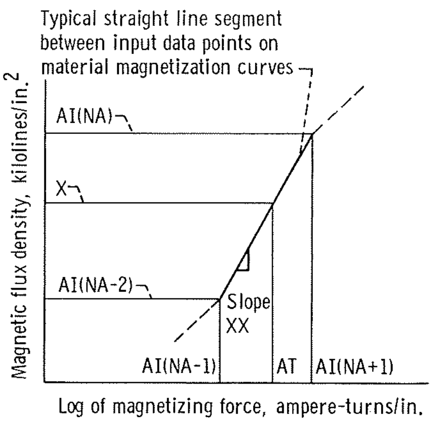


Figure 17. - Variables used in interpolation between points on magnetization curves.

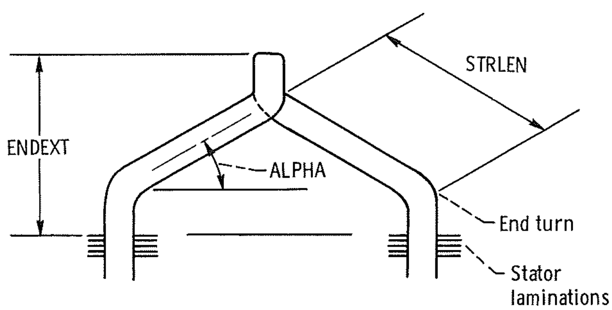


Figure 18. - Variables used in end-turn length calculations.

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