NASA TECHNICAL NOTE

NASA TN D-5814

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NASA TN D-5814

DESCRIPTION AND EVALUATION OF DIGITAL-COMPUTER PROGRAM FOR ANALYSIS OF STATIONARY OUTSIDE-COIL LUNDELL ALTERNATORS

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NATIONAL AERONAUTICS AND SPACE ADMINISTRATION • WASHINGTON, D. C. • JUNE 1970

1. Report No.
NASA TN D-5814

2. Government Accession No.

3. Recipient's Catalog No.

4. Title and Subtitle DESCRIPTION AND EVALUATION OF DIGITAL-COMPUTER PROGRAM FOR ANALYSIS OF STATIONARY OUTSIDE-COIL LUNDELL ALTERNATORS

5. Report Date
June 1970

6. Performing Organization Code

7. Author(s)
Gary Bollenbacher

8. Performing Organization Report No.
E-5326

9. Performing Organization Name and Address
Lewis Research Center
National Aeronautics and Space Administration
Cleveland, Ohio 44135

10. Work Unit No.
120-27

11. Contract or Grant No.

12. Sponsoring Agency Name and Address
National Aeronautics and Space Administration
Washington, D.C. 20546

13. Type of Report and Period Covered
Technical Note

14. Sponsoring Agency Code

15. Supplementary Notes

16. Abstract

A digital computer program for analyzing the electromagnetic design of Lundell alternators is presented. The program, which is written in FORTRAN IV programming language, is briefly described. The calculational methods are outlined or appropriate references are cited. Calculated results for a 14.3-kVA alternator are compared with experimental data. The comparison identifies two sources of error in the program: the rotor leakage permeance, which affects the field excitation calculation; and the no-load pole-face loss, which, if large compared to other losses, affects the accuracy of the efficiency calculation. Despite these sources of error, the agreement between calculated and experimental data is reasonable, and the program is useful for parametric analysis and design optimization.

17. Key Words *(Suggested by Author(s))*
Alternator analysis
Brushless alternator
Solid rotor alternator
Lundell alternator
Digital computer program

18. Distribution Statement
Unclassified - unlimited

19. Security Classif. (of this report)
Unclassified

20. Security Classif. (of this page)
Unclassified

21. No. of Pages
118

22. Price*
$3.00

*For sale by the Clearinghouse for Federal Scientific and Technical Information
Springfield, Virginia 22151

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SUMMARY

A digital computer program for analyzing the electromagnetic design of stationary, outside coil Lundell alternators is presented. The program, which is written in FORTRAN IV programming language, calculates the open-circuit saturation curve, field-current requirements at rated voltage for various loads, losses, efficiency, reactances, and weights. The method used to calculate these items is outlined briefly, or appropriate references are cited.

The results of the computer calculations are compared with experimental data. The comparison shows that the maximum error for the calculated field excitation requirement is 13 percent. It is shown that this error is due largely to the error in the rotor leakage permeance calculation. The comparison further shows that for the efficiency calculations the maximum error is 16 percent, this error being caused by the inaccuracy of the no-load pole-face loss calculation. Improvements in the method of estimating no-load pole-face losses and rotor leakage permeances, although very desirable, are beyond the scope of this report.

The program is useful for parametric studies and alternator design optimization. Instructions for using the program and typical program input and output for a 14.3-kilovolt-ampere alternator are given in the appendixes. Also included are an alphabetical lists of most FORTRAN symbols and complete program listings with flow charts.

INTRODUCTION

The first dynamic energy conversion systems developed at the Lewis Research Center for use in space incorporated homopolar inductor alternators. A computer program for analyzing this type of alternator was developed as a result. This program is described in reference 1. As more advanced power systems were studied, it became apparent that higher rotor speeds and higher gas pressures in the alternator cavity were necessary to achieve low weight-to-power ratios. These requirements increased alternator windage loss to such an extent that it became a critical parameter in system analysis. This prompted the selection of the Lundell alternator for advanced, high-speed systems. The Lundell alternator offers potentially lower windage loss while still retaining the desirable features of the homopolar inductor alternator: solid-rotor construction and absence of brushes and of rotating windings.

With the selection of the Lundell alternator came the need for a Lundell computer program, similar to the homopolar-inductor-alternator program, which would facilitate parametric system studies and design optimization. The quickest way to develop such a program was to modify the existing homopolar program as necessary. Reference 2 was particularly helpful in this process.

Most of the necessary modifications stem directly from the differences between the two machines. Primarily, these differences alter the magnetic calculations. Other modifications include the addition of a more general method for calculating windage loss (ref. 3) and a change in the method of accounting for the demagnetizing effect of armature currents. While the resultant Lundell program differs substantially from the homopolar-inductor-alternator computer program, there still remain many similarities. The homopolar and the Lundell programs are each written in FORTRAN IV programming language. Most of the FORTRAN symbols used are the same, and the input requirements and output formats are very similar.

This report describes the program in some detail and evaluates program accuracy by comparing the calculated and experimental data for a Lundell alternator used with the 36 000-rpm 1200-hertz Brayton cycle power conversion system (refs. 4 and 5). Instructions for using the program, the program listing and flow charts, and a FORTRAN symbol list are included in the appendixes.

COMPUTER PROGRAM DESCRIPTION

GENERAL DESCRIPTION

The stationary-coil, outside-coil Lundell 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, field-current requirements at rated voltage for various loads, losses and efficiency, several reactances, and weights of electromagnetic components. The results of the calculations, together with the input, are then printed out to provide a complete, self-explanatory record. 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 may be used with any computer system which accepts FORTRAN IV. For program execution, approximately 13 200 storage locations are needed. 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 preexecution time is 1.25 minutes and typical execution time is 0.08 minute per alternator design.

Figure 1 shows a simplified flow chart of the complete Lundell program. As can be seen, the program consists of a main program LUNDEL and four subroutines labeled SUBLUN, 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 labeled COMMON blocks, except for subroutine WINDGE which uses a call vector.

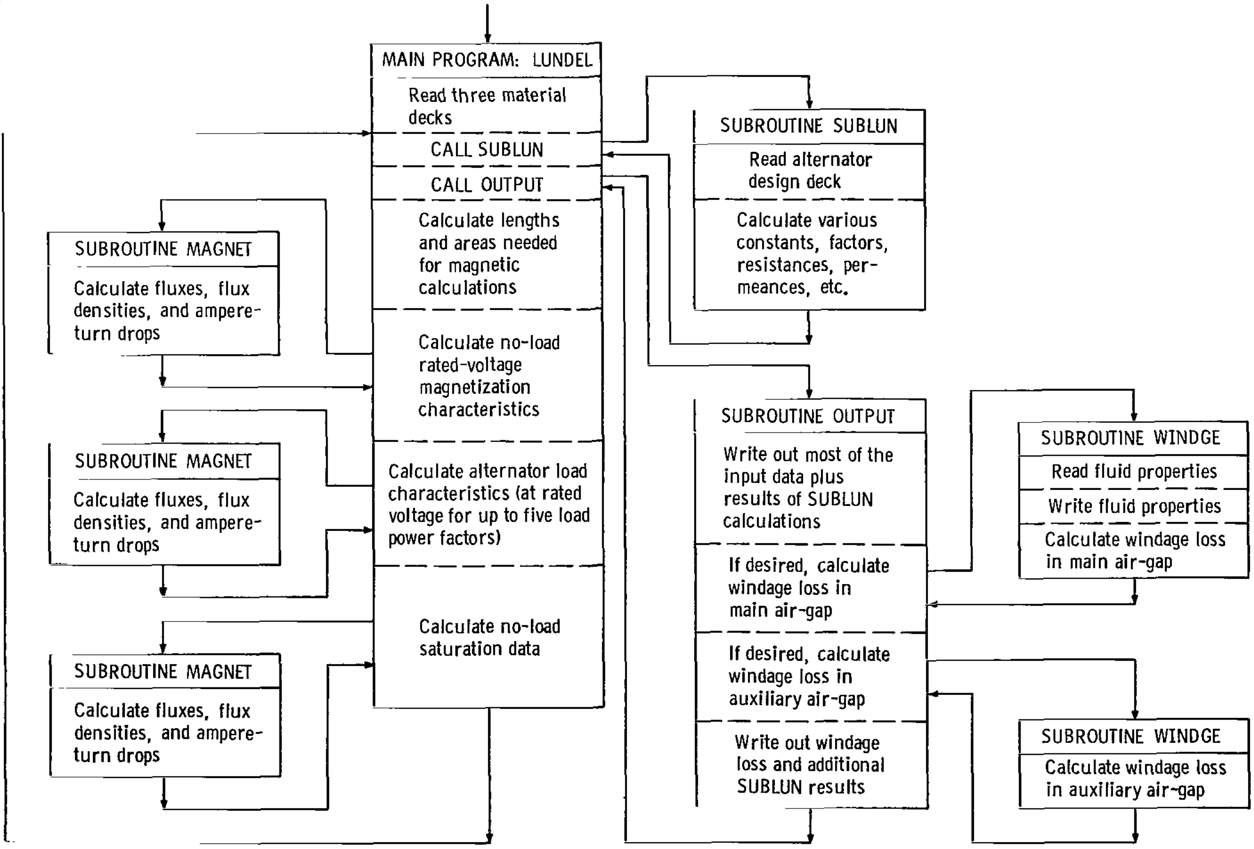


Figure 1. - Simplified flow chart of Lundell alternator computer program.

TABLE I. - CROSS-REFERENCE TABLE SHOWING

USAGE OF COMMON BLOCKS

COMMON block	Program or subroutine name			
	LUNDEL	SUBLUN	OUTPUT	MAGNET
COM1		x	x	
COM2	x	x	x	
COM3	x			x
COM4	x	x		
COM5	x	x	x	x

Table I lists the COMMON blocks and shows in which surbroutines they occur.

DESCRIPTION OF ALTERNATOR TO WHICH PROGRAM IS APPLICABLE

The basic alternator for which the computer program was written is the stationary-coil outside-coil Lundell alternator, henceforth for brevity called a Lundell alternator. The basic configuration of a Lundell alternator with each major electromagnetic component identified, is illustrated in figure 2. Although the alternator shown has its field

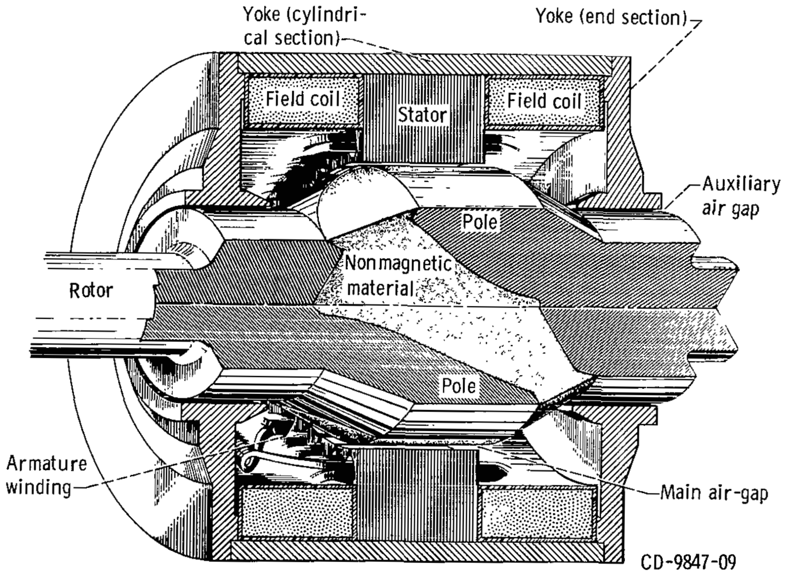


Figure 2. - Stationary-coil outside-coil Lundell alternator (four pole, two coil version shown).

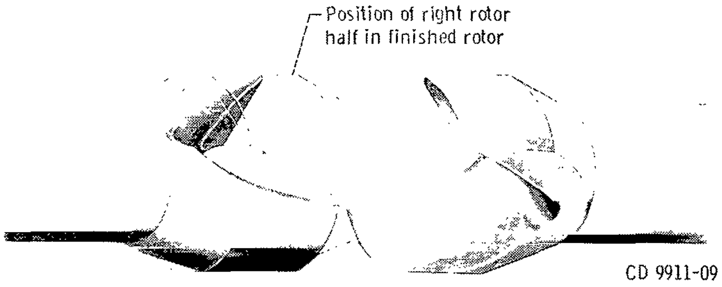


Figure 3. - Exploded view of magnetic rotor parts of four-pole Lundell alternator.

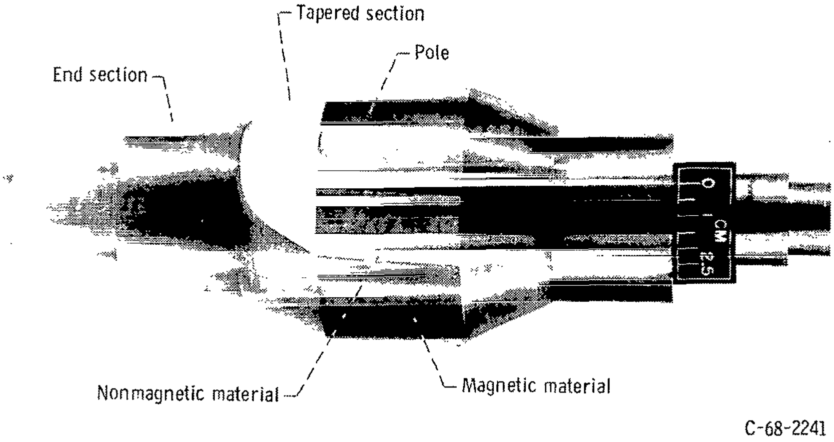


Figure 4. - Alternator rotor.

winding divided into two identical coils, one coil positioned on each end of the alternator, it is also permissible to have the entire field winding located in the center of the alternator between the stator and the cylindrical section of the yoke.

The rotor construction for a four-pole Lundell alternator is illustrated in figure 3. As shown, the rotor consists of two identical magnetic parts. In the finished rotor the two magnetic parts are positioned relative to each other as shown by the broken lines. Inserted in the space between them is a nonmagnetic separator. The three pieces are welded or brazed together. A finished rotor is shown in figure 4.

To describe the flux path, a cross-sectional view of a Lundell alternator is shown in figure 5. For clarity, the figure shows a two-pole machine. The useful flux (shown by solid arrows) starts at a rotor north pole, crosses the main air gap and proceeds 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 con-

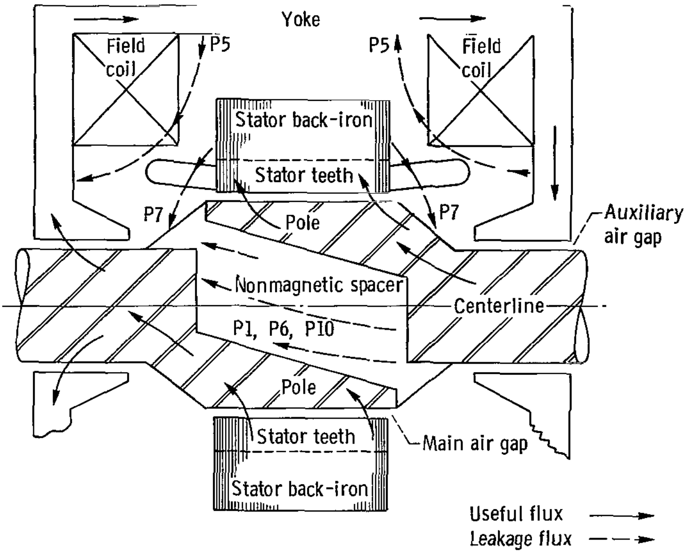


Figure 5. - Cross-sectional view of Lundell alternator showing useful and leakage flux paths.

tinues radially across the main air gap into a south pole. From there the flux goes axially down the rotor and crosses the first auxiliary air gap into the yoke. It leaves the other end of the yoke, crosses the second auxiliary air gap, and completes its path back to the rotor north pole from which it started. In addition to the useful flux there are several leakage fluxes as shown by the broken arrows.

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

(1) Shaft and poles are made of the same magnetic material.

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

(3) There are no windings or circuits of any kind on the rotor.

(4) The rotor diameter under the auxiliary air gap is constant.

(5) The alternator can have only one field winding. The winding may be split into two identical coils and positioned as shown in figure 5. Both coils are assumed connected in series.

(6) There is no leakage flux across the space between the yoke and the stator back iron.

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

(1) Armature conductors and field conductors may be round or rectangular.

(2) Armature conductors may consist of any number of strands.

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

(4) There are six allowable field coil locations or configurations.

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

METHOD OF CALCULATION

This section of the report will outline in general terms the method of calculation used in the computer program. However, due to the length of the program and the large

TABLE II. - FORTRAN VARIABLES USED IN MAGNETIC CALCULATIONS

	Areas, in.^{2}	Lengths, in.	Flux densities, kilolines/in.^{2}		Ampere turns		Total flux,[b] kilolines	Permeances, lines/amp-turn
			Sub-scripted[a]	Nonsub-scripted[a]	Sub-scripted[a]	Nonsub-scripted[a]		
Main air gap	GA	GE	--------	BG	FGLL1	FGL1	[c]PPL	P8
Auxiliary air gap	AG2	G2	--------	BAG2	FGLL2	FGL2	PPL3	P9
Teeth	ATOOTH	HS	BTLL	BTL	FTLL	FTL	[c]PPL	---
Core	ACORE	DCORE	BCLL	BCL	FCLL	FCL	[c]PPL	---
Pole	PA and PAA	CL	[d]BPLL	BPL	FPLL	FPL	FLUX3	---
Rotor tapered section	(e)	DSHMID	[d]BROTL	BROT	FROTL	FROT	PPL2	---
Rotor end section	ASHFT	LG2	[d]BSHFTL	BSHFT	FSHFTL	FSHFT	(e)	---
Pole tip	PA1	---------	--------	------	-------	------	PPL11	---
Pole base	PA2	---------	--------	------	-------	------	PPL1	---
Yoke end section	(e)	10. *DYK2	[d]BYCLL2	BYCL2	FYCLL2	FYCL2	[f]PPL3 or PPL4	---
Yoke cylindrical section	AYK1	DYK1	BYCLL1	BYCL1	FYCLL1	FYCL1	[f]PPL3 or PPL4	---
Total demagnetizing ampere-turns at rated load	--------	---------	-------	------	-------	FGML	--------	---
Demagnetizing ampere turns (direct axis)	--------	---------	-------	------	-------	FGXL	--------	---
Total field excitation	--------	---------	-------	------	FFLL	FFL	--------	---

[a]Nonsubscripted variables are used in MAGNET. These variables are then stored in subscripted arrays after return to LUNDEL.

[b]Total flux = Useful flux + Leakage flux.

[c]PPL is the total useful flux per pole.

[d]Flux density is not constant. The variable given is the maximum flux density in the element.

[e]Area or flux are not constant. See figs. 10 and 11 for assumed variation.

[f]Whether PPL3 or PPL4 depends on field coil location.

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 2. In addition, detailed information and specific equations may be found in the program listings and flow charts in appendix C. To assist in locating specific information in the listing COMMENT cards are used freely to identify the major calculations. Of further value are appendix D, which is a FORTRAN symbol list, and table II, which gives the most important variables used in MAGNET in a convenient format.

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 leakage fluxes, shown in figure 5 by the broken arrows, have a pronounced effect on the saturation curves and, to a lesser degree, on alternator efficiency and weight. Because the leakage paths 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.

Three primary leakage permeances are considered by the program:

(1) Field coil leakage permeance - This leakage permeance is denoted by P5. Leakage flux through P5 affects only the flux density in the yoke.

(2) Stator-to-rotor leakage permeance - This permeance, labeled P7, accounts for the leakage flux from the stator to the tapered section of the rotor.

(3) Rotor leakage permeance - This leakage permeance has the greatest effect on alternator performance. The flux through this permeance is assumed confined entirely to the volume occupied by the nonmagnetic separator in the rotor. The rotor leakage permeance is made up of a number of components: P1, P2, P3, P4, and P6 (fig. 6). The component P1 is the pole tip leakage permeance. The flux through P1 is assumed to flow through the entire pole from pole tip to pole base while the flux through P6 flows

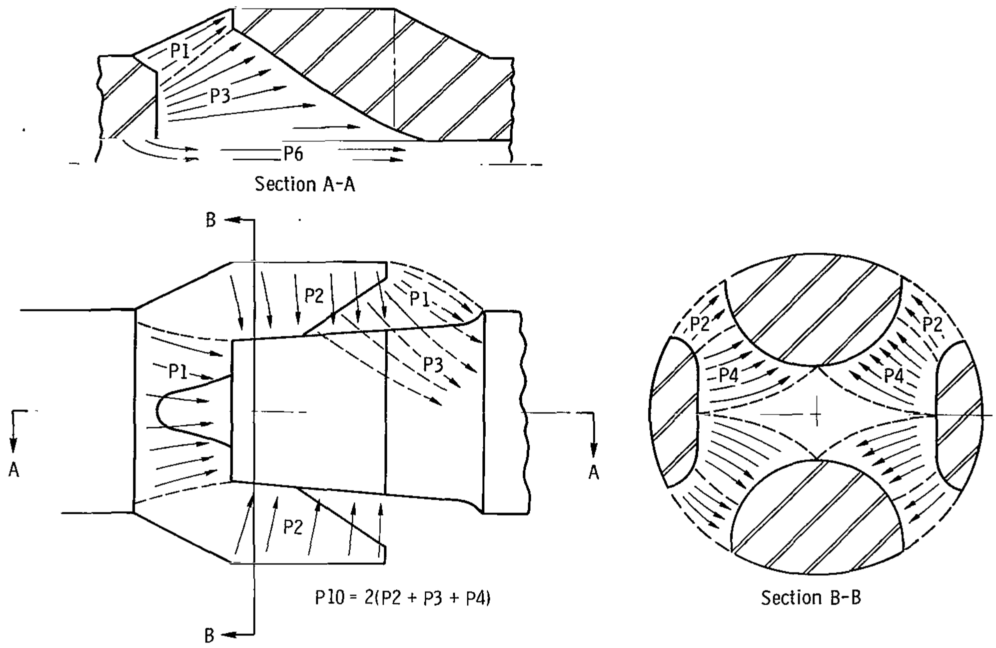


Figure 6. - Rotor leakage permeances.

from rotor end section to rotor end section without ever entering the poles. The components P2, P3, and P4 are distributed over the entire pole. For convenience they are combined into one permeance P10 = 2(P2 + P3 + P4). The total rotor leakage permeance from one magnetic pole piece to the other is

$$\mathscr{P}_{RL} = (PX)(P1 + P2 + P3 + P4) + P6$$

$$= (PX)\left(P1 + \frac{P10}{2}\right) + P6$$

Because of the many possible geometries, and because all geometries are complex, it is difficult to program leakage permeance calculations. For this reason allowance has been made for the programmer to calculate leakage permeances as desired and to use the values so computed as input to the program. However, as a convenience, approximate formulas for the leakage permeances P1, P2, P3, P4, P5, and P6 have been incorporated in the program. The formulas used were taken from reference 6 and are applied very loosely to the machine geometry. No attempt was made to calculate P7 even approximately. Thus, P7 must be read into the program, or it will be assumed to be zero.

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, which are repeated for several combinations of load, voltage, and power factor 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 LUNDEL as required (see fig. 1). However, prior to calling MAGNET for the first time all areas and lenghts needed by MAGNET are calculated in LUNDEL.

Just prior to each transfer to the subroutine two additional quantities needed by MAGNET are calculated in LUNDEL. The two quantities are the actual flux per pole in the main air gap (PPL) and the demagnetizing ampere-turns due to armature current (FGXL). Both PPL and FGXL are functions of voltage, load, and load power factor.

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

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

$$\mathrm{FGXL} = 0$$

where

FQ	air-gap flux per pole at no-load rated voltage (calculated in SUBLUN)
EDD	constant of proportionality; here, equal to alternator output voltage normalized to rated voltage

Under load (at rated voltage) the calculation of PPL and FGXL requires reference to the alternator phasor diagram shown in figure 7. Construction of the diagram starts with the terminal voltage and line current phasors which, along with the angle between them are determined by the particular load for which PPL 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 SUBLUN. This locates the direct axis.

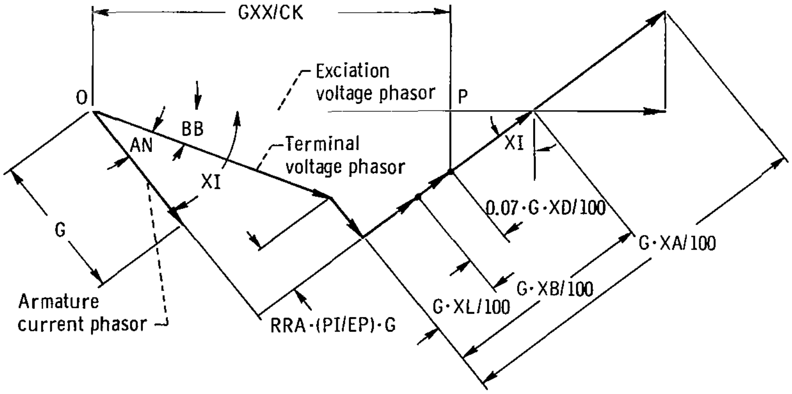


Figure 7. - Phasor diagram. This phasor diagram is in per unit system and is for rated voltage and load G at power factor cos (AN). Hence the length of the terminal voltage phasor is one, and the length of the armature current phasor is G. Values of reactances XL, XB, and XA are in percent.

The angle between the direct axis and the current phasor is of interest for calculating FGXL. This angle, labeled XI and called the internal power factor angle, can readily be calculated from the geometry of the phasor diagram. The length $\overline{OP}$ is also readily determined from the phasor diagram. Both PPL and FGXL can now be determined from the following equation:

$$\text{FGXL} = 2 \cdot \text{FGML} \cdot \text{G} \cdot \sin(\text{XI})$$

For power factors less than 0.95,

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

for power factors ≥ 0.95

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

where

FQ	flux per pole at no-load rated voltage
FGML	demagnitizing ampere-turns at rated load
G	volt-ampere output of alternator normalized to rated volt-ampere

The PPL and FGXL calculations are summarized in table III.

With PPL 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 which represent

TABLE III. - SUMMARY OF CALCULATIONS FOR PPL AND FGXL

	No-load rated-voltage magnetization characteristics	Alternator load characteristics (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
Demagnetizing ampere-turns (direct axis) (FGXL)	FGXL = 0	FGXL = 2 · FGML · G · sin(XI)[a]	FGXL = 0

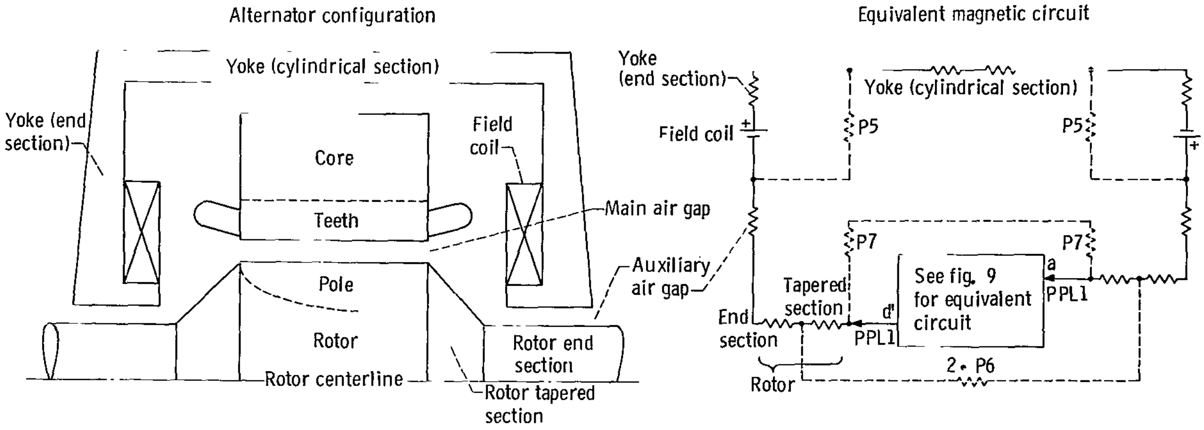
[a] $\overline{OP}$ and XI are obtained from vector diagram shown in fig. 7.

a part of the flux path through iron must be considered nonlinear. The exact equivalent circuit used depends on the value of TYPY, which, in code form, gives the field coil location. The permissible field coil locations, the corresponding equivalent circuit, and the code value of TYPY are shown in figure 8. The only difference between the six circuits is the location of the leakage permeance P5.

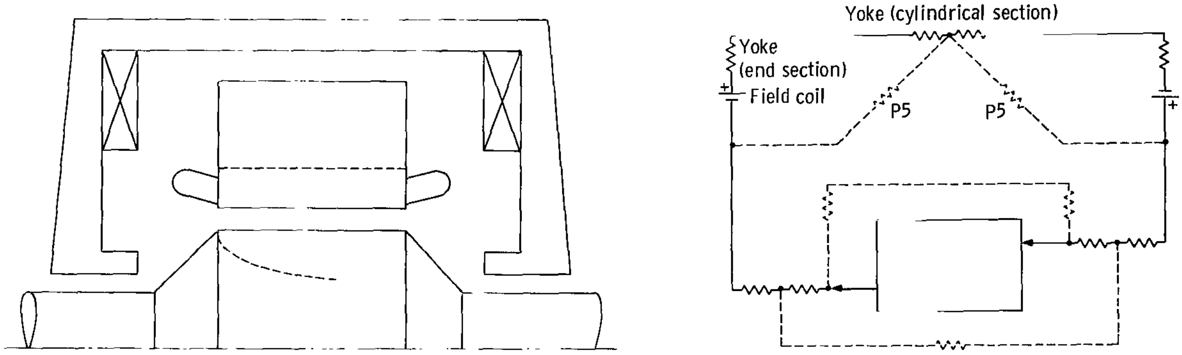
The equivalent circuit of the flux path between the base of one pole and the base of the adjacent pole is independent of the field coil location and is given in figure 9. The figure shows the outline of two adjacent poles. Each pole is arbitrarily broken into 10 segments. Flux is assumed to leave each pole segment and to split into two components, the useful flux FLUX1, and the rotor leakage flux FLUX2. The useful flux flows across the main air gap, teeth, and core to the opposite segment of the adjacent pole. The leakage flux flows in an electrically parallel path through permeance P10. Within each pole the flux is assumed to flow axially; once the flux leaves the pole, the flow is assumed radial and circumferential, but not axial. These assumptions, when translated into the equivalent electrical circuit of figure 9 results in the 10 vertical branches representing the main air gap, teeth, and stator. Similarly, the leakage flux path is assumed to consist of 10 vertical branches, each having a permeance P10/10.

The FORTRAN symbols used in figure 9 are as follows:

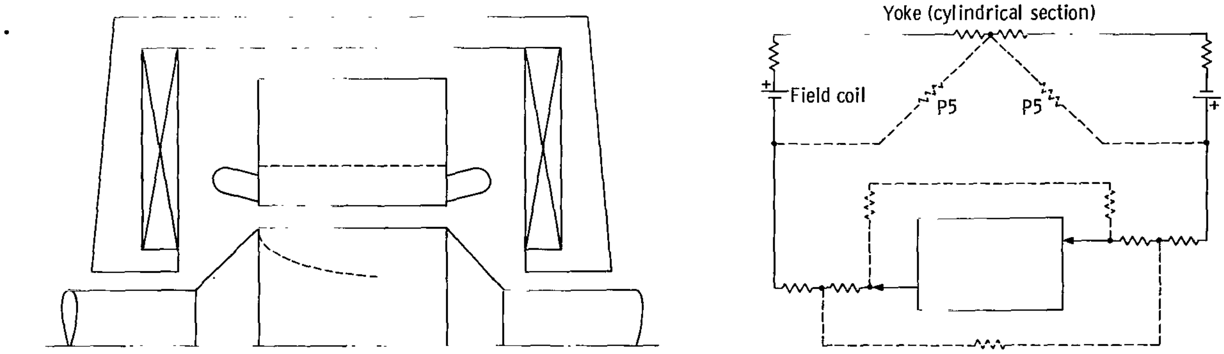
FLUX1(I)	useful flux leaving I^{th} pole segment; from symmetry, FLUX1(I) = FLUX1(11-I)
FLUX2(I)	rotor leakage flux leaving I^{th} pole segment; from symmetry FLUX2(I) = FLUX2(11-I)
FLUX3(I)	total flux passing through center of I^{th} pole segment



(a) Field coil location code TYPY = 1.



(b) Field coil location code TYPY = 2.

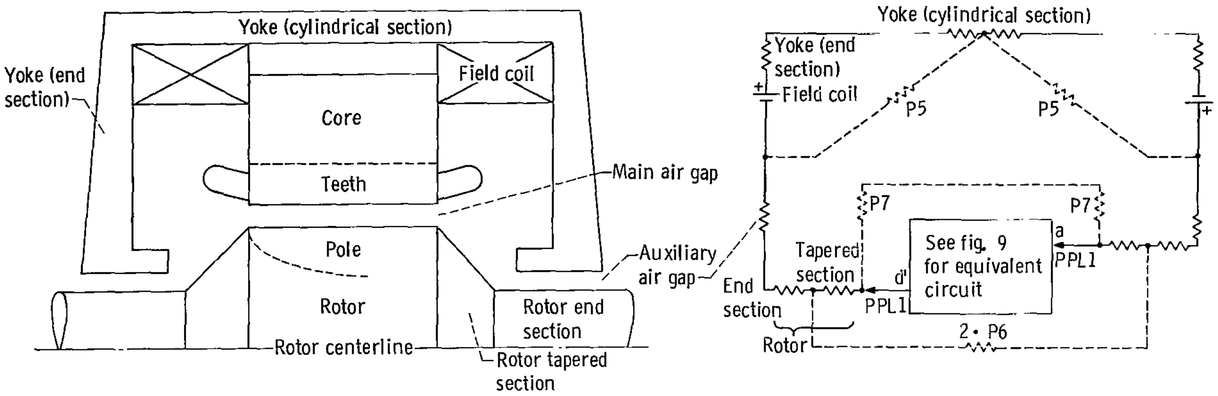


(c) Field coil location code TYPY = 3.

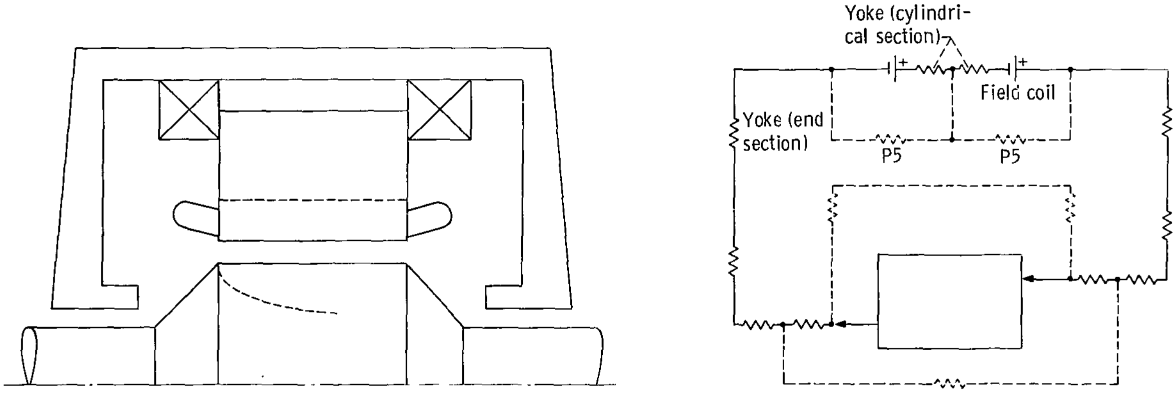
--ʌʌʌ-- Leakage permeance
—ʌʌʌ— Main permeance
——— Main flux path
------ Leakage flux path

Each leakage permeance is identified by its FORTRAN symbol

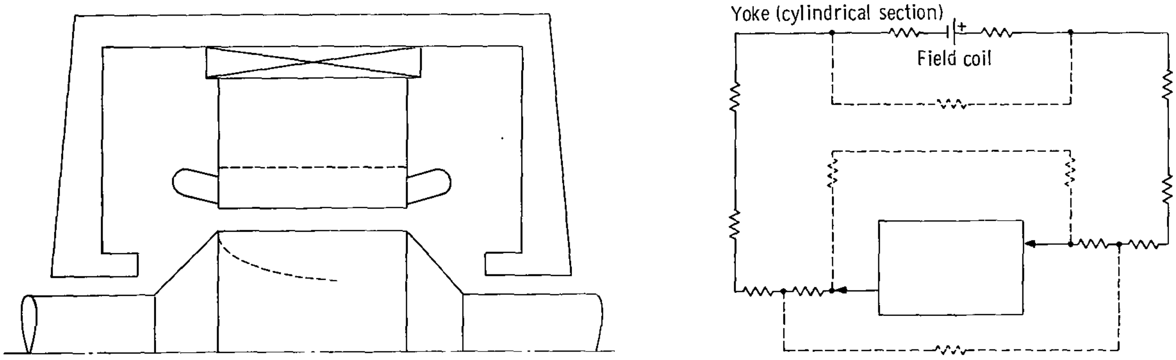
Figure 8. - Alternator configurations and equivalent magnetic circuits.



(d) Field coil location code TYPY = 4.



(e) Field coil location code TYPY = 5.



(f) Field coil location code TYPY = 6.

--ᴧᴧᴧ-- Leakage permeance
—ᴧᴧᴧ— Main permeance
——— Main flux path
------ Leakage flux path

Each leakage permeance is identified by its FORTRAN symbol

Figure 8. - Concluded.

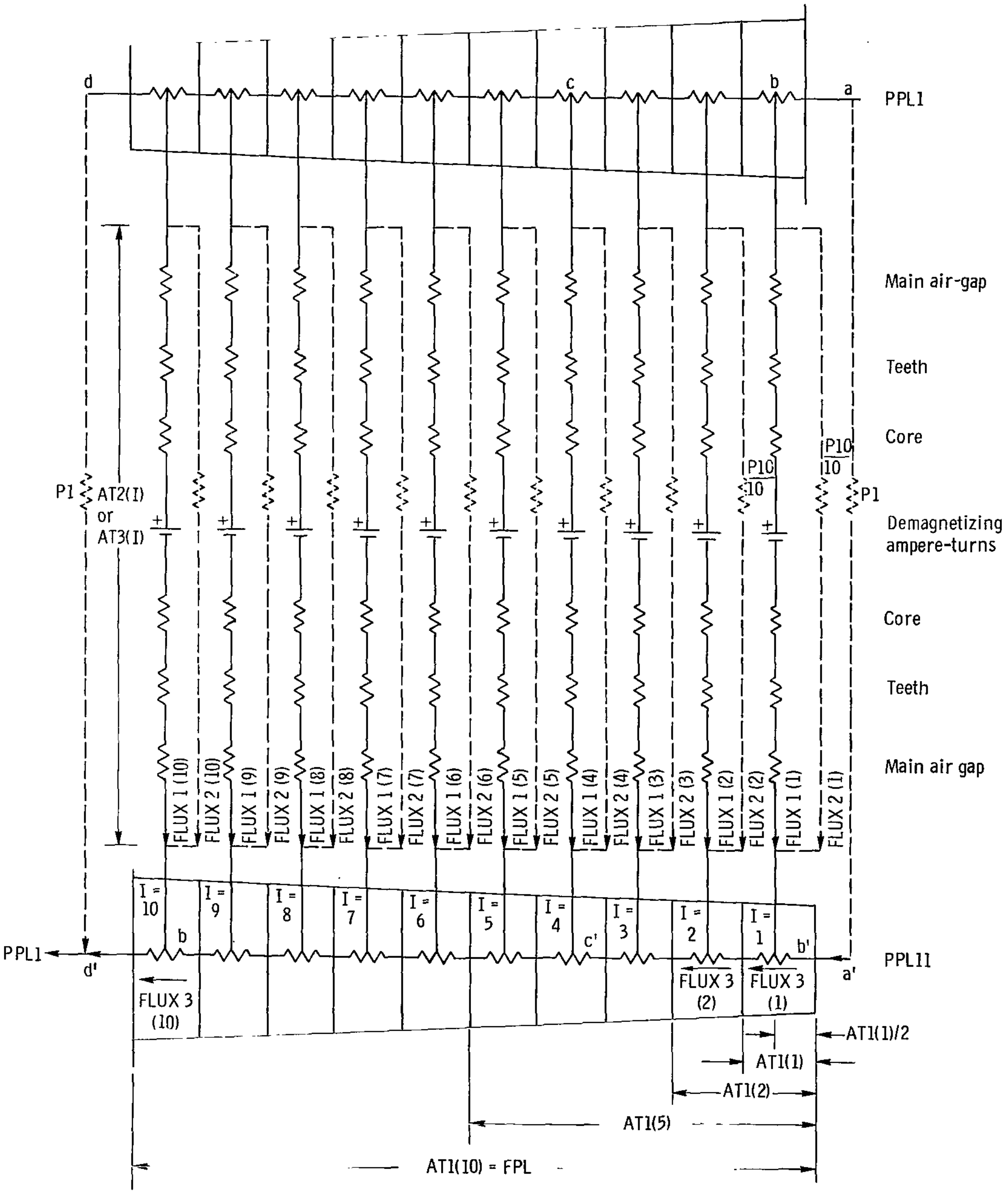


Figure 9. - Equivalent circuit of stator, teeth, and poles.

AT2(I) AT3(I)	ampere-turn drop from one pole segment to opposite pole segment of adjacent pole due to flux FLUX1(I) (AT2(I) $\approx$ AT3(I) after iteration has converged)
AT1(I)	ampere-turn drop from pole tip to end of I^{th} pole segment
P1 and P10	rotor leakage permeances
FPL = AT1(10)	total ampere-turn drop along pole
FBB	ampere-turn drop from base of one pole (point a, figs. 8 and 9) to base of adjacent pole (point d', figs. 8 and 9)

The equivalent circuit is analyzed by MAGNET to obtain the flux, flux densities, and ampere-turn drops for each element. Since the only flux known is the air-gap flux per pole, PPL, the logical place to start the analysis is with the equivalent circuit of figure 9. The solution of the circuit must satisfy the condition that the magnetic potential drop FBB must be the same regardless of the path along which it is computed. For example, paths a-b-b'-d', a-c-c'-d', and a-d-d' must all give the same result. To meet this condition it is necessary to assume a nonuniform air-gap flux distribution, that is, $\text{FLUX1(I)} \neq \text{FLUX1(J)}\ I \neq J$. However, the total air-gap flux $\sum_{I=1}^{10} \text{FLUX1(I)}$ must remain equal to PPL.

Determination of the flux distribution requires an iteration process. The steps in the iteration are outlined in table IV. Complete details of the iteration are in appendix C (program listing and flow chart of subroutine MAGNET). Very briefly the iteration involves the following steps:

(1) Initially, assume a uniform air-gap flux distribution.

(2) Calculate FBB for each of the 10 possible paths.

(3) Check that 10 values of FBB are within a given tolerance of each other. If "yes," the iteration is complete; if "no," proceed to step (4).

(4) Adjust flux distribution to more nearly equalize all 10 values of FBB, while keeping the total air-gap flux equal to PPL.

(5) Repeat steps (2) to (5) as necessary.

With the iteration complete, not only is the air-gap flux distribution and ampere-turn drop known, but also the flux densities and ampere-turn drops for the teeth, the core, and the poles. In addition, the iteration gives the pole-tip leakage flux (PPL11), the flux leaving the base of the pole (PPL1), and the ampere-turn drop from pole base to pole base (FBB).

It may happen that the iteration for the air-gap flux distribution fails to converge. In that case a uniform flux distribution is assumed and the calculations are continued on that basis. A message is then printed on the output record informing the program

TABLE IV. - DETAILED STEPS IN THE ITERATION FOR AIR-GAP FLUX DISTRIBUTION

Step	Explanation of steps in iteration	Mathematical expression for steps in iteration
1	Assume initially that air-gap flux distribution is uniform and that flux in each segment is 1/10 of total air-gap flux	FLUX1(1)=FLUX1(2)=. . . FLUX1(10)=PPL/10.
2	Calculate ampere-turn drop due to flux FLUX1(I) across main air gap (FGL1), teeth (FTL), and core (FCL) for all 10 paths; the total drop is called AT3(I)	AT3(I)=(FGL1+FTL+FCL+FGXL/2.)*2.
3	Calculate pole-tip leakage flux, PPL11	PPL11=AT3(1)*0.001*P1
4	Calculate rotor leakage flux FLUX2(I) in each of 10 paths; the rotor leakage permeance P10 is assumed to be divided into 10 equal, parallel paths	FLUX2(I)=AT3(I)*P10*0.0001
5	With FLUX1, FLUX2, and the pole-tip leakage flux known, flux at center of each pole segment (FLUX3) is calculated	for I = 1 FLUX3(I)=PPL11+(FLUX1(I)+FLUX2(I))/2. for I > 1 FLUX3(I)=FLUX3(I-1)+(FLUX1(I-1)+FLUX2(I-1))/2. +(FLUX1(I)+FLUX2(I))/2
6	Calculate ampere-turn drop from pole-tip to end of each pole segment; these ampere-turn drops are called AT1(I); 1 ≤ I ≤ 10; AT1(10) is also labeled FPL	See appendix C for details
7	Calculate FBB, the ampere-turn drop from pole base to pole base, along path a-b-b'-d'	FBB=FPL+AT3(1)-0.5*(AT1(1)+AT1(9)-AT1(10))

8	Calculate what AT3 should be along every path (such as a-c-c'-d') such that FBB is independent of path (i.e., same value as in step 7); call value that AT3 should be AT2	AT2(I)=FBB-2.*FPL+0.5*(AT1(I)+AT1(II))
		IF (I.NE.10) AT2(I)=AT2(I)+(AT1(II-1))*0.5
		IF (I.NE.1) AT2(I)=AT2(I)+(AT1(I-1))*0.5
		where II = 11 - I

9	Compare AT2 and AT3 and compute (a) error in each path, ERROR1(I) (b) cumulative error, ERROR	ERROR1(I)=AT2(I)-AT3(I) $\mathrm{ERROR} = {}_{I=1}^{10}\ \mathrm{ABS}(\mathrm{AT2}(I)-\mathrm{AT3}(I))$
10	Recompute FLUX1(I) such that AT2(I) and AT3(I) will be more nearly equal	FLUX1(I)=(AT2(I)/AT3(I))**(ERROR3(I)/AA)*FLUX1(I) where ERROR3(I) is the value of ERROR1(I) on the previous pass and AA=ERROR3(I)-ERROR1(I)
11	Calculate total air-gap flux resulting from flux distribution calculated in step 10	$\mathrm{FLUX} = \sum_{I=1}^{10} \mathrm{FLUX1}(I)$
12	Recalculate FLUX1(I) such that FLUX=PPL	FLUX1(I)=FLUX1(I)*(PPL/FLUX)
13	If ERROR $< 0.5\times10^{-3}$, iteration is complete; proceed to step 15	
14	If ERROR $\geq 0.5\times10^{-3}$, return to step 2 and repeat each step in the iteration procedure; but, if, after 25 iterations, ERROR is still >0.5 E-3, go back to step 1, execute steps 1 to 7 and then skip to step 15	
15	Calculate total flux through base of pole, PPL1	PPL1=FLUX3(10)+(FLUX1(10)+FLUX2(10))/2.

user that a uniform air-gap flux distribution was assumed.

With the circuit of figure 9 completely analyzed, calculations proceed with the appropriate circuit of figure 8 to determine fluxes, flux densities, and ampere-turn drops for the auxiliary air gap, the yoke, and the end and tapered sections of the rotor.

In the analysis of the equivalent circuit, a calculation that repeatedly occurs is the determination of the ampere-turn drop across an element. This calculation is most easily carried out for those elements in which the flux density is constant throughout. After calculating the flux density, the ampere-turn drop per inch of element length corresponding to that flux density is found by interpolation between points on the appropriate material magnetization curve. Points on the magnetization curve for rotor, stator, and yoke materials are input to the program. The ampere-turn drop per inch of element length is then multiplied by the length of the element to obtain the total ampere-turn drop across that element.

For the rotor end section, the tapered rotor section, and the yoke end section the flux density is not constant throughout. These three elements are each arbitrarily broken into 10 segments. The flux density is calculated at the center of each segment and assumed constant throughout that segment. The ampere-turn drops for each of the

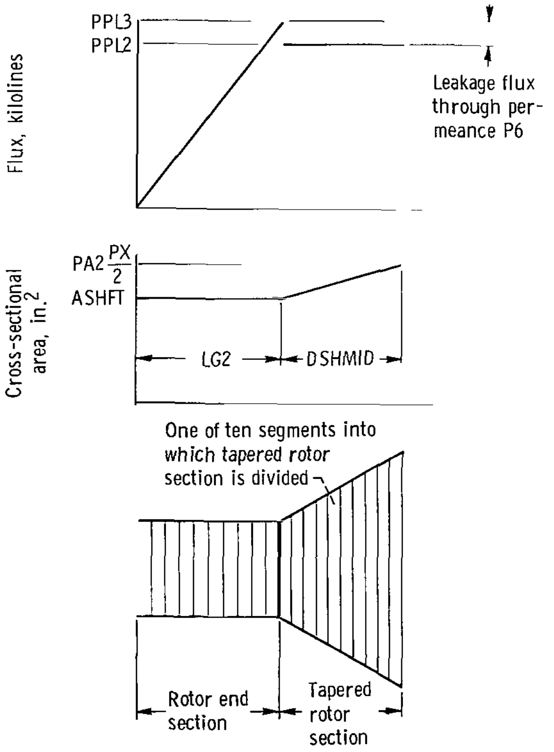


Figure 10. - Assumed flux and area variation along rotor end section and tapered rotor section.

10 segments are then calculated and added to obtain the total ampere-turn drop across the element.

To calculate the flux density at the center of each segment requires that the area and flux at these points be known. In general, however, area and flux are known only at both ends of these elements. Thus, the assumption is made that the area and flux vary linearly between the values at both ends. This assumption allows the calculation of flux and area, and therefore flux density, at any point along the entire length of the element. Figures 10 and 11 illustrate these assumptions of linear variation graphically. At the bottom of figure 10, for example, is the outline of the tapered and end sections of the rotor. Directly above the outline drawing are two graphs, one gives the cross-sectional area of the rotor and the other gives the flux passing axially through each segment. Note, for instance, that for the rotor end section, the flux is assumed to vary linearly from zero to the value PPL3 while for the tapered rotor section the flux is constant at PPL2. The difference between PPL2 and PPL3 is the leakage flux through permeance P6, all of which is assumed to enter the rotor at the interface between the tapered section and the end section. Figure 11, which is for the yoke end section, is similar to figure 10.

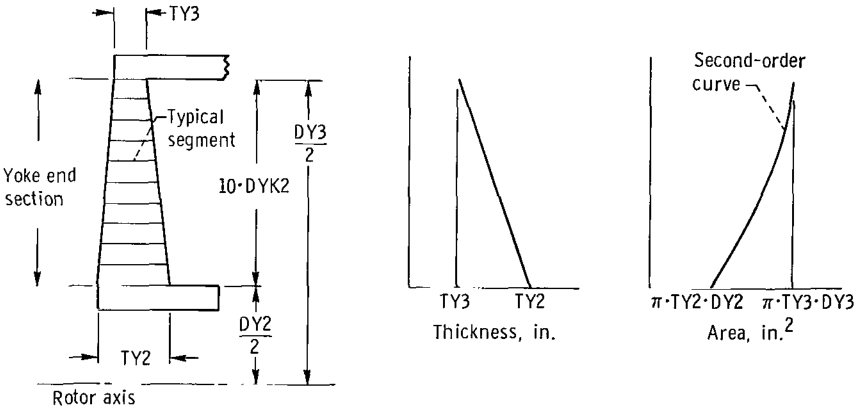


Figure 11. - Assumed thickness and area variation of yoke end section.

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 T_{NL} is known or can be estimated.

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

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

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

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

where

I_G	current in winding at load G
I_{RL}	current at rated load
I_{NL}	current at no-load, equal to zero for armature winding

If the programmer, by exercising one of the input options, elects not to have the program compute load characteristics for rated load, then the field current at rated load I_{RL} will not be calculated. In that case, when the preceding equation is applied to the field temperature calculation, the field current corresponding to the load closest to rated load will be used for I_{RL}.

Armature conductor eddy loss (EX). - References 2 and 7 present a discussion of armature conductor eddy losses. In the program these losses are assumed to be zero for round conductors. For rectangular conductors they are given by

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

where

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

Pole face losses (WN and PP). - The no-load pole-face loss (see refs. 2 and 8) is calculated from the equation

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

where

GA	main air gap area, in.^{2}
D1	empirical factor, function of pole-face lamination thickness
D2	empirical factor, function of air-gap flux density
D3	empirical factor, function of slot frequency
D4	empirical factor, function of slot pitch
D5	empirical factor, function of slot opening to air-gap ratio
D6	empirical factor, function of pole embrace

As given in reference 2, the empirical curve which 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 is given by

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

where

k	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

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

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

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

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

and where weights are given in pounds.

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 (WF). - If an accurate value for windage loss is known, it may be read into the program for use in the efficiency calculation. If the windage loss is not read into the program, it will be assumed to be zero. The program user may also elect to have the program calculate the windage loss according to reference 3. For this purpose subroutine WINDGE has been included. This subroutine is called twice by subroutine OUTPUT: once to calculate windage loss in the main air gap and once to calculate windage loss in the auxiliary air gap.

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

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

EVALUATION OF COMPUTER PROGRAM

Accuracy of the program is evaluated by comparing results of computer calculations with experimental data for the following calculations: the rotor leakage permeance, the open-circuit saturation curve, the field current at several loads, various losses, and efficiencies. The experimental data, taken from reference 5, is for a 1200-hertz 36 000-rpm alternator. The analytic results for the same alternator come from the computer output shown in appendix B.

DESCRIPTION OF ALTERNATOR USED FOR PROGRAM EVALUATION

The alternator used for the evaluation of the computer program is a 1200-hertz four-pole Lundell alternator (ref. 5). The alternator was designed for space application as part of a Brayton cycle energy-conversion system. The rated alternator output is 14.3 kilovolt-amperes at 120/208-volt, 0.75 power factor.

The alternator rotor (shown in fig. 4) is made of SAE 4340 steel with a stainless steel, nonmagnetic separator. No effort was made to reduce pole-face losses by laminating or grooving the pole faces. Figure 4 also shows that the pole width at the tip is less than at the base. The effect of this is that the pole embrace is not constant; for computational purposes the average pole embrace is used. The stator is made of 0.004-inch AL 4750 laminations. SAE 1010 steel is used for the yoke.

For voltage regulation, the alternator has two separate field windings. Each winding is split into two coils and one coil of each winding is located on each side of the stator. For the test results reported in reference 5 both field windings were connected in series.

When used with the Brayton cycle system the alternator cavity will be filled with helium-xenon mixture having a molecular weight of 83.8. The pressure in the cavity will be 44.4 psia at a temperature of 177° C. These conditions, coupled with the 36 000 rpm shaft speed, illustrate the importance of having a smooth rotor to minimize windage losses.

Other alternator parameters and dimensions may be obtained from appendix B.

COMPARISON OF EXPERIMENTAL AND CALCULATED RESULTS

Rotor Leakage Permeance

The values for the rotor leakage permeances P1, P2, P3, P4, P6, and P10 as calculated by the program are given in the first column of table V. When these values are used to compute the total rotor leakage permeance $\mathscr{P}_{RL}$ the result is

$$\mathscr{P}_{RL} = (PX)(P1 + P3 + P2 + P4) + P6$$

$$= (4)(1.04 + 2.43 + 6.22 + 3.22) + 0.41$$

$$= 52.95 \text{ lines/ampere-turn}$$

While it is not possible to measure the individual components of $\mathscr{P}_{RL}$, it is possible to measure $\mathscr{P}_{RL}$ approximately. This was done as described in appendix E. The experimental value obtained was $\mathscr{P}_{RL} = 108$ lines per ampere-turn. This shows that the true value of $\mathscr{P}_{RL}$ is considerably greater than the calculated value of 52 lines per ampere-turn, although, for reasons discussed in appendix E, it is also slightly less than the experimental value of 108 lines per ampere-turn.

For the purpose of evaluating the computer program it was decided to obtain two sets of computer results: one set (shown in appendix B) for which the rotor leakage permeances are as calculated by the program and a second set for which the values of rotor leakage permeance shown in the second column of table V were used as input to the program. The second column of table V was obtained by multiplying each permeance value in the first column by the ratio 108/52 = 2.08.

TABLE V. - TWO SETS OF ROTOR LEAKAGE PERMEANCE VALUES FOR WHICH COMPUTER OUTPUT WAS OBTAINED

Permeance, lines/amp-turn	Value calculated by computer program[a]	Values[b] based on experimental data
P1	1.04	2.16
P2	6.22	12.94
P3	2.43	5.05
P4	3.22	6.70
P6	.412	.86
P10 [=2·(P2+P3+P4)]	23.74	49.38
$\mathscr{P}_{RL}$ [=PX·(P1+P10/2.)+P6]	52.05	[c]108

[a] From appendix B.

[b] Except for $\mathscr{P}_{RL}$, these values are obtained by multiplying the previous column by 108/52 = 2.08.

[c] Experimentally determined value (see appendix E).

Open-Circuit Saturation Curve

The experimental and two calculated open-circuit saturation curves are shown in figure 12. The two sets of calculated points correspond to the two sets of rotor leakage

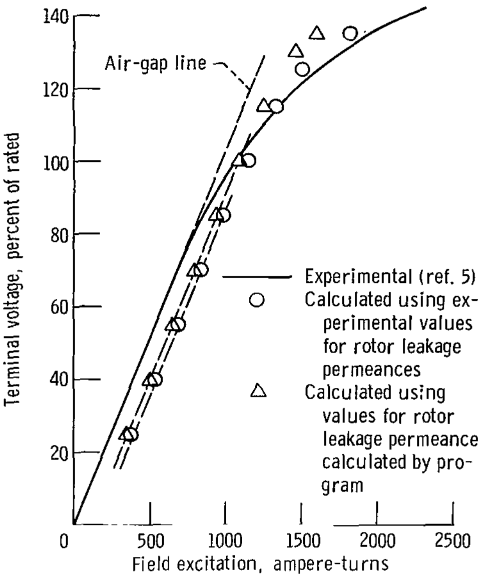


Figure 12. - Comparison of experimental and calculated open-circuit saturation curve.

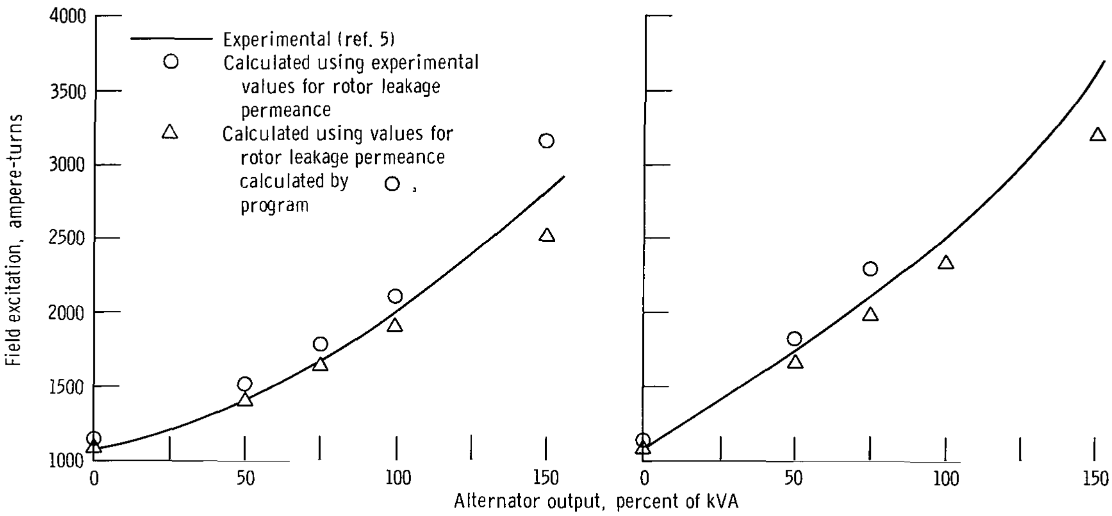
permeances given in table V. In general, the calculated values of field excitation are too high at low terminal voltages. The discrepancies, 115 and 150 ampere-turns, respectively, for the two sets of calculated values, are independent of terminal voltage from 20 to 90 percent of the rated voltage. This has the effect of making the calculated air-gap lines parallel to, but shifted to the right of, the experimental air-gap line. At high terminal voltages, as the alternator becomes saturated, the calculated values of field excitation are lower than experimentally observed.

The effect of changing the rotor leakage permeance by a factor of 2.08 is very minor at voltages less than rated voltage. At higher voltages the effect becomes more pronounced with the experimental value of rotor leakage permeance definitely giving better agreement with the experimental data. For example, at 135 percent of rated voltage, the calculated field excitation, using the values of rotor leakage permeance as calculated by the program, is low by 18 percent. This error is reduced to less than 8 percent by using the experimental value of rotor leakage permeance.

At rated voltage, the respective errors for field excitation, corresponding to the calculated and experimental values of rotor leakage permeance, are 2.3 and 7 percent.

Field Excitation Under Load

Experimentally determined field excitation requirements as a function of load for two power factors are plotted in figure 13. Superimposed on each curve are two sets of



(a) Power factor, 1.0.

(b) Power factor, 0.75 lagging.

Figure 13. - Comparison of experimental and calculated field excitation requirements.

calculated points which correspond to the two sets of rotor leakage permeances in table V. As can be seen from the figure, the higher value of rotor leakage permeance gives calculated values of field excitation higher than the experimental data while the reverse is true for the lower value of rotor leakage permeance. As discussed earlier, the true value of rotor leakage permeance lies between those values given in the two columns of table V; thus, the corresponding calculation for field excitation should be intermediate in value between those plotted in figure 13. In other words, using a more accurate value of rotor leakage permeance should improve agreement between calculated and measured field excitation requirement under load.

While the inaccuracy of the rotor leakage permeance calculation does introduce an error into the field excitation calculation, the result nevertheless shows fair agreement with experimental data. The maximum error, using the values of rotor leakage permeance calculated by the program, is less than 13 percent.

Losses and Efficiency

The losses that will be compared for the purpose of evaluating program accuracy are the armature conductor loss, the field conductor loss, the open-circuit core loss, and the stray-load loss. The open-circuit core loss and the stray-load loss, though commonly measured, are not specifically calculated by the computer program. To permit comparison of the open-circuit core loss and the stray-load loss reported in reference 5 with those losses calculated by the program, the following equivalences are assumed.

$$\text{Open-circuit core loss} = (\text{No-load pole-face loss}) + (\text{No-load stator tooth loss}) + (\text{No-load stator core loss})$$

$$= PP(1) + ST(1) + WQL(1)$$

$$\text{Stray-load loss} = (\text{Armature conductor eddy loss}) + (\text{Miscellaneous load loss}) + (\text{Pole face, stator tooth, and stator core losses due to load})$$

$$= [EX(J)] + [WMIS(J)] + \left\{[PP(J) - PP(1)] + [ST(J) - ST(1)] + [WQL(J) - WQL(1)]\right\}$$

$$= [EX(J) + WMIS(J) + PP(J) + ST(J) + WQL(J)] - [\text{Open-circuit core loss}] \quad J > 1$$

While the stray-load loss equivalence is not completely valid, it is nevertheless useful for the purpose of evaluating program accuracy.

Field conductor and armature conductor losses. - The accuracy of the ohmic loss calculations for the armature and field windings is related directly to how precisely the winding resistance, the winding temperature, and the winding current are known. The accuracy of field-current calculations was discussed in the previous section. A discussion of armature current accuracy has no relevance since (in the program) armature current is essentially an independent variable, which is chosen rather than calculated. Thus, the comparison of calculated and measured winding losses will be preceded by an examination of winding resistances, and of winding temperature variation with current.

Table VI gives both experimental and calculated values for the field and armature winding resistances at 25° C. The calculated results agree quite well with the measured

TABLE VI. - COMPARISON OF CALCULATED

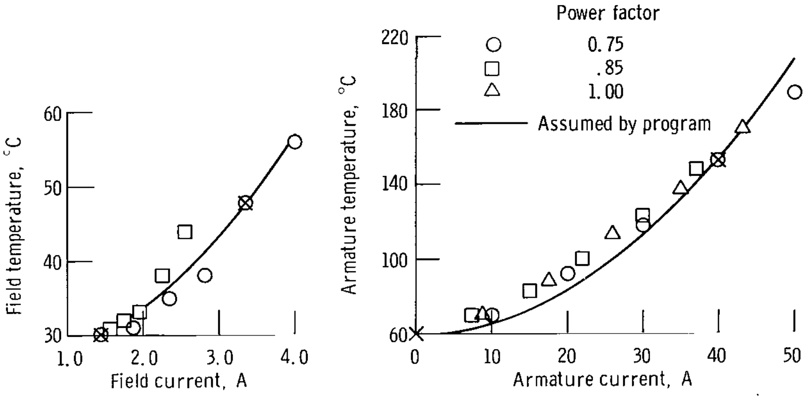
AND MEASURED WINDING RESISTANCES

Winding	Measured[a] resistance at 25° C, ohm	Calculated resistance at 25° C, ohm
Field	4.882	5.118
Armature	.0307	.0309

[a] Obtained with a Kelvin bridge.

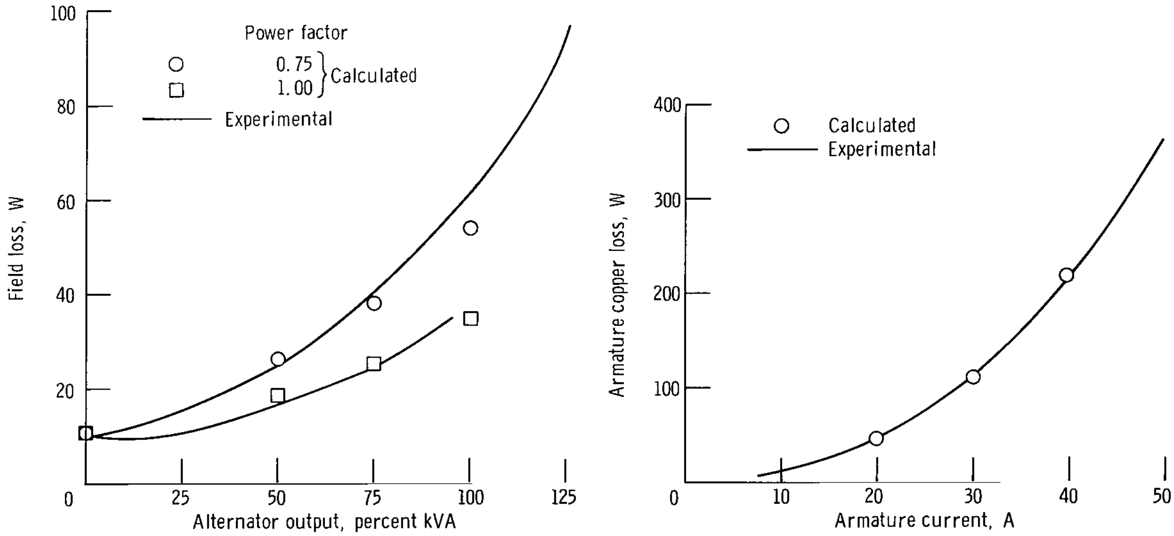
values; the error of field resistance calculation is less than 5 percent; the armature resistance calculation error is less than 1 percent.

Winding temperature is estimated in the program, as described in the section METHOD OF CALCULATION, by assuming that the winding temperature is a parabolic function of winding current. The validity of this assumption is illustrated in figure 14. Of course, the accuracy of estimating temperatures in this manner depends largely on the accuracy of the no-load and rated-load temperatures read into the program.



(a) Field winding. (b) Armature winding.

Figure 14. - Temperature variation with current for field and armature windings. Program assumes temperature variation obtained by parabolic interpolation between points marked X. Temperature at points marked X are input to program.



(a) Field losses. (b) Armature loss.

Figure 15. - Comparison of experimental and calculated field and armature losses.

A comparison of field and armature losses is made in figure 15. The maximum error in the field loss calculation is less than 13 percent. Some of the discrepancy between calculated and measured field losses is due to the error in the field-current calculation. If this error were eliminated, the field-loss calculation would be more accurate at high loads and less accurate at low loads. Armature loss calculation, on the other hand, are within $2\frac{1}{2}$ percent of experimental data.

Open-circuit core loss. - The calculated open-circuit core loss, as defined earlier, is given by

$$\begin{aligned}\text{Open-circuit core loss} &= PP(1) + ST(1) + WQL(1)\\ &= 959 + 64 + 140\\ &= 1163\ \text{W}\end{aligned}$$

The measured value given in reference 5 is 340 watts. Since the calculated value exceeds the measured value by 823 watts, it is clear, from examining the magnitudes of the three losses, that the only component which can be in error by that amount is PP(1), the no-load pole-face loss. More specifically, the calculated value of no-load pole-face loss is too high by at least 619 watts. This error predominates any other possible error in the open-circuit core loss calculation to such an extent that future improvement in the open-circuit core loss calculation must begin with the no-load pole-face loss.

One contributing factor to this large error may be the high slot frequency (21 600 Hz) of the alternator used for the program evaluation. Extrapolation to that frequency of the empirical equations used to calculate the no-load pole-face loss may not be valid.

The large error in the no-load pole-face loss calculation will also affect the accuracy of the stray-load loss, the total loss, and the efficiency calculations discussed in the next sections.

Stray-load loss. - With the method of calculation used by the computer program the pole-face loss at any given load is directly proportional to the no-load pole-face loss. Thus, the error in the no-load pole-face loss calculation discussed in the previous section causes a large error in all pole-face loss calculations. This error, in turn, affects the stray-load loss calculations. To make a meaningful comparison of measured and computed stray-load loss, the calculated values of pole-face loss shown in appendix B were first adjusted downward to the value they would have been, had the no-load face loss

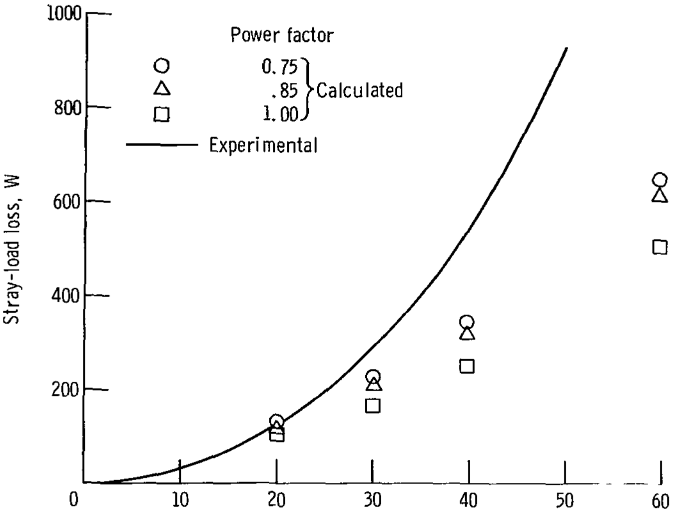


Figure 16. - Comparison of experimental and calculated stray-load loss.

been 136 watts.[a] These adjusted values were then used to compute the stray-load loss. The result is shown in figure 16. It is evident from the figure that the calculated values of stray-load loss are a function of load power factor, while the experimental values, which are measured with the alternator short-circuited, are not. This is not unexpected since the assumed equivalence of stray-load loss and the sum of several calcluated losses is not completely valid. Other sources of error in the stray-load loss calculation are errors in the individual losses that add to give the calculated stray-load loss. At rated current the error ranges from 37 percent at 0.75 power factor to 54 percent at unity power factor.

Electromagnetic efficiency. - Experimental and calculated efficiencies are compared in figure 17. Two sets of calculated points are shown. One set shows the efficiency points exactly as calculated by the program, that is, using the obviously incorrect value of no-load pole-face loss and the correspondingly high values of stray-load loss. The other set of points was computed using the adjusted no-load pole-face loss and the corresponding values of stray-load loss. The computed efficiencies, using the adjusted pole-face loss, differ from the measured efficiencies by no more than 2.4 percent out of 92 percent for an error of only 2.7 percent for the range of 50 to 100 percent of rated kilovolt-ampere.

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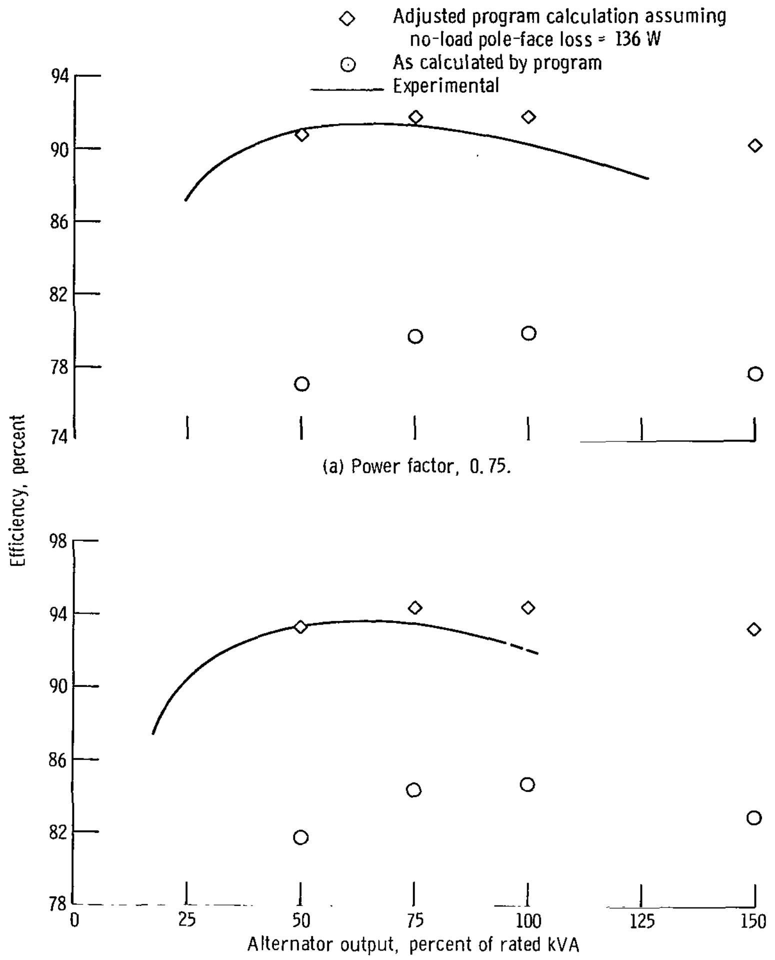
[a] Assuming that the no-load core and tooth loss calculations are correct, 136 watts must be the value of the no-load pole face loss to give agreement between the experimental and calculated values of open-circuit core loss.



(b) Power factor, 1.00.

Figure 17. - Comparison of experimental and calculated efficiencies.

CONCLUDING REMARKS

This report describes a digital computer program for the analysis of Lundell alternators. The accuracy of the calculations is evaluated by comparing the computer results with experimental data for one alternator. The evaluation begins by comparing the calculated and measured values of rotor leakage permeance. The comparison shows, not unexpectedly, that the calculated value is very approximate, being low by a factor of two for the particular alternator used in the evaluation. This error affects the accuracy of the field-excitation calculations. It is shown that elimination of the error would improve the agreement between experimental and calculated open circuit saturation curves and between experimental and calculated field excitation requirements under load. However, even without this correction, the maximum error in field excitation at rated voltage is 13 percent.

Field and armature loss calculations are accurate to within 13 and 3 percent, respectively. Other loss calculations could not be evaluated precisely because of a lack of detailed experimental data. However, it is clear that the no-load pole-face loss calculation is greatly in error for the alternator used in this evaluation. One possible explanation for this large error is that the empirical method of calculation used in the program is not valid for the high slot frequency encountered in this alternator.

The error in the no-load pole-face loss calculation in turn affects the accuracy of the stray load loss and efficiency calculations. Thus, caution must be used in interpreting the efficiency results, especially if the calculated no-load pole-face loss is high. When allowance is made for the inaccuracy in the no-load pole-face loss and its effect on stray-load loss, efficiency calculations are close to the experimentally observed value.

Lewis Research Center,
National Aeronautics and Space Administration,
Cleveland, Ohio, November 14, 1969,
120-27.

APPENDIX A

HOW TO USE COMPUTER PROGRAM

Input Data Requirements

To use this computer program for the analysis of Lundell 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, rotor, and yoke. The design information must then be transferred onto data cards for use with the program. A typical set of data cards is shown in figure 18. It consists of three 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, rotor material, and yoke material. There must be exactly three material decks in each data deck even if two or all three materials are identical. The last card of the alternator design deck ($WIND) is 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 anal-

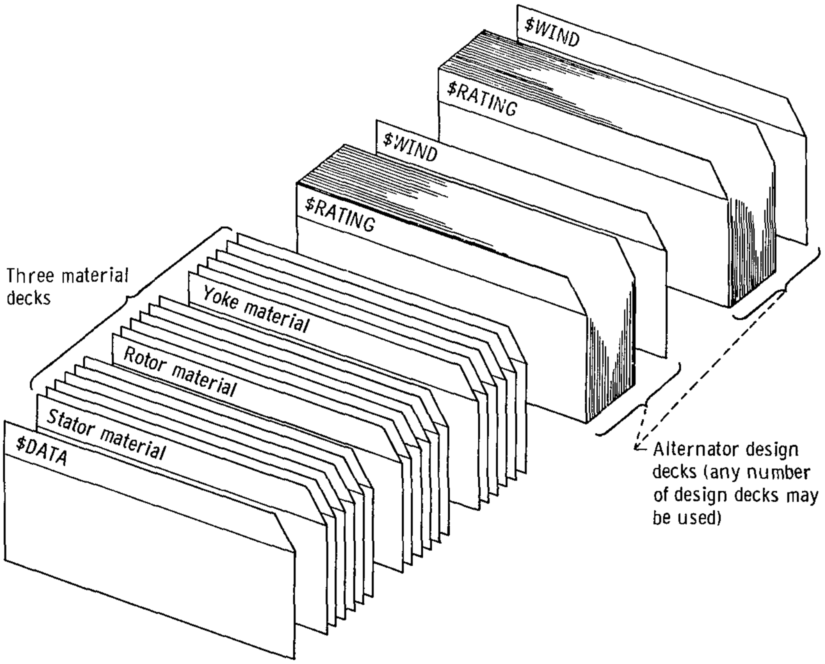


Figure 18. - Typical data deck makeup.

ysis complete with an individual output record. However, the same three 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 serves two functions: it identifies the material deck, and it is read by the computer and stored for later printout on the output record. The remaining four cards contain 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 re-

TABLE VII. - 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), $1 \le J \le 29$	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), $31 \le J \le 59$	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)
11	YMAT	6A6	Yoke material name
12 - 15	AI(J), $61 \le J \le 89$	8F10. 1	AI(61) is the saturation flux density of the yoke material; AI(62) to AI(89) are, alternately, values of flux density (kilolines/in.^{2}) and magnetizing force (A-turn/in.) for 14 points on the yoke material magnetization curve; the 14 points are arranged in order of increasing flux density; note that AI(61) = AI(88)

constructed by interpolation between points. The interpolation assumes a straight line on semilog paper between data points.

Table VII lists those variables associated with the three 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 19. The material name should start in column 1 and may extend up to column 36.

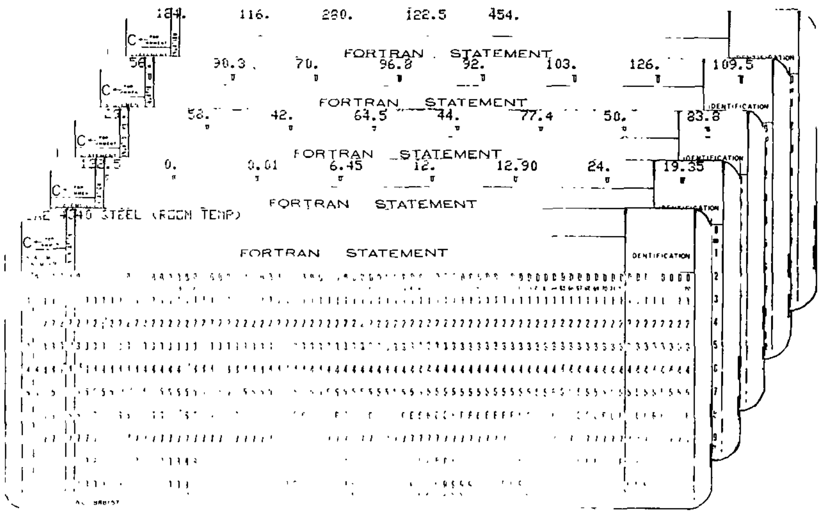
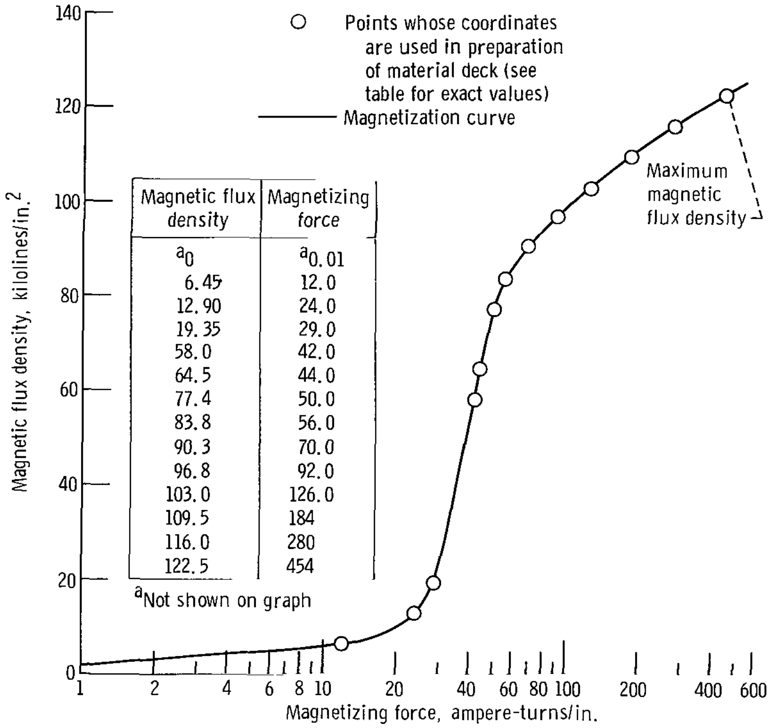


Figure 19. - Material deck for SAE 4340 steel.

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 20. 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 flux density of the points chosen. In the example, this value is 122. 5 kilolines per square inch. This is followed in ascending order, by alternate values of magnetic flux density and magnetizing force. Again, in the example, with reference to the table insert, the values appear in the following sequence on the data cards: 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 19.



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 20. - Average magnetization curve for SAE 4340 steel.

Preparation of Alternator Design Deck

The alternator design deck contains all the dimensions, the geometric configuration (in numerical code), and the winding parameters needed for an electromagnetic analysis of the alternator design. Unlike the material decks, which are read according to a FORMAT statement, the alternator design decks are read with a READ statement referencing a NAMELIST name. For each NAMELIST name one or more data cards are required to numerically define the variables included in that NAMELIST name. In all there are 10 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 VIII 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

TABLE VIII. - 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 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 (normalized to rated VA) at which load characteristics are calculated (see appendix B, pp. 51 to 53), 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 (see appendix B, pp. 51 to 53)	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 (see appendix B, p. 54), 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	Slot type	M	See fig. 21
	BO	Slot dimension (use with slot type 2, 3, 4), in.	C	↓
	B3	Slot dimension (use with slot type 3), in.	↓	↓
	BS	Slot dimension (use with slot type 1, 2, 4, 5), in.	↓	↓
	HO	Slot dimension (use with slot type 2, 3, 4), in.	↓	↓
	HX	Slot dimension (use with slot type 1, 2, 3, 5), in.	↓	↓
	HY	Slot dimension (use with slot type 1, 2, 3, 5), in.	↓	↓
	HS	Slot dimension (use with slot type 1, 2, 3, 4, 5), in.	M	↓
	HT	Slot dimension (use with slot type 2, 3), in.	C	↓
	IQQ	Number of slots	M	----------------------------------

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

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

NAMELIST name	FORTRAN symbol	Definition	Classification (a)	Remarks
WINDNG	RF	Type of coil	M	RF = 1.0 for form wound coil; RF = 0 for random wound coil
	SC	Number of conductors per slot	↓	In fig. 24, SC = 4
	YY	Slots spanned per coil (number of slots between coil sides plus one)		--------------------------------
	C	Number of parallel circuits per phase		--------------------------------
	DW	Strand diameter or width, in.		See fig. 24
	SN	Strand per conductor in depth (radial direction)	C	Read for rectangular wire only (in fig. 24, SN = 2)
	SN1	Total strands per conductor	M	In fig. 24, SN = 4
	DW1	Uninsulated stator strand thickness (radial direction), in.	C	Read for rectangular wire only; see fig. 24
	CE	Straight portion of coil extension, in	M	See fig. 24
	SD	Distance between centerline of strands in depth, in.	M	See fig. 24
	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	End turn length, in.	O	Read in if exact value is known; if not, program will calculate approximate value
AIRGAP	GC	Main air gap (radial dimension), in.	M	See fig. 23
	G2	Auxiliary air gap (radial dimension), in.	M	See fig. 23
	LG2	Auxiliary air-gap length (axial dimension), in.	M	See fig. 23
	WF	Windage losses, W	O	Read in actual value; if not read in, program assumes windage to be zero; to have program calculate approximate windage loss, set WF = 1.0 and add data card for NAMELIST name WIND to end of alternator design deck

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

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

NAMELIST name	FORTRAN symbol	Definition	Classification (a)	Remarks
ROTOR	PL	Pole body length (axial direction), in.	C	See fig. 23; omit if rotor leakage permeances are input to program
	PE	Pole embrace	O	If not read in, program calculates PE for pole width (PW1+PW2)/2
	WROTOR	Rotor weight, lb	O	If not read in, program will calculate an approximate rotor weight
	D1	Pole face loss factor	O	If not read in, D1 = 7.0; factor is used for no-load pole-face loss calculations; for a solid rotor factor is normally equal to 7 (see ref. 2). Setting D1 = 0 reduces pole-face losses to zero
	C1	Ratio of fundamental maximum to actual maximum value of field form (field form is air-gap flux density distribution due to field only)	O	Identical to those defined for conventional salient pole alternator (ref. 10); if not an input, values are calculated from formulas given in refs. 2 and 10
	CP	Ratio of average to maximum value of field form	O	
	CM	Demagnetizing factor (direct axis)	O	
	CQ	Cross magnetizing factor (quadrature axis)	O	
	DISH	Inside shaft diameter (for hollow shaft), in.	C	Read in only for hollow shaft (see fig. 23)
	PW1	Pole width at narrow end, in.	M	------------------------------------
	PW2	Pole width at wide end, in.		------------------------------------
	PT1	Pole thickness at narrow end, in.		------------------------------------
	PT2	Pole thickness at wide end, in.		------------------------------------
	PA	Pole cross-sectional areas, in.^{2}	C	PA is a subscripted variable (array size is 11); PA(1) is the pole tip area; PA(11) is the area at the base of the pole; PA(2) through PA(10) are defined at equally spaced intervals between PA(1) and PA(11); PA(1) must be read in unless PA1 is read; PA(11) must be read in unless PA2 is read in; any or all of the remaining PA's may be omitted. In that case the computer will fill in the missing values by linear interpolation
	PA1	Pole cross-sectional area at pole-tip, in.^{2}	C	Need not be read in if PA(1) is read in
	PA2	Pole cross-sectional area at base of pole, in.^{2}	C	Need not be read in if PA(11) is read in
	GAMMAR	Density of nonmagnetic rotor material, lb/in.^{3}	O	If not read in, GAMMAR = 0.283 will be assumed; if WROTOR is read in, then GAMMAR is not needed
	DISH1	Shaft diameter under auxiliary air gap, in.	M	See fig. 23
	SHL1	Rotor length at diameter DR, in.	O	If not read in SHL1 = CL will be assumed (used for weight calculation only); see fig. 23
	SHL2	Rotor length between rotor end sections, in.	M	See fig. 23

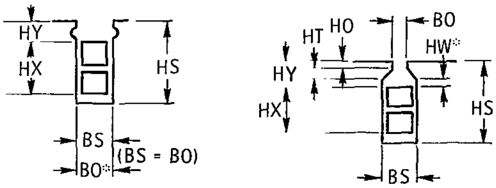
[a] M, mandatory; C, conditional; O, optional.

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

NAMELIST name	FORTRAN symbol	Definition	Classification (a)	Remarks
YOKE	TY	Yoke dimension, in.	M	See fig. 22
	TYL	Yoke dimension, in.	↓	↓
	DYC	Yoke outside diameter, in.	↓	↓
	TYE	Yoke dimension, in.	↓	↓
	TYR	↓	↓	↓
	TY2	↓	C	If not read in, TY2 = TY3 will be assumed (see fig. 22)
	TY3	↓	M	See fig. 22
	WYOKE	Yoke weight, lb	O	If not read in, program will calculate an approximate value
FIELD	PCOIL	Field coil inside diameter, in.	M	------------------------------------
	DCOIL	Field coil outside diameter, in.	↓	------------------------------------
	PT	Number of field turns per coil	↓	------------------------------------
	RD	Field conductor diameter or width, in.	↓	------------------------------------
	RT	Field conductor thickness, in.	C	Do not read in for round conductors
	BCOIL	Field coil width, in.	M	------------------------------------
	T2	Rated-load field temperature, °C	M	Used in loss and efficiency calculations
	T22	No-load field temperature, °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, °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
	TYPY	Field coil location code	M	See fig. 8
PERMCE	P1	Leakage permeance, lines/am-turn	O	See figs. 6 and 8; if these permeances are omitted from program input, the program will calculate approximate values except for P7; if P7 is omitted it will be assumed zero; if P10 is read in, P2, P3, and P4 may be omitted
	P2	↓	↓	
	P3	↓	↓	
	P4	↓	↓	
	P5	↓	↓	
	P6	↓	↓	
	P7	↓	↓	
	P10	↓	↓	
WIND[b]	RO	Density of gas in alternator cavity at pressure PRESS and temperature TEMP, lb/ft^3	O	If RO is not read in, then M must be read in; program then calculates RO
	VIS	Viscosity of gas in alternator cavity at temperature TEMP and pressure PRESS, lb/sec-ft	O	If VIS is not read in, program assumes viscosity of air at 25° C (= 1.24×10^{-5})
	PRESS	Pressure of gas in alternator cavity, lb/in.^{2}	O	If not read in, program assumes PRESS = 14.7
	M	Molecular weight of gas in alternator cavity	C	This must be read in if RO is not read in; otherwise it may be omitted
	TEMP	Temperature of gas in alternator cavity, °C	O	If not read in, program assumed TEMP = 25

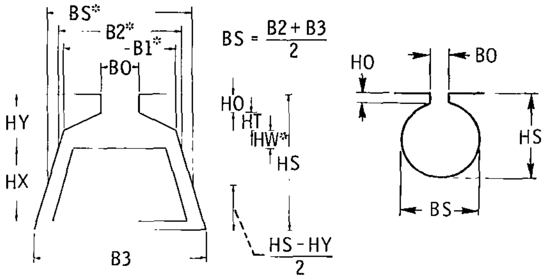
[a] M, mandatory; C, conditional; O, optional.

[b] This card is needed only if WF of NAMELIST name AIRGAP is unity.



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 21. - Stator slot dimensions. (Starred variables are not input, they are shown for reference only.)

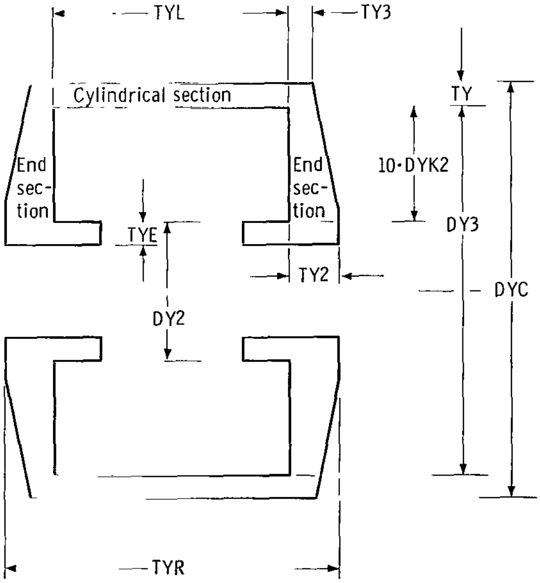


Figure 22. - Yoke dimensions.

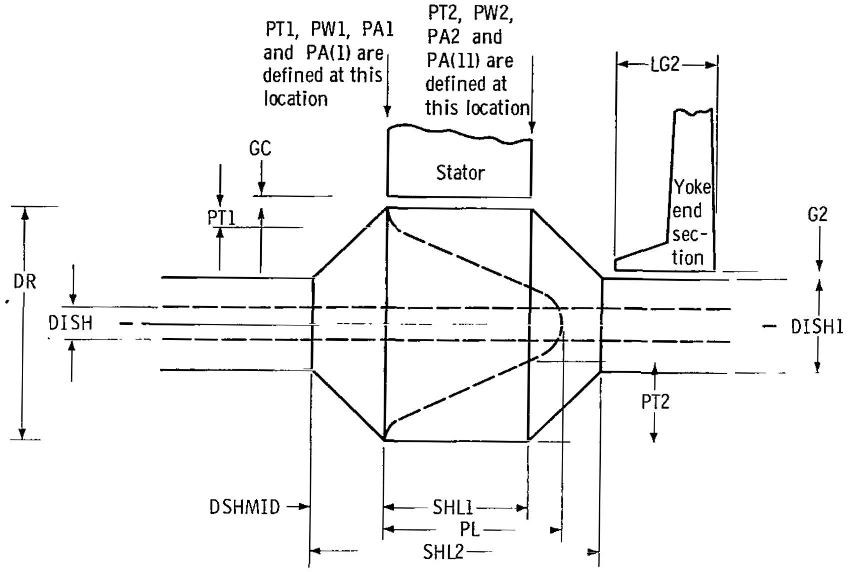


Figure 23. - Dimensions associated with rotor, main and auxiliary air gaps.

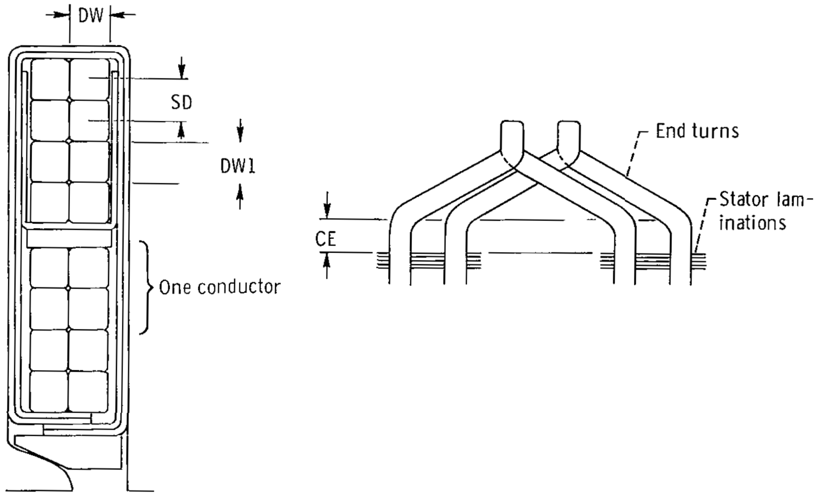


Figure 24. - Definition of variables used with NAMELIST name WINDNG.

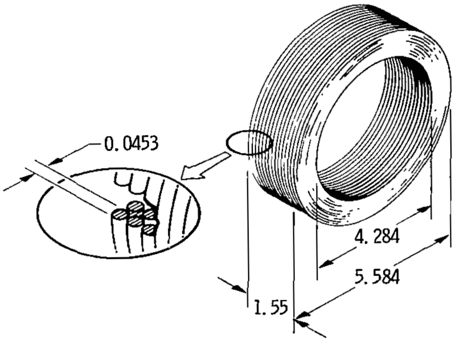
each case where an optional variable is omitted from the program input, an assumption regarding that variable is made internal to the program. The remarks column of the table supplies specific explanations in regard to all conditional or optional variables.

To further clarify the definition of some variables, figures 21 to 24 are given. These figures are referenced in the table where applicable.

Preparation of an alternator design deck will be illustrated with the construction of a typical data card for the NAMELIST name FIELD. The data that will be used is for the 1200-hertz 14.3-kilovolt-ampere 120/208-volt Brayton cycle alternator (refs. 4

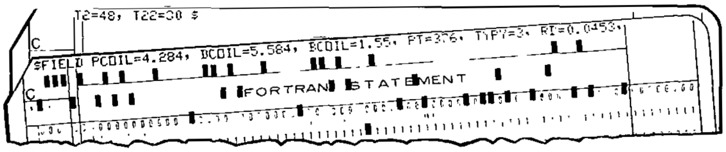
and 5). Figure 25(a) gives all pertinent design data for the Brayton cycle alternator field circuit. Figure 25(b) shows how the design data are related to the variables of NAMELIST name FIELD and how these data are transferred to the data card $FIELD.

Data cards for the remaining NAMELIST names are prepared in a similar manner. To illustrate the results, a complete data deck listing for the Brayton cycle alternator is shown in figure 26. The output, which resulted from the data deck shown in figure 26 is presented in appendix B.



Number of field coils	2
Number of turns per coil	376
Rated-load field temperature, °C	48
No-load field temperature, °C	30
Material	Copper
Field coil location code	3

(a) Field coil design parameters.



```
$FIELD PCOIL=4.284, DCOIL=5.584, BCOIL=1.55, PT=376, TYPY=3, RD=0.0453,
T2=48, T22=30 $
```

PCOIL	4.284
DCOIL	5.584
BCOIL	1.55
PT	376
RD	0.0453
RT	Not applicable to round conductors
T2	48
T22	30
RR	Need not be read in; program will automatically assume value for copper
ALPHAR	Need not be read in; program will automatically assume value for copper
TYPY	3 (see fig. 8(c))
TF	Field resistance will be printed out at this temperature. Since it is not read in, program will assume TF = 25° C

(b) Correspondence of design parameters to FORTRAN symbols and data card $FIELD.

Figure 25. - Procedure for preparing data card for NAMELIST name FIELD.

```
$DATA
AL 4750 STEEL
   103.       0.        0.01      7.74      0.2       22.6      0.4       51.6
   1.0        64.5      2.0       72.       3.        74.5      4.        76.
   5.         79.5      7.        90.       15.       93.5      20.       97.
   30.        100.      50.       103.      200.
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.
SAE 1010 STEEL (NOT ANNEALED)
  128.        0.        .01      1.0       1.0       7.0       3.0       11.0
  4.0         17.5      5.0      46.0      10.       72.0      20.       83.5
  30.         91.0      40.      55.5      50.       107.0     100.      116.
 200.         121.      300.     128.      500.
 $RATING VA=14.3, EP=120, F=1200, IPX=4, PFC=0.75, 0.85, 1.0, VMIN=0.25,
     G=0., 0.5, 0.75, 1.0, 1.50 $
 $STATOR DI=3.30, DL=5.364, CL=1.65, LTS=0.004, SF=0.9, WL=22, BK=77.4 $
 $SLOTS ZZ=3, BC=0.05, B3=0.23, HY=0.05, HO=0.02, HT=0.01, HX=0.423,
     HS=0.483, ICC=36 $
 $WINDNG RF=0, SC=18, YY=6, C=4, DW=0.0201, SN=1, SN1=5, CE=0.25, SD=0.0215,
     PBA=60, T1=153, T11=60 $
 $AIRGAP GC=0.02, G2=0.02, LG2=1.3, WF=1.0 $
 $ROTOR PW1=1.6, PW2=1.756, PT1=0.215, PT2=1.27, PA2=1.74, D1=7.0,
     PA(1)=0.24, PA(2)=0.34, PA(3)=0.47, PA(4)=0.65, PA(5)=0.82, PA(6)=0.98,
     PA(11)=1.73, DISH1=2.19, PL=2.4, SHL1=1.65, SHL2=3.65, PA1=0.245,
     DISH=0.5 $
 $YOKE TY=0.26, DYC=6.18, TYL=5.05, TYR=6.25, TYE=0.25, TY3=0.3, TY2=0.5 $
 $FIELD PCOIL=4.284, DCOIL=5.584, BCOIL=1.55, PT=376, TYPY=3, RD=0.0453,
     T2=48, T22=30 $
 $PERMCE P7=12.0 $
 $WIND VIS=2.3E-5, PRESS=44.4, TEMP=177, M=83.8 $
```

Figure 26. - Listing of data deck for 1200-hertz 120/208-volt 14.3-kilovolt-ampere Brayton alternator.

APPENDIX B

TYPICAL COMPUTER PROGRAM OUTPUT LISTING

The following is the output listing of the Lundell computer program resulting from the input data shown in figure 26. 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 or not windage loss was computed by the program.

Note that on page 54 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.

```
             *** STATIONARY OUTSIDE-COIL LUNDELL ALTERNATOR ***
                              (TWO FIELD COILS)


ALTERNATOR RATING

         ALTERNATOR KVA            14.3
         LINE-LINE VOLTAGE        208.
         LINE-NEUT. VOLTAGE       120.
         PHASE CURRENT             39.72
         POWER FACTOR               0.75
         PHASES                     3
         FREQUENCY               1200.
         POLES                      4
         RPM                    36000.0


STATOR SLOTS

   TYPE-CONSTANT TOOTH WIDTH
                                                           1              1
                                                           1------B1------1
         B0                     0.050 INCHES               1              1
         B1                     0.151                      1     -B0-     1
         B2                     0.154           -----------1----*    *----1-----------
         B3                     0.230                      1    *    *    1        H0
         BS = (B2+B3)/2         0.192                      1    *    *----1-----------
         H0                     0.020                      1  *        *  1        HT
         HX                     0.423                      *              *-----------
         HT                     0.010            HS       *                *       HW
         HW                     0.020                    *   ************   *---------
         HS                     0.483                   *1   *          *   1*
                                                       * 1   *          *   1 *    HX
         NO. OF SLOTS              36                 *  1   ************   1  *------
                                                     *   1                  1   *
         SLOT PITCH             0.288 INCHES    ----******************************
                                                    1    1                  1    1
         SLOT PITCH                                 1    1--------B2--------1    1
           AT 1/3 DIST.         0.316 INCHES        1    1                  1    1
                                                    1-------------B3-------------1
                                                    1                            1
```

```
AIR GAP

     MAIN AIR GAP                        0.020 INCHES
     AUXILIARY AIR GAP                   0.020
     LENGTH OF AUXILIARY AIR GAP         1.300
     EFFECTIVE AIR GAP                   0.021

     CARTER COEFFICIENT                  1.074


ARMATURE WINDING (Y-CONNECTED, RANDOM WOUND)

     STRAND DIAMETER                           0.0201 INCHES
     DISTANCE BTWN CL OF STRANDS (RADIAL)      0.0215

     STRANDS/CONDUCTOR IN RADIAL DIR.          1.
     TOTAL STRANDS/CONDUCTOR                   5.
     CONDUCTOR AREA                            0.0016 SQ-IN.
     CURRENT DENSITY AT FULL LOAD           6262.41   AMP/SQ-IN.

     COIL EXTENSION BEYOND CORE                0.250  INCHES
     MEAN LENGTH OF 1/2 TURN                   5.121
     END TURN LENGTH                           3.471
     STATOR SLOT SKEW                          0.

     RESISTIVITY AT 20 DEG. C                  0.6940 MICRO OHM INCHES
     STATOR RESISTANCE AT   25. DEG. C         0.0309 OHMS

     NO. OF EFFECTIVE SERIES TURNS            22.44
     TOTAL EFFECTIVE CONDUCTORS              140.31
     SLOTS SPANNED                             6.
     SLOTS PER POLE PER PHASE                  3.00
     CONDUCTORS/SLOT                          18.
     NO. OF PARALLEL CIRCUITS                  4.
     PHASE BELT ANGLE                         60.     DEGREES

     SKEW FACTOR                               1.000
     DISTRIBUTION FACTOR                       0.960
     PITCH FACTOR                              0.866

FIELD WINDING

     CONDUCTOR DIAMETER                        0.0453 INCHES
     CONDUCTOR AREA                            0.0015 SQ-IN.

     NO. OF FIELD COILS                        2
     NO. OF TURNS (PER COIL)                 376.
     MEAN LENGTH OF TURN                      15.501  INCHES

     RESISTIVITY AT 20 DEG. C                  0.6940 MICRO OHM INCHES
     FIELD RESISTANCE AT  25. DEG. C           5.1179 OHMS
          (BOTH COILS IN SERIES)
     COIL INSIDE DIAMETER                      4.284  INCHES
     COIL OUTSIDE DIAMETER                     5.584
     COIL WIDTH                                1.550

     LOCATION CODE (TYPY)                       3

CONSTANTS

     C1, FUNDAMENTAL/MAX. OF FIELD FLUX   1.117
     CP, POLE CONSTANT                    0.693
     CM, DEMAGNETIZATION FACTOR           0.848
     CQ, CROSS MAGNETIZATION FACTOR       0.487
     DI, POLE FACE LOSS FACTOR            7.000
```

```
STATOR

         STATOR INSIDE DIAMETER                   3.30  INCHES
         STATOR OUTSIDE DIAMETER                  5.36
         OVERALL CORE LENGTH                      1.65
         EFFECTIVE CORE LENGTH                    1.48
         DEPTH BELOW SLOT                         0.55

         STACKING FACTOR                          0.90

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

         CORE LOSS AT   77.4 KILOLINES/SQ.IN.    22.0   WATTS/LB.
         LAMINATION THICKNESS                     0.004 IN.

YOKE

           1                      1  1  TY3
           1------   TYL    ------1  1---
           1                      1  1     1
                                           1
        ****************************** ------
        *                            *   TY
        *                            *
        *  ************************--*-------
        *  *                      *  *     1
        *  *                      *  *     1
       *   *                      *   *
       *   *                      *   *
       *   *                      *   *
      *    *                 1    *    *
      *    *                 1    *    *
      *    ***              --- ***    *
      *      *              TYE *      *
      ********              --- ********
      1      1               1    1    1
------1  LG2 1------          ----1    1---- TY2
      1      1                         1
      1--------------TYR --------------1
      1                                1

        TY                         0.26 INCHES
        TY2                        0.50
        TY3                        0.30
        TYL                        5.05
        TYE                        0.25
        TYR                        6.25
        LG2                        1.30

        YOKE OUTSIDE DIAMETER      6.18
```

```
ROTOR

        1                     1
        1------   3.65  ------1
        1                     1
        1                     1
        1                     1
        1    ************  -------------------------
        1   **          **    1                   1
        1  * *          * *   1                   1
          *  *          *  *                      1
         *   *          *   *                     1
   ******    *          *    ****** ------        1
        *    *          *    *           1        1
        *    *          *    *           1
        *    *          *    *           1       3.26
        *    *          *    *
        *    *          *    *         2.19       1
        *    *          *    *                    1
        *    *          *    *           1        1
   ******    *          *    ****** ------        1
         *   *          *   *                     1
          *  *          *  *                      1
           * *          * *                       1
            **          **                        1
             ************  -------------------------

             1          1
             1          1
         ----1    1.65  1----
             1          1

        POLE DIMENSIONS (INCHES)

          NARROW END
              WIDTH               1.60
              THICKNESS           0.21
              AREA                0.24

          WIDE END
              WIDTH               1.76
              THICKNESS           1.27
              AREA                1.74

          POLE LENGTH             2.40
          INSIDE SHAFT DIAMETER
            (FOR HOLLOW SHAFT)    0.500

        POLE EMBRACE              0.69

        PERIPHERAL SPEED      30748.32 FEET/MIN.
          (AT MAIN AIR GAP)
        SPEC. TANGENTIAL FORCE    0.99 LBS/SQ.IN.

        DENSITY OF NON-MAGNETIC
          ROTOR MATERIAL          0.283 LBS/CU.IN.
```

```
WEIGHTS

         STATOR COND.            1.689 POUNDS
         FIELD COND.             6.031
         STATOR IRON             4.584
         ROTOR                   9.662
         YOKE                   11.287

         TOTAL
          (ELECTROMAGNETIC)     33.252

WINDAGE

         FLUID PROPERTIES
            VISCOSITY                2.300E-05 LBS/SEC-FT
            DENSITY                  4.2664 LBS/CU.FT.
            PRESSURE                44.40 LBS/SQ. IN
            TEMPERATURE            177.00 DEG. C
            MOLECULAR WEIGHT        83.8

         REYNOLDS NUMBER
            MAIN AIR GAP        15831.50
            AUX. AIR GAP        10635.27
         WINDAGE LOSS (WATTS)
            MAIN AIR GAP          652.43
            AUX. AIR GAP          114.39
            TOTAL                 881.22

PERMEANCES

         WINDING LEAKAGE
         (PER INCH OF CORE LENGTH)
           STATOR SLOT                        5.903 LINES/AMPERE TURN
           STATOR END                         8.009
           SPECIAL (SPS)                      0.

         P1 (POLE TIP)                        1.042
         P2                                   6.218
         P3                                   2.431
         P4                                   3.224
         P5                                  20.218
         P6                                   0.412
         P7                                  12.000
         P8 (MAIN AIR GAP)                 2540.897
         P9 (AUX. AIR GAP)                 1439.618
         P10                                 23.748
```

```
REACTANCES

          AMPERE CONDUCTORS/INCH                537.518
          REACTANCE FACTOR                        0.990

          STATOR WINDING LEAKAGE                 13.775 PERCENT
          ARM. REACTION (DIRECT)                142.623
          ARM. REACTION (QUAD.)                  73.318
          SYNCHRONOUS (DIRECT)                  156.398
          SYNCHRONOUS (QUAD.)                    87.092
          FIELD LEAKAGE                         451.382
          TRANSIENT                             122.182

          FIELD SELF INDUCTANCE                   2.356 HENRIES

          OPEN CIRCUIT TIME CONSTANT
             (FIELD ONLY, AT 25. DEG. C)           0.46042 SECONDS

          SHORT CIRCUIT AMPERE-TURNS           1180.916
          SHORT CIRCUIT RATIO                     0.922


STATOR MATERIAL - AL 4750 STEEL

ROTOR MATERIAL -- SAE 4340 STEEL (ROOM TEMP)

YOKE MATERIAL --- SAE 1010 STEEL (NOT ANNEALED)


MAGNETIZATION CHARACTERISTICS (NO LOAD, RATED VOLTAGE)

          TG, TOTAL USEFUL FLUX                564.33 KILOLINES
          FQ, MAIN AIR-GAP FLUX/POLE            97.82
          PPL1, FLUX LEAVING BASE OF POLE      109.21
          PPL2, FLUX IN TAPERED ROTOR SECT.    222.15
          PPL3, FLUX INTO ROTOR END SECT.      222.41
          PPL4, (LEAKAGE THROUGH P5)+PPL3      237.87

          FLUX DENSITIES (KILOLINES/SQ IN)
             MAIN AIR GAP                        32.990
             AUXILIARY AIR GAP                   24.857
             STATOR CORE                         60.245
             STATOR TEETH                        75.039
             YOKE - CYLINDRICAL SECTION          49.193
                    END SECTION                  53.720
             ROTOR - POLE                        62.690
                     END SECTION                 59.177
                     TAPERED SECTION             63.755

          AMPERE-TURNS
             MAIN AIR GAP                       223.042
             AUXILIARY AIR GAP                  154.493
             STATOR CORE                          5.789
             STATOR TEETH                         2.093
             YOKE - CYLINDRICAL SECTION          29.127
                    END SECTION                  15.000
             ROTOR - POLE                        65.638
                     END SECTION                 38.075
                     TAPERED SECTION             43.537
             TOTAL                             1089.115
```

ALTERNATOR LOAD CHARACTERISTICS (RATED VOLTAGE, 0.75 POWER FACTOR)

PERCENT KVA	0.	50.	75.	100.	150.
FLUX DENSITIES (KL/SQ-IN)					
TEETH	75.04	80.45	83.18	86.22	93.44
CORE	60.25	64.59	66.78	69.22	75.01
YOKE - CYLINDRICAL SECTION	49.19	59.68	65.48	71.50	84.83
END SECTION	53.72	65.18	71.50	78.19	92.70
ROTOR - POLE	62.69	73.24	78.98	85.02	97.95
END SECTION	59.18	69.98	75.89	82.11	95.42
TAPERED SEC.	63.76	75.35	81.69	88.37	102.54
AMPERE-TURNS					
MAIN AIR GAP	223.04	239.14	247.25	256.28	277.72
AUX. AIR GAP	154.49	182.70	198.13	214.37	249.13
TEETH	2.09	3.62	4.42	5.51	9.51
CORE	5.79	7.31	8.23	9.39	15.71
YOKE - CYLINDRICAL SECTION	29.13	38.53	44.96	52.94	34.53
END SECTION	15.00	19.55	22.67	26.74	40.75
ROTOR - POLE	65.64	71.26	74.89	80.52	110.03
END SECTION	38.07	41.19	43.02	45.22	53.23
TAPERED SEC.	43.54	48.58	53.06	63.28	115.64
TOTAL AMPERE TURNS	1089.11	1653.88	1982.35	2342.84	3232.85
FIELD CURRENT (AMPS)	1.45	2.20	2.64	3.12	4.30
CURRENT DENS. (FIELD)	898.60	1364.58	1635.59	1933.02	2667.35
FIELD VOLTS	7.56	11.75	14.35	17.36	25.71
TEMPERATURES (DEG.C)					
FIELD	30.00	36.48	41.48	48.00	68.75
ARMATURE	60.00	83.25	112.31	153.00	269.25
RESISTANCES (OHMS)					
FIELD	5.22	5.34	5.44	5.57	5.98
ARMATURE	0.0350	0.0378	0.0412	0.0461	0.0599
ALTERNATOR LOSSES (WATTS)					
FIELD	10.94	25.85	37.82	54.08	110.54
WINDAGE	881.22	881.22	881.22	881.22	881.22
STATOR TOOTH	64.50	74.14	79.25	85.15	100.00
STATOR CORE	139.70	160.59	171.66	184.43	216.59
POLE FACE	958.70	1224.29	1556.27	2021.05	3348.99
STATOR COPPER	0.	44.71	109.79	218.09	637.92
EDDY	0.	0.	0.	0.	0.
MISC. LOAD	0.	71.50	107.25	143.00	214.50
TOTAL	2055.06	2482.29	2943.27	3587.02	5509.75
ALTERNATOR OUTPUT (KVA)	0.	7.15	10.72	14.30	21.45
ALTERNATOR OUTPUT (KW)	0.	5.36	8.04	10.72	16.09
EFFICIENCY (PER CENT)					
ELECTRO-MAGNETIC	0.	77.01	79.60	79.85	77.55
OVER-ALL	0.	63.36	73.21	74.94	74.49

```
                 ALTERNATOR LOAD CHARACTERISTICS (RATED VOLTAGE, 0.85 POWER FACTOR)
                 -----------------------------------------------------------------

PERCENT KVA                        0.          50.          75.         100.         150.

FLUX DENSITIES (KL/SQ-IN)
   TEETH                        75.04        78.93        80.84        83.09        87.93
   CORE                         60.25        63.37        64.90        66.71        70.50
   YOKE - CYLINDRICAL SECTION   49.19        58.03        63.19        68.76        80.93
          END SECTION           53.72        63.37        69.00        75.09        88.44
   ROTOR - POLE                 62.69        71.40        76.37        81.77        93.57
           END SECTION          59.18        68.17        73.34        78.94        91.19
           TAPERED SEC.         63.76        73.40        78.95        84.95        98.09

AMPERE-TURNS
   MAIN AIR GAP                223.04       234.61       240.29       246.96       261.37
   AUX. AIR GAP                154.49       177.96       191.46       206.08       233.07
   TEETH                         2.09         3.20         3.73         4.39         6.24
   CORE                          5.79         6.85         7.44         8.20        10.12
   YOKE - CYLINDRICAL SECTION   29.13        36.87        42.30        49.08        73.43
          END SECTION           15.00        18.75        21.38        24.73        35.45
   ROTOR - POLE                 65.64        70.22        73.15        77.24        95.94
           END SECTION          38.07        40.64        42.24        44.04        49.95
           TAPERED SEC.         43.54        47.66        50.58        56.52        93.02
TOTAL AMPERE TURNS            1089.11      1585.72      1891.78      2226.48      3015.73

FIELD CURRENT (AMPS)             1.45         2.11         2.52         2.96         4.01
CURRENT DENS. (FIELD)          898.60      1308.34      1560.87      1837.02      2433.25
FIELD VOLTS                      7.56        11.23        13.62        16.37        23.54

TEMPERATURES (DEG.C)
   FIELD                        30.00        35.56        40.01        45.78        63.09
   ARMATURE                     60.00        83.25       112.31       153.00       259.25
RESISTANCES (OHMS)
   FIELD                         5.22         5.33         5.41         5.53         5.87
   ARMATURE                     0.0350       0.0378       0.0412       0.0461       0.0599

ALTERNATOR LOSSES (WATTS)
   FIELD                        10.94        23.68        34.26        48.46        94.39
   WINDAGE                     881.22       881.22       881.22       881.22       881.22
   STATOR TOOTH                 64.50        71.36        74.86        79.07        88.57
   STATOR CORE                 139.70       154.56       162.14       171.27       191.84
   POLE FACE                   958.70      1224.29      1556.27      2021.05      3348.99
   STATOR COPPER                 0.          44.71       109.79       218.09       637.92
   EDDY                          0.           0.           0.           0.           0.
   MISC. LOAD                    0.          71.50       107.25       143.00       214.50
   TOTAL                      2055.06      2471.32      2925.79      3562.15      5457.44

ALTERNATOR OUTPUT (KVA)          0.           7.15        10.72        14.30        21.45
ALTERNATOR OUTPUT (KW)           0.           6.08         9.12        12.15        18.23

EFFICIENCY (PER CENT)
   ELECTRO-MAGNETIC              0.          79.26        81.68        81.93        79.94
   OVER-ALL                      0.          71.09        75.70        77.34        75.95
           (STARTING WITH COLUMN  5 ALL CALCS ASSUME UNIFORM AIR-GAP FLUX DISTRIBUTION)
```

ALTERNATOR LOAD CHARACTERISTICS (RATED VOLTAGE, 1.00 POWER FACTOR)

PERCENT KVA	0.	50.	75.	100.	150.
FLUX DENSITIES (KL/SQ-IN)					
TEETH	75.04	80.14	78.04	76.43	75.86
CORE	60.25	54.34	62.66	61.36	60.90
YOKE - CYLINDRICAL SECTION	49.19	55.91	58.00	61.01	69.44
END SECTION	53.72	61.06	63.34	66.62	75.88
ROTOR - POLE	62.69	69.89	71.13	73.29	80.40
END SECTION	59.18	65.39	67.98	70.51	78.30
TAPERED SEC.	63.76	71.50	73.20	75.90	84.24
AMPERE-TURNS					
MAIN AIR GAP	223.04	238.20	231.97	227.18	225.48
AUX. AIR GAP	154.49	173.32	177.48	184.09	204.42
TEETH	2.09	3.54	2.94	2.52	2.36
CORE	5.79	7.21	6.59	6.15	6.00
YOKE - CYLINDRICAL SECTION	29.13	34.84	36.84	39.91	49.96
END SECTION	15.00	17.76	18.73	20.22	25.18
ROTOR - POLE	65.64	69.31	70.08	71.40	76.27
END SECTION	38.07	40.11	40.58	41.35	43.81
TAPERED SEC.	43.54	45.78	47.56	48.84	55.54
TOTAL AMPERE TURNS	1089.11	1395.77	1612.30	1877.58	2505.29
FIELD CURRENT (AMPS)	1.45	1.86	2.14	2.50	3.33
CURRENT DENS. (FIELD)	898.60	1152.44	1330.27	1549.15	2067.05
FIELD VOLTS	7.56	9.81	11.43	13.51	18.78
TEMPERATURES (DEG.C)					
FIELD	30.00	33.20	35.91	39.79	51.29
ARMATURE	60.00	83.25	112.31	153.00	269.25
RESISTANCES (OHMS)					
FIELD	5.22	5.28	5.33	5.41	5.64
ARMATURE	0.0350	0.0378	0.0412	0.0461	0.0599
ALTERNATOR LOSSES (WATTS)					
FIELD	10.94	18.21	24.52	33.72	62.55
WINDAGE	881.22	881.22	881.22	881.22	881.22
STATOR TOOTH	64.50	73.56	69.76	66.91	65.91
STATOR CORE	139.70	159.33	151.11	144.93	142.77
POLE FACE	958.70	1224.29	1556.27	2021.05	3348.99
STATOR COPPER	0.	44.71	109.79	218.09	637.92
EDDY	0.	0.	0.	0.	0.
MISC. LOAD	0.	71.50	107.25	143.00	214.50
TOTAL	2055.06	2472.81	2899.92	3508.93	5353.88
ALTERNATOR OUTPUT (KVA)	0.	7.15	10.72	14.30	21.45
ALTERNATOR OUTPUT (KW)	0.	7.15	10.72	14.30	21.45
EFFICIENCY (PER CENT)					
ELECTRO-MAGNETIC	0.	81.79	84.16	84.48	82.75
OVER-ALL	0.	74.30	78.72	80.30	80.03

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

VOLTAGE
   PERCENT             25.00      40.00      55.00      70.00      85.00     100.00     115.00     130.00     135.00        0.

   LINE-NEUTRAL        30.00      48.00      65.00      84.00     102.00     120.00     138.00     156.00     162.00        0.
   LINE-LINE           51.96      83.14     114.32     145.49     176.67     207.85     239.02     270.20     280.59        0.

FIELD CURRENT           0.47       0.67       0.85       1.05       1.25       1.45       1.67       1.96       2.13        0.

FLUX PER POLE          24.45      39.13      53.80      68.47      83.14      97.82     112.49     127.15     132.05        0.

FLUX DENSITIES
   CORE                15.35      24.21      33.19      42.20      51.24      60.25      69.28      78.20      81.03        0.
   TEETH               19.12      30.16      41.34      52.56      63.82      75.04      86.29      97.40     100.99        0.
   YOKE
     END SECTION       13.62      21.65      29.63      37.63      45.64      53.72      61.94      70.73      74.43        0.
     CYL. SECT.        12.47      19.82      27.14      34.46      41.80      49.19      56.72      64.77      58.15        0.
   ROTOR
     POLE              15.64      25.03      34.42      43.82      53.23      62.69      72.26      82.27      85.19        0.
     END SECTION       14.78      23.64      32.49      41.36      50.24      59.18      68.23      77.76      81.57        0.
     TAPERED SEC.      15.92      25.46      35.00      44.56      54.12      63.76      73.51      83.77      87.87        0.

AMPERE-TURNS
   MAIN AIR-GAP        56.82      89.64     122.88     156.24     189.70     223.04     256.48     289.52     300.17        0.
   AUX AIR-GAP         38.59      61.71      84.33     107.97     131.16     154.49     178.13     203.01     212.05        0.
   CORE                 1.04       1.53       2.03       2.70       3.60       5.79       9.42      22.48      28.55        0.
   TEETH                0.16       0.25       0.35       0.51       0.93       2.09       5.53      15.52      38.11        0.
   YOKE
     END SECTION        6.03       7.57       8.96      10.61      12.58      15.00      18.13      22.25      24.33        0.
     CYL. SECT.        11.25      14.15      16.91      20.20      24.15      29.13      35.60      44.12      43.29        0.
   ROTOR
     POLE              36.45      46.41      51.25      56.06      60.79      65.64      70.52      77.21      81.55        0.
     END SECTION       15.74      23.97      28.52      32.57      35.57      38.07      40.66      43.61      45.02        0.
     TAPERED SEC.      26.08      30.66      33.55      36.74      40.23      43.54      47.71      55.03      62.21        0.

   TOTAL              349.80     506.70     648.45     792.34     937.68    1089.11    1255.27    1470.22    1503.25        0.
                                 STATOR TOOTH IS SATURATED
```

APPENDIX C

COMPLETE FORTRAN LISTINGS AND FLOW CHARTS OF LUNDELL ALTERNATOR ANALYSIS PROGRAM

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

```
C      MAIN PROGRAM  LUNDEL
C      FOR USE WITH STATIONARY, OUTSIDE COIL LUNDELL ALTERNATORS
C
       COMMON /COM2/ AC.AS,B3,BK,BO,B S.C,C1,D1,DI,DISH,DISH1,DJ,DYC,EE,EP
      1.F.GC.HC.HM,NFC,PA1,PE.PF.PI.PL.PT,RPM,RR,RS,SC,SD,SH,SHL2,SN,SS,T
      2S,TT,TY,TYL,WF,WL,XA,XB,XD,XL
       COMMON /COM3/ ACORE,AI.ASHFT,ATOOTH,AYK1,BAG2,BCL,BPL,BROT,BSHFT,B
      1TL,BYCL1,BYCL2,DCORE,DSHMID,DYK1,DYK2,FCL,FFL,FGL1,FGL2,FSXL,FPL,F
      2ROT,FSHFT,FTL,FYCL1,FYCL2,KSAT,PAA,ITRTN
       COMMON /COM4/ AB,ALPHAR,ALPHAS,BG,FGML,FH,FQ,G,GA,PA,PFC,QQ,RY,T1,
      1T11,T2,T22,TG,VMIN,ZG,ZZ
       COMMON /COM5/ AA,AG2,CL,CP,DY2,DY3,HS,LG2,P1,P10,P5,P6,P7,P8,P9,PA
      12,PPL,PPL1,PPL2,PPL3,PPL4,PX,TY2,TY3,TYPY
C
       INTEGER ZZ
C
       REAL LG2
C
       DIMENSION FQLL(10), QPERV(10), QVLL(10), QVLN(10), FGLL1(10), BPLL
      1(10), FFLL(10), BCLL(10), BTLL(10), BYCLL1(10), BYCLL2(10), FYCLL1
      2(10), FYCLL2(10), FPLL(10), FTLL(10), FCLL(10), FGLL2(10), FI(10),
      3 BSHFTL(10), FSHFTL(10), BROTL(10), FROTL(10), TTB(5), TTA(5), RRA
      4(5), RRB(5), EZ(5), WMIS(5), CDD(5), EF(5), PR(5), ST(5), WQL(5),
      5PP(5), PS(5), EX(5), SP(5), AKVA(5), WA(5), E1(5), E(5), AI(90), G
      6(5), YMAT(6), RMAT(6), SMAT(6), PFC(5), PA(11), PAA(10), CMPNT(28)
C
       DATA CMPNT(1)/24H       ROTOR END SECTION/,CMPNT(5)/24H   TAPERED
      1ROTOR SECTION/,CMPNT(9)/24H            STATOR TOOTH/,CMPNT(13)/24H
      2            STATOR CORE/,CMPNT(17)/24H                   POLE/,C
      3MPNT(21)/24H        YOKE END SECTION/,CMPNT(25)/24HCYLINDRICAL YOK
      4E SECTION/
C
C
       READ (5,1) SMAT                                                          1
       READ (5,2) (AI(I),I=1,29)                                                3
       READ (5,1) RMAT                                                         10
       READ (5,2) (AI(I),I=31,59)                                              12
       READ (5,1) YMAT                                                         19
       READ (5,2) (AI(I),I=61,89)                                              21
1      FORMAT (6A6)
2      FORMAT (8F10.1)
3      CALL SUBLUN                                                             29
       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
      AYK1=3.1416*(DYC-TY)*TY
      DYK1=(TYL+TY3)/2.
      DYK2=(DYC-2.*TY-DY2)/6.
      ATOOTH=QQ*SS*SM*PE/PX
      ACORE=SS*((DO-(DI+2.*HS))/2.)
      DCORE=((2.*(DI+2.*HS)+DO)/3.)*3.1415/PX
      AG2=LG2*3.1416*DISH1
      ASHFT=0.7854*(DISH1**2-DISH**2)
      DSHMID=(SHL2-CL)/2.
      I=1
9     I=I+1
      IF (PA(I).LE.0.) GO TO 10
      IF (I.LT.9) GO TO 9
      GO TO 14
10    J=I
11    J=J+1
      IF (PA(J).GT.0.) GO TO 12
      GO TO 11
12    JJ=J-1
      DO 13 K=I,JJ
13    PA(K)=((PA(J)-PA(I-1))/FLOAT(J-I+1))*FLOAT(K-I+1)+PA(I-1)
      I=J
      GO TO 9
14    DO 15 I=1,10
15    PAA(I)=(PA(I)+PA(I+1))/2.
C
C     INITIALIZE SUBSCRIPTED VARIABLES USED IN LOAD CHARACT. CALCS
C
      DO 16 J=1,275
16    FGLL1(J)=0.
C
C     ----------------------------------------------------------------
C     NO-LOAD, RATED VOLTAGE MAGNETIZATION CHARACTERISTICS
C     ----------------------------------------------------------------
C
      FGXL=0.
      PPL=FQ
      ITRTV=10
      CALL MAGNET
      J=1
      FYCLL1(J)=FYCL1
      FYCLL2(J)=FYCL2
      FPLL(J)=FPL
      FTLL(J)=FTL
      FCLL(J)=FCL
```

```
      FFLL(J)=FFL
      FSHFTL(J)=FSHFT
      BYCLL1(J)=BYCL1
      BYCLL2(J)=BYCL2
      BPLL(J)=BPL
      BTLL(J)=BTL
      BCLL(J)=BCL
      BSHFTL(J)=BSHFT
      FGLL1(J)=FGL1
      BROTL(J)=BROT
      FROTL(J)=FROT
      FGLL2(J)=FGL2
C
C     SHORT CIRCUIT RATIO AND SHORT CIRCUIT AMPERE-TURNS CALCS
C
      FSC=XA*(FGL1+FGL2)*0.02
      SCR=FFL/FSC
      WRITE (6,17) FSC,SCR
17    FORMAT (1HK,9X,27H SHORT CIRCUIT AMPERE-TURNS,F15.3/10X,20H SHORT
     1CIRCUIT RATIO,F23.3)
      WRITE (6,18) SMAT
18    FORMAT (1H1,18H STATOR MATERIAL -,1H ,6A6)
      WRITE (6,19) RMAT
19    FORMAT (1HK,18H ROTOR MATERIAL --,1H ,6A6)
      WRITE (6,20) YMAT
20    FORMAT (1HK,18H YOKE MATERIAL ---,1H ,6A6)
      WRITE (6,21) TG,FQ,PPL1,PPL2,PPL3,PPL4
21    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,32H PPL1, FLUX LEAVING BASE
     3 OF POLE,F10.2/10X,34H PPL2, FLUX IN TAPERED ROTOR SECT.,F8.2/10X,
     432H PPL3, FLUX INTO ROTOR END SECT.,F10.2/10X,32H PPL4, (LEAKAGE T
     5HROUGH P5)+PPL3,F10.2//10X,33H FLUX DENSITIES (KILOLINES/SQ IN))
      WRITE (6,22) BG,BAG2,BCL,BTL,BYCL1,BYCL2,BPL,BSHFT,BROT
22    FORMAT (13X,13H MAIN AIR GAP,F27.3/13X,18H AUXILIARY AIR GAP,F22.3
     1/13X,12H STATOR CORE,F28.3/13X,13H STATOR TEETH,F27.3/13X,27H YOKE
     2 - CYLINDRICAL SECTION,F13.3/18X,14H   END SECTION,F21.3/13X,13H R
     3OTOR - POLE,F27.3/21X,12H END SECTION,F20.3/21X,16H TAPERED SECTIO
     4N,F16.3)
      WRITE (6,23)
23    FORMAT (1HK,9X,13H AMPERE-TURNS)
      WRITE (6,22) FGL1,FGL2,FCL,FTL,FYCL1,FYCL2,FPL,FSHFT,FROT
      WRITE (6,24) FFL
24    FORMAT (1H ,12X,6H TOTAL,F34.3///)
      IF (ITRTN.EQ.0) WRITE (6,25)
25    FORMAT (1H ,20X,54H(ABOVE CALCS ASSUME UNIFORM AIR-GAP FLUX DISTRI
     1BUTION))
      IF (KSAT.EQ.10) GO TO 27
      J=4*KSAT
      I=J-3
      WRITE (6,26) (CMPNT(K),K=I,J)
26    FORMAT (20X,4A6,36H SATURATED AT NO-LOAD, RATED VOLTAGE)
      GO TO 3
```

```
C
C     NO-LOAD POLE-FACE LOSS CALCULATION
C

27    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) 28,28,29
28    D4=TS**1.285*0.81
      GO TO 32
29    IF (TS-1.5) 30,30,31
30    D4=TS**1.145*0.79
      GO TO 32
31    D4=TS**0.79*0.92
32    IF (GT-1.7) 33,33,34
33    D5=GT**2.31*0.3
      GO TO 39
34    IF (GT-3.0) 35,35,36
35    D5=GT**2.0*0.35
      GO TO 39
36    IF (GT-5.0) 37,37,38
37    D5=GT**1.4*0.676
      GO TO 39
38    D5=GT**0.965*1.38
39    D6=10.0**(0.932*C1-1.606)
      WN=D1*D2*D3*D4*D5*D6*GA
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 41 J=1,4
      IA=5-J
      DO 41 I=1,IA
      IF (G(I).GT.G(I+1)) GO TO 40
      GO TO 41
40    POL=G(I)
      G(I)=G(I+1)
      G(I+1)=POL
41    CONTINUF
      G(1)=0.
C
      MM=5
      DO 42 I=2,5
42    IF (G(I).GE.1.0.AND.G(I-1).LT.0.999) MM=I
C
C     DEFINING NPF
C
      DO 43 I=1,5
43    IF (PFC(I).LT.0.001) GO TO 44
      I=I+1
44    NPF=I-1
```

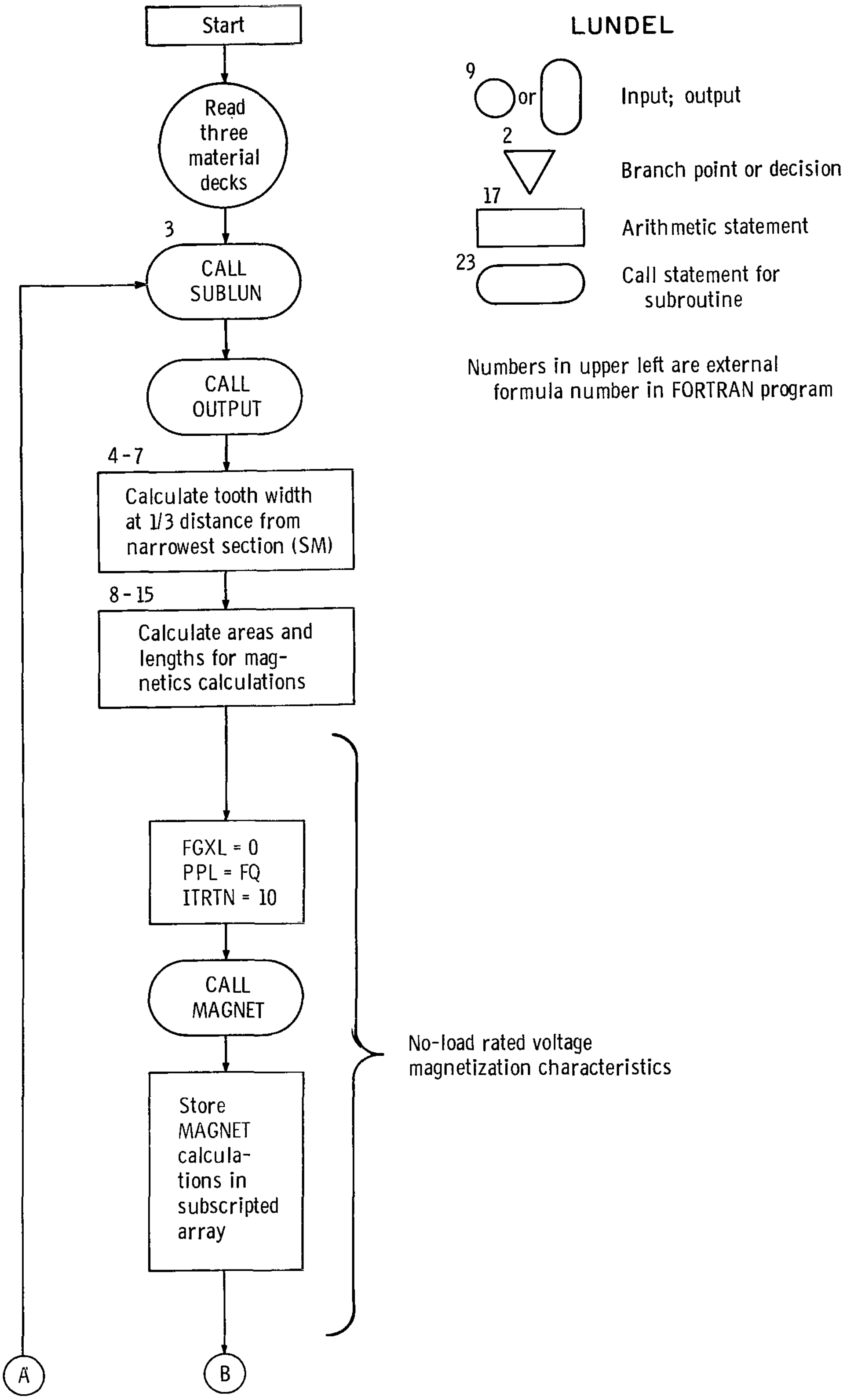
```
C
C     ----------------------------------------------------------------
C     CALCULATE ALTERNATOR LOAD CHARACTERISTICS
C     ----------------------------------------------------------------
C
      I=0
45    I=I+1
      K=0
      ITRTN=10
      IA=10
      PF=PFC(I)
      CK=1.0
      IF (PF.GE.0.95) CK=1.10
      AN=ARCOS(PF)
      EZ( 1)=1.0
      J=0
      JA=5
C
C     ARMATURE TEMPERATURE AND RESISTANCE CALCULATION
C
46    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 46
C
C     EDDY FACTOR CALCULATIONS
C
      IF (SH) 47,47,48
47    EZ(J)=1.
      GO TO 49
48    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
49    XI=ATAN((((XD*G(J))/100.)+SIN(AN))/(PF+RRA(J)*(PI/EP)*G(J)))
      BB=XI-AN
      GXX=(COS(BB)+(RRA(J)*(PI/EP)*G(J)*COS(XI))+((XL+0.07*XD)*SIN(XI)*G
     1(J)*0.01))*CK
      FGXL=FGML*G(J)*SIN(XI)*2.
      PPL=FQ*GXX
      CALL MAGNET
      IF (ITRTN.EQ.0) ITRTN=J
      FYCLL1(J)=FYCL1
      FYCLL2(J)=FYCL2
      FPLL(J)=FPL
      FTLL(J)=FTL
      FCLL(J)=FCL
      FFLL(J)=FFL
      FSHFTL(J)=FSHFT
      BYCLL1(J)=BYCL1
      BYCLL2(J)=BYCL2
      BPLL(J)=BPL
      BTLL(J)=BTL
      BCLL(J)=BCL
      BSHFTL(J)=BSHFT
      FGLL1(J)=FGL1
```

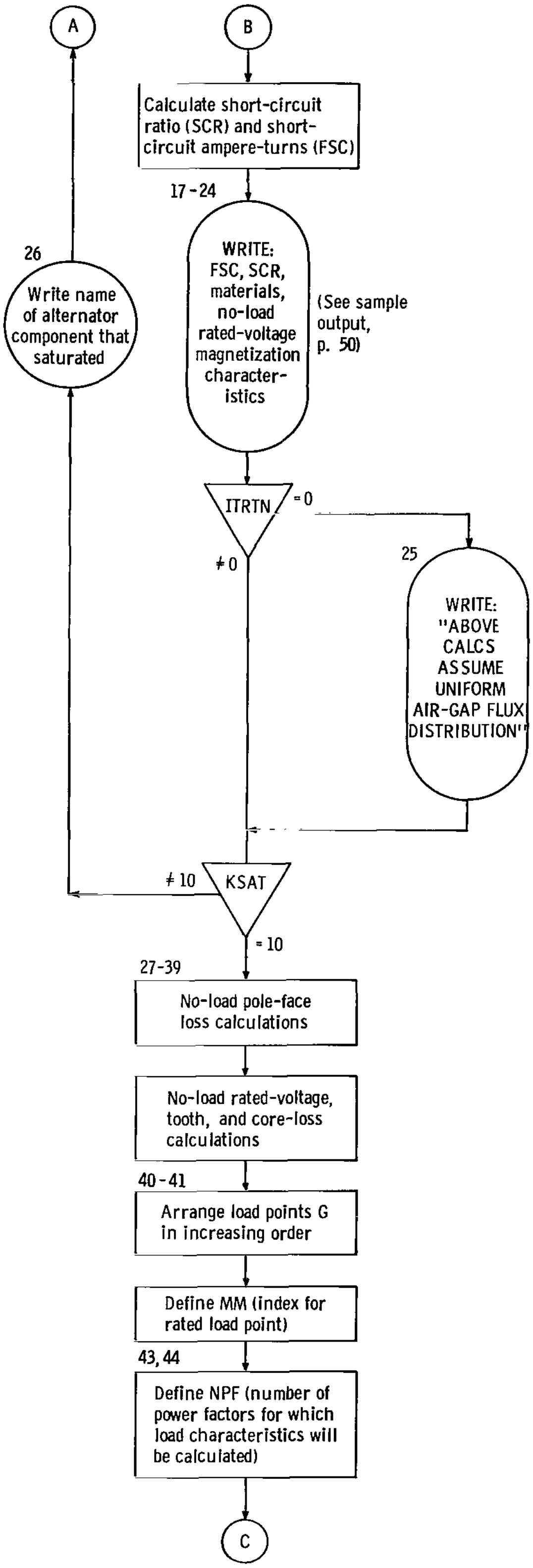
```
      FGLL2(J)=FGL2
      BROTL(J)=BROT
      FROTL(J)=FROT
      IF (KSAT.NE.10) GO TO 50
      IF (K.NE.0) GO TO 51
      IF (J.LT.5) GO TO 46
      GO TO 55
50    IA=KSAT
      IF ((G(J)-G(J-1)).LE.0.099) GO TO 52
      G(J)=G(J)-0.10
      J=J-1
      K=K+1
      GO TO 46
51    IF (J.EQ.5) GO TO 55
      J=J+1
52    JA=J-1
53    M=270+J
      DO 54 K=J,M,5
54    FGLL1(K)=0.
      J=J+1
      IF (J.LT.6) GO TO 53
      IF (MM.GT.JA) MM=JA
55    IF (I.EQ.1) FIMM=FFLL(MM)/(PT*FLOAT(NFC))
      VV=3.*PI*EP*PF
C
C     LOSSES AND EFFICIENCY UNDER LOAD
C
      M=0
56    M=M+1
      UA=G(M)
      FI(M)=FFLL(M)/(PT*FLOAT(NFC))
      CDD(M)=FI(M)/AS
      IF (MM.NE.1) GO TO 57
      TTB(M)=T22
      GO TO 58
57    TTB(M)=(((T2-T22)*FI(M)**2)+(T22*FIMM**2-T2*FI(1)**2))/(FIMM**2-FI
     1(1)**2)
58    RRB(M)=(1.0E-6)*RR*(1.0+ALPHAR*(TTB(M)-20.))*ZG
      PR(M)=FI(M)*FI(M)*RRB(M)
      EF(M)=FI(M)*RRB(M)
      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.
      AKVA(M)=WA(M)/PF
      WMIS(M)=AKVA(M)*10.0
      PP(M)=((GF*UA)**2.0+1.0)*WN
      EX(M)=(EZ(M)-1.0)*PS(M)*(CL/HM)
      SP(M)=PP(M)+PR(M)+PS(M)+EX(M)+ST(M)+WF+WQL(M)+WMIS(M)
      E(M)=(WA(M)/(WA(M)+(SP(M)-WF)/1000.))*100.
      E1(M)=(WA(M)/(WA(M)+SP(M)/1000.))*100.
      IF (M.LT.JA) GO TO 56
      WRITE (6,59) PF,(G(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 (6,60) (BTLL(I),I=1,5),(BCLL(I),I=1,5),(BYCLL1(I),I=1,5),(BY
```

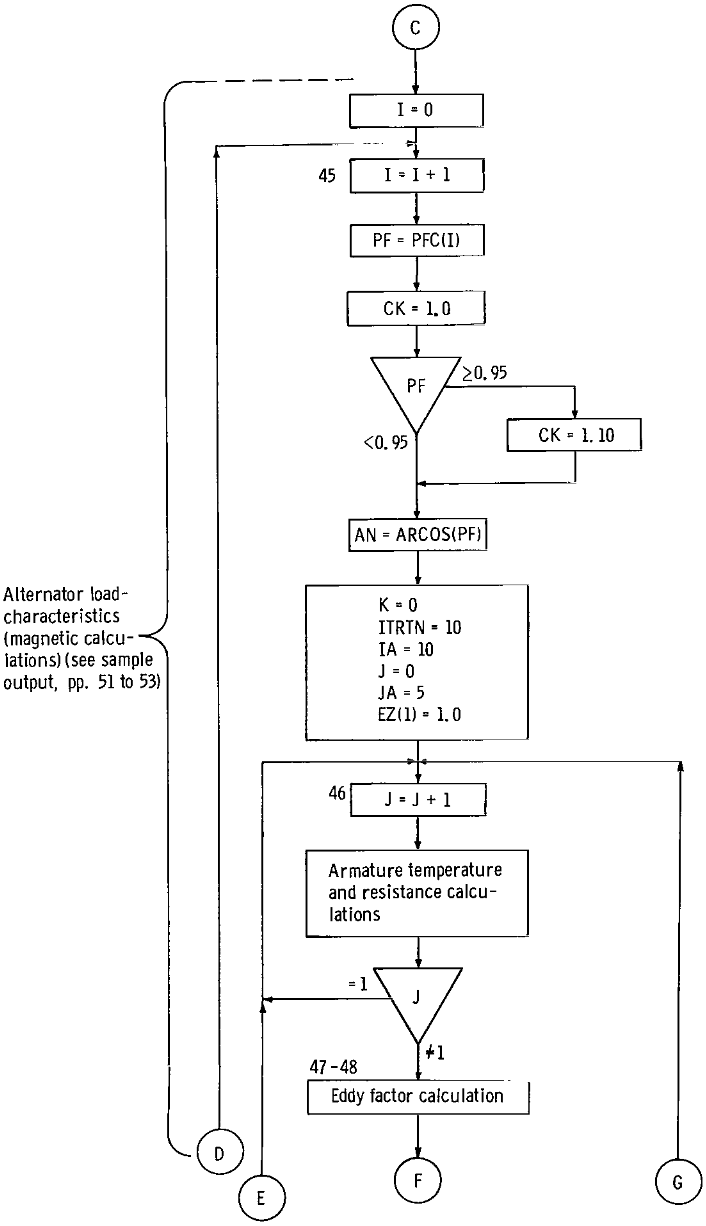
```
     1CLL2(I),I=1,5),(BPLL(I),I=1,5),(BSHFTL(I),I=1,5),(BROTL(I),I=1,5)
      WRITE (6,61) (FGLL1(I),I=1,5),(FGLL2(I),I=1,5)
      WRITE (6,60) (FTLL(I),I=1,5),(FCLL(I),I=1,5),(FYCLL1(I),I=1,5),(FY
     1CLL2(I),I=1,5),(FPLL(I),I=1,5),(FSHFTL(I),I=1,5),(FROTL(I),I=1,5)
      WRITE (6,62) (FFLL(I),I=1,5),(FI(I),I=1,5),(CDD(I),I=1,5),(EF(I),I
     1=1,5)
59    FORMAT (1H1,26X47HALTERNATOR LOAD CHARACTERISTICS (RATED VOLTAGE,F
     15.2,14H POWER FACTOR)/27X,11(5H------),//7X11HPERCENT KVA,12X,2PF1
     27.0,4F19.0//7X25HFLUX DENSITIES (KL/SQ-IN))
60    FORMAT (10X5HTEETH15X5F19.2/10X4HCORE16X5F19.2/10X26HYOKE - CYLIND
     1RICAL SECTION,F13.2,4F19.2/14X,14H    END SECTION,2X,5F19.2/10X,12H
     2ROTOR - POLE,8X,5F19.2/18X,11HEND SECTION,1X,5F19.2/13X,12HTAPERED
     3 SEC.,5F19.2)
61    FORMAT (1H /7X,12HAMPERE-TURNS/10X,12HMAIN AIR GAP,8X,5F19.2/10X,1
     12HAUX. AIR GAP,8X,5F19.2)
62    FORMAT (1H ,6X18HTOTAL AMPERE TURNS5X5F19.2//7X20HFIELD CURRENT (A
     1MPS)3X5F19.2/7X21HCURRENT DENS. (FIELD)2X5F19.2/7X11HFIELD VOLTS12
     2X5F19.2)
      WRITE (6,63) (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),WF,WF,WF,WF,WF,(ST(I),I=1,5),(WQL(I),I=1,5),(
     2PP(I),I=1,5),(PS(I),I=1,5),(EX(I),I=1,5),(WMIS(I),I=1,5),(SP(I),I=
     31,5),(AKVA(I),I=1,5),(WA(I),I=1,5),(E(I),I=1,5)
63    FORMAT (1HK,6X20HTEMPERATURES (DEG.C)/10X5HFIELD15X5F19.2/10X8HARM
     1ATURE12X5F19.2/7X18HRESISTANCES (OHMS)/10X5HFIELD15X5F19.2/10X8HAR
     2MATURE12X5F19.4//7X25HALTERNATOR LOSSES (WATTS)/10X5HFIELD15X5F19.
     32/10X7HWINDAGE13X5F19.2/10X12HSTATOR TOOTH8X5F19.2/10X11HSTATOR CO
     4RE9X5F19.2/10X9HPOLE FACE11X5F19.2/10X13HSTATOR COPPER7X5F19.2/10X
     54HEDDY16X5F19.2/10X10HMISC. LOAD10X5F19.2/10X5HTOTAL15X5F19.2//7X2
     63HALTERNATOR OUTPUT (KVA)5F19.2/7X22HALTERNATOR OUTPUT (KW)1X5F19.
     72//7X,21HEFFICIENCY (PER CENT)/10X,16HELECTRO-MAGNETIC,4X,5F19.2)
      IF (WF.GT.0.) WRITE (6,64) (EL(I),I=1,5)
64    FORMAT (10X,8HOVER-ALL,12X,5F19.2)
      IF (ITRTN.NE.10) WRITE (6,65) ITRTN
65    FORMAT (1H ,20X,21H(STARTING WITH COLUMN,I3,52H ALL CALCS ASSUME U
     1NIFORM AIR-GAP FLUX DISTRIBUTION))
      KSAT=IA
      IF (KSAT.EQ.10) GO TO 67
      J=4*KSAT
      M=J-3
      WRITE (6,66) (CMPNT(K),K=M,J)
66    FORMAT (1H ,20X,4A6,13H IS SATURATED)
67    IF (I.GE.NPF) GO TO 68
      GO TO 45
C
C     INITIALIZE VARIABLES  USED IN NO-LOAD MAGNETIC CALCS
C
68    PF=PFC(1)
      DO 69 J=1,220
69    FOLL(J)=0.
C
C     -----------------------------------------------------------------
C     CALCULATE NO-LOAD SATURATION DATA
C     -----------------------------------------------------------------
C
      FGXL=0.
      IDELR=15
```

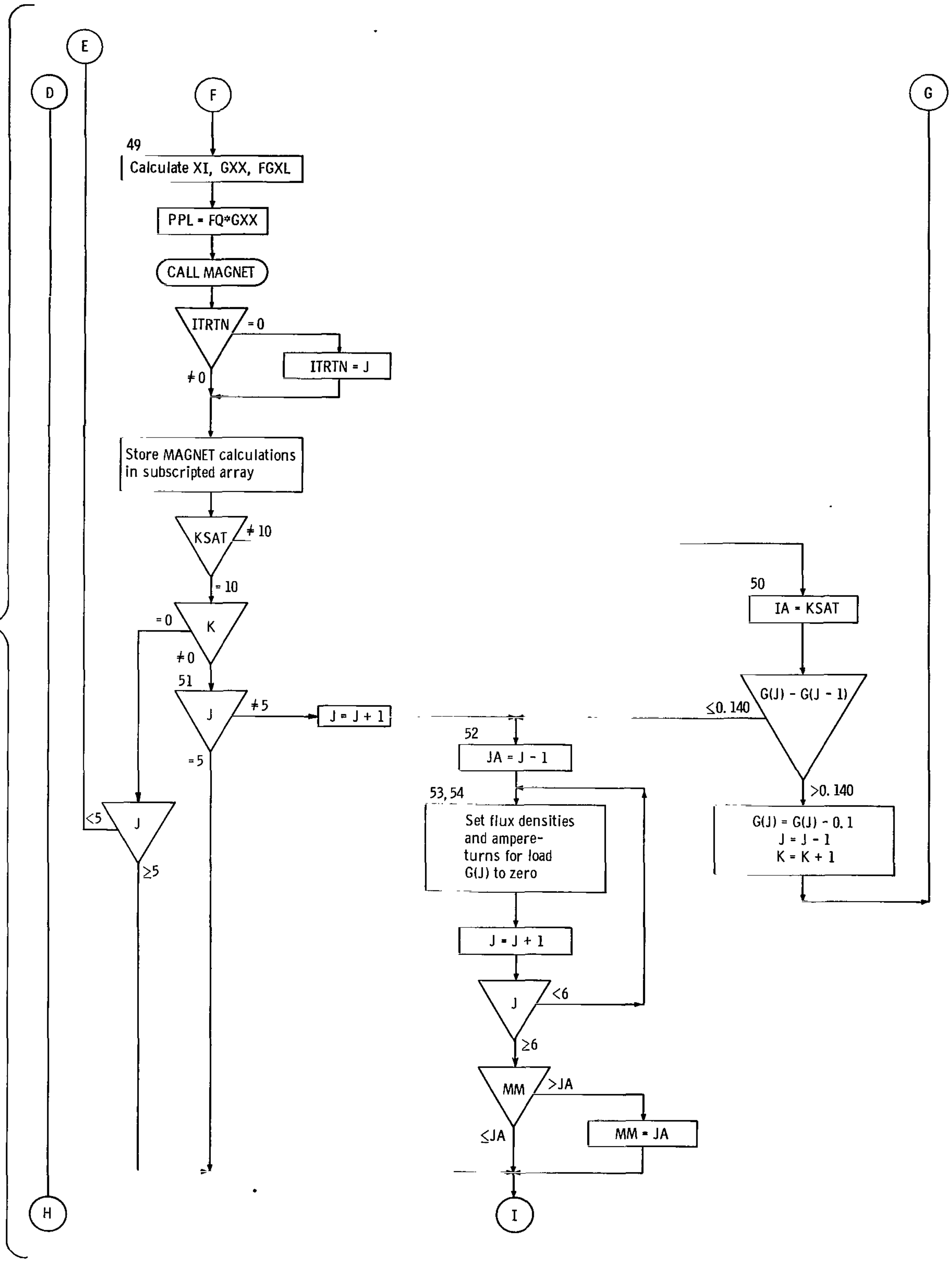
```
      EDD=VMIN
      ITRTN=10
      J=1
70    PPL=FQ*EDD
      CALL MAGNET
      IF (ITRTN.EQ.0) ITRTN=J
      IF (KSAT.NE.10) GO TO 71
      FQLL(J)=PPL
      QPERV(J)=100.*EDD
      QVLL(J)=EE*EDD
      QVLN(J)=QVLL(J)/SQRT(3.)
      FI(J)=FFL/(PT*FLOAT(NFC))
      FYCLL1(J)=FYCL1
      FYCLL2(J)=FYCL2
      FPLL(J)=FPL
      FTLL(J)=FTL
      FCLL(J)=FCL
      FFLL(J)=FFL
      FSHFTL(J)=FSHFT
      BYCLL1(J)=BYCL1
      BYCLL2(J)=BYCL2
      BPLL(J)=BPL
      BTLL(J)=BTL
      BCLL(J)=BCL
      BSHFTL(J)=BSHFT
      FGLL1(J)=FGL1
      FGLL2(J)=FGL2
      BROTL(J)=BROT
      FROTL(J)=FROT
      IF (J.EQ.10) GO TO 74
      J=J+1
      EDD=EDD+FLOAT(IDELR)/100.
      GO TO 70
71    EDD=EDD-FLOAT(IDELR)/100.
      IF (IDELR.GT.5) GO TO 72
      IF (IDELR.GT.2) GO TO 73
      GO TO 74
72    IDELR=(IDELR/6)*5
      EDD=EDD+FLOAT(IDELR)/100.
      GO TO 70
73    IDELR=(IDELR/3)*2
      EDD=EDD+FLOAT(IDELR)/100.
      GO TO 70
74    WRITE (6,75) (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)
75    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,14HFLUX DENSITIES)
      WRITE (6,76) (BCLL(K),K=1,10),(BTLL(K),K=1,10),(BYCLL2(K),K=1,10),
     1(BYCLL1(K),K=1,10),(BPLL(K),K=1,10),(BSHFTL(K),K=1,10),(BROTL(K),K
     2=1,10)
76    FORMAT (1H ,4X,4HCORE,9X,10F11.2/5X,5HTEETH,3X,10F11.2/5X,4HYOKE/7
     1X,11HEND SECTION,10F11.2/7X,10HCYL. SECT.,1X,10F11.2/5X,5HROTOR/7X
     2,4HPOLE,7X,10F11.2/7X,11HEND SECTION,10F11.2/7X,12HTAPERED SEC.,F1
     30.2,9F11.2)
```

```
      WRITE (6,77)                                                      A 439
77    FORMAT (1HK,1X,12HAMPERE-TURNS)                                   A 440
      WRITE (6,78) (FGLL1(K),K=1,10),(FGLL2(K),K=1,10)                  A 441
78    FORMAT (1H ,4X,12HMAIN AIR-GAP,F12.2,9F11.2/5X,11HAUX AIR-GAP,2X,1 A 442
     10F11.2)                                                           A 443
      WRITE (6,76) (FCLL(K),K=1,10),(FTLL(K),K=1,10),(FYCLL2(K),K=1,10), A 444
     1(FYCLL1(K),K=1,10),(FPLL(K),K=1,10),(FSHFTL(K),K=1,10),(FROTL(K),K A 445
     2=1,10)                                                            A 446
      WRITE (6,79) (FFLL(K),K=1,10)                                     A 447
79    FORMAT (1HK,4X,5HTOTAL,8X,10F11.2)                                A 448
      IF (ITRTN.NE.10) WRITE (6,65) ITRTN                               A 449
      IF (KSAT.EQ.10) GO TO 3                                           A 450
      J=4*KSAT                                                          A 451
      I=J-3                                                             A 452
      WRITE (6,66) (CMPNT(K),K=I,J)                                     A 453
      GO TO 3                                                           A 454
      END                                                               A 455-
```

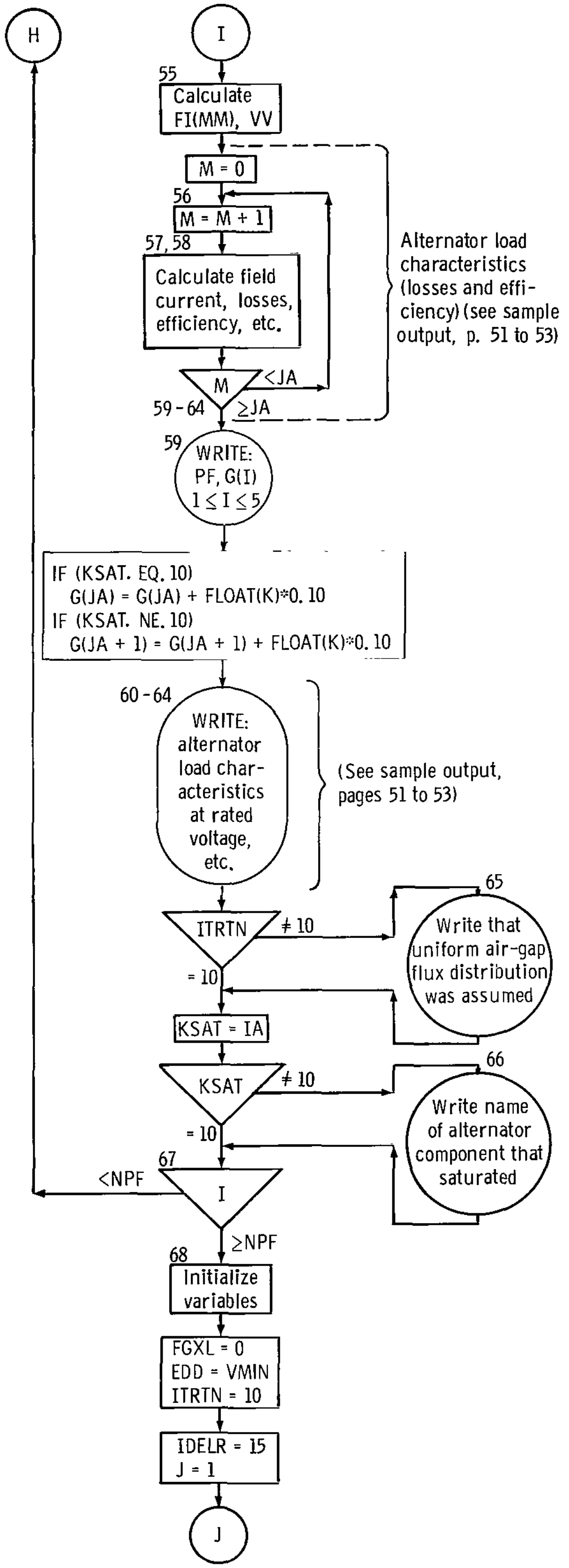

LUNDEL
9
or
Input; output
2
Branch point or decision
17
Arithmetic statement
23
Call statement for subroutine
Numbers in upper left are external formula number in FORTRAN program
Start
Read three material decks
3
CALL SUBLUN
CALL OUTPUT
4-7
Calculate tooth width at 1/3 distance from narrowest section (SM)
8-15
Calculate areas and lengths for magnetics calculations
FGXL = 0
PPL = FQ
ITRTN = 10
CALL MAGNET
Store MAGNET calculations in subscripted array
No-load rated voltage magnetization characteristics
A
B

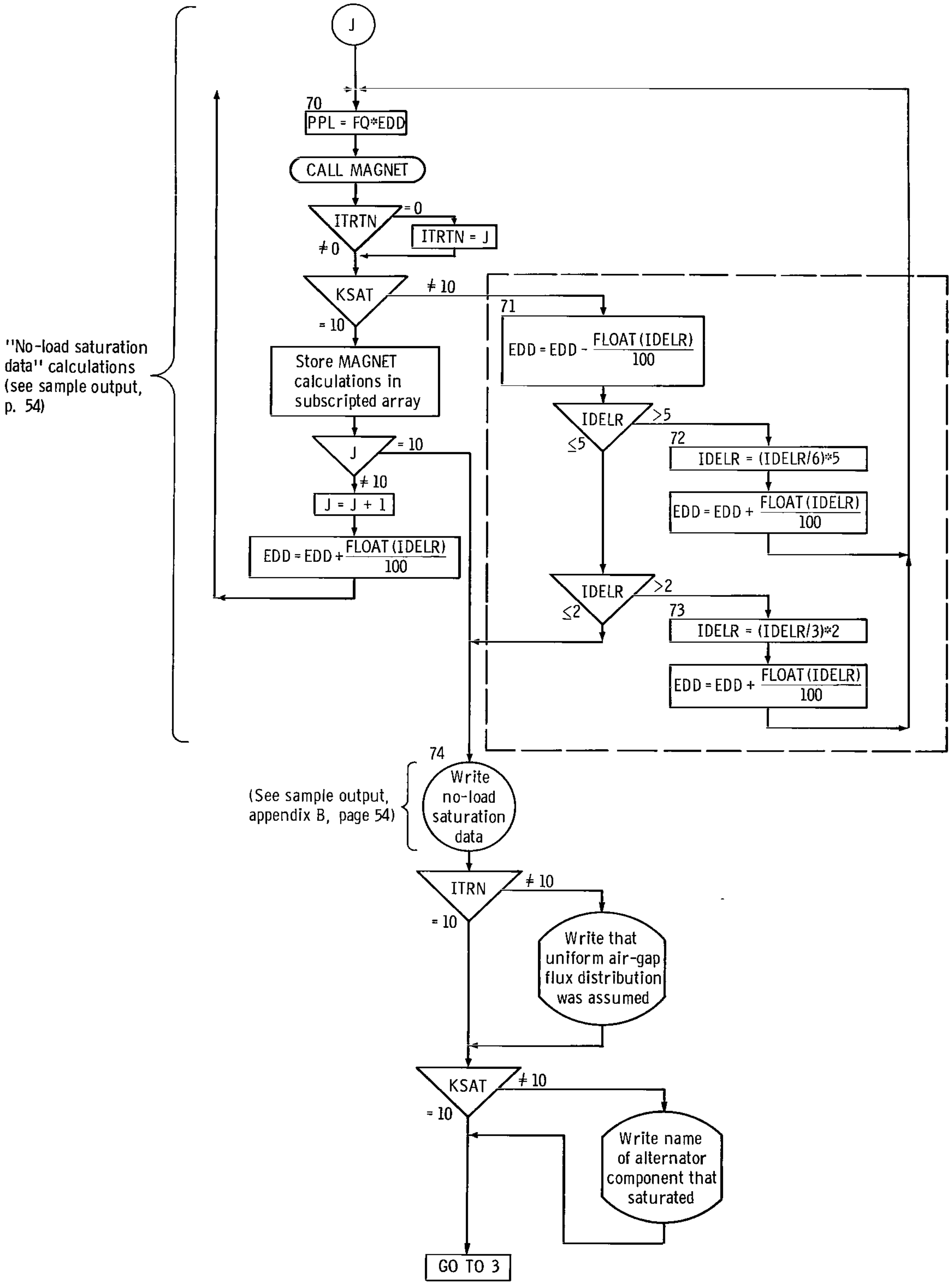

A
B
Calculate short-circuit ratio (SCR) and short-circuit ampere-turns (FSC)
17-24
WRITE: FSC, SCR, materials, no-load rated-voltage magnetization characteristics
(See sample output, p. 50)
26
Write name of alternator component that saturated
ITRTN
= 0
≠ 0
25
WRITE: "ABOVE CALCS ASSUME UNIFORM AIR-GAP FLUX DISTRIBUTION"
KSAT
≠ 10
= 10
27-39
No-load pole-face loss calculations
No-load rated-voltage, tooth, and core-loss calculations
40-41
Arrange load points G in increasing order
Define MM (index for rated load point)
43, 44
Define NPF (number of power factors for which load characteristics will be calculated)
C


C
I = 0
45
I = I + 1
PF = PFC(I)
CK = 1.0
PF
≥0.95
<0.95
CK = 1.10
AN = ARCOS(PF)
K = 0
ITRTN = 10
IA = 10
J = 0
JA = 5
EZ(1) = 1.0
Alternator load-characteristics (magnetic calculations) (see sample output, pp. 51 to 53)
46
J = J + 1
Armature temperature and resistance calculations
J
= 1
≠1
47-48
Eddy factor calculation
D
E
F
G



Alternator load-characteristics (magnetic calculations) (see sample output, pp. 51 to 53)


H
I
55
Calculate FI(MM), VV
M = 0
56
M = M + 1
57, 58
Calculate field current, losses, efficiency, etc.
M
<JA
≥JA
59 - 64
Alternator load characteristics (losses and efficiency) (see sample output, p. 51 to 53)
59
WRITE: PF, G(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
60 - 64
WRITE: alternator load characteristics at rated voltage, etc.
(See sample output, pages 51 to 53)
ITRTN
≠ 10
= 10
65
Write that uniform air-gap flux distribution was assumed
KSAT = IA
KSAT
≠ 10
= 10
66
Write name of alternator component that saturated
67
<NPF
I
≥NPF
68
Initialize variables
FGXL = 0
EDD = VMIN
ITRTN = 10
IDELR = 15
J = 1
J


J
70
PPL = FQ*EDD
CALL MAGNET
ITRTN
= 0
ITRTN = J
≠ 0
KSAT
≠ 10
= 10
71
EDD = EDD - FLOAT(IDELR)/100
"No-load saturation data" calculations (see sample output, p. 54)
Store MAGNET calculations in subscripted array
IDELR
>5
≤5
72
IDELR = (IDELR/6)*5
J
= 10
≠ 10
J = J + 1
EDD = EDD + FLOAT(IDELR)/100
EDD = EDD + FLOAT(IDELR)/100
IDELR
>2
≤2
73
IDELR = (IDELR/3)*2
EDD = EDD + FLOAT(IDELR)/100
74
(See sample output, appendix B, page 54)
Write no-load saturation data
ITRN
≠ 10
= 10
Write that uniform air-gap flux distribution was assumed
KSAT
≠ 10
= 10
Write name of alternator component that saturated
GO TO 3

```
      SUBROUTINE SUBLUN
      COMMON /COM1/ A,B1,B2,BCOIL,BV,CC,CE,CF,CM,CQ,DCOIL,DF,DR,DW,DW1,E
     1C,EL,EW,FE,FK1,FS,G2,GAMMAR,GE,HO,HT,HV,HW,HX,HY,IPN,IPX,IQQ,IZZ,L
     2TS,P2,P3,P4,PBA,PC,PCOIL,PT1,PT2,PW1,PW2,QN,RC,RD,RF,RG1,RT,S,SF,S
     3HL1,SI,SIGMA,SK,SN1,SPS,STATET,TC,TF,TST,TYE,TYR,VA,VR,WC,WI,WROTO
     4R,WTOTAL,WYOKE,XF,XQ,XR,XU,YY
      COMMON /COM2/ AC,AS,B3,BK,BO,BS,C,C1,D1,DI,DISH,DISH1,DU,DYC,EE,EP
     1,F,GC,HC,HM,NFC,PA1,PE,PF,PI,PL,PT,RPM,RR,RS,SC,SD,SH,SHL2,SN,SS,T
     2S,TT,TY,TYL,WF,WL,XA,XB,XD,XL
      COMMON /COM4/ AB,ALPHAR,ALPHAS,BG,FGML,FH,FQ,G,GA,PA,PFC,QQ,RY,T1,
     1T11,T2,T22,TG,VMIN,Z3,ZZ
      COMMON /COM5/ AA,AG2,CL,CP,DY2,DY3,HS,LG2,P1,P10,P5,P6,P7,P8,P9,PA
     12,PPL,PPL1,PPL2,PPL3,PPL4,PX,TY2,TY3,TYPY
C
      INTEGER TYPY,ZZ
C
      REAL LTS,LG2
C
      DIMENSION DA(8), DX(6), DY(8), DZ(8), G(5), PFC(5), PA(11)
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,EL,YY,C,DW,SN,SN1,DW1,CE,SD,PBA,SK,T1,RS,ALPHAS,T11,TST/AIRGAP/GC
     3,G2,WF,LG2/ROTOR/C1,CP,CM,CQ,PW1,PW2,PT1,PT2,PL,WROTOR,D1,PA1,PA2,
     4PA,PE,GAMMAR,DISH,DISH1,SHL1,SHL2/YOKE/TY,TYL,DYC,WYOKE,TYE,TYR,TY
     52,TY3/FIELD/PCOIL,DCOIL,PT,RD,RT,T2,BCOIL,TF,T22,RR,ALPHAR,TYPY/PE
     6RMCE/P1,P2,P3,P4,P5,P6,P7,P10
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*0.00034,0.0013
     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,50H*** STATIONARY OUTSIDE-COIL LUNDELL ALTERNATOR
     1***)
      DO 2 I=1,5
2     PFC(I)=0.
      C1=0
      RS=0.694
      RR=0.694
      ALPHAS=0.00393
      ALPHAR=0.00393
      P1=0.
      P2=0.
      P3=0.
      P4=0.
      P5=0.
      P6=0.
      P7=0.
```

```
      P8=0.
      P10=0.
      SPS=0.
      RT=0.
      TF=25.
      TST=25.
      PE=0.
      PL=0.
      SHL1=0.
      PBA=60.
      SN=1.0
      DW1=0
      CW=0
      CP=0
      EL=0
      CM=0
      G(1)=0.
      G(2)=0.75
      G(3)=1.00
      G(4)=1.25
      G(5)=1.50
      VMIN=0.7
      CQ=0
      WF=0
      TY=0
      XF=0.
      EP=0.
      EE=0.
      IPN=3
      PN=3.
      IPX=0
      F=0.
      RPM=0.
      SF=0.
      LTS=0.
      WROTOR=0.
      HV=0.
      BV=0.
      BCOIL=0.
      SK=0
      PA1=0.
      PA2=0.
      GAMMAR=0.283
      DY2=0.
      TY2=0.
      NFC=2
      D1=7.0
      WYOKE=0.
      DO 3 I=1,11
    3 PA(I)=0.
      READ (5,RATING)
      READ (5,STATOR)
      READ (5,SLOTS)
      READ (5,WINDNG)
      READ (5,AIRGAP)
      READ (5,ROTOR)
```

```
      READ (5.YOKE)                                                      B 107
      READ (5,FIELD)                                                     B 108
      READ (5,PERMCE)                                                    B 109
      IF (TYPY.EQ.6) NFC=1                                               B 110
      IF (NFC.EQ.1) WRITE (6,4)                                          B 111
      IF (NFC.EQ.2) WRITE (6,5)                                          B 112
4     FORMAT (1H ,31X,16H(ONE FIELD COIL))                               B 113
5     FORMAT (1H ,31X,17H(TWO FIELD COILS))                              B 114
      PF=PFC(1)                                                          B 115
      IF (EP.EQ.0.) EP=EE/1.732051                                       B 116
      IF (EE.EQ.0.) EE=EP*1.732051                                       B 117
      IF (DW1.NE.0.) SH=DW1                                              B 118
      IF (IPX.EQ.0.AND.RPM.NE.0.) IPX=(F*120.)/RPM                       B 119
      PX=IPX                                                             B 120
      IF (RPM.EQ.0..AND.PX.NE.0.) RPM=(F*120.)/PX                        B 121
      IF (F.EQ.0.) F=PX*RPM/120.                                         B 122
      HW=HY-HO-HT                                                        B 123
      QQ=IQQ                                                             B 124
      IF (ZZ.NE.3) GO TO 6                                               B 125
      B1=(HO+HT-HS)*(6.283185/QQ)+B3                                     B 126
      B2=B1+(6.283185*HW/QQ)                                             B 127
      BS=(B2+B3)/2.                                                      B 128
6     CONTINUE                                                           B 129
      PI=(VA*1000.)/(EE*SQRT(3.))                                        B 130
      IF (ZZ.EQ.1.OR.ZZ.EQ.5) BO=BS                                      B 131
      IZZ=ZZ                                                             B 132
      DB=.25                                                             B 133
      IF (DU.GE.8.) DB=0.5                                               B 134
      FE=3.1416*(PCOIL+DCOIL)/2.                                         B 135
      DR=DI-2.*GC                                                        B 136
      IF (SHL1.EQ.0.) SHL1=CL                                            B 137
      PHW=(PW1+PW2)/2.                                                   B 138
      IF (PE.EQ.0.) PE=(PX/3.1415927)*(ARSIN(PHW/DR))                    B 139
      HC=(DU-DI-2.0*HS)*0.5                                              B 140
      IF (PA1.EQ.0.) PA1=PA(1)                                           B 141
      IF (PA2.EQ.0.) PA2=PA(11)                                          B 142
      IF (PA(1).LE.0.) PA(1)=PA1                                         B 143
      IF (PA(11).LE.0.) PA(11)=PA2                                       B 144
      DY2=DISH1+2.*G2+2.*TYE                                             B 145
      DY3=DYC-2.*TY                                                      B 146
      IF (TY2.EQ.0.) TY2=TY3                                             B 147
      ZY=0.7*HS                                                          B 148
      DO 7 I=1,5                                                         B 149
7     IF (G(I).GT.9.) G(I)=G(I)/100.                                     B 150
      QN=QQ/(PX*PN)                                                      B 151
      CS=YY/(PN*QN)                                                      B 152
C                                                                        B 153
C     CHECK FOR ERROR CONDITIONS                                         B 154
C                                                                        B 155
      IF (CS.GT.1.0.OR.CS.LT.0.5) WRITE (6,9) CS                         B 156
      IF (EP*EE.EQ.0..OR.ABS(EE/EP-1.732051).GT.0.01) WRITE (5,10)       B 157
      IF (PX*F*RPM.EQ.0..OR.ABS(F-PX*RPM/120.).GT.0.1) WRITE (5,11)      B 158
      IF (HC.LT.ZY) WRITE (6,12) HC,HS                                   B 159
      IF (DCOIL.GT.DY3) WRITE (6,13)                                     B 160
      IF (RT.LT.1.0E-10) GO TO 8                                         B 161
      IF ((((DCOIL-PCOIL)*BCOIL)/(RT*RD)).LE.2.*PT) WRITE (6,14)         B 162
```

```
      GO TO 15
8     IF ((DCOIL-PCOIL)*BCOIL/RD**2.LE.1.7146*PT) WRITE (6,14)
9     FORMAT (5X,27H CS (PER UNIT POLE PITCH) =,F7.3/10X,31H CS MUST BE
     1BETWEEN 0.5 AND 1.0)
10    FORMAT (1H ,38H EITHER PHASE OR LINE VOLTAGE IS WRONG)
11    FORMAT (1H ,44H FREQUENCY, RPM, OR NO. OF POLES IS IN ERROR)
12    FORMAT (1H /5X54HDEPTH BELOW SLOT IS LESS THAN 70 PERCENT OF SLOT
     1DEPTH/10X,4HDBS=F8.4/10X,4H SD=F8.4)
13    FORMAT (1H ,34H FIELD COIL O.D. EXCEEDS YOKE I.D.)
14    FORMAT (1H ,81H FIELD COIL DIMENSIONS ARE TOO SMALL FOR THE SPECIF
     1IED NO. OF TURNS AND WIRE SIZE)
C
C     DETERMINE STATOR STACKING FACTOR
C
15    IF (SF.NE.0.) GO TO 17
      IF (LTS.EQ.0.) GO TO 16
      SF=1.0-(12.5E-4/LTS)
      GO TO 17
16    SF=1.0
C
C
17    SS=SF*(CL-HV*BV)
      SIGMA=(54.E3/DI**2)*(PF/SS)*(VA/RPM)
      VR=0.262*DR*RPM
      TP=3.142*DI/PX
      TS=3.142*DI/QQ
      IF (ZZ-4) 18,19,18
18    TT=(.667*HS+DI)*3.142/QQ
      GO TO 20
19    TT=(DI+2.0*HO+1.333*BS)*3.1416/QQ
C
C     CALCULATE CARTER COEFFICIENT
C
20    IF (ZZ.GT.1.AND.ZZ.LT.5) GO TO 21
      CC=(5.0*GC+BS)*TS/((5.0*GC+BS)*TS-BS*BS)
      GO TO 22
21    QC=(4.44*GC+0.75*BO)*TS
      CC=QC/(QC-BO*BO)
C
C     PITCH FACTOR AND SKEW FACTOR CALCULATIONS
C
22    CF=SIN(YY*1.571/(PN*QN))
      IF (SK) 23,23,24
23    FS=1.0
      GO TO 25
24    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
25    D=1.0
      IF (PBA.GT.61.0) D=2.0
      IZY=IPX*IPN
      IDM=0
26    IDM=IDM+IZY
      IF (IQQ-IDM) 28,27,26
```

```
C
C     CALCULATE DISTRIBUTION FACTOR FOR INTEGRAL SLOT WINDING
C
27    DF=SIN(1.571*D/PN)/(QN*D*SIN(1.571/(PN*QN)))
      GO TO 32
C
C     CALCULATE DISTRIBUTION FACTOR FOR FRACTIONAL SLOT WINDING
C
28    IIQQ=IQQ
      I=2
29    IF ((IZY/I)*I.EQ.IZY.AND.(IIQQ/I)*I.EQ.IIQQ) GO TO 30
      IF (I.GT.IZY) GO TO 31
      I=I+1
      GO TO 29
30    IZY=IZY/I
      IIQQ=IIQQ/I
      GO TO 29
31    FNQ=IIQQ
      DF=SIN(1.571*D/PN)/(FNQ*D*SIN(1.571/(FNQ*PN)))
32    EC=QQ*SC*CF*FS/C
C
C     COMPUTE ARMATURE CONDUCTOR AREA
C
      IF (DW1) 33,33,34
33    AC=0.785*DW*DW*SN1
      GO TO 46
34    ZY=0.0
      DT=AMIN1(DW,DW1)
      DG=AMAX1(DW,DW1)
35    IF (DT-.05) 38,38,36
36    JA=0
37    JA=JA+1
      IF (DT-DA(JA)) 39,39,37
38    D=0
      IF (ZY) 45,45,58
39    IF (DG-0.188) 40,40,41
40    CY=DX(JA-1)
      CZ=DX(JA)
      GO TO 44
41    IF (DG-0.75) 42,42,43
42    CY=DY(JA-1)
      CZ=DY(JA)
      GO TO 44
43    CY=DZ(JA-1)
      CZ=DZ(JA)
44    D=CY+(CZ-CY)*(DT-DA(JA-1))/(DA(JA)-DA(JA-1))
      IF (ZY) 45,45,58
45    AC=(DT*DG-D)*SN1
C
C     CALCULATE END EXTENSION LENGTH
C
46    IF (EL) 47,47,55
47    IF (RF) 48,48,54
48    IF (PX-2.0) 49,49,50
49    U=1.3
      GO TO 53
```

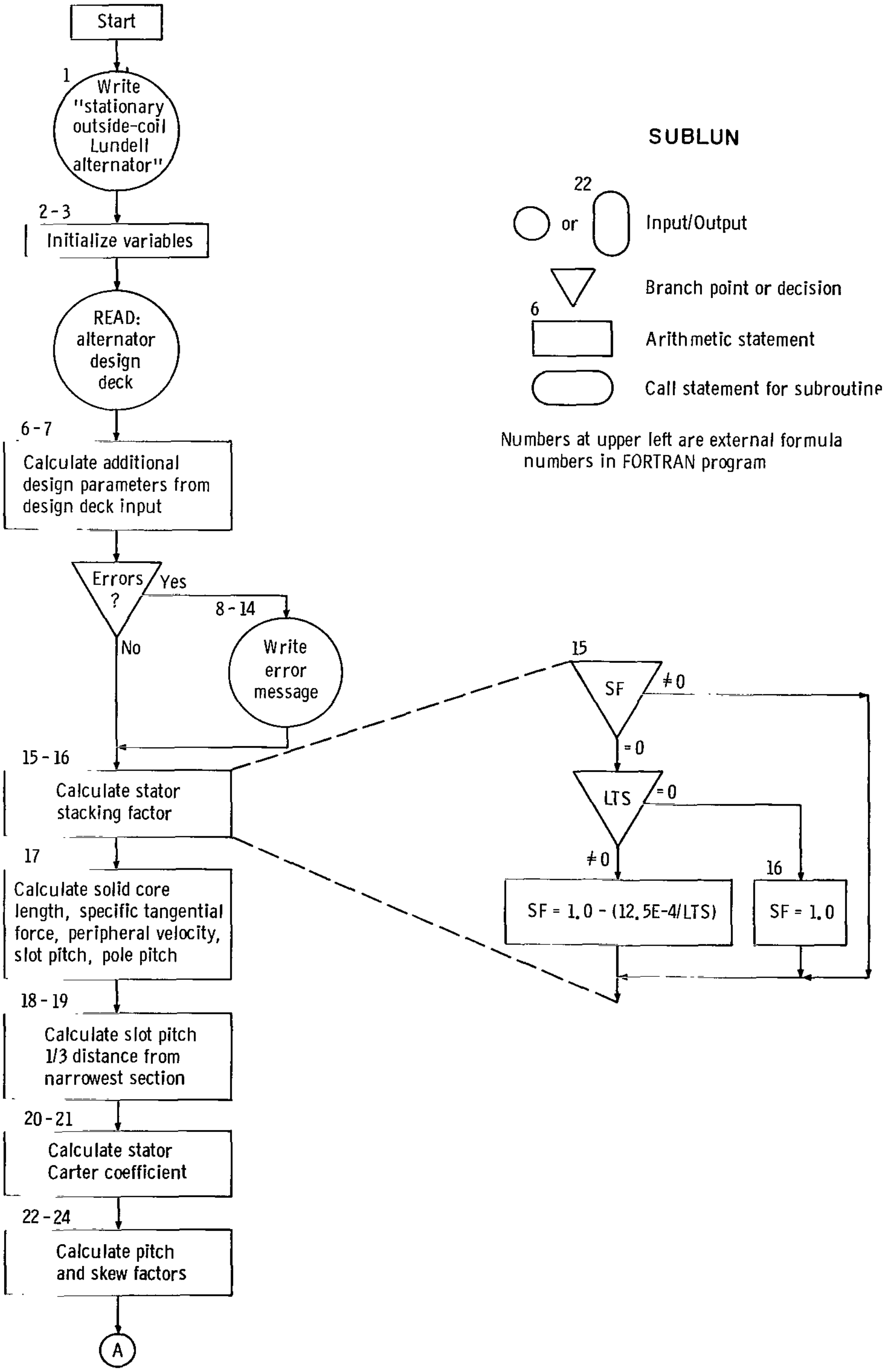
```
50      IF (PX-4.0) 51,51,52                                                          B 275
51      U=1.5                                                                         B 276
        GO TO 53                                                                      B 277
52      U=1.7                                                                         B 278
53      EL=3.1416*U*YY*(DI+HS)/QQ+0.5                                                 B 279
        GO TO 55                                                                      B 280
54      EL=2.0*CE+(3.1416*(0.5*HX+DB))+(YY*TS*TS/(SQRT(TS*TS-BS*BS)))                 B 281
55      HM=CL+EL                                                                      B 282
C                                                                                     B 283
C       CALCULATE STATOR RESISTANCE                                                   B 284
C                                                                                     B 285
        A=PI*SC*CF/(C*TS)                                                             B 286
        RY=SC*QQ*HM/(PN*AC*C*C)                                                       B 287
        RG1=(1.E-6)*RS*(1.0+ALPHAS*(TST-20.))*RY                                      B 288
        S=PI/(C*AC)                                                                   B 289
C                                                                                     B 290
C       COMPUTE FIELD CONDUCTOR AREA                                                  B 291
C                                                                                     B 292
        IF (RT) 56,56,57                                                              B 293
56      AS=.7854*RD*RD                                                                B 294
        GO TO 59                                                                      B 295
57      ZY=1.0                                                                        B 296
        DT=AMIN1(RT,RD)                                                               B 297
        DG=AMAX1(RT,RD)                                                               B 298
        GO TO 35                                                                      B 299
58      AS=DT*DG-D                                                                    B 300
C                                                                                     B 301
C       COMPUTE FIELD RESISTANCE                                                      B 302
C                                                                                     B 303
59      ZG=(PT*FE/AS)*FLOAT(NFC)                                                      B 304
        FK1=(1.E-6)*RR*(1.0+ALPHAR*(TF-20.))*ZG                                       B 305
C                                                                                     B 306
C       NO LOAD MAGNETIC CALCULATIONS                                                 B 307
C                                                                                     B 308
        GA=3.1416*DI*(CL-HV*BV)                                                       B 309
        AG2=3.1416*(DISH1+G2)*LG2                                                     B 310
        GE=CC*GC                                                                      B 311
        IF (C1) 61,60,61                                                              B 312
60      C1=(.649*ALOG(PE)+1.359)                                                      B 313
61      CW=(0.707/1.732)*C1*DF                                                        B 314
        TG=EE/(CW*EC*RPM)*6.0E6                                                       B 315
        BG=TG/GA                                                                      B 316
        FH=BG*GE/0.00319                                                              B 317
        IF (CP) 62,62,63                                                              B 318
62      CP=PE*(ALOG(GC/TP)*.0378+1.191)                                               B 319
63      FQ=TG*CP/PX                                                                   B 320
C                                                                                     B 321
C       DETERMINE DEMAGNETIZING AMPERE TURNS (RATED LOAD)                             B 322
C                                                                                     B 323
        IF (CM) 64,64,65                                                              B 324
64      AA=SIN(3.142*PE)                                                              B 325
        AB=SIN(1.571*PE)*4.0                                                          B 326
        CM=(3.142*PE+AA)/AB                                                           B 327
65      CONTINUE                                                                      B 328
        FGML=.45*EC*PI*CM*DF/PX                                                       B 329
C                                                                                     B 330
```

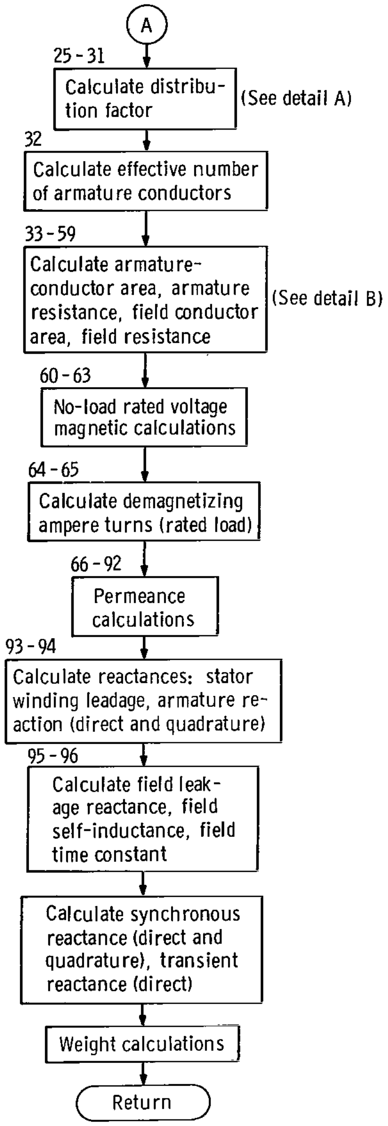
```
C      REACTANCE FACTOR CALCULATION                                      B 331
C                                                                        B 332
       XR=.0707*A*DF/(C1*BG)                                             B 333
C                                                                        B 334
C      SPECIFIC ARMATURE SLOT AND END-TURN LEAKAGE PERMEANCES            B 335
C                                                                        B 336
       FACTOR=YY/(PN*QN)                                                 B 337
       IF (PBA.LT.61.) GO TO 66                                          B 338
       FF=.05*(24.*FACTOR-1.)                                            B 339
       IF (FACTOR.GE.0.667) FF=.75                                       B 340
       IF (ZZ.EQ.5) FF=1.                                                B 341
       GO TO 67                                                          B 342
66     FF=.25*(6.*FACTOR-1.)                                             B 343
       IF (FACTOR.GE.0.667) FF=.25*(3.*FACTOR+1.)                        B 344
       IF (ZZ.EQ.5) FF=1.                                                B 345
67     CX=FF/(CF*CF*DF*DF)                                               B 346
       Z=CX*20.0/(PN*QN)                                                 B 347
       BT=3.142*DI/QQ-BO                                                 B 348
       ZA=BT*BT/(16.0*TS*GC)                                             B 349
       ZB=0.35*BT/TS                                                     B 350
       ZC=HO/BO                                                          B 351
       ZD=HX*.333/BS                                                     B 352
       ZE=HY/BS                                                          B 353
       IF (ZZ-2) 68,69,70                                                B 354
68     PC=Z*(ZE+ZD+ZA+ZB)                                                B 355
       GO TO 74                                                          B 356
69     PC=Z*(ZC+(2.0*HT/(BO+BS))+(HW/BS)+ZD+ZA+ZB)                       B 357
       GO TO 74                                                          B 358
70     IF (ZZ-4) 71,72,73                                                B 359
71     PC=Z*(ZC+(2.0*HT/(BO+B1))+(2.0*HW/(B1+B2))+(HX/(3.*B2))+ZA+ZB)    B 360
       GO TO 74                                                          B 361
72     PC=Z*(ZC+0.62)                                                    B 362
       GO TO 74                                                          B 363
73     PC=Z*(ZE+ZD+(0.5*GC/TS)+(0.25*TS/GC)+0.6)                         B 364
74     EK=EL/(10.0**(0.103*YY*TS+0.402))                                 B 365
       IF (DI-8.0) 75,75,76                                              B 366
75     EK=SQRT(EK)                                                       B 367
76     ZF=.612*ALOG(10.0*CS)                                             B 368
       EW=6.28*EK*ZF*(TP**(0.62-(.228*ALOG(ZF))))/(CL*DF*DF)             B 369
       IF (SPS.NE.0.) GO TO 78                                           B 370
       AA=TP-PW2                                                         B 371
       AB=TS-BO                                                          B 372
       IF (AA.LT.AB) GO TO 77                                            B 373
       SPS=0.                                                            B 374
       GO TO 78                                                          B 375
77     SPS=(6.67*CX/QN)/(2.*CL*GC)                                       B 376
       AA=((AB-AA)*0.5)**2                                               B 377
       AA=(AA*CL)/(PW2-PW1)                                              B 378
       SPS=SPS*AA                                                        B 379
C                                                                        B 380
C      LEAKAGE PERMEANCES USED IN MAGNETIC CALCULATIONS                  B 381
C                                                                        B 382
78     IF (P1.NE.0.) GO TO 79                                            B 383
       P1=(3.19*PA1)/(PL-CL)                                             B 384
79     IF (P10.NE.0.) GO TO 84                                           B 385
       IF (P2.NE.0.) GO TO 80                                            B 386
```

```
      P2=(3.19*PL*(PT1+PT2)*0.5)/(TP-PHW)                               B 387
80    IF (P3.NE.0.) GO TO 81                                            B 388
      P3=((3.19*PHW*0.64)/((4./CL)*(PL-CL)+1.0))*2.                     B 389
81    IF (P4.NE.0.) GO TO 83                                            B 390
      IF (IPX.LT.4) GO TO 82                                            B 391
      P4=(0.64*3.19*CL)/((((TP-PHW)/(PHW/2.))+1.0)                      B 392
      P4=P4*(1.0/(1.0-2.0/FLOAT(IPX)))                                  B 393
      GO TO 83                                                          B 394
82    P4=(3.19*CL*PHW/2.)/(DR-PT1-PT2)                                  B 395
83    P10=2.*(P3+P2+P4)                                                 B 396
84    IF (P5.NE.0.) GO TO 91                                            B 397
      AA=DISH1/2.+G2+TYE                                                B 398
      AB=DYC/2.-TY                                                      B 399
      IF (TYPY-1) 85,85,86                                              B 400
85    P5=10.53*(AA+0.425*(LG2-TY2))                                     B 401
      GO TO 91                                                          B 402
86    IF (TYPY-5) 87,88,89                                              B 403
87    AA=(AB-AA+(TYL-CL)/2.)/2.                                         B 404
      GO TO 90                                                          B 405
88    AA=(DU-DI+TYL-CL)/4.                                              B 406
      GO TO 90                                                          B 407
89    AA=(TYL-CL)/3.                                                    B 408
90    AB=AB-AA                                                          B 409
      P5=10.53*(AB+0.425*AA)                                            B 410
      IF (TYPY.EQ.6) P5=0.5*P5                                          B 411
91    IF (P6.NE.0.) GO TO 92                                            B 412
      P6=3.19*((0.7854*(DR-2.*PT2)**2)/(2.*PL-CL))                      B 413
92    P8=(3.19*(GA))/GE                                                 B 414
      P9=(3.19*AG2)/G2                                                  B 415
C                                                                       B 416
C     STATOR WINDING LEAKAGE AND ARMATURE REACTION REACTANCES           B 417
C                                                                       B 418
      IF (CQ) 93,93,94                                                  B 419
93    AB=3.1416*PE                                                      B 420
      CQ=(4.*PE+1.)/5.-SIN(AB)/3.1416                                   B 421
94    XL=XR*(PC+EW+SPS)                                                 B 422
      FG1=BG*GE*313.                                                    B 423
      FG2=((FQ*PX)/P9)*500.                                             B 424
      XD=(0.45*EC*PI*CM*DF*100.)/((FG1+FG2)*PX)                         B 425
      XQ=((CQ)/(CM*C1))*XD                                              B 426
C                                                                       B 427
C     FIELD LEAKAGE REACTANCE. SELF INDUCTANCE AND TIME CONSTANT        B 428
C                                                                       B 429
      STATET=QQ*SC*DF*CF/(2.*PN*C)                                      B 430
      AA=P7+P10*PX                                                      B 431
95    AB=2.*((P9*AA+P9*P5+P5*AA)/(P9+AA))                               B 432
      IF (TYPY.EQ.6) AB=P5+0.5*((P9*AA)/(P9+AA))                        B 433
      AB=AB*(PT**2)*1.0E-6                                              B 434
      IF (XF.GT.0.) GO TO 96                                            B 435
      XF=9.42478*F*AB*((STATET/PT)**2)*(PI/EP)                          B 436
      AA=AA+CP*P8                                                       B 437
      GO TO 95                                                          B 438
96    SI=AB*1.0E-2                                                      B 439
      TC=SI/FK1                                                         B 440
C                                                                       B 441
C     SYNCHRONOUS AND TRANSIENT REACTANCES CALCULATIONS                 B 442
```

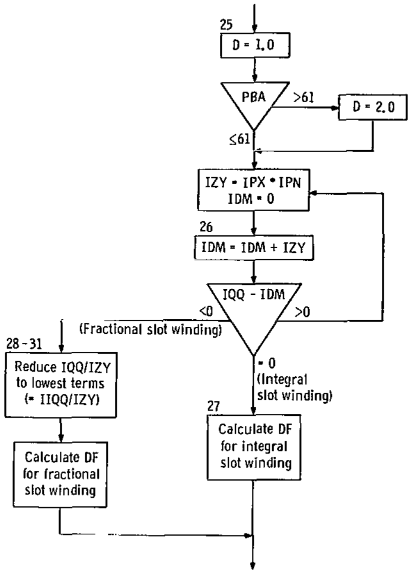
```
C
      XA=XL+XD
      XB=XL+XQ
      XU=XL+(XF*XD)/(XF+XD)
C
C     WEIGHT CALCULATIONS
C
      IF (ZZ-3) 97,98,97
97    WI=((DU+DI)*(DU-DI)*3.1416)/4.
      IF (ZZ.NE.4) WI=WI-QQ*(BS*HS-((HO+0.5*HT)*(BS-BO)))
      IF (ZZ.EQ.4) WI=WI-QQ*(BS*BS*3.1416/4.+HO*BO)
      GO TO 99
98    WI=(DU-HC)*3.1416*HC
      WI=WI+HS*((DI+2.*HS)*3.1416-QQ*B3)
      WI=WI+QQ*((HO+0.5*HT)*(BS-BO))
99    WI=WI*0.283*SS
C
      RC=(.321*PT*FE*AS)*FLOAT(NFC)
C
      WC=.321*SC*QQ*AC*HM
C
      IF (WYOKE.NE.0.) GO TO 100
      WYOKE=DYC-2.*TY
      WYOKE=(1./12.)*(TY2-TY3)*(DY2**2+DY2*WYOKE+WYOKE**2)+0.25*(TY3*WYO
     1KE**2)
      WYOKE=WYOKE-0.25*(DY2**2)*TY2
      WYOKE=WYOKE+(2.*(DISH1+2.*G2+TYE)*TYE*LG2)
      WYOKE=WYOKE+((DYC-TY)*TY*(TYL+2.*TY3))
      WYOKE=WYOKE*3.1416*0.283
C
100   IF (WROTOR.NE.0.) GO TO 101
      WROTOR=(DISH1**2-DISH**2)*(TYR-SHL2)
      WROTOR=WROTOR+(0.333*(DISH1**2+DISH1*DR+DR**2)-DISH**2)*(SHL2-SHL1
     1)
      WROTOR=WROTOR+(DR**2-DISH**2)*(SHL1)*(GAMMAR/0.283)
      WROTOR=WROTOR*0.7854*0.283
      WROTOR=WROTOR-(PX/2.)*(PA1+PA2)*(SHL1)*(0.283-GAMMAR)
101   WTOTAL=WC+WI+RC+WYOKE+WROTOR
      RETURN
      END
```

SUBLUN

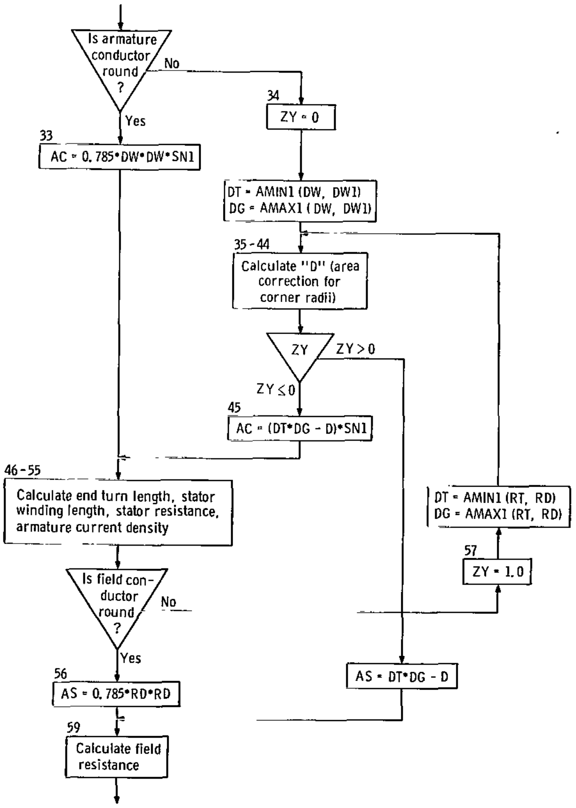

Start
1
Write "stationary outside-coil Lundell alternator"
2-3
Initialize variables
READ: alternator design deck
6-7
Calculate additional design parameters from design deck input
Errors ?
Yes
No
8-14
Write error message
15-16
Calculate stator stacking factor
17
Calculate solid core length, specific tangential force, peripheral velocity, slot pitch, pole pitch
18-19
Calculate slot pitch 1/3 distance from narrowest section
20-21
Calculate stator Carter coefficient
22-24
Calculate pitch and skew factors
A
15
SF
≠0
=0
LTS
=0
≠0
16
SF = 1.0 - (12.5E-4/LTS)
SF = 1.0
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


A
25 - 31
Calculate distribution factor
(See detail A)
32
Calculate effective number of armature conductors
33 - 59
Calculate armature-conductor area, armature resistance, field conductor area, field resistance
(See detail B)
60 - 63
No-load rated voltage magnetic calculations
64 - 65
Calculate demagnetizing ampere turns (rated load)
66 - 92
Permeance calculations
93 - 94
Calculate reactances: stator winding leadage, armature reaction (direct and quadrature)
95 - 96
Calculate field leakage reactance, field self-inductance, field time constant
Calculate synchronous reactance (direct and quadrature), transient reactance (direct)
Weight calculations
Return

SUBLUN



Detail A



Detail B

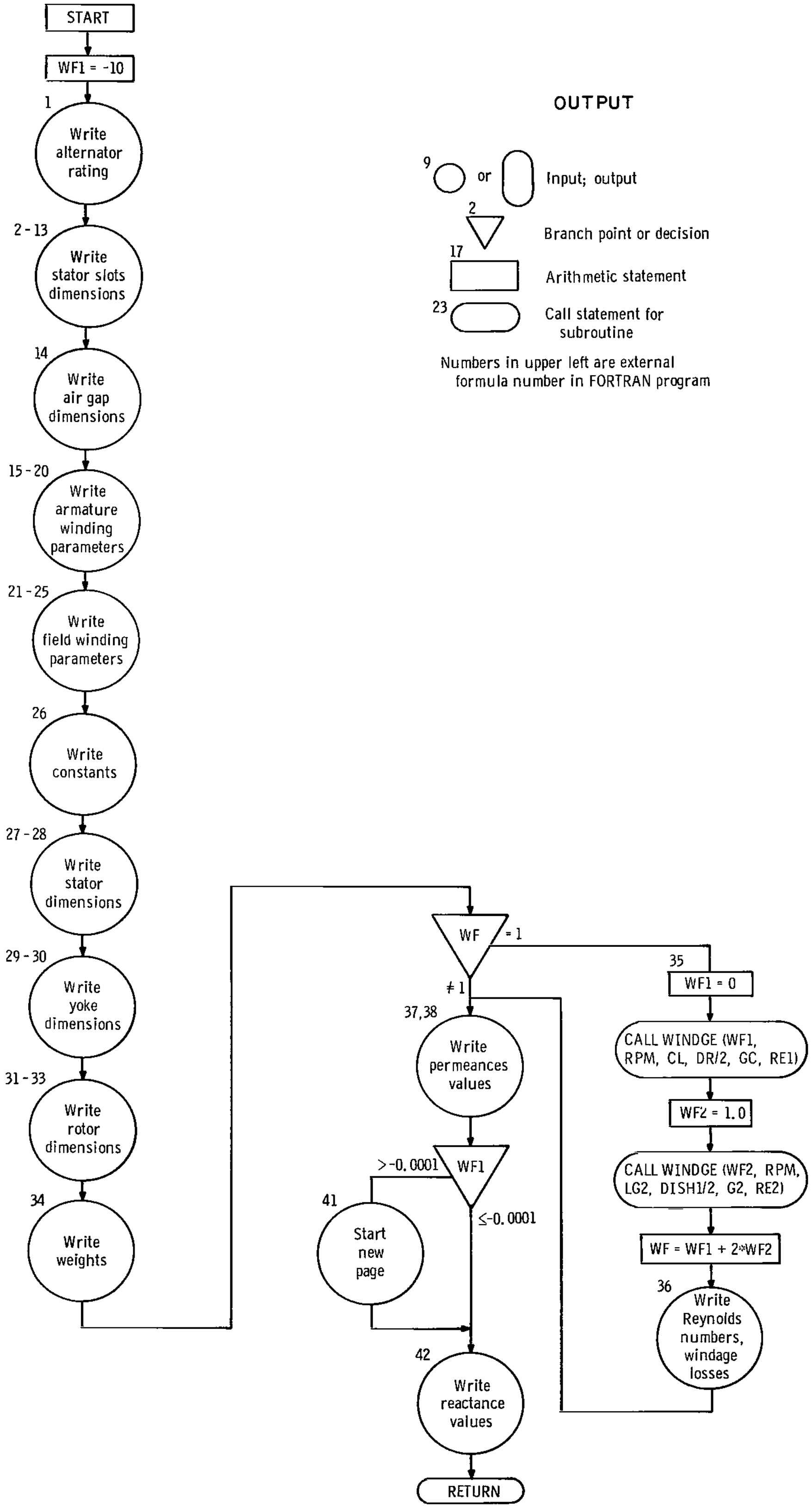
```
      SUBROUTINE OUTPUT
C
      COMMON /COM1/ A,B1,B2,BCOIL,BV,CC,CE,CF,CM,CQ,DCOIL,DF,DR,DW,DW1,E
     1C,EL,EW,FE,FK1,FS,G2,GAMMAR,GE,HO,HT,HV,HW,HX,HY,IPN,IPX,IQQ,IZZ,L
     2TS,P2,P3,P4,PBA,PC,PCOIL,PT1,PT2,PW1,PW2,QN,RC,RD,RF,RG1,RT,S,SF,S
     3HL1,SI,SIGMA,SK,SN1,SPS,STATET,TC,TF,TST,TYE,TYR,VA,VR,WC,WI,WROTO
     4R,WTOTAL,WYOKE,XF,XQ,XR,XU,YY
      COMMON /COM2/ AC,AS,BB,BK,BO,BS,C,C1,D1,DI,DISH,DISH1,DU,DYC,EE,EP
     1,F,GC,HC,HM,NFC,PA1,PE,PF,PI,PL,PT,RPM,RR,RS,SC,SD,SH,SHL2,SN,SS,T
     2S,TT,TY,TYL,WF,WL,XA,XB,XD,XL
      COMMON /COM5/ AA,AG2,CL,CP,DY2,DY3,HS,LG2,P1,P10,P5,P6,P7,P8,P9,PA
     12,PPL,PPL1,PPL2,PPL3,PPL4,PX,TY2,TY3,TYPY
C
      DIMENSION STAR(5), DASH(5)
C
      INTEGER TYPY
C
      REAL LTS,LG2
C
      DATA STAR(1)/30H******************************/,DASH(1)/30H-------
     1-----------------------/
C
C
      WF1=-10.
      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--------*,12X5
     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*-----/62X1HI,12X1HI/62X14HI-----BS-----I/62X1HI,12X1HI)
      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,5X1H*,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,F25.3,1X6HINCHES,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
      WRITE (6,14) GC,G2,LG2,GE,CC
14    FORMAT (1HL,8H AIR GAP//10X,13H MAIN AIR GAP,F23.3,1X,6HINCHES/10X
     1,18H AUXILIARY AIR GAP,F18.3/10X,28H LENGTH OF AUXILIARY AIR GAP,F
     28.3/10X,18H EFFECTIVE AIR GAP,F18.3//10X,19H CARTER COEFFICIENT,F1
     37.3)
      IF (RF.LT..5) WRITE (6,15)
      IF (RF.GE..5) WRITE (6,16)
15    FORMAT (1H1,45H ARMATURE WINDING (Y-CONNECTED, RANDOM WOUND)//)
16    FORMAT (1H1,43H ARMATURE WINDING (Y-CONNECTED, FORM WOUND)//)
      IF (DW1.EQ.0.) WRITE (6,17) DW
```

```
17     FORMAT (1H ,9X,16H STRAND DIAMETER,F32.4,1X6HINCHES)
       IF (DW1.GT.0.) WRITE (6,18) DW,DW1
18     FORMAT (1H ,9X,18H STRAND DIMENSIONS,F30.4,2H X,1X,F6.4,1X,6HINCHE
      1S)
       WRITE (6,19) SD,SN,SN1,AC,S,CE,HM,EL,SK,RS,TST,RG1,STATET,EC,YY,QN
19     FORMAT (1H ,10X36HDISTANCE BTWN CL OF STRANDS (RADIAL),F11.4//10X,
      133H STRANDS/CONDUCTOR IN RADIAL DIR.,F11.0/10X,24H TOTAL STRANDS/C
      2ONDUCTOR,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,F31.3/10X,17H STATOR SLOT SKEW,F30.
      63//10X,25H RESISTIVITY AT 20 DEG. C,F23.4,1X16HMICRO OHM INCHES/10
      7X,21H STATOR RESISTANCE AT,F6.0,7H DEG. C,F14.4,1X4HOHMS//10X,30H
      8NO. OF EFFECTIVE SERIES TURNS,F16.2/10X,27H TOTAL EFFECTIVE CONDUC
      9TORS,F19.2/10X,14H SLOTS SPANNED,F30.0/10X,25H SLOTS PER POLE PER
      $PHASE,F21.2)
       WRITE (6,20) SC,C,PBA,FS,DF,CF
20     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 (6,21) RD
       IF (RT.GT.0.) WRITE (6,22) RD,RT
21     FORMAT (1HL,14H FIELD WINDING//10X19H CONDUCTOR DIAMETER,F29.4,1X6
      1HINCHES/)
22     FORMAT (1HL,14H FIELD WINDING//10X,21H CONDUCTOR DIMENSIONS,F27.4,
      12H X,1XF6.4,1X6HINCHES/)
       WRITE (6,23) AS,NFC,PT,FE,RR,TF,FK1
23     FORMAT (1H ,9X15H CONDUCTOR AREA,F33.4,1X5HSQ-IN.//10X,19H NO. OF
      1FIELD COILS,I24/10X,24H NO. OF TURNS (PER COIL),F20.0/10X20H MEAN
      2LENGTH OF TURN,F27.3,2X6HINCHES//10X25H RESISTIVITY AT 20 DEG. C,F
      323.4,1X16HMICRO OHM INCHES/10X20H FIELD RESISTANCE AT,F5.0,7H DEG.
      4 C,F16.4,1X4HOHMS)
       IF (NFC.EQ.2) WRITE (6,24)
24     FORMAT (1H ,15X,23H (BOTH COILS IN SERIES))
       WRITE (6,25) PCOIL,DCOIL,BCOIL,TYPY
25     FORMAT (10X21H COIL INSIDE DIAMETER,F26.3,2X6HINCHES/10X22H COIL O
      1UTSIDE DIAMETER,F25.3/10X11H COIL WIDTH,F36.3//10X,21H LOCATION CO
      2DE (TYPY),I23)
       WRITE (6,26) C1,CP,CM,CQ,D1
26     FORMAT (1HL,10H CONSTANTS//10X,35H C1, FUNDAMENTAL/MAX. OF FIELD F
      1LUX,F8.3/10X,18H CP, POLE CONSTANT,F25.3/10X,27H CM, DEMAGNETIZATI
      2ON FACTOR,F16.3/10X,31H CQ, CROSS MAGNETIZATION FACTOR,F12.3/10X,2
      36H D1, POLE FACE LOSS FACTOR,F17.3)
       WRITE (6,27) DI,DU,CL,SS,HC,SF,HV,BV,BK,WL
27     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 (6,28) LTS
28     FORMAT (10X,21H LAMINATION THICKNESS,F24.3,4H IN.)
       WRITE (6,29) DASH(1),DASH(1),DASH(1),(STAR(I),I=1,5),DASH(1),(STAR
      1(I),I=1,4),DASH(1),STAR(1),STAR(1),DASH(1),(DASH(I),I=1,5)
29     FORMAT (1HL,5H YOKE///16X,1H1,22X,9H1  1  TY3/16X,1H1,A6,3X,3HTYL,
```

```
     14X,A6,4H1  1,A3/16X,1H1,22X,4H1  1,5X,1H1/48X,1H1/13X,5A6,1X,A6/13    C 163
     2X,1H*,28X,1H*,4X,2HTY/13X,1H*,28X,1H*/13X,1H*,2X,4A6,4H--*-,A6/2(1    C 164
     33X,4H*  *,22X,4H*  *,5X,1H1/),3(12X5H*   *,22X5H*   */),2(11X,6H*    C 165
     4    *,17X,1H1,4X,6H*    */),11X,8H*    ***,14X,12H--- ***    */11X,   C 166
     58H*      *,14X,5HTYE *,6X,1H*/11X,A6,2H**,14X,3H---,1X,A6,2H**,/11    C 167
     6X,1H1,6X,1H1,15X,1H1,4X,1H1,4X,1H1/5X,A6,8H1  LG2 1,A6,10X,18H----    C 168
     71    1---- TY2/11X,1H1,6X,1H1,25X,1H1/11X,1H1,2H--,2A6,4HTYR ,2A6,    C 169
     82H--, 1H1/11X,1H1,32X,1H1)                                            C 170
      WRITE (6,30) TY,TY2,TY3,TYL,TYE,TYR,LG2,DYC                           C 171
30    FORMAT (1HL,9X,2HTY,F30.2,7H INCHES/10X,3HTY2,F29.2/10X,3HTY3,F29.    C 172
     12/10X,3HTYL,F29.2/10X,3HTYE,F29.2/10X,3HTYR,F29.2/10X,3HLG2,F29.2/    C 173
     2/10X,21HYOKE OUTSIDE DIAMETER,F11.2)                                  C 174
      WRITE (6,31) DASH(1),SHL2,DASH(1),STAR(1),STAR(2),(DASH(I),I=1,4),    C 175
     1STAR(1),STAR(1),STAR(1),STAR(1),DASH(1),DR,DISH1                      C 176
31    FORMAT (1H1,6H ROTOR//10X,1H1,20X,1H1/10X,1H1,A6,F7.2,1X,A6,1H1/3(    C 177
     110X,1H1,20X,1H1/)10X,1H1,4X,2A6,2X,4A6/10X,1H13X,A2,10X,A2,3X,1H1,    C 178
     219X,1H1/10X,6H1  * *,10X,6H* *  1,19X,1H1/2X,2(10X,4H*  *),21X,1H1    C 179
     3/1X,2(10X,5H*   *),20X,1H1/5X,A6,4X,1H*,10X,1H*,4X,A6,1X,A6,7X,1H1    C 180
     4/2(10X,1H*,4X,1H*),10X,1H1,8X,1H1/2(10X,1H*,4X,1H*),10X,1H1/2(10X,    C 181
     51H*,4X,1H*),10X,1H1,F11.2/2(10X,1H*,4X,1H*)/2(10X,1H*,4X,1H*),F13.    C 182
     62,6X,1H1/2(10X,1H*,4X,1H*),19X,1H1/2(10X,1H*,4X,1H*),2X,2(8X,1H1))    C 183
      WRITE (6,32) STAR(1),STAR(1),DASH(1),STAR(1),STAR(1),(DASH(I),I=1,    C 184
     14),SHL1                                                               C 185
32    FORMAT (5X,A6,4X,1H*,10X,1H*,4X,A6,1X,A6,7X,1H1/11X,1H*,3X,1H*,10X    C 186
     1,1H*,3X,1H*,20X,1H1/12X,1H*,2X,1H*,10X,1H*,2X,1H*,21X,1H1/13X,1H*,    C 187
     21X,1H*,10X,1H*,1X,1H*,22X,1H1/14X,2H**,10X,2H**,23X,1H1/15X,2A6,2X    C 188
     3,4A6//2(15X,1H1,10X,1H1/)11X,5H----1,F8.2,2X,5H1----/5X,2(10X,1H1)    C 189
     4)                                                                     C 190
      WRITE (6,33) PW1,PT1,PA1,PW2,PT2,PA2,PL,DISH,PE,VR,SIGMA,GAMMAR       C 191
33    FORMAT (1HL,9X,25H POLE DIMENSIONS (INCHES)//12X,11H NARROW END/16    C 192
     1X,6H WIDTH,F18.2/16X,10H THICKNESS,F14.2/16X,5H AREA,F19.2//12X,9H    C 193
     2 WIDE END/16X,6H WIDTH,F18.2/16X,10H THICKNESS,F14.2/16X,5H AREA,F    C 194
     319.2//12X,12H POLE LENGTH,F16.2/12X,22H INSIDE SHAFT DIAMETER/14X,    C 195
     419H (FOR HOLLOW SHAFT),F8.3//10X,13H POLE EMBRACE,F17.2//10X,17H P    C 196
     5ERIPHERAL SPEED,F13.2,10H FEET/MIN./12X,18H (AT MAIN AIR GAP)/10X,    C 197
     623H SPEC. TANGENTIAL FORCE,F7.2,11H LBS/SQ.IN.//10X,24H DENSITY OF    C 198
     7 NON-MAGNETIC/12X,15H ROTOR MATERIAL,F14.3,11H LBS/CU.IN.)            C 199
      WRITE (6,34) WC,RC,WI,WROTOR,WYOKE,WTOTAL                             C 200
34    FORMAT (1H1,8H WEIGHTS//10X13H STATOR COND.,F17.3,1X6HPOUNDS/10X12    C 201
     1H FIELD COND.,F18.3/10X12H STATOR IRON,F18.3/10X,6H ROTOR,F24.3/10    C 202
     2X,5H YOKE,F25.3//10X,6H TOTAL/11X18H (ELECTROMAGNETIC),F11.3)         C 203
C                                                                           C 204
C     COMPUTE WINDAGE LOSS (MAIN AND AUXILIARY AIR GAPS)                    C 205
C                                                                           C 206
      IF (WF-1.0) 37,35,37                                                  C 207
35    WF1=0.                                                                C 208
      CALL WINDGE (WF1,RPM,CL,DR/2.,GC,RE1)                                 C 209
      WF2=1.0                                                               C 210
      CALL WINDGE (WF2,RPM,LG2,DISH1/2.,G2,RE2)                             C 211
      WF=WF1+WF2*2.                                                         C 212
      WRITE (6,36) RE1,RE2,WF1,WF2,WF                                       C 213
36    FORMAT (1HK,9X,16H REYNOLDS NUMBER/13X,13H MAIN AIR GAP,F17.2/13X,    C 214
     113H AUX. AIR GAP,F17.2/10X,21H WINDAGE LOSS (WATTS)/13X,13H MAIN A    C 215
     2IR GAP,F17.2/13X,13H AUX. AIR GAP,F17.2/13X,6H TOTAL,F24.2)           C 216
37    CONTINUE                                                              C 217
      WRITE (6,38) PC,EW,SPS,P1                                             C 218
```

```
      IF ((P2+P3+P4).GT.1.0E-4) WRITE (6,39) P2,P3,P4                   C 219
      WRITE (6,40) P5,P6,P7,P8,P9,P10                                   C 220
 38   FORMAT (1HL,11H PERMEANCES//10X,16H WINDING LEAKAGE/10X,25H (PER I C 221
     1NCH OF CORE LENGTH)/12X,12H STATOR SLOT,F26.3,18H LINES/AMPERE TUR C 222
     2N,/13X,10HSTATOR END,F27.3/13X,13HSPECIAL (SPS),F24.3//10X,14H P1  C 223
     3(POLE TIP),F26.3)                                                 C 224
 39   FORMAT (10X,3H P2,F37.3/10X,3H P3,F37.3/10X,3H P4,F37.3)          C 225
 40   FORMAT (10X,3H P5,F37.3/10X,3H P6,F37.3/10X,3H P7,F37.3/10X,18H P8 C 226
     1 (MAIN AIR GAP),F22.3/10X,18H P9 (AUX. AIR GAP),F22.3/10X,4H P10,F C 227
     236.3)                                                             C 228
      IF (WF1.GT.-0.0001) WRITE (6,41)                                  C 229
 41   FORMAT (1H1)                                                      C 230
      WRITE (6,42) A,XR,XL,XD,XQ,XA,XB,XF,XU,SI,TF,TC                   C 231
 42   FORMAT (1HL,11H REACTANCES//10X23H AMPERE CONDUCTORS/INCH,F20.3/10 C 232
     1X17H REACTANCE FACTOR,F26.3//10X23H STATOR WINDING LEAKAGE,F20.3,1 C 233
     2X,7HPERCENT/10X23H ARM. REACTION (DIRECT),F20.3/10X22H ARM. REACTI C 234
     3ON (QUAD.),F21.3/10X21H SYNCHRONOUS (DIRECT),F22.3/10X20H SYNCHRON C 235
     4OUS (QUAD.),F23.3/10X14H FIELD LEAKAGE,F29.3/10X10H TRANSIENT,F33. C 236
     53//10X22H FIELD SELF INDUCTANCE,F21.3,1X7HHENRIES//10X27H OPEN CIR C 237
     6CUIT TIME CONSTANT/13X,16H (FIELD ONLY, AT,F4.0,8H DEG. C),F15.5,1 C 238
     7X 7HSECONDS)                                                      C 239
      RETURN                                                            C 240
      END                                                               C 241-
```


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
WF1 = -10
1
Write alternator rating
2 - 13
Write stator slots dimensions
14
Write air gap dimensions
15 - 20
Write armature winding parameters
21 - 25
Write field winding parameters
26
Write constants
27 - 28
Write stator dimensions
29 - 30
Write yoke dimensions
31 - 33
Write rotor dimensions
34
Write weights
WF
= 1
≠ 1
35
WF1 = 0
CALL WINDGE (WF1, RPM, CL, DR/2, GC, RE1)
WF2 = 1.0
CALL WINDGE (WF2, RPM, LG2, DISH1/2, G2, RE2)
WF = WF1 + 2*WF2
36
Write Reynolds numbers, windage losses
37,38
Write permeances values
WF1
> -0.0001
≤ -0.0001
41
Start new page
42
Write reactance values
RETURN

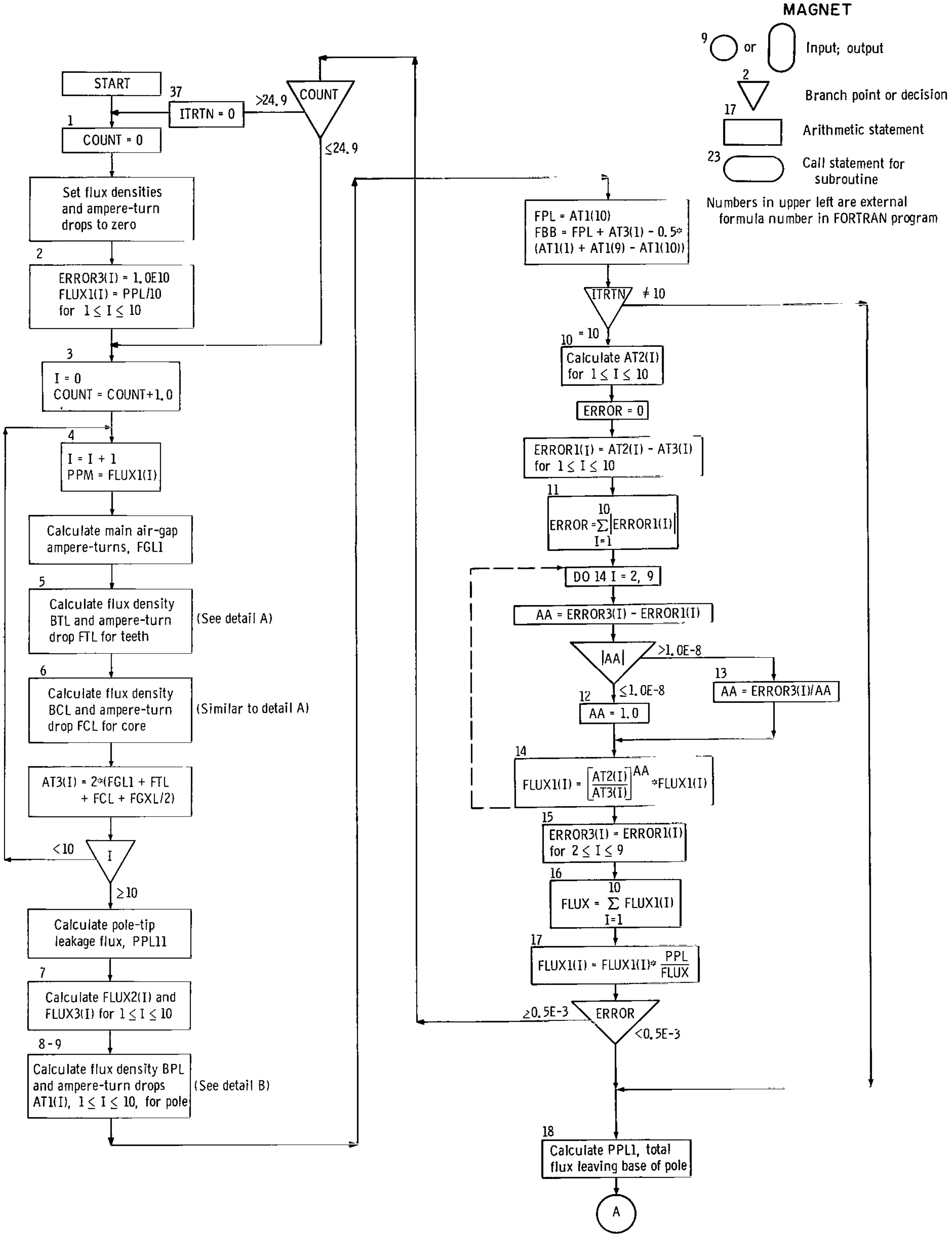
OUTPUT

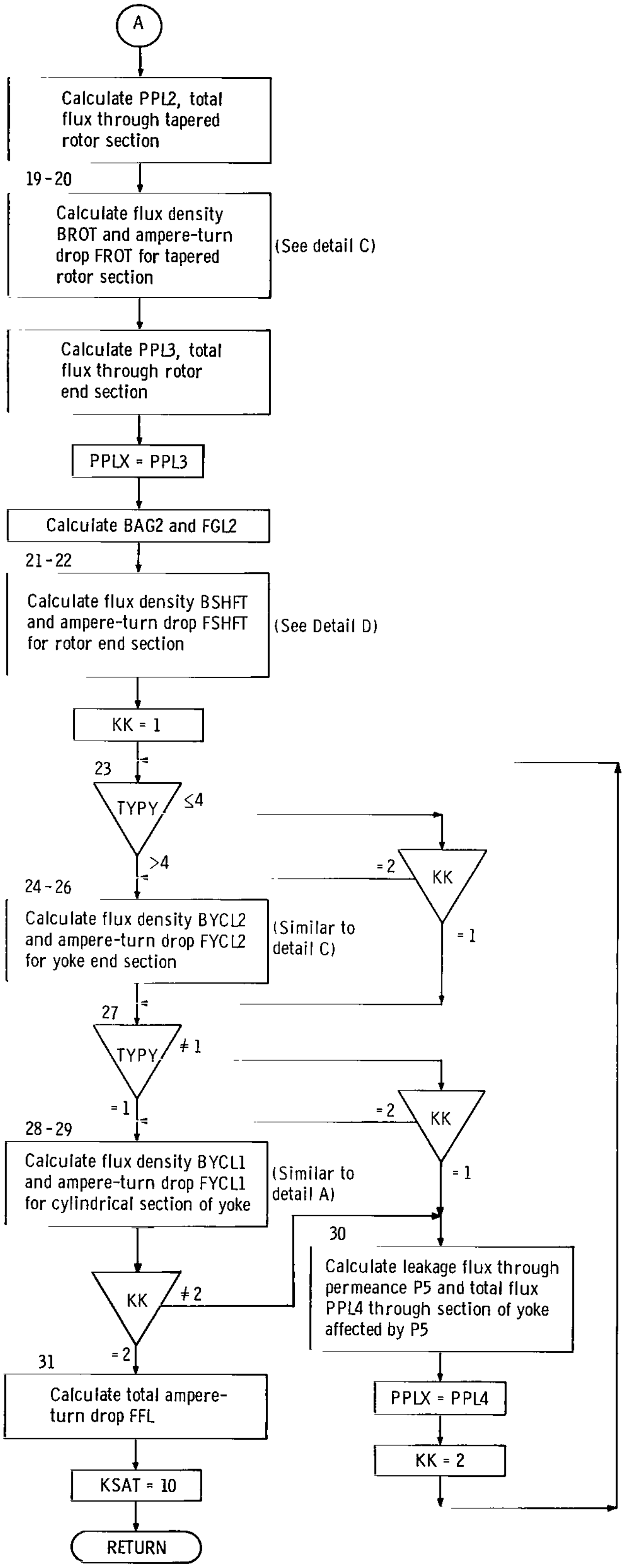
```
$IBFTC LUNDL3
      SUBROUTINE MAGNET
C
      COMMON /COM3/ ACORE,AI,ASHFT,ATOOTH,AYK1,BAG2,BCL,BPL,BROT,BSHFT,B
     1TL,BYCL1,BYCL2,DCORE,DSHMID,DYK1,DYK2,FCL,FFL,FGL1,FGL2,FGXL,FPL,F
     2ROT,FSHFT,FTL,FYCL1,FYCL2,KSAT,PAA,ITRTN
      COMMON /COM5/ AA,AG2,CL,CP,DY2,DY3,HS,LG2,P1,P10,P5,P6,P7,P8,P9,PA
     12,PPL,PPL1,PPL2,PPL3,PPL4,PX,TY2,TY3,TYPY
C
      INTEGER TYPY
C
      REAL LG2
C
      DIMENSION AI(90), PAA(10), AT1(10), AT2(10), AT3(10), FLUX1(10), F
     1LUX2(10), FLUX3(10), ERROR1(10), ERROR3(10)
C
1     COUNT=0.
      BYCL1=0.
      BYCL2=0.
      BPL=0.
      BTL=0.
      BCL=0.
      FFL=0.
      FYCL1=0.
      FYCL2=0.
      FPL=0.
      FCL=0.
      BROT=0
      FROT=0
      BSHFT=0.
      FSHFT=0.
      FTL=0.
      DO 2 I=1,10
      ERROR3(I)=1.0E10
2     FLUX1(I)=PPL/10.
C
3     I=0
      COUNT=COUNT+1.0
4     I=I+1
      PPM=FLUX1(I)
C
C     CALCULATE MAIN AIR-GAP AMPERE-TURNS
C
      FGL1=(((PPM/CP)*PX)/P8)*1.0E4
C
C     FLUX DENSITY AND AMPERE-TURNS FOR TEETH
C
      BTL=(PPM/ATOOTH)*10.
      X=BTL
      NA=1
      K=1
```

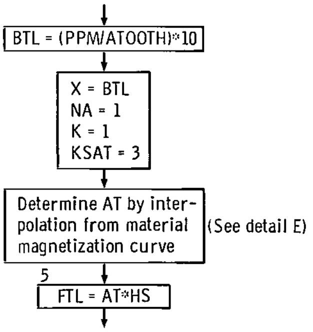
```
      KSAT=3
      GO TO 32
5     FTL=AT*HS
C
C     FLUX DENSITY AND AMPERE-TURNS FOR CORE
C
      BCL=(PPM/(ACORE*2.))*10.
      X=BCL
      NA=1
      KSAT=4
      K=2
      GO TO 32
6     FCL=AT*DCORE
C
      AT3(1)=(FGL1+FTL+FCL+FGXL/2.)*2.
      IF (I.LT.10) GO TO 4
C
C     POLE-TIP LEAKAGE FLUX
C
      PPL11=AT3(1)*0.001*P1
      DO 7 I=1,10
      FLUX2(I)=AT3(I)*P10*0.0001
      IF (I.EQ.1) FLUX3(1)=PPL11+(FLUX1(1)+FLUX2(1))/2.
7     IF (I.GT.1) FLUX3(I)=FLUX3(I-1)+(FLUX1(I-1)+FLUX2(I-1)+FLUX1(I)+F
     1UX2(I))/2.
C
C     FLUX DENSITIES AND AMPERE TURNS FOR POLE
C
      K=3
      KSAT=5
      BPL=0.
      I=0
8     I=I+1
      NA=31
      X=FLUX3(I)/PAA(I)
      BPL=AMAX1(BPL,X)
      GO TO 32
9     AT1(I)=AT*CL/10.
      IF (I.GT.1) AT1(I)=AT1(I)+AT1(I-1)
      IF (I.LT.10) GO TO 8
      FPL=AT1(10)
      FBB=FPL+AT3(1)-0.5*(AT1(1)+AT1(9)-AT1(10))
      IF (ITRTN.NE.10) GO TO 18
      DO 10 I=1,10
      II=11-I
      AT2(I)=FBB-2.*FPL+0.5*(AT1(I)+AT1(II))
      IF (I.NE.10) AT2(I)=AT2(I)+(AT1(II-1))*0.5
10    IF (I.NE.1) AT2(I)=AT2(I)+(AT1(I-1))*0.5
C
      ERROR=0.
      DO 11 I=1,10
      ERROR1(I)=AT2(I)-AT3(I)
11    ERROR=ERROR+ABS(ERROR1(I))
      DO 14 I=2,9
      AA=ERROR3(I)-ERROR1(I)
      IF (ABS(AA)-1.0E-8) 12,12,13
```

```
12    AA=1.0
      GO TO 14
13    AA=ERROR3(I)/AA
14    FLUX1(I)=((AT2(I)/AT3(I))**(AA))*FLUX1(I)
      DO 15 I=2,9
15    ERROR3(I)=ERROR1(I)
      FLUX=0.
      DO 16 I=1,10
16    FLUX=FLUX+FLUX1(I)
      DO 17 I=1,10
17    FLUX1(I)=(FLUX1(I))*(PPL/FLUX)
      IF (ERROR.LT.0.5E-3) GO TO 18
      IF (COUNT.LE.24.9) GO TO 3
      ITRTN=0
      GO TO 1
18    PPL1=FLUX3(10)+(FLUX1(10)+FLUX2(10))/2.
C
C     TOTAL FLUX THROUGH TAPERED ROTOR SECTION
C
      PPL2=(PPL1*PX/2.)+(AT3(1)/2.)*(0.001)*(P7)+PPL11*(PX/2.)
C
C     FLUX DENSITY AND AMPERE-TURNS FOR TAPERED SECTION OF ROTOR
C
      K=7
      DN=-0.05
      KSAT=2
      ARMID=PA2*(PX/2.)
19    DN=DN+0.1
      NA=31
      AREA=ARMID-((ARMID-ASHFT)*DN)
      X=(PPL2)/(AREA)
      BROT=AMAX1(X,BROT)
      GO TO 32
20    FROT=FROT+AT*DSHMID/10.
      IF (DN.LT.0.9) GO TO 19
C
C     TOTAL FLUX THROUGH ROTOR END SECTION
C
      PPL3=PPL2+(FBB+2.*FROT)*P6*0.001
      PPLX=PPL3
C
C     FLUX DENSITY AND AMPERE-TURNS FOR AUXILIARY AIR-GAP
C
      BAG2=PPL3/AG2
      FGL2=PPL3/(P9*0.001)
C
C     FLUX DENSITY AND AMPERE-TURNS FOR ROTOR END SECTION
C
      K=6
      DN=-0.05
      KSAT=1
21    DN=DN+0.1
      NA=31
      X=PPL3*DN
      X=X/ASHFT
      BSHFT=AMAX1(X,BSHFT)
```

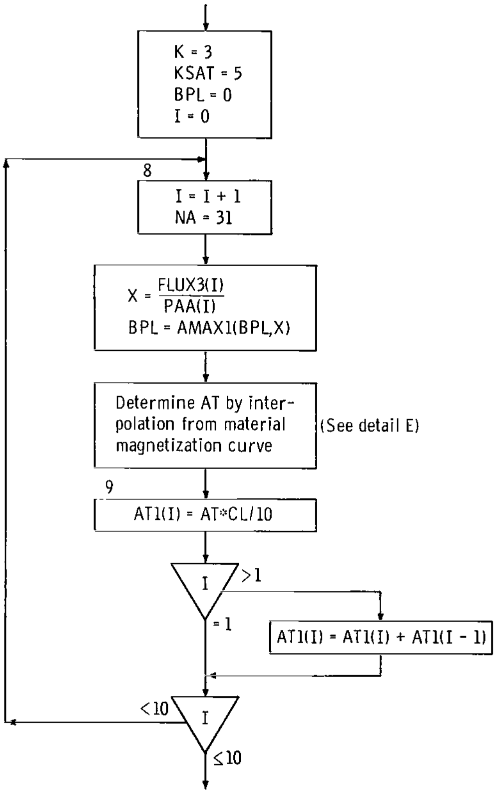
```
      GO TO 32
22    FSHFT=FSHFT+AT*LG2/10.
      IF (DN.LT.0.90) GO TO 21
C
C     FLUX DENSITIES AND AMPERE-TURNS FOR END SECTION OF YOKE
C
      KK=1
23    IF (TYPY.LE.4) GO TO (27,24),KK
24    DN=-0.05
      KSAT=6
      K=4
      DYK2=(DY3-DY2)/20.
25    DN=DN+0.1
      AREA=3.1416*(DY2+(20.*DYK2*DN))
      AREA=AREA*(TY3+((TY2-TY3)*(1.0-DN)))
      X=PPLX/AREA
      BYCL2=AMAX1(X,BYCL2)
      NA=61
      GO TO 32
26    FYCL2=AT*(DYK2)+FYCL2
      IF (DN.LT.0.9) GO TO 25
C
C     FLUX DENSITY AND AMPERE-TURNS FOR CYLINDRICAL PORTION OF YOKE
C
27    IF (TYPY.NE.1) GO TO (30,28),KK
28    BYCL1=PPLX/AYK1
      X=BYCL1
      NA=61
      KSAT=7
      K=5
      GO TO 32
29    FYCL1=AT*DYK1
      IF (KK.EQ.2) GO TO 31
C
C     FLUX THROUGH SECTION OF YOKE AFFECTED BY PERMEANCE P5
C
30    AT=FBB+FGL2+FSHFT+FROT
      IF (TYPY.GT.4) AT=AT+FYCL2
      IF (TYPY.EQ.6) AT=2.*AT
      IF (TYPY.EQ.1) AT=AT+FYCL1
      PPL4=AT*P5*0.001+PPL3
      PPLX=PPL4
      KK=2
      GO TO 23
C
C     TOTAL AMPERE-TURNS
C
31    FFL=(FYCL2+FBB/2.+FGL2+FYCL1+FSHFT+FROT)*2.
      KSAT=10
      RETURN
C
C     INTERPOLATION PROCEDURE FOR MATERIAL CURVES
C
32    IF (AI(NA).LT.X) GO TO 36
      NA=NA+3
33    IF (AI(NA)-X) 34,35,35
34    NA=NA+2
      GO TO 33
35    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 (5,6,9,26,29,22,20),K
36    IF (ITRTN.EQ.0) RETURN
      IF (KSAT.LT.3.OR.KSAT.GT.5) RETURN
      ITRTN=0
      GO TO 1
      END
```


MAGNET
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
37
ITRTN = 0
>24.9
COUNT
≤24.9
1
COUNT = 0
Set flux densities and ampere-turn drops to zero
2
ERROR3(I) = 1.0E10
FLUX1(I) = PPL/10
for 1 ≤ I ≤ 10
3
I = 0
COUNT = COUNT+1.0
4
I = I + 1
PPM = FLUX1(I)
Calculate main air-gap ampere-turns, FGL1
5
Calculate flux density BTL and ampere-turn drop FTL for teeth
(See detail A)
6
Calculate flux density BCL and ampere-turn drop FCL for core
(Similar to detail A)
AT3(I) = 2*(FGL1 + FTL + FCL + FGXL/2)
<10
I
≥10
Calculate pole-tip leakage flux, PPL11
7
Calculate FLUX2(I) and FLUX3(I) for 1 ≤ I ≤ 10
8-9
Calculate flux density BPL and ampere-turn drops AT1(I), 1 ≤ I ≤ 10, for pole
(See detail B)
FPL = AT1(10)
FBB = FPL + AT3(1) - 0.5*(AT1(1) + AT1(9) - AT1(10))
ITRTN
≠ 10
= 10
10
Calculate AT2(I) for 1 ≤ I ≤ 10
ERROR = 0
ERROR1(I) = AT2(I) - AT3(I) for 1 ≤ I ≤ 10
11
ERROR = $\sum_{I=1}^{10} |ERROR1(I)|$
DO 14 I = 2, 9
AA = ERROR3(I) - ERROR1(I)
|AA|
>1.0E-8
≤1.0E-8
12
AA = 1.0
13
AA = ERROR3(I)/AA
14
FLUX1(I) = $\left[\frac{AT2(I)}{AT3(I)}\right]^{AA}$ *FLUX1(I)
15
ERROR3(I) = ERROR1(I) for 2 ≤ I ≤ 9
16
FLUX = $\sum_{I=1}^{10}$ FLUX1(I)
17
FLUX1(I) = FLUX1(I)* $\frac{PPL}{FLUX}$
≥0.5E-3
ERROR
<0.5E-3
18
Calculate PPL1, total flux leaving base of pole
A

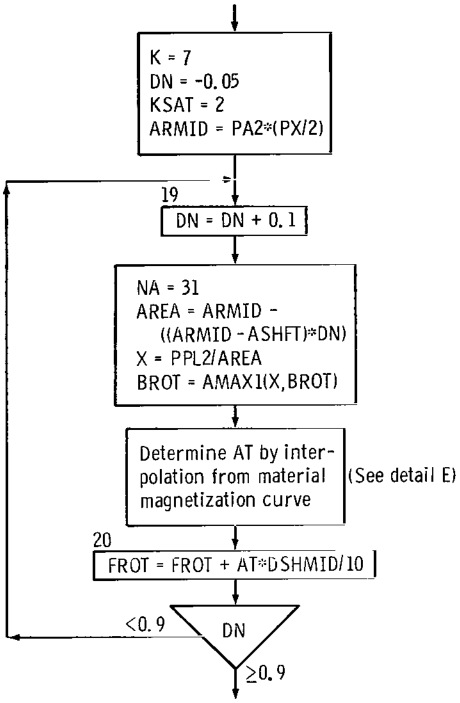




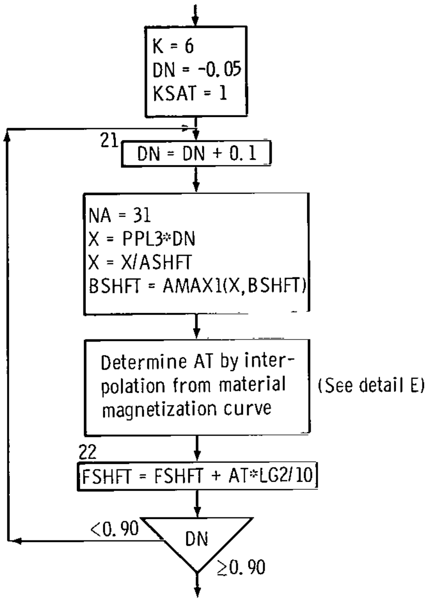
Detail A



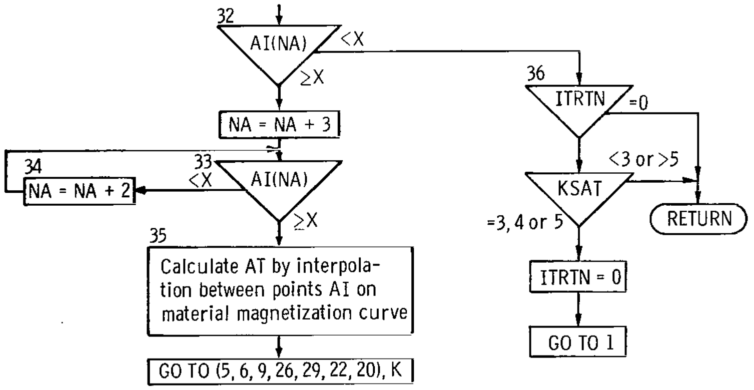
Detail B



Detail C

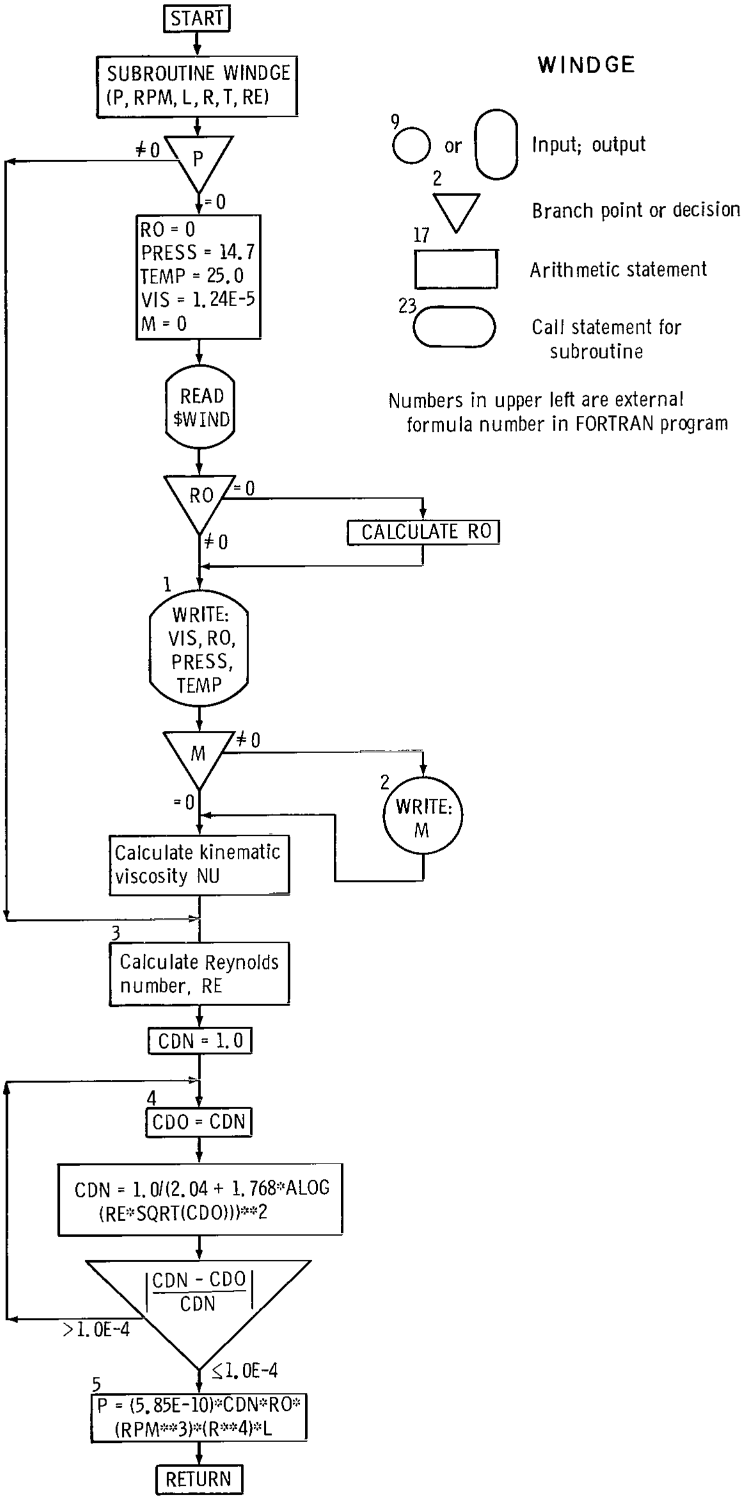


Detail D



Detail E

```
      SUBROUTINE WINDGE (P,RPM,L,R,T,RE)
C
      REAL L,NU,M
C
      NAMELIST /WIND/ RO,VIS,PRESS,M,TEMP
C
      IF (P.NE.0.) GO TO 3
      RO=0.0
      PRESS=14.7
      TEMP=25.
      VIS=1.24E-5
      M=0.
      READ (5,WIND)
      IF (RO.EQ.0.0) RO=(PRESS*M*5.16E-02)/(TEMP+273.0)
      WRITE (6,1) VIS,RO,PRESS,TEMP
      IF (M.NE.0.) WRITE (6,2) M
1     FORMAT (1HL,8H WINDAGE//10X,17H FLUID PROPERTIES/13X,10H VISCOSITY
     1,1PE25.3,11H LBS/SEC-FT/13X,8H DENSITY,F24.4,11H LBS/CU.FT./13X,9H
     2 PRESSURE,0PF21.2,11H LBS/SQ. IN/13X,12H TEMPERATURE,F18.2,7H DEG.
     3 C)
2     FORMAT (1H ,12X,17H MOLECULAR WEIGHT,F12.1)
      NU=(VIS/RO)*144.0
3     RE=3.14159*R*T*RPM/(30.0*NU)
      CDN=1.0
4     CDO=CDN
      CDN=1.0/(2.04+1.768*ALOG(RE*SQRT(CDO)))**2
      IF (ABS(CDN-CDO)/CDN.LE.1.0E-04) GO TO 5
      GO TO 4
5     P=(5.85E-10)*CDN*RO*(RPM**3)*(R**4)*L
      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 (P, RPM, L, R, T, RE)
P
≠0
= 0
RO = 0
PRESS = 14.7
TEMP = 25.0
VIS = 1.24E-5
M = 0
READ $WIND
RO
= 0
≠0
CALCULATE RO
1
WRITE: VIS, RO, PRESS, TEMP
M
≠0
= 0
2
WRITE: M
Calculate kinematic viscosity NU
3
Calculate Reynolds number, RE
CDN = 1.0
4
CDO = CDN
CDN = 1.0/(2.04 + 1.768*ALOG (RE*SQRT(CDO)))**2
|CDN - CDO / CDN|
>1.0E-4
≤1.0E-4
5
P = (5.85E-10)*CDN*RO* (RPM**3)*(R**4)*L
RETURN

APPENDIX D

DEFINITION OF FORTRAN VARIABLES

Following are two alphabetic lists of nearly all FORTRAN variables used in the program. The first list gives the variables used in LUNDEL, SUBLUN, OUTPUT, and MAGNET. The second list gives the variables used in WINDGE. Each variable is defined and the units used in the program for each variable are given. Variables that are subscripted (dimensioned) or that are permissible program input are identified by a + or *, respectively.

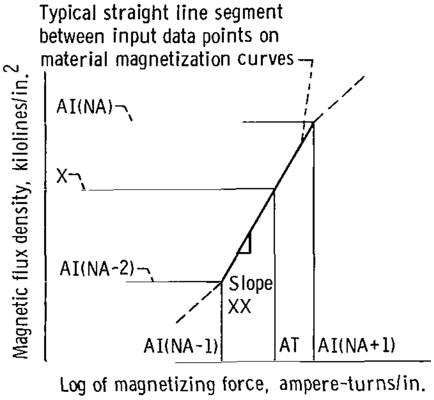


Figure 27. - Variables used in interpolation between points on magnetization curves.

FORTRAN SYMBOLS USED IN LUNDEL, SUBLUN, OUTPUT, AND MAGNET

	A	ampere conductors per inch of stator periphery, A/in.
	AA	dummy variable used for variety of calculations
	AB	dummy variable used for variety of calculations
	AC	armature conductor area, in.^2
	ACORE	core cross-sectional area used in magnetic calculations, in.^2
	AG2	auxiliary air-gap area, in.^2
*+	AI	coordinates of points on material magnetization curves (see figs. 20 and 27)
	AIRGAP	NAMELIST name

+	AKVA	alternator output at load point G, kVA
*	ALPHAR	temperature coefficient of RR, $^{\circ}C^{-1}$
*	ALPHAS	temperature coefficient of RS, $^{\circ}C^{-1}$
	AN	power factor angle (see fig. 7), rad
	AREA	dummy variable (generally an area)
	ARMID	=PA2*(PX/2.), in.^{2}
	AS	field conductor area, in.^{2}
	ASHFT	cross-sectional area of rotor under auxiliary air gap, in.^{2}
	AT	ampere-turns per inch at flux density X for magnetic materials (see fig. 27), A-turn/in.
+	AT1	ampere-turn drop from pole tip to i^{th} pole segment (see fig. 9), A-turns
+	AT2	ampere-turn drop across teeth, core, and main air gap, A-turn
+	AT3	ampere-turn drop across teeth, core, and main air gap, A-turn
	ATOOTH	tooth area used in magnetic calculations, in.^{2}
	AYK1	yoke area used in magnetic calculations, in.^{2}
	B1	stator slot dimension (see fig. 21), in.
	B2	stator slot dimension (see fig. 21), in.
*	B3	stator slot dimension (see fig. 21), in.
	BAG2	auxiliary air-gap flux density, kilolines/in.^{2}
	BB	displacement angle (see fig. 7), rad
	BB	dummy variable
	BCL	core flux density, kilolines/in.^{2}
+	BCLL	core flux density, kilolines/in.^{2}
*	BCOIL	field coil width, in.
	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}
*	BO	stator slot dimension (see fig. 21), in.
	BPL	pole flux density, kilolines/in.^{2}
+	BPLL	pole flux density, kilolines/in.^{2}

	BROT	flux density in tapered section of rotor, kilolines/in.^{2}
+	BROTL	flux density in tapered section of rotor, kilolines/in.^{2}
*	BS	stator slot dimension (see fig. 21), in.
	BSHFT	shaft flux density (under auxiliary air gap), kilolines/in.^{2}
+	BSHFTL	shaft flux density (under auxiliary air gap), kilolines/in.^{2}
	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.
	BYCL1	yoke flux density (cylindrical section), kilolines/in.^{2}
	BYCL2	yoke flux density (end section), kilolines/in.^{2}
+	BYCLL1	yoke flux density (cylindrical section), kilolines/in.^{2}
+	BYCLL2	yoke flux density (end section), kilolines/in.^{2}
*	C	number of parallel armature circuits per phase
*	C1	ratio of fundamental to actual value of field form
	CC	Carter coefficient
+	CDD	current density in field winding, A/in.^{2}
*	CE	straight portion of coil extension, 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 for saturation message print-out
	COM1	COMMON block name
	COM2	COMMON block name
	COM3	COMMON block name
	COM4	COMMON block name
	COM5	COMMON block name
	COUNT	counts number of iteration cycles in MAGNET

*	CP	ratio of average to maximum value of field form
*	CQ	cross-magnetizing factor (quadrature axis)
	CS	per unit pole pitch
	CW	winding constant
	CX	dummy variable used in slot leakage permeance calculation
	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 conductor, 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, in.^{2}
+	DASH	used in OUTPUT to draw diagrams
	DB	diameter of bender pin for forming armature coils, in.
*	DCOIL	field coil outside diameter, in.
	DCORE	core length used in magnetic calculations, in.
	DF	distribution factor
	DG	maximum dimension of rectangular conductor, in.
*	DI	stator inside diameter, in.
*	DISH	shaft inside diameter (of hollow shaft) (see fig. 23), in.
*	DISH1	rotor diameter under auxiliary air gap (see fig. 23), in.
	DN	used in magnetic calculation for rotor and yoke
	DR	rotor diameter at main air gap (see fig. 23), in.
	DSHMID	(SHL2-CL)/2. (see fig. 23), in.
	DT	minimum dimension of rectangular conductor, in.

*	DU	stator outside diameter, in.
*	DW	armature strand diameter or width (see fig. 24), in.
*	DW1	armature strand thickness (uninsulated) (see fig. 24), in.
+	DX	used in rectangular conductor area calculation, in.^{2}
+	DY	used in rectangular conductor area calculation, in.^{2}
	DY2	yoke dimension (see fig. 22), in.
	DY3	yoke dimension (see fig. 22), in.
*	DYC	yoke outside diameter (see fig. 22), in.
	DYK1	yoke dimension used in magnetic calculations, in.
	DYK2	1/10 of yoke end section length (see fig. 22), in.
+	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, V dc
	EK	leakage reactive factor for stator end turns
*	EL	end extension length of armature coil, in.
*	EP	line-to-neutral rated alternator voltage, V rms
	ERROR	ERROR1(1)+ERROR1(2)+ . . . +ERROR(10), A-turn
+	ERROR1	error in interation of air-gap flux distribution, A-turn
+	ERROR3	values of ERROR1 from pervious iteration step, A-turn
	ET	eddy factor (top)
	EW	specific stator end winding leakage permeance, lines/A-turn
+	EX	eddy loss, W
+	EZ	eddy factor (average)
*	F	frequency, Hz

	FACTOR	dummy variable in slot leakage permeance calculations
	FBB	ampere-turn drop from pole base to pole base, A-turn
	FCL	core ampere turns, A-turn
+	FCLL	core ampere turns, A-turn
	FE	mean length of one field coil turn, in.
	FF	dummy variable in slot leakage permeance calculation
	FFL	total ampere turns, A-turn
+	FFLL	total ampere turns, A-turn
	FG1	main air-gap ampere-turn drop (uniform flux distribution), A-turn
	FG2	auxiliary air-gap ampere-turn drop (negligible leakage flux), A-turn
	FGL1	main air-gap ampere turns, A-turn
	FGL2	auxiliary air-gap ampere turns, A-turn
+	FGLL1	main air-gap ampere turns, A-turn
+	FGLL2	auxiliary air-gap ampere turns, A-turn
	FGML	demagnetizing ampere-turns per pole at rated load, A-turn
	FGXL	demagnetizing ampere-turns at load G (see table III), A-turn
	FH	air-gap ampere-turns at no-load rated voltage, A-turn
+	FI	field current, A
	FIELD	NAMELIST name
	FIMM	field current at rated load, A
	FK1	field winding resistance at temperature TF, ohm
	FLUX	total air-gap flux after calculation new flux distribution, kilolines
+	FLUX1	useful air-gap flux distribution (see fig. 9), kilolines
+	FLUX2	flux through rotor leakage permeance P10 (see fig. 9), kilolines
+	FLUX3	flux at center of each of 10 pole segments (see fig. 9), kilolines
	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
	FROT	ampere-turn drop across tapered rotor section, A-turn
+	FROTL	ampere-turn drop across tapered rotor section, A-turn
	FS	skew factor
	FSC	short-circuit ampere turns for rated armature current, A-turn
	FSHFT	ampere turn drop across rotor end section, A-turn
+	FSHFTL	ampere turns across portion of shaft under auxiliary air gap, A-turn
	FTL	tooth ampere turns, A-turn
+	FTLL	tooth ampere turns, A-turn
	FYCL1	yoke (cylindrical section) ampere turns, A-turn
	FYCL2	yoke (end section) ampere turns, A-turn
+	FYCLL1	yoke (cylindrical section) ampere turns, A-turn
+	FYCLL2	yoke (end section) ampere turns, A-turn
*+	G	volt-ampere alternator output at which load characteristics are calculated, per unit or percent
*	G2	auxiliary air gap (radial length) (see fig. 23), in.
	GA	main air-gap area, in.^{2}
*	GAMMAR	density of nonmagnetic rotor material, lb/in.^{3}
*	GC	main air gap (radial length) (see fig. 23), in.
	GE	effective main air gap, in.
	GF	constant used in load pole-face loss calculation
	GT	ratio of slot opening width to main air gap
	GXX	flux per pole multiplying factor (see fig. 7)
	HC	stator depth below slot, in.
	HM	armature conductor length (=1/2 coil length), in.
*	HO	stator slot dimension (see fig. 21), in.
*	HS	stator slot dimension (see fig. 21), in.
*	HT	stator slot dimension (see fig. 21), in.

*	HV	number of stator cooling ducts
	HW	stator slot dimension (see fig. 21), in.
*	HX	stator slot dimension (see fig. 21), in.
*	HY	stator slot dimension (see fig. 21), in.
	IDELR	increment by which QPERV is increased, percent
	IDM	(Integer) * (Number of poles) * (Number of phases)
	IIQQ	used to calculate DF for fractional slot winding
	IPN	number of phases
*	IPX	number of poles
*	IQQ	number of stator slots
	ITRTN	if ITRTN ≠ 10 uniform air-gap flux distribution was assumed
	IZY	(Number of poles) * (Number of phases)
	IZZ	type of stator slot (see fig. 21)
	JA	number of load calculations made before alternator saturated
	KSAT	saturation indicator (if KSAT ≠ 10 alternator is saturated)
*	LG2	auxiliary air-gap length (axial direction) (see fig. 23), in.
*	LTS	stator lamination thickness, in.
	LUNDEL	main program name
	MAGNET	subroutine name
	MM	subscript of load point G such that G(MM) = 1.0
	NFC	number of field coils
	NPF	number of power factors for which load calculations are made
	OUTPUT	subroutine name
*	P1	pole tip leakage permeance (see fig. 6), lines/A-turn
*	P10	leakage permeance = 2. * (P3 + P2 + P4), lines/A-turn
*	P2	leakage permeance (see fig. 6), lines/A-turn
*	P3	leakage permeance (see fig. 6), lines/A-turn
*	P4	leakage permeance (see fig. 6), lines/A-turn
*	P5	leakage permeance (see figs. 5 and 8), lines/A-turn

*	P6	leakage permeance (see fig. 6), lines/A-turn
*	P7	leakage permeance (see figs. 5 and 8), lines/A-turn
	P8	main air-gap permeance, lines/A-turn
	P9	auxiliary air-gap permeance, lines/A-turn
*+	PA	area at ends of each of 10 pole segments (see fig. 23), in.^2
*	PA1	pole area at tip of pole (see fig. 23), in.^2
*	PA2	pole area at base of pole (see fig. 23), in.^2
+	PAA	area at center of each of 10 pole segments, in.^2
*	PBA	phase belt angle, deg
	PC	specific stator slot winding leakage permeance, lines/A-turn
*	PCOIL	field coil inside diameter, in.
*	PE	pole embrace
	PERMCE	NAMELIST name
	PF	design power factor
	PF	power factor at which load characteristics are calculated
*+	PFC	power factors at which load characteristics are calculated
	PHW	average pole width, in.
	PI	rated line current, A
*	PL	pole length (see fig. 23), in.
	PN	number of phases
	POL	dummy variable
+	PP	pole-face losses, W
	PPL	flux per pole in main air gap, core, and teeth, kilolines
	PPL1	total flux leaving base of pole (see figs. 8 to 10), kilolines
	PPL11	pole-tip leakage flux through permeance P1 (see figs. 9 and 10), kilolines
	PPL2	flux in tapered rotor section (see fig. 10), kilolines
	PPL3	flux in rotor end section, auxiliary air gap and yoke (see fig. 10), kilolines
	PPL4	flux in yoke including leakage through P5, kilolines

	PPLX	dummy variable (PPLX = PPL3 or PPLX = PPL4), kilolines
	PPM	=FLUX1(I)
+	PR	field losses, W
+	PS	stator copper loss, W
*	PT	number of field turns per field coil
*	PT1	pole thickness at pole tip (see fig. 23), in.
*	PT2	pole thickness at pole base (see fig. 23), in.
*	PW1	pole width at pole tip (see fig. 23), in.
*	PW2	pole width at pole base (see fig. 23), in.
	PX	number of poles
	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
	RATING	NAMELIST name
	RB	resistivity of stator conductor at temperature TTA, μohm-in.
	RC	field coil weight, lb
*	RD	field conductor diameter or width, in.
	RE1	Reynolds number for main air gap
	RE2	Reynolds number in auxiliary air gap
*	RF	type of stator winding (random or form wound)
	RG1	stator winding resistance at temperature TST, ohms
*+	RMAT	rotor material name
	ROTOR	NAMELIST name
*	RPM	rotor speed, rpm
*	RR	field coil resistivity at 20° C, μohm-in.
+	RRA	armature resistance, ohm
+	RRB	field coil resistance of NFC coils in series, ohms

*	RS	stator conductor resistivity at 20° C, μohm-in.
*	RT	field conductor thickness, in.
	RY	RRA(J)/RB, μin.$^{-1}$
	S	armature current density at rated load, A/in.^{2}
*	SC	number of conductors per stator slot
	SCR	short circuit ratio
*	SF	distance between centerlines of stator strands (depth) (see fig. 24), in.
*	SF	stator stacking factor
	SH	uninsulated strand height, in.
*	SHL1	shaft length (see fig. 23), in.
*	SHL2	shaft length (see fig. 23), 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 stator conductor in depth
*	SN1	total strands per stator conductor
+	SP	total losses, W
	SPS	special permeance (see ref. 2), lines/A-turn
	SS	solid stator stack length, in.
+	ST	stator tooth loss, W
+	STAR	used in subroutine OUTPUT to draw diagram
	STATET	number of effective aramature winding turns
	STATOR	NAMELIST name
	SUBLUN	subroutine name
*	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, °C
	TC	open-circuit time constant (field only), sec
*	TF	field coil temperature at which FK1 and TC are calculated, °C
	TG	total air-gap flux at no-load rated voltage, kilolines
	TP	pole pitch, in.
	TS	stator slot pitch at stator inside diameter, in.
*	TST	armature winding temperature at which RG1 is calculated, °C
	TT	stator slot pitch at 1/3 distance from narrow section, in.
+	TTA	armature winding temperature, °C
+	TTB	field winding temperature, °C
*	TY	yoke dimension (see fig. 22), in.
*	TY2	yoke dimension (see fig. 22), in.
*	TY3	yoke dimension (see fig. 22), in.
*	TYE	yoke dimension (see fig. 22), in.
*	TYL	yoke dimension (see fig. 22), in.
*	TYPY	field coil location code (see fig. 8)
*	TYR	yoke dimension (see fig. 22), in.
	U	used to calculate end extension length
	UA	=G(M), per unit
*	VA	rating of alternator, kVA
*	VMIN	minimum voltage at which no-load saturation curve is calculated, per unit
	VR	rotor peripheral velocity at main air gap, ft/min
	VV	rating of alternator, W
+	WA	alternator output power, kW
	WC	armature winding weight (copper only), lb
*	WF	total windage loss, W
	WF1	windage loss in main air gap, W
	WF2	windage loss in auxiliary air gap, W
	WI	stator iron weight, lb

	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
	WQ	no-load rated-voltage core loss, W
+	WQL	core loss, W
*	WROTOR	rotor weight, lb
	WT	no-load rated-voltage tooth loss, W
	WTOTAL	total electromagnetic weight, lb
*	WYOKE	yoke weight, lb
	X	flux density at which AT is found by interpolation (see fig. 27), kilolines/in.^{2}
	XA	synchronous reactance (direct), percent
	XB	synchronous reactance (quadrature), percent
	XD	armature reaction reactance (direct), percent
	XF	field winding leakage reactance, percent
	XI	angle between line current phasor and D-axis (internal power factor angle) (see fig. 7), rad
	XL	stator winding leakage reactance, percent
	XQ	armature reaction reactance (quadrature), percent
	XR	reactance factor
	XU	transient reactance (direct), percent
	XX	slope of magnetization curve at flux density X (see fig. 27)
	Y	used in interpolation procedure of material curves
*+	YMAT	yoke material name
	YOKE	NAMELIST name
*	YY	slots spannd per coil (=No. of slots between coil sides + 1)
	Z	dummy variable used in slot leakage permeance calculation

	ZA	dummy variable used in slot leakage permeance calculation
	ZB	dummy variable used in slot leakage permeance calculation
	ZC	dummy variable used in slot leakage permeance calculation
	ZD	dummy variable used in slot leakage permeance calculation
	ZE	dummy variable used in slot leakage permeance calculation
	ZF	dummy variable used in slot leakage permeance calculation
	ZG	(length of field winding conductor)/(field conductor area), in.$^{-1}$
	ZY	0.7 * HS, in.
	ZY	used as an index in armature and field conductor area calculations
*	ZZ	type of slot (see fig. 21)

FORTRAN VARIABLES USED IN WINDGE

	CDN	skin friction coefficient (new value in iteration)
	CDD	skin friction coefficient (old value in iteration)
	L	air-gap length (axial direction), in.
*	M	molecular weight of fluid in air gap
	NU	kinematic viscosity, in.^{2}/sec
	P	windage power loss, W
*	PRESS	pressure of gas in air gap, lb/in.^{2}
	R	radius of rotor at air gap, in.
	RE	Reynolds number
*	RO	density of gas in air gap at temperature TEMP and pressure PRESS, lb/ft^3
	RPM	rotor speed, rpm
	T	air-gap length (radial direction), in.
*	TEMP	temperature of gas in air gap, ^{o}C

*	VIS	fluid viscosity, lb/ft-sec
	WIND	NAMELIST name
	WINDGE	subroutine name

APPENDIX E

ROTOR LEAKAGE PERMEANCE MEASUREMENT

The permeance $\mathscr{P}$ of a section of flux path is defined as the ratio

$$\mathscr{P} = \frac{\varphi}{Ni}$$

where φ is the flux through the section of the flux path under consideration and Ni is the ampere-turn drop across the same flux path section.

In a Lundell alternator, a permeance that is of particular interest is the rotor leakage permeance ($\mathscr{P}_{RL}$). This is the permeance of the path followed by the flux that goes from one rotor half to the other without entering the stator. This flux is termed leakage flux in that it bypasses the armature and therefore does not generate a voltage in the armature winding. The magnitude of the rotor leakage permeance $\mathscr{P}_{RL}$ has a large effect on the calculation of field excitation requirements. In the evaluation of the com-

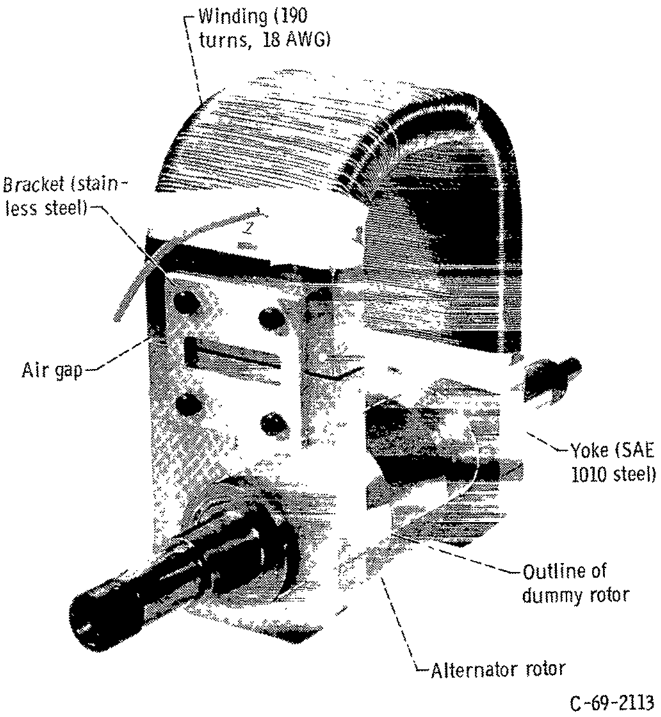


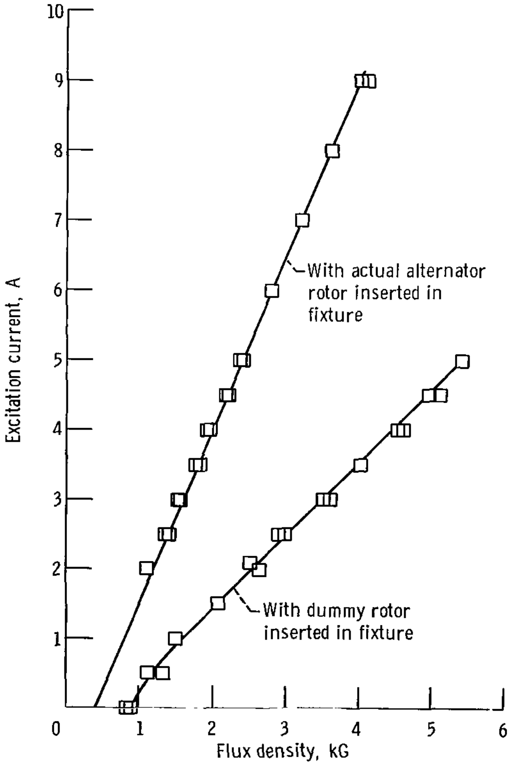
Figure 28. - Rotor leakage permeance measuring fixture.

puter program accuracy, it was of some interest, therefore, that an accurate value be known.

To obtain an accurate value for $\mathscr{P}_{RL}$, a fixture was built which would allow measuring the leakage permeance of the rotor. This fixture, with the rotor inserted, is shown in figure 28. Essentially, the fixture establishes a well defined, low reluctance flux path from one end of the rotor to the other. The distributed winding around the yoke of the fixture provides a means of exciting the magnetic circuit, which consists of the yoke, an air gap, and the rotor in series. The purpose of the air gap is to allow a gaussmeter probe to be inserted into the magnetic circuit to measure flux densities within the yoke.

To obtain $\mathscr{P}_{RL}$ using this fixture, the ampere-turn drop across and the total flux through the nonmagnetic section of the rotor are measured. These values are then substituted into the basic definition of permeance.

The ampere-turn drop across the nonmagnetic rotor section is measured as follows. A dummy rotor made of solid SAE 1010 steel in the shape of a cylinder is inserted in the fixture in place of the actual rotor. The winding is then excited and a curve of excitation current against air gap flux density is obtained. This is the lower curve shown in figure 29. Essentially, this curve gives, at any given value of air gap flux density, the



With actual alternator rotor inserted in fixture

With dummy rotor inserted in fixture

Figure 29. - Experimental data used to obtain ampere-turn drop across nonmagnetic rotor section. Winding used to obtain these curves had 190 turns.

ampere-turn drop across the yoke, the air gap, and the magnetic rotor sections. A similar curve is then obtained with the actual alternator rotor inserted in the fixture. This is the upper curve shown in figure 29. At any value of air-gap flux density, the difference between the two curves gives the ampere-turn drop across the nonmagnetic section of the alternator rotor. For example, at the air-gap flux densities of 1.5 and 2.5 kilogauss, the ampere-turn drop across the rotor leakage permeance is 351 and 627, respectively.

The flux through the nonmagnetic rotor section is measured at the air-gap in the yoke. It consists of two components: the flux through the air-gap proper and the flux due to fringing around the air-gap. The flux in the air-gap proper is merely the product of the air-gap area (3.31 in.^{2}) and the flux density, which is constant throughout the air gap. The flux in the fringe pattern was obtained by measuring the flux density at many, regularly spaced grid points in an approximately 14-square-inch area surrounding the yoke at the air gap. The results of these measurements are as follows: at an air-gap flux density of 1.5 kilogauss, the total flux through the yoke is 38.9 kilolines; at 2.5 kilogauss air-gap flux density, the total yoke flux is 66.5 kilolines.

When these values, and the values for ampere-turn drop are substituted into the basic definition for permeance, the result is, for an air-gap flux density of 1.5 kilogauss,

$$\mathscr{P}_{RL} = \frac{38.9\times 10^3}{351} = 111 \text{ lines/ampere-turn}$$

or, for an air-gap flux density of 2.5 kilogauss,

$$\mathscr{P}_{RL} = \frac{66.5\times 10^3}{627} = 106 \text{ lines/ampere-turn}$$

The difference between the two values is within the experimental error and $\mathscr{P}_{RL}$ will be taken to be the average, that is, $\mathscr{P}_{RL} = 108$ lines per ampere-turn.

An assumption made in these calculations is that all the flux in the air gap of the fixture, including that due to fringing, passes through the nonmagnetic rotor section. This is, of course, not completely correct. Some of the flux leaks across the fixture without ever entering the rotor. Some additional flux leaks around the nonmagnetic material and into the space normally occupied by the stator. This flux, as regards the alternator, is not leakage flux. The import of this is that the measured value, obtained as described in this appendix, is higher than the actual rotor leakage permeance.

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