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FORTRAN PROGRAM FOR INDUCTION MOTOR ANALYSIS

Gary Bollenbacher

Lewis Research Center

Cleveland, Ohio 44135

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16. Abstract

A FORTRAN program for induction motor analysis is described. The analysis includes calculations of torque-speed characteristics, efficiency, losses, magnetic flux densities, weights, and various electrical parameters. The program is limited to three-phase Y-connected, squirrel-cage motors. Detailed instructions for using the program are given. The analysis equations are documented, and the sources of the equations are referenced. The appendixes include a FORTRAN symbol list, a complete explanation of input requirements, and a list of error messages.

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FORTRAN PROGRAM FOR INDUCTION MOTOR ANALYSIS

by Gary Bollenbacher

Lewis Research Center

SUMMARY

A FORTRAN program for the analysis of squirrel-cage induction motors is described. The analysis encompasses calculations of torque-speed characteristics, electrical characteristics, magnetic flux densities, weight, and various other parameters. Detailed instructions for use of the program are given. The analysis equations are documented, and the sources of the equations are referenced. The appendixes include a FORTRAN symbol list, a complete explanation of input requirements, and a list of error messages.

INTRODUCTION

A FORTRAN program that has been used at the Lewis Research Center to analyze the electromagnetic design of three-phase induction motors is described in this report. The analysis equations used throughout the program are those commonly found in the literature. It is the purpose of this report to document these equations, to cite the source references, to provide instructions for using the program, and to assist in interpreting program output. The report also provides information to facilitate program modification.

Specific information regarding the computer program is given in the appendixes: Appendix A gives the input requirements. A typical set of input data and the resultant output are shown in appendix B. Program listings, error messages, and FORTRAN symbol lists are provided by appendixes C, D, and E, respectively.

The input data and computer output shown in appendix B are for a 1200-hertz induction motor designed for the Brayton program. This motor, which operates with the cavity filled with oil, has been built and tested at the Lewis Research Center. Preliminary comparison of the test results with the computer program output shows the computer analysis to be very accurate.

The program described in this report uses only U.S. customary units. The International System of Units (SI) is used in the main text to conform to publishing requirements. For clarity in presenting the program, only U.S. customary units are used in the appendixes.

MOTOR TYPES SUITABLE FOR PROGRAM ANALYSIS

The program described in this report can be used to analyze only a three-phase induction motor with a squirrel-cage rotor winding. The analysis is limited to steady-state, balanced conditions with the motor operating in the motoring mode.

The armature is assumed to have a two-layer, Y-connected winding. The winding material may be either copper, aluminum, or brass.

The rotor stack is assumed to be the same axial length as the stator stack. Double squirrel-cage windings are not permitted. Materials for the rotor winding, as for the armature winding, may be either copper, aluminum, or brass. Deep rotor bars are permitted, but no correction is made in the analysis for nonuniform current distribution in the bars at high percentages of slip.

A cross-section of a typical induction motor assumed for this analysis is shown in figure 1. Rotor and stator slots may be open or partially closed; they may be rectangular, trapezoidal, round, or trapezoidal with a rounded bottom. If the slots are trapezoidal, the tooth width may be constant or the slot sides may diverge at any other specified angle.

The effects of windage on motor performance may be either omitted or included in the analysis. If they are to be included, the windage loss for a similar motor must be known. The program will then scale this known windage loss with respect to all pertinent parameters in order to approximate the windage loss of the motor under analysis. The scaling is unnecessary if windage loss at synchronous speed can be supplied to the program directly.

Thermal analysis is not a part of the program. Hence, winding temperatures must be calculated or estimated for input to the program.

PROGRAM DESCRIPTION

General Information

The computer program consists of a main program called INDMTR and five subroutines called CIRCT, MAGNET, SLOTS, WDGFCT, and CMBNTN. The program also calls a data-plotting subroutine PLOTXY (ref. 1), which is part of the Lewis subroutine library.

The main program INDMTR handles all input and output functions (with the exception of some error messages) and most of the calculations. Figure 2 shows a simplified flow chart of the main program and its subroutine usage. A brief description of each subroutine follows.

Subroutine CIRCT treats the induction motor as a two-terminal electrical circuit consisting of resistors and inductors (fig. 3). Analysis of the electrical circuit is equivalent to analysis of the motor and allows the determination of all motor performance parameters of interest. Subroutine CIRCT performs the necessary circuit analysis. The numerical values of the resistive and inductive circuit elements are calculated by the main program.

Subroutine MAGNET computes the flux densities in the stator and rotor back iron and in the stator and rotor teeth. It also computes the ampere-turn drops throughout the magnetic circuit. If any portion of the motor saturates, an indicator is set to alert the main program.

Subroutine SLOTS is called twice by the main program: once for the stator slots and once for the rotor slots. Its function is to compute all slot dimensions that are not input to the program but that are needed in subsequent calculations. SLOTS also computes slot areas and the slot permeance ratio.

Subroutine WDGFCT computes the distribution factor and pitch factor for the stator winding. It also checks that the winding specified is physically realizable; if it is not, an error message is printed.

Subroutine CMBNTN checks if the number of rotor slots, the number of stator slots, and the number of poles are mutually compatible. An incompatible combination is one that may result in noise or vibration problems or one that may cause undesirable torque-speed characteristics. If compatibility exists, control is returned to the main program; if not, the subroutine prints out an error message and lists the number of rotor slots that may be used instead.

The program is written in the FORTRAN IV programming language for use on the Lewis 7044-7094 direct-couple system. On this system, typical preexecution time, including compiling, is 80 seconds. Approximate execution time is 4.0 seconds for each motor analysis (more than one analysis may be performed with each computer run). The core storage requirement is approximately 13 000 (decimal) words.

Synopsis of Input Requirements

Program input consists of one or more data sets. Each data set contains three types of data:

(1) Magnetic materials data: These data consist of two material decks, one for the rotor and one for the stator. Each material deck contains magnetization curve data and core-loss data. The core-loss data may be omitted for the rotor material.

(2) Windage loss data: These data include a known windage loss at a known (reference) condition. The program scales the given windage loss from the reference condition to the motor design. A windage loss data card must be included with the input data, although windage data may be omitted.

(3) Motor design data: These data include all physical dimensions that affect the motor electromagnetic performance. Also included are the winding temperatures and the electrical rating, such as voltage and frequency. Any number of motor design data sets may follow the materials and windage data.

Material data decks must appear in pairs in the input stream. They must be followed by the windage data. Following the windage data are the motor design data decks. The material data and the windage data apply to all motor design data decks that follow until new material and windage data are encountered by the program. The appearance of a new magnetic materials data deck signals the beginning of a new data set.

To keep keypunching to a minimum, much of the input is optional and need not be read in. If optional data are omitted from the input, assumptions regarding the omitted data are made internal to the program.

Detailed discussion of the input requirements is included in appendix A. Appendix A also identifies the optional data and explains the assumptions made for omitted data.

Output

For each motor design data deck the program produces six pages of printed output. The first three pages provide a record of most input plus other dimensions or parameters calculated by the program, such as reactances and weights. The next two pages give the motor performance for slip values from 1 percent to 100 percent in 1-percent increments. Motor performance consists of calculated values of torque, input power, input current, power factor, efficiency, and a loss breakdown. The sixth page gives a plot of torque against slip.

Each time a new data set is encountered, one page of output is printed that summarizes the material properties applying to all subsequent motor designs. This summary consists of magnetization curve data for both the stator and rotor material and core-loss data for the stator material only. Appendix B shows a typical output.

In addition to the standard output, the program prints error messages as necessary. Appendix E lists all possible error messages, identifies the subroutine in which each message originates, and gives the probable cause of the error.

Calculational Methods

General. - The key to the induction motor analysis is the equivalent circuit shown in figure 3. In the circuit, R1 represents the phase resistance of the armature winding, X1 the armature leakage reactance per phase, and R2 the resistance of the rotor winding referred to the armature winding. The resistance element R2/(S/100) shown in figure 3 represents the combined effect of the rotor winding resistance and the shaft load. The symbol X2 is the rotor winding leakage reactance per phase. Both R2 and X2 are referred to the armature winding. Resistance R0 and reactance X0 allow for the effects of core loss and magnetizing current, respectively. Values of R1, R2, X1, and X2 are calculated from the physical dimension of the motor. Values for X0 and R0 are arrived at through an iteration process in the no-load magnetic calculations. The symbol S denotes the rotor slip in percent.

The values of the circuit elements, once calculated, are assumed to be constant for all values of slip. Motor performance is computed by doing steady-state alternating-current circuit analysis for each pertinent value of slip.

All equations given are expressed in FORTRAN notation including FORTRAN symbols, FORTRAN arithmetic operations, and FORTRAN function names. The only departure from FORTRAN notation is for fractions, which are written upright for better readability.

The SI units are used throughout the main body of the text. In particular the following units are employed consistently:

(1) Length in meters
(2) Areas in square meters
(3) Resistances and reactances in ohms
(4) Currents and magnetomotive force in amperes
(5) Voltages in volts
(6) Power in watts
(7) Frequency in hertz
(8) Rotational speed in revolutions per minute
(9) Resistivity in μ-ohm-meter
(10) Mass in kilograms
(11) Magnetic flux density in webers

Viscosity may be expressed in any unit provided consistency is maintained.

Slot permeance ratios. - The rotor and stator slot permeance ratios are required to calculate the primary and the secondary slot-reactances. Both slot permeance ratios are calculated in subroutine SLOTS. The equations used are discussed in this section. Six slot shapes are allowed by the program; the permeance ratio calculations are similar for all.

Equation (7.9) of reference 2 gives the slot leakage permeance for an open slot, such as slot type 1 (fig. 4) in the program. The equation is repeated here.

$$P_{S1} = \frac{K_S}{w}\left(d_3 + \frac{d_1}{3}\right) + \frac{d_1}{12w}(1 - K_S) - \frac{d_2}{4w}\left(K_S - \frac{2}{3}\right) \tag{1}$$

This equation is rewritten below using the FORTRAN symbols of subroutine SLOTS. These symbols are defined in appendix D and in figure 4.

$$AXX = \frac{KX}{WSX} * \left(D2X + \frac{D1X}{3.}\right) + \frac{D1X}{12.*WSX} * (1. - KX) - \frac{D5X}{4.*WSX} * (KX - 0.6667) \tag{2}$$

Rearranging the equation gives

$$AXX = KX* \left(\frac{D2X}{WSX}\right) + A1* \left(\frac{D1X}{WSX}\right) - A2* \left(\frac{D5X}{WSX}\right) \tag{3}$$

where

$$A1 = 0.25*KX + \frac{1.}{12.}$$

and

$$A2 = 0.25*KX - \frac{1.}{6.}$$

The ratio D2X/WSX in equation (3) gives the contribution of the slot opening to the total slot permeance ratio for an open slot. Thus, the equation may be rewritten as

$$AXX = KX*\begin{pmatrix}\text{Permeance ratio}\\ \text{for slot}\\ \text{opening}\end{pmatrix} + \left(\frac{D1X}{WSX}\right)*A1 - \left(\frac{D5X}{WSX}\right)*A2 \tag{4}$$

This equation may be generalized to other slot types by substituting the correct expression for the slot-opening permeance ratio and by replacing WSX by the slot width appropriate for the slot type. The results of these substitutions for the various slot types are as follows:

For slot type 1,

$$AXX = KX^* \left(\frac{D2X}{WSX}\right) + \left(\frac{D1X}{WSX}\right) * A1 - \left(\frac{D5X}{WSX}\right) * A2 \tag{5}$$

For slot type 2,

$$AXX = \frac{2. * KX^* D2X}{WSX + WSX4} + \left(\frac{D1X}{WSX4}\right) * A1 - \left(\frac{2. * D5X}{WSX4 + WSX5}\right) * A2 \tag{6}$$

For slot type 3,

$$AXX = KX^* \left[\frac{D4X}{WSX1} + \left(\frac{D3X}{WSX - WSX1}\right) * ALOG\left(\frac{WSX}{WSX1}\right) + \frac{D2X}{WSX}\right] + \left(\frac{D1X}{WSX}\right) * A1 - \left(\frac{D5X}{WSX}\right) * A2 \tag{7}$$

For slot type 4,

$$AXX = KX^* \left[\frac{D4X}{WSX1} + \left(\frac{D3X}{WSX2 - WSX1}\right) * ALOG\left(\frac{WSX2}{WSX1}\right) + \frac{2. * D2X}{WSX2 + WSX4}\right] + \left(\frac{D1X}{WSX4}\right) * A1 - \left(\frac{2. * D5X}{WSX4 + WSX5}\right) * A2 \tag{8}$$

For slot type 6,

$$AXX = KX^* \left[\frac{D4X}{WSX1} + \left(\frac{D3X}{WSX2 - WSX1}\right) * ALOG\left(\frac{WSX2}{WSX1}\right) + \frac{2. * D2X}{WSX2 + WSX4}\right] + \left(\frac{D1X}{WSX4}\right) * A1 - \left(\frac{2. * D5X}{WSX4 + WSX5}\right) * A2 \tag{9}$$

For slot type 5 (round slot) the expression for AXX is not readily derived from equation (4). Instead AXX is computed as shown on page 235 of reference 2. The equation, in FORTRAN symbols, is

$$AXX = KX^* \left(\frac{D4X}{WSX1}\right) + 0.625 * KX \tag{10}$$

The equations just given apply to both the stator and rotor slots. However, for rotor slots the factor KX (pp. 184 and 185, ref. 2) is always equal to unity, and the slot dimension D5X is assumed to be zero. To change these equations to the FORTRAN symbols used in the main program, change the X in each symbol to S for stator slots or to R for rotor slots. The only exception is AXX, which changes to AXS and AXR, respectively.

Equivalent circuit elements. - The equivalent circuit elements calculated directly from the physical dimensions are R1, R2, X1, X2, and X0AG. The calculation of circuit elements X0 and R0 is described in the section No-load magnetic calculation.

That component of X0 that is attributable to the airgap of the motor is called X0AG. It is used as an initial estimate of the value of X0 in the iteration procedure employed to compute X0. It is also required to calculate several other reactances, notably the skew reactance, the rotor and stator zigzag reactances, and the peripheral airgap reactance. Since X0AG is a function of the physical dimensions of the motor only, its calculation is explained here.

The quantity X0AG is computed as shown in equation (7.1) of reference 2. The equation is repeated here.

$$X_M = \frac{6.38\ qfN^2K_p^2K_d^2DL}{k_i g_e P^2 \times 10^8} \quad \text{ohms/phase} \tag{11}$$

To obtain the equation used in the program, the number of phases is set to three and the factor k_i is set to unity. (In the reference, P is the number of pole pairs and N is the number of stator turns in series per phase. In the program, P refers to the number of poles, and N is the number of conductors in series per phase.) Thus, in FORTRAN notation and with the symbols of the main program,

$$\text{X0AG} = \frac{3.02\text{E-}5* \left(\dfrac{\text{N}}{2.*\text{KPS}*\text{KDS}}\right)**2*\text{D}*\text{L}*\text{F}}{\text{P}*\text{P}*\text{GE}} \tag{12}$$

The armature leakage reactance X1 is made up of several components as shown in the following equation:

$$\text{X1} = \text{XSS} + \text{XSE} + \text{XSK} + \text{XSZ} + \text{XP} \tag{13}$$

where

XSS primary slot leakage reactance

XSE stator end-connection leakage reactance

XSK one-half of the skew reactance

XSZ stator zigzag leakage reactance

XP peripheral airgap leakage reactance

The individual components of the armature leakage reactance are computed as follows:

$$XSS = 2.36E\text{-}5 * N * N * F * L * \left(\frac{AXS}{QS}\right) \tag{14}$$

$$XSE = \frac{9.45E\text{-}6 * N * N * F * (KPS * KDS) ** 2}{P} * \left(B + \frac{F1}{2.} + \frac{DSS}{4.}\right) \tag{15}$$

$$XSK = 0.5 * \frac{X0AG}{12.} * \left(P * \frac{SKEW}{D}\right) ** 2 \tag{16}$$

$$XSZ = 0.833 * X0AG * \frac{KS}{(KPS * KDS) ** 2} * \frac{\left(\frac{6.}{CCS}\right) - 1.0}{5. * \left(\frac{QS}{P}\right) ** 2} \tag{17}$$

$$XP = 0.525 * X0AG * \left(\frac{P * G}{D}\right) ** 2 \tag{18}$$

For equations (14), (17), and (18), see reference 2 (eqs. (7.2), (7.47), and (7.69), respectively). For equation (17) also refer to reference 2 (top of p. 202). Equations (14) and (15) are documented in reference 2 (pp. 336 and 337). The factor KS is discussed on pages 184 and 185 of reference 2.

The rotor winding leakage reactance X2 is similarly computed. The equations used in the program are as follows:

$$X2 = XRS + XRE + XSK + XRZ \tag{19}$$

where

XRS secondary slot leakage reactance

XRE rotor end-connection leakage reactance

XSK one-half of the skew reactance

XRZ rotor zigzag leakage reactance

$$XRS = 2.36E{-}5 * N * N * F * L * \left(\frac{AXR}{NB}\right) * (KPS * KDS) ** 2 \tag{20}$$

$$XRE = \frac{28.54 * AY}{P} * \left[2. * P * BR + \frac{3.1416 * D * DC}{1.7 * TER + 0.6 * (DER1 - DER2) + 1.4 * DC}\right] \tag{21}$$

where

$$AY = \frac{N * N * F * (KPS * KDS) ** 2 * 2.4E{-}7}{P}$$

$$XSK = 0.5 * \left(\frac{X0AG}{12.}\right) * \left(P * \frac{SKEW}{D}\right) ** 2 \tag{22}$$

$$XRZ = 0.833 * X0AG * \frac{KS}{(KPS * KDS) ** 2} * \frac{\left(\frac{6.}{CCR}\right) - 1.0}{5. * \left(\frac{NB}{P}\right) ** 2} \tag{23}$$

Equations (21) and (22) are given in reference 2 (p. 237). Equations (20) and (23) are described in reference 2 (eqs. (7.11) and (7.47), respectively). Also refer to reference 2 (top of p. 220) for further modification of equation (7.47).

The armature resistance R1 is given by

$$R1 = \frac{(LS * N * RSTVTY * 1.0E{-}6)}{(PC * SS)} \tag{24}$$

where RSTVTY is the resistivity of the stator winding material at 20° C. Then R1 is corrected for the winding temperature specified in the input data.

The rotor resistance R2 (referred to the armature winding) is the sum of the end-ring resistance and the resistance of the rotor bars. It is computed by (eq. (206), ref. 3)

$$R2 = [3.*RSTVTY*(N*KPS*KDS)**2]*\left(\frac{LB - TER}{SB*NB} + \frac{0.64*DER1*KRING}{P*P*SER}\right) \quad (25)$$

The end-ring thickness TER is subtracted from the rotor bar length LB because it is assumed that the axial current flow does not extend to the ends of the rotor bars. The factor KRING is included to allow for unequal current distribution in the rotor and rings. This factor is fully described in reference 4. Like R1, the value of R2 is adjusted for the specified winding temperature.

Core-loss calculations. - For all core-loss calculations, the value of WFE must be known. This is the core-loss expressed in watts per unit of mass at a given lamination thickness, frequency F, and flux density BK. Its value is computed from the input data contained on the $FELOSS data cards that are part of the stator material deck. Up to ten $FELOSS data cards are allowed with each material deck, one for each lamination thickness for which calculations are anticipated. The program searches through the FELOSS cards to find the data for the lamination thickness nearest that specified in the motor design deck. The core loss WFE is then calculated by

$$WFE = WCORE*\left(\frac{F}{FCORE}\right)**SLOPE \quad (26)$$

where F is the motor design frequency as specified in the motor design deck and FCORE, WCORE, SLOPE are given on the FELOSS data cards. (The symbols FCORE, WCORE, and SLOPE are defined in appendix A, in fig. 11, and in appendix E.) Computation of no-load core loss is deferred until the no-load magnetic calculations. The no-load core loss is then used to compute the value of R0 in the equivalent circuit. Core loss at all other loads is the power dissipated in the resistance R0 as determined during the equivalent circuit analysis.

No-load magnetic calculations. - The magnetic calculations accomplish several things:

(1) Computation of flux densities throughout the magnetic circuit of the motor at no load

(2) Computation of ampere-turn drops across various parts of the magnetic circuit

(3) Computation of magnetizing current and magnetizing reactance X0

(4) Computation of values of core loss W0 and the value of the resistive element R0 used in the equivalent circuit to represent the core loss

The calculations are performed as follows: Initial extimates for X0, W0, and R0 are made by using the equations

$$X0 = 0.5*X0AG \quad (27)$$

$$W0 = 3.*(WSYOKE + WSTOTH)*WFE \qquad (28)$$

$$R0 = \frac{5.*V1*V1}{W0} \qquad (29)$$

Next subroutine CIRCT is called to compute the airgap voltage V2 and the magnetizing current IMAG (fig. 5). From V2 the total flux and the flux per pole are calculated, allowing subroutine MAGNET to compute the stator yoke and stator tooth flux densities, as well as ATTOT, the total magnetomotive force. This permits the calculation of a new, more accurate value of core loss W0 and resistance R0 as follows:

$$W0 = 3.*WFE*\left[WSYOKE*\left(\frac{BSY}{BK}\right)**2 + WSTOTH*\left(\frac{BST}{BK}\right)**2\right] \qquad (30)$$

$$R0 = \frac{(3.*V2*V2)}{W0} \qquad (31)$$

where

WSYOKE	stator back-iron weight
WSTOTH	stator tooth weight
BSY	back-iron flux density
BST	stator tooth flux density
V2	airgap voltage (fig. 3)

The process is then repeated using the latest value of R0 until R0 converges.

When R0 has converged, the ATTOT value calculated by MAGNET and the values of V2 and IMAG calculated by CIRCT are used to compute a new value of X0 as follows:

$$X0 = \frac{V2}{0.5*(IMAG + IMAG2)} \qquad (32)$$

where

$$IMAG2 = \frac{(2.22*P*ATTOT)}{(3.*N*KPS*KDS)}$$

With this new value of X0, the calculations for R0 are then repeated. This double convergence procedure is performed until both R0 and X0 have converged to their final values. These values are then held constant throughout the remaining motor analysis for all values of slip.

This convergence procedure guarantees that the magnetizing current and the no-load core loss as obtained from the equivalent circuit analysis are the same as those calculated from the magnetic material properties.

In addition to computing the values of X0 and R0, the double convergence procedure yields all no-load flux densities, no-load magnetomotive force across all parts of the magnetic circuit, no-load core loss, no-load magnetizing current, total useful flux, and total useful flux per pole. (Fig. 5 illustrates the no-load magnetic calculations in flow-chart format.)

Windage loss calculations. - The windage loss calculations may be divided into two steps. The first step is to obtain the value of FW1, the windage loss at synchronous rotor speed. The second step, which is performed in subroutine CIRCT, is to calculate the windage loss at any other rotor speed from the equation

$$FW = FW1*\left(\frac{RPM}{NSYNCH}\right)**C \tag{33}$$

where

FW1	windage loss at synchronous speed
FW	windage loss at RPM
RPM	rotor speed
NSYNCH	synchronous rotor speed
C	constant (in the program, C = 2.5)

The value of FW1 is allowable input to the program; if known, it may be read in directly. If FW1 is not known, it may be omitted from the input data, in which case the program assumes it to be zero. Or, if a value of windage loss WL for a similar motor is known, WL may be read in. WL is called the reference windage loss; the motor for which the windage loss WL is known is called the reference motor. Assuming that sufficient additional information is provided to the program, the value WL will be scaled (multiplied by dimensionless parameters) to obtain the value FW1. The additional information required by the program to scale WL is a complete description of the conditions under which the value WL was obtained. These conditions, called the reference conditions, consist of the following:

(1) DIAREF, the diameter of the reference motor

(2) LREF, the rotor length of the reference motor

(3) RPMREF, the rotor speed for which the value WL was obtained

(4) GAPREF, the radial gap of the reference motor

In addition, though not required, the reference viscosity VSCREF and the reference pressure PREF of the fluid in the reference motor cavity may be supplied. Then, assuming that the viscosity and pressure of the fluid in the motor being analyzed are also specified, further scaling with regard to these parameters will also take place. The exact format of the windage data required by the program is described in appendix A.

Figure 6 is a flow chart that shows precisely how the value of FW1 is determined by the program. Note that the program initializes the variables that specify the reference conditions prior to reading the windage data. This initialization makes certain that all variables have numeric values, and it allows determination of which variables were omitted from the windage data. After having read the windage data the program checks if VSCREF was read in. If it was not, the program attempts to calculate a value from the constants C0 to C4 and the temperature TREF. If C0 to C4 were also omitted from the data, the value of VSCREF will remain zero and no scaling with regard to viscosity will be performed.

The windage calculations described to this point are executed only once for each data set. By contrast, the remaining calculations are carried out once for each motor design data deck.

Prior to reading the motor design data deck, a number of additional variables are initialized as shown in the flow chart. The design deck is then read and a heading "WINDAGE" is written on the output record. The program then checks if FW1 was read in. If it was, its numerical value is printed out and all other windage calculations are bypassed. If FW1 was not supplied, the program checks the value of WL. If WL equals 0, the program leaves FW1 set to zero and proceeds as above. If WL is not zero, the program checks that numeric values for DIAREF, LREF, RPMREF, and GAPREF are supplied. If not, an error message is issued and FW1 is left unchanged at zero. Otherwise, the program proceeds to compute

$$\mathrm{FW1} = \mathrm{WL}*\left(\frac{\mathrm{DR}}{\mathrm{DIAREF}}\right)^{3.25}*\left(\frac{\mathrm{L}}{\mathrm{LREF}}\right)*\left(\frac{\mathrm{NSYNCH}}{\mathrm{NREF}}\right)^{2.5}*\left(\frac{\mathrm{GAPREF}}{\mathrm{G}}\right)^{0.25} \tag{34}$$

where

DR	rotor diameter of the motor being analyzed
NSYNCH	synchronous shaft speed, rpm
L	rotor length
G	radial gap between rotor and stator

Following this basic scaling operation the program will, if possible, scale FW1 with respect to fluid viscosity and fluid pressure. This concludes the computation of FW1, the windage loss at synchronous rotor speed. The result, together with all pertinent data, is printed out.

Calculation of windage loss at all rotor speeds other than synchronous is left to subroutine CIRCT using equation (32).

Motor performance calculations. - Motor performance is computed at a given line-to-neutral voltage and line frequency. It consists of computing line current, shaft torque, output power, efficiency, power factor, input power, and internal losses. These performance parameters are computed by analyzing the motor's equivalent circuit. Analyzing the circuit is equivalent to analyzing the motor. The performance parameters obtained directly from the equivalent circuit are line current, power factor, and input power.

The power dissipated in the resistive element R1 is the ohmic loss of one phase of the armature winding. The power dissipated in R0 is one-third of the motor core loss.

The power W2 is three times the power dissipated in the resistive element (R2* 100)/S. It is given by

$$W2 = \frac{3. * I2 * I2 * R2 * 100.}{S} \tag{35}$$

The symbol W2 represents both the loss in the rotor winding and the power delivered to the shaft. It is divided into its respective components as follows:

$$W2 = 3. * I2 * I2 * R2 + \frac{3. * I2 * I2 * R2 * (100. - S)}{S} \tag{36}$$

where

3. * I2* I2* R2	power dissipated in the rotor winding
3. * I2* I2* R2* (100. - S)/S	gross shaft power

Windage loss FW is subtracted from the gross shaft power to obtain the net power output from the motor at this point. The net shaft torque is then computed from the net power output and the shaft speed.

All circuit analyses, as well as calculations of output power, efficiency, and losses are performed in subroutine CIRCT for one value of slip. The main program INDMTR increments the value of slip by 1 percent from zero to 100 percent. For each value of slip, subroutine CIRCT is called to perform all calculations described in this section. Following each call to subroutine CIRCT the main program prints the results of the calculations for the one value of slip.

If input data specify a value for rated torque, the main program will check the computed value of torque after each call to subroutine CIRCT but before printing the results of the calculations. If the computed torque exceeds the specified rated torque, printout of the results is temporarily suppressed and normal processing is interrupted. The value of slip is no longer incremented by 1 percent. Instead the program searches, through an iteration process, for the value of slip that produces the rated output torque. Motor performance at that value of slip is then printed out. This output line is both preceded and followed by a blank line to offset it from the other output. Normal processing is then resumed with the value of slip at which processing was interrupted. Further comparison of computed torque with rated torque is discontinued.

Lewis Research Center,
National Aeronautics and Space Administration,
Cleveland, Ohio, October 30, 1975,
506-23.

APPENDIX A

INPUT REQUIREMENTS

Input Data Requirements

The use of this computer program for the analysis of induction motors requires that the complete electromagnetic design be known. This includes physical dimensions, armature and rotor winding parameters, winding temperatures, and the magnetic characteristics of the materials to be used in the stator and the rotor. The design information is then transferred onto data cards for use with the program. A typical data deck is shown in figure 7. It consists of one or more data sets, all similar in makeup. Each data set contains, in the order required, two material data decks, windage data, and any number of motor design data decks. The material data decks must be in the order shown in the figure, that is, stator material data decks followed by the rotor material data deck. There must be two material data decks even if the rotor and stator are made of the same material.

The material data decks and the windage data apply to all motor design data decks that follow, until a new material data deck is encountered. The appearance of a new material data deck within the input data signals the beginning of a new data set.

Preparation of Material Data Decks

A material deck consists of from 5 to 16 cards as shown in figure 8. The first card is the material deck identification card. Its main purpose is to give the material name, which 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 next four cards are the saturation curve data cards. They contain the coordinate values of as many as 14 arbitrary data points located on the magnetization curve of the material. Following this are as many as 10 core-loss data cards - one for each lamination thickness at which core-loss calculations are anticipated. At least one core-loss data card is required for the stator material deck. The last card identifies the end of the material deck. Core-loss data cards and the last card are not needed for the rotor material deck.

Each type of card that goes into the material data deck is described in detail here.

Material deck identification card. - The material deck identification card must contain an "M"-punch in card column 1. Column 2 should be blank. The material name should start in column 3 and may extend through column 80.

Saturation curve data cards. - The four saturation curve data cards contain points on the magnetization curve for the material. Each card is divided into eight 10-column fields. The entry in the first field of the first card must be the highest value of flux density of the selected points on the saturation curve. This is followed by paired values of magnetic flux density and magnetizing force. The values of flux density must be in ascending order. If less than 14 points are chosen for input such that less than four cards are required, blank cards must be inserted. The units must be kilolines per square inch for flux density and ampere-turns per inch for magnetizing force. During program execution, the original magnetization curve is approximately reconstructed by interpolation between points. The interpolation assumes a straight line on semilog paper between data points.

Core-loss data cards. - The core-loss data cards are identified by the NAMELIST name FELOSS. Thus, they must contain the entry $FELOSS starting in card column 2. Other required entries on each card are of the form

Variable name = Numeric value

The permissible variable names and their definitions are shown in table I. The entries may be in any order, separated by commas. Each core-loss data card must be terminated by a "$"-punch.

The last core-loss data card must be

$FELOSS LAST=.TRUE. $

Typical example. - Preparation of a material data deck is illustrated for M-19 silicon steel. The first card of this material deck is shown in figure 9.

To prepare the next four cards of the material data deck, the magnetization curve of the material is needed. The magnetization curve for M-19 steel is shown in figure 10. The 14 selected points are indicated by data symbols. The numeric values of these points are listed in the table insert of figure 10. The sequence in which the numbers are punched onto data cards is as follows: 116., 26., 1.30, 30., 1.45, ..., 110., 130., 116., 135.0.

Core loss as a function of frequency for M-19 steel is shown in figure 11. The figure is for a lamination thickness of 0.014 inch and a flux density of 64.5 kilolines per square inch. The slope obtained from the figure is

$$\mathrm{SLOPE} = \frac{\ln (W1/W2)}{\ln (F1/F2)}$$

where W1, W2, F1, and F2 are arbitrarily selected points on the curve. Substituting numeric values gives

$$\mathrm{SLOPE} = \frac{\ln (70./1.3)}{\ln (1500./100.)} = 1.47$$

Thus, the core-loss data card for M-19 steel with a thickness of 0.014 inch would appear as

$FELOSS WCORE=9.4, FCORE=400, BK=64.5, LT=0.014, SLOPE=1.47 $

The value of SLOPE, plus one point on the core-loss-against-frequency curve defined by the coordinates WCORE and FCORE, allows the approximate reconstruction of the curve. Figure 11 shows how the program reconstructs the core-loss-against-frequency curve from these data.

As many as nine additional cards for other lamination thicknesses may be added. The complete material deck for M-19 steel is shown in figure 9.

Preparation of Windage Loss Data Cards

A data card referencing the NAMELIST name WNDAGE must be included with each data set even if no windage calculations are to be performed by the program. If windage loss is to be neglected, no entry is required. If a known windage loss WL is to be scaled from the reference conditions to give the windage loss of the motor design at synchronous speed, the entries as defined in table II should be included. If it is desired to read in a value of windage loss at synchronous speed and bypass the internal windage loss scaling operation, the entry FW1 of NAMELIST name RATING (see next section and table III) should be used. For a description of windage loss calculations, see the main-text section Windage loss calculations.

Preparation of Motor Design Data Deck

The motor design data deck contains all the dimensions, the geometric configuration (in numerical code), and the winding parameters needed for an electromagnetic analysis of the motor design. The first card of the motor design deck is a title card similar to the first card of the material data deck. The first two columns of the title card must be blank. Any type of descriptive or identifying information may be punched in columns 3 to 80. This information is written on the output record for identification purposes. The remaining cards of the motor design data deck 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. There are eight NAMELIST names; each is suggestive of the type of variable included in its list. Detailed information about each NAMELIST name is provided in table III, which lists all variables used with the alternator design data 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 either required or optional. Optional variables are read in at the discretion of the program user. In each case where an optional variable is omitted from the program input, an assumption regarding that variable is made internal to the program. The remarks column of table III supplies specific explanations in regard to all optional variables.

To further clarify the definition of some variables, figures 12 and 13 are given. These figures are referenced in the table where applicable.

A typical data card from the motor design deck is

$STATOR D=1.07, L=1.24, SFS=0.909, DOS=2.50, LTS=0.006 $

The card is for NAMELIST name STATOR and must be the second card following the motor design deck title card.

TABLE I. - ENTRIES ON CORE-LOSS DATA CARDS

[NAMELIST name, FELOSS.]

Classification	FORTRAN symbol	Description	Remarks
Required[a]	WCORE	Core loss at frequency FCORE, at flux density BK, and for lamination thickness LT, W/lb	
	FCORE	Frequency at which WCORE is determined, Hz	FCORE should be close to motor design frequency F to minimize the error of extrapolating WCORE from frequency FCORE to frequency F.
	BK	Flux density at which WCORE is determined, kilolines/in.^{2}	
	LT	Lamination thickness at which WCORE is determined, in.	
Optional	LAST	LAST=.TRUE. indicates end of core-loss data set.	This variable is required on the last card of core-loss data set. It must be the only variable on that data card and it must be set equal to .TRUE. If this variable appears on any other card, it must be set equal to .FALSE.
	SLOPE	Slope of core loss-against-frequency plot (assumed linear on log-log paper) for constant flux density BK; if W1 is core loss at frequency F1 and W2 is core loss at frequency F2, $$\mathrm{SLOPE} = \frac{\ln \frac{W_1}{W_2}}{\ln \frac{F_1}{F_2}}$$ (fig. 11)	If SLOPE is omitted from input, the program will assume a value of slope given by $$\mathrm{SLOPE} = \frac{1. + 164.*\mathrm{LT}}{1. + 82.*\mathrm{LT}}$$ SLOPE may also be omitted if F of NAMELIST name RATING equals FCORE.

[a]For stator material only.

TABLE II. - ENTRIES ON WINDAGE-LOSS DATA CARDS

[NAMELIST name; WNDAGE.]

Classification	FORTRAN symbol	Description	Remarks
Required[a]	WL DIAREF LREF RPMREF GAPREF	Windage loss at reference conditions, W Reference diameter, in. Reference length, in. Reference rotational speed, rpm Reference gap length, in.	If the windage loss for the motor being analyzed is known, its value may be read in by using the variable FW1 of NAMELIST name RATING (table III). If FW1 is used, the scaling will be bypassed and hence no entries on the WNDAGE data card are required.
Optional	VSCREF	Reference viscosity, lbm/ft-sec	If VSCREF is omitted, the program will attempt to calculate a value based on the polynomial VSCREF = C0 + C1* TREF + C2* TREF* * 2 + C3* TREF* * 3 + C4* TREF* * 4 If the result of the calculation is ≤0, no windage loss scaling with respect to viscosity will be made.
	C0 C1 C2 C3 C4	These constants are coefficients of a fourth-degree polynomial that gives the viscosity as a function of temperature. The constants must be chosen such that viscosity is in lbm/ft-sec for temperature in $^{\circ}C$.	Any or all constants omitted from the input will be assumed to equal zero.
	TREF	Fluid temperature at reference conditions, $^{\circ}C$	TREF is the temperature for which VSCREF is calculated if necessary.
	PREF	Pressure of fluid in airgap at reference conditions, $lb/in.^2$	If omitted, scaling of windage loss with pressure is not possible.

[a]These variables are required only if it is desired to scale the windage loss from a known condition to the motor being analyzed. If scaling is not desired, no entries are required.

TABLE III. - INPUT REQUIREMENTS FOR MOTOR DESIGN DECK

NAMELIST name	Classification	FORTRAN symbol	Description	Remarks
RATING[a]	Required	NSYNCH F V1	Synchronous speed, rpm Line frequency, Hz Line-to-neutral voltage, V	
	Optional	TRATED	Rated torque, in.-lb	Normally motor characteristics are computed at predetermined values of slip only. If a value of TRATED is specified, motor characteristics at the value of slip corresponding to torque TRATED will also be computed.
		FW1	Windage loss at synchronous speed, W	If specified, the internal windage loss scaling will be bypassed.
		X0 X1 X2 R0 R1 R2	Reactance values of induction motor equivalent circuit (fig. 3), Ω Resistance values of induction motor equivalent circuit (fig. 3), Ω	If any of these reactances and resistances are specified, internal calculations for that circuit element are bypassed. If all are specified, all internal calculations are bypassed except for the equivalent circuit analysis. In this case, all remaining data cards should be omitted. (The material data decks and the $WNDAGE data set are still required; the data therein are not used.)
STATOR	Required	D L LTS DOS	Stator inside diameter, in. Stator stack length, in. Stator lamination thickness, in. Stator outside diameter, in.	
	Optional	SFS	Stator stacking factor	If omitted, stacking factor is calculated as follows: $SFC = \frac{LTS}{LTS + 0.0005}$
SSLOTS	Required	SSTYPE	Stator slot type (Choose from type 1 to type 6, as shown in fig. 12.)	SSTYPE is required for all stator slots.

[a]This card must be preceded by a title card (see input, p. 43.)

TABLE III. - Continued.

NAMELIST name	Classification	FORTRAN symbol	Description	Remarks
SSLOTS	Required	D1S	Conductor depth (fig. 12), in.	One of these variables is required for all stator slot types.
		or		
		DSS	Slot depth (fig. 12), in.	
		or		
		SCAREA	Slot area (fig. 12), $in.^2$	
		or		
		CSRATO	Space factor	
		D6S	Stator slot dimension (fig. 12), in.	D6S and QS are required for all stator slots.
		QS	Number of stator slots	
		D2S	Slot dimension (fig. 12(a))	One of these variables is required for stator slot type 1 only.
		D5S		
		WSS		
		WSS6		
		D2S	Slot dimension (fig. 12(b))	Required for stator slot type 2 only.
		D5S		
		WSS6		
		WSS		
		or		
		STWDTH	Stator tooth width if constant, in.	
		D2S	Slot dimension (fig. 12(c)), in.	Required for stator slot type 3 only.
		D3S		
		D4S		
		D5S		
		WSS		
		WSS1		
		WSS6		
		D2S	Slot dimension (fig. 12(d)), in.	Required for stator slot type 4 only.
		D3S		
		D4S		
		D5S		
		WSS1		
		WSS6		
		WSS2		
		or		
		STWDTH	Stator tooth width if constant, in.	

TABLE III. - Continued.

NAMELIST name	Classification	FORTRAN symbol	Description	Remarks
SSLOTS	Required	D4S WSS1	Slot dimension (fig. 12(e)), in. Slot dimension (fig. 12(e)), in.	Required for stator slot type 5 only.
		D2S D3S D4S D5S WSS1 WSS6 WSS2 or STWDTH	Stator slot dimension (fig. 12(f)), in. Stator tooth width, in.	Required for stator slot type 6 only.
	Optional	PHIS	One-half of angle at which sides of stator slots diverge (fig. 12), deg	PHIS is allowable input only if WSS2 is specified and STWDTH is omitted for slot types 2, 4, or 6. If, in that case, PHIS is also omitted, constant tooth width is assumed.
		WSS2	Stator slot dimension (fig. 12(e)), in.	Optional for slot type 5 only
STRWDG	Required	CSS PC B SPITCH ASTRND or AWG S	Number of conductors per stator slot Number of parallel circuits Armature coil extension (fig. 12), in. Stator winding pitch, per unit Cross-sectional area of stator conductor strand, $in.^2$ Gage size of stator conductor strand, AWG Clearance between armature coils at end turns (fig. 13), in.	
	Optional	SWMAT	Stator winding material code	SWMAT = 1 for aluminum SWMAT = 2 for brass SWMAT = 3 for copper Unless one of the other two is specified, SWMAT = 3 is assumed.
		LS	Length of one armature conductor (one-half of armature coil length), in.	If omitted from input data, program calculates value internally. The calculations assume a form-wound armature.

TABLE III. - Continued.

NAMELIST name	Classification	FORTRAN symbol	Description	Remarks
STRWDG	Optional	TSW	Temperature of stator winding, ^{o}C	A temperature of 25^{o} C is assumed unless otherwise specified.
		STRNDS	Number of strands per armature conductor	One strand per conductor is assumed.
ROTOR	Required	LTR DIR	Rotor lamination thickness, in. Rotor lamination inside diameter, in.	
	Optional	SKEW	Rotor slot skew, in.	If omitted from input data, program assumes it to equal rotor slot pitch <u>or</u> stator slot pitch, whichever is greater.
		SFR	Rotor lamination stacking factor	If omitted, stacking factor is calculated as follows: $$SFR = \frac{LTR}{LTR + 0.0005}$$
RSLOTS	Required	RSTYPE	Rotor slot type (choose from type 1 to type 6 as shown in fig. 12)	Required for all rotor slots.
		SB or D1R or DSR	Rotor bar cross-sectional area (fig. 12), in.^{2} Slot depth (fig. 12), in.	One of these is required for all rotor slots
		D6R	Slot dimension (fig. 12), in.	Required for all rotor slots
		D2R WSR WSR6	Slot dimension (fig. 12(a)) Slot dimension (fig. 12(a)) Slot dimension (fig. 12(a))	Required for rotor slot type 1 only.
		D2R WSR6 WSR or RTWDTH	Slot dimension (fig. 12(b)) Slot dimension (fig. 12(b)) Slot dimension (fig. 12(b)) Rotor tooth width if constant, in.	Required for rotor slot type 2 only.

TABLE III. - Continued.

NAMELIST name	Classification	FORTRAN symbol	Description	Remarks
RSLOTS	Required	D2R D3R D4R WSR WSR1 WSR6	Slot dimension (fig. 12(c)), in.	Required for rotor slot type 3 only.
		D2R D3R D4R WSR1 WSR6 WSR2 or RTWDTH	Slot dimension (fig. 12(d)), in. Rotor tooth width if constant, in.	Required for rotor slot type 4 only.
		D4R WSR1	Slot dimension (fig. 12(e)), in. Slot dimension (fig. 12(e)), in.	Required for rotor slot type 5 only.
		D2R D3R D4R WSR1 WSR6 WSR2 or RTWDTH	Rotor slot dimension (fig. 12(f)), in. Rotor tooth width, in.	Required for rotor slot type 6 only.
	Optional	WSR2	Rotor slot dimension (fig. 12(e)), in.	If omitted, WSR2 = DSR - D4R for slot type 5 only.
		PHIR	One-half of angle at which sides of rotor slots diverge (fig. 12), deg	Allowable input only if RTWDTH is omitted for slot type 2, 4, or 6 and WSR2 is specified. If, in that case, PHIR is also omitted, constant tooth width is assumed.
RTRWDG	Required	NB TER BR	Number of rotor bars End-ring thickness (measured in axial direction), in. Axial clearance between end-ring and rotor laminations, in.	

TABLE III. - Concluded.

NAMELIST name	Classification	FORTRAN symbol	Description	Remarks
RTRWDG	Optional	LB	Rotor bar length, in.	If omitted, LB is calculated as follows: $LB = \sqrt{L^2 + SKEW^2} + 2*(BR + TR)$
		DER1	End-ring outside diameter, in.	If omitted, DER1 is calculated as follows: DER1 = DR - 2.*(D4R + D3R)
		DER2	End-ring inside diameter, in.	If omitted, DER2 is calculated as follows: DER2 = DR - 3.*DSR or DER2 = 1.1*DIR whichever is greater.
		RWMAT	Rotor winding material code	RWMAT = 1 for aluminum = 2 for brass = 3 for copper Unless one of the other two is specified, RWMAT = 3 is assumed.
		TRW	Rotor winding temperature, $^{\circ}C$	A temperature of 25° C is assumed unless otherwise specified.
AIRGAP	Required	G	Airgap, in.	
	Optional	TFLUID	Temperature of fluid in airgap, $^{\circ}C$	If omitted, it is assumed that TFLUID = TREF. (See NAMELIST name WNDAGE.)
		VSCFLD	Viscosity of fluid in motor cavity, lbm/ft-sec	If omitted, program will calculate value of VSCFLD based on temperature TFLUID and the constants C0 to C4 of NAMELIST name WNDAGE. If all values C0 to C4 are omitted from the input data, the results of the calculation will be VSCFLD = 0. In this case, the windage loss WL will not be scaled with regard to viscosity.
		PFLUID	Pressure of fluid in airgap, psi	This needs to be included only if it is desired to scale the windage loss value WL to the new pressure level PFLUID.
		FLDNME	Name of fluid in airgap (may be a maximum of six characters long and must be enclosed in single quotation marks)	If specified, the name will be printed on the output record. No other action occurs.

APPENDIX B

TYPICAL INPUT AND RESULTANT OUTPUT

A complete data set identifying the material deck, the windage data, and the motor design deck is given here:

Stator material data

```
M*VANADIUM PERMENDUR
   154.        12.9       1.92       38.7       2.62       77.4       3.23       90.3
   2.53        103.       4.35       109.7      5.25       116.       6.66       122.5
   8.68        129.       12.5       135.5       20.2      142.       44.4       145.3
   101.        148.3      363.       154.       2020.
 $FELOSS  WCORE=21.0, FCORE=800., SLOPE=1.22, BK=77.4, LT=0.006   $
 $FELOSS  WCORE=24.5, FCORE=600., SLOPE=1.34, BK=77.4, LT=0.008   $
 $FELOSS  WCORE=30.0, FCORE=800., SLOPE=1.45, BK=77.4, LT=0.010   $
 $FELOSS  WCORE=40.0, FCORE=500., SLOPE=1.57, BK=77.4, LT=0.014   $
 $FELOSS   LAST=.TRUE.   $
```

Rotor material data

```
M*VANADIUM PERMENDUR
   154.        12.9       1.92       38.7       2.62       77.4       3.23       90.3
   3.53        103.       4.35       109.7      5.25       116.       6.66       122.5
   8.68        129.       12.5       135.5       20.2      142.       44.4       145.3
   101.        148.3      363.       154.       2020.
 $FELOSS  WCORE=21.0, FCORE=800., SLOPE=1.22, BK=77.4, LT=0.006   $
 $FELOSS  WCORE=24.5, FCORE=600., SLOPE=1.34, BK=77.4, LT=0.008   $
 $FELOSS  WCORE=30.0, FCORE=800., SLOPE=1.45, BK=77.4, LT=0.010   $
 $FELOSS  WCORE=40.0, FCORE=800., SLOPE=1.57, BK-77.4, LT=0.014   $
 $FELOSS   LAST=.TRUE.   $
```

Windage data

```
 $WNDAGE  WL=45.0, DIAREF=1.75, LREF=1.125, RPMREF=12000, GAPREF=0.010,
   C0=1.728E-3, C1=-0.02832E-3, C2=0.3876E-6, C3=-0.3294E-8, C4=0.105E-10,
   TREF = 20.   $
```

Title card

```
 1200 HZ COOLANT PUMP MOTOR
```

Motor design data

```
 $RATING NSYNCH=12000, F=1200, V1=120, TRATED=2.0   $
 $STATOR D=1.07, L=1.24, SFS=0.909, DOS=2.50, LTS=0.006   $
 $SSLOTS  QS=36, SSTYPE=6, D2S= 0.100, D4S=0., D5S=0.,
   WSS1=0.043, D5S=0.0105, STWDTH=1.045, DSS=0.520,
   D6S=0.015,  WSS6=0.0193  $
 $STRWDG  AWG = 25, CSS=56, PC=2, Y=0.1, SWMAT=3., SPITCH=.6667, S=0.0105,
   TSW=30., LS=2.53   $
 $ROTOR LTR=0.006, SFR=0.91, DIR = 0.45   $
 $RSLOTS RSTYPE = 1, D4R=0.030, D3R=0., WSR1=0.045, D2R=0.005,
   DSR=0.092, WSR=0.053, D6R=0., WSR6=0.033   $
 $RTRWDG  NB=29, TER=.135, RWMAT =3., FR=0., DER1=1.013, DER2=0.50, TRW=30.   $
 $AIRGAP  G=0.006, TFLUID = 75., FLDNME= 'DC-200'   $
```

The output that resulted from using this data set with the induction motor computer program is as follows:

```
STATOR MATERIAL
  VANADIUM PERMENDUR

        B                    H

(KILOLINES/SQ-IN)       (A-TURN/IN)

      12.90                 1.92
      38.70                 2.62
      77.40                 3.23
      90.30                 3.53
     103.00                 4.35
     109.70                 5.25
     116.00                 6.66
     122.50                 8.68
     129.00                12.50
     135.50                20.20
     142.00                44.40
     145.30               101.00
     148.30               363.00
     154.00              2020.00

  CORE-LOSS DATA
     CORE-LOSS     LAM THK      FREQ      FLUX DNSTY      SLOPE
       21.0         .006        800.0        77.4           1.2
       24.5         .008        800.0        77.4           1.3
       30.0         .010        800.0        77.4           1.5
       40.0         .014        800.0        77.4           1.6

ROTOR MATERIAL
  VANADIUM PERMENDUR

        B                    H

(KILOLINES/SQ-IN)       (A-TURN/IN)

      12.90                 1.92
      38.70                 2.62
      77.40                 3.23
      90.30                 3.53
     103.00                 4.35
     109.70                 5.25
     116.00                 6.66
     122.50                 8.68
     129.00                12.50
     135.50                20.20
     142.00                44.40
     145.30               101.00
     148.30               363.00
     154.00              2020.00

1200 HZ COOLANT PUMP MOTOR

  RATING
     SYNCHRONOUS SPEED                    12000. RPM
     FRECUENCY                             1200. HZ
     POLES                                   12.
     L-N VOLTAGE                            120.0 VOLT
     RATED TORQUE                             2.0 IN-LBS

  STATOR
     BORE DIAMETEP                          1.070
     OUTSIDE DIAMETER                       2.500
     CEPTH BELOW SLOT                        .195
     LENGTH                                 1.240
     LAMINATION THICKNESS                    .006
     STACKING FACTOR                         .909
     STATOR IRON WEIGHT                      .743
```

STATOR SLOTS

SLOT TYPE	6	NO. OF SLOTS	36.
TOOTH WIDTH	.045	SLOT DEPTH	.520
WSS1	.048	D1S	.405
WSS2	.048	D2S	.100
WSS3	.128	D3S	.000
WSS4	.066	D4S	.000
WSS5	.128	D5S	.010
WSS6	.010	D6S	.015
USABLE AREA	.029	TOTAL AREA	.047
SPACE FACTOR	.491		

STATOR WINDING

MATERIAL	3
CONDUCTORS PER SLOT	56.
PARALLEL CIRCUITS	2.
PITCH	.667
AXIAL EXTENSION BEYOND CORE	.100
CONDUCTOR CROSS-SECTION	.252-03
STRAND CROSS-SECTION	.252-03
CONDUCTOR LENGTH	2.530
CLRNCE BTWN END-TURNS	.010
TEMPERATURE (C)	30.
AXIAL END-TURN LENGTH	.730
OVERALL ARMATURE LENGTH	2.700
PITCH FACTOR	.866
DISTRIBUTION FACTOR	1.000
ARMATURE WEIGHT	.412
TOTAL ARMATURE WIRE LENGTH	425.040 FEET
STRANDS/CONDUCTOR	1.
STRAND SIZE	25

ROTOR

ROTOR DIAMETER	1.058
INSIDE DIAMETER	.450
LAMINATION THICKNESS	.006
STACKING FACTOR	.910
SLOT SKEW	.115
DEPTH BELOW SLOT	.212
ROTOR IRON WEIGHT	.185

ROTOR SLOTS

SLOT TYPE	1	NO. OF SLOTS	29.
SLOT WIDTH	.053	SLOT DEPTH	.092
WSR1	.000	D1R	.087
WSR2	.000	D2R	.005
WSR3	.000	D3R	.000
WSR4	.053	D4R	.000
WSR5	.053	D6R	.000
WSR6	.003		
USABLE AREA	.004	TOTAL AREA	.005

ROTOR WINDING

MATERIAL	3
BAR LENGTH	1.515
BAR CROSS-SECTION	.004
END-RING OUTSIDE DIA	1.013
END-RING INSIDE DIA	.500
END-RING THICKNESS	.135
STACK-TO-END-RING CLRNCE	.000
WINDING TEMPERATURE (C)	30.
WEIGHT	.100
COMPONENT OF R2 DUE TO BARS	2.084
COMPONENT OF R2 DUE TO END RINGS	.071

```
AIRGAP
    ACTUAL AIRGAP                                         .0060
    EFFECTIVE AIRGAP                                      .0141
    MAGNETIZING REACTANCE (AIR GAP ONLY)                12.73

LEAKAGE REACTANCES (OHM)
                                STATOR               ROTOR
    SLOT                         8.332                1.673
    END-CONNECTION                .579                 .161
    SKEW                          .877                 .877
    ZIG-ZAG                       .619                1.173
    PERIPHERAL                    .030

WEIGHT
    TOTAL (ELECTROMAGNETIC)                              1.440

STATOR MATERIAL - VANADIUM PERMENDUR
                  B MAX □ 154.
                  CORE LOSS AT  77.4 KL/SQ-IN= 34.4 W/LB

ROTOR MATERIAL -- VANADIUM PERMENDUR
                  B MAX = 154.

MAGNETIZATION CHARACTERISTICS
  (NO-LOAD, RATED VOLTAGE)

    TOTAL USEFUL FLUX                                  158.42 KILOLINES
    USEFUL FLUX/POLE                                     8.41

    FLUX DENSITIES
        AIRGAP                                          38.01 KL/SQ-IN
        STATOR TOOTH                                    86.76
        STATOR YOKE                                     19.13
        ROTOR TOOTH                                     88.07
        ROTOR YOKE                                      17.58

    AMPERE-TURNS PER POLE
        AIRGAP                                         167.53
        STATOR TOOTH                                     1.79
        STATOR YOKE                                       .62
        ROTOR TOOTH                                       .32
        ROTOR YOKE                                        .18

        TOTAL                                          170.44

    MAGNETIZING CURRENT                                  5.22 AMPERES
    AIRGAP VOLTAGE                                      65.19
    N.L. CURRENT DENSITY                             10380.04
    CORE LOSS                                           41. WATT

WINDAGE
                              DESIGN           REFERENCE
                              CONDITION        CONDITION

    WINDAGE LOSS, W             56.              45.
    DIAMETER                     1.058            1.050
    LENGTH                       1.240            1.125
    RPM                      12000.           12000.
    GAP                           .006             .010
    TEMP, DEG C                 25.              20.
    VSCSTY, LBM/FT-SEC         .121-02          .129-02
    PRESSURE, LBS/SQ-IN         .000             .000

    FLUID                               DC-200
```

EQUIVALENT CIRCUIT PARAMETERS

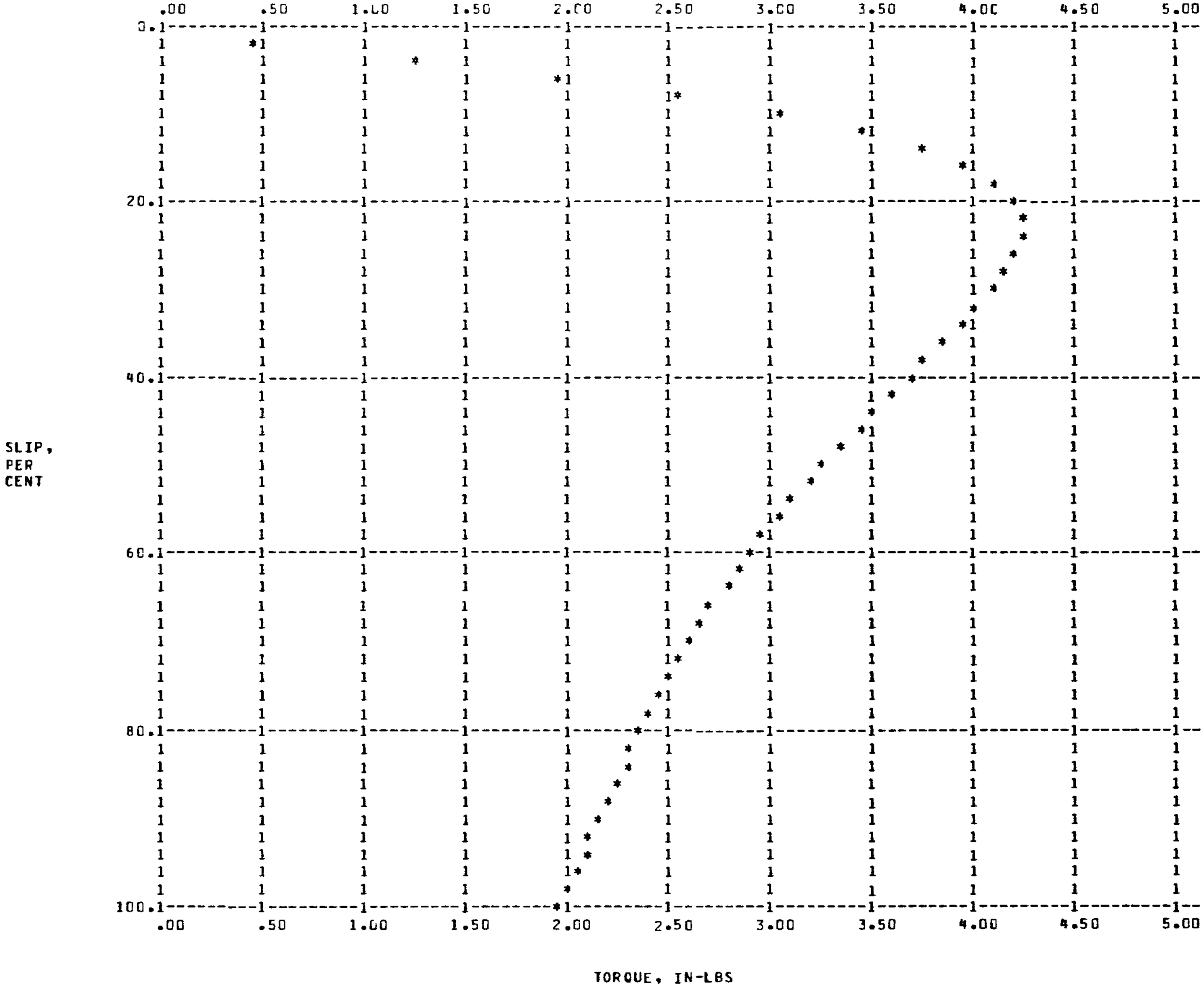
R1 =	1.190	X1 =	10.436
R2 =	2.155	X2 =	3.882
R0 =	312.278	X0 ■	12.510

MOTOR PERFORMANCE AT 120.00 VOLT, 1200.0 HZ

TORQUE (IN-LBS)	SLIP (PERCENT)	RPM	P-OUT (HP)	P-OUT (WATT)	I (AMP)	EFF (PERCENT)	PF (*=LEADING)	P-IN (WATT)	PRI LOSS (WATT)	SEC LOSS (WATT)	IRON LOSS (WATT)	FW (WATT)
.03	1.00	11880.00	.00	3.69	5.23	1.87	.10	197.23	97.67	.59	40.66	54.62
.44	2.00	11760.00	.08	61.05	5.26	23.87	.14	255.72	98.80	2.33	40.29	53.26
.84	3.00	11640.00	.15	115.47	5.31	36.90	.16	312.96	100.61	5.18	39.80	51.91
1.23	4.00	11520.00	.22	166.48	5.37	45.19	.19	368.36	103.05	9.04	39.20	50.58
1.59	5.00	11400.00	.29	213.69	5.45	50.71	.21	421.39	106.08	13.84	38.51	49.27
1.94	6.00	11280.00	.34	256.64	5.54	54.46	.24	471.63	109.61	19.46	37.73	47.99
2.00	6.20	11255.47	.36	265.15	5.56	55.07	.24	481.52	110.39	20.70	37.56	47.73
2.25	7.00	11160.00	.40	295.77	5.64	57.02	.26	518.73	113.58	25.78	36.88	46.72
2.54	8.00	11040.00	.44	330.41	5.75	58.74	.27	562.46	117.92	32.69	35.97	45.47
2.81	9.00	10920.00	.48	360.81	5.86	59.87	.29	602.67	122.54	40.06	35.02	44.25
3.05	10.00	10800.00	.52	387.05	5.97	60.54	.30	639.30	127.38	47.79	34.04	43.04
3.26	11.00	10680.00	.55	409.32	6.09	60.88	.31	672.36	132.37	55.76	33.05	41.86
3.44	12.00	10560.00	.57	427.65	6.21	60.95	.31	701.93	137.46	63.89	32.04	40.69
3.61	13.00	10440.00	.59	442.66	6.32	60.82	.32	728.12	142.58	72.08	31.04	39.55
3.74	14.00	10320.00	.61	454.66	6.43	60.53	.32	751.09	147.70	80.27	30.05	38.42
3.86	15.00	10200.00	.62	463.51	6.54	60.11	.33	771.04	152.76	88.38	29.08	37.31
3.96	16.00	10080.00	.63	469.70	6.65	59.59	.33	788.17	157.75	96.37	28.13	36.22
4.04	17.00	9960.00	.63	473.52	6.75	58.99	.33	802.70	162.63	104.19	27.21	35.16
4.10	18.00	9840.00	.64	475.22	6.85	58.32	.33	814.83	167.39	111.80	26.31	34.11
4.15	19.00	9720.00	.64	475.07	6.94	57.60	.33	824.79	172.00	119.19	25.45	33.08
4.19	20.00	9600.00	.63	473.29	7.03	56.83	.33	832.77	176.46	126.34	24.62	32.06
4.21	21.00	9480.00	.63	470.11	7.12	56.03	.33	838.99	180.75	133.22	23.83	31.07
4.23	22.00	9360.00	.62	465.72	7.20	55.21	.33	843.61	184.88	139.85	23.07	30.10
4.23	23.00	9240.00	.62	460.30	7.27	54.36	.32	846.82	188.84	146.20	22.34	29.14
4.23	24.00	9120.00	.61	454.01	7.35	53.49	.32	848.77	192.63	152.28	21.65	28.21
4.22	25.00	9000.00	.60	446.99	7.41	52.61	.32	849.62	196.26	158.09	20.99	27.29
4.21	26.00	8880.00	.59	439.37	7.48	51.72	.32	849.49	199.72	163.65	20.37	26.39
4.18	27.00	8760.00	.58	431.27	7.54	50.83	.31	848.51	203.02	168.94	19.77	25.50
4.16	28.00	8640.00	.57	422.77	7.60	49.93	.31	846.78	206.16	173.99	19.21	24.64
4.13	29.00	8520.00	.55	413.97	7.65	49.03	.31	844.40	209.16	178.80	18.67	23.79
4.10	30.00	8400.00	.54	404.94	7.71	48.12	.30	841.47	212.01	183.39	18.17	22.96
4.06	31.00	8280.00	.53	395.74	7.76	47.22	.30	838.05	214.73	187.75	17.69	22.15
4.02	32.00	8160.00	.52	386.42	7.80	46.32	.30	834.22	217.31	191.90	17.23	21.36
3.99	33.00	8040.00	.51	377.05	7.85	45.43	.29	830.05	219.77	195.85	16.80	20.58
3.95	34.00	7920.00	.49	367.65	7.89	44.53	.29	825.58	222.11	199.61	16.39	19.82
3.90	35.00	7800.00	.48	358.26	7.93	43.64	.29	820.86	224.34	203.18	16.00	19.08
3.86	36.00	7680.00	.47	348.92	7.96	42.76	.28	815.94	226.46	206.59	15.63	18.35
3.82	37.00	7560.00	.46	339.63	8.00	41.89	.28	810.86	228.47	209.83	15.28	17.65
3.77	38.00	7440.00	.44	330.44	8.03	41.02	.28	805.65	230.39	212.92	14.94	16.95
3.73	39.00	7320.00	.43	321.34	8.07	40.15	.28	800.33	232.22	215.86	14.63	16.28
3.69	40.00	7200.00	.42	312.37	8.10	39.29	.27	794.94	233.96	218.66	14.33	15.62
3.64	41.00	7080.00	.41	303.52	8.12	38.44	.27	789.49	235.62	221.33	14.04	14.98
3.60	42.00	6960.00	.40	294.81	8.15	37.60	.27	784.01	237.21	223.87	13.77	14.35
3.56	43.00	6840.00	.38	286.24	8.18	36.77	.26	778.51	238.71	226.30	13.51	13.74
3.51	44.00	6720.00	.37	277.82	8.20	35.94	.26	773.01	240.15	228.62	13.27	13.15
3.47	45.00	6600.00	.36	269.56	8.23	35.12	.26	767.52	241.53	230.83	13.04	12.57

3.43	46.00	6480.00	.35	261.45	8.25	34.31	.26	762.05	242.84	232.94	12.81	12.00
3.39	47.00	6360.00	.34	253.50	8.27	33.50	.25	756.61	244.10	234.96	12.60	11.45
3.35	48.00	6240.00	.33	245.71	8.29	32.71	.25	751.21	245.29	236.89	12.40	10.92
3.31	49.00	6120.00	.32	238.07	8.31	31.92	.25	745.86	246.44	238.73	12.21	10.40
3.27	50.00	6000.00	.31	230.60	8.33	31.14	.25	740.56	247.54	240.50	12.03	9.90
3.23	51.00	5880.00	.30	223.28	8.34	30.36	.24	735.32	248.59	242.19	11.85	9.41
3.19	52.00	5760.00	.29	216.11	8.36	29.60	.24	730.13	249.59	243.81	11.68	8.94
3.15	53.00	5640.00	.28	209.10	8.38	28.84	.24	725.01	250.55	245.36	11.52	8.48
3.11	54.00	5520.00	.27	202.23	8.39	28.09	.24	719.96	251.48	246.84	11.37	8.04
3.08	55.00	5400.00	.26	195.52	8.41	27.35	.24	714.98	252.36	248.27	11.22	7.61
3.04	56.00	5280.00	.25	188.95	8.42	26.61	.23	710.07	253.21	249.63	11.08	7.19
3.01	57.00	5160.00	.24	182.52	8.44	25.88	.23	705.23	254.02	250.95	10.95	6.79
2.97	58.00	5040.00	.24	176.23	8.45	25.16	.23	700.47	254.81	252.21	10.82	6.40
2.94	59.00	4920.00	.23	170.08	8.46	24.44	.23	695.78	255.56	253.42	10.70	6.03
2.90	60.00	4800.00	.22	164.05	8.47	23.74	.23	691.17	256.28	254.58	10.58	5.67
2.87	61.00	4680.00	.21	158.16	8.48	23.03	.22	686.63	256.97	255.70	10.47	5.32
2.84	62.00	4560.00	.20	152.39	8.50	22.34	.22	682.16	257.64	256.78	10.36	4.99
2.81	63.00	4440.00	.20	146.75	8.51	21.65	.22	677.77	258.28	257.81	10.26	4.66
2.78	64.00	4320.00	.19	141.23	8.52	20.97	.22	673.45	258.90	258.81	10.16	4.36
2.75	65.00	4200.00	.18	135.82	8.53	20.30	.22	669.21	259.50	259.77	10.06	4.06
2.72	66.00	4080.00	.17	130.52	8.54	19.63	.22	665.04	260.07	260.70	9.97	3.78
2.69	67.00	3960.00	.17	125.34	8.54	18.96	.21	660.94	260.63	261.59	9.88	3.50
2.66	68.00	3840.00	.16	120.26	8.55	18.31	.21	656.92	261.16	262.45	9.80	3.24
2.63	69.00	3720.00	.15	115.29	8.56	17.66	.21	652.96	261.68	263.28	9.71	3.00
2.61	70.00	3600.00	.15	110.42	8.57	17.01	.21	649.07	262.17	264.08	9.64	2.76
2.58	71.00	3480.00	.14	105.65	8.58	16.37	.21	645.25	262.65	264.86	9.56	2.54
2.55	72.00	3360.00	.14	100.97	8.59	15.74	.21	641.50	263.12	265.61	9.49	2.32
2.53	73.00	3240.00	.13	96.38	8.59	15.11	.21	637.81	263.56	266.33	9.42	2.12
2.50	74.00	3120.00	.12	91.89	8.60	14.49	.20	634.19	264.00	267.03	9.35	1.93
2.48	75.00	3000.00	.12	87.48	8.61	13.87	.20	630.63	264.42	267.70	9.28	1.75
2.45	76.00	2880.00	.11	83.16	8.61	13.26	.20	627.14	264.82	268.36	9.22	1.58
2.43	77.00	2760.00	.11	78.93	8.62	12.65	.20	623.70	265.21	268.99	9.16	1.42
2.41	78.00	2640.00	.10	74.77	8.63	12.05	.20	620.33	265.59	269.60	9.10	1.27
2.38	79.00	2520.00	.09	70.69	8.63	11.46	.20	617.01	265.96	270.19	9.04	1.13
2.36	80.00	2400.00	.09	66.69	8.64	10.87	.20	613.76	266.31	270.77	8.99	1.00
2.34	81.00	2280.00	.08	62.76	8.64	10.28	.20	610.56	266.66	271.32	8.93	.88
2.32	82.00	2160.00	.08	58.91	8.65	9.70	.20	607.41	266.99	271.86	8.88	.77
2.30	83.00	2040.00	.07	55.12	8.65	9.12	.19	604.32	267.32	272.39	8.83	.67
2.28	84.00	1920.00	.07	51.41	8.66	8.55	.19	601.28	267.63	272.89	8.78	.57
2.25	85.00	1800.00	.06	47.76	8.66	7.98	.19	598.30	267.93	273.38	8.74	.49
2.23	86.00	1680.00	.06	44.17	8.67	7.42	.19	595.36	268.23	273.86	8.69	.41
2.21	87.00	1560.00	.05	40.65	8.67	6.86	.19	592.48	268.52	274.33	8.65	.34
2.19	88.00	1440.00	.05	37.19	8.68	6.31	.19	589.64	268.79	274.78	8.60	.28
2.18	89.00	1320.00	.05	33.79	8.68	5.76	.19	586.86	269.06	275.21	8.56	.22
2.16	90.00	1200.00	.04	30.45	8.69	5.21	.19	584.11	269.33	275.64	8.52	.18
2.14	91.00	1080.00	.04	27.17	8.69	4.67	.19	581.42	269.58	276.05	8.48	.14
2.12	92.00	960.00	.03	23.94	8.69	4.14	.18	578.77	269.83	276.45	8.45	.10
2.10	93.00	840.00	.03	20.76	8.70	3.60	.18	576.16	270.07	276.84	8.41	.07
2.08	94.00	720.00	.02	17.65	8.70	3.08	.18	573.60	270.31	277.22	8.38	.05
2.06	95.00	600.00	.02	14.58	8.71	2.55	.18	571.08	270.54	277.59	8.34	.03
2.05	96.00	480.00	.02	11.56	8.71	2.03	.18	568.60	270.76	277.95	8.31	.02
2.03	97.00	360.00	.01	8.60	8.71	1.52	.18	566.16	270.97	278.30	8.28	.01
2.01	98.00	240.00	.01	5.68	8.72	1.01	.18	563.76	271.19	278.64	8.24	.00
2.00	99.00	120.00	.00	2.82	8.72	.50	.18	561.39	271.39	278.97	8.21	.00
1.97	100.00	.00	.00	.00	8.72	.00	.18	559.07	271.59	279.29	8.18	.00

CURRENT DENSITY AT RATED TORQUE IN ROTOR BAR = 12573.
IN END RING = 13134.
IN ARMATURE = 11047.



.00
.50
1.00
1.50
2.00
2.50
3.00
3.50
4.00
4.50
5.00
0.
20.
40.
60.
80.
100.
SLIP, PER CENT
TORQUE, IN-LBS

APPENDIX C

PROGRAM LISTINGS

The complete FORTRAN listings of the main program and the five subroutines, which together constitute the induction motor computer program, are shown in this appendix. The main program is INDMTR and the five subroutines are, in the order given, CIRCT, MAGNET, SLOTS, WDGFCT, and CMBNTN.

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      COMMON /CIR/ R0,R1,R2,X0,X1,X2,FW1,NSYNCH,V1,S,I1,RPM,PF,T,HP,EFF,
     1PIN,W1,W2,W0,FW,IMAG,V2,POUT,PHASE
      COMMON /MAG/ BST,BSY,BRT,BRY,ATST,ATSY,ATRT,ATRY,ASYOKE,ASTOTH,ARY
     1OKE,ARTOTH,LSYOKE,LRYOKE,DSS,DSR,FTOTAL,FPOLE,KSAT,AI,ATAG,ATTOT
      COMMON /INITL/ ASTRND,AWG,CSRATO,DER1,DER2,D1R,D1S,D2R,D2S,D3R,D3S
     1,D4R,D4S,D5S,JBAR,LB,LS,PFLUID,RTWDTH,SB,SCAREA,SFR,SFS,SKEW,SSARE
     2A,STWDTH,TRATED,VSCFLD,WSR1,WSR2,WSR3,WSR4,WSR5,WSS,WSS1,WSS2,WSS3
     3,WSS4
C
      EQUIVALENCE (RESET1(1),ASTRND), (RESET2(1),R0)
C
      REAL I1,IBAR,JBAR,JRING,LARM,LT,LTS,LTR,LSYOKE,LRYOKE,LTOTAL,IMAG,
     1IMAG2,NSYNCH,KPS,KDS,N,LB,NB,KRING,L,LS,KS,LREF,MATDEK,NAME
C
      INTEGER SSTYPE,RSTYPE,AWG,RWMAT,SWMAT
C
      LOGICAL LAST
C
      DIMENSION SLIP(70), TORQUE(70), PP(61), XLGND(3), AI(60), SMAT(13)
     1, RMAT(13), WAREA(40), RSTVTY(5), TMPCF(5), TITLE(13), DNSTY(5), C
     2LOSS(5,10), RESET1(38), RESET2(7), NAME(13)
C
      NAMELIST /RATING/ NSYNCH,F,X0,X1,X2,R0,R1,R2,FW1,V1,TRATED/STATOR/
     1D,L,LTS,SFS,DOS/SSLOTS/D6S,WSS6,QS,DSS,WSS,SSTYPE,D2S,D1S,D4S,D3S,
     2WSS1,WSS2,PHIS,D5S,STWDTH,SCAREA,CSRATO/STRWDG/CSS,PC,B,SWMAT,SPIT
     3CH,LS,ASTRND,TSW,S,AWG,STRNDS/ROTOR/SKEW,LTR,SFR,DIR/RSLOTS/SB,D6R
     4,WSR6,RSTYPE,D4R,D3R,WSR1,WSR,D2R,D1R,WSR2,PHIR,DSR,RTWDTH/RTRWDG/
     5LB,NB,DER1,DER2,TER,RWMAT,TRW,BR/AIRGAP/G,TFLUID,VSCFLD,PFLUID,FLD
     6NME
      NAMELIST /FELOSS/ WCORE,FCORE,SLOPE,BK,LT,LAST/WNDAGE/WL,DIAREF,LR
     1EF,RPMREF,VSCREF,C0,C1,C2,C3,C4,GAPREF,TREF,PREF
C
      DATA RSTVTY/1.08,2.95,0.678,0.,0./,TMPCF/.00415,.002,.00393,0.,0./
     1,DNSTY/0.0975,0.308,0.321,0.,0./
      DATA (WAREA(I),I=1,40)/0.06573,.05213,.04134,.03278,.02600,.02062,
     1.01635,.01297,.01028,0.008155,0.006467,0.005129,0.004067,0.003225,
     20.002558,0.002028,0.001609,0.001276,0.001012,0.0008023,0.0006363,0
     3.0005046,0.0004002,0.0003173,0.0002517,0.0001996,0.0001583,0.00012
     455,9.953E-5,7.894E-5,6.260E-5,4.964E-5,3.937E-5,3.122E-5,2.476E-5,
     51.964E-5,1.557E-5,1.235E-5,9.793E-6,7.766E-6/
      DATA XLGND(1)/18HSLIP, PER   CENT  /,(PP(I),I=5,10),KODE/2.,5.,0.,
     120.,4.,0.,56/
      DATA BLANK/6H      /,MATDEK/1HM/
C
C     THE FOLLOWING ARITHMETIC STATEMENT FUNCTION GIVES THE VISCOSITY
C        OF THE FLUID IN THE MOTOR CAVITY AS A FUNCTION OF TEMPERATURE,
C        VSCSTY IS IN LBM/FT-SEC AND T IN DEG C
C
      VSCSTY(T)=C0+T*(C1+T*(C2+T*(C3+C4*T)))
C
10    READ (5,20) DEKTYP,NAME
20    FORMAT (A1,1X,13A6)
      IF (DEKTYP.EQ.MATDEK) GO TO 40
      DO 30 I=1,13
```

```
30    TITLE(I)=NAME(I)
      GO TO 140
40    DO 50 I=1,13
50    SMAT(I)=NAME(I)
C
C
C     INITIALIZATION AT START OF A NEW DATA SET
C
      LAST=.FALSE.
      TREF=25.
      VSCREF=0.
      PREF=0.
      RPMREF=0.
      LREF=0.
      DIAREF=0.
      GAPREF=0.
      C0=0.
      C1=0.
      C2=0.
      C3=0.
      C4=0.
      WL=0.
C
C     READ AND WRITE STATOR MATERIAL MAGNETIZATION DATA
C
      READ (5,60) (AI(I),I=1,29)
60    FORMAT (8F10.1)
      WRITE (6,70) SMAT
70    FORMAT (1H1,4X,15HSTATOR MATERIAL/7X,13A6)
      WRITE (6,80) (AI(I),I=2,29)
80    FORMAT (1HK,12X,1HB,20X,1HH//5X,17H(KILOLINES/SQ-IN),7X,11H(A-TURN
     1/IN)//(F16.2,F21.2))
C
      WRITE (6,90)
90    FORMAT (1HK,6X,14HCORE-LOSS DATA/10X,9HCORE-LOSS,5X,7HLAM THK,5X,4
     1HFREQ,5X,10HFLUX DNSTY,5X,5HSLOPE)
C
C     READ CORE LOSS DATA FOR STATOR MATERIAL
C
      DO 100 I=1,11
      SLOPE=0.
      READ (5,FELOSS)
      IF (LAST) GO TO 120
      CLOSS(1,I)=WCORE
      CLOSS(2,I)=FCORE
      IF (SLOPE.LT.1.0E-15) SLOPE=(1.0+164.*LT)/(1.0+82.*LT)
      CLOSS(3,I)=SLOPE
      CLOSS(4,I)=BK
      CLOSS(5,I)=LT
100   WRITE (6,110) WCORE,LT,FCORE,BK,SLOPE
110   FORMAT (1H ,F15.1,F14.3,F11.1,F11.1,F12.1)
120   NCARDS=I-1
C
C     READ ROTOR MATERIAL MAGNETIZATION DATA
C
      READ (5,20) DEKTYP,RMAT
      READ (5,60) (AI(I),I=31,59)
      WRITE (6,130) RMAT
130   FORMAT (1HL,4X,14HROTOR MATERIAL/7X,13A6)
      WRITE (6,80) (AI(I),I=32,59)
C
C     READ WINDAGE DATA
C
      READ (5,WNDAGE)
      IF (VSCREF.LT.1.0E-15) VSCREF=VSCSTY(TREF)
C
      READ (5,20) DEKTYP,TITLE
C
140   WRITE (6,150) TITLE
150   FORMAT (1H1/1H ,2X,13A6)
C
C     INITIALIZATION AT BEGINNING OF A NEW MOTOR DESIGN DECK
C
```

```
      DO 160 I=1,38
160   RESET1(I)=0.
      DO 170 I=1,7
170   RESET2(I)=0.
      DSR=0.
      DSS=0.
      FLDNME=BLANK
      PHIR=0.
      PHIS=0.
      RWMAT=3
      STRNDS=1.0
      SWMAT=3
      TFLUID=TREF
      TRW=25.
      TSW=25.
      DO 180 I=12,61
180   PP(I)=BLANK
C
C     READ 'MOTOR DESIGN' DECK
C
      READ (5,RATING)
      IF (X0*X1*X2*R0*R1*R2.GT.1.0E-15) GO TO 720
      READ (5,STATOR)
      READ (5,SSLOTS)
      READ (5,STRWDG)
      READ (5,ROTOR)
      READ (5,RSLOTS)
      READ (5,RTRWDG)
      READ (5,AIRGAP)
C
C     RETRIEVE CORE LOSS DATA FROM ARRAY CLOSS FOR DESIGN LAMINATION
C        THICKNESS
C
      DIFF=10.
      DO 190 I=1,NCARDS
      DIFF1=ABS(LTS-CLOSS(5,I))
      IF (DIFF1.GT.DIFF) GO TO 190
      IA=I
      DIFF=DIFF1
190   CONTINUE
      IF (DIFF.GT.0.0005) WRITE (6,200) CLOSS(5,IA)
200   FORMAT (1HK,68HCORE-LOSS DATA IS NOT GIVEN AT SPECIFIED STATOR LAM
     1INATION THICKNESS/1H ,3X,12HUSE DATA FOR,F6.3,12H LAMINATIONS)
C
C     CALCULATE CORE LOSS AT DESIGN FREQUENCY
C
      WFE=CLOSS(1,IA)*((F/CLOSS(2,IA))**CLOSS(3,IA))
      BK=CLOSS(4,IA)
C
C     CALCULATE VARIOUS DIMENSIONS FROM INPUT DATA
C
      DR=D-2.*G
      T1R=(3.1416*(DR))/NB
      T1S=(3.1416*D)/QS
      IF (SKEW.LT.1.0E-15) SKEW=AMAX1(T1R,T1S)
      IF (LB.LT.1.0E-15) LB=SQRT(L*L+SKEW*SKEW)+2.*(BR+TER)
      IF (ASTRND.LT.1.0E-15) ASTRND=WAREA(AWG)
      SS=ASTRND*STRNDS
      IF (SFR.LT.1.0E-15) SFR=LTR/(LTR+0.0005)
      IF (SFS.LT.1.0E-15) SFS=LTS/(LTS+0.0005)
C
      IF (DSS.GT.1.0E-15.OR.D1S.GT.1.0E-15) GO TO 230
      IF (SCAREA.GT.1.0E-15) GO TO 240
      IF (CSRATO.GT.1.0E-15) GO TO 220
      WRITE (6,210)
210   FORMAT (1HK,59HINSUFFICIENT STATOR SLOT DATA, SPACE FACTOR OF 0.70
     1 ASSUMED)
      CSRATO=0.70
220   SCAREA=CSS*SS/CSRATO
      GO TO 250
230   SCAREA=0.
240   CSRATO=0.
C
```

```
250   IF (SPITCH.LE.0.3333) KS=0.75*SPITCH
      IF (SPITCH.GT.0.3333.AND.SPITCH.LT.0.6667) KS=1.5*SPITCH-0.25
      IF (SPITCH.GE.0.6667) KS=0.75*SPITCH+0.25
C
      CALL SLOTS (1.0,SSTYPE,WSS,WSS1,WSS2,WSS3,WSS4,WSS5,DSS,D1S,D2S,D3
     1S,D4S,D5S,STWDTH,SCAREA,SSAREA,QS,D6S,WSS6,D,KS,AXS,STWMAG,PHIS)
C
      CALL SLOTS (-1.0,RSTYPE,WSR,WSR1,WSR2,WSR3,WSR4,WSR5,DSR,D1R,D2R,D
     13R,D4R,0.,RTWDTH,SB,RSAREA,NB,D6R,WSR6,DR,1.0,AXR,RTWMAG,PHIR)
C
C     STATOR AND ROTOR IRON WEIGHTS
C
      WSTOTH=(3.1416*(D+DSS)*DSS-(SSAREA*QS))*L*SFS*.283
      WSYOKE=(0.7854*(DOS*DOS-(D+2.*DSS)**2))*L*SFS*0.283
      WSTAT=WSTOTH+WSYOKE
      WROT=(0.7854*(DR*DR-DIR*DIR)-NB*(RSAREA))*L*SFR*0.283
C
C     END RING DIMENSIONS
C
      IF (DER1.LT.1.0E-15) DER1=DR-2.*(D4R+D3R)
      IF (DER2.LT.1.0E-15) DER2=AMAX1(DR-3.*DSR,1.1*DIR)
      SER=0.5*(DER1-DER2)*TER
C
      IF (CSRATO.LT.1.0E-15) CSRATO=CSS*SS/SCAREA
      P=FLOAT(IFIX(((120.*F)/NSYNCH)+0.1))
      N=(QS*CSS)/(PC*3.)
      DBS=(DOS-D)*0.5-DSS
      DBRS=(DR-DIR)*0.5-DSR
C
C     CHECK IF STATOR-ROTOR SLOT COMBINATION IS ACCEPTABLE
C
      CALL CMBNTN (QS,NB,P)
C
C     CALCULATE DISTRIBUTION AND PITCH FACTORS
C
      CALL WDGFCT (60.,P,QS,KDS,PC,KPS,SPITCH)
C
C     CARTER COEFFICIENTS AND EFFECTIVE AIRGAP
C
      IF (RSTYPE.GT.2) GO TO 260
      CCR=(T1R*(5.*G+WSR))/(T1R*(5.*G+WSR)-WSR*WSR)
      GO TO 270
260   CCR=(T1R*(4.4*G+0.75*WSR1))/(T1R*(4.4*G+0.75*WSR1)-WSR1*WSR1)
270   IF (SSTYPE.GT.2) GO TO 280
      CCS=(T1S*(5.*G+WSS))/(T1S*(5.*G+WSS)-WSS*WSS)
      GO TO 290
280   CCS=(T1S*(4.4*G+0.75*WSS1))/(T1S*(4.4*G+0.75*WSS1)-WSS1*WSS1)
290   GE=G*CCR*CCS
C
C     STATOR RESISTANCE CALCULATION (R1)
C
      IF (SSTYPE.EQ.2.OR.SSTYPE.EQ.4.OR.SSTYPE.EQ.6) SALPHA=(0.5*(WSS4+W
     1SS5)+S-2.*WSS6)/(3.1416*(D+DSS)/QS)
      IF (SSTYPE.EQ.1.OR.SSTYPE.EQ.3) SALPHA=(WSS+S-2.*WSS6)/T1S
      IF (SSTYPE.EQ.5) SALPHA=(WSS3+S-2.*WSS6)/(3.1416*(D+2.*D4S+WSS3)/Q
     1S)
      CALPHA=SQRT(1.-SALPHA**2)
      AY=(3.1416*(D+DSS)*SPITCH)/(P*CALPHA)
      IF (LS.LT.1.0E-15) LS=AY+2.*B+DSS+L
      IF (R1.GT.1.0E-15) GO TO 300
      R1=(LS*N*RSTVTY(SWMAT)*1.0E-6)/(PC*SS)
      R1=R1*(1.+TMPCF(SWMAT)*(TSW-20.))
C
C     AXIAL EXTENSION OF END TURN AND OVERALL ARMATURE LENGTH
C
300   ENDTRN=AY*0.5*SALPHA+B+DSS
      LTOTAL=L+2.*ENDTRN
C
C     ARMATURE WEIGHT AND TOTAL WIRE LENGTH
C
      LARM=(LS*CSS*QS*STRNDS)/12.
      WARM=DNSTY(SWMAT)*LARM*ASTRND*12.
C
```

```
C     ROTOR RESISTANCE CALCULATION (R2)
C
      BRSTVY=1.0E-6*RSTVTY(RWMAT)*(1.0+TMPCF(RWMAT)*(TRW-20.))
      IF (R2.GT.1.0E-15) GO TO 310
      RATIO=DER2/DER1
      KRING=0.50*P*(1.-RATIO)*(1.+RATIO**P)/(1.-RATIO**P)
      AY=((N*KPS*KDS)**2)*3.*BRSTVY
      R2BAR=AY*((LB-TER)/(SB*NB))
      R2RING=AY*((0.64*DER1*KRING)/(P*P*SER))
      R2=R2BAR+R2RING
C
C     ROTOR WINDING WEIGHT AND TOTAL ELECTROMAGNETIC MOTOR WEIGHT
C
310   WRWNDG=DNSTY(RWMAT)*(NB*SB*(LB-2.*TER)+SER*3.1416*(DER1+DER2))
      WEIGHT=WARM+WRWNDG+WROT+WSTAT
C
C     MAGNETIZING REACTANCE (AIR GAP ONLY)
C
      X0AG=7.66E-7*F*(N/2.*KPS*KDS)**2*D*L/(P*P*GE)
C
C     PRIMARY SLOT LEAKAGE REACTANCE (XSS)
C
      AY=6.E-7*N*N*F*L
      XSS=AY*AXS/QS
C
C     SECONDARY SLOT LEAKAGE REACTANCE (XRS)
C
      XRS=AY*(KPS*KDS)**2*AXR/NB
C
C     ROTOR AND STATOR END-CONNECTION LEAKAGE REACTANCE
C
      DC=(D+2.*(D4S+D3S+D2S)+D1S-0.50*(DER1+DER2))*0.50
      AY=((N*N*F*(KPS*KDS)**2)/P)*2.4E-7
      F1=1.5708*(D+DSS)*SPITCH*SQRT(1.0-CALPHA*CALPHA)/(P*CALPHA)
      XSE=AY*(B+0.5*(F1+DSS/2.))
      XRE=(0.725*AY/P)*(2.*P*BR+(3.1416*D*DC)/(1.7*TER+0.6*(DER1-DER2)+1
     1.4*DC))
C
C     SKEW REACTANCE (XSK)
C
      XSK=0.5*(X0AG/12.)*(P*SKEW/D)**2
C
C     STATOR AND ROTOR ZIGZAG LEAKAGE REACTANCE
C
      XZ=0.8333*X0AG*(KS/(KPS*KDS)**2)
      XRZ=XZ*((6./CCR-1.)/(5.*(NB/P)**2))
      XSZ=XZ*((6./CCS-1.)/(5.*(QS/P)**2))
C
C     PERIPHERAL AIR-GAP LEAKAGE REACTANCE (XP)
C
      XP=0.525*X0AG*(P*G/D)**2
C
C     TOTAL ARMATURE AND ROTOR LEAKAGE REACTANCES (X1 AND X2)
C
      IF (ABS(X1).LT.1.0E-15) X1=XSS+XSE+XSK+XSZ+XP
      IF (X2.LT.1.0E-15) X2=XRS+XRE+XSK+XRZ
C
C     WRITE OUTPUT
C
      WRITE (6,320) NSYNCH,F,P,V1
320   FORMAT (1HL,5X,6HRATING/10X,17HSYNCHRONOUS SPEED,F26.0,4H RPM/10X,
     19HFREQUENCY,F34.0,3H HZ/10X,5HPOLES,F38.0/10X,11HL-N VOLTAGE,F33.1
     2,5H VOLT)
      IF (TRATED.GT.1.0E-15) WRITE (6,330) TRATED
330   FORMAT (1H ,9X,12HRATED TORQUE,F32.1,7H IN-LBS)
C
      WRITE (6,340) D,DOS,DBS,L,LTS,SFS,WSTAT
340   FORMAT (1HL,5X,6HSTATOR/10X,13HBORE DIAMETER,F33.3/10X,16HOUTSIDE
     1DIAMETER,F30.3/10X,16HDEPTH BELOW SLOT,F30.3/10X,6HLENGTH,F40.3/10
     2X,20HLAMINATION THICKNESS,F26.3/10X,15HSTACKING FACTOR,F31.3/10X,1
     38HSTATOR IRON WEIGHT,F28.3)
C
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```
      WRITE (6,350) SSTYPE,QS
350   FORMAT (1HL,5X,12HSTATOR SLOTS/10X,9HSLOT TYPE,I8,9X,12HNO. OF SLO
     1TS,F5.0)
      IF (SSTYPE.EQ.1.OR.SSTYPE.EQ.3) WRITE (6,360) WSS,DSS
      IF ((SSTYPE/2)*2.EQ.SSTYPE) WRITE (6,370) STWDTH,DSS
      IF (SSTYPE.EQ.5) WRITE (6,380) WSS3,DSS
360   FORMAT (10X,10HSLOT WIDTH,F10.3,6X,10HSLOT DEPTH,F10.3)
370   FORMAT (10X,11HTOOTH WIDTH,F9.3,6X,10HSLOT DEPTH,F10.3)
380   FORMAT (10X,13HSLOT DIAMETER,F7.3,6X,10HSLOT DEPTH,F10.3)
      WRITE (6,390) WSS1,D1S,WSS2,D2S,WSS3,D3S,WSS4,D4S,WSS5,D5S,WSS6,D6
     1S,SCAREA,SSAREA,CSRATO
390   FORMAT (10X,4HWSS1,F16.3,6X,3HD1S,F17.3/10X,4HWSS2,F16.3,6X,3HD2S,
     1F17.3/10X,4HWSS3,F16.3,6X,3HD3S,F17.3/10X,4HWSS4,F16.3,6X,3HD4S,F1
     27.3/10X,4HWSS5,F16.3,6X,3HD5S,F17.3/10X,4HWSS6,F16.3,6X,3HD6S,F17.
     33/10X,11HUSABLE AREA,F9.3,6X,10HTOTAL AREA,F10.3/10X,12HSPACE FACT
     4OR,F8.3)
C
      WRITE (6,400) SWMAT,CSS,PC,SPITCH,B,SS,ASTRND,LS,S,TSW,ENDTRN,LTOT
     1AL,KPS,KDS,WARM,LARM,STRNDS
400   FORMAT (1HL,5X,14HSTATOR WINDING/10X,8HMATERIAL,I35/10X,19HCONDUCT
     1ORS PER SLOT,F24.0/10X,17HPARALLEL CIRCUITS,F26.0/10X,5HPITCH,F41.
     23/10X,27HAXIAL EXTENSION BEYOND CORE,F19.3/10X,23HCONDUCTOR CROSS-
     3SECTION,E27.3/10X,20HSTRAND CROSS-SECTION,E30.3/10X,16HCONDUCTOR L
     4ENGTH,F30.3/10X,21HCLRNCE BTWN END-TURNS,F25.3/10X,15HTEMPERATURE
     5(C),F28.0/10X,21HAXIAL END-TURN LENGTH,F25.3/10X,23HOVERALL ARMATU
     6RE LENGTH,F23.3/10X,12HPITCH FACTOR,F34.3/10X,19HDISTRIBUTION FACT
     7OR,F27.3/10X,15HARMATURE WEIGHT,F31.3/10X,26HTOTAL ARMATURE WIRE L
     8ENGTH,F20.3,5H FEET/10X,17HSTRANDS/CONDUCTOR,F26.0)
      IF (AWG.GT.0) WRITE (6,410) AWG
410   FORMAT (1H ,9X,11HSTRAND SIZE,I32)
C
      WRITE (6,420) DR,DIR,LTR,SFR,SKEW,DBRS,WROT
420   FORMAT (1H1,5X,5HROTOR/10X,14HROTOR DIAMETER,F32.3/10X,15HINSIDE D
     1IAMETER,F31.3/10X,20HLAMINATION THICKNESS,F26.3/10X,15HSTACKING FA
     2CTOR,F31.3/10X,9HSLOT SKEW,F37.3/10X,16HDEPTH BELOW SLOT,F30.3/10X
     3,17HROTOR IRON WEIGHT,F29.3)
C
      WRITE (6,430) RSTYPE,NB
430   FORMAT (1HL,5X,11HROTOR SLOTS/10X,9HSLOT TYPE,I8,9X,12HNO. OF SLOT
     1S,F5.0)
      IF (RSTYPE.EQ.1.OR.RSTYPE.EQ.3) WRITE (6,440) WSR,DSR
      IF ((RSTYPE/2)*2.EQ.RSTYPE) WRITE (6,450) RTWDTH,DSR
      IF (RSTYPE.EQ.5) WRITE (6,460) WSR3,DSR
440   FORMAT (10X,10HSLOT WIDTH,F10.3,6X,10HSLOT DEPTH,F10.3)
450   FORMAT (10X,11HTOOTH WIDTH,F9.3,6X,10HSLOT DEPTH,F10.3)
460   FORMAT (10X,13HSLOT DIAMETER,F7.3,6X,10HSLOT DEPTH,F10.3)
      WRITE (6,470) WSR1,D1R,WSR2,D2R,WSR3,D3R,WSR4,D4R,WSR5,D6R,WSR6,SB
     1,RSAREA
470   FORMAT (10X,4HWSR1,F16.3,6X,3HD1R,F17.3/10X,4HWSR2,F16.3,6X,3HD2R,
     1F17.3/10X,4HWSR3,F16.3,6X,3HD3R,F17.3/10X,4HWSR4,F16.3,6X,3HD4R,F1
     27.3/10X,4HWSR5,F16.3,6X,3HD6R,F17.3/10X,4HWSR6,F16.3/10X,11HUSABLE
     3 AREA,F9.3,6X,10HTOTAL AREA,F10.3)
C
      WRITE (6,480) RWMAT,LB,SB,DER1,DER2,TER,BR,TRW,WRWNDG,R2BAR,R2RING
480   FORMAT (1HL,5X,13HROTOR WINDING/10X,8HMATERIAL,I35/10X,10HBAR LENG
     1TH,F36.3/10X,17HBAR CROSS-SECTION,F29.3/10X,20HEND-RING OUTSIDE DI
     2A,F26.3/10X,19HEND-RING INSIDE DIA,F27.3/10X,18HEND-RING THICKNESS
     3,F28.3/10X,24HSTACK-TO-END-RING CLRNCE,F22.3/10X,23HWINDING TEMPER
     4ATURE (C),F20.0/10X,6HWEIGHT,F40.3/10X,27HCOMPONENT OF R2 DUE TO B
     5ARS,F19.3/10X,32HCOMPONENT OF R2 DUE TO END RINGS,F14.3)
C
      WRITE (6,490) G,GE,XOAG
490   FORMAT (1HL,5X,6HAIRGAP/10X,13HACTUAL AIRGAP,F34.4/10X,16HEFFECTIV
     1E AIRGAP,F31.4/10X,36HMAGNETIZING REACTANCE (AIR GAP ONLY),F9.2)
C
      WRITE (6,500) XSS,XRS,XSE,XRE,XSK,XSK,XSZ,XRZ,XP
500   FORMAT (1HL,5X,24HLEAKAGE REACTANCES (OHM)/33X,6HSTATOR,11X,5HROTO
     1R/10X,4HSLOT,F26.3,F16.3/10X,14HEND-CONNECTION,F16.3,F16.3/10X,4HS
     2KEW,F26.3,F16.3/10X,7HZIG-ZAG,F23.3,F16.3/10X,10HPERIPHERAL,F20.3)
C
      WRITE (6,510) WEIGHT
510   FORMAT (1HL,5X,6HWEIGHT/10X,23HTOTAL (ELECTROMAGNETIC),F23.3/1H1)
C
```

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C     CROSS-SECTIONAL AREAS AND LENGTHS OF FLUX PATHS NEEDED FOR
C        MAGNETIC CALCULATIONS
C
      ASYOKE=DBS*L*SFS
      LSYOKE=3.1416*(DOS+D+2.*DSS)/(4.0*P)
      ARYOKE=DBRS*L*SFR
      LRYOKE=3.1416*(DR-2.*DSR+DIR)/(4.0*P)
      ARTOTH=RTWMAG*L*SFR*NB
      ASTOTH=STWMAG*L*SFS*QS
C
C     NO-LOAD MAGNETIC CALCULATIONS
C
      XX=1.0
      XY=1.0
      IF (XO.GT.1.0E-15) XX=0.0
      IF (RO.GT.1.0E-15) XY=0.0
      XO=XO+(0.5*XOAG)*XX
      WO=(WSYOKE+WSTOTH)*WFE*3.0
      RO=(5.*V1*V1/WO)*XY+RO
      S=0.
      ICNT2=0
520   ICNT2=ICNT2+1
      IF (ICNT2.GE.16) GO TO 550
      ICNT1=0
530   ICNT1=ICNT1+1
      IF (ICNT1.GE.11) GO TO 540
      CALL CIRCT
      ROOLD=RO
      FTOTAL=V2*P*1.0E+05/(1.414*N*F*KPS*KDS)
      FPOLE=FTOTAL*0.637/P
      BG=FTOTAL/(3.1416*D*L)
      ATAG=BG*GE*313.
      CALL MAGNET
      WO=(WSYOKE*(BSY/BK)**2+WSTOTH*(BST/BK)**2)*WFE*3.0
      RO=((3.*V2*V2/WO)-RO)*XY+RO
      IF (ABS(RO-ROOLD)/RO.GE.0.001) GO TO 530
540   IMAG2=2.22*P*ATTOT/(3.*N*KPS*KDS)
      XO=XO+((V2/(0.5*(IMAG+IMAG2)))-XO)*XX
      IF (ABS((IMAG-IMAG2)/IMAG).GT..005) GO TO 520
550   CURDEN=(SQRT(IMAG**2+(V2/RO)**2))/(PC*SS)
      IF (ICNT1.GE.11) WRITE (6,560)
      IF (ICNT2.GE.16) WRITE (6,570)
      IF (KSAT.EQ.0) WRITE (6,580)
560   FORMAT (1H ,38HSHUNT RESISTANCE RO FAILED TO CONVERGE//)
570   FORMAT (1H ,38HMAGNETIZING CURRENT FAILED TO CONVERGE//)
580   FORMAT (1H ,17HMACHINE SATURATED//)
C
C     WRITE RESULTS OF NO-LOAD MAGNETIC CALCULATIONS
C
      WRITE (6,590) SMAT,AI(1),BK,WFE
590   FORMAT (1H ,5X,17HSTATOR MATERIAL -,1H ,13A6/24X,7HB MAX =,F5.0/24
     1X,12HCORE LOSS AT,F6.1,10H KL/SQ-IN=,F5.1,5H W/LB)
      WRITE (6,600) RMAT,AI(31)
600   FORMAT (1HK,5X,17HROTOR MATERIAL --,1H ,13A6/24X,7HB MAX =,F5.0)
C
C     WRITE NO-LOAD MAGNETIZATION CHARACTERISTICS
C
      WRITE (6,610) FTOTAL,FPOLE,BG,BST,BSY,BRT,BRY,ATAG,ATST,ATSY,ATRT,
     1ATRY,ATTOT,IMAG,V2,CURDEN,WO
610   FORMAT (1HL,5X,29HMAGNETIZATION CHARACTERISTICS/7X25H (NO-LOAD, RA
     1TED VOLTAGE)//9X,18H TOTAL USEFUL FLUX,F28.2,10H KILOLINES/9X17H U
     2SEFUL FLUX/POLE,F29.2//9X15H FLUX DENSITIES/13X7H AIRGAP,F35.2,9H
     3KL/SQ-IN/13X13H STATOR TOOTH,F29.2/13X12H STATOR YOKE,F30.2/13X12H
     4 ROTOR TOOTH,F30.2/13X11H ROTOR YOKE,F31.2//9X22H AMPERE-TURNS PER
     5 POLE/13X7H AIRGAP,F35.2,/13X13H STATOR TOOTH,F29.2/13X12H STATOR
     6YOKE,F30.2/13X12H ROTOR TOOTH,F30.2/13X11H ROTOR YOKE,F31.2//13X6H
     7 TOTAL,F36.2//9X20H MAGNETIZING CURRENT,F26.2,8H AMPERES/10X,14HAI
     8RGAP VOLTAGE,F31.2/10X,20HN.L. CURRENT DENSITY,F25.2/10X,9HCORE LO
     9SS,F34.0,5H WATT)
C
C     SCALE WINDAGE LOSS FROM REFERENCE CONDITIONS TO DESIGN CONDITIONS
C
```

```
      WRITE (6,620)
620   FORMAT (1HL,5X,7HWINDAGE)
      IF (FW1.GT.1.0E-15) GO TO 700
      IF (WL.LE.1.0E-15) GO TO 630
      IF (DIAREF*LREF*RPMREF*GAPREF.GT.1.0E-15) GO TO 650
630   WRITE (6,640)
640   FORMAT (1HK,39HINSUFFICIENT DATA TO SCALE WINDAGE LOSS//)
      GO TO 700
650   FW1=WL*((DR/DIAREF)**3.25)*(L/LREF)*((NSYNCH/RPMREF)**2.5)*((GAPRE
     1F/G)**0.25)
      IF (VSCREF.LT.1.0E-15) GO TO 670
      IF (VSCFLD.GT.1.0E-15) GO TO 660
      VSCFLD=VSCSTY(TFLUID)
      IF (VSCFLD.LT.1.0E-15) GO TO 670
660   FW1=FW1*((VSCFLD/VSCREF)**0.50)
670   IF (PREF.LT.1.0E-15) GO TO 680
      IF (PFLUID.LT.1.0E-15) GO TO 680
      FW1=FW1*(PFLUID/PREF)
C
C     WRITE WINDAGE DATA
C
680   WRITE (6,690) FW1,WL,DR,DIAREF,L,LREF,NSYNCH,RPMREF,G,GAPREF,TFLUI
     1D,TREF,VSCFLD,VSCREF,PFLUID,PREF,FLDNME
690   FORMAT (1H ,31X,6HDESIGN,9X,9HREFERENCE/26X,2(6X,9HCONDITION)//10X
     1,15HWINDAGE LOSS, W,F13.0,F15.0/10X,8HDIAMETER,F23.3,F15.3/10X,6HL
     2ENGTH,F25.3,F15.3/10X,3HRPM,F25.0,F15.0/10X,3HGAP,F28.3,F15.3/10X,
     311HTEMP, DEG C,F17.0,F15.0/10X,18HVSCSTY, LBM/FT-SEC,E13.3,E15.3/1
     40X,19HPRESSURE, LBS/SQ-IN,F11.3,F15.3//10X,5HFLUID,26X,A6/1H1)
      GO TO 720
700   WRITE (6,710) FW1
710   FORMAT (1H ,9X,33HWINDAGE LOSS AT SYNCHRONOUS SPEED,F10.0,5H WATT/
     11H1)
C
C     WRITE VALUES OF EQUIVALENT CIRCUIT ELEMENTS
C
720   WRITE (6,730) R1,X1,R2,X2,R0,X0
730   FORMAT (1HK,5X,29HEQUIVALENT CIRCUIT PARAMETERS/10X,4HR1 =,F9.3,15
     1X,5HX1 = ,F7.3/10X,4HR2 =,F9.3,15X,5HX2 = ,F7.3/10X,4HR0 =,F9.3,15
     2X,4HX0 =,F8.3)
C
C     EQUIVALENT CIRCUIT ANALYSIS
C
      KT=1
      IF (TRATED.LT.1.0E-15) KT=3
      DELTAS=1.0
      SMAX=100.
      IA=IFIX((SMAX/(50.*DELTAS))+0.5)
      S=0.
      I=0
      TOLD=0.
      WRITE (6,740) V1,F
740   FORMAT (1HK,5X,20HMOTOR PERFORMANCE AT,F7.2,6H VOLT,,F7.1,3H HZ//6
     1X,6HTORQUE,4X,4HSLIP,6X,3HRPM,12X,5HP-OUT,12X,1HI,7X,3HEFF,7X,2HPF
     2,6X,4HP-IN,6X,3HPRI,6X,3HSEC,7X,4HIRON,9X,2HFW/5X,8H(IN-LBS),1X,9H
     3(PERCENT),14X,4H(HP),4X,6H(WATT),5X,5H(AMP),2X,9H(PERCENT),11H(*=L
     4EADING),6H(WATT),5X,4HLOSS,5X,4HLOSS,6X,4HLOSS,7X,6H(WATT)/93X,6H(
     5WATT),3X,6H(WATT),4X,6H(WATT)//)
C
750   S=S+DELTAS
      I=I+1
      IF (S.GT.SMAX) GO TO 870
760   CALL CIRCT
      IF (T.GT.1.0E-15) GO TO 780
      WRITE (6,770) S
770   FORMAT (1H ,5X,44HF+W TORQUE EXCEEDS AVAILABLE SHAFT TORQUE AT,F8.
     13,13H PERCENT SLIP)
      IF (S.GT.15.) GO TO 870
      T=0.
      GO TO 820
780   GO TO (790,840,800),KT
790   IF (T.GE.TRATED) GO TO 830
      TOLD=T
      SOLD=S
```

```
800   WRITE (6,810) T,S,RPM,HP,POUT,I1,EFF,PF,PHASE,PIN,W1,W2,W0,FW
810   FORMAT (1H ,7F10.2,F8.2,A1,F9.2,4F10.2)
820   J=I/IA
      IF (J*IA.NE.I) GO TO 750
      IF (J.GT.50) GO TO 750
      SLIP(J)=S
      TORQUE(J)=T
      GO TO 750
C
C     CALCULATE VALUE OF S AT TORQUE TRATED
C
830   S=(((TRATED-TOLD)/(T-TOLD))*(S-SOLD))+SOLD
      KT=2
      GO TO 760
C
C     WRITE MOTOR CHARACTERISTICS AT RATED TORQUE
C
840   IF ((ABS(T-TRATED)).GT.0.005) GO TO 830
      WRITE (6,850)
850   FORMAT (1H )
      WRITE (6,810) T,S,RPM,HP,POUT,I1,EFF,PF,PHASE,PIN,W1,W2,W0,FW
      WRITE (6,850)
C
C     CURRENT DENSITIES AT RATED TORQUE
C
      IF (NB.LT.1.0E-15) GO TO 860
      WBAR=(W2/NB)*(R2BAR/R2)
      IBAR=SQRT((WBAR*SB)/(RRSTVY*LB))
      JBAR=IBAR/SB
      WRING=(W2-WBAR)*0.5
      JRING=SQRT(WRING/(RRSTVY*SER*1.5708*(DER1+DER2)))
      CURDEN=I1/(PC*SS)
860   KT=3
      S=SOLD+DELTAS
      GO TO 760
C
870   IF (JBAR.GT.1.0E-15) WRITE (6,880) JBAR,JRING,CURDEN
880   FORMAT (1HK,10X,46HCURRENT DENSITY AT RATED TORQUE IN ROTOR BAR =,
     1F7.0/44X,13HIN END RING =,F7.0/44X,13HIN ARMATURE =,F7.0)
C
C     PLOT TORQUE-SPEED CURVE
C
      PP(1)=J
      IA=J/2+10
      PP(IA)=XLGND(1)
      PP(IA+1)=XLGND(2)
      PP(IA+2)=XLGND(3)
      CALL PLOTXY (SLIP,TORQUE,KODE,PP)
      WRITE (6,890)
890   FORMAT (2HPL,70X,14HTORQUE, IN-LBS)
      GO TO 10
      END
```

```
      SUBROUTINE CIRCT
      COMMON /CIR/ R0,R1,R2,X0,X1,X2,FW1,NSYNCH,V1,S,I1,RPM,PF,T,HP,EFF,
     1PIN,W1,W2,W0,FW,IMAG,V2,POUT,PHASE
      REAL NSYNCH,I1,I2,IMAG
      COMPLEX D,Z0,Z1,Z2,E1,E2,IA,IB,IC
      DATA STAR,BLANK/1H*,1H /
C
      C=2.5
      PHASE=BLANK
      POUT=0.
      EFF=0.
      HP=0.
      T=0.
      E1=CMPLX(V1,0.)
      Z1=CMPLX(R1,X1)
      Z0=CMPLX(R0*X0*X0/(R0*R0+X0*X0),X0*R0*R0/(R0*R0+X0*X0))
```

```
      IF (S.LT.1.0E-10) GO TO 10
      Z2=CMPLX(R2*100./S,X2)
      D=(Z1+Z0)*(Z2+Z0)-Z0*Z0
      IA=(E1*(Z0+Z2))/D
      IB=(E1*Z0)/D
      IC=IA-IB
      GO TO 20
10    IA=E1/(Z1+Z0)
      IB=(0.,0.)
      IC=IA
20    E2=(IA-IB)*Z0
      A=REAL(E2)
      B=AIMAG(E2)
      V2=SQRT(A*A+B*B)
      IMAG=V2/X0
      W0=V2*V2/R0*3.
      A=REAL(IA)
      B=AIMAG(IA)
      IF (B.GT.0.) PHASE=STAR
      I1=SQRT(A*A+B*B)
      PF=A/I1
      A=REAL(IB)
      B=AIMAG(IB)
      I2=SQRT(A*A+B*B)
      W1=I1*I1*R1*3.
      W2=I2*I2*R2*3.
      RPM=NSYNCH*(1.-S/100.)
      FW=FW1*(RPM/NSYNCH)**C
      PIN=V1*I1*PF*3.
      IF (S.GT.0.) GO TO 30
      POUT=-FW
      GO TO 40
30    POUT=W2*((100.-S)/S)-FW
40    EFF=100.*POUT/PIN
      HP=POUT/746.
      IF (S.LT.99.9) GO TO 50
      T=((.847E4/S)*W2)/NSYNCH
      GO TO 60
50    T=(HP/RPM)*6.34E4
60    RETURN
      END
```

```
      SUBROUTINE MAGNET
      COMMON /MAG/ BST,BSY,BRT,BRY,ATST,ATSY,ATRT,ATRY,ASYOKE,ASTOTH,ARY
     1OKE,ARTOTH,LSYOKE,LRYOKE,DSS,DSR,FTOTAL,FPOLE,KSAT,AI,ATAG,ATTOT
      DIMENSION AI(60)
      REAL LSYOKE,LRYOKE
      BST=0
      BSY=0
      BRT=0
      BRY=0
      ATST=0
      ATSY=0
      ATRT=0
      ATRY=0
      ATTOT=0
      KSAT=10
C
C     STATOR TOOTH
C
      BST=FTOTAL/ASTOTH
      NA=1
      K=1
      X=BST
      GO TO 90
10    ATST=AT*DSS
C
C     STATOR YOKE
C
```

```
 20     BSY=FPOLE/(2.*ASYOKE)
        NA=1
        K=2
        X=BSY
        GO TO 90
 30     ATSY=AT*LSYOKE
 C
 C      ROTOR TOOTH
 C
 40     BRT=FTOTAL/ARTOTH
        NA=31
        K=3
        X=BRT
        GO TO 90
 50     ATRT=AT*DSR
 C
 C      ROTOR YOKE
 C
 60     BRY=FPOLE/(2.*ARYOKE)
        NA=31
        K=4
        X=BRY
        GO TO 90
 70     ATRY=AT*LRYOKE
 C
 80     ATTOT=ATAG+ATST+ATSY+ATRT+ATRY
        RETURN
 C
 C      INTERPOLATION PROCEDURE FOR MATERIAL CURVES
 C
 90     IF (AI(NA).LT.X) GO TO 130
        NA=NA+3
 100    IF (AI(NA)-X) 110,120,120
 110    NA=NA+2
        GO TO 100
 120    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 (10,30,50,70),K
 130    KSAT=0
        GO TO (20,40,60,80),K
        END
```

```
        SUBROUTINE SLOTS (SLTLOC,XSTYPE,WSX,WSX1,WSX2,WSX3,WSX4,WSX5,DSX,D
       11X,D2X,D3X,D4X,D5X,XTWDTH,CAREA,SAREA,N,D6X,WSX6,DIA,KX,AXX,YTWMAG
       2,PHIX)
 C
 C      FOR STATOR SLOTS SLTLOC=1.0 * FOR ROTOR SLOTS SLTLOC=-1.0
 C
        REAL N,KX
 C
        INTEGER XSTYPE
 C
        D(WA,CAREA)=((-WA+SQRT(WA*WA+4.*CAREA*TANPHI)))/(2.*TANPHI)
        WB(D,WA)=WA+2.*D*TANPHI
        A(W)=0.25*W*W*(((1.5708+PHIX)/(COSPHI*COSPHI))+TANPHI)
 C
        IF (CAREA+DSX+D1X.LT.1.0E-15) GO TO 310
        A1=0.25*KX+(1.0/12.0)
        A2=0.25*(KX-0.66667)
 C
        GO TO (10,20,30,90,210,90),XSTYPE
 C
 10     WSX1=0.
        D3X=0.
        D4X=0.
        AXX=0.
        GO TO 40
 C
```

```
20    WSXA=WSX
      WSX1=0.
      WSX2=0.
      D3X=0.
      D4X=0.
      AXX=0.
      GO TO 100
C
30    AXX=KX*(D4X/WSX1+(D3X/(WSX-WSX1))*(ALOG(WSX/WSX1)))
40    WSX2=0.
      WSX3=0.
      WSX4=WSX
      WSX5=WSX
      XTWDTH=0.
      IF (DSX.GT.1.0E-15) GO TO 50
      IF (D1X.LT.1.0E-15) GO TO 60
      DSX=D1X+D4X+D3X+D2X+D6X
      GO TO 80
50    IF (D1X.LT.1.0E-15) GO TO 70
      GO TO 80
60    DSX=CAREA/(WSX-2.*WSX6)+D5X+D6X+D2X+D3X+D4X
70    D1X=DSX-(D4X+D3X+D2X+D6X)
80    SAREA=WSX*(DSX-D4X-D3X)+0.5*(WSX1+WSX)*D3X+WSX1*D4X
      IF (CAREA.LT.1.0E-15) CAREA=(WSX-2.*WSX6)*(D1X-D5X)
      AXX=AXX+(D1X*A1-D5X*A2+KX*D2X)/WSX
      XTWMAG=((DIA+0.6667*SLTLOC*DSX)*(3.1416/N))-WSX
      GO TO 300
C
90    WSXA=WSX2
      WSX=0.
100   IF (WSXA.GT.1.0E-15) GO TO 130
      IF (XTWDTH.LT.1.0E-15) GO TO 310
      WSXA=((3.1416*(DIA+2.*SLTLOC*(D4X+D3X)))/N)-XTWDTH
110   PHIX=(3.1415927/N)*SLTLOC
      GO TO 140
120   XTWDTH=((3.1416*(DIA+2.*SLTLOC*(D4X+D3X)))/N)-WSXA
      GO TO 110
130   IF (ABS(PHIX).LT.1.0E-15) GO TO 120
      PHIX=(ABS(PHIX*0.017453))*SLTLOC
      XTWDTH=0.
140   IF (XSTYPE.LT.3) GO TO 150
      WSX2=WSXA
      AXX=KX*(D4X/WSX1+(D3X/(WSXA-WSX1))*(ALOG(WSXA/WSX1)))
      GO TO 160
150   WSX=WSXA
160   TANPHI=TAN(PHIX)
      COSPHI=COS(PHIX)
      SINPHI=SIN(PHIX)
      WSX4=WB(D2X,WSXA)
      IF (DSX.GT.1.0E-15) GO TO 170
      IF (D1X.GT.1.0E-15) GO TO 190
      Y1=D(WSX4-2.*WSX6,CAREA/2.)
      W=WB(D2X+Y1+D5X,WSXA)
      IF (XSTYPE.EQ.6) GO TO 260
      Y2=D(W-2.*WSX6,CAREA/2.)
      DSX=Y1+Y2+D3X+D2X+D4X+D6X+D5X
      GO TO 180
170   IF (D1X.GT.1.0E-15) GO TO 200
180   D1X=DSX-D4X-D3X-D2X-D6X
      GO TO 200
190   DSX=D1X+D4X+D3X+D2X+D6X
200   IF (XSTYPE.EQ.6) GO TO 280
      WSX5=WB(D2X+D1X,WSXA)
      WSX3=WB(DSX-D3X-D4X,WSXA)
      SAREA=0.5*(WSX3+WSXA)*(DSX-D4X-D3X)+0.5*(WSXA+WSX1)*D3X+WSX1*D4X
      AXX=AXX+((2.*KX*D2X)/(WSXA+WSX4))+(D1X/WSX4)*A1-((2.00*D5X)/(WSX4+
     1WSX5))*A2
      XTWMAG=((DIA+2.*SLTLOC*DSX)*(3.1416/N))-WSX3
      IF (CAREA.GT.1.0E-15) GO TO 300
      A3=D1X*(WSX5+WSX4-4.*WSX6)
      CAREA=0.5*A3-D5X*SQRT((WSX5-2.*WSX6)**2-A3*TANPHI-(D5X*TANPHI)**2)
      GO TO 300
C
210   WSX=0
```

```
      WSX2=0.
      WSX4=0.
      XTWDTH=0.
      D2X=0.
      D3X=0.
      D5X=0.
      WSX5=0.
      WSX6=0.
      IF (DSX.GT.1.0E-15) GO TO 240
      IF (D1X.LT.1.0E-15) GO TO 220
      DSX=D1X+2.*D6X+D4X
      GO TO 250
220   DSX=(SQRT(4.*CAREA/3.1416))+D4X+2.*D6X
230   D1X=DSX-2.*D6X-D4X
      GO TO 250
240   IF (D1X.LT.1.0E-15) GO TO 230
      IF (ABS(D1X+D4X+2.*D6X-DSX).GT.0.001) GO TO 310
250   IF (WSX2.LT.1.0E-15) WSX2=DSX-D4X
      SAREA=0.7854*WSX2*WSX2+WSX1*D4X
      IF (CAREA.LT.1.0E-15) CAREA=0.7854*(WSX2-2.*D6X)**2
      AXX=(0.625+D4X/WSX1)*KX
      XTWMAG=(DIA+(2.*D4X+1.333*WSX2)*SLTLOC)*(3.1416/N)-0.94*WSX2
      GO TO 340
C
260   W1=W-2.*D6X
      AS=A(W1)
      IF (2.*AS/CAREA.GT.1.00) GO TO 310
270   AR=0.5*CAREA-AS
      Y2=D(W1,AR)
      W2=WB(Y2,W1)
      AS=A(W2)
      IF (ABS(2.*(AR+AS)/CAREA-1.0).GE.0.001) GO TO 270
      DSX=D4X+D3X+D2X+D6X+Y1+Y2+D5X+(W2/2.)*(1./COSPHI+TANPHI)
      D1X=DSX-D4X-D3X-D2X-D6X
280   WSX3=(2.*(DSX-D4X-D3X)*SINPHI+WSX2*COSPHI)/(SINPHI+1.0)
      WSX5=WSX3
      SAREA=A(WSX3*COSPHI)+0.5*(WSX3*COSPHI+WSX2)*(DSX-0.5*WSX3*(1.0+SIN
     1PHI)-D4X-D3X)+0.5*D3X*(WSX2+WSX1)+WSX1*D4X
      AXX=AXX+((2.*KX*D2X)/(WSXA+WSX4))+(D1X/WSX4)*A1-((2.00*D5X)/(WSX4+
     1WSX5))*A2
      XTWMAG=((DIA+2.*SLTLOC*(D4X+D3X))*(3.1416/N))-WSX2
      IF (CAREA.GT.1.0E-15) GO TO 300
      Y1=0.5*DSX
      W=0.5*(WSX4+WSX5)
      CAREA2=1000.
290   CAREA=A(WSX3*COSPHI-2.*D6X)+0.5*(WSX3*COSPHI+W-4.*D6X)*(DSX-0.5*WS
     1X3*(1.0+SINPHI)-D4X-D3X-D2X-Y1-D5X)+(0.5*(Y1+D5X)*(W+WSX4-4.*WSX6)
     2)-(W-2.*WSX6)*D5X
      IF (ABS(CAREA2/CAREA-1.0).LT.0.001) GO TO 300
      Y1=D(WSX4-2.*WSX6,CAREA/2.)
      W=WB(Y1+D5X+D2X,WSX2)
      CAREA2=CAREA
      GO TO 290
C
300   IF (ABS(D1X+D2X+D3X+D4X+D6X-DSX).LT.0.001) GO TO 340
C
310   IF (SLTLOC.LT.0.) WRITE (6,320)
      IF (SLTLOC.GT.0.) WRITE (6,330)
320   FORMAT (1HK,41HINSUFFICIENT OR INCORRECT ROTOR SLOT DATA)
330   FORMAT (1HK,42HINSUFFICIENT OR INCORRECT STATOR SLOT DATA)
340   RETURN
      END
```

```
      SUBROUTINE WDGFCT (PBA,P,QS,DF,PC,PF,WDGPCH)
C
C     PITCH FACTOR CALCULATION
C
      YY=FLOAT(IFIX(((QS/P)*WDGPCH)+0.01))
      IF (ABS(YY-QS/P*WDGPCH).GT.1.0E-2) WRITE (6,10) WDGPCH
```

```
10    FORMAT (1HK,F5.3,22H PITCH IS NOT POSSIBLE)
      PF=SIN(YY*1.571/(QS/P))
C
C     DISTRIBUTION FACTOR CALCULATIONS
C
      IPX=IFIX(P+0.1)
      IQQ=IFIX(QS+0.1)
      IC=IFIX(PC+0.1)
      IPN=3
      PN=3.
      QN=QS/(3.*P)
C
C     CHECK IF WINDING HAS INTEGRAL NO. OF SLOTS PER POLE PER PHASE
C
      D=1.0
      IF (PBA.GT.61.0) D=2.0
      IZY=IPX*IPN
      IDM=0
20    IDM=IDM+IZY
      IF (IQQ-IDM) 40,30,20
C
C     CALCULATE DISTRIBUTION FACTOR FOR INTEGRAL SLOT WINDING
C
30    DF=SIN(1.571*D/PN)/(QN*D*SIN(1.571/(PN*QN)))
      GO TO 90
C
C     REDUCE THE FRACTION IQQ/IZY TO LOWEST TERMS
C
40    IIQQ=IQQ
      I=2
50    IF ((IZY/I)*I.EQ.IZY.AND.(IIQQ/I)*I.EQ.IIQQ) GO TO 60
      IF (I.GT.IZY) GO TO 70
      I=I+1
      GO TO 50
60    IZY=IZY/I
      IIQQ=IIQQ/I
      GO TO 50
C
C     CALCULATE DISTRIBUTION FACTOR FOR FRACTIONAL SLOT WINDING
C
70    FNQ=IIQQ
      DF=SIN(1.571*D/PN)/(FNQ*D*SIN(1.571/(FNQ*PN)))
      IF ((IZY/3)*3.EQ.IZY) WRITE (6,80)
      IF ((IPX/IZY)*IZY.NE.IPX) WRITE (6,80)
80    FORMAT (1HK,40HIMPROPER FRACTIONAL-SLOT WINDING IS USED)
C
C     CHECK IF SPECIFIED NUMBER OF PARALLEL CIRCUITS ARE POSSIBLE
C
      IPX=IPX/IZY
90    IF ((IPX/IC)*IC.EQ.IPX) GO TO 110
      WRITE (6,100) IC
100   FORMAT (1HK,I2,35H PARALLEL CIRCUITS ARE NOT POSSIBLE)
110   RETURN
      END
```

```
      SUBROUTINE CMBNTN (QS,NB,P)
C
      REAL NB
      DIMENSION L(100)
C
      X=1.0E-15
      K=0
      F=NB
10    D=ABS(QS-F)
      M=1
      DO 20 I=1,1000
      A=3.*FLOAT(I)*P
      IF (ABS(D-A).LT.X) GO TO 40
      IF (A.GT.D) GO TO 30
```

```
20      CONTINUE
30      IF (ABS(D-P).LT.X) GO TO 40
        IF (ABS(P-FLOAT(IFIX(F/P+0.0001))).LT.X) GO TO 40
        M=2
        IF (F.GT.QS+P/2.) GO TO 40
        M=3
        IF (ABS(D-P/2.).LT.X) GO TO 40
        IF (ABS(QS-F).LT.X) GO TO 40
        IF (ABS(D-1.).LT.X) GO TO 40
        IF (ABS(D-2.).LT.X) GO TO 40
        IF (ABS(D-P+1.).LT.X) GO TO 40
        IF (ABS(D-P-1.).LT.X) GO TO 40
        IF (ABS(D-P-2.).LT.X) GO TO 40
        IF (ABS(D-P+2.).LT.X) GO TO 40
        IF (K.EQ.0) GO TO 150
        I1=I1+1
        L(I1)=IFIX(F+0.01)
        GO TO 110
40      IF (K.GT.0) GO TO 110
        K=1
        F=FLOAT(IFIX(0.60*QS))
        I1=0
C
        GO TO (50,70,90),M
C
50      WRITE (6,60)
60      FORMAT (1HK,82HROTOR-STATOR SLOT COMBINATION MAY PRODUCE UNDESIRAB
       1LE TORQUE-SPEED CHARACTERISTICS)
        GO TO 110
C
70      WRITE (6,60)
        FF=(P/2.)/(P/2.+QS)
        WRITE (6,80) FF
80      FORMAT (1H ,19HMINIMIZE BY SKEWING,F6.3,30H TIMES ROTOR CIRCUMFERE
       1NCE, OR)
        GO TO 110
C
90      WRITE (6,100)
100     FORMAT (1HK,61HROTOR-STATOR SLOT COMBINATION MAY PRODUCE NOISE AND
       1 VIBRATION)
C
110     F=F+1.0
        IF (F.LE.1.4*QS) GO TO 10
        IF (I1.LT.1) GO TO 130
C
        WRITE (6,120) (L(I),I=1,I1)
120     FORMAT (1H ,52HCHANGE NUMBER OF ROTOR SLOTS TO ONE OF THE FOLLOWIN
       1G/(10I6))
        GO TO 150
C
130     WRITE (6,140)
140     FORMAT (1H ,29HCHANGE NUMBER OF STATOR SLOTS)
C
150     RETURN
        END
```

APPENDIX D

ERROR MESSAGES

This appendix lists the various error messages that may result during program execution. For each error message the subroutine from which the message originated is identified and the probable cause of the error is suggested. The purpose of these error messages is only to warn and to inform. In no case is program execution terminated. This information is provided in the following table:

Number	Error message	Responsible subroutine	Explanation
1	CORE LOSS DATA IS NOT GIVEN AT SPECIFIED STATOR LAMINATION THICKNESS USE DATA FOR xx. xxx LAMINATIONS	INDMTR	(1) The stator material deck does not contain core-loss data card ($FELOSS) for lamination thickness within 0.0005 in. of lamination thickness specified on the motor design deck data card $STATOR. The program will use the best available core-loss data. (2) Core-loss data may have been omitted entirely.
2	INSUFFICIENT STATOR SLOT DATA, SPACE FACTOR OF 0.70 ASSUMED	INDMTR	DSS, D1S, SCAREA, and CSRATO are all less than 1.0E-15. The program assumes a value of CSRATO = 0.70.
3	SHUNT RESISTANCE R0 FAILED TO CONVERGE	INDMTR	The iteration for R0 in the no-load magnetic calculations did not converge after 10 iterations. This generally means that the magnetic flux path is saturated or nearly saturated.
4	MAGNETIZING CURRENT FAILED TO CONVERGE	INDMTR	The iteration for magnetizing current and X0 in the no-load magnetic calculations did not converge after 15 iterations. This generally implies that the motor is magnetically saturated or nearly saturated or that the material has square-loop characteristics with the flux density falling near the knee of the curve.

Number	Error message	Responsible subroutine	Explanation
5	MACHINE SATURATED	INDMTR	One or more parts of the magnetic circuit of the motor saturated at no load. In order to determine which part or parts, compare the computed flux densities with the maximum flux density for the appropriate material. The ampere-turn drop across any part of the magnetic circuit that saturated is assumed to be zero.
6	INSUFFICIENT DATA TO SCALE WINDAGE LOSS	INDMTR	(1) One or more of the following variables is very small or zero: DIAREF, LREF, RPMREF, GAPREF. All of these variables must be defined to permit scaling of windage loss. (2) The variable WL is very small or zero. The synchronous windage loss will be assumed to be zero.
7	F + W TORQUE EXCEEDS AVAILABLE SHAFT TORQUE AT xxx.xx PERCENT SLIP	INDMTR	This message is printed if the total electromagnetic shaft torque computed in subroutine CIRCT is less than the computed windage torque at the specified value of slip. If this error occurs for values of slip greater than 15 percent, equivalent circuit analysis is terminated and the program proceeds to plot the torque-speed curve. For values of slip below 15 percent the program continues to increment slip in the normal manner.
8	INSUFFICIENT OR INCORRECT ROTOR SLOT DATA	SLOTS	(1) SB, DSR, and D1R are all less than 1.0E-15. At least one of these variables must be read in. (2) For slot type 6 only: if area AR (fig. 14) becomes negative, this message is printed. In order to eliminate this problem, make the slot narrower and deeper.

Number	Error message	Responsible subroutine	Explanation
9	INSUFFICIENT OR INCORRECT STATOR SLOT DATA	SLOTS	(1) DSS, D1S, and SCAREA are all less than 1.0E-15 at the time subroutine SLOTS is called to compute stator slot dimensions. In general, this implies one of the following: CSS is zero or negative ASTRND is zero or negative AWG is not between 1 and 40 inclusive STRNDS is zero or negative. (2) For slot type 6 only: see error message 8.
10	.xxx PITCH IS NOT POSSIBLE	WDGFCT	This message is printed if the number of stator slots per pole times the stator winding pitch WDGPCH is not within 0.01 of an integer value.
11	xx PARALLEL CIRCUITS ARE NOT POSSIBLE	WDGFCT	This message is printed for either fractional or integral slot windings. It means that a balanced, three-phase winding is not possible with the number of parallel circuits specified in the input data.
12	IMPROPER FRACTIONAL SLOT WINDING IS USED	WDGFCT	(1) The denominator of the slots per pole (reduced to lowest common denominator) is not divisible by 3. (2) The number of poles is not divisible by the denominator of the slots per pole per phase (reduced to lowest terms).
13	ROTOR-STATOR SLOT COMBINATION MAY PRODUCE UNDESIRABLE TORQUE-SPEED CHARACTERISTICS	CMBNTN	See reference 3 (pp. 317-320) and reference 5.
14	ROTOR-STATOR SLOT COMBINATION MAY PRODUCE NOISF AND VIBRATION	CMBNTN	See reference 3 (pp. 317-320) and reference 5.
15	MINIMIZE BY SKEWING x.xxx TIMES ROTOR CIRCUMFERENCE, OR	CMBNTN	This message can only follow error message 13 and is always followed by message 16 or 17. It states that the undesirable effects referred to in error message 13 can be reduced or eliminated by skewing the specified amount.

Number	Error message	Responsible subroutine	Explanation
16	CHANGE NUMBER OF ROTOR SLOTS TO ONE OF THE FOLLOWING xxx xxx xxx	CMBNTN	This error message follows error message 13, 14, or 15 but never in conjunction with message 17. It lists the number of rotor slots that may be used without incurring the problems referenced in message 13 or 14.
17	CHANGE NUMBER OF STATOR SLOTS	CMBNTN	This message follows error message 13, 14, or 15 but never in conjunction with message 16. It is displayed only if it is not possible to find a number of rotor slots that will eliminate the problems referenced in error message 13 or 14.

APPENDIX E

ALPHABETIC FORTRAN SYMBOL LIST

An alphabetic FORTRAN symbol list is given for the main program and each subroutine. The symbol list for the main program is given first. This list is complete, showing every symbol used in the main program. The symbol lists for the subroutines follow in this order: SLOTS, CMBNTN, WDGFCT, MAGNET, and CIRCT. The symbol lists for the subroutines list only those FORTRAN variables that do not appear in the main program or those which, if they do appear in the main program, have a definition different from that in the main program.

Where symbols define stator or rotor slot dimensions, further clarification may be obtained by referring to figures 4, 12, and 14. Figure 4 shows all slot dimensions that are needed to calculate the slot permeance ratio. Figure 12 shows all slot dimensions that are allowable input. Figure 14 shows those slot dimensions that are not shown in either of the other two figures.

Main Program

AI	coordinates of points on rotor and stator material magnetization curves
AIRGAP	NAMELIST name
ARTOTH	cross-sectional area of rotor teeth (used in magnetic calculations), $in.^2$
ARYOKE	cross-sectional area of rotor yoke (used in magnetic calculations), $in.^2$
ASTOTH	cross-sectional area of stator teeth (used in magnetic calculations), $in.^2$
ASTRND	cross-sectional area of stator strand, $in.^2$
ASYOKE	cross-sectional area of stator yoke (used in magnetic calculations), $in.^2$
ATAG	ampere-turns across airgap, ampere-turns
ATRT	ampere-turns across rotor tooth, ampere-turns
ATRY	ampere-turns across rotor yoke, ampere-turns
ATST	ampere-turns across stator tooth, ampere-turns
ATSY	ampere-turns across stator yoke, ampere-turns
ATTOT	total ampere-turn drop, ampere-turns
AWG	strand size of stator winding (American Wire Gage)

AXR	rotor slot leakage permeance ratio
AXS	stator slot leakage permeance ratio
AY	length of one end-turn, in.
AY	multiplier in slot and end-connection reactance calculations and in rotor resistance calculations
B	armature coil extension, in.
BG	average airgap flux density, kilolines/in.^{2}
BK	flux density at which WFE and WCORE are specified, kilolines/in.^{2}
BLANK	storage location for storing a BCD blank
BR	spacing between end-ring and rotor laminations (ref. 3, p. 336, fig. 199), in.
BRT	flux density in rotor tooth, kilolines/in.^{2}
BRY	flux density in rotor yoke, kilolines/in.^{2}
BST	flux density in stator tooth, kilolines/in.^{2}
BSY	flux density in stator yoke, kilolines/in.^{2}
C0	coefficient of viscosity polynomial (see VSCSTY)
C1	coefficient of viscosity polynomial (see VSCSTY)
C2	coefficient of viscosity polynomial (see VSCSTY)
C3	coefficient of viscosity polynomial (see VSCSTY)
C4	coefficient of viscosity polynomial (see VSCSTY)
CALPHA	cosine (alpha) (ref. 3, p. 209, fig. 135)
CCR	Carter coefficient (rotor)
CCS	Carter coefficient (stator)
CIR	common block name
CIRCT	subroutine name
CLOSS	array containing core-loss data
CMBNTN	subroutine name
CSRATO	space factor (=CSS* SS/SCAREA)
CSS	number of conductors per stator slot

CURDEN	current density in armature, $A/in.^2$
D	stator bore diameter, in.
D1R	overall conductor depth in rotor slot, in.
D1S	overall conductor depth in stator slot, in.
D2R	rotor slot dimension, in.
D2S	stator slot dimension, in.
D3R	rotor slot dimension, in.
D3S	stator slot dimension, in.
D4R	rotor slot dimension (slot-opening depth), in.
D4S	stator slot dimension (slot-opening depth), in.
D5S	stator slot dimension, in.
D6R	rotor slot dimension, in.
D6S	stator slot dimension, in.
DBRS	depth below rotor slot, in.
DBS	depth below stator slot, in.
DC	distance between center of end-ring and center of stator slot (ref. 3, p. 336, fig. 199), in.
DEKTYP	character in card column 1 of first card following each motor design deck if DEKTYP = M, it marks start of new data set; if DEKTYP = BLANK it marks start of new motor design data deck
DELTAS	increment by which S is increased, percent
DER1	end-ring outside diameter, in.
DER2	end-ring inside diameter, in.
DIAREF	reference diameter for scaling windage loss, in.
DIFF	smallest of all values of DIFF1 calculated, in.
DIFF1	difference between stator lamination thickness and lamination thickness specified on $FELOSS data card, in.
DIR	rotor lamination inside diameter, in.
DNSTY	array containing density values for various rotor and stator winding material possibilities, $lb/in.^3$

DOS	stator lamination outside diameter, in.
DR	rotor lamination outside diameter, in.
DSR	rotor slot depth, in.
DSS	stator slot depth, in.
EFF	efficiency, percent
ENDTRN	axial length of end turn, in.
F	frequency of line voltage, Hz
F1	part of horizontal extension of armature winding (ref. 3, p. 209, fig. 135), in.
FCORE	frequency at which WCORE is given, Hz
FELOSS	NAMELIST name
FLDNME	name of fluid in motor cavity (must be limited to six characters or less)
FPOLE	flux per pole, kilolines
FTOTAL	total flux, kilolines
FW	windage loss at rotor speed (rpm), W
FW1	windage loss at synchronous speed, W
G	airgap, in.
GAPREF	reference gap for scaling windage loss, in.
GE	effective airgap, in.
HP	shaft power, hp
I	subscript or index
I1	line current, A
IA	subscript or index
IBAR	rms current in one rotor bar, A
ICNT1	counts number of iterations on R0 during no-load magnetic calculations
ICNT2	counts number of iterations on magnetizing current during no-load magnetic calculations
IMAG	magnetizing current, A
IMAG2	magnetizing current, A

INITL	common block name
J	subscript or index
JBAR	current density in rotor bar, A/in.^{2}
JRING	current density in end ring, A/in.^{2}
KDS	distribution factor for stator winding
KODE	input to plotting routine PLOTXY
KPS	pitch factor for stator winding
KRING	correction factor for end-ring resistance (ref. 3, p. 334, fig. 194; and ref. 4)
KS	slot leakage pitch factor (ref. 2, p. 185, fig. 7.3)
KSAT	saturation indicator
KT	index
L	stator core length, in.
LARM	total length of wire of armature winding, ft
LAST	logical variable - LAST=.TRUE. - indicates last core-loss data card has been read
LB	length of rotor bar (including portion inserted in end-ring), in.
LREF	reference length for scaling windage loss, in.
LRYOKE	length of flux path through rotor yoke, in.
LS	length of one armature conductor (half of armature coil length), in.
LSYOKE	length of flux path through stator yoke, in.
LT	thickness of laminations at which core-loss data are given in material deck, in.
LTOTAL	overall axial armature length (2.*ENDTRN + L), in.
LTR	thickness of rotor laminations, in.
LTS	thickness of stator laminations, in.
MAG	common block name
MAGNET	subroutine name
MATDEK	alphabetic constant (defined to be character "M" in a data statement)

N	number of stator conductors in series per phase (2* (number of stator turns in series per phase))
NAME	subscripted array containing information in columns 3 to 80 of first card following each motor design deck
NB	number of rotor bars (equal to number of rotor slots)
NCARDS	number of core-loss data cards ($FELOSS) read in (last card ($FELOSS LAST=.TRUE. $) is not counted)
NSYNCH	synchronous speed of motor, rpm
P	number of poles
PC	number of parallel circuits
PF	power factor
PFLUID	pressure of fluid in airgap, psi
PHASE	if PHASE equals BCD BLANK, PF is lagging; if PHASE equals *, PF is leading
PHIR	one-half of angle at which rotor slot sides diverge, deg
PHIS	one-half of angle at which stator slot sides diverge, deg
PIN	power input to motor, W
PLOTXY	subroutine name
POUT	output power available at motor shaft, W
PP	input to plotting routine PLOTXY
PREF	reference pressure of fluid in airgap used for scaling windage loss, psi
QS	number of stator slots
R0	shunt resistance of equivalent circuit, ohms
R0OLD	value of R0 calculated during previous iteration pass, ohms
R1	armature resistance, ohms
R2	rotor resistance referred to stator winding, ohms
R2BAR	component of R2 attributable to rotor bars, ohms
R2RING	component of R2 attributable to end rings, ohms
RATING	NAMELIST name

RATIO	WSS4/WSS3 for trapezoidal stator slot; WSR4/WSR3 for trapezoidal rotor slot; DER2/DER1 for rotor-winding end-ring
RESET1	array made equivalent to common block INITL
RESET2	array made equivalent to first seven entries in common block CIR
RMAT	array containing description of rotor lamination material
ROTOR	NAMELIST name
RPM	rotor speed at slip S, rpm
RPMREF	reference RPM for scaling windage loss, rpm
RRSTVY	resistivity of rotor winding material at temperature TRW, μin.-ohm
RSAREA	rotor slot area, in.^{2}
RSLOTS	NAMELIST name
RSTVTY	array containing resistivity values for various rotor and stator winding materials at 20° C, μin.-ohm
RSTYPE	rotor slot type
RTRWDG	NAMELIST name
RTWDTH	rotor tooth width (if constant), in.
RTWMAG	rotor tooth width used in magnetic calculations, in.
RWMAT	code for rotor winding material: 1 for aluminum; 2 for brass; 3 for copper
S	clearance between armature coils at end turns (ref. 2, p. 309, table 26; and p. 209, fig. 135), in.
SALPHA	sin (ALPHA) (ref. 2, p. 209, fig. 135)
SB	cross-sectional area of rotor bar, in.^{2}
SCAREA	slot area remaining after subtracting, from total slot area, slot opening and approximate areas occupied by slot liners, separators, wedges, etc. (shaded area in fig. 12), in.^{2}
SER	end-ring cross-sectional area, in.^{2}
SFR	rotor lamination stacking factor
SFS	stator lamination stacking factor
SKEW	skew of rotor slots measured along rotor circumference, in.

SLIP	array containing values of slip at which motor performance is calculated, percent
SLOPE	slope of core-loss-against-frequency curve (for constant flux density) on log-log graphs, measured at frequency FCORE and flux density BK
SLOTS	subroutine name
SMAT	array containing description of stator lamination material
SMAX	maximum value of S for which motor performance is calculated, percent
SOLD	previous value of S at which motor performance was calculated (used to calculate S at rated torque and to resume calculations at proper value of S following calculations at rated torque), percent
SPITCH	stator winding pitch expressed as a decimal fraction, per unit
SS	cross-sectional area of stator conductor, $in.^2$
SSAREA	total area of stator slot, $in.^2$
SSLOTS	NAMELIST name
SSTYPE	stator slot type
STATOR	NAMELIST name
STRNDS	number of strands per armature conductor
STRWDG	NAMELIST name
STWDTH	stator tooth width (if constant), in.
STWMAG	stator tooth width used in magnetic calculations, in.
SWMAT	code for stator winding material: 1 for aluminum; 2 for brass; 3 for copper
T	shaft torque at slip S, in.-lb
T1R	rotor slot pitch at airgap, in.
T1S	stator slot pitch at airgap, in.
TER	end-ring thickness, in.
TFLUID	temperature of fluid in motor cavity, ^{o}C
TITLE	array which contains name or description of design to be analyzed, used to print heading on output listing
TMPCF	array containing temperature coefficients of resistivity for various possible rotor and stator winding materials, per ^{o}C

TOLD	value of T at previous value of S, in.-lb
TORQUE	array containing values of T corresponding to values of S stored in array SLIP, in.-lb
TRATED	rated torque, in.-lb
TREF	reference temperature for scaling windage loss, ^{o}C
TRW	temperature of rotor winding, ^{o}C
TSW	temperature of stator winding, ^{o}C
V1	line-to-neutral voltage, rms volts
V2	airgap voltage, rms volts
VSCFLD	viscosity of fluid in motor cavity, lbm/ft-sec
VSCREF	reference viscosity for scaling windage loss, lbm/ft-sec
VSCSTY	arithmetic statement function, VSCSTY = C0 + C1* T + C2* T* * 2 + C3* T* * 3 + C4* T* * 4, where VSCSTY is fluid viscosity in lbm/ft-sec and T is fluid temperature in ^{o}C; C0 to C4 are program input
W0	core loss, W
W1	losses in armature winding, W
W2	losses in rotor winding, W
WAREA	array containing cross-sectional areas of standard wire gages, $in.^{2}$
WARM	weight of armature (exclusive of insulation), lb
WBAR	power loss in one rotor bar, W
WCORE	core loss for stator laminations at frequency FCORE and at flux density BK, W/lb
WDGFCT	subroutine name
WEIGHT	total electromagnetic weight, lb
WFE	core loss for stator laminations at frequency F and at flux density BK, W/lb
WL	windage loss at reference conditions, W
WNDAGE	NAMELIST name
WRING	loss per end-ring, W
WROT	rotor iron weight, lb

WRWNDG	weight of rotor winding, lb
WSR	rotor slot width (if constant), in.
WSR1	width of rotor slot opening (for partially closed slot), in.
WSR2	rotor slot dimension, in.
WSR3	rotor slot dimension, in.
WSR4	rotor slot dimension, in.
WSR5	rotor slot dimension, in.
WSR6	rotor slot dimension, in.
WSS	stator slot width (if constant), in.
WSS1	width of stator slot opening (for partially closed slot), in.
WSS2	stator slot dimension, in.
WSS3	stator slot dimension, in.
WSS4	stator slot dimension, in.
WSS5	stator slot dimension, in.
WSS6	stator slot dimension, in.
WSTAT	stator iron weight, lb
WSTOTH	weight of stator teeth, lb
WSYOKE	weight of stator yoke (back iron), lb
X0	magnetizing reactance, ohms
X0AG	magnetizing reactance of airgap only, ohms
X1	armature leakage reactance, ohms
X2	rotor leakage reactance referred to stator winding, ohms
XLGND	array containing legend printed to left of slip-torque plot
XP	peripheral airgap leakage reactance, ohms
XRE	rotor end-turn leakage reactance, ohms
XRS	rotor slot leakage reactance, ohms
XRZ	rotor zigzag reactance, ohms
XSE	stator end-turn leakage reactance, ohms

Main Program

XSK	one-half of total skew reactance, ohms
XSS	stator slot leakage reactance, ohms
XSZ	stator zigzag reactance, ohms
XX	index used during no-load magnetic calculations: 1.0 if X0 is to be calculated; 0. if X0 was read in
XY	index used during no-load magnetic calculations: 1.0 if R0 is to be calculated; 0. if R0 was read in
XZ	multiplier for zigzag reactances

Subroutine CIRCT

Definitions of those variables that are not listed are the same as in the main program.

A	real part of various complex variables
B	imaginary part of various complex variables
C	constant (C = 2.5)
D	determinant of coefficients of circuit equations
F1	complex input voltage to equivalent circuit (line-to-neutral input voltage to motor), rms
F2	complex voltage across shunt branch of equivalent circuit, rms
I2	current through Z2, A
IA	complex current through Z1, A
IB	complex current through Z2, A
IC	complex current through Z0, A
STAR	storage location storing BCD character *
Z0	impedance of shunt branch of equivalent circuit, ohms
Z1	stator impedance, ohms
Z2	rotor impedance referred to stator, ohms

Subroutine MAGNET

Definitions of those variables that are not listed are the same as in the main program.

AT ampere-turn drop across various sections of magnetic circuit, ampere-turns

NA subscript

K index

X flux density at which AT is found by interpolation between points on magnetization curve, kilolines/in.^{2}

XX slope of magnetization curve at flux density X

Y used in interpolation procedure for AT

Subroutine SLOTS

Definitions of those variables that are not listed are the same as in the main program.

A arithmetic function

A1 constant used in slot permeance ratio calculations

A2 constant used in slot permeance ratio calculations

AR slot area (fig. 14) needed for intermediate calculations for slot type 6 only, in.^{2}

AS slot area (fig. 14) needed for intermediate calculations for slot type 6 only, in.^{2}

AXX slot leakage permeance ratio

CAREA slot area remaining after subtracting slot opening, slot liners, separator, etc., in.^{2}

CAREA2 value of CAREA during a previous iteration pass (used with slot type 6 only)

COSPHI cos (phi)

D arithmetic function

D1X slot dimension, in.

D2X slot dimension, in.

D3X slot dimension, in.

Subroutine SLOTS

D4X	slot dimension, in.
D5X	slot dimension, in.
D6X	slot dimension, in.
DIA	rotor outside diameter if SLTLOC = -1.0; stator inside diameter if SLTLOC = 1.0, in.
DSX	slot dimension, in.
KX	equals 1.0 for rotor slots; equals slot leakage pitch factor for stator slots (ref. 2, p. 185, fig. 7.3)
N	number of slots
PHIX	one-half of angle at which slot sides diverge (PHIX is negative for rotor slots, positive for stator slots), rad
SAREA	total slot area, $in.^2$
SINPHI	sin (phi)
SLOTS	subroutine name
SLTLOC	indicates slot location: 1.0 for stator slots; 1.0 for rotor slots
TANPHI	tan (phi)
W	slot dimension, in.
W1	slot dimension, in.
W2	slot dimension, in.
WA	dummy variable used in arithmetic function definition
WB	arithmetic function
WSX	slot dimension, in.
WSX1	slot dimension, in.
WSX2	slot dimension, in.
WSX3	slot dimension, in.
WSX4	slot dimension, in.
WSX5	slot dimension, in.
WSX6	slot dimension, in.
WSXA	equals WSX for slot type 2; equals WSX2 for slot types 4 and 6, in.

Subroutine SLOTS

XSTYPE	slot type
XTWDTH	tooth width (for slot types 2, 4, and 6 only), in.
XTWMAG	average tooth width used in magnetic calculations in subroutine MAGNET, in.
Y1	slot dimension, in.
Y2	slot dimension, in.

Subroutine WDGFCT

Definitions of those variables that are not listed are the same as in the main program.

D	constant: 1.0 for windings with phase belt less than 60°; 2.0 for windings with phase belt greater than 60°
DF	distribution factor
FNQ	real variable equal to IIQQ after fraction "slots per pole per phase" has been reduced to lowest terms
I	integer that is tested to see if it is a common divisor of fraction "slots per pole per phase"
IC	number of parallel circuits (integer variable)
IDM	multiple of IZY
IIQQ	numerator of fraction "slots per pole per phase"
IPN	number of phases (set equal to 3)
IPX	number of poles (integer variable)
IQQ	number of stator slots (integer variable)
IZY	product of number of poles and number of phases
P	number of poles (real variable)
PBA	phase belt angle, deg
PC	number of parallel circuits (real variable)
PF	pitch factor
PN	number of phases (set equal to 3)

Subroutine WDGFCT

QN	number of stator slots per pole per phase
QS	number of stator slots (real variable)
WDGFCT	subroutine name
WDGPCH	stator winding pitch expressed as decimal fraction, per unit
YY	slots spanned per armature coil (number slots between coil sides plus 1)

Subroutine CMBNTN

Definitions of those variables that are not listed are the same as in the main program.

A	3* FLOAT(I)* P, where I = 1, 2, 3, . . . , 1000
CMBNTN	subroutine name
D	ABS(QS-F)
F	number of rotor bars
FF	rotor skew, expressed as fraction of rotor circumference, necessary to eliminate certain undesirable characteristics in torque-speed curve
I	index
I1	index
K	indicator (if K = 1 the slot combination is found to be undesirable; the subroutine will then search for an alternate number of rotor slots)
L	F (L is an integer variable)
M	an indicator showing seriousness of an undesirable slot combination (M = 1 is most serious; M = 3 is least serious)
NB	number of rotor slots
P	number of poles
QS	number of stator slots
X	constant (1.0E-15)

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1. Dellner, Lois T.: A Set of FORTRAN IV Subroutines for Generating Printed Plots. NASA TM X-1419, 1967.

2. Kuhlmann, John H.: Design of Electrical Apparatus. 3rd ed., John Wiley & Sons, Inc., 1950.

3. Alger, Philip L.: The Nature of Polyphase Induction Machines. John Wiley & Sons, Inc., 1951.

4. Trickey, P. H.: Induction Motor Resistance Ring Width. Elec. Eng., vol. 55, no. 2, Feb. 1936, pp. 144-150.

5. Kron, Gabriel: Induction Motor Slot Combinations. Am. Inst. Elec. Engrs., Trans., vol. 50, June 1931, pp. 757-767.

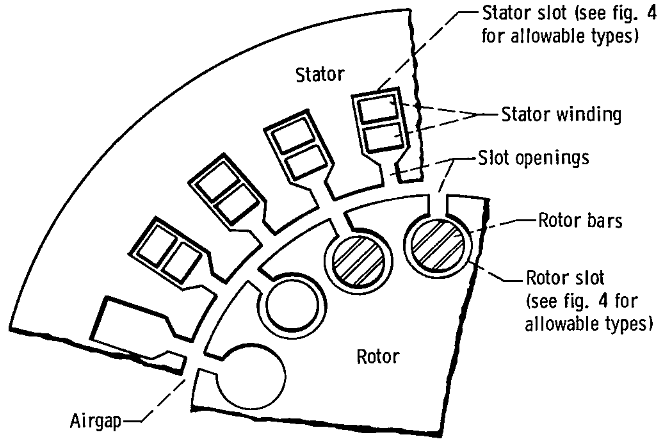


Figure 1. - Cross-section of induction motor assumed in this analysis.

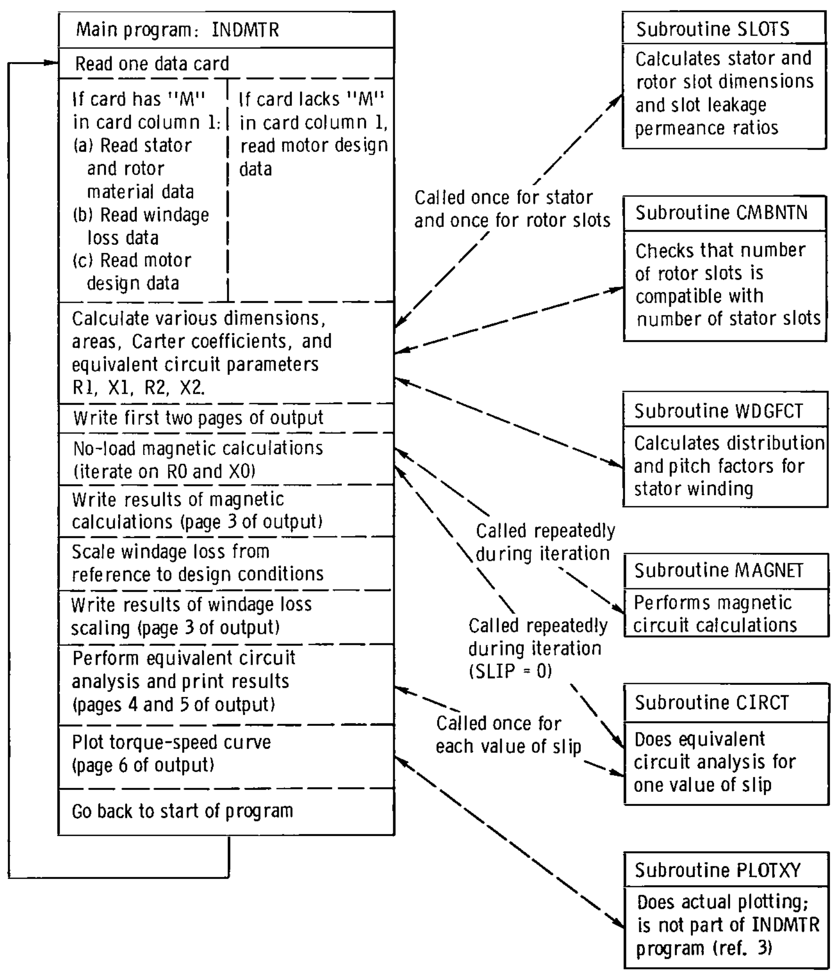


Figure 2. - Simplified flow chart of induction motor computer program.

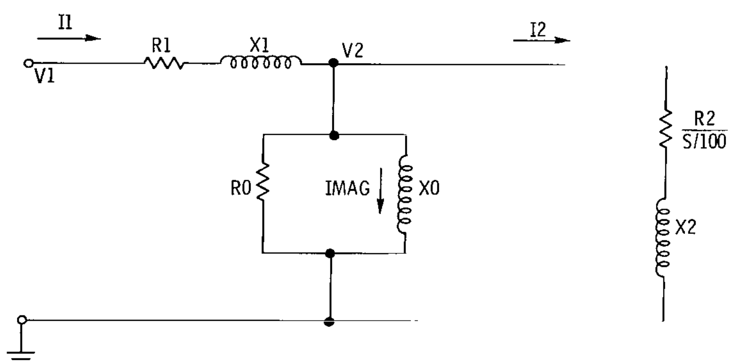
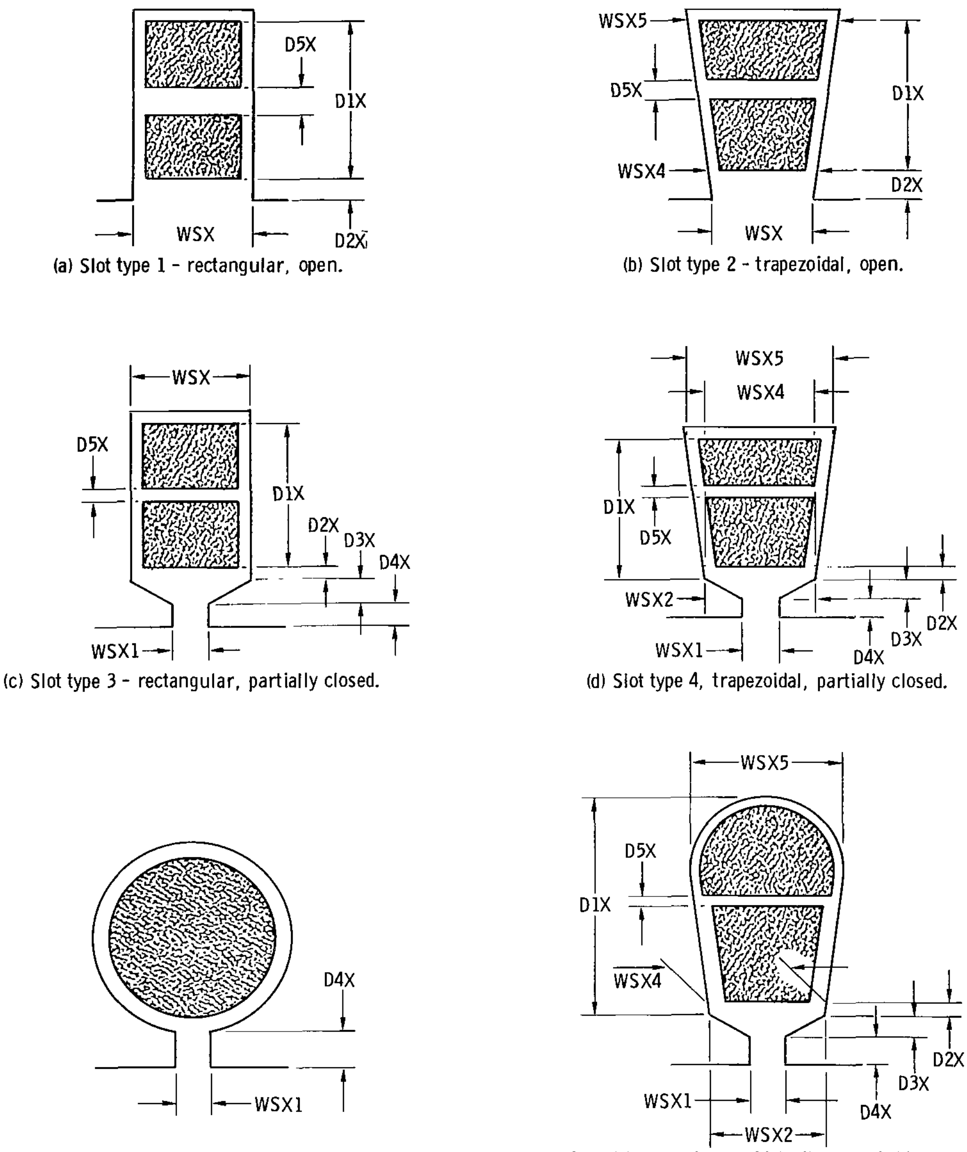


Figure 3. - Equivalent circuit of induction motor showing FORTRAN symbols used by main program. (S is rotor slip in percent.)



(a) Slot type 1 - rectangular, open.

(b) Slot type 2 - trapezoidal, open.

(c) Slot type 3 - rectangular, partially closed.

(d) Slot type 4, trapezoidal, partially closed.

(e) Slot type 5 - round.

(f) Slot type 6 - trapezoidal with rounded bottom, partially closed.

Figure 4. - Allowable rotor and stator slot types with dimensions needed to calculate slot permeance ratio. (Symbols shown are those used in subroutine SLOTS. To change the symbols to those used in main program, replace each X with S for stator slots or each X with R for rotor slots. For other dimensions see figs. 12 and 14.)

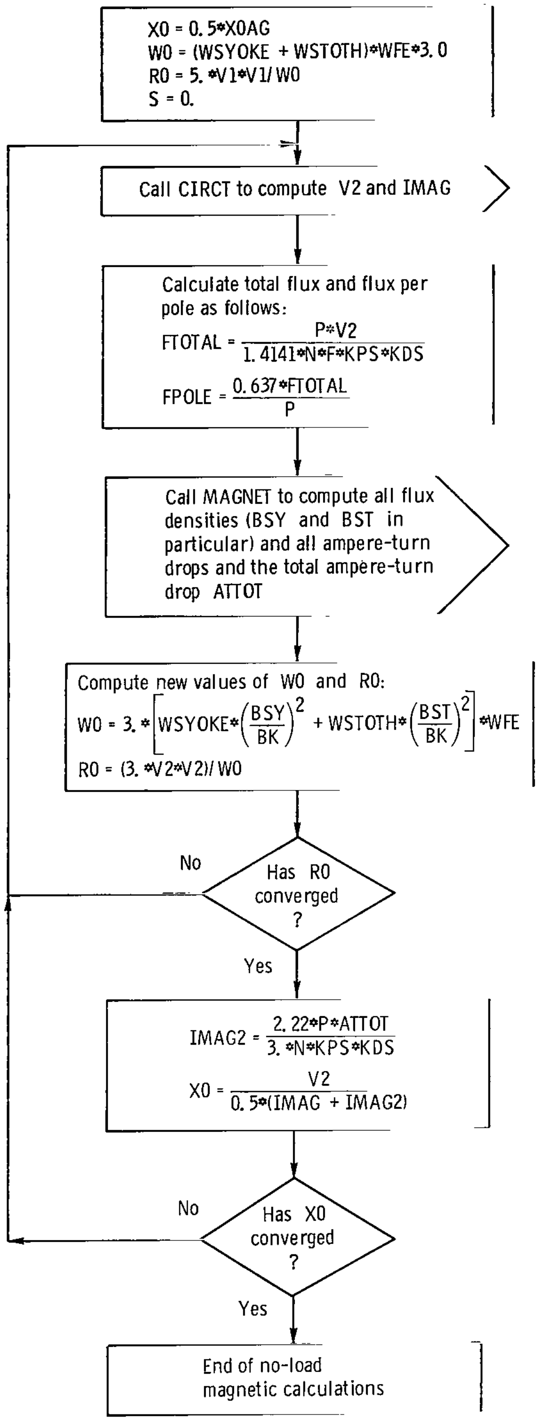


Figure 5. - Flow chart of no-load magnetic calculations.

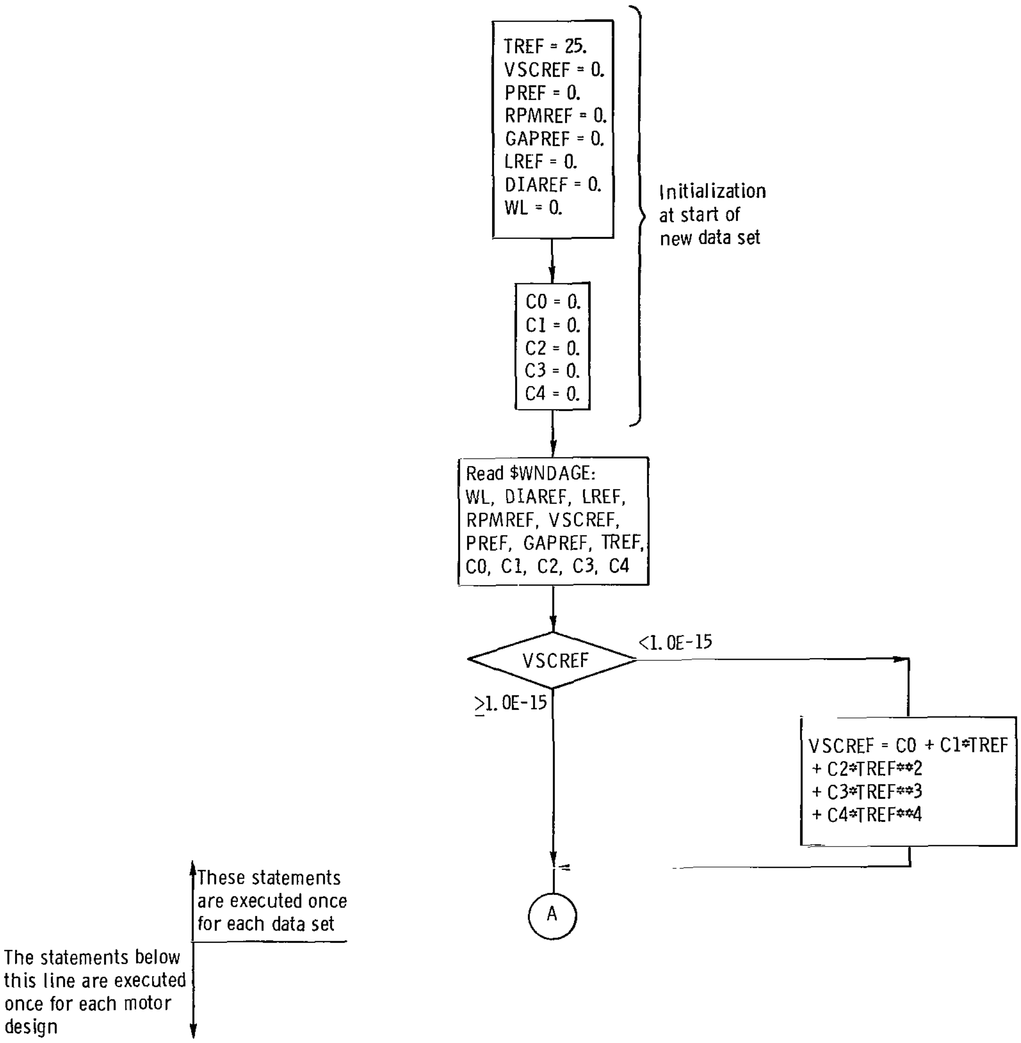


Figure 6. - Flow chart of synchronous windage loss calculation.

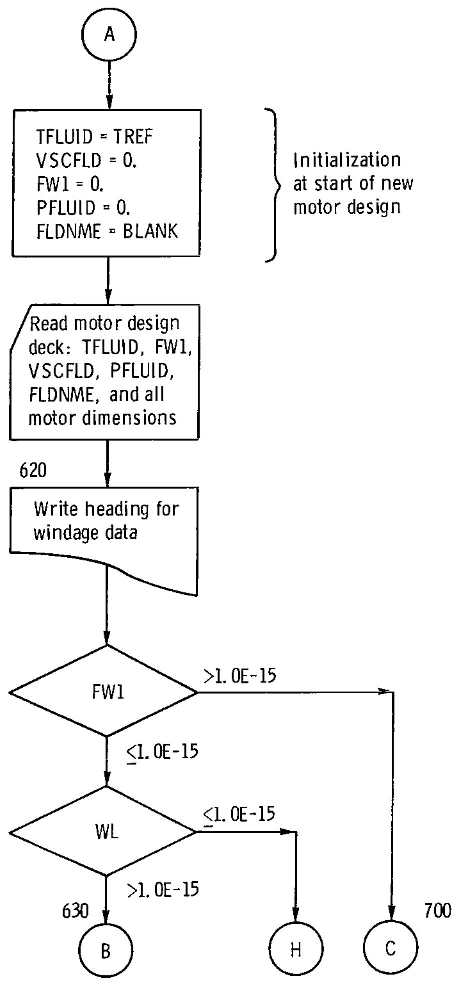


Figure 6. - Continued.

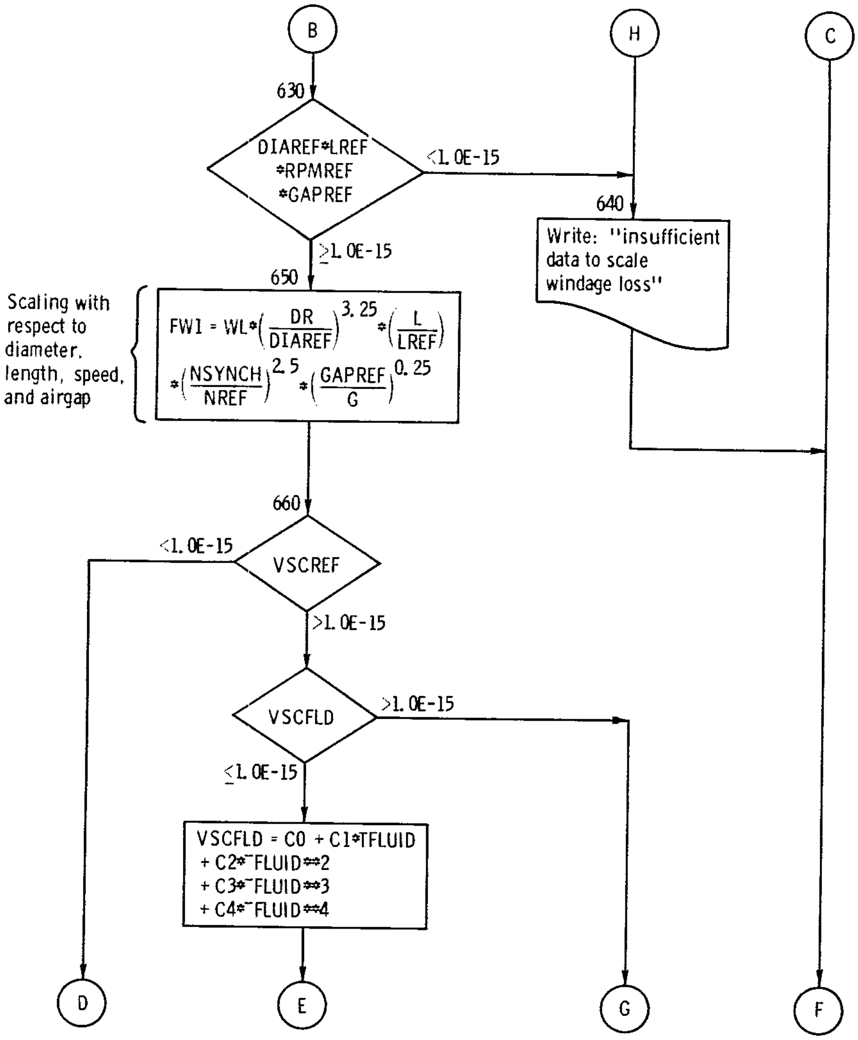


Figure 6. - Continued.

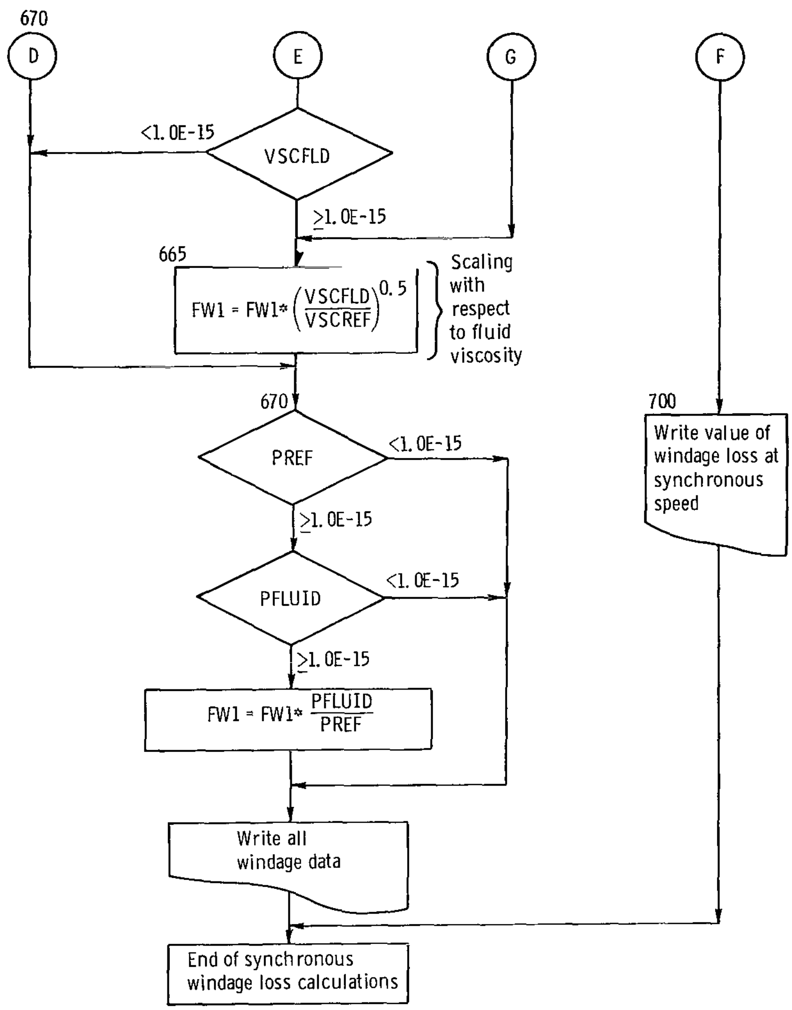


Figure 6. - Concluded.

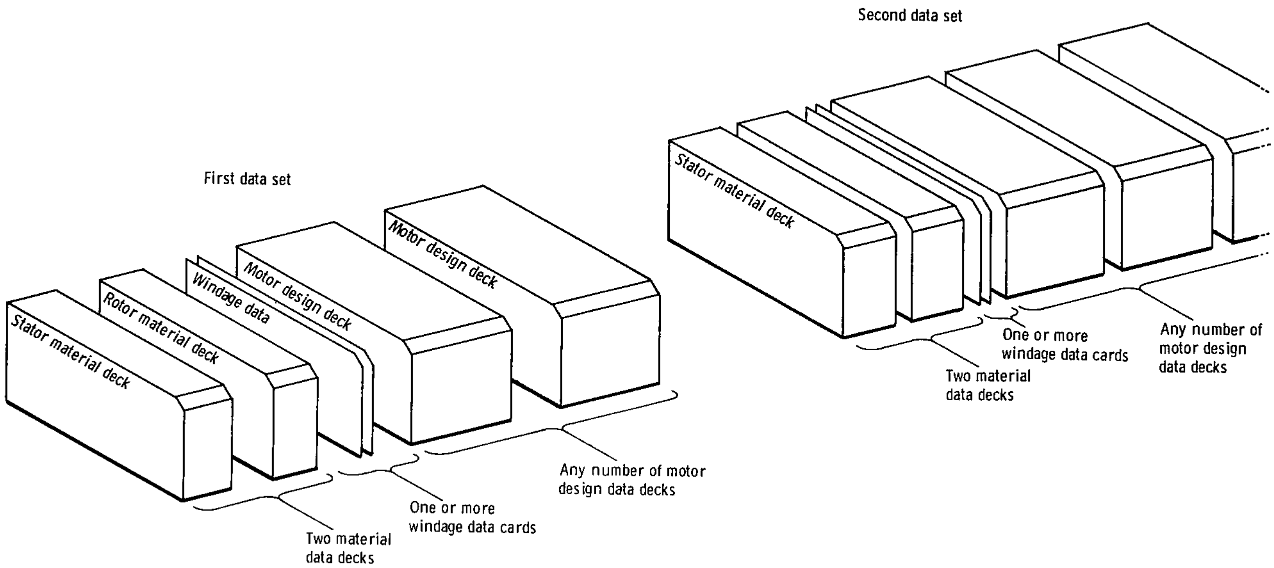


Figure 7. - Data deck setup. (Number of data sets used is optional. See appendix B for typical data set listing.)

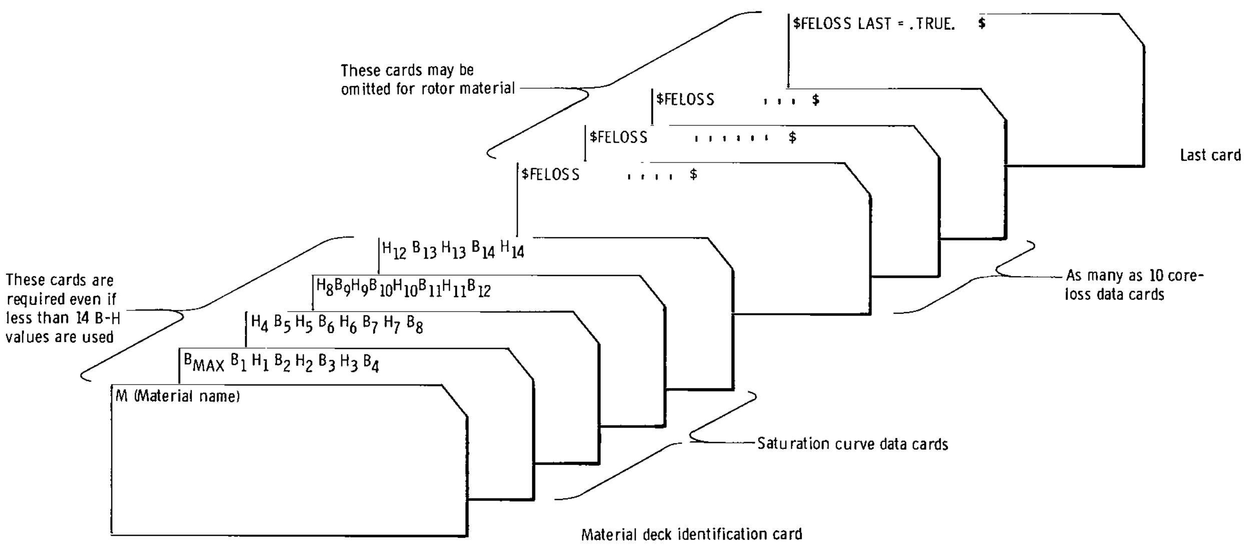


Figure 8. - Material deck setup.

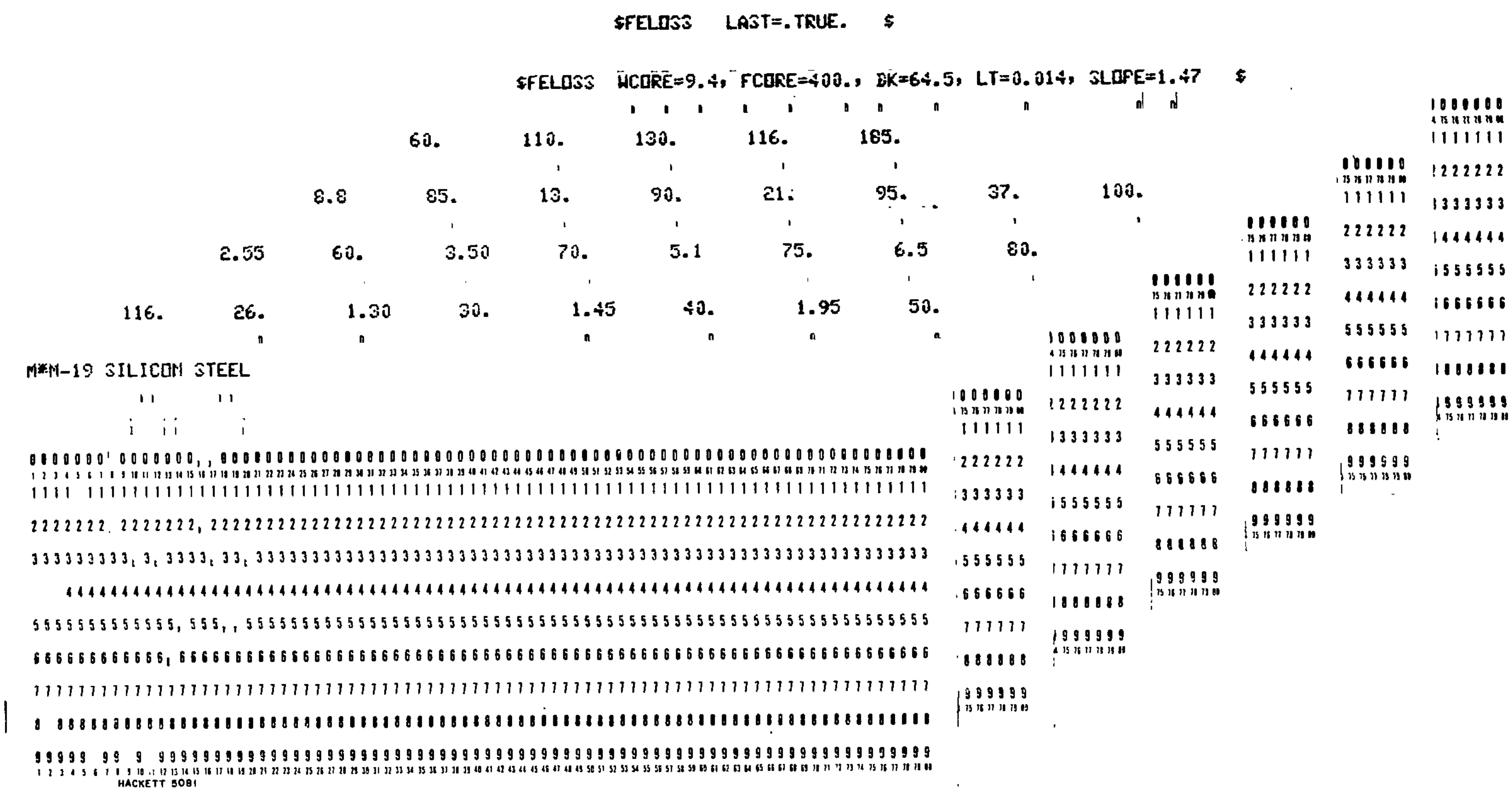
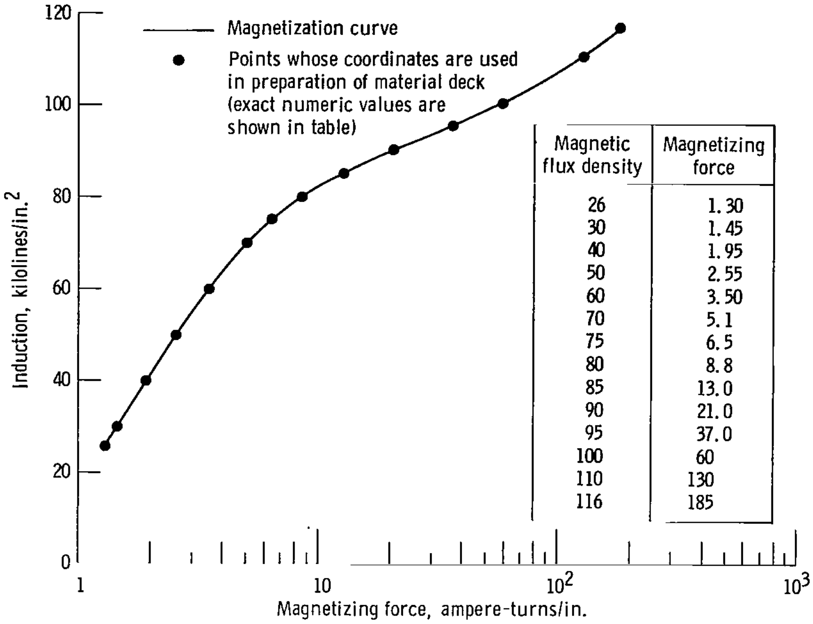


Figure 9. - Material deck for M-19 silicon steel.



Magnetic flux density	Magnetizing force
26	1.30
30	1.45
40	1.95
50	2.55
60	3.50
70	5.1
75	6.5
80	8.8
85	13.0
90	21.0
95	37.0
100	60
110	130
116	185

Figure 10. - Magnetization curve for M-19 steel.

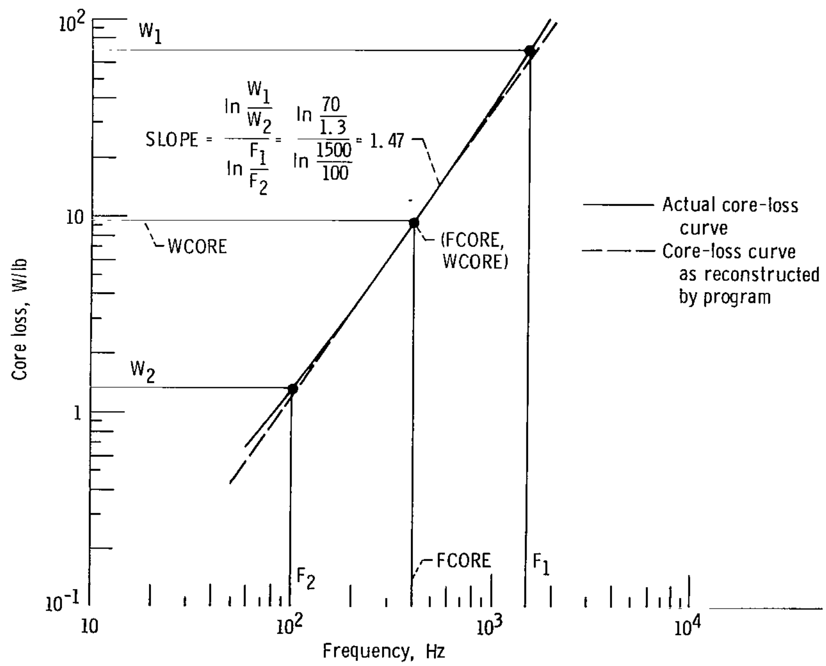
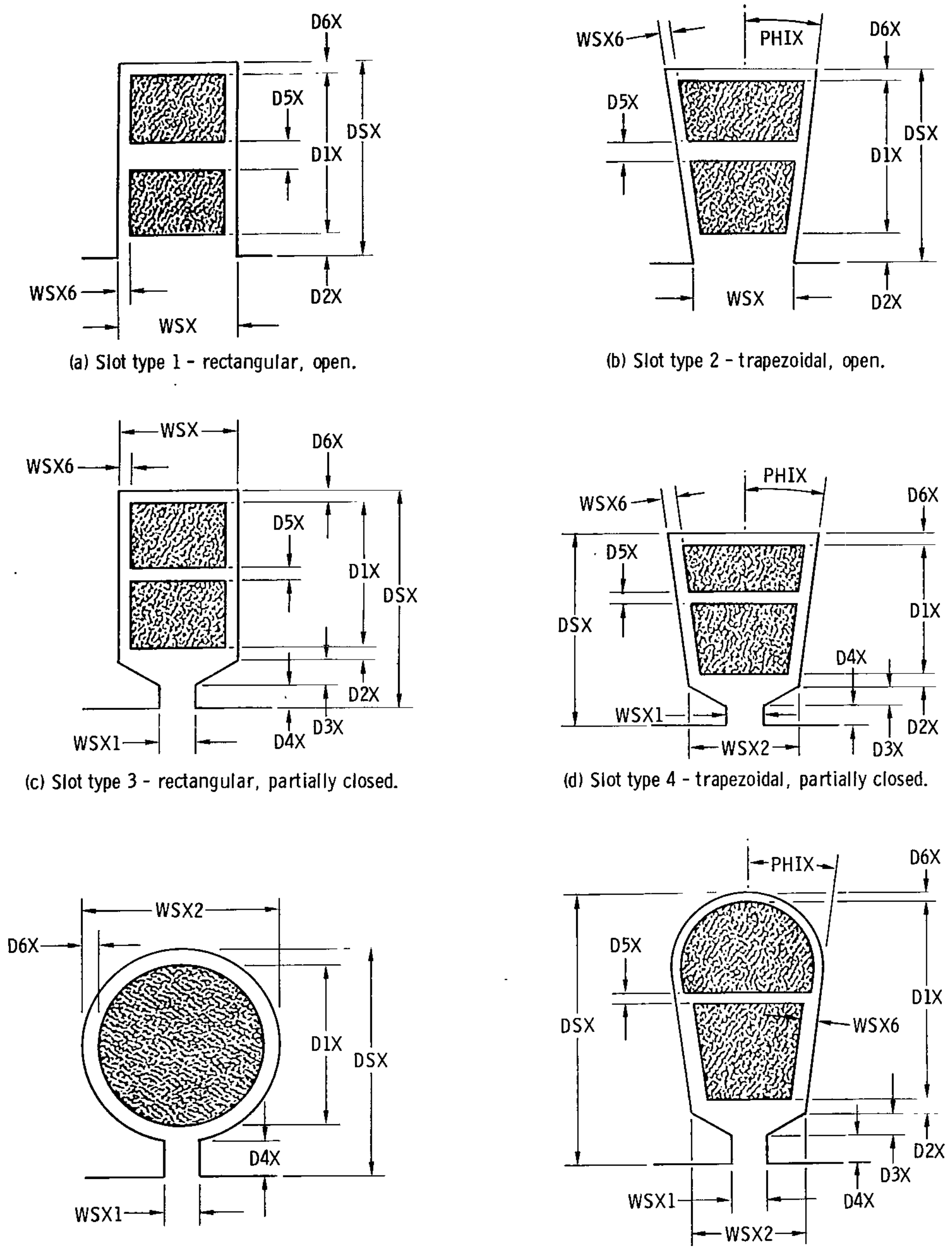


Figure 11. - Core loss as function of frequency for M-19 steel (0.014-in.-thick laminations) at 64.5 kilolines per square inch.



(a) Slot type 1 - rectangular, open.

(b) Slot type 2 - trapezoidal, open.

(c) Slot type 3 - rectangular, partially closed.

(d) Slot type 4 - trapezoidal, partially closed.

(e) Slot type 5 - round.

(f) Slot type 6 - trapezoidal with rounded bottom, partially closed.

Figure 12. - Slot dimensions allowable as program input. (Symbols shown are those used in subroutine SLOTS. To change to symbols used in main program, replace each X with S for stator slots or each X with R for rotor slots. The shaded area is CAREA in the notation of subroutine SLOTS. In the main program the shaded area is called SCAREA for stator slots and SB for rotor slots. Where shaded area is shown in two halves, it is assumed each half is CAREA/2. For other slot dimensions see figs. 4 and 14.)

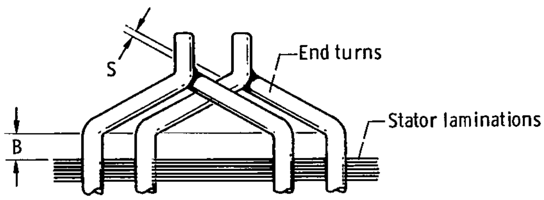
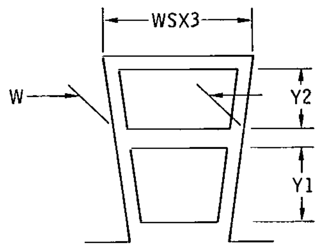
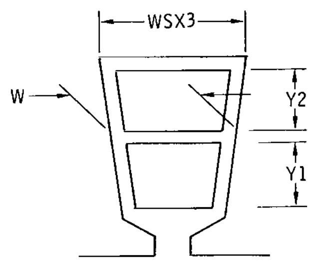


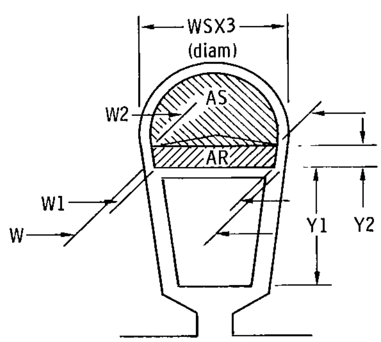
Figure 13. - End-turn dimensions.



(a) Slot type 2 - trapezoidal open.



(b) Slot type 4 - trapezoidal, partially closed.



(c) Slot type 6 - trapezoidal with rounded bottom, partially closed. AR + AS = CAREA/2.

Figure 14. - Slot dimensions used in subroutine SLOTS. (For other slot dimensions see figs. 4 and 12.)

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