FORTRAN PROGRAM FOR
INDUCTION MOTOR ANALYSIS

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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 appendices 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

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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

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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, $R_1$ represents the phase resistance of the armature winding, $X_1$ the armature leakage reactance per phase, and $R_2$ the resistance of the rotor winding referred to the armature winding. The resistance element $R_2/(S/100)$ shown in figure 3 represents the combined effect of the rotor winding resistance and the shaft load. The symbol $X_2$ is the rotor winding leakage reactance per phase. Both $R_2$ and $X_2$ are referred to the armature winding. Resistance $R_0$ and reactance $X_0$ allow for the effects of core loss and magnetizing current, respectively. Values of $R_1$, $R_2$, $X_1$, and $X_2$ are calculated from the physical dimension of the motor. Values for $X_0$ and $R_0$ 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 $\mu$-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.

\[
P_{s1} = \frac{K_S}{w} \left( d_3 + \frac{d_1}{3} \right) + \frac{d_1}{12w} (1 - K_S) - \frac{d_2}{4w} \left( K_S - \frac{2}{3} \right)
\]  

(1)

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

\[
AXX = \frac{KX}{WSX} \left( \frac{D2X}{WSX} + \frac{D1X}{WSX} \right) + \frac{D1X}{12 \cdot WSX} (1 - KX) - \frac{D5X}{4 \cdot WSX} (KX - 0.6667) \tag{2}
\]

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

\[
A1 = 0.25 \cdot KX + \frac{1}{12}.
\]

and

\[
A2 = 0.25 \cdot KX - \frac{1}{6}.
\]

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

\[
AXX = KX \left( \text{Permeance ratio for slot opening} \right) + \left( \frac{D1X}{WSX} \right) A1 - \left( \frac{D5X}{WSX} \right) A2 \tag{4}
\]

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,

\[ AXX = KX \left( \frac{D2X}{WSX} \right) + \left( \frac{D1X}{WSX} \right) A1 - \left( \frac{D5X}{WSX} \right) A2 \]  

(5)

For slot type 2,

\[ AXX = 2 \cdot KX \cdot D2X + \left( \frac{D1X}{WSX} \right) A1 - \left( \frac{2 \cdot D5X}{WSX + WSX4} \right) A2 \]  

(6)

For slot type 3,

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

(7)

For slot type 4,

\[ AXX = KX \left[ \frac{D4X}{WSX1} + \left( \frac{D3X}{WSX2 - WSX1} \right) ALOG \left( \frac{WSX2}{WSX1} \right) + \frac{2 \cdot D2X}{WSX2 + WSX4} \right] + \left( \frac{D1X}{WSX4} \right) A1 \]

\[ - \left( \frac{2 \cdot D5X}{WSX4 + WSX5} \right) A2 \]  

(8)

For slot type 6,

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

(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

\[ AXX = KX \left( \frac{D4X}{WSX1} \right) + 0.625 \cdot KX \]  

(10)
The equations just given apply to both the stator and rotor slots. However, for rotor slots the factor $K_X$ (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 $R_1$, $R_2$, $X_1$, $X_2$, 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.

\begin{equation}
X_M = \frac{6.38 \ \text{qfN}^2 K_e^2 K_d^2 D L}{k_i \ \text{ge} \ P^2 \times 10^8} \text{ohms/phase}
\end{equation}

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,

\begin{equation}
X0AG = \frac{3.02E-5 \times \left(\frac{N}{2 \times \text{KPS} \times \text{KDS}}\right) \times 2 \times D \times L \times F}{P \times P \times \text{GE}}
\end{equation}

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

\begin{equation}
X1 = XSS + XSE + XSK + XSZ + XP
\end{equation}
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:

\[
XSS = 2.36 \times 10^{-5} N^* N^* F^* L^* \left( \frac{AXS}{QS} \right) \quad (14)
\]

\[
XSE = 9.45 \times 10^{-6} \frac{N^* N^* F^* (KPS* KDS) \times 2}{P} \left( B + \frac{F1}{2} + \frac{DSS}{4} \right) \quad (15)
\]

\[
XSK = 0.5 \times \frac{X0AG}{12} \left( \frac{P* SKEW}{D} \right) \times 2 \quad (16)
\]

\[
XSZ = 0.833 \times X0AG \frac{KS}{(KPS* KDS) \times 2} \left( \frac{6}{CCS} \right) - 1.0 \quad (17)
\]

\[
XP = 0.525 \times X0AG \left( \frac{P* G}{D} \right) \times 2 \quad (18)
\]

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:

\[
X2 = XRS + XRE + XSK + XRZ \quad (19)
\]
where

\[ XRS = 2.36 \times 10^{-5} N^* N^* F^* L^* \left( \frac{AXR}{NB} \right) (KPS*KDS)^{**2} \]  
\[ (20) \]

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

where

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

\[ XSK = 0.5\left( \frac{X0AG}{12.} \right) * \left( \frac{SKEW}{D} \right)^{**2} \]  
\[ (22) \]

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

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 \( R_1 \) is given by

\[ R_1 = \frac{(LS*N*RSTVTY*1.0E-6)}{(PC*SS)} \]  
\[ (24) \]

where \( RSTVTY \) is the resistivity of the stator winding material at \( 20^\circ C \). Then \( R_1 \) is corrected for the winding temperature specified in the input data.

The rotor resistance \( R_2 \) (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)
\[ R2 = [3 \times RSTVTY \times (N \times KPS \times KDS) \times 2] \times \left( \frac{LB - TER}{SB \times NB} + \frac{0.64 \times DER \times KRING}{P \times P \times SER} \right) \] (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

\[ WFE = WCORE \times \left( \frac{F}{FCORE} \right)^{SLOPE} \] (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 estimates for \( X0, W0, \) and \( R0 \) are made by using the equations

\[ X0 = 0.5 \times X0AG \] (27)
\[ W_0 = 3. \times (W_{YOKE} + W_{STOTH}) \times WFE \]  \hspace{1cm} (28)

\[ R_0 = \frac{5. \times V_1 \times V_1}{W_0} \]  \hspace{1cm} (29)

Next subroutine CIRCT is called to compute the airgap voltage \( V_2 \) and the magnetizing current \( IMAG \) (fig. 5). From \( V_2 \) 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 \( W_0 \) and resistance \( R_0 \) as follows:

\[ W_0 = 3. \times WFE \times \left[ W_{YOKE} \times \left( B_{SY} \right) \times 2 + W_{STOTH} \times \left( B_{ST} \right) \times 2 \right] \]  \hspace{1cm} (30)

\[ R_0 = \frac{\left( 3. \times V_2 \times V_2 \right)}{W_0} \]  \hspace{1cm} (31)

where

- \( W_{YOKE} \) stator back-iron weight
- \( W_{STOTH} \) stator tooth weight
- \( B_{SY} \) back-iron flux density
- \( B_{ST} \) stator tooth flux density
- \( V_2 \) airgap voltage (fig. 3)

The process is then repeated using the latest value of \( R_0 \) until \( R_0 \) converges.

When \( R_0 \) has converged, the \( ATTOT \) value calculated by MAGNET and the values of \( V_2 \) and \( IMAG \) calculated by CIRCT are used to compute a new value of \( X_0 \) as follows:

\[ X_0 = \frac{V_2}{0.5 \times (IMAG + IMAG2)} \]  \hspace{1cm} (32)

where

\[ IMAG2 = \frac{(2.22 \times P \times ATTOT)}{(3. \times N \times KPS \times KDS)} \]

With this new value of \( X_0 \), the calculations for \( R_0 \) are then repeated. This double
convergence procedure is performed until both $R_0$ and $X_0$ 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 $X_0$ and $R_0$, 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 $FW_1$, 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

$$FW = FW_1 \cdot \left(\frac{\text{RPM}}{\text{NSYNCH}}\right)^C$$

where

- $FW_1$ 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 $FW_1$ is allowable input to the program; if known, it may be read in directly. If $FW_1$ 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 $FW_1$. 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. $\text{DIAREF}$, the diameter of the reference motor
2. $\text{LREF}$, 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

\[
FW1 = WL \ast \left( \frac{DR}{DIAREF} \right)^{3.25} \ast \left( \frac{L}{LREF} \right) \ast \left( \frac{NSYNCH}{NREF} \right)^{2.5} \ast \left( \frac{GAPREF}{G} \right)^{0.25}
\]

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

\[ W2 = \frac{3 \cdot I2^* I2^* R2 \cdot 100}{S} \]  

(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:

\[ W2 = 3 \cdot I2^* I2^* R2 + \frac{3 \cdot I2^* I2^* R2^* (100 - S)}{S} \]  

(36)

where

- \( 3 \cdot I2^* I2^* R2 \) power dissipated in the rotor winding
- \( 3 \cdot I2^* I2^* R2^* (100 - S)/S \) 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 cal-
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

\[
SLOPE = \frac{\ln(W1/W2)}{\ln(F1/F2)}
\]

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

\[ SLOPE = \ln \frac{70. / 1.3}{1500. / 100.} = 1.47 \]

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

$\text{STATOR D=}1.07, \text{ L=}1.24, \text{ SFS=}0.909, \text{ DOS=}2.50, \text{ LTS=}0.006$ 

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.**

<table>
<thead>
<tr>
<th>Classification</th>
<th>FORTRAN symbol</th>
<th>Description</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>Required</td>
<td>WCORE</td>
<td>Core loss at frequency FCORE, at flux density BK, and for lamination thickness LT, W/lb</td>
<td>FCORE should be close to motor design frequency F to minimize the error of extrapolating WCORE from frequency FCORE to frequency F.</td>
</tr>
<tr>
<td></td>
<td>FCORE</td>
<td>Frequency at which WCORE is determined, Hz</td>
<td></td>
</tr>
<tr>
<td></td>
<td>BK</td>
<td>Flux density at which WCORE is determined, kilolines/in.²</td>
<td>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.</td>
</tr>
<tr>
<td></td>
<td>LT</td>
<td>Lamination thickness at which WCORE is determined, in.</td>
<td>If SLOPE is omitted from input, the program will assume a value of slope given by SLOPE = ( \frac{1. + 164. \times LT}{1. + 82. \times LT} ). SLOPE may also be omitted if F of NAMELIST name RATING equals FCORE.</td>
</tr>
<tr>
<td>Optional</td>
<td>LAST</td>
<td>LAST=. TRUE. indicates end of core-loss data set.</td>
<td></td>
</tr>
</tbody>
</table>

**SLOPE**

Slope of core loss-against-frequency plot (assumed linear on log-log paper) for constant flux density BK; if \( W_1 \) is core loss at frequency \( F_1 \) and \( W_2 \) is core loss at frequency \( F_2 \),

\[
SLOPE = \frac{\ln \frac{W_1}{W_2}}{\ln \frac{F_1}{F_2}}
\]

(fig. 11)

---

*a For stator material only.*
TABLE II. - ENTRIES ON WINDAGE-LOSS DATA CARDS

\[ \text{[NAMELIST name; WNDAGE.]} \]

<table>
<thead>
<tr>
<th>Classification</th>
<th>FORTRAN symbol</th>
<th>Description</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>Required(^a)</td>
<td>WL</td>
<td>Windage loss at reference conditions, W</td>
<td>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.</td>
</tr>
<tr>
<td></td>
<td>DIAREF</td>
<td>Reference diameter, in.</td>
<td></td>
</tr>
<tr>
<td></td>
<td>LREF</td>
<td>Reference length, in.</td>
<td></td>
</tr>
<tr>
<td></td>
<td>RPMREF</td>
<td>Reference rotational speed, rpm</td>
<td></td>
</tr>
<tr>
<td></td>
<td>GAPREF</td>
<td>Reference gap length, in.</td>
<td></td>
</tr>
<tr>
<td>Optional</td>
<td>VSCREF</td>
<td>Reference viscosity, lbm/ft-sec</td>
<td>If VSCREF is omitted, the program will attempt to calculate a value based on the polynomial ( VSCREF = C0 + C1 \times TREF + C2 \times TREF^2 + C3 \times TREF^3 + C4 \times TREF^4 ). If the result of the calculation is ( \leq 0 ), no windage loss scaling with respect to viscosity will be made. Any or all constants omitted from the input will be assumed to equal zero.</td>
</tr>
<tr>
<td></td>
<td>TREF</td>
<td>Fluid temperature at reference conditions, °C</td>
<td>TREF is the temperature for which VSCREF is calculated if necessary.</td>
</tr>
<tr>
<td></td>
<td>PRESS</td>
<td>Pressure of fluid in airgap at reference conditions, lb/in.(^2)</td>
<td>If omitted, scaling of windage loss with pressure is not possible.</td>
</tr>
</tbody>
</table>

\(^a\)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

<table>
<thead>
<tr>
<th>NAMELIST name</th>
<th>Classification</th>
<th>FORTRAN symbol</th>
<th>Description</th>
<th>Remarks</th>
</tr>
</thead>
</table>
| RATING<sup>a</sup> | Required | NSYNCH<sup>F</sup> 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 | Reactance values of induction motor equivalent circuit | | 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.) |
| X1 | Reactance values of induction motor equivalent circuit (fig. 3), Ω | | |
| X2 | Reactance values of induction motor equivalent circuit (fig. 3), Ω | | |
| R0 | Resistance values of induction motor equivalent circuit | | |
| R1 | Resistance values of induction motor equivalent circuit | | |
| R2 | Resistance values of induction motor equivalent circuit | | |
| STATOR | Required | D | Stator inside diameter, in. | If omitted, stacking factor is calculated as follows: |
| L | Stator stack length, in. | | $SFC = \frac{LTS}{LTS + 0.0005}$ |
| LTS | Stator lamination thickness, in. | | |
| DOS | Stator outside diameter, in. | | |
| Optional | SFS | Stator stacking factor | | |
| 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. |

<sup>a</sup>This card must be preceded by a title card (see input, p. 43.)
<table>
<thead>
<tr>
<th>NAMELIST name</th>
<th>Classification</th>
<th>FORTRAN symbol</th>
<th>Description</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>SSLOTS</td>
<td>Required</td>
<td>D1S or DSS or SCAREA or CSRATO</td>
<td>Conductor depth (fig. 12), in. Slot depth (fig. 12), in. Slot area (fig. 12), in.² Space factor</td>
<td>One of these variables is required for all stator slot types.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>D6S or QS</td>
<td>Stator slot dimension (fig. 12), in. Number of stator slots</td>
<td>D6S and QS are required for all stator slots.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>D2S or D5S or WSS or WSS6</td>
<td>Slot dimension (fig. 12(a))</td>
<td>One of these variables is required for stator slot type 1 only.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>D2S or D5S or WSS or WSS6 or STWDTH</td>
<td>Slot dimension (fig. 12(b))</td>
<td>Required for stator slot type 2 only.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>D2S or D3S or D4S or D5S or WSS or WSS1 or WSS6</td>
<td>Slot dimension (fig. 12(c)), in.</td>
<td>Required for stator slot type 3 only.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>D2S or D3S or D4S or D5S or WSS1 or STWDTH</td>
<td>Slot dimension (fig. 12(d)), in.</td>
<td>Required for stator slot type 4 only.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>D2S or D3S or D4S or D5S or WSS1 or STWDTH</td>
<td>Stator tooth width if constant, in.</td>
<td></td>
</tr>
</tbody>
</table>
**TABLE III. - Continued.**

<table>
<thead>
<tr>
<th>NAMELIST name</th>
<th>Classification</th>
<th>FORTRAN symbol</th>
<th>Description</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>SLOTS</td>
<td>Required</td>
<td>D4S</td>
<td>Slot dimension (fig. 12(e)), in.</td>
<td>Required for stator slot type 5 only.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>WSS1</td>
<td>Slot dimension (fig. 12(e)), in.</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Optional</td>
<td>D2S</td>
<td>Stator slot dimension (fig. 12(f)), in.</td>
<td>Required for stator slot type 6 only.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>D3S</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>D4S</td>
<td></td>
<td></td>
</tr>
<tr>
<td>STRWDG</td>
<td>Required</td>
<td>CSS</td>
<td>Number of conductors per stator slot</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>PC</td>
<td>Number of parallel circuits</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>B</td>
<td>Armature coil extension (fig. 12), in.</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>SPITCH</td>
<td>Stator winding pitch, per unit</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>ASTRND</td>
<td>Cross-sectional area of stator conductor strand, in.</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>AWG</td>
<td>Gage size of stator conductor strand, AWG</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>S</td>
<td>Clearance between armature coils at end turns (fig. 13), in.</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Optional</td>
<td>SWMAT</td>
<td>Stator winding material code</td>
<td>SWMAT = 1 for aluminum</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>SWMAT = 2 for brass</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>SWMAT = 3 for copper</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Unless one of the other two is specified, SWMAT = 3 is assumed.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>LS</td>
<td>Length of one armature conductor (one-half of armature coil length), in.</td>
<td>If omitted from input data, program calculates value internally. The calculations assume a form-wound armature.</td>
</tr>
<tr>
<td>NAME LIST name</td>
<td>Classification</td>
<td>FORTRAN symbol</td>
<td>Description</td>
<td>Remarks</td>
</tr>
<tr>
<td>----------------</td>
<td>----------------</td>
<td>----------------</td>
<td>-------------</td>
<td>---------</td>
</tr>
<tr>
<td>STRWDG</td>
<td>Optional</td>
<td>TSW</td>
<td>Temperature of stator winding, °C</td>
<td>A temperature of 25° C is assumed unless otherwise specified.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>STRNDS</td>
<td>Number of strands per armature conductor</td>
<td>One strand per conductor is assumed.</td>
</tr>
<tr>
<td>Rotor</td>
<td>Required</td>
<td>LTR</td>
<td>Rotor lamination thickness, in.</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>DIR</td>
<td>Rotor lamination inside diameter, in.</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Optional</td>
<td>SKEW</td>
<td>Rotor slot skew, in.</td>
<td>If omitted from input data, program assumes it to equal rotor slot pitch or stator slot pitch, whichever is greater.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>SFR</td>
<td>Rotor lamination stacking factor</td>
<td>If omitted, stacking factor is calculated as follows: [ SFR = \frac{LTR}{LTR + 0.0005} ]</td>
</tr>
<tr>
<td>RSLOTS</td>
<td>Required</td>
<td>RSType</td>
<td>Rotor slot type (choose from type 1 to type 6 as shown in fig. 12)</td>
<td>Required for all rotor slots.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>SB or DIR or DSR</td>
<td>Rotor bar cross-sectional area (fig. 12), in.²</td>
<td>One of these is required for all rotor slots</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Slot depth (fig. 12), in.</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>D6R</td>
<td>Slot dimension (fig. 12), in.</td>
<td>Required for all rotor slots</td>
</tr>
<tr>
<td></td>
<td></td>
<td>D2R, WSR, WSR6</td>
<td>Slot dimension (fig. 12(a))</td>
<td>Required for rotor slot type 1 only.</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Slot dimension (fig. 12(b))</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>D2R, WSR6, WSR or RTWDT</td>
<td>Slot dimension (fig. 12(a))</td>
<td>Required for rotor slot type 2 only.</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Slot dimension (fig. 12(b))</td>
<td></td>
</tr>
</tbody>
</table>

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### TABLE III. - Continued.

<table>
<thead>
<tr>
<th>NAMELIST name</th>
<th>Classification</th>
<th>FORTRAN symbol</th>
<th>Description</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>RSLOTS</td>
<td>Required</td>
<td>D2R</td>
<td>Slot dimension (fig. 12(c)), in.</td>
<td>Required for rotor slot type 3 only.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>D3R</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>D4R</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>WSR</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>WSR1</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>WSR6</td>
<td></td>
<td></td>
</tr>
<tr>
<td>or RTWDTH</td>
<td></td>
<td>D2R</td>
<td>Slot dimension (fig. 12(d)), in.</td>
<td>Required for rotor slot type 4 only.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>D3R</td>
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<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>D4R</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>WSR1</td>
<td></td>
<td></td>
</tr>
<tr>
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<td></td>
<td>WSR6</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>WSR2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>or RTWDTH</td>
<td></td>
<td>D4R</td>
<td>Slot dimension (fig. 12(e)), in.</td>
<td>Required for rotor slot type 5 only.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>WSR1</td>
<td>Slot dimension (fig. 12(e)), in.</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Optional</td>
<td>D2R</td>
<td>Rotor slot dimension (fig. 12(f)), in.</td>
<td>Required for rotor slot type 6 only.</td>
</tr>
<tr>
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<td></td>
<td>D3R</td>
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<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>D4R</td>
<td></td>
<td></td>
</tr>
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<td></td>
<td>WSR1</td>
<td></td>
<td></td>
</tr>
<tr>
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<td></td>
<td>WSR6</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>WSR2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>or RTWDTH</td>
<td></td>
<td>D2R</td>
<td>Rotor tooth width, in.</td>
<td>If omitted, WSR2 = DSR - D4R for slot type 5 only.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>D3R</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>D4R</td>
<td></td>
<td></td>
</tr>
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<td></td>
<td>WSR1</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>WSR6</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>WSR2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>or RTWDTH</td>
<td></td>
<td>WSR2</td>
<td>Rotor slot dimension (fig. 12(e)), in.</td>
<td>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.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>PHIR</td>
<td>One-half of angle at which sides of rotor slots diverge (fig. 12), deg</td>
<td></td>
</tr>
<tr>
<td>RTRWDG</td>
<td>Required</td>
<td>NB</td>
<td>Number of rotor bars</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>TER</td>
<td>End-ring thickness (measured in axial direction), in.</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>BR</td>
<td>Axial clearance between end-ring and rotor laminations, in.</td>
<td></td>
</tr>
<tr>
<td>NAMELIST name</td>
<td>Classification</td>
<td>FORTRAN symbol</td>
<td>Description</td>
<td>Remarks</td>
</tr>
<tr>
<td>---------------</td>
<td>----------------</td>
<td>----------------</td>
<td>-------------</td>
<td>---------</td>
</tr>
<tr>
<td>RTRWDG</td>
<td>Optional</td>
<td>LB</td>
<td>Rotor bar length, in.</td>
<td>If omitted, LB is calculated as follows: $LB = \sqrt{L^2 + SKEW^2 + 2*(BR + TR)}$</td>
</tr>
<tr>
<td>DER1</td>
<td>End-ring outside diameter, in.</td>
<td>If omitted, DER1 is calculated as follows: $DER1 = DR - 2. \times (D4R + D3R)$</td>
<td></td>
<td></td>
</tr>
<tr>
<td>DER2</td>
<td>End-ring inside diameter, in.</td>
<td>If omitted, DER2 is calculated as follows: $DER2 = DR - 3. \times DSR$ or $DER2 = 1.1 \times DIR$ whichever is greater.</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
| 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$^\circ$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

<table>
<thead>
<tr>
<th>Stator</th>
<th>Rotor</th>
<th>Windage data</th>
<th>Title card</th>
<th>Motor design data</th>
</tr>
</thead>
<tbody>
<tr>
<td>Material data</td>
<td>Material data</td>
<td>Windage data</td>
<td>Title card</td>
<td>Motor design data</td>
</tr>
</tbody>
</table>

**P*VANADiUM PERMIUM**

<table>
<thead>
<tr>
<th>Condition</th>
<th>Value</th>
<th>Condition</th>
<th>Value</th>
<th>Condition</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>15%</td>
<td>17.9</td>
<td>25%</td>
<td>1.98</td>
<td>35%</td>
<td>34.7</td>
</tr>
<tr>
<td>75%</td>
<td>103.5</td>
<td>85%</td>
<td>4.35</td>
<td>95%</td>
<td>104.7</td>
</tr>
<tr>
<td>95%</td>
<td>142</td>
<td>95%</td>
<td>12.45</td>
<td>105%</td>
<td>115.6</td>
</tr>
<tr>
<td>105%</td>
<td>146.3</td>
<td>105%</td>
<td>16.1</td>
<td>115%</td>
<td>154</td>
</tr>
</tbody>
</table>

**$FELDOS$**

- WCRE = 21.0, FCREM = 1.72, SLOPE = 1.22, BK = 77.4, LT = 0.006
- WCRE = 24.5, FCREM = 1.34, SLOPE = 1.24, BK = 77.4, LT = 0.008
- WCRE = 24.5, FCREM = 1.34, SLOPE = 1.45, BK = 77.4, LT = 0.010
- WCRE = 24.5, FCREM = 1.34, SLOPE = 1.57, BK = 77.4, LT = 0.014

**LST=1FLUL**

- 15% | 1.98 | 28.7 | 2.62 | 77.4 | 3.23 | 90.3
- 35% | 4.35 | 104.7 | 5.25 | 116.3 | 6.66 | 122.6
- 75% | 12.45 | 115.6 | 20.2 | 142.4 | 44.4 | 145.3
- 115% | 146.3 | 16.1 | 154.0 | 20.2 |

**$WINDAE$**

- KL = 45.0, DIREF = 1.0, LREF = 1.12, PPREM = 120.0, GAPREM = 0.010,
- CM = 1.72, C1 = 0.2, C2 = 32.3, C3 = 0.3876, C4 = 0.3294, C5 = 0.105, C6 = 0.010
- TREF = 3.0

**1200 Hz COOLANT FUMP**

- $X$YNCH = 1200, $F$YRT = 121.4, $Y$ERTER = 2.0
- $SS$WQ = 11.97, $L$WQ = 3.74, $SS$ $S$ $F$ $W$ $Q$ = 0.052.3, $L$WS = 7.06
- $SS$WQ = 0.135, $SS$WQ = 0.135, $SS$WQ = 0.135, $SS$WQ = 0.135
- $SS$WQ = 0.135, $SS$WQ = 0.135
- $SS$WQ = 0.135, $SS$WQ = 0.135
- $SS$WQ = 0.135, $SS$WQ = 0.135
- $SS$WQ = 0.135, $SS$WQ = 0.135
- $SS$WQ = 0.135, $SS$WQ = 0.135
- $SS$WQ = 0.135, $SS$WQ = 0.135

**$SLOT$**

- 1 slot, $G$ET = 25, $SS$ = 5.6, $SS$ = 3.2, $SS$ = 1.2, $SS$ = 0.105
- $SS$ = 0.135, $SS$ = 0.135, $SS$ = 0.135, $SS$ = 0.135
- $SS$ = 0.135, $SS$ = 0.135
- $SS$ = 0.135, $SS$ = 0.135
- $SS$ = 0.135, $SS$ = 0.135
- $SS$ = 0.135, $SS$ = 0.135
- $SS$ = 0.135, $SS$ = 0.135
- $SS$ = 0.135, $SS$ = 0.135
- $SS$ = 0.135, $SS$ = 0.135

**$S$**

- $S$ = 0.135, $SS$ = 0.135, $SS$ = 0.135, $SS$ = 0.135
- $SS$ = 0.135, $SS$ = 0.135
- $SS$ = 0.135, $SS$ = 0.135
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- $SS$ = 0.135, $SS$ = 0.135
- $SS$ = 0.135, $SS$ = 0.135
- $SS$ = 0.135, $SS$ = 0.135

**$S$**

- $SS$ = 0.135, $SS$ = 0.135, $SS$ = 0.135, $SS$ = 0.135
- $SS$ = 0.135, $SS$ = 0.135
- $SS$ = 0.135, $SS$ = 0.135
- $SS$ = 0.135, $SS$ = 0.135
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- $SS$ = 0.135, $SS$ = 0.135
- $SS$ = 0.135, $SS$ = 0.135
- $SS$ = 0.135, $SS$ = 0.135
- $SS$ = 0.135, $SS$ = 0.135

**$S$**

- $SS$ = 0.135, $SS$ = 0.135, $SS$ = 0.135, $SS$ = 0.135
- $SS$ = 0.135, $SS$ = 0.135
- $SS$ = 0.135, $SS$ = 0.135
- $SS$ = 0.135, $SS$ = 0.135
- $SS$ = 0.135, $SS$ = 0.135
- $SS$ = 0.135, $SS$ = 0.135
- $SS$ = 0.135, $SS$ = 0.135
- $SS$ = 0.135, $SS$ = 0.135
- $SS$ = 0.135, $SS$ = 0.135

**$S$**

- $SS$ = 0.135, $SS$ = 0.135, $SS$ = 0.135, $SS$ = 0.135
- $SS$ = 0.135, $SS$ = 0.135
- $SS$ = 0.135, $SS$ = 0.135
- $SS$ = 0.135, $SS$ = 0.135
- $SS$ = 0.135, $SS$ = 0.135
- $SS$ = 0.135, $SS$ = 0.135
- $SS$ = 0.135, $SS$ = 0.135
- $SS$ = 0.135, $SS$ = 0.135
- $SS$ = 0.135, $SS$ = 0.135

**$S$**

- $SS$ = 0.135, $SS$ = 0.135, $SS$ = 0.135, $SS$ = 0.135
- $SS$ = 0.135, $SS$ = 0.135
- $SS$ = 0.135, $SS$ = 0.135
- $SS$ = 0.135, $SS$ = 0.135
- $SS$ = 0.135, $SS$ = 0.135
- $SS$ = 0.135, $SS$ = 0.135
- $SS$ = 0.135, $SS$ = 0.135
- $SS$ = 0.135, $SS$ = 0.135
- $SS$ = 0.135, $SS$ = 0.135

29
The output that resulted from using this data set with the induction motor computer program is as follows:

<table>
<thead>
<tr>
<th>STATOR MATERIAL</th>
<th>VANADIUM PERMENDUR</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>B</td>
</tr>
<tr>
<td></td>
<td>H</td>
</tr>
<tr>
<td>(KILOLINES/SO-IN)</td>
<td>(A-TURN/IN)</td>
</tr>
<tr>
<td>12.90</td>
<td>1.92</td>
</tr>
<tr>
<td>38.70</td>
<td>2.62</td>
</tr>
<tr>
<td>77.40</td>
<td>3.23</td>
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<tr>
<td>90.30</td>
<td>3.53</td>
</tr>
<tr>
<td>103.00</td>
<td>4.35</td>
</tr>
<tr>
<td>109.70</td>
<td>5.25</td>
</tr>
<tr>
<td>116.00</td>
<td>6.66</td>
</tr>
<tr>
<td>122.50</td>
<td>8.68</td>
</tr>
<tr>
<td>129.00</td>
<td>12.50</td>
</tr>
<tr>
<td>135.50</td>
<td>20.20</td>
</tr>
<tr>
<td>142.00</td>
<td>44.40</td>
</tr>
<tr>
<td>145.30</td>
<td>101.00</td>
</tr>
<tr>
<td>148.30</td>
<td>363.00</td>
</tr>
<tr>
<td>154.00</td>
<td>2020.00</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>CORE-LOSS DATA</th>
<th>LAM THK</th>
<th>FREQ</th>
<th>FLUX DNSTY</th>
<th>SLOPE</th>
</tr>
</thead>
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<td>21.0</td>
<td>006</td>
<td>800.0</td>
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<td>1.2</td>
</tr>
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<td>24.5</td>
<td>008</td>
<td>800.0</td>
<td>77.4</td>
<td>1.3</td>
</tr>
<tr>
<td>30.0</td>
<td>010</td>
<td>800.0</td>
<td>77.4</td>
<td>1.5</td>
</tr>
<tr>
<td>40.0</td>
<td>014</td>
<td>800.0</td>
<td>77.4</td>
<td>1.6</td>
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</table>

<table>
<thead>
<tr>
<th>ROTOR MATERIAL</th>
<th>VANADIUM PERMENDUR</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>B</td>
</tr>
<tr>
<td></td>
<td>H</td>
</tr>
<tr>
<td>(KILOLINES/SO-IN)</td>
<td>(A-TURN/IN)</td>
</tr>
<tr>
<td>12.90</td>
<td>1.92</td>
</tr>
<tr>
<td>38.70</td>
<td>2.62</td>
</tr>
<tr>
<td>77.40</td>
<td>3.23</td>
</tr>
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<td>90.30</td>
<td>3.53</td>
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<td>148.30</td>
<td>363.00</td>
</tr>
<tr>
<td>154.00</td>
<td>2020.00</td>
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</tbody>
</table>

<table>
<thead>
<tr>
<th>1200 HZ COOLANT PUMP MOTOR</th>
</tr>
</thead>
<tbody>
<tr>
<td>RATING</td>
</tr>
<tr>
<td>Synchronous Speed</td>
</tr>
<tr>
<td>Frequency</td>
</tr>
<tr>
<td>Poles</td>
</tr>
<tr>
<td>L-N Voltage</td>
</tr>
<tr>
<td>Rated Torque</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>STATOR</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bore Diameter</td>
</tr>
<tr>
<td>Outside Diameter</td>
</tr>
<tr>
<td>Depth Below Slot</td>
</tr>
<tr>
<td>Length</td>
</tr>
<tr>
<td>Lamination Thickness</td>
</tr>
<tr>
<td>Stacking Factor</td>
</tr>
<tr>
<td>Stator Iron Weight</td>
</tr>
</tbody>
</table>
### Stator Slots

<table>
<thead>
<tr>
<th>Slot Type</th>
<th>No. of Slots</th>
<th>Tooth Width</th>
<th>Slot Depth</th>
</tr>
</thead>
<tbody>
<tr>
<td>WX51</td>
<td>6</td>
<td>.045</td>
<td>.520</td>
</tr>
<tr>
<td>WX52</td>
<td></td>
<td>.040</td>
<td>.405</td>
</tr>
<tr>
<td>WX53</td>
<td></td>
<td>.120</td>
<td>.100</td>
</tr>
<tr>
<td>WX54</td>
<td></td>
<td>.066</td>
<td>.000</td>
</tr>
<tr>
<td>WX55</td>
<td></td>
<td>.120</td>
<td>.010</td>
</tr>
<tr>
<td>WX56</td>
<td></td>
<td>.010</td>
<td>.015</td>
</tr>
</tbody>
</table>

| Usable Area | .029 | Total Area | .047 |

| Slot Depth | .045 | .040 | .120 | .066 | .120 | .010 | .029 | .047 |

### Stator Winding

<table>
<thead>
<tr>
<th>Material</th>
<th>3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Conductors per Slot</td>
<td>56</td>
</tr>
<tr>
<td>Parallel Circuits</td>
<td>2</td>
</tr>
<tr>
<td>Pitch</td>
<td>.667</td>
</tr>
<tr>
<td>Axial Extension Beyond Core</td>
<td>.100</td>
</tr>
<tr>
<td>Conductor Cross-Section</td>
<td>.252-03</td>
</tr>
<tr>
<td>Strand Cross-Section</td>
<td>.252-03</td>
</tr>
<tr>
<td>Conductor Length</td>
<td>2.530</td>
</tr>
<tr>
<td>Clearance Between End-Turns</td>
<td>.010</td>
</tr>
<tr>
<td>Temperature (°C)</td>
<td>30</td>
</tr>
<tr>
<td>Axial End-Turn Length</td>
<td>.730</td>
</tr>
<tr>
<td>Overall Armature Length</td>
<td>2.700</td>
</tr>
<tr>
<td>Pitch Factor</td>
<td>.866</td>
</tr>
<tr>
<td>Distribution Factor</td>
<td>1.000</td>
</tr>
<tr>
<td>Armature Weight</td>
<td>.912</td>
</tr>
<tr>
<td>Total Armature Wire Length</td>
<td>425,000 Feet</td>
</tr>
</tbody>
</table>

| Strands/Conductor | 1 |
| Strands Size | 25 |

### Rotor

| Rotor Diameter | 1.058 |
| Inside Diameter | .450 |
| Lamination Thickness | .005 |
| Stacking Factor | .910 |
| Slot Skew | .115 |
| Depth Below Slot | .212 |
| Rotor Iron Weight | .185 |

### Rotor Slots

<table>
<thead>
<tr>
<th>Slot Type</th>
<th>No. of Slots</th>
<th>Slot Width</th>
<th>Slot Depth</th>
</tr>
</thead>
<tbody>
<tr>
<td>WS51</td>
<td>1</td>
<td>.053</td>
<td>.092</td>
</tr>
<tr>
<td>WS52</td>
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<td>.000</td>
<td>.087</td>
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<tr>
<td>WS53</td>
<td></td>
<td>.000</td>
<td>.005</td>
</tr>
<tr>
<td>WS54</td>
<td></td>
<td>.053</td>
<td>.000</td>
</tr>
<tr>
<td>WS55</td>
<td></td>
<td>.053</td>
<td>.000</td>
</tr>
<tr>
<td>WS56</td>
<td></td>
<td>.003</td>
<td>.005</td>
</tr>
</tbody>
</table>

| Usable Area | .004 | Total Area | .005 |

### Rotor Winding

<table>
<thead>
<tr>
<th>Material</th>
<th>3</th>
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<tbody>
<tr>
<td>Bar Length</td>
<td>1.515</td>
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<tr>
<td>Bar Cross-Section</td>
<td>.004</td>
</tr>
<tr>
<td>End-Ring Outside Dia</td>
<td>1.013</td>
</tr>
<tr>
<td>End-Ring Inside Dia</td>
<td>.500</td>
</tr>
<tr>
<td>End-Ring Thickness</td>
<td>.135</td>
</tr>
<tr>
<td>Stack-to-End-Ring Clearance</td>
<td>.000</td>
</tr>
<tr>
<td>Winding Temperature (°C)</td>
<td>30</td>
</tr>
<tr>
<td>Weight</td>
<td>.100</td>
</tr>
<tr>
<td>Component of R2 Due to Bars</td>
<td>2.084</td>
</tr>
<tr>
<td>Component of R2 Due to End Rings</td>
<td>.074</td>
</tr>
</tbody>
</table>

31
AIR GAP
ACTUAL AIR GAP  .0060
EFFECTIVE AIR GAP  .0141
MAGNETIZING REACTANCE (AIR GAP ONLY)  12.73

LEAKAGE REACTANCES (OHM)

<table>
<thead>
<tr>
<th>SLOT</th>
<th>STATOR</th>
<th>ROTOR</th>
</tr>
</thead>
<tbody>
<tr>
<td>END-CONNECTION</td>
<td>.579</td>
<td>.361</td>
</tr>
<tr>
<td>SKEW</td>
<td>.877</td>
<td>.877</td>
</tr>
<tr>
<td>JIC-ZAG</td>
<td>.639</td>
<td>1.173</td>
</tr>
<tr>
<td>PERIPHERAL</td>
<td>.030</td>
<td></td>
</tr>
</tbody>
</table>

WEIGHT
TOTAL (ELECTROMAGNETIC)  1.440

STATOR MATERIAL - VANADIUM PERMENDUR
B MAX = 154
CORE LOSS AT 77.4 KL/SO-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/SO-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
AIRGAP VOLTAGE  65.19
N.L. CURRENT DENSITY  10380.04
CORE LOSS  41 WATT

WINDAGE

| WINDAGE LOSS, W | 56° | 45° |
| DIAHETER        | 1.056 | 1.050 |
| LENGTH          | 1.290 | 1.125 |
| RPM             | 12000 | 12000 |
| GAP             | .006 | .010 |
| TEMPERATURE, DEG C | 25° | 20° |
| VISCOSITY, LBS/FT-SEC | .121-02 | .129-02 |
| PRESSURE, LBS/SO-IN | .000 | .000 |
| FLUID           | DC-200 |   |
| TORQUE (IN-LBS) | SLIP (PERCENT) | RPM | P-OUT (HP) | 1 (AMP) | EFF (PERCENT) | PF | P-IN (WATT) | PRI LOSS (WATT) | SEC LOSS (WATT) | ION LOSS (WATT) | IRON LOSS (WATT) | ION LOSS (FW) |
|----------------|----------------|-----|------------|---------|---------------|----|-------------|---------------|----------------|----------------|-----------------|-----------------|------------|
| 1.00           | 11880.00       |     | 1.69       | 5.23    | 1.37          | .10 | 197.23      | 97.67         | .59            | 40.66          | 58.62           |            |
| 2.00           | 11880.00       |     | 1.69       | 5.23    | 1.37          | .10 | 197.23      | 97.67         | .59            | 40.66          | 58.62           |            |
| 3.00           | 11880.00       |     | 1.69       | 5.23    | 1.37          | .10 | 197.23      | 97.67         | .59            | 40.66          | 58.62           |            |
| 4.00           | 11880.00       |     | 1.69       | 5.23    | 1.37          | .10 | 197.23      | 97.67         | .59            | 40.66          | 58.62           |            |
| 5.00           | 11880.00       |     | 1.69       | 5.23    | 1.37          | .10 | 197.23      | 97.67         | .59            | 40.66          | 58.62           |            |
| 6.00           | 11880.00       |     | 1.69       | 5.23    | 1.37          | .10 | 197.23      | 97.67         | .59            | 40.66          | 58.62           |            |
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.

```fortran
COMMON /CIR/ RO, R1, R2, X0, X1, X2, F1, NSYNCH, V1, S, I, 1, RMP, PP, T, HP, EFF
1FIN, W1, W2, W0, F, IMAG, V2, POUT, PHASE
COMMON /MAG/ BST, BSY, BRT, BRY, ASTY, ASY, ASTY, ASTY, ASTY, ASTY
10K, RTO, LSYOE, LSYOE, DSS, DSS, DSS, DSS, DSS, DSS, DSS, DSS, DSS, DSS, DSS, DSS
1, D4B, D4S, D5B, JBAR, LS, PLP, D2R, TWDTH, S5, SCARE, S5, S5, S5, S5, S5
2A, STWDTH, TRATED, VSCFLD, W5R1, W5R2, W5R3, W5R4, W5R5, WSS, WSS, WSS, WSS, WSS
3A, WSS, WSS, WSS
A 1
A 2
A 3
A 4
A 5
A 6
A 7
A 8
A 9
A 10
A 11
A 12
A 13
A 14
A 15
A 16
A 17
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A 38
A 39
A 40
A 41
A 42
A 43
A 44
A 45
A 46
A 47
A 48
A 49
A 50
A 51
A 52
A 53
A 54
```

The following FORTRAN statement gives the viscosity of the fluid in the motor cavity as a function of temperature, \( \nu(T) \):

\[
\nu(T) = C_0 + C_1 T + (C_2 + C_3 T)(C_4 + C_5 T)
\]
INITIALIZATION AT START OF A NEW DATA SET

LA ST=. FALSE.
VSCREP=0.
PRBP=O.
EPHREP=O.
LREF=O.
TREP25.
DIAREP=O.
GAPRE-0.
I1=0.
C1=0.
C2=0.
C3=0.
C4=0.
wL=0.

READ AND WRITE STATOR MATERIAL MAGNETIZATION DATA

READ (5,60) (AI(I),I=1,29)
WRITE (6,70) SMAT
FORMAT (1H1,4X,15HSTATOR MATERIAL/7X,13A6)
WRITE (6,80) (AI(I),I=2,29)
FORMAT (1H12X,1HB,20X,1HH//5X,17H(KILOLINES/SQ-IN),7X,11H(A-TURB)
1/IN)//(F16.2,F21.2)
WRITE (6,90)
FORMAT (1H14HCORE-LOSS DATA/10X,9HCORE-LOSS,5X,7HLAM THK,5X,G,1HFMREG,5X,10HFLOX DNSTY,5X,5HSLOPE)
READ CORE LOSS DATA FOR STATOR MATERIAL
DO 100 I=1,11
SLOPE=0.
IF (LAST) GO TO 120
CROSS(1,I)=WCORE
CROSS(2,I)=FCORE
IF (SLOPE.LT.1.0E-15) SLOPE=(1.3+164.*LT)/(1.0+82.*LT)
CROSS(3,I)=SLOPE
CROSS(4,I)=BK
CROSS(5,I)=LT
WRITE (6,110) WCORE,LT,FCORE,BK,SLOPE
WRITE (6,120) RHAT
FORMAT (1H1,4X,14HROTOR MATERIAL/7X,13A6)
WRITE (6,130) DEKTYP,TITLE
WRITE (6,140) TITLE
FORMAT (1H1/1H,5X,1F15.1,F14.3,F11.1,F11.1,F12.1)
MCARDS=I-1
READ ROTOR MATERIAL MAGNETIZATION DATA
READ (5,20) DEKTYP,RMAT
READ (5,60) (AI(I),I=31,59)
WRITE (6,130) RMAT
FORMAT (1H1,4X,14HROTOR MATERIAL/7X,13A6)
WRITE (6,80) (AI(I),I=32,59)
READ WINDAGE DATA
READ (5,WINDAGE)
IF (VSCREF.LT.1.0E-15) VSCREF=VSCSTY(TREF)
READ (5,20) DEKTYP,TITLE
WRITE (6,150) TITLE
FORMAT (1H1/1H,2X,13A6)
INITIALIZATION AT BEGINNING OF A NEW MOTOR DESIGN DECK
DO 160 I=1,38
160 RESET1(I)=0.
DO 170 I=1,7
170 RESET2(I)=0.
DSR=0.
DSS=0.
FNAME=BLANK
PHIR=0.
PHIS=0.
RMAT=3
STRNDS=1.0
SWMAT=3
TFLUID=TREF
TRW=25.
TSW=25.
DO 180 I=12,61
180 PP(I)=BLANK
READ 'MOTOR DESIGN' DECK
READ (5,RATING)
IF [XO*X1*X2*RO*R1*R2.GT. 1.OE-15) GO TO 720
READ (5,STATOR)
READ (5,SSLOTS)
READ (5,STRWGD)
READ (5,ROTOR)
READ (5,RSLOTS)
READ (5,RTRWDG)
READ (5,AIRGAP)
RETRIEVE CORE LOSS DATA FROM ARRAY CLOSS FOR DESIGN LAMINATION THICKNESS
DIFF= 10.
DO 190 I=1,NCARDS
190 DIFF1=ABS(LTS-CLOSS (5,IA))
IF [DIFF1.GT.DIFF) GO TO 190
IA=I
DIFFP=DIFF1
CONT
IF (DIFF.GT.0.0005) WRITE (6,230) CLOSS (5,IA)
FORNAT (1HK,68HCORE-LOSS DATA IS NOT GIVEN AT SPECIFIED STATOR LAMINATION THICKNESS/lH ,3X, l2HUSE DATA FOR,F6.3,12H LAMINATIONS)
CALCULATE CORE LOSS AT DESIGN FREQUENCY
WPE=CLOSS(1,IA)*((P/CL3SS(2,IA)) **CLOSS(3,IA))
BK=CLOSS (4,IA)
CALCULATE VARIOUS DIMENSIONS FROM INPUT DATA
DR=D-2.*G
TIR=(3.1416*DB)/NB
TIS=(3.1416*D)/QS
IF (SKEW.LT.1.0E-15) SKEW=AMAX1(T18,T1S)
IF (LB.LT.1.0E-15) LB=SQRT(L*L+SKEW*SKEW)+2.0*(BR+TB)
IF (ASTRND.LT.1.0E-15) ASTRND=WAREA(AWG)
SS=ASTRND*STRNDS
IF (SFR.LT.1.0E-15) SFR=LTR/(LTR+0.0005)
IF (SPS.LT.1.0E-15) SPS=LTR/(LTR+0.0005)
IF (DSS.GT.1.0E-15.OR.D15.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
WHITE (6,210)
210 FORMAT (1HK,5HRIINSUFFICIENT STATOR SLOT DATA, SPACE FACTOR OF 0.70 ASSUMED)
CSRATO=0.70
220 SCAREA=CSS*SS/CSRATO
GO TO 250
230 SCAREA=0.
240 CSRATO=0.
C
250  IF (SPITCH.LT.0.333) KS=0.75*SPITCH  A 201
250  IF (SPITCH.GT.0.333.AND_MODIFIED) KS=1.5*SPITCH-0.25  A 202
250  IF (SPITCH.GE.0.6667) KS=0.75*SPITCH+0.25  A 203
250  CALL SLOTS (1.0,SSTYPE,WSS,WSS1,WSS2,WSS3,WSS4,WSS5,DSS,DSS,DSS,DSS,DSS)
250  15,D4S,D5S,STWT,D4S,STRE,SSAREA,SSAREA,Q1,DS6,DSS,WSS,6,DSS,6,DSS,6,AX,R,STWMAO,PHIS)  A 204
250  CALL SLOTS (-1.0,STLE,WSS,WSS1,WSS2,WSS3,WSS4,WSS5,DSS,DSS,DSS,DSS,DSS)
250  13,B4R,0.8,STWT,D4S,STRE,SSAREA,SSAREA,R1,DS8,WSS6,DS1,0.1,AX,RTWMAO,PHIS)  A 205
250  STATOR AND ROTOR IRON WEIGHTS
250  WSTOTH=(3.1416*(D+DSS)*DSS-SSAREA*QSS)*L*SPS*2.283  A 2102
250  WSTOE=(0.7854*(DSS-QSS)*(D+DSS)**2)*L*SPS*2.283  A 214
250  WSTAT=WSTOTH+WSTOE  A 215
250  WSTOE=(0.7854*(D+DSS-DIR)*N*QSS)*L*SPS*2.283  A 216
250  END RING DIMENSIONS
250  IF (DER1.LT.1.0E-15) DER1=DER2-2.*D4R*D38  A 220
250  IF (DER2.LT.1.0E-15) DER2=DER2-ADJ(DR-3.*DSR,1.1*DIR)  A 221
250  SSS=0.5*(DER1-DER2)*TER  A 222
250  CALL CNBMTX (QSS,NB,P)  A 223
250  CALCULATE DISTRIBUTION AND PITCH FACTORS  A 224
250  CALL WDGFC (60.,P,QSS,KSS,PCS,PCS,PCSP,SPITCH)  A 225
250  CARTER COEFFICIENTS AND EFFECTIVE AIRGAP  A 226
250  IF (SSTYPE.GT.2) GO TO 260  A 227
250  CCR=(T1R*G+WSS)/T1R*(G+WSS)-WSS*WSS)  A 228
250  GO TO 270  A 229
250  CCR=(T1R*(4.4*G+WSS))/T1R*(4.4*G+WSS1)-WSS1*WSS11)  A 230
250  GO TO 290  A 231
250  CCS=(T1S*(5.5*WSS))/T1S*(5.5*WSS1)-WSS1*WSS1)  A 232
250  GE=GCC*CCS  A 233
250  STATOR RESISTANCE CALCULATION (R1)  A 234
250  IF (SSTYPE.EQ.2.OR.SSTYPE.EQ.4.OR.SSTYPE.EQ.6) SALPHA=(0.5*(WSS4+WSS5)+2.)*WSS1/WSS5)  A 235
250  15S5)/F(D*QSS)  A 236
250  IF (SSTYPE.EQ.1.OR.SSTYPE.EQ.3) SALPHA=(WSS+S-2.*WSS6)/T1S  A 237
250  IF (SSTYPE.EQ.5) SALPHA=(WSS3+S-2.*WSS51)/T1S  A 238
250  15S)/Q  A 239
250  CALPHA=SQRT(1.-SALPHA**2)  A 240
250  AY=(3.1416*(D+DSS)*SPITCH)/(P*SALPHA)  A 241
250  IF (LS.RT.LT.0.5E-1) LS=AY+2.*B+DSS+L  A 242
250  IF (R1.GT.1.0E-15) GO TO 300  A 243
250  R1=(LSN*RSTTY(SWAT))**(1.0E-6)/(P*QSS)  A 244
250  R1=R1**(1.0*(MPSCF(SWAT))**(TSW-20.))  A 245
250  IF AXIAL EXTENSION OF END TURN AND OVERALL ARMATURE LENGTH  A 246
300  ENDRTN=AY*0.5*SALPHA+B+DSS  A 247
300  LTOTAL=L+2.*ENDRTN  A 248
300  ARMATURE WEIGTH AND TOTAL WIRE LENGTH  A 249
300  LARM=LSN*CSS*QS*STRE/12.  A 250
300  WARM=DNSTY(SWAT)*LARM*ASTRND*12.
ROTOR RESISTANCE CALCULATION (R2)

\[
\text{BBSTVY} = 1.0 \times 6 \times \text{BBSTVY} (\text{RWMAT}) \times (1.0 + \text{MPCP} (\text{RWMAT}) \times (\text{TRW} - 20.))
\]

IF (R2 GT 1.0E-15) GO TO 310

\[
\text{RATIO} = \text{DER2} / \text{DER1}
\]

\[
\text{R2RING} = 0.50 \times \text{P} \times (1. - \text{RATIO}) \times (1. + \text{RATIO} \times \text{P})
\]

\[
\text{AY} = \left((\text{KPS} \times \text{KDS}) \times 2 \right) \times \text{BBSTVY}
\]

\[
\text{R2BAR} = \text{AY} \times \left((0.64 \times \text{DER1} \times \text{R2RING}) / (\text{P} \times \text{P} \times \text{SER})\right)
\]

\[
\text{R2} = \text{R2BAR} + \text{R2RING}
\]

ROTOR WINDING WEIGHT AND TOTAL ELECTROMAGNETIC MOTOR WEIGHT

\[
\text{WWWDG} = \text{DBSTV} (\text{RWMAT}) \times (\text{NR} \times \text{SR} \times (\text{LB} - 2. \times \text{TER}) + \text{SP} \times 3.1416 \times (\text{DER1} + \text{DER2}))
\]

\[
\text{WEIGHT} = \text{WWWDG} + \text{WWNDG} + \text{WROT} + \text{WSTAT}
\]

MAGNETIZING reactance (AIR GAP ONLY)

\[
\text{XOAG} = 7.66E-7 \times \text{P} \times (\text{N} / 2. \times \text{KPS} \times \text{KDS}) \times (2 \times \text{RRSTVY})
\]

\[
\text{R2BAR} = \text{AY} \times \left((\text{LB} - \text{TER}) / (\text{SB} \times \text{NB})\right)
\]

\[
\text{R2RING} = \text{AY} \times \left((0.64 \times \text{DER1} \times \text{R2RING}) / (\text{P} \times \text{P} \times \text{SER})\right)
\]

\[
\text{R2} = \text{R2BAR} + \text{R2RING}
\]

PRIMARY SLOT LEAKAGE reactance (XSS)

\[
\text{AT} = 6.2 - 7 \times \text{NR} \times \text{P} \times \left((\text{KPS} \times \text{KDS}) \times 2 \times \text{D} \times \text{L} / (\text{P} \times \text{P} \times \text{GE})\right)
\]

\[
\text{XSS} = \text{AT} \times \text{XS} / \text{QS}
\]

SECONDARY SLOT LEAKAGE reactance (XRS)

\[
\text{XRS} = \text{AY} \times (\text{KPS} \times \text{KDS}) \times (2 \times \text{AXR} / \text{NR})
\]

ROTOR AND STATOR END-CONNECTION LEAKAGE reactance

\[
\text{DC} = (\text{D} \times 2. \times (\text{D} \times \text{D} \times 3.1416) \times (\text{DER1} \times \text{DER2}) \times 0.5)
\]

\[
\text{AT} = \left((\text{N} \times \text{N} \times \text{P} \times (\text{KPS} \times \text{KDS}) \times 2) / \text{P} \right) \times 2.4E-7
\]

\[
\text{F1} = 1.5708 \times (\text{D} \times \text{D} \times 3.1416) \times \left((1.0 - \text{CALPHA} \times \text{CALPHA}) / (\text{P} \times \text{CALPHA})\right)
\]

\[
\text{XSE} = \text{AY} \times \left(8 + 0.5 \times (\text{F1} / 2. \times \text{P})\right)
\]

\[
\text{XRE} = (0.725 \times \text{AY} / \text{P}) \times \left(2 \times \text{P} \times \text{FIR} \times (3.1416 \times \text{D} \times \text{DC}) / (1.7 \times \text{TFR} + 0.4 \times \text{h} \times (\text{DER1} - \text{DER2}) \times 1.4 \times \text{DC})\right)
\]

SKEW reactance (XSK)

\[
\text{XSK} = 0.5 \times \text{XOAG} / 12 \times (\text{KPS} / (\text{KPS} \times \text{KDS}) \times 2)
\]

STATOR AND ROTOR ZIGZAG LEAKAGE reactance

\[
\text{XZ} = 0.8333 \times \text{XOAG} \times (\text{KPS} / (\text{KPS} \times \text{KDS}) \times 2)
\]

\[
\text{XRZ} = \text{XZ} \times (6 / \text{CCR} - 1) / (5 \times (\text{NR} / \text{P}) \times 2)
\]

\[
\text{XSZ} = \text{XZ} \times (6 / \text{CCS} - 1) / (5 \times (\text{QS} / \text{P}) \times 2)
\]

PERIPHERAL AIR-GAP LEAKAGE reactance (XP)

\[
\text{XP} = 0.525 \times \text{XOAG} \times (\text{P} \times \text{G} / (\text{P} \times \text{G} \times \text{D}) \times 2)
\]

TOTAL ARMATURE AND ROTOR LEAKAGE reactances (X1 AND X2)

IF (ABS(X1) LT 1.0E-15) X1 = XSS + XSE + XSK + XSZ + XP

IF (X2 LT 1.0E-15) X2 = XRS + XRE + XSK + XHZ

WRITE OUTPUT

WRITE (6, 320) BSYNCH, P, P, V1

FORMAT (1H, 9X, 6H SLATING, P, P, V1)

WRITE (6, 330) TRATED

FORMAT (1H, 9X, 12H SLATING TORQUE, F32.1, 7H IN-LBS)

WRITE (6, 349) D, DSS, DRS, L, LTS, SPS, USTAI

FORM (1H, 5X, 6H SLATING /10X, 13H SLATING DIAMETER, F33.3/10X, 16H SLATING END SLATE, F33.3/10X, 16H SLATING TB, F33.3/10X, 16H SLATING THICKNESS, F33.3/10X, 16H SLATING FACTOR, F31.3/10X, 16H SLATING WEIGHT, F32.3)

WRITE (6, 350) D, DSS, DRS, L, LTS, SPS, USTAI

FORM (1H, 5X, 6H SLATING /10X, 13H SLATING DIAMETER, F33.3/10X, 16H SLATING END SLATE, F33.3/10X, 16H SLATING TB, F33.3/10X, 16H SLATING THICKNESS, F33.3/10X, 16H SLATING FACTOR, F31.3/10X, 16H SLATING WEIGHT, F32.3)
WRITE (6,350) SSTYPE,GS
FORMAT (1HL,5X,12HSLOTAR SLOTS/10X,9RSLOT TYPE,18,9X,12HNO. OF SLO
1TS,F5.0) A 346
IF (SSTYPE.EQ.1.OR.SSTYPE.EQ.3) WRITE (6,360) WSS,DSS A 349
IF ((SSTYPE/2)*2.EQ.SSTYPE) WRITE (6,370) STWIDTH,DSS A 350
IF (SSTYPE.EQ.5) WRITE (6,380) WSS3,DSS A 351
360 FORMAT (10X,10HSLOT WIDTH,P10.1,6X,10HSLOT DEPTH,P10.3) A 352
370 FORMAT (10X,11TOOTH WIDTH,P9.3,6X,10HSLOT DEPTH,P10.3) A 353
380 FORMAT (10X,13HSLOT DIAMETER,F7.3,6X,10HSLOT DEPTH,P10.3) A 354
WRITE (6,390) WSS1,DIS,WSS2,D2S,WSS3,D3S,WSS4,D4S,WSS5,D5S,WSS6,D6S A 355
15S,SCAREA,SSAREA,CSRATO A 356
390 FORMAT (10X,4WHS1,P16.3,6X,3HD15,P17.3/10X,4WHS2,P16.3,6X,3HD25,P1 A 357
17.3/10X,4WHS3,P16.3,6X,3HD35,P17.3/10X,4WHS4,P16.3,6X,3HD45,F1 A 358
27.3/10X,4WHS5,P16.3,6X,3HD55,P17.3/10X,4WHS6,P16.3,6X,3HD65,F1 A 359
13/10X,11HUSABLE AREA,P9.3,6X,10HTOTAL AREA,P10.3/10X,12HSPACE FACT A 360
40R,F8.3) A 361
410 FORMAT (1H,9X,11HSTRAND SIZE,132) A 362
420 WRITE (6,420) DR,DER,LTB,SPR,SKEW,DBRS,WROT A 364
430 FORMAT (1HL,5X,14HSLOTAR WINDING/10X,ARMATERIAL,15/10X,19HCONDUCT A 365
1ORS PER SLOT,F24.0/10X,17PARALLEL CIRCUITS,F26.0/10X,5HSPIT,FPN1. A 366
23/10X,27HAXIAL EXTENSION BEYOND CORE,19H3/10X,23HCONDUCTOR CROSS- A 367
3SECTION,P27.3/10X,20HROUND CROSS-SECTION,F30.3/10X,16HCONDUCTOR L A 368
4LENGTH,F30.3/10X,2THCIRCUMFERENCE ATN END-TURNS,F25.3/10X,15HTEMPERATURE A 369
5(S),P26.3/10X,21HEND-TO-END LENGTH,F25.3/10X,23HCONDUCTOR ARMATURE L A 370
6LENGTH,F23.1/10X,12HSPIT FACTOR,F34.3/10X,19HDISTRIBUTION FACT A 371
7OR,F27.3/10X,15HARMATURE WEIGHT,F31.3/10X,26HTOTAL ARMATURE WIRE L A 372
8LENGTH,F29.3/10X,15FETTS/10X,17HSTRANDS/CONDUCTOR,F26.0) A 373
IF (AMG.GT.0) WRITE (6,440) AW3 A 374
440 FORMAT (1H,9X,11HSTRAND SIZE,132) A 375
450 WRITE (6,430) RSTYPE,RR A 376
460 FORMAT (1HL,5X,14HSLOTAR SLOTS/10X,9RSLOT TYPE,18,9X,12HNO. OF SLO A 378
1TS,F5.0) A 381
IF (RSTYPE.EQ.1.OR.RSTYPE.EQ.3) WRITE (6,440) WSR,DSR A 384
IF ((RSTYPE/2)*2.EQ.RSTYPE) WRITE (6,450) RTWIDTH,DSR A 387
IF (RSTYPE.EQ.5) WRITE (6,460) WSR3,DSR A 388
470 FORMAT (10X,10HSLOT WIDTH,P10.1,6X,10HSLOT DEPTH,P10.3) A 389
480 FORMAT (10X,11TOOTH WIDTH,P9.3,6X,10HSLOT DEPTH,P10.3) A 390
490 FORMAT (10X,13HSLOT DIAMETER,F7.3,6X,10HSLOT DEPTH,P10.3) A 391
WRITE (6,470) WSR1,DIR,WSR2,D2S,WSR3,D3S,WSR4,D4R,WSR5,DSR,WS6,S A 392
1,RSAREA A 393
500 FORMAT (10X,4WHS1,P16.3,6X,3HD15,P17.3/10X,4WHS2,P16.3,6X,3HD25,P1 A 394
17.3/10X,4WHS3,P16.3,6X,3HD35,P17.3/10X,4WHS4,P16.3,6X,3HD45,F1 A 395
27.3/10X,4WHS5,P16.3,6X,3HD55,P17.3/10X,4WHS6,P16.3,6X,3HD65,F1 A 396
13/10X,11HUSABLE AREA,P9.3,6X,10HTOTAL AREA,P10.3) A 397
C WRITE (6,480) RWMAT,LS,DER1,DER2,TER,TRN,WWMNG,FRB2AB,EBRING A 399
480 FORMAT (1HL,5X,13HSTRAND WINDING/10X,8HARMATERIAL,13/10X,10HBAR LEN A 400
1TH,P36.3/10X,17HBAR CROSS-SECTION,F29.3/10X,20HEND-RING OUTSIDE DI A 401
3,28.3/10X,24HSTANDARD-END-TOR RING CLANCE,F22.3/10X,23HCONDUCTOR L A 403
4ATURE (C),F20.0/10X,6HWEIGHT,F40.3/10X,27HCOMPONENT OF E2 DUE TO B A 404
5ARS,F19.3/10X,32HCOMPONENT OF H2 DUE TO END RINGS,F14.3) A 405
C WRITE (6,490) G,GE,YAG A 406
490 FORMAT (1HL,5X,6HARCIAL AIRGAP/10X,13HACTUAL AIRGAP,F14.4/10X,16HEFFECTI A 408
V1E AIRGAP,F31.4/10X,36HARMAGNETIZING REACTANCE (AIR GAP ONLY),P9.2) A 409
C WRITE (6,500) XXS,XRS,XRE,XSU,XSK,XZS,FZ,A,XP A 410
500 FORMAT (1HL,5X,24HLEAKAGE REACTANCES (OHM)/3X,6HSTRATOR,11X,5HROTO A 411
1R/10X,4HSLOT,F26.3,F16.3/10X,14HEND-CONNECTION,F16.3,15.3/10X,4HS A 413
C WRITE (6,510) WEIGHT A 415
510 FORMAT (1HL,5X,6HWEIGHT/10X,23HTOTAL (ELECTROMAGNETIC),P23.3/1H1) A 417
C
C CROSS-SECTIONAL AREAS AND LENGTHS OF FLUX PATHS NEEDED FOR
C MAGNETIC CALCULATIONS
ASTORE=DS*L*SFS
LSYOKE=3.1416*(DS*D2.*DSS)/(.40.*P)
ARTOK=DSBS*L*SFR
LRTYOKE=3.1416*(DR-2.*DSS+DIR)/(.40.*P)
AINTOTH=STTMAG*L*SFS*SB
ASTOTH=STTMAG*L*SFS*QS

C NO-LOAD MAGNETIC CALCULATIONS
XX=1.O
XY=1.O
IF (XO.GT.1.OE-15) XX=O.O
IF (RO.GT.1.OE-15) XY=O.O
XO=XO+(O.S*XOAG)*XX
W0=(WSYOK+WS3OTH)*WFE*3.O
RO=(5.*V1*V1/W0)*XY+RO
S=O.
ICNT2=O

520 ICNT2=ICNT2+1
IF (ICNT2.GE.16) GO TO 550
ICNT1=O

530 ICNT1=ICNT1+1
IF (ICNT1.GE.11) GO TO 540
CALL CHCT
ROOLD=RO
POTAL=Y2*P*1.OE+05/(1.414*P*P*KPS*KDS)
FPOLE=POTAL/0.637/P
BG=POTAL/(3.1416*P)
ATAG=BG*GE/313.

CALL MAGNET
W0=(WSYOK+(BSY/BK)**2*WSTOTH*(BST/BK)**2)*WFE*1.O
RO=((3.*V2*V2-W0)*RO)*XY+RO
IF (ABS(RO-ROOLD)/RO.GE.0.001) GO TO 530

540 IMAG2=2.2*P*ATT0T/(3.*P*KPS*KDS)
X0=X0+((V2/0.5*(IMAG*IMAG2))-X0)*XX
IF (ABS((IMAG-IMAG2)/IMAG).GE.305) GO TO 520

550 CUBDEN=(SORT(IMAG**2)/(V2/RO)**2)/(PC**SS)
IF (ICNT1.GE.11) WRITE (6,560)
IF (ICNT2.GE.16) WRITE (6,570)
IF (KST.EQ.0) WRITE (6,580)

560 FORMAT (1H,38HGAMETIZING CURRENT FAILED TO CONVERGE//)

570 FORMAT (1H,17HMACHINE SATURATED//)

580 FORMAT (1H,610) SMAT,AI (1),RK,WFE

590 FORMAT (1H,5X,17HSATAR MATERIAL --,1H ,13A6/24X,7HB MAX =,F5.3/24
1X,12HCORE LOSS AT,5.1,10H KL/SQ-1N=,F5.1,5H W/LB)
WRITE (6,600) RMAT,AI (1)

600 FORMAT (1H,5X,17HROTOR MATERIAL --,1H ,13A6/24X,7HB MAX =,F5.0)

C WRITE NO-LOAD MAGNETIZATION CHARACTERISTICS

C WRITE (6,610) POTAL,FPOLE,BG,BST,BSY,BST,BRY,ATAG,ASTT,ATSY,AT7,
1ATTY,ATT0T,IMAG,V2,CUBDEN,RO

610 FORMAT (1H,5X,29HMAGNETIZATION CHARACTERISTICS/7X25H (NO-LOAD, RA
1TED VOLTAGE)/9X,18H TOTAL USEFUL FLUX,29.2,10H KILOLINES/9X17H U
2SEFUL FLUX/Powe,F29.2/9X15H FLUX DENSITIES/13X7H AERGAP,F35.2,9H
3KL/SQ-1H/13X13H STATOR TOOTH,F29.2/13X12H STATOR YOKF,F30.2/13X12H
4 Rotor Tooth,F30.2/13X12H ROTOR YOKF,F31.2/9X22H AMPERE-TURNS PER
5 POLY/13X12H AERGAP,F35.2/13X12H STATOR TOOTH,F29.2/13X12H STATOR
6YOKF,F30.2/13X12H ROTOR TOOTH,F30.2/13X11H ROTOR YOKF,F31.2/13X6H
7 TOTAL,F36.2/9X20H MAGNETIZING CURRENT,F26.2,8H AMPERES/10X,14HAI
8 BCP VOLTAGE,F31.2/10X,20H/L. CURRENT DENSIT,F25.2/10X,9HCORE LO
9S5,F34.0,5H WATT)

C SCALE WINDAGE LOSS FROM REFERENCE CONDITIONS TO DESIGN CONDITIONS

C A 419
C A 420
C A 421
C A 422
C A 423
C A 424
C A 425
C A 426
C A 427
C A 428
C A 429
C A 430
C A 431
C A 432
C A 433
C A 434
C A 435
C A 436
C A 437
C A 438
C A 439
C A 440
C A 441
C A 442
C A 443
C A 444
C A 445
C A 446
C A 447
C A 448
C A 449
C A 450
C A 451
C A 452
C A 453
C A 454
C A 455
C A 456
C A 457
C A 458
C A 459
C A 460
C A 461
C A 462
C A 463
C A 464
C A 465
C A 466
C A 467
C A 468
C A 469
C A 470
C A 471
C A 472
C A 473
C A 474
C A 475
C A 476
C A 477
C A 478
C A 479
C A 480
C A 481
C A 482
C A 483
C A 484
C A 485
C A 486
C A 487
C A 488
C A 489
C A 490
WRITE (6, 620) A 491
620 FORMAT (1HL,5X,7HWINDAGE) A 492
IF (FW1,GT,1.0E-15) GO TO 700 A 493
IF (WL,LE,1.0E-15) GO TO 630 A 494
IF (DIAREF*LRREF*RPBASE*GAPREF,GT,1.0E-15) GO TO 650 A 495
630 WRITE (6, 640) A 496
640 FORMAT (1HK,39HINSUFFICIENT DATA TO SCALE WINDAGE LOSS//) A 497
GO TO 700 A 498
650 FW1=W1*(DB/DIAREF)**3.25*(L/LREF)*((NSYMP/BPMBEF)**2.5)*((GBREF/1F/G)**0.25) A 499
IF (VSCREF,LT,1.0E-15) GO TO 670 A 500
IF (VSCFLE,GT,1.0E-15) GO TO 660 A 501
VSCFLD=VSCSTY (TFLUID) A 502
IF (VSCFLE,LT,1.0E-15) GO TO 670 A 503
660 FW1=FW1*((VSCFLD/VSCREF)**0.50) A 504
670 IF (PREP,LT,1.0E-15) GO TO 680 A 505
IF (PFLUID,LT,1.0E-15) GO TO 670 A 506
FW1=FW1*(PFLUID/PREF) A 507
C A 508
WRITE WINDAGE DATA C A 510
WRITE (6, 690) FW1, WL, DL, DIAREF, L, LRREF, NSYMP, BPMBEF, GBREF, TFLUID, C A 511
1D, TREF, VSCFLE, VSCREF, PFLUID, PBREF, PLDME C A 512
690 FORMAT (1H,9X,33HWINDAGE LOSS AT SYNCHRONOUS SPEED,F10.0,SHWATT//) A 513
11H1) A 514
WRITE VALUES C A 524
WRITE (6, 710) FW1 A 525
710 FORMAT (1H,9X,33HWINDAGE LOSS AT SYNCHRONOUS SPEED,F10.0,SHWATT//) A 526
11H1) A 527
WRITE VALUES C A 530
WRITE (6, 730) PW1, X1, X2, R0, X0 A 532
730 FORMAT (1HK,5X,29HEQUIVALENT CIRCUIT PARAMETERS//) A 533
10X,4HR1 =,F9.3,15 S=0. A 534
1X,5HX1 =,F7.3,10X,4HR2 =,F9.1,15 A 535
2X,4HR0 =,F9.3,15 T=0. A 536
2X,4HR0 =,F9.3) A 537
C A 538
C A 539
C A 540
C A 541
C A 542
C A 543
C A 544
C A 545
C A 546
C A 547
C A 548
S=S+DELTA S A 549
I=I+1 A 550
IF (S.GT,SMAX) GO TO 870 A 551
CALL CIRCBT I A 552
IF (T.GT,1.0E-15) GO TO 780 C A 553
WRITE (6, 770) S C A 554
770 FORMAT (1H,9X,44HTE), WINDAGE EXCEEDS AVAILABLE SHAFT TORQUE AT,P8. A 555
13,13H PERCENT SLIP) A 556
IF (S.GT,TMAX) GO TO 870 A 557
T=0. A 558
GO TO 820 A 559
780 GO TO (790, 580, 800), KT C A 560
790 IF (TG,GT,TREATED) GO TO 830 A 561
TOLD=T C A 562
SOLD=S C A 563

SUBROUTINE CIRCT
COMMON /CIR/ RO,R1,R2,XO,X1,X2,FW1,NSYNCH,V1,5,I1,RPM,PF,T,HP,EFF,
PIN,W1,W2,W0,FW,IMAG,V2,POUT,PHASE
REAL NSYNCH,I1,I2,IMAG
COMPLEX D,20,Z1,Z2,E1,E2,IA,IN,IC
DATA STAR,BLANK,1H*,1H /
C
C=2.5
R=0.5
K=0.5
C=0.
CS=0.
IF (J*IA.NE.I) GO TO 750
IF (J.GT.50) GO TO 750
SLIP(J) = S
GO TO 750
CALCULATE VALUE OF S AT TORQUE RATED
S = ((TRATED-TOLD)/(T-TOLD)) *(S-SOLD)+SOLD
K=2
GO TO 760
WRITE MOTOR CHARACTERISTICS AT RATED TORQUE
IF ((ABS(T-TRATED)).GT.0.005) GO TO 830
WRITE (6,850)
FORMAT (1H ,7F10.2, P8.2,A 1,F9.2,4F10.2)
WRITE MOTOR CHARACTERISTICS AT RATED TORQUE
IF (NB.LT.1.0E-15) GO TO 860
WRITE (6,890)
FORMAT (2HPL,70X, 14HTORQUE, IN-LBS)
GO TO 10
END
C
WRITE (6,810) T,S,RP,HP,POUT,I1,EFF,PF,PHASE,PIN,W1,W2,W0,FW A 564
WRITE (6,810) T,S,RP,HP,POUT,I1,EFF,PF,PHASE,PIN,W1,W2,W0,FW A 565
J=I/IA
IF (J*IA.NE.I) GO TO 750
IF (J.GT.50) GO TO 750
SLIP(J) = S
GO TO 750
WRITE (6,810) T,S,RP,HP,POUT,I1,EFF,PF,PHASE,PIN,W1,W2,W0,FW A 567
WRITE (6,810) T,S,RP,HP,POUT,I1,EFF,PF,PHASE,PIN,W1,W2,W0,FW A 568
SLIP(J) = S
GO TO 750
WRITE (6,810) T,S,RP,HP,POUT,I1,EFF,PF,PHASE,PIN,W1,W2,W0,FW A 569
WRITE (6,810) T,S,RP,HP,POUT,I1,EFF,PF,PHASE,PIN,W1,W2,W0,FW A 570
SLIP(J) = S
GO TO 750
WRITE (6,810) T,S,RP,HP,POUT,I1,EFF,PF,PHASE,PIN,W1,W2,W0,FW A 571
WRITE (6,810) T,S,RP,HP,POUT,I1,EFF,PF,PHASE,PIN,W1,W2,W0,FW A 572
WRITE (6,810) T,S,RP,HP,POUT,I1,EFF,PF,PHASE,PIN,W1,W2,W0,FW A 573
WRITE (6,810) T,S,RP,HP,POUT,I1,EFF,PF,PHASE,PIN,W1,W2,W0,FW A 574
WRITE (6,810) T,S,RP,HP,POUT,I1,EFF,PF,PHASE,PIN,W1,W2,W0,FW A 575
WRITE (6,810) T,S,RP,HP,POUT,I1,EFF,PF,PHASE,PIN,W1,W2,W0,FW A 576
WRITE (6,810) T,S,RP,HP,POUT,I1,EFF,PF,PHASE,PIN,W1,W2,W0,FW A 577
WRITE (6,810) T,S,RP,HP,POUT,I1,EFF,PF,PHASE,PIN,W1,W2,W0,FW A 578
WRITE (6,810) T,S,RP,HP,POUT,I1,EFF,PF,PHASE,PIN,W1,W2,W0,FW A 579
WRITE (6,810) T,S,RP,HP,POUT,I1,EFF,PF,PHASE,PIN,W1,W2,W0,FW A 580
WRITE (6,810) T,S,RP,HP,POUT,I1,EFF,PF,PHASE,PIN,W1,W2,W0,FW A 581
WRITE (6,810) T,S,RP,HP,POUT,I1,EFF,PF,PHASE,PIN,W1,W2,W0,FW A 582
WRITE (6,810) T,S,RP,HP,POUT,I1,EFF,PF,PHASE,PIN,W1,W2,W0,FW A 583
WRITE (6,810) T,S,RP,HP,POUT,I1,EFF,PF,PHASE,PIN,W1,W2,W0,FW A 584
WRITE (6,810) T,S,RP,HP,POUT,I1,EFF,PF,PHASE,PIN,W1,W2,W0,FW A 585
WRITE (6,810) T,S,RP,HP,POUT,I1,EFF,PF,PHASE,PIN,W1,W2,W0,FW A 586
WRITE (6,810) T,S,RP,HP,POUT,I1,EFF,PF,PHASE,PIN,W1,W2,W0,FW A 587
WRITE (6,810) T,S,RP,HP,POUT,I1,EFF,PF,PHASE,PIN,W1,W2,W0,FW A 588
WRITE (6,810) T,S,RP,HP,POUT,I1,EFF,PF,PHASE,PIN,W1,W2,W0,FW A 589
WRITE (6,810) T,S,RP,HP,POUT,I1,EFF,PF,PHASE,PIN,W1,W2,W0,FW A 590
WRITE (6,810) T,S,RP,HP,POUT,I1,EFF,PF,PHASE,PIN,W1,W2,W0,FW A 591
WRITE (6,810) T,S,RP,HP,POUT,I1,EFF,PF,PHASE,PIN,W1,W2,W0,FW A 592
WRITE (6,810) T,S,RP,HP,POUT,I1,EFF,PF,PHASE,PIN,W1,W2,W0,FW A 593
WRITE (6,810) T,S,RP,HP,POUT,I1,EFF,PF,PHASE,PIN,W1,W2,W0,FW A 594
WRITE (6,810) T,S,RP,HP,POUT,I1,EFF,PF,PHASE,PIN,W1,W2,W0,FW A 595
WRITE (6,810) T,S,RP,HP,POUT,I1,EFF,PF,PHASE,PIN,W1,W2,W0,FW A 596
WRITE (6,810) T,S,RP,HP,POUT,I1,EFF,PF,PHASE,PIN,W1,W2,W0,FW A 597
WRITE (6,810) T,S,RP,HP,POUT,I1,EFF,PF,PHASE,PIN,W1,W2,W0,FW A 598
WRITE (6,810) T,S,RP,HP,POUT,I1,EFF,PF,PHASE,PIN,W1,W2,W0,FW A 599
WRITE (6,810) T,S,RP,HP,POUT,I1,EFF,PF,PHASE,PIN,W1,W2,W0,FW A 600
WRITE (6,810) T,S,RP,HP,POUT,I1,EFF,PF,PHASE,PIN,W1,W2,W0,FW A 601
WRITE (6,810) T,S,RP,HP,POUT,I1,EFF,PF,PHASE,PIN,W1,W2,W0,FW A 602
WRITE (6,810) T,S,RP,HP,POUT,I1,EFF,PF,PHASE,PIN,W1,W2,W0,FW A 603
WRITE (6,810) T,S,RP,HP,POUT,I1,EFF,PF,PHASE,PIN,W1,W2,W0,FW A 604
WRITE (6,810) T,S,RP,HP,POUT,I1,EFF,PF,PHASE,PIN,W1,W2,W0,FW A 605
WRITE (6,810) T,S,RP,HP,POUT,I1,EFF,PF,PHASE,PIN,W1,W2,W0,FW A 606
WRITE (6,810) T,S,RP,HP,POUT,I1,EFF,PF,PHASE,PIN,W1,W2,W0,FW A 607
WRITE (6,810) T,S,RP,HP,POUT,I1,EFF,PF,PHASE,PIN,W1,W2,W0,FW A 608
WRITE (6,810) T,S,RP,HP,POUT,I1,EFF,PF,PHASE,PIN,W1,W2,W0,FW A 609
WRITE (6,810) T,S,RP,HP,POUT,I1,EFF,PF,PHASE,PIN,W1,W2,W0,FW A 610
WRITE (6,810) T,S,RP,HP,POUT,I1,EFF,PF,PHASE,PIN,W1,W2,W0,FW A 611
WRITE (6,810) T,S,RP,HP,POUT,I1,EFF,PF,PHASE,PIN,W1,W2,W0,FW A 612
WRITE (6,810) T,S,RP,HP,POUT,I1,EFF,PF,PHASE,PIN,W1,W2,W0,FW A 613
WRITE (6,810) T,S,RP,HP,POUT,I1,EFF,PF,PHASE,PIN,W1,W2,W0,FW A 614
WRITE (6,810) T,S,RP,HP,POUT,I1,EFF,PF,PHASE,PIN,W1,W2,W0,FW A 615-
IF (S.LT.1.0E-10) GO TO 10
Z2=CMPLX(R2*100.,S2)
D=(Z1*Z0)*(Z2+Z0)-Z0*Z0
IA=(E1*(Z0+Z2))/D
IB=(E1*Z0)/D
IC=IA-IB
GO TO 20
IA=E1/(Z1+Z0)
IB=(0.,0.)
IC=IA

10 E2=(IA-IR)*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(IF)
B=AIMAG(IF)
I2=SQRT(A*A+B*B)
W1=I1*I1*R1*3.
W2=I2*I2*R2*3.
BPM=NSYNCH*(1.-S/100.)
FP=PF1*(PFM/NSYNCH)**C
PIN=I1*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=(1.847E4/S)*W2/NSYNCH
GO TO 60
50 T=(HP/PPM)*6.34E4
60 RETURN

COMMON /MAG/, BST, BSY, RST, BRY, ATST, ATSY, ATRY, ASYKE, ASTOTH, ARY

DIMENSION AI(60)
REAL LSYOKE, LRYOKE
BST=0
BSY=0
BET=0
BRY=0
ATST=0
ATSY=0
ATRY=0
ATTOT=0
KSAT=10
10 BST=FTOTAL/ASTOTH
NA=1
K=1
X=BST
GO TO 90
10 ATST=AT*DSS
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

SHRTROUTINE MAGNET

C
C
C
C
C
C
C
C
C
C
C
45
20 BSY=FPOLE/(2.*ASYOKE)
NA=1
K=2
X=BSY
GO TO 90
30 ATSY=AT*LSYOE
C
C ROTOR TOOTH
C
40 BRT=FTOTAL/AR*OTH
NA=31
K=3
X=BRT
GO TO 90
50 ATRT=AT*DSR
C
C ROTOR YOKE
C
60 BRY=FPOLE/(2.*APYOE)
NA=31
K=4
X=BRY
GO TO 90
70 ATRY=AT*LYOKE
C
80 ATTOT=ATAG+ATST+ATSY+ATRT+ATRY
RETURN
C
C INTERPOLATION PROCEDURE FOR MATERIAL CURVES
C
90 IF (AI(NA).LT.Y) 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)+0.7001)))
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,D X, D2X, D3X, D4X, D5X, XTWDTH,CARFA,SAREA,K,DSX,WSX6,DIA,KX,AXX,YTMAG,2,PHIX)
FOR STATOR SLOTS SLTLOC=1.0 * FOR ROTOR SLOTS SLTLOC=-1.0
REAL N,KX
INTEGER XSTYPE
D(WA,CAREA)=((-WA+SOHT(WA*WA+4.*CAREA*TANPHI))/2.*TANPHI)
D 11
WB(D,W)=WA+2.*D*TANPHI
D 12
A(W)=0.25*KX*(1.57073*PHIX)/(COSPHI*COSPHI)+TANPHI
D 13
IF (CARFA+DSX+D1X.LT.1.0E-15) GO TO 310
A1=0.25*KX+1.0/12.0
A2=0.25*(KX-0.66667)
D 14
GO TO (10,20,30,90,210,90),XSTYPE
D 15
WSX1=0.
D 16
D3X=0.
D 17
D4X=0.
D 18
AXX=0.
D 19
GO TO 40
D 20
20 WSXA=WSX
WSX1=0.
WSX2=0.
D3X=0.
DNX=0.
AXX=0.
GO TO 100
C
30 AXX=KX*(DSX/WSX+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 (DIX.LT.1.0E-15) GO TO 60
DSX=DIX+D4X+D3X+D2X+D4X
GO TO 80
50 IF (DIX.LT.1.0E-15) GO TO 70
GO TO 80
60 DSX=CARFA/(WSX2.0.0WSX6)*D5X+D6X+DZX+D43X+D4X
70 D1X=DSX*(1.0+0.5*DSX)*D43X+D4X
80 SAREA=WSX*DSX+D43X+0.5*(WSX1+WSX)*DIX+WSX1*D4X
IF (CARFA.LT.1.0E-15) CARFA=(WSX-2.0.0WSX6)*(DIX-DSX)
AXX=AXX+(D1X*DSX/A+2.0D3X)/WSX
XTWMAG=((DSX+0.6667*SLTLOC*DSX)*(1.1416/N))-WSX
GO TO 300
C
90 WSX=WSX2
WSX=0.
100 IF (WSXA.GT.1.0E-15) GO TO 130
IF (XTWDTH.GT.1.0E-15) GO TO 110
WSX=1/(3.1415927/N)*SLTLOC
110 PHI X=(3.1415927/N)*SLTLOC
GO TO 140
120 XTWDTH=(1.1416*(DSX+2.0SLTLOC*(D4X+D3X)))/WSX
GO TO 110
130 IF (PHIX.GT.1.0E-15) GO TO 120
PHIX=(ABS(PHIX)*0.017453)*SLTLOC
XTWDTH=0.
140 IF (XSTYPE.LT.1.0) GO TO 150
WSX=WSX2
AXX=KX*(D4X/WSX1+(D3X/(WSX-SLYA)))*(ALOG(WSXA/WSX1))
GO TO 160
150 WSX=WSX2
160 TANPHI=TAN(PHIX)
COSPHI=COS(PHIX)
SINPHI=SIN(PHIX)
WSX=W(B(D2X,WSX))
170 IF (DSX.GT.1.0E-15) GO TO 170
IF (DIX.GT.1.0E-15) GO TO 190
Y1=(WSX4-2.0WSX6, CARFA/2.)
W=W(D2X+F1D5Y,4SXA)
180 IF (XSTYPE.EQ.0) GO TO 260
Y2=D(W-2.0WSX6,CARFA/2.)
190 DSX=Y1+Y2+D3X+D2X+D4X+D1X+D5X
GO TO 180
170 IF (DIX.GT.1.0E-15) GO TO 200
P1X=DSX-D4X-D3X-D2X-D4X
GO TO 200
190 DSX=D1X+D4X+D2X+D4X
200 IF (XSTYPE.EQ.0) GO TO 280
WSX5=MR(D2X,D1X,WSX)
WSX5=RB(DSX-D3X-D4X,WSX)
SAREA=0.5*(WSX1+WSX4)*(DSX-X4-D14)*/DSX+DSX61*D4X
AXX=AXX+((2.*KX*D2X)/(WSX+WSX4))/DSX-Y4/WSX4*A1-(2.*(3.*D5X)/(WSX4+1.0W5X))/DSX-A2
XTWMAG=(DSX.2.*SLTLOC*DSX)*(1.1416/N)-WSX
IF (CARFA.GT.1.0E-15) GO TO 300
C
210 WSX=0
D 27
D 28
D 29
D 30
D 31
D 32
D 33
D 34
D 35
D 16
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D 97
D 98
D 99
D 100
WSX2 = 0.
WSX4 = 0.
XTWHM = 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 = (SORT(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) .LT. 1.0E-01) GO TO 310
DSX = D1X + 2.*D6X + D4X
SAREA = 0.7854*WSX2*WSX2 + WSX2*D4X
IF (CAREA.LT.1.0E-15) CAREA = 0.7854*(WSX2 - 2.*D5X) + 2
AUX = (0.625*D4X/WSX1)*KX
XTWMA = (DIA + (2.*D4X + 1.333*WSX2)*SLTLOC) *(3.1416/N) - 0.94*WSX2
GO TO 340
C
C
260 W1 = W2 - 2.*D6X
A5 = A(W1)
IF (ABS(A2/CAREA.LT.1.00)) GO TO 310
C
C
270 AR = 0.5*CAREA - AR
Y2 = D(W1, AR)
W2 = WB(Y2, W1)
A5 = A(W2)
IF (ABS(A2*(4*A5)/CAREA - 1.0E-01)) GO TO 270
D1X = D4X + D3X + D2X + D6X + D1X
D1X = (SORT(4.*CAREA/3.1416) + D4X + 2.*D6X)
D1X = D4X + D3X + D2X + D6X
GO TO 250
280 WSX3 = (2.*(DSX - D4X - D3X)) * SINPHI*WSX2*WSX2
SAREA = WSX3*COSPHI + 0.5*(WSX3*COSPHI + WSX2) * (DSX - 0.5*WSX3*(1.0 + STN)
12PHI = D4X - D3X + D5X + D6X + D1X
W1 = D(W1, AR)
IF (ABS(CAREA - 1.0E-15)) GO TO 300
Y1 = 0.5*DSX
W0 = 0.5*(WSX4 + WSX5)
CAREA2 = 1000.
C
C
290 CAREA = WSX3*COSPHI - 2.*D6X + 0.5*(WSX3*COSPHI + W4)*D6X*(DSX - 0.5*WSX3*COSPHI - W4)*D6X
T3 = (1.0 + SINPHI) - D4X - D3X - D2X - Y1 - D5X
Y1 = D(DW4X = 2.*WSX6, CAREA/2.)
W1 = WB(Y1 + D5X + D2X, WSX2)
CAREA2 = CAREA
GO TO 290
C
C
300 IF (ABS(D1X + D2X + D3X + D4X + D6X - DSX).LT.0.001) GO TO 340
C
C
310 IF (SLTLOC.LT.0.) WRITE (6,320)
IF (SLTLOC.LT.0.) WRITE (6,330)
320 FORMAT (1HW,42HINSUFFICIENT ON INCOMPLETE ROTOR SLOT DATA)
330 FORMAT (1HW,42HINSUFFICIENT ON INCOMPLETE STATOR SLOT DATA)
340 RETURN
END
SUBROUTINE WDGFCT (PBA, P, QS, DF, PC, PF, WDGPCH)
C
C
YY = FLOAT(IFIX( (QS/P) * WDGPCH) + 0.01))
IF (ABS(YY-QS/P*WDGPCH).LT.1.0E-2) WRITE (6,10) WDGPCH
C
C
48
FORHAT (1HK,FS. 3,228 PITCH IS NOT POSSIBLE)

PF=SIN(Y*1.571/(QS/P))

DISTRIBUTION FACTOR CALCULATIONS

IPX=IFIX(P+0.1)
IQQ=IFIX(QS+0.1)
IC=IFIX(PC+0.1)
IPN=3.
PN=3.
QN=QS/(3.*P)

CHECK IF WINDING HAS INTEGRAL NO. OF SLOTS PER POLE PER PHASE

D=1.0
IZY=IPX*IPN

CALCULATE DISTRIBUTION FACTOR FOR INTEGRAL SLOT WINDING

DF=SIN(1.571*D/PN)/(QN*D*SIN(1.571/(PN*QN)))

REDUCE THE FRACTION IQQ/IZY TO LOWEST TERMS

IQQ=IQQ/T
IZY=IZY/T

CALCULATE DISTRIBUTION FACTOR FOR FRACTIONAL SLOT WINDING

FN=IQQ
FN=SIN(1.571*D/PN)/(FNQ*D*SIN(1.571/(FNQ*PN)))

CHECK IF SPECIFIED NUMBER OF PARALLEL CIRCUITS ARE POSSIBLE

IF ((IPX/IC)*IC.EQ.IPX) WRITE (6,100) IC
WRITE (6,59) FORMAT (1HK,12,35H PARALLEL CIRCUITS ARE NOT POSSIBLE)

RETURN
END

SUBROUTINE CMRNTN (QS,N9,P)

REAL NB
DIMENSION L (100)

X=1.0E-15
K=0
F=NB
D=ABS(QS-F)
N=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

10 FORMAT (1HK,FS.3,22H PITCH IS NOT POSSIBLE)
CONTINUE

IF (ABS(D-P) .LT. X) GO TO 40
IF (ABS (P-FLOAT(IFIX(F/P+0.0001))) .LT. X) GO TO 40
N=2
IF (F.GT.QS+F/2.) GO TO 40
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-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+3.) .LT.X) GO TO 40
IF (K.EQ.0) GO TO 150
II=II+1
L(II)=IFIX(F+0.01)
GO TO 110
IF (K.GT.0) GO TO 110
K=1
P=FLOAT(IFIX(0.60*QS))
II=0
GO TO (50,70,90)

WRITE (6,60)
FORMAT (1HK,B2)ROTOR-STATOR SLOT COMBINATION MAY PRODUCE UNDESIRABLE 
TORQUE-SPEED CHARACTERISTICS
GO TO 110

WRITE (6,60)
FORMAT (1HK,B2)MINIMIZE BY SKewing, F6.3,30H TIMES ROTOR CIRCUMFEREN 
VELOCITY, OR)
GO TO 110

WRITE (6,100)
FORMAT (1HK,B2)ROTOR-STATOR SLOT COMBINATION MAY PRODUCE NOISE AND 
VIBRATION

WRITE (6,120) (L(II), II=1,II)
FORMAT (1HK,B2)CHANGE NUMBER OF ROTOR SLOTS TO ONE OF THE FOLLOWIN 
1G/(10I6))
GO TO 150

WRITE (6,140)
FORMAT (1HK,B2)CHANGE NUMBER OF STATOR SLOTS

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:

<table>
<thead>
<tr>
<th>Number</th>
<th>Error message</th>
<th>Responsible subroutine</th>
<th>Explanation</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>CORE LOSS DATA IS NOT GIVEN AT SPECIFIED STATOR LAMINATION THICKNESS</td>
<td>INDMTR</td>
<td>(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.</td>
</tr>
<tr>
<td></td>
<td>USE DATA FOR xx.xxx LAMINATIONS</td>
<td></td>
<td>(2) Core-loss data may have been omitted entirely.</td>
</tr>
<tr>
<td>2</td>
<td>INSUFFICIENT STATOR SLOT DATA, SPACE FACTOR OF 0.70 ASSUMED</td>
<td>INDMTR</td>
<td>DSS, D1S, SCAREA, and CSRATO are all less than 1.0E-15. The program assumes a value of CSRATO = 0.70.</td>
</tr>
<tr>
<td>3</td>
<td>SHUNT RESISTANCE R0 FAILED TO CONVERGE</td>
<td>INDMTR</td>
<td>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.</td>
</tr>
<tr>
<td>4</td>
<td>MAGNETIZING CURRENT FAILED TO CONVERGE</td>
<td>INDMTR</td>
<td>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.</td>
</tr>
</tbody>
</table>

51
<table>
<thead>
<tr>
<th>Number</th>
<th>Error message</th>
<th>Responsible subroutine</th>
<th>Explanation</th>
</tr>
</thead>
<tbody>
<tr>
<td>5</td>
<td>MACHINE SATURATED</td>
<td>INDMTR</td>
<td>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.</td>
</tr>
<tr>
<td>6</td>
<td>INSUFFICIENT DATA TO SCALE WINDAGE LOSS</td>
<td>INDMTR</td>
<td>(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.</td>
</tr>
<tr>
<td>7</td>
<td>F + W TORQUE EXCEEDS AVAILABLE SHAFT TORQUE AT xxx.xx PERCENT SLIP</td>
<td>INDMTR</td>
<td>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.</td>
</tr>
<tr>
<td>8</td>
<td>INSUFFICIENT OR INCORRECT ROTOR SLOT DATA</td>
<td>SLOTS</td>
<td>(1) SB, DSR, and DIR 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.</td>
</tr>
<tr>
<td>Number</td>
<td>Error message</td>
<td>Responsible subroutine</td>
<td>Explanation</td>
</tr>
<tr>
<td>-------</td>
<td>----------------------------------------------------------------------------------------------------</td>
<td>------------------------</td>
<td>---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------</td>
</tr>
<tr>
<td>9</td>
<td>INSUFFICIENT OR INCORRECT STATOR SLOT DATA</td>
<td>SLOTS</td>
<td>(1) DSS, DI(S), 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 STRND(S) is zero or negative. (2) For slot type 6 only: see error message 8.</td>
</tr>
<tr>
<td>10</td>
<td>.xxx PITCH IS NOT POSSIBLE</td>
<td>WDGFCT</td>
<td>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.</td>
</tr>
<tr>
<td>11</td>
<td>xx PARALLEL CIRCUITS ARE NOT POSSIBLE</td>
<td>WDGFCT</td>
<td>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.</td>
</tr>
<tr>
<td>12</td>
<td>IMPROPER FRACTIONAL SLOT WINDING IS USED</td>
<td>WDGFCT</td>
<td>(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).</td>
</tr>
<tr>
<td>13</td>
<td>ROTOR-STATOR SLOT COMBINATION MAY PRODUCE UNDESIRABLE TORQUE-SPEED CHARACTERISTICS</td>
<td>CMBNTN</td>
<td>See reference 3 (pp. 317-320) and reference 5.</td>
</tr>
<tr>
<td>14</td>
<td>ROTOR-STATOR SLOT COMBINATION MAY PRODUCE NOISE AND VIBRATION</td>
<td>CMBNTN</td>
<td>See reference 3 (pp. 317-320) and reference 5.</td>
</tr>
<tr>
<td>15</td>
<td>MINIMIZE BY SKewing x.xxx TIMES ROTOR CIRCUMFERENCE, OR</td>
<td>CMBNTN</td>
<td>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.</td>
</tr>
<tr>
<td>Number</td>
<td>Error message</td>
<td>Responsible subroutine</td>
<td>Explanation</td>
</tr>
<tr>
<td>--------</td>
<td>---------------------------------------------------</td>
<td>------------------------</td>
<td>---------------------------------------------------------------------------------------------------</td>
</tr>
<tr>
<td>16</td>
<td>CHANGE NUMBER OF ROTOR SLOTS TO ONE OF THE FOLLOWING xxx xxx xxx .......</td>
<td>CMBNTN</td>
<td>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.</td>
</tr>
<tr>
<td>17</td>
<td>CHANGE NUMBER OF STATOR SLOTS</td>
<td>CMBNTN</td>
<td>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.</td>
</tr>
</tbody>
</table>
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.$^2$
ASTYNND 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)
Main Program

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

56
Main Program

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
Main Program

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
Main Program

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.
LSYOKES  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)
Main Program

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
Main Program

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°F, 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.
Main Program

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, $^\circ$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 $^\circ$C
Main Program

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, $^\circ$C
TRW temperature of rotor winding, $^\circ$C
TSW temperature of stator winding, $^\circ$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,

$$VSCSTY = C_0 + C_1 T + C_2 T^2 + C_3 T^3 + C_4 T^4,$$

where $VSCSTY$ is fluid viscosity in lbm/ft-sec and $T$ is fluid temperature in $^\circ$C; $C_0$ to $C_4$ 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
WFEL 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
Main Program

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
WSYOKO 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.
66
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 $3 \times \text{FLOAT}(I) \times P$, where $I = 1, 2, 3, \ldots, 1000$
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 $F \times L$ 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 ($1.0 \times 10^{-15}$)
REFERENCES


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

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

<table>
<thead>
<tr>
<th>Main program:</th>
<th>SUBROUTINE SLOTS</th>
<th>SUBROUTINE WBDFCT</th>
<th>SUBROUTINE CMBNTN</th>
<th>SUBROUTINE MAGNET</th>
<th>SUBROUTINE CIRCT</th>
<th>SUBROUTINE PLOTXY</th>
</tr>
</thead>
<tbody>
<tr>
<td>Read one data card</td>
<td>Calculates stator and rotor slot dimensions and slot leakage permeance ratios</td>
<td>Calculates distribution and pitch factors for stator winding</td>
<td>Checks that number of rotor slots is compatible with number of stator slots</td>
<td>Performs magnetic circuit calculations</td>
<td>Does equivalent circuit analysis for one value of slip</td>
<td>Does actual plotting; is not part of INDMTR program (ref. 3)</td>
</tr>
<tr>
<td>If card has &quot;M&quot; in card column 1: (a) Read stator and rotor material data (b) Read windage loss data (c) Read motor design data</td>
<td>Called once for stator and once for rotor slots</td>
<td>Called repeatedly during iteration</td>
<td>Called repeatedly during iteration (SLIP = 0)</td>
<td>Called once for each value of slip</td>
<td></td>
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</tr>
<tr>
<td>Calculate various dimensions, areas, Carter coefficients, and equivalent circuit parameters R1, X1, R2, X2.</td>
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<tr>
<td>Write first two pages of output</td>
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<tr>
<td>No-load magnetic calculations (iterate on RO and XD)</td>
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<tr>
<td>Write results of magnetic calculations (page 3 of output)</td>
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<tr>
<td>Scale windage loss from reference to design conditions</td>
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<tr>
<td>Write results of windage loss scaling (page 3 of output)</td>
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<tr>
<td>Perform equivalent circuit analysis and print results (pages 4 and 5 of output)</td>
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<tr>
<td>Plot torque-speed curve (page 6 of output)</td>
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<tr>
<td>Go back to start of program</td>
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</tr>
</tbody>
</table>
Figure 3. Equivalent circuit of induction motor showing FORTRAN symbols used by main program. (S is rotor slip in percent.)
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.)
XO = 0.5*X0AG
WO = (WSY0KE + WSTOTH)*WFE*3.0
RO = 5. *V1*V1/WD
S = 0.

Call CIRCT to compute V2 and IMAG

Calculate total flux and flux per pole as follows:
\[ P = \frac{\text{V2}}{1.414*W*F*KPS*KDS} \]
\[ FPOLE = \frac{0.637*F_{\text{TOTAL}}}{P} \]

Call MAGNET to compute all flux densities (BSY and BST in particular) and all ampere-turn drops and the total ampere-turn drop ATTOT

Compute new values of W0 and R0:
\[ W0 = 3. * \left[ \frac{WSY0KE * \left( \frac{B_{SY}}{BK} \right)^2 + WSTOTH * \left( \frac{B_{ST}}{BK} \right)^2}{WFE} \right] \]
\[ R0 = (3. * \text{V2}^2)/WD \]

Has RO converged?

No

IMAG2 = \[ 2.22*P*ATTOT/(3.*W*KPS*KDS) \]
X0 = \[ V2 / (0.5*\text{IMAG} + \text{IMAG2}) \]

Has X0 converged?

No

End of no-load magnetic calculations

Yes

Call CIRCT to compute V2 and IMAG

Calculate total flux and flux per pole as follows:
\[ P = \frac{\text{V2}}{1.414*W*F*KPS*KDS} \]
\[ FPOLE = \frac{0.637*F_{\text{TOTAL}}}{P} \]

Call MAGNET to compute all flux densities (BSY and BST in particular) and all ampere-turn drops and the total ampere-turn drop ATTOT

Compute new values of W0 and R0:
\[ W0 = 3. * \left[ \frac{WSY0KE * \left( \frac{B_{SY}}{BK} \right)^2 + WSTOTH * \left( \frac{B_{ST}}{BK} \right)^2}{WFE} \right] \]
\[ R0 = (3. * \text{V2}^2)/WD \]

Has RO converged?

No

IMAG2 = \[ 2.22*P*ATTOT/(3.*W*KPS*KDS) \]
X0 = \[ V2 / (0.5*\text{IMAG} + \text{IMAG2}) \]

Has X0 converged?

No

End of no-load magnetic calculations

Yes

Figure 5. - Flow chart of no-load magnetic calculations.
These statements are executed once for each data set

Initialization at start of new data set

CO = 0.
C1 = 0.
C2 = 0.
C3 = 0.
C4 = 0.

Read $WNDAGE:
WL, DIAREF, LREF, RPMREF, VSCREF, PREF, GAPREF, TREF, CO, C1, C2, C3, C4

These statements are executed once for each data set

Figure 6. - Flow chart of synchronous windage loss calculation.
TFLUID = TREF
VSCFLD = 0.
FW1 = 0.
PFLUID = 0.
FLDNME = BLANK

Initialization at start of new motor design

Read motor design deck: TFLUID, FW1, VSCFLD, PFLUID, FLDNME, and all motor dimensions

Write heading for windage data

FW1

>1.0E-15

<1.0E-15

WL

<1.0E-15

>1.0E-15

630

B

H

C

Figure 6. - Continued.
Scaling with respect to diameter, length, speed, and airgap

\[
FW1 = WL \left( \frac{DR}{DIAREF} \right)^{3.25} \left( \frac{L}{LREF} \right) \left( \frac{NSYNCH}{NREF} \right)^{2.5} \left( \frac{GAPREF}{G} \right)^{0.25}
\]

Write: "insufficient data to scale windage loss"
Write value of windage loss at synchronous speed

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.
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.
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. \( AR + AS = \text{CAREA}/2 \).

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