FORTRAN PROGRAM FOR INDUCTION MOTOR ANALYSIS

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16. Abstract

A FORTRAN program for induction motor analysis is described. The analysis includes calculations of torque-speed characteristics, efficiency, losses, magnetic flux densities, weights, and various electrical parameters. The program is limited to three-phase Y-connected, squirrel-cage motors. Detailed instructions for using the program are given. The analysis equations are documented, and the sources of the equations are referenced. The 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, WDGFCI, and CMBNTN. The program also
calls a data-plotting subroutine PLOTXY (ref. 1), which is part of the Lewis subroutine library.

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

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

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

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

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

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

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

Synopsis of Input Requirements

Program input consists of one or more data sets. Each data set contains three types of data:
(1) Magnetic materials data: These data consist of two material decks, one for the rotor and one for the stator. Each material deck contains magnetization curve data and core-loss data. The core-loss data may be omitted for the rotor material.

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

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

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

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

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

Output

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

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

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

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

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

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

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

1. Length in meters
2. Areas in square meters
3. Resistances and reactances in ohms
4. Currents and magnetomotive force in amperes
5. Voltages in volts
6. Power in watts
7. Frequency in hertz
8. Rotational speed in revolutions per minute
9. Resistivity in \( \mu \)-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.

\[ AXX = \frac{KX}{WSX} \left( D2X + \frac{D1X}{3} \right) + \frac{D1X}{12 \cdot WSX} * (1 - KX) - \frac{D5X}{4 \cdot WSX} * (KX - 0.6667) \]  

(2)

Rearranging the equation gives

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

(3)

where

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

and

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

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

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

(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,

\[
AXX = KX\left(\frac{D2X}{WSX}\right) + \left(\frac{D1X}{WSX}\right)A1 - \left(\frac{D5X}{WSX}\right)A2 \quad (5)
\]

For slot type 2,

\[
AXX = 2.0KX\frac{D2X}{WSX + WSX4} + \left(\frac{D1X}{WSX4}\right)A1 - \left(\frac{2.0D5X}{WSX4 + WSX5}\right)A2 \quad (6)
\]

For slot type 3,

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

For slot type 4,

\[
AXX = KX\left[\frac{D4X}{WSX1} + \left(\frac{D3X}{WSX2 - WSX1}\right)\text{ALOG}\left(\frac{WSX2}{WSX1}\right) + \frac{2.0D2X}{WSX2 + WSX4}\right] + \left(\frac{D1X}{WSX4}\right)A1
\]

\[\quad - \left(\frac{2.0D5X}{WSX4 + WSX5}\right)A2 \quad (8)
\]

For slot type 6,

\[
AXX = KX\left[\frac{D4X}{WSX1} + \left(\frac{D3X}{WSX2 - WSX1}\right)\text{ALOG}\left(\frac{WSX2}{WSX1}\right) + \frac{2.0D2X}{WSX2 + WSX4}\right]
\]

\[\quad + \left(\frac{D1X}{WSX4}\right)A1 - \left(\frac{2.0D5X}{WSX4 + WSX5}\right)A2 \quad (9)
\]

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

\[
AXX = K\left(\frac{D4X}{WSX1}\right) + 0.625KX \quad (10)
\]
The equations just given apply to both the stator and rotor slots. However, for rotor slots the factor $KX$ (pp. 184 and 185, ref. 2) is always equal to unity, and the slot dimension $D5X$ is assumed to be zero. To change these equations to the FORTRAN symbols used in the main program, change the $X$ in each symbol to $S$ for stator slots or to $R$ for rotor slots. The only exception is $AXX$, which changes to $AXS$ and $AXR$, respectively.

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

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

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

$$X_M^{OM} = \frac{6.38 \frac{qfN^2K^2K_D^2DL}{P^2d}}{k_1g_eP^2 \times 10^8} \text{ ohms/phase}$$

To obtain the equation used in the program, the number of phases is set to three and the factor $k_1$ 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,

$$X0AG = \frac{3.02E-5 \left( \frac{N}{2.0KPS.KDS} \right) ** 2 \times D^L^*F}{P^*P^*GE}$$

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

$$X1 = XSS + XSE + XSK + XSZ + XP$$
where

\( \text{XSS} \) primary slot leakage reactance
\( \text{XSE} \) stator end-connection leakage reactance
\( \text{XSK} \) one-half of the skew reactance
\( \text{XSZ} \) stator zigzag leakage reactance
\( \text{XP} \) peripheral airgap leakage reactance

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

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

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

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

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

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

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

The rotor winding leakage reactance \( \text{X2} \) is similarly computed. The equations used in the program are as follows:

\[
\text{X2} = \text{XRS} + \text{XRE} + \text{XSK} + \text{XRZ} \tag{19}
\]
where

\[ X_{RS} \] secondary slot leakage reactance

\[ X_{RE} \] rotor end-connection leakage reactance

\[ X_{SK} \] one-half of the skew reactance

\[ X_{RZ} \] rotor zigzag leakage reactance

\[
X_{RS} = 2.36 \times 10^{-5} N F L \left( \frac{A}{N} \right) (KPS \times KDS)^2
\]

\[
X_{RE} = \frac{28.54 A Y}{P} \left[ 2 \times P_{BR} + \frac{3.1416 D DC}{1.7 \times \text{TER} + 0.6 (D_{ER1} - D_{ER2}) + 1.4 DC} \right]
\]

where

\[
AY = \frac{N F (KPS \times KDS)^2}{P} \times 2 \times 10^{-7}
\]

\[
X_{SK} = 0.5 \times \left( \frac{X_{OAG}}{12} \right) \times \left( \frac{P \times \text{SKEW}}{D} \right)^2
\]

\[
X_{RZ} = 0.833 X_{OAG} \times \frac{K_{S}}{(KPS \times KDS)^2} \times \left( \frac{6}{C_{CR}} - 1.0 \right) \times \frac{5.4 (N_{B})}{P} \times 2
\]

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

\[
R_1 = \frac{(L S N R_{STVTY} \times 1 \times 10^{-6})}{(P C S S)}
\]

where \( R_{STVTY} \) is the resistivity of the stator winding material at \( 20^\circ \text{C} \). 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)
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 $W_{FE}$ 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 $B_K$. 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 $W_{FE}$ is then calculated by

$$W_{FE} = W_{CORE} \times \left( \frac{F}{F_{CORE}} \right)^{**SLOPE}$$

where $F$ is the motor design frequency as specified in the motor design deck and $F_{CORE}$, $W_{CORE}$, SLOPE are given on the FELOSS data cards. (The symbols $F_{CORE}$, $W_{CORE}$, 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 $R_0$ in the equivalent circuit. Core loss at all other loads is the power dissipated in the resistance $R_0$ 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 $X_0$
4. Computation of values of core loss $W_0$ and the value of the resistive element $R_0$ used in the equivalent circuit to represent the core loss.

The calculations are performed as follows: Initial estimates for $X_0$, $W_0$, and $R_0$ are made by using the equations

$$X_0 = 0.5 \times X_{0AG}$$

(27)
\[ W_0 = 3. \times (WSYOKE + WSTOTH) \times WFE \]  

\[ R_0 = \frac{5 \times V_1 \times V_1}{W_0} \]

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:

\[ W_0 = 3. \times WFE \times \left[ WSYOKE \times \left( \frac{BSY}{BK} \right) \times 2 + WSTOTH \times \left( \frac{BST}{BK} \right) \times 2 \right] \]

\[ R_0 = \frac{3 \times V_2 \times V_2}{W_0} \]

where

- \( WSYOKE \) stator back-iron weight
- \( WSTOTH \) stator tooth weight
- \( BSY \) back-iron flux density
- \( BST \) 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:

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

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 \( R0 \) and \( X0 \) have converged to their final values. These values are then held constant throughout the remaining motor analysis for all values of slip.

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

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

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

\[
FW = FW1 \times \left( \frac{RPM}{NSYNCH} \right)^C
\]

where

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

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

1. \( DIAREF \), the diameter of the reference motor
2. \( LREF \), the rotor length of the reference motor
(3) RPMREF, the rotor speed for which the value WL was obtained
(4) GAPREF, the radial gap of the reference motor

In addition, though not required, the reference viscosity VSCREF and the reference pressure PREF of the fluid in the reference motor cavity may be supplied. Then, assuming that the viscosity and pressure of the fluid in the motor being analyzed are also specified, further scaling with regard to these parameters will also take place.

The exact format of the windage data required by the program is described in appendix A.

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

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

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

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

(34)

where

DR          rotor diameter of the motor being analyzed
NSYNCH     synchronous shaft speed, rpm
L           rotor length
G           radial gap between rotor and stator
Following this basic scaling operation the program will, if possible, scale FW1 with respect to fluid viscosity and fluid pressure. This concludes the computation of FW1, the windage loss at synchronous rotor speed. The result, together with all pertinent data, is printed out.

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

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

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

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

\[
W2 = \frac{3 \cdot I2^2 \cdot R2 \cdot 100}{S}
\]  

(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:

\[
W2 = 3 \cdot I2^2 \cdot R2 + \frac{3 \cdot I2^2 \cdot R2 \cdot (100 - S)}{S}
\]  

(36)

where

3 \cdot I2^2 \cdot R2  

power dissipated in the rotor winding

3 \cdot I2^2 \cdot R2 \cdot (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

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

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

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

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

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

**Preparation of Windage Loss Data Cards**

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

**Preparation of Motor Design Data Deck**

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

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

A typical data card from the motor design deck is

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

The card is for NAMELIST name STATOR and must be the second card following the motor design deck title card.
**TABLE I. - ENTRIES ON CORE-LOSS DATA CARDS**

```fortran
[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&lt;sup&gt;a&lt;/sup&gt;</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.</td>
<td></td>
</tr>
<tr>
<td></td>
<td>LT</td>
<td>Lamination thickness at which WCORE is determined, in.</td>
<td></td>
</tr>
<tr>
<td>Optional</td>
<td>LAST</td>
<td>LAST=. TRUE. indicates end of core-loss data set.</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>SLOPE</td>
<td>Slope of core loss-against-frequency plot (assumed linear on log-log paper) for constant flux density BK; if W1 is core loss at frequency F1 and W2 is core loss at frequency F2,</td>
<td>If SLOPE is omitted from input, the program will assume a value of slope given by</td>
</tr>
</tbody>
</table>
| | | \[
| &nbsp;&nbsp;&nbsp;&nbsp;&nbsp;\ln \frac{W_1}{W_2} \\
| &nbsp;&nbsp;&nbsp;&nbsp;&nbsp;\frac{\ln F_1}{\ln F_2} \\
| SLOPE = \frac{\ln F_1}{\ln F_2} \\
| (fig. 11) \] | \[
| SLOPE = \frac{1. + 164. \times LT}{1. + 82. \times LT} \]
| | | SLOPE may also be omitted if F of NAMELIST name RATING equals FCORE. | |

<sup>a</sup>For stator material only.


<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).</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</td>
</tr>
</tbody>
</table>

\[
\text{VSCREF} = C_0 + C_1 \times TREF + C_2 \times TREF^2 + C_3 \times TREF^3 + C_4 \times TREF^4
\]

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.

\(^a\)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>
<thead>
<tr>
<th>NAMELIST name</th>
<th>Classification</th>
<th>FORTRAN symbol</th>
<th>Description</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>RATING&lt;sup&gt;a&lt;/sup&gt;</td>
<td>Required</td>
<td>NSYNCH</td>
<td>Synchronous speed, rpm</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>F</td>
<td>Line frequency, Hz</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>V1</td>
<td>Line-to-neutral voltage, V</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Optional</td>
<td>TRATED</td>
<td>Rated torque, in.-lb</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>FW1</td>
<td>Windage loss at synchronous speed, W</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>X0</td>
<td>Reactance values of induction motor equivalent circuit</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>X1</td>
<td>(fig. 3), Ω</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>X2</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>R0</td>
<td>Resistance values of induction motor equivalent circuit</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>R1</td>
<td>(fig. 3), Ω</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>R2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>STATOR</td>
<td>Required</td>
<td>D</td>
<td>Stator inside diameter, in.</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>L</td>
<td>Stator stack length, in.</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>LTS</td>
<td>Stator lamination thickness, in.</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Optional</td>
<td>SFS</td>
<td>Stator stacking factor</td>
<td></td>
</tr>
<tr>
<td>SSLOTS</td>
<td>Required</td>
<td>SSTYPE</td>
<td>Stator slot type (Choose from type 1 to type 6, as shown in fig. 12.)</td>
<td></td>
</tr>
</tbody>
</table>

<sup>a</sup>This card must be preceded by a title card (see input, p. 43.)

Remarks:
- 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.
- If specified, the internal windage loss scaling will be bypassed.
- 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.)
- If omitted, stacking factor is calculated as follows:

\[
SFC = \frac{LTS}{LTS + 0.0005}
\]

- SSTYPE is required for all stator slots.
### 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>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 WSS6 or WSS 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 WSS or WSS1 or WSS6 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></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>SSLOTS</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></td>
<td></td>
<td>D5S</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>WSS1</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>WSS6</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>WSS2</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>or STWDTH</td>
<td>Stator tooth width, in.</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.²</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>or 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></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></td>
</tr>
</tbody>
</table>

**Remarks**

- PHIS is allowable input only if WSS2 is specified and STWDTH is omitted for slot types 2, 4, or 6. If, in that case, PHIS is also omitted, constant tooth width is assumed.
- Optional for slot type 5 only
- SWMAT = 1 for aluminum
- SWMAT = 2 for brass
- SWMAT = 3 for copper
- Unless one of the other two is specified, SWMAT = 3 is assumed.
- If omitted from input data, program calculates value internally. The calculations assume a form-wound armature.
TABLE III. - Continued.

<table>
<thead>
<tr>
<th>NAME LIST</th>
<th>Classification</th>
<th>FORTRAN symbol</th>
<th>Description</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<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 D1R 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>D6R</td>
<td>Slot dimension (fig. 12), in.</td>
<td>Required for all rotor slots</td>
</tr>
<tr>
<td></td>
<td></td>
<td>D2R or WSR or 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>D2R or WSR6 or WSR or RTWDT</td>
<td>Slot dimension (fig. 12(b))</td>
<td>Required for rotor slot type 2 only.</td>
</tr>
</tbody>
</table>

26
### 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, D3R, D4R, WSR, WSR1, WSR6, D2R, D3R, D4R, WSR1, WSR6, or RTWDTH</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></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>D4R, WSR1</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>D2R, D3R, D4R, WSR1, WSR6, WSR2, or RTWDTH</td>
<td>Rotor slot dimension (fig. 12(f)), in.</td>
<td>Required for rotor slot type 6 only.</td>
</tr>
<tr>
<td></td>
<td>Optional</td>
<td>WSR2</td>
<td>Rotor slot dimension (fig. 12(e)), in.</td>
<td></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, TER, BR</td>
<td>Number of rotor bars, End-ring thickness (measured in axial direction), in.</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Axial clearance between end-ring and rotor laminations, in.</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Remarks**
- Required for rotor slot type 3 only.
- Required for rotor slot type 4 only.
- Required for rotor slot type 5 only.
- Required for rotor slot type 6 only.
- If omitted, WSR2 = DSR - D4R for slot type 5 only.
- 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.
### TABLE III. - Concluded.

<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>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></td>
<td></td>
<td>DER1</td>
<td>End-ring outside diameter, in.</td>
<td>If omitted, DER1 is calculated as follows: ( DER1 = DR - 2*(D4R + D3R) )</td>
</tr>
<tr>
<td></td>
<td></td>
<td>DER2</td>
<td>End-ring inside diameter, in.</td>
<td>If omitted, DER2 is calculated as follows: ( DER2 = DR - 3.<em>DSR ) or ( DER2 = 1.1</em>DIR ) whichever is greater.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>RWMAT</td>
<td>Rotor winding material code</td>
<td>RWMAT = 1 for aluminum = 2 for brass = 3 for copper Unless one of the other two is specified, RWMAT = 3 is assumed.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>TRW</td>
<td>Rotor winding temperature, °C</td>
<td>A temperature of 25°C is assumed unless otherwise specified.</td>
</tr>
<tr>
<td>AIRGAP</td>
<td>Required</td>
<td>G</td>
<td>Airgap, in.</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Optional</td>
<td>TFLUID</td>
<td>Temperature of fluid in airgap, °C</td>
<td>If omitted, it is assumed that TFLUID = TREF. (See NAMELIST name WNDAGE.)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>VSCFLD</td>
<td>Viscosity of fluid in motor cavity, lbm/ft-sec</td>
<td>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.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>PFLUID</td>
<td>Pressure of fluid in airgap, psi</td>
<td>This needs to be included only if it is desired to scale the windage loss value WL to the new pressure level PFLUID.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>FLDNME</td>
<td>Name of fluid in airgap (may be a maximum of six characters long and must be enclosed in single quotation marks)</td>
<td>If specified, the name will be printed on the output record. No other action occurs.</td>
</tr>
</tbody>
</table>
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:
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>
<th>B</th>
<th>H</th>
</tr>
</thead>
<tbody>
<tr>
<td>(KILOLINES/50-IN)</td>
<td>(A-TURN/IN)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>12.90</td>
<td>1.92</td>
<td></td>
<td></td>
</tr>
<tr>
<td>38.70</td>
<td>2.62</td>
<td></td>
<td></td>
</tr>
<tr>
<td>77.40</td>
<td>3.23</td>
<td></td>
<td></td>
</tr>
<tr>
<td>90.30</td>
<td>3.53</td>
<td></td>
<td></td>
</tr>
<tr>
<td>103.00</td>
<td>4.35</td>
<td></td>
<td></td>
</tr>
<tr>
<td>109.70</td>
<td>5.25</td>
<td></td>
<td></td>
</tr>
<tr>
<td>116.00</td>
<td>6.66</td>
<td></td>
<td></td>
</tr>
<tr>
<td>122.50</td>
<td>8.68</td>
<td></td>
<td></td>
</tr>
<tr>
<td>129.00</td>
<td>12.50</td>
<td></td>
<td></td>
</tr>
<tr>
<td>135.50</td>
<td>20.20</td>
<td></td>
<td></td>
</tr>
<tr>
<td>142.00</td>
<td>44.40</td>
<td></td>
<td></td>
</tr>
<tr>
<td>145.30</td>
<td>101.00</td>
<td></td>
<td></td>
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<tr>
<td>148.30</td>
<td>363.00</td>
<td></td>
<td></td>
</tr>
<tr>
<td>154.00</td>
<td>2020.00</td>
<td></td>
<td></td>
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</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>
<tbody>
<tr>
<td>21.0</td>
<td>.006</td>
<td>800.0</td>
<td>77.4</td>
<td>1.2</td>
</tr>
<tr>
<td>24.5</td>
<td>.008</td>
<td>800.0</td>
<td>77.4</td>
<td>1.3</td>
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<tr>
<td>30.0</td>
<td>.010</td>
<td>800.0</td>
<td>77.4</td>
<td>1.5</td>
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<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>
<th>B</th>
<th>H</th>
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</thead>
<tbody>
<tr>
<td>(KILOLINES/50-IN)</td>
<td>(A-TURN/IN)</td>
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<td></td>
</tr>
<tr>
<td>12.90</td>
<td>1.92</td>
<td></td>
<td></td>
</tr>
<tr>
<td>38.70</td>
<td>2.62</td>
<td></td>
<td></td>
</tr>
<tr>
<td>77.40</td>
<td>3.23</td>
<td></td>
<td></td>
</tr>
<tr>
<td>90.30</td>
<td>3.53</td>
<td></td>
<td></td>
</tr>
<tr>
<td>103.00</td>
<td>4.35</td>
<td></td>
<td></td>
</tr>
<tr>
<td>109.70</td>
<td>5.25</td>
<td></td>
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</tr>
<tr>
<td>116.00</td>
<td>6.66</td>
<td></td>
<td></td>
</tr>
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<td>122.50</td>
<td>8.68</td>
<td></td>
<td></td>
</tr>
<tr>
<td>129.00</td>
<td>12.50</td>
<td></td>
<td></td>
</tr>
<tr>
<td>135.50</td>
<td>20.20</td>
<td></td>
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</tr>
<tr>
<td>142.00</td>
<td>44.40</td>
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<td>145.30</td>
<td>101.00</td>
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<td>148.30</td>
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<td>154.00</td>
<td>2020.00</td>
<td></td>
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<table>
<thead>
<tr>
<th>1200 Hz COOLANT PUMP MOTOR</th>
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<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>

| STATOR                     |
| BORE DIAMETER              | 1.070       |
| OUTSIDE DIAMETER           | 2.500       |
| DEPTH BELOW SLOT           | .195        |
| LENGTH                     | 1.240       |
| LAMINATION THICKNESS       | .006        |
| STACKING FACTOR            | .989        |
| STATOR IRON WEIGHT         | .743        |
### Stator Slots

<table>
<thead>
<tr>
<th>Slot Type</th>
<th>NO. of Slots</th>
<th>Tooth Width</th>
<th>Slot Depth</th>
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<tbody>
<tr>
<td>WSS1</td>
<td>6</td>
<td>.048</td>
<td>.15</td>
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<tr>
<td>WSS2</td>
<td>6</td>
<td>.048</td>
<td>.10</td>
</tr>
<tr>
<td>WSS3</td>
<td>6</td>
<td>.128</td>
<td>.00</td>
</tr>
<tr>
<td>WSS4</td>
<td>6</td>
<td>.068</td>
<td>.00</td>
</tr>
<tr>
<td>WSS5</td>
<td>6</td>
<td>.128</td>
<td>.010</td>
</tr>
<tr>
<td>WSS6</td>
<td>6</td>
<td>.010</td>
<td>.015</td>
</tr>
<tr>
<td>Usable Area</td>
<td>.029</td>
<td>.047</td>
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</tr>
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### Usable Area

<table>
<thead>
<tr>
<th>Slot Depth</th>
<th>Usable Area</th>
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</thead>
<tbody>
<tr>
<td>.520</td>
<td>.047</td>
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<tr>
<td>.405</td>
<td>.047</td>
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<tr>
<td>.100</td>
<td>.047</td>
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<tr>
<td>.000</td>
<td>.047</td>
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<tr>
<td>.010</td>
<td>.047</td>
</tr>
<tr>
<td>.015</td>
<td>.047</td>
</tr>
</tbody>
</table>

### Stator Winding

- **Material**: 3
- **Conductors Per Slot**: 56
- **Parallel Circuits**: 2
- **Pitch**: .667
- **Axial Extension Beyond Core**: .100
- **Conductor Cross-Section**: .252-03
- **Strand Cross-Section**: .252-03
- **Conductor Length**: 2.530
- **Clarence Between End-Turns**: .010
- **Temperature (°C)**: 30
- **Axial End-Turn Length**: 2.300
- **Overall Armature Length**: 2.700
- **Pitch Factor**: .666
- **Distributor Factor**: 1.000
- **Armature Weight**: 4.12
- **Total Armature Wire Length**: 425.000 Feet
- **Strands/Conductor**: 1
- **Strand Size**: 25

### Rotor

- **Rotor Diameter**: 1.058
- **Inside Diameter**: .450
- **Lamination Thickness**: .006
- **Stacking Factor**: .910
- **Slot Skew**: .115
- **Depth Below Slot**: .212
- **Rotor Iron Weight**: .185

### Rotor Slots

<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>WSS1</td>
<td>1</td>
<td>.000</td>
<td>.087</td>
</tr>
<tr>
<td>WSS2</td>
<td>1</td>
<td>.000</td>
<td>.005</td>
</tr>
<tr>
<td>WSS3</td>
<td>1</td>
<td>.053</td>
<td>.000</td>
</tr>
<tr>
<td>WSS4</td>
<td>1</td>
<td>.053</td>
<td>.000</td>
</tr>
<tr>
<td>WSS5</td>
<td>1</td>
<td>.003</td>
<td>.000</td>
</tr>
<tr>
<td>WSS6</td>
<td>1</td>
<td>.004</td>
<td></td>
</tr>
<tr>
<td>Usable Area</td>
<td>.004</td>
<td>.005</td>
<td></td>
</tr>
</tbody>
</table>

### Rotor Winding

- **Material**: 3
- **Bar Length**: 1.515
- **Bar Cross-Section**: .004
- **End-Ring Outside Dia**: 1.013
- **End-Ring Inside Dia**: .135
- **End-Ring Thickness**: .135
- **Stack-to-End Ring Clearance**: .000
- **Winding Temperature (°C)**: 30
- **Weight**: .100
- **Component of R2 Due to Bars**: 2.084
- **Component of R2 Due to End Rings**: .071
<table>
<thead>
<tr>
<th>AIRGAP</th>
<th></th>
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</thead>
<tbody>
<tr>
<td>ACTUAL AIRGAP</td>
<td>0.0060</td>
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<tr>
<td>EFFECTIVE AIRGAP</td>
<td>0.0141</td>
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<tr>
<td>MAGNETIZING REACTANCE (AIR GAP ONLY)</td>
<td>12.73</td>
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</table>

<table>
<thead>
<tr>
<th>LEAKAGE REACTANCES (OHM)</th>
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</thead>
<tbody>
<tr>
<td>SLOT</td>
<td>8.332</td>
</tr>
<tr>
<td>END-CONNECTION</td>
<td>0.579</td>
</tr>
<tr>
<td>SKREW</td>
<td>0.877</td>
</tr>
<tr>
<td>JIG-ZAG</td>
<td>0.639</td>
</tr>
<tr>
<td>PERIPHERAL</td>
<td>0.030</td>
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</table>

<table>
<thead>
<tr>
<th>STATOR REACTANCES (OHM)</th>
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<tr>
<td>SLOT</td>
<td>1.673</td>
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<tr>
<td>END-CONNECTION</td>
<td>0.361</td>
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<tr>
<td>SKREW</td>
<td>0.877</td>
</tr>
<tr>
<td>JIG-ZAG</td>
<td>1.173</td>
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<tr>
<td>PERIPHERAL</td>
<td>0.30</td>
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<table>
<thead>
<tr>
<th>WEIGHT</th>
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</thead>
<tbody>
<tr>
<td>TOTAL (ELECTROMAGNETIC)</td>
<td>1.440</td>
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</table>

<table>
<thead>
<tr>
<th>STATOR MATERIAL</th>
<th></th>
</tr>
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<tbody>
<tr>
<td>B MAX</td>
<td>154</td>
</tr>
<tr>
<td>CORE LOSS AT 77.4 KL/50-IN</td>
<td>34.4 W/LB</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>ROTOR MATERIAL</th>
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</tr>
</thead>
<tbody>
<tr>
<td>B MAX</td>
<td>154</td>
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</table>

<table>
<thead>
<tr>
<th>MAGNETIZATION CHARACTERISTICS</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>TOTAL USEFUL FLUX</td>
<td>158.42 KILOLINES</td>
</tr>
<tr>
<td>USEFUL FLUX/POLE</td>
<td>8.41</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>FLUX DENSITIES</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>AIRGAP</td>
<td>38.01 KL/50-IN</td>
</tr>
<tr>
<td>STATOR TOOTH</td>
<td>86.76</td>
</tr>
<tr>
<td>STATOR YOKE</td>
<td>19.13</td>
</tr>
<tr>
<td>ROTOR TOOTH</td>
<td>88.07</td>
</tr>
<tr>
<td>ROTOR YOKE</td>
<td>17.58</td>
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</table>

<table>
<thead>
<tr>
<th>AMPERE-TURNS PER POLE</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>AIRGAP</td>
<td>167.53</td>
</tr>
<tr>
<td>STATOR TOOTH</td>
<td>1.79</td>
</tr>
<tr>
<td>STATOR YOKE</td>
<td>4.62</td>
</tr>
<tr>
<td>ROTOR TOOTH</td>
<td>3.2</td>
</tr>
<tr>
<td>ROTOR YOKE</td>
<td>1.18</td>
</tr>
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</table>

| TOTAL                         | 170.44 |

<table>
<thead>
<tr>
<th>MAGNETIZING CURRENT</th>
<th></th>
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<tbody>
<tr>
<td>AIRGAP VOLTAGE</td>
<td>65.19</td>
</tr>
<tr>
<td>N.L* CURRENT DENSITY</td>
<td>10380.04 N</td>
</tr>
<tr>
<td>CORE LOSS</td>
<td>41. WATT</td>
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</tbody>
</table>

<table>
<thead>
<tr>
<th>WINDAGE</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>DESIGN CONDITION</td>
<td></td>
</tr>
<tr>
<td>WINDAGE LOSS, W</td>
<td>56.</td>
</tr>
<tr>
<td>DIAMETER</td>
<td>1.056</td>
</tr>
<tr>
<td>LENGTH</td>
<td>1.240</td>
</tr>
<tr>
<td>RPM</td>
<td>12000</td>
</tr>
<tr>
<td>GAP</td>
<td>.006</td>
</tr>
<tr>
<td>TEMP, DEG C</td>
<td>25.</td>
</tr>
<tr>
<td>VISCOSITY, LB/FT-SEC</td>
<td>.121-02</td>
</tr>
<tr>
<td>PRESSURE, LBS/50-IN</td>
<td>.000</td>
</tr>
<tr>
<td>FLUID</td>
<td>DC-200</td>
</tr>
</tbody>
</table>

| REFERENCE CONDITION           |       |
| WINDAGE LOSS, W               | 45.   |
| DIAMETER                      | 1.050 |
| LENGTH                        | 1.125 |
| RPM                           | 12000 |
| GAP                           | .010  |
| TEMP, DEG C                   | 20.   |
| VISCOSITY, LB/FT-SEC          | .129-02 |
| PRESSURE, LBS/50-IN           | .000  |
| FLUID                         | DC-200 |
### Equivalent Circuit Parameters

| $R_1$ | 1.190 | $X_1$ | 10.430 |
| $R_2$ | 2.155 | $X_2$ | 3.884 |
| $R_{31}$ | 3.2176 | $X_{31}$ | 12.515 |

### Motor Performance at 120.00 Volt, 1200.0 Hz

<table>
<thead>
<tr>
<th>Torque (In-Lbs)</th>
<th>Slip (Percent)</th>
<th>RPM</th>
<th>P-Out (Watt)</th>
<th>I (Amp)</th>
<th>Eff. (Percent)</th>
<th>PF</th>
<th>P-In (Watt)</th>
<th>Pri. Loss (Watt)</th>
<th>Sec. Loss (Watt)</th>
<th>Iron Loss (Watt)</th>
<th>Total Loss (Watt)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.33</td>
<td>1.00</td>
<td>11880.00</td>
<td>0.00</td>
<td>3.89</td>
<td>5.23</td>
<td>1.07</td>
<td>0.10</td>
<td>197.23</td>
<td>97.67</td>
<td>5.59</td>
<td>40.66</td>
</tr>
<tr>
<td>0.44</td>
<td>2.00</td>
<td>11760.00</td>
<td>0.08</td>
<td>61.85</td>
<td>5.26</td>
<td>23.87</td>
<td>0.14</td>
<td>255.72</td>
<td>98.80</td>
<td>2.33</td>
<td>40.29</td>
</tr>
<tr>
<td>0.64</td>
<td>3.00</td>
<td>11640.00</td>
<td>0.15</td>
<td>115.47</td>
<td>5.31</td>
<td>36.90</td>
<td>0.16</td>
<td>312.96</td>
<td>100.61</td>
<td>5.18</td>
<td>39.80</td>
</tr>
<tr>
<td>1.23</td>
<td>4.00</td>
<td>11520.00</td>
<td>0.22</td>
<td>369.58</td>
<td>5.49</td>
<td>46.03</td>
<td>0.10</td>
<td>339.30</td>
<td>102.30</td>
<td>4.37</td>
<td>39.60</td>
</tr>
<tr>
<td>1.55</td>
<td>5.00</td>
<td>11400.00</td>
<td>0.29</td>
<td>213.96</td>
<td>5.47</td>
<td>50.71</td>
<td>0.21</td>
<td>421.39</td>
<td>106.08</td>
<td>3.84</td>
<td>36.51</td>
</tr>
<tr>
<td>1.94</td>
<td>6.00</td>
<td>11280.00</td>
<td>0.34</td>
<td>256.44</td>
<td>5.54</td>
<td>54.46</td>
<td>0.24</td>
<td>471.63</td>
<td>109.61</td>
<td>19.46</td>
<td>37.73</td>
</tr>
</tbody>
</table>

- **Motor Performance at 120.00 Volt, 1200.0 Hz**

- **Torque**: 1.00 to 6.00
- **Slip (Percent)**: 0.00 to 1.00
- **RPM**: 11880.00 to 11280.00
- **P-Out (Watt)**: 0.00 to 471.63
- **I (Amp)**: 3.89 to 6.01
- **Eff. (Percent)**: 1.07 to 54.46
- **PF**: 0.10 to 0.24
- **P-In (Watt)**: 197.23 to 471.63
- **Pri. Loss (Watt)**: 97.67 to 109.61
- **Sec. Loss (Watt)**: 5.59 to 19.46
- **Iron Loss (Watt)**: 40.66 to 37.73
- **Total Loss (Watt)**: 58.62 to 47.99
| CURRENT DENSITY AT RATED TORQUE IN ROTOR BAR | 12573. |
| IN END RING | 13154. |
| IN ARMATURE | 11047. |
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, XX, FW1, NSYNCH, VI, S, I1, RPM, PF, T, HP, EFF, A 1
1FIN, W1, W2, NO, FM, IMAG, V2, POUT, PHASE A 2
COMMON /MAC/ BST, BSY, BR, BRY, ASTY, AT, ATR, ASYE, ASTOY, ARTY A 3
10, KTO, LSYOKE, LRYOKE, DSS, DSS, FFOTAL, POL, SSAT, D1AT, ATTO T A 4
COMMON /INIT/ ASTRD, AWG, CSRAP, DER1, DER2, D1R, D1S, D2R, D2S, D3R, D3S A 5
1, D4R, D4S, D5S, JBAR, LB, LS, PLFLUID, RWDWT, SB, SCAREA, SPR, SPS, SKW, SSARE A 6
2A, SWDTH, TRATED, VSCFLD, WSR1, WSR2, WSR3, WSR4, WSR5, WSS, WSS1, WSS2, WSS3 A 7
3, WSS4 A 8
C
C EQUIVALENCE (RESST1 (1), ASTRD), (RESST2 (1), RO) A 9
C
C REAL I, JBAR, JRING, LARE, LT, LTS, LTR, LSYOKE, LRYOKE, LTOTAL, IMAG A 10
10(IFM2, NSYNCH, KPS, KDS, W, LB, NB, KB, KRING, L, KS, IREF, NADK, NAME A 11
C
C INTEGER STYPE, RSTYPE, AWG, BWLAT, SWMAT A 12
C
C LOGICAL LAST A 13
C
C DIMENSION SLIP (70), TORQUE (70), PP (61), XLGND (3), AI (50), SMAT (13) A 14
1, RAMAT (13), WAREA (10), RSTVY (5), TMPCF (5), TITLE (13), DNSTY (5), C A 15
2LOSS (5, 10), RESST1 (38), RESST2 (7), NAME (13) A 16
C
C NAMELIST /RATING/ NSYNCH, Y0, X0, XI, X2, RO, R1, R2, FW1, VI, TRATED /STAT3R/ A 17
1, D1L, LTS, DFS, DSS /SLLOTS /DSS, WS56, Q5, DSS, WSS, SWTYPE, DSS, DIS, DIS, DIS, DIS A 18
2WS5, WS52, PHIS, DSS, SWDTH, SCAREA, CSRATO /STWDG /CSS, PC, SMAT, SPIT A 19
3CH, LS, ASTRD, TSW, S, AWG, STRNDS /3TOR /SKW, LTR, SFR, DIR /RLSLOTS /S, DIR A 20
4, WSR6, BSTYPE, D4R, D4S, WSR1, WSR2, D1R, D1S, D2R, D2S, D3R, D3S, D4R, D4S, D5R, D5S A 21
5LB, NB, DER1, DER2, TB, RMAT, TW, WS, ISGAP, ST, PFLUID, VSCFLD, PLFLUID, PLD A 22
6WME A 23
C
C NAMELIST /PELOSS/ WCORE, PCORE, SLOPE, BK, LT, LAST /MDNAGE /WL, D1AREP, LB A 24
1EF, RPMREF, VSCREF, C0, C1, C2, C3, C4, GAPREF, TREF, PREE A 25
C
C DATA RSTVY /1.00, 2.95, 0.678, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0/ A 26
1, 0.0975, 0.309, 0.321, 0.0, 0.0 /33
C
C DATA [WAREA (I)] = I, 1.40, 0.06573, 0.05213, 0.04134, 0.03278, 0.02600, 0.02062, A 27
1.01635, 0.01297, 0.008155, 0.006467, 0.005129, 0.004067, 0.003225, 0.002600 A 28
20.002028, 0.001012, 0.000802, 0.000636, 0.000521, 0.000413, 0.000328, 0.000260 A 29
20.002028, 0.001012, 0.000802, 0.000636, 0.000521, 0.000413, 0.000328, 0.000260 A 30
C
C DATA XLGND (1) = 1, 1853, 5.97, 3.7, 0.94, 5.5, 3.06, 0.54, 3.93, 5.1, 5.9, 7.9, 6.7, 6.6, A 31
C
C DATA BLANK /6H /MATDEK /1BM/ A 32
C
C THE FOLLOWING ARITHMETIC STATEMENT FUNCTION GIVES THE VISCOSITY A 33
C
C OF THE FLUID IN THE MOTOR CAVITY AS A FUNCTION OF TEMPERATURE, A 34
C
C VSCSTY IS IN LBM/FT-SEC AND T IN DEG C A 35
C
C VSCSTY (T) = C0 * T * (C1 * T * (C2 + C4 * T)) A 36
C
C READ (5, 20) DEKTY, NAME A 37
20 FORMAT (A1, 1X, 13A0) A 38
IF (DEKTY EQ. MATDEK) GO TO 40 A 39
DO 30 I = 1, 13 A 40
TITLE(I)=NAME(I)
GO TO 140
40 DO 50 I=1,13
50 SMAT(I)=NAME(I)
C C
C INITIALIZATION AT START OF A NEW DATA SET
C C
LAST=.FALSE.
TREF=25.
VSREF=0.
PREF=0.
FRREF=0.
LREF=0.
DRBREF=0.
GRREF=0.
C0=0.
C1=0.
C2=0.
C3=0.
C4=0.
WL=0.
C C READ AND WRITE STATOR MATERIAL MEGNETIZATION DATA
C C
READ (5,60) (AI(I),I=1,29)
60 FORMAT (8F10.1)
WRITE (6,70) SMAT
70 FORMAT (1H1,4X,15HSTATOR MATERIAL/7X,13A6)
WRITE (6,80) (AI(I),I=2,29)
80 FORMAT (1H1,12X,1H5,20X,1HH//5X,17H(KILOLINES/SQ-IN),7X,11H(A-TURN)
1/IN) //(F16.2,F14.3,F11.1,F11.1,F12.1)
W L (6,90)
90 FORMAT (1H1,6X,14HCORE-LOSS DATA/10X,9HCORE-LOSS,5X,7HLAM THK,5X,4
1HMM2,5X,10HFLOX DNSTY,5X,5SHSLOPE)
C C READ CORE LOSS DATA FOR STATOR MATERIAL
C C
DO 100 I=1,11
SLOPE=0.
READ (5,P60) (AI(I) ,I=1,29)
100 FORMAT (8F10.1)
IF (LAST) GO TO 120
CLOSE(I)=WCORE
CLOSE(2,I)=FCORE
IF (SLOPE.LT.1.0E-15) SLOPE=(1.3+164.*LT)/(1.0+82.*LT)
CLOSE(3,I)=BK
CLOSE(4,I)=LT
CLOSE(5,I)=LT
WRITE (6,110) WCOEE,LT,FCORE,BK, SLOPE
PORHAT
(1H1,4X,14HSTATOR MATERIAL/7X,13A6)
WRITE (6,120)
120 FORMAT (1H1/1H,2X,13A6)
C C READ ROTOR MATERIAL MAGNETIZATION DATA
C C
READ (5,20) DEKTYP,RMAT
READ (5,60) (AI(I),I=31,59)
WRITE (6,130) RMAT
130 FORMAT (1H1,4X,14HROTOR MATERIAL/7X,13A6)
WRITE (6,80) (AI(I),I=32,59)
C C READ WINDAGE DATA
C C
READ (5,WNDAGE)
IF (VSCREF.LT.1.0E-15) VSCREF=VSCSTY(TREF)
C C READ (5,20) DEKTYP,TITLE
140 WRITE (6,150) TITLE
150 FORMAT (1H1/1H,2X,13A6)
C C INITIALIZATION AT BEGINNING OF A NEW MOTOR DESIGN DECK
C
DO 160 I=1,38
160  RESET1(I)=0.
DO 170 I=1,7
170  RESET2(I)=0.
DSR=0.
DSS=0.
FNAME=BLANK
PHIR=0.
PHI=0.
RMAT=3
STREDS=1.0
SWAT=3
TFLUID=TREF
TRW=25.
TSW=25.
DO 180 I=12,61
180  PP(I)=BLANK
READ 'MOTOR DESIGN' DECK
READ (5,RATING)
IF [X0*X1*X2*RO*RL*RF+GT.1.OE-15) GO TO 720
READ (5,STATOR)
READ (5,SSLOTS)
READ (5,STRWGD)
READ (5,ROTOR)
READ (5,RSLOTS)
READ (5,RTWWDG)
READ (5,AIRGAP)
RETRIEVE CORE LOSS DATA FROM ARRAY CLOSS FOR DESIGN LAMINATION
DIFF=10.
DO 190 I=1,NCARDS
190  DIFFl=ABS(LTS-CLOSS(5,I))
IF (DIFF1.GT.DIFF) GO TO 190
IA=I
DIFP=DIFF1
CONTINUE
IF (DIFF.GT.0.0005) WRITE (6,230) CLOSS(5,IA)
FORNAT (1HK,68HCORE-LOSS DATA IS NOT GIVEN AT SPECIFIED STATOR LAMINATION THICKNESS)
WPE=CLOSS(1,IA)*((P/CL3SS(2,IA)) **CLOSS(3,IA))
BK=CLOSS(4,IA)
CALCULATE VARIOUS DIMENSIONS FROM INPUT DATA
TR=(3.1416*D)/NB
TS=(3.1416*D)/QS
IF (SKW.ILT.1.0E-15) SKW=AMAX1(T1B,T1S)
IF (LB.ILT.1.0E-15) LB=SQR(T*L*SKW*SKW)+2.*(BR+TBR)
IF (ASTRM.ILT.1.0E-15) ASTRM=W/AREA(AWG)
SS=ASTRM*STRNDS
IF (SFR.ILT.1.0E-15) SFR=LTR/(LTR+0.0005)
IF (SFS.ILT.1.0E-15) SFS=LTR/(LTR+0.0005)
IF (DSS.GT.1.0E-15.0R.DS.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)
FORMAT (1HK,59HINSUFFICIENT STATOR SLOT DATA, SPACE FACTOR OF 0.70 ASSUMED)
CSRATO=0.70
220  SCAREA=SS*SS/CSRATO
GO TO 250
230  SCAREA=0.
240  CSRATO=0.
C
38
C CALL SLOTS (1.0, SSTYPE, WSS, WSS1, WSS2, WSS3, WSS4, WSS5, DSS, D1S, D2S, D3
15, D4S, D5S, STWIDTH, SCAREA, SSAREA, Q5, D6S, WSS6, D, R, RSC, RST, SWMAG, PHIS)
C CALL SLOTS (-1.0, SSTYPE, WSR, WSR1, WSR2, WSR3, WSR4, WSR5, DSR, D1R, D2R, D3
13R, D4R, 0., BTWTH, SB, RSAREA, NB, D6R, WSR6, DR, 1.0, AR, RTWMA, PHIR)
C STATOR AND ROTOR IRON WEIGHTS
C WSTOTH=(3.1416*(D+DSS)*DSS-(SSAREA*Q5))*L*SPS*.283
C WSTOK=(0.7854*(DOS*DOS-(D+2.*DSS)**2))*L*SPS*.283
C WSTAT=WSTOTH+WSTOE
C WROT=(0.7854*(DR*DR-DIR*DIR)-N8*(RSAREA))*L*SPF*.283
C END RING DIMENSIONS
C IF (DER1.LT.1.0E-15) DER1=DR-2.*DR3
C IF (DER2.LT.1.0E-15) DER2=MAX1(DR-3.*D5R, 1.1*DIR)
C SHR=0.5*(DER1-DER2)*TER
C IF (CSRATO.LT.1.0E-15) CSRATO=CSS*SS/SCAREA
C P=FLOAT(IFIX(((120.*F)/NSYCH)+0.1))
C N=(QSSCSS)/(PC*3.)
C DBS=(DOS-D)*0.5-DSS
C DBRS=(DR-DIR)*0.5-DSR
C CHECK IF STATOR-ROTOR SLOT COMBINATION IS ACCEPTABLE
C CALL CMNTH (Q5, NB, P)
C CALCULATE DISTRIBUTION AND PITCH FACTORS
C CALL WDGFT ((60., P, Q5, K5D, PC, EPS, SPITCH)
C CARTER COEFFICIENTS AND EFFECTIVE AIRGAP
C IF (SSTYPE.GT.2) GO TO 260
C CCR=(T1R*(5.*S+WSR))/K(R*(5.*S+WSR)-WSR*WSR)
C GO TO 270
C 260 CCR=(T1R*(4.4*G+0.75*WSS1))/K(R*(4.4*G+0.75*WSS1)-WSS1*WSS1)
C GO TO 290
C 270 CCR=(T1S*(5.*G+WS5))/K(R*(5.*G+WS5)-WSS*WS5)
C GO TO 290
C 280 CCR=(T1S*(4.4*G+0.75*WSS1))/K(R*(4.4*G+0.75*WSS1)-WSS1*WSS1)
C 290 GEG=CCCR*CCS
C STATOR RESISTANCE CALCULATION (R1)
C IF (SSTYPE.EQ.2.OR.SSTYPE.EQ.4.OR.SSTYPE.EQ.6) SALPHA=(0.5*(WSS4+W
15SS)+S2.*WSS6)/(1.3*WSS)/(Q5)
C IF (SSTYPE.EQ.1.OR.SSTYPE.EQ.3) SALPHA=(WSS*S-2.)*WSS6/TS1
C IF (SSTYPE.EQ.5) SALPHA=(WSS3+S-2.*WSS6)/(1.3*WSS*(D+2.*DSS+S53))/Q
C 15)
C CALPHA=SQR(1.-SALPHA**2)
C AY=(1.31416*(D+DSS)*SPITCH)/(P*SALPHA)
C IF (LS.LT.1.0E-15) LS=AY+2.*B+DSS+L
C IF (R1.GT.1.0E-15) GO TO 300
C R1=(LS**RSTTY(SWAT))*1.0E-6/(PC*SS)
C R1=R1*(1.+TMPCF(SWAT)*(TSW-20.))
C AXIAL EXTENSION OF END TURN AND OVERALL ARMATURE LENGTH
C 300 ENDTRN=AY*0.5*SALPHA*B+DSS
C LTOTAL=L+2.*ENDTRN
C ARMATURE WEIGHT AND TOTAL WIRE LENGTH
C LARM=(LS*CSS*Q5*STNDS)/12.
C WARM=DSNSTY(SMAT)*LARM*ASTNDS*12.
ROTOR RESISTANCE CALCULATION (R2)

\[
RSTVY = 1.0 \times 10^{-6} \times RSTVTY \times (RWMAT) \times (1.0 + 2 \times RPSR) \times (RWMAT) \times (TRW - TR2)
\]

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

RATIO = DERZ / DER1

KRING = 0.50 * P * (1.0 - RATIO) / (1.0 + RATIO * P)

AY = ((KPS * KDS) ** 2) * 3.0 * RSTVY

R2BAR = AY * ((LB - TER) / (SB * NB))

R2RING = AY * (0.64 * DER1 * KRING) / (P * P * SEB)

R2 = R2BAR + R2RING

ROTOR WINDING WEIGHT AND TOTAL ELECTROMAGNETIC MOTOR WEIGHT

\[
WWDGD = DSTDY \times (RWNAT) \times (HR + HB + (LB - 2.0 * TER)) + SEP \times 3.1416 \times (DEH1 + DEB2)
\]

WEIGHT = WARN + WRWNDG + W ROT + W ST A

IAGNETIZING REACTANCE (AIR GAP ONLY)

\[
XOAG = 7.66 \times 10^{-7} \times (N / 2.0) \times KPS^2 \times D \times L / (P \times P \times GE)
\]

ROTOR AND STATOR END-CONNECTION LEAKAGE REACTANCE

\[
DC = (D1 + 2.0 \times (D2 + D3 + D2S) + D1S - 0.50 \times (DEH1 + DEB2)) / 0.50
\]

AY = ((W * KPS * KDS) ** 2) / (P) / (2.0 - 1.0) / (P * P * SEB)

KSE = AY * (1.0 - CALPHA * CALPHA) / (P * CALPHA)

XRE = (0.725 * AY / P) / (2.0 * P * FIR + (3.1416 * D)) / (1.7 * TER + 0.6 * (DER1 - DER2) + 1.4 * DC)

SKEW REACTANCE (XSK)

\[
XSK = 0.5 \times XOAG / 12.0 \times (P * P * SEB / DC) \times 2.4 \times 10^{-7}
\]

PERIPHERAL AIR-GAP LEAKAGE REACTANCE (XP)

\[
XP = 0.52 \times XOAG / (P * G / DC) \times 2.0
\]

TOTAL ARMATURE AND ROTOR LEAKAGE REACTANCES (X1 AND X2)

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

IF (ABS(X2).LT.1.0E-15) X2 = XSS + XSE + XSK + XHZ

WRITE OUTPUT

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

FORMAT (9H SYNCHRONOUS SPEED, P26.0, 4H RPM/10X, 19H FREQUENCY, P34.0, 3H Hz/10X, 5H POLES, P38.0/10X, 11H H-VOLTAGE, F33.1, 25H VOLT)

IF (TRATED.GT.1.0E-15) WRITE (6,330) TRATED

WRITE (6,340) D, DOS, DRS, L, LTS, SF, WSTAT

FORMAT (9H, 96, 12H HARMONIC TORQUE, F32.1, 7H IN-LBS)

WRITE (6,350) D, DOS, DRS, L, LTS, SF, WSTAT
C CROSS-SECTIONAL AREAS AND LENGTHS OF FLUX PATHS NEEDED FOR
C MAGNETIC CALCULATIONS
C
ASTOKE=DBS*L*SFS
LSYOKE=3.1416*(DOS+D+2.*DSS)/(4.*P)
ARTOKE=DBRS*L*SFR
ARTYOKE=3.1416*(DR-2.*DSS+DIR)/(4.*P)
ARTOOTH=STXWAG*L*SFS*QS
ASTOOTH=STXWAG*L*SFS*QS
C
C NO-LOAD MAGNETIC CALCULATIONS
C
XX=1.0
XY=1.0
IF (XO.GT.1.0E-15) XX=0.0
IF (RO.GT.1.0E-15) XY=0.0
XO=XX+0.5*XOAG*XX
YO=(XOYOKE+WSTOTH)*WFE*3.0
RO=(5.0*V1*V1/W0)*XY+RO
S=0.
ICNT2=0
ICNT2=ICNT2+1
IF (ICNT2.GE.16) GO TO 550
ICNT1=0
ICNT1=ICNT1+1
IF (ICNT1.GE.11) GO TO 540
CALL CIRCT
ROOLD=RO
FTOTAL=V2*P*1.0E+05/(1.414*G*P*KPS*KDS)
FGOLE=FTOTAL/0.637/P
BG=FTOTAL/(3.1416*G*L)
ATAG=BG*G*E*313.
C
CALL MAGNET
W0=(WTOKE+(BSY/BK)**2)**2+WSTOTH*(BSY/BK)**2)*WFE*3.0
RO=((3.0*V2*V2-W0-RO)*XY+RO
IF (ABS(RO-ROOLD)/RO.GE.0.001) GO TO 530
IMAG2=2.22*P*ATTOT/(3.*G*KPS*KDS)
XO=(XO+((V2/0.5*IMAG2)-XO)*XX
IF (ABS(IMAG-IMAG2)/IMAG.GT.0.005) GO TO 520
CURREN=(SORT(IMAG**2)/(V2/RO)**2)/(PC*SS)
IF (ICNT1.GE.11) WRITE (6,560)
IF (ICNT2.GE.16) WRITE (6,570)
IF (KSAT.EQ.0) WRITE (6,580)
C
560 FORMAT (1H 'NO-LOAD MAGNETIZATION CURRENT FAILED TO CONVERGE//')
570 FORMAT (1H '17H MACHINE SATURATED//')
580 FORMAT (1H '17H MACHINE SATURATED//')
C
WRITE RESULTS OF NO-LOAD MAGNETICAL CALCULATIONS
C
WRITE (6,550) SMAT,AT,(1),BG*WFE
590 FORMAT (1H5X,17HSTATOR MATERIAL =-',1H',13A6/24X,7HB MAX =',F5.3/24 1X,12H CORE LOSS AT,F6.1.10H KL/SQ-EN=',F5.1.5H W/LB)
WRITE (6,600) BAT,(11)
600 FORMAT (1H5X,17HSTATOR MATERIAL =-',1H',13A6/24X,7HB MAX =',F5.0)
C
WRITE NO-LOAD MAGNETIZATION CHARACTERISTICS
C
WRITE (6,610) FTOTAL,FGOLE,BG*BSY*BSY,BBT,BRY,ATAG,ATST,ATSY,ATBT,
1ATH,ATTOT,IMAG,V2,CURREN,W0
C
SCALE WINDAGE LOSS FROM REFERENCE CONDITIONS TO DESIGN CONDITIONS
C
C
C
WRITE (6,620) A 491
620 FORMAT (1HL5X,7HWIN DAGE) A 492
IF (FW1.GT.1.OE-15) GO TO 700 A 493
IF (WL.OL.E-15) GO TO 630 A 494
IF (DIAREF*LRBF*RPREF*GAPREF.GT.1.OE-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
IF (VSCREP.LT.1.OE-15) GO TO 670 A 500
IF (VSCFLD.GT.1.OE-15) GO TO 660 A 501
VSCPLD=VSCSTY(TPLUID) A 502
IF (VSCPLD.LT.1.OE-15) GO TO 670 A 503
PW1=FW1* (VSCFLD/VSCRBP)**O.50) A 504
IF (PREP.LT.1.OE-15) GO TO 680 A 505
IF (PFLUID.LT.1.OE-15) GO TO 680 A 506
PW1=FW1* (PFLUID/PRIP) A 507
WRITE WINDAGE DATA A 508
WRITE (6,690) PW1, WL, DR, DIAREF, L, LREF, NSYNCH, RPMREF, G, GAPREF, TPLUID, TREP, VSCFLD, VSCREP, PFLUID, PREP, PLUMNE A 510
WRITE VALUES OF EQUIVALENT CIRCUIT ELEMENTS A 511
WRITE (6,730) R1, X1, R2, X2, P0, XO FOR RAT (1H K, 5X, 29H EQUIVALENT CIRCUIT PARAMETERS/ L0X, 4H TORQUE, 4X, 4H SLP, 6X, 3HP, 7X, 3HP, 7X, 2HP A 524
C C WRITE VALUES OF EQUIVALENT CIRCUIT ELEMENTS A 525
C 720 WRITE (6,730) R1,X1,R2,X2,PO,XO A 526
C 730 FORMAT (1HK,5X,29HEQUIVALENT CIRCUIT PARAMETERS/10X,4HR1 =,F9.3,15 A 527
1X,5X1 =,F7.3/10X,4HR2 =,F9.3,15 A 528
X,4X2 =,F7.3/10X,4HR0 =,F9.3,15 A 529
X,4X3 =,F9.3) A 530
C C EQUIVALENT CIRCUIT ANALYSIS A 531
C KT=1 A 532
IF (TRATED.LT. 1. OE-15) KT=3 A 533
SMAX=100. A 534
IA=IFIX ((SMAX/ (50.*DELTAS))+0.5) A 535
S=0. A 536
T=0. A 537
TOLD=0. A 538
SOLD=S A 539
WRITE (6,740) V1, F A 540
740 FORMAT (1HK,5X,20H MOTOR PERFORMANCE AT,F7.2,6H VOLT,,F7.1,3Hhz//6 A 541
1X,6HTORQUE,4X,4HSLIP,6X,3HPMP,12X,5HP-OUT,12X,1H1,7X,3HEFF,7X,2HP A 542
2.6X,4HPIN,6X,3HPRI,6X,3HSEC,7X,4HIRON,9X,2HPMP/5X,8H(IN-LBS),17X,9H A 543
3,(PERCENT),14X,4H (HP),4X,6H(WATT),5X,5H (AMP),2X,9H (PERCENT),11H(*=L A 544
4EDGING),6H(WATT),5X,4HLOSS,5X,4HLOSS,6X,4HLOSS,7X,6H(WATT) /93X,6H A 545
5WATT), 3X, 6H(WATT), 4X, 6H(WATT) //) A 546
S=S+DELTAS A 547
I=I+1 A 548
IF (S.GT.SMAX) GO TO 870 A 549
CALL CIRCT A 550
IF (T.GT.1.0E-15) GO TO 780 A 551
WRITE (6,770) S A 552
770 FORMAT (1HK,5X,20HEQUIVALENT CIRCUIT ANALYSIS AT, F8. A 553
13,13H PERCENT SLIP) A 554
IF (S.GT.15.) GO TO 870 A 555
T=0. A 556
GO TO 820 A 557
780 GO TO (790,840,800), KT A 558
790 IF (T.GE.TRATED) GO TO 830 A 559
TOLD=T A 560
SOLD=S A 561
GO TO 820 A 562
780 GO TO (790,840,800), KT A 563
800 WRITE (6,810) T, S, RPM, HP, POUT, I1, EFF, PF, PHASE, PIN, W1, W2, W0, FW
810 FORMAT (1H1,7F10.2,8F10.2)
820 J=I/IA
IF (J*IA.NE.I) GO TO 750
IF (J.GT.50) GO TO 750
SLIP(J)=S
TORQUE(J)=T
GO TO 750
C CALCULATE VALUE OF S AT TORQUE TRATED
830 S=((TRATED-TOOLD)/(T-TOOLD))*(S-SOLD)+SOLD
KT=2
GO TO 760
C WRITE MOTOR CHARACTERISTICS AT RATED TORQUE
840 IF ((ABS(T-TRATED)).GT.0.005) GO TO 830
WRITE (6,850)
FORMAT (1H1,7F10.2,9F10.2)
850 WRITE (6,850)
FORMAT (1H1,7F10.2,9F10.2)
860 IF (NB.LT.1.0E-15) GO TO 860
WBAR=(W2/NS)+((R2BAR/P2)
IBAR=SQRT(WBAR/NS)/(RSTVY+NR)
JBAR=IBAR/IB
WRING=(W2-WBAR)*0.5
JRNG=SQRT(WRING/((RSTVY+SR*1.5708*(DE1*DER2)))
CURVEN=II/(PC*SS)
KT=3
S=SOLD+DELTAAS
GO TO 760
C CURRENT DENSITIES AT RATED TORQUE
870 IF (JBAR.GT.1.0E-15) WRITE (6,880) JBAR,JUING,CURDEN
880 IF (NB.LT.1.0E-15) GO TO 860
WRITE (6,890)
FORMAT (1H1,7F10.2)
890 WRITE (6,890)
FORMAT (1H1,7F10.2)
SUBROUTINE CIRCT
COMMON /CIR/ RO,R1,B2,X0,X1,X2,PW1,NSYNCH,V1,S,11,RPM,PF,T,HP,EFF,
B 2
PIN,W1,W2,W0,FW,IMAG,V2,OUT,PHASE
REAL NSYNCH,I1,I2,IMAG
COMPLEX D,20,Z1,Z2,E1,E2,G1,G2,GB
DATA STAR,BLANK,1H*,1H /
C C=2.5
PHASE=BLANK
POUT=0.
EFF=0.
HP=0.
T=0.
E1=CMPLX(V1,0.)
Z1=CMPLX(R1,X1)
Z0=CMPLX(R0*X0*X0/(R0*R0+X0*X0),X0*X0*R0/(R0*R0+X0*X0))
IF (S.LT.1.0E-10) GO TO 10
Z2=CMPLX(R2*1000./S,X2)
D=(Z1+Z2)*(Z2+Z2)-Z2*Z2
IA=(Z1*(Z2+Z2))/D
IB=(Z1*Z2)/D
IC=IA-IB
GO TO 20
IA=S1/(Z1*Z2)
IB=(0.,0.)
IC=IA

20 E2=(IA-IR)*Z0
A=REAL(E2)
B=AIMAG(E2)
V2=SQRT(A*A+B*B)
IMAG=V2/X0
WO=V2*V2/R0*3.
A=REAL(IA)
B=AIMAG(IA)
IF (B.GT.0.) PHASE=STAP
I1=SQRT(A*A+B*B)
PF=A/I1
A=REAL(I1)
B=AIMAG(I1)
I2=SQRT(A*A+B*B)
W1=I1*I2*RI*3.
W2=I2*I2*RI*3.
BPM=NSYCH*(1.-S/100.)
FW=PF*W1*(PF/NSTAP)**C
PIN=V1*I1*PF*3.
IF (S.GT.0.) GO TO 31
A=REAL(I2)
B=AIMAG(I2)
I2=SQRT(A*A+B*B)
W1=I1*I2*RI*3.
W2=I2*I2*RI*3.
BPM=NSYCH*(1.-S/100.)
FW=PF*W1*(PF/NSTAP)**C
PIN=V1*I1*PF*3.
IF (S.LT.99.9) GO TO 53
T=1847E+4/S)*W2/NSYCH
G0 TO 60

50 T=(HP/PPM)*6.34E4
RETURN
END

SUBROUTINE MAGNET
COMMON /MAG/ BST,BSY,BRT,BRY,ATST,ATSY,ATR,ATRY,ASYKE,ASTOTH,ARY
10E,ARTOTH,LSYKE,LSYKE,LRTOT,DRST,FTOTAL,FPOL,PST,KSAT,AI,ATAG,ATTOT,
DIMENSION AI(60)
REAL LSYKE,LSYKE
BST=0
BSY=0
BRT=0
BRY=0
ATST=0
ATSY=0
ATR=0
ATRY=0
ATTOT=0
KSA=10

C C STATOR TOOTH
C BST=FTOTAL/ASTOTH
NA=1
K=1
X=BST
GO TO 90
ATST=AT*DSS
C C STATOR YOKE
C
SUBROUTINE SLOTS (SLTLOC, XSTYPE, WSX, WSX1, WSX2, WSX3, WSX4, WSX5, DSX, D 1
                                11X, DX2, DX3, DX4, DX5, XTWDTH, CARFA, SAREA, N, DEX, WSX6, DIA, RX, AX, AXX, YTMAC  D 2
                                2, PHIX)  D 3
C FOR STATOR SLOTS SLTLOC=1.0 * FOR ROTOR SLOTS SLTLOC=-1.0  
C REAL N, KX  
C INTEGER XSTYPE  
C D(W, CARFA) = ((-WA + SQRT(WA*WA - 4.*CARFA*PANPHI))/2.*PANPHI))  D 11
  D(WA) = WA + 2.*D*TANPHI  D 12
  A(W) = 0.25*SIN(((1.5708*PHIX)/COSPHI*COSPHI) + PANPHI)  D 13
C IF (CARFA + DSX + DX1.LT.1.0E-15) GO TO 310  D 14
  A1 = 0.25*KX*(1.0/12.0)  D 15
  A2 = 0.25*(KX-0.66667)  D 16
C GO TO (10, 20, 30, 40, 50, 60, 70)  D 17
C D3X = 0.  D 18
D4X = 0.  D 19
A XX = 0.  D 20
GO TO 40  D 21
20  WSXA=WSX
    WSX=0.
    WSX=0.
    D3X=0.
    DX=0.
    AXX=0.
    GO TO 100

30  AXX=KK*(D4X/WSX+1*(D3X/(WSX-WSX)))*(ALOG(WSX/WSX1))
40  WSX=0.
    WSX=0.
    WSX=WSX
    WSX=WSX
    WSX=(WSX)
    XTWDTH=0.
    IF (DSX.GT.1.0E-15) GO TO 50
    IF (DIX.LT.1.0E-15) GO TO 60
    D4X=D1X*DSX+D3X*D2X*D4X
    GO TO 80
50  IF (DIX.LT.1.0E-15) GO TO 70
    GO TO 80
60  D4X=CARFA/(WSX-2.*WSX6)+DSX*DSX+DSX*DSX
70  DIX=DSX=(D4X+D3X+D2X+D1X)
80  SAREA=WSX*DSX*D4X+0.5*(WSX1+WSX)*DIX+WSX*D4X
    IF (CARFA.LT.1.0E-15) CARFA=(WSX-2.*WSX6)*(D1X-DSX)
    AXX=AXX*(D1X*DSX+KX*DSX)/WSX
    XTWDAG=((DIA+0.6667*SLTLOC+DSX)*((1.1416/N)))-WSX
    GO TO 300

C
90  WSXA=WSX
    WSX=0.
100 IF (WSYA.GT.1.0E-15) GO TO 110
    IF (XTWDTH.LT.1.0E-15) GO TO 110
    WSX=(3.1416*(DSX+DSX)+0.5*(WSX1+WSX)*DIX+WSX1*D4X
110  PHIX=(3.1416927/N)*SLTLOC
    GO TO 140
120  XTWDTH=((3.1416*(DIA+2.*SLTLOC*DSX))/N)-WSX
    GO TO 110
130  IF (ABS(PHIX)<LT.1.0E-15) GO TO 120
    PHIX=(ABS(PHIX<0.01745)))*SLTLOC
    XTWDTH=0.
140  IF (XSTYPE.LT.1) GO TO 150
    WSX=WSX
    AXX=AXX*(D4X/WSX1+D3X/(WSX-WSX))/ALOG(WSXA/WSX1))
    GO TO 160
150  WSX=WSX
160  TANPHI=TAN(PHIX)
    COSPHI=COS(PHIX)
    SINPHI=SIN(PHIX)
    WSX=W*WSX
    IF (DXY.GT.1.0E-15) GO TO 170
    IF (DIX.LT.1.0E-15) GO TO 190
    Y1=W*WSX2+CARFA/2.
    WSX=W*WSX1+10*WSX2
170  IF (XSTYPE.GT.2.0) GO TO 260
    Y2=V*WSX6+CARFA/2.
    D4X=D4X*D1X+D3X*D2X+D4X
    GO TO 180
180  IF (DIX.LT.1.0E-15) GO TO 200
190  D4X=D4X*D3X+D2X+D1X
    GO TO 200
200  IF (DXY.EQ.0) GO TO 280
    WSX=MR(D2X+D1X,WSX)
    WSX=W*DSX-DSX+DSX+WSX
    SAREA=0+((WSX-AK1+350*WSX1)*((DSXY-X4-Y4/(DSXY+4))+(DSXY+3)*DSX/DSY)
    AXX=AXX*(((2.*KX*D2X/WSX)+WSX)*Y4)+((1.1416/N)+Y5)
    GO TO 300

C
210  WSX=0
SUBROUTINE WDGFC1 (PBA, P, QS, DF, PC, PF, WDGPCH)

C PITCH FACTOR CALCULATION

C

C YY=FLOAT(IFIX((QS/P)^WDGPCH)+0.01))

C IF (ABS (YY-QS/P*WDGPCH).LT.0.001) WRITE (6,10)

C (DSX,GT.1.0E-15) GO TO 240

C (D1X,LT.1.0E-15) GO TO 220

C DSX=D1X+2.*D6X+D4X

C GO TO 250

C IF (ABS (D1X+D4X+D6X-DX).LT.0.001) GO TO 310

C DSX=(SORT(4.*CAREA/3.1416)+D6X+2.*D6X)

C DSX=DSX-2.*D6X-D4X

C IF (DSX.LT.1.OE-15) GO TO 230

C IF (ABS (2.+(AR+PS)/CAREA).LT.0.301) GO TO 320

C DSX=DSX-2.*D6X-D4X-D3X-D2X

C IF (ABS (DSX-2.*D6X-D4X-D3X-D2X).LT.0.001) GO TO 340

C IF (ABS (2.+(AR+PS)/CAREA).GT.1.0E-15) GO TO 300

C WRITE (6,320)

C FORMAT (2HK,41HINSUFFICIENT OR INCORRECT Rotor Slot Data)

C FORMAT (2HK,42HINSUFFICIENT OR INCORRECT Stator Slot DATA)

C END

SUBROUTINE WDGFCT (PBA, P, QS, DF, PC, PF, WDGPCH)
SUBROUTINE CMRNTN (QS, NB, P)

REAL NB
DIMENSION L(100)

X=1.0E-15
K=0
F=NB
D=ABS(QS-P)
M=1
DO 20 I=1,1000
A=3.*FLOAT(I)*P
IF (ABS(D-A).LT.X) GO TO 40
IF (A.GT.D) GO TO 30

FORMAT (1HK,F5.3,22H PITCH IS NOT POSSIBLE)
PF=SIN(Y*1.571/(QS/P))

C DISTRIBUTION FACTOR CALCULATIONS
IPX=IFIX(P+0.1)
IQQ=IFIX(QS+0.1)
IC=IFIX(PC+0.1)
PN=3.
QN=QS/(3.*P)

C CHECK IF WINDING HAS INTEGRAL NO. OF SLOTS PER POLE PER PHASE
D=1.0
IF (PBA.GT.61.0) D=2.0
IZY=IPX*IPN
IDM=0
IF (IIQ-IDM) 40, 30, 20

C CALCULATE DISTRIBUTION FACTOR FOR INTEGRAL SLOT WINDING
DP=SIN(1.571*D/PN)/(QN*D*SIN (1.571/(PN*QN)))
GO TO 90

C REDUCE THE FRACTION IIQ/IZY TO LOWEST TERMS
I=2
IF ((IZY/I) I.EQ.IZY) GO TO 60
IF (I.GT.IZY) GO TO 70
IZY=IZY/I
IIQ=IIQ/I
GO TO 50

C CALCULATE DISTRIBUTION FACTOR FOR FRACTIONAL SLOT WINDING
FNQ=IIQ
DP=SIN(1.571*D/PN)/(FNQ*D*SIN (1.571/(FNQ*PN)))
IF ((IZY/FNQ)*FNQ.IZY) WRITE (6,80)
IF ((IPX/FNQ)*FNQ.IPY) WRITE (6,80)

FORMAT (1HK,40H INTINONAL-SLOT WINDING IS USED)

C CHECK IF SPECIFIED NUMBER OF PARALLEL CIRCUITS ARE POSSIBLE
IF ((IPX/IC)*IC.EQ.IPX) GO TO 110
WRITE (6,100) IC
FORMAT (1HK,I2,35H PARALLEL CIRCUITS ARE NOT POSSIBLE)
RETURN
END
CONTINUE

IF (ABS(D-P).LT.X) GO TO 40
IF (ABS(P-FLOAT(IFIX(F/P+0.0001))).LT.X) GO TO 40
M=2
IF (F.GT.QS+P/2.) GO TO 40
M=3
IF (ABS(D-P/2.).LT.X) GO TO 40
IF (ABS(OS-F).LT.X) GO TO 40
IF (ABS(D-1.).LT.X) GO TO 40
IF (ABS(D-2.).LT.X) GO TO 40
IF (ABS(D-P-1.).LT.X) GO TO 40
IF (ABS(D-P-2.).LT.X) GO TO 40
IF (ABS(D-P-2.).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
F=FLOAT(IFIX(0.60*QS))
II=0
GO TO (50,70,90),1
F=(P/2.)/(P/2.+QS)
WRITE (6,80) FF
FORMAT (1H,19HMINIMIZE BY SKEWING,F6.3,30H TIMES ROTOR CIRCUMFERENCE)
GO TO 110
WRITE (6,100) F1
Format (1H,2H,19H,52H NUMBER OF ROTOR SLOTS TO ONE OF THE FOLLOWING)
GO TO 150
WRITE (6,140) F1
Format (1H,2H,29H NUMBER OF STATOR SLOTS)
RETURN
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 USE DATA FOR xx.xxx LAMINATIONS</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. (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>
<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>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, DlS, and SCAREA are all less than 1.0E-15 at the time subroutine SLOTS is called to compute stator slot dimensions. In general, this implies one of the following: CSS is zero or negative, ASTRND is zero or negative, AWG is not between 1 and 40 inclusive, STRNDS is zero or negative. (2) For slot type 6 only: see error message 8.</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>
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<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
ASTRND cross-sectional area of stator strand, in.²
ASYOKE cross-sectional area of stator yoke (used in magnetic calculations), in.²
ATAG ampere-turns across airgap, ampere-turns
ATRT ampere-turns across rotor tooth, ampere-turns
ATRY ampere-turns across rotor yoke, ampere-turns
ATST ampere-turns across stator tooth, ampere-turns
ATSY ampere-turns across stator yoke, ampere-turns
ATTOT total ampere-turn drop, ampere-turns
AWG strand size of stator winding (American Wire Gage)
Main Program

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

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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.

**D1R** rotor lamination inside diameter, in.

**DNSTY** array containing density values for various rotor and stator winding material possibilities, lb/in.\(^3\)
### Main Program

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

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### Main Program

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

RSTYPE  rotor slot type

RTRWDG NAMELIST name

RTWDTH  rotor tooth width (if constant), in.

RTWMAG  rotor tooth width used in magnetic calculations, in.

RWMAT  code for rotor winding material: 1 for aluminum; 2 for brass; 3 for copper

S  clearance between armature coils at end turns (ref. 2, p. 309, table 26; and p. 209, fig. 135), in.

SALPHA  sin(ALPHA) (ref. 2, p. 209, fig. 135)

SB  cross-sectional area of rotor bar, in.^2

SCAREA  slot area remaining after subtracting, from total slot area, slot opening and approximate areas occupied by slot liners, separators, wedges, etc. (shaded area in fig. 12), in.^2

SER  end-ring cross-sectional area, in.^2

SFR  rotor lamination stacking factor

SFS  stator lamination stacking factor

SKEW  skew of rotor slots measured along rotor circumference, in.
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, °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 °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, \( ^{\circ} \text{C} \)

TRW temperature of rotor winding, \( ^{\circ} \text{C} \)

TSW temperature of stator winding, \( ^{\circ} \text{C} \)

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, \( \text{VSCSTY} = C_0 + C_1 \times T + C_2 \times T^2 + C_3 \times T^3 + C_4 \times T^4 \), where \( \text{VSCSTY} \) is fluid viscosity in lbm/ft-sec and \( T \) is fluid temperature in \( ^{\circ} \text{C} \); \( C_0 \) 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 \( \text{FCORE} \) and at flux density \( \text{BK} \), W/lb

WDGFCT subroutine name

WEIGHT total electromagnetic weight, lb

WFE core loss for stator laminations at frequency \( \text{F} \) and at flux density \( \text{BK} \), 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
WSYOK   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
XLEGND  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 cal- culated; 0. if X0 was read in
XY   index used during no-load magnetic calculations: 1.0 if R0 is to be cal- culated; 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 pro- gram.

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

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

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

**NA**  subscript

**K**  index

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

**XX**  slope of magnetization curve at flux density **X**

**Y**  used in interpolation procedure for **AT**

Subroutine SLOTS

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

**A**  arithmetic function

**A1**  constant used in slot permeance ratio calculations

**A2**  constant used in slot permeance ratio calculations

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

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

**AXX**  slot leakage permeance ratio

**CAREA**  slot area remaining after subtracting slot opening, slot liners, separator, etc., in.$^2$

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

**COSPHI**  cos (phi)

**D**  arithmetic function

**D1X**  slot dimension, in.

**D2X**  slot dimension, in.

**D3X**  slot dimension, in.
Subroutine SLOTS

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

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

Subroutine WDGFCT

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

D constant: 1.0 for windings with phase belt less than $60^\circ$; 2.0 for windings with phase belt greater than $60^\circ$
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 \[3 \times \text{FLOAT}(I) \times P, \text{where } I = 1, 2, 3, \ldots, 1000\]
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 (L is an integer variable)
M an indicator showing seriousness of an undesirable slot combination (M = 1 is most serious; M = 3 is least serious)
NB number of rotor slots
P number of poles
QS number of stator slots
X constant (1.0E-15)
REFERENCES


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

Figure 2. - Simplified flow chart of induction motor computer program.
Figure 3. Equivalent circuit of induction motor showing FORTRAN symbols used by main program. (S is rotor slip in percent.)
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
W0 = (WSYOE + WSTOT)/WF*3.0
RO = 5. *V1^2/W0
S = 0.

Call CIRCT to compute V2 and IMAG

Calculate total flux and flux per pole as follows:
P = V2
F TOTAL = 1.4141*P*KPS*KDS
FPOLE = 0.637*F 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 RO:
W0 = 3. * [WSYOE*(BSY/KB)^2 + WSTOT*(BST/KB)^2] / WF
RO = (3. *V2^2/W0)

Has RO converged?

No

Has X0 converged?

No

End of no-load magnetic calculations

Yes

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

- $T_{REF} = 25$
- $V_{SCREF} = 0$
- $P_{REF} = 0$
- $RPM_{REF} = 0$
- $GAP_{REF} = 0$
- $L_{REF} = 0$
- $DIAREF = 0$
- $WL = 0$

CO = 0, C1 = 0, C2 = 0, C3 = 0, C4 = 0

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

$V_{SCREF} > 1.0 \times 10^{-15}$

$V_{SCREF} = CO + C1 \times TREF + C2 \times TREF^2 + C3 \times TREF^3 + C4 \times TREF^4$

The statements below this line are executed once for each motor design

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

700

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

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

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

Figure 6. - Concluded.
Second data set

First data set

Motor design deck

Stator material deck

Rotor design deck

Stator material deck

One or more winnige data cards

Two material data decks

Any number of motor design data decks

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

These cards may be omitted for rotor material

$FELOSS LAST = .TRUE.

$FELOSS

$FELOSS

$FELOSS

H_{12} H_{13} H_{14} B_{15} B_{16}

H_{17} B_{18} B_{19} B_{20} B_{21}

R_{MAX} B_{1} B_{2} B_{3} B_{4} B_{5}

Material deck identification card

Figure 8. - Material deck setup.

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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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