THE COLLEGE OF EARTH AND MINERAL SCIENCES

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MINE ELECTRICAL SYSTEMS EVALUATION - MODEL COAL MINE ELECTRICAL SYSTEM SPECIFICATIONS

Lloyd A. Morley, Jeffery L. Kohler

DEPARTMENT OF MINERAL ENGINEERING
THE PENNSYLVANIA STATE UNIVERSITY

USBM GRANT FINAL REPORT (Grant No. GO-133077)

November 11, 1974

DEPARTMENT OF THE INTERIOR
BUREAU OF MINES
WASHINGTON, D. C.

THE PENNSYLVANIA STATE UNIVERSITY

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"The views and conclusions in this document are those of the authors and should not be interpreted as necessarily representing the official policies of the Interior Department's Bureau of Mines or the U.S. Government."

CERTIFICATION OF THE ABSENCE OF PATENTS AND INVENTIONS

This statement certifies that at the grant report date, no inventions have been developed from Grant GO-133077. Consequently, no patents are pending.

Lloyd A. Morley, Project Director

FOREWARD

This report was prepared by The Pennsylvania State University, College of Earth and Mineral Sciences, Department of Mineral Engineering, University Park, Pennsylvania, under USBM Grant No. GO-133077. The grant was initiated under the Coal Mine Health and Safety Research Program. It was administered under the technical direction of the Pittsburgh Mining and Safety Research Center with Mr. G. J. Conroy acting as the technical project officer. Mr. J. A. Herickes was the grant administrator for the Bureau of Mines.

This report is a summary of the work recently completed as part of this grant during the period 19 June, 1974 to 15 October, 1974. This report was submitted by the authors on 11 November, 1974.

This technical report has been reviewed and approved.

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INTRODUCTION

Previous research conducted for the USBM by Penn State personnel (Grant GO-101729) found that a need existed to physically model a typical a-c/d-c coal mine section electrical system. Its purpose would be to permit preliminary evaluations of electrical problem solutions prior to launching full-scale investigations. Such use can result in greater flexibility than afforded by present computer models. Furthermore, numerous problems, which would be virtually impossible to incorporate in a computer model at this time, are more easily analyzed with physical simulation. The development of this system is now proceeding at the USBM's Bruceton Research Facilities. However, electrical specifications of scaled down components for its construction are required. This project is a result of that need and has been funded as an extension to Grant GO-133077. The following report covers these specifications.

Scope of Work

To represent a mixed a-c/d-c coal mine section, the typical component specifications must detail at least:

a. one a-c continuous miner,
b. two a-c or d-c shuttle cars,
c. one a-c or d-c roof bolter,
d. one a-c section fan, and
e. feeder cables.

Further, each machine should be portrayed by each of its general operational modes which can be tersely described as:

- a. for the continuous miner,
    1. starting hydraulic pump motor,
    2. starting cutting motors,
    3. starting conveyor motor,
    4. idling any or all motors,
    5. cutting and loading,
    6. tramming,
    7. maneuvering,
    8. loading with cutters off;
- b. for the shuttle cars,
    1. loading,
    2. unloading,
    3. tramming empty,
    4. tramming loaded;
- c. for the roof bolter,
    1. idling motor,
    2. maneuvering,
    3. installing bolt,
    4. torquing bolt; and
- d. for the fan,
    1. starting,
    2. running.

Input power limitations have been set by the USBM as a total a-c (input) of 45kVA at 440 V, three phase, 60Hz with a total d-c power (derived from the a-c input) of 30kW at either 300 Vdc or 600Vdc.

In the succeeding chapters, the derivation of the model is first covered. After an analysis is provided to ascertain valid model use, applications then specifications conclude the report.

MODEL DEVELOPMENT

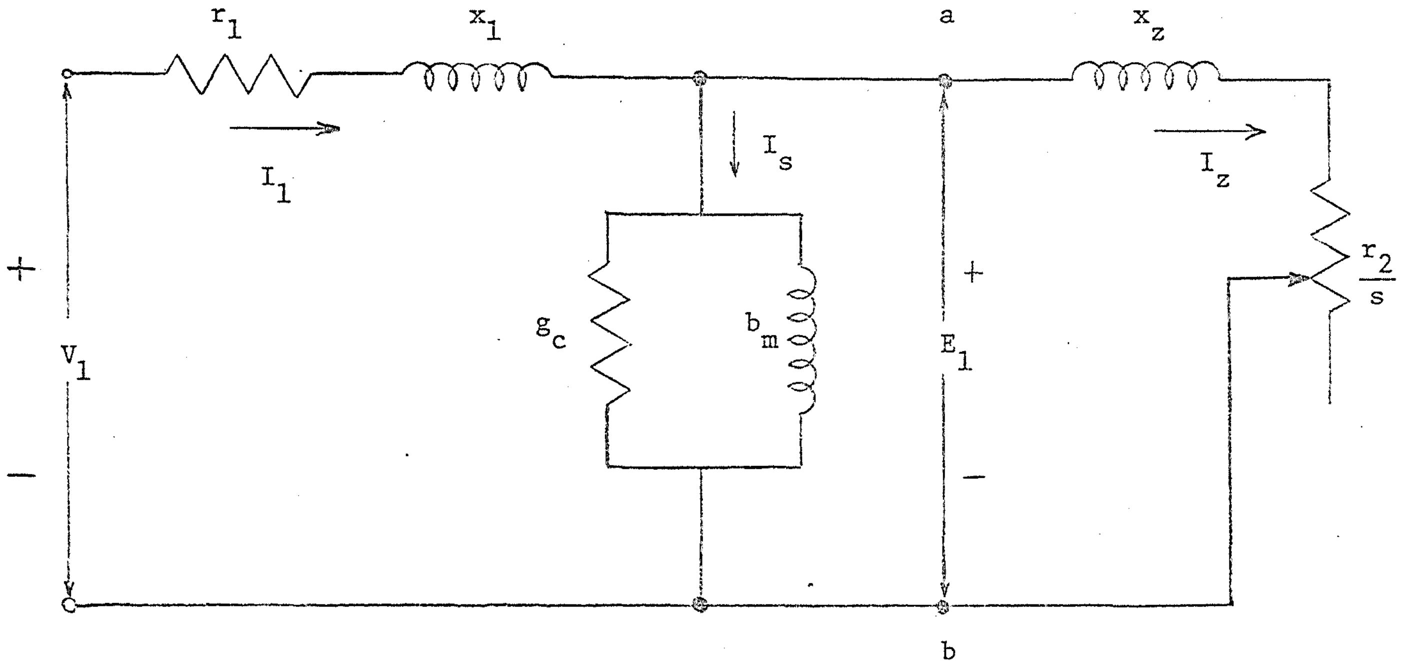
INTRODUCTION

Developing any mathematical representation of a physical process usually involves compromises. These may be to simplify mathematics or to attain an equivalent of a system which is not yet fully understood. Precise and explicit quantification of all model changes is imperative during both development and application. This insures more meaningful and valid results.

A mathematical model is used to obtain the specifications for the physical model. Resistors, inductors, capacitors, and active sources are an obvious choice for system components, but their selection is restricted by both economics and engineering feasibility. These limitations necessitate further simplifications in the working model.

EQUIVALENT CIRCUIT DEVELOPMENT

The model of a particular machine in a given operational mode is essentially the equivalent circuit of polyphase induction motors performing in that mode with all the circuit parameters defined. One phase of an equivalent circuit for a polyphase induction machine is shown in Figure 1. The core loss conductance (g_c) and the magnetizing susceptance (b_m) of the parallel shunt are analagous to transformer exciting impedance. However, unlike the transformer where this impedance can usually be neglected, the shunt current (I_s) can account for 30 to 50 percent of I_1 at normal operating conditions. The quantity r_2/s relates converted mechanical power at the motor shaft to rotor circuit copper losses due to resistance (r_2) at a specified per unit slip(s).



The circuit to the left of ab is the stator equivalent circuit and the circuit to the right, the rotor equivalent circuit.

r_1 = effective stator resistance

x_2 = effective rotor reactance referred to the stator

s = slip

b_m = magnetizing suseptance

x_1 = effective stator reactance

r_2 = effective rotor resistance referred to the stator

g_c = core loss conductance

s = per unit slip

Figure 1. Equivalent Circuit for a Polyphase Induction Motor.

As the load-torque requirements change, the motor characteristics can be calculated. Among others, variations of current, speed, voltage, power factor, losses, and starting torque are easily determined. Consequently, Figure 1 appears ideal for this application. However, it is extremely difficult to obtain internal impedance values for polyphase induction motors utilized by some mining machines. Similarly, torque-slip curves are sometimes not available. In addition, it is usually not possible to study only one motor at a time, as several motors might be operating during one particular mode of operation (for example, during continuous miner cutting and loading).

The normal machine power parameters (current, voltage, and power factor, recorded while time-studying) can provide sufficient data to construct the desired models. The power parameters of several machines have been recorded by this organization under USBM Grants GO-101729 and GO-133077. (1,4) General system connections used are illustrated in Figure 2.

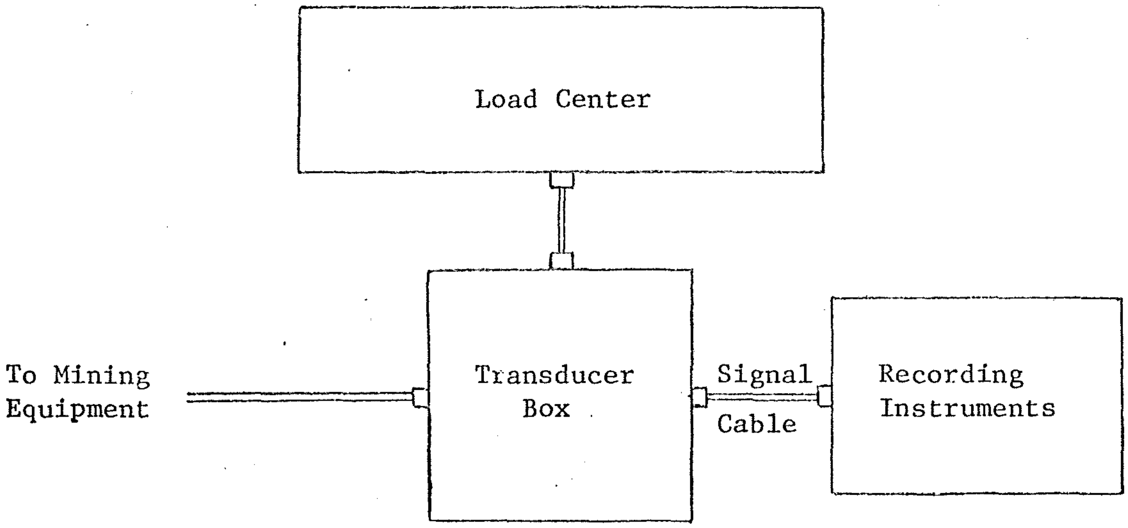


Figure 2. Monitoring Connections

Correlation of the time-study data and the power parameter recordings results in a "black box" representing the machine during a particular operation as illustrated by Figure 3a. From the known terminal characteristics, the equivalent impedance inside the box can be calculated. This circuit, as shown in Figure 3b, contains the passive elements of resistance, inductance, and capacitance.

EQUIVALENT CIRCUIT CALCULATION

Solving the equivalent circuit in terms of known input parameters is easily accomplished using basic circuit analysis which is outlined here in terms of Figure 3b. By definition,

$$Z = R + jX \tag{1}$$

where

Z = complex impedance,

R = resistance,

X = reactance.

$$X = X_1 - X_c \tag{2}$$

where

X_1 = inductive reactance,

X_c = capacitive reactance.

$$P = VI \cos \phi \tag{3}$$

where

P = real power,

V = terminal voltage,

I = terminal phase current,

ϕ = angle between the voltage and current phasor,

$\cos \phi$ = power factor (P.F.)

$$Q = VI \sin \phi \tag{4}$$

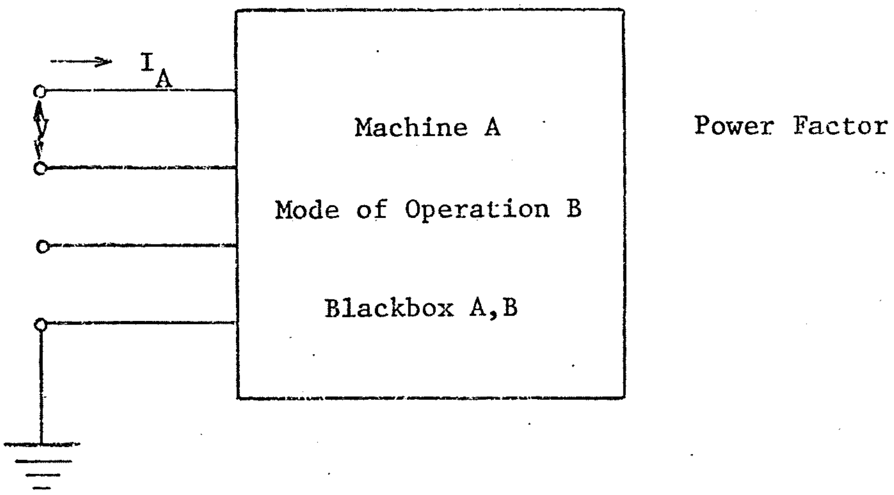


Figure 3a. Model Terminal Characteristics.

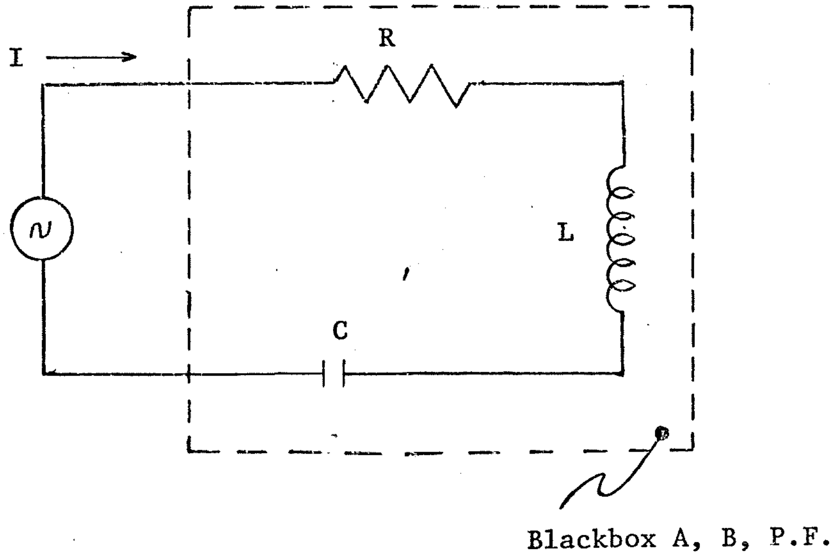


Figure 3b. Equivalent Circuit Line Diagram.

where

Q = reactive power.

$$S = P + jQ \tag{5}$$

where

S = complex power.

Finally,

$$S = I^2 Z \tag{6}$$

By substituting equations (3) and (4) into equation (5) and equation (1) into equation (6), then equating (5) and (6),

$$I^2 (R + jX) = VI \cos \phi + jVI \sin \phi. \tag{7}$$

Equating the real and imaginary parts of equation (7), equation (8) and (9) respectively follow:

$$I^2 R = VI \cos \phi. \tag{8}$$

and

$$I^2 X = VI \sin \phi \tag{9}$$

Solving equation (8) for R_1,

$$R = \frac{V}{I} \cos \phi = \frac{V}{I} PF. \tag{10}$$

Solving equation (9) for X,

$$X = \frac{V}{I} \sin \phi. \tag{11}$$

Since the black box has a lagging current, the capacitor can be replaced by a short circuit, then

$$X = X_1 \tag{12}$$

and

$$X_1 = WL = 2\pi fL \tag{13}$$

where

W = angular frequency,

f = forced frequency.

Substituting equation (13) into (11) and solving for L,

$$L = \frac{V}{IW} \sin \phi = \frac{V}{WI} \sqrt{1 - PF^2} \tag{14}$$

Therefore, the equivalent circuit of Figure 3b can be defined in terms of the measured terminal parameters. However, circuit capacitance is dropped (since X_1 is much greater than X_c), but a value can be calculated as a function of the inductance. This is presented here for completeness:

$$X_c = 1/WC, \tag{15}$$

resulting in

$$X_1 - X_c = \frac{V}{I} \sin \phi \tag{16}$$

and

$$WL - \frac{1}{WC} = \frac{V}{I} \sin \phi \tag{17}$$

Solving for C as a function of L,

$$C = \frac{I}{IW^2L - WV \sin \phi} \tag{18}$$

If $L = \frac{V}{WI} \sin \phi$, the capacitance will be infinite (i.e., the capacitor is replaced by a short circuit). Consequently, to include capacitance C in the model, the denominator of equation (18) must be greater than zero or

$$IW^2L > WV \sin \phi \tag{19}$$

and

$$L = \frac{kV}{WI} \sin \phi. \tag{20}$$

where

k > 1 and chosen to restrict the value of C to a given range.

Based on the measured normal power parameters, the model is now defined by the RLC series circuit, where

$$R = \frac{V}{I} PF, \tag{21}$$

$$L = \frac{kV}{IW} \sqrt{1 - PF^2} \qquad (22)$$

$$C = \frac{I}{IW^2L - WV \sqrt{1 - PF^2}} \qquad (23)$$

As stated previously when k = 1, the model reduces to an RL series circuit for the polyphase induction motor.

ANALYSIS OF THE EQUIVALENT CIRCUIT

The circuit defined by equations (21), (22), and (23) represents the equivalent impedance of the circuit shown in Figure 1. In other words, if the measured utilization voltage is applied to either model (Figure 1 or 3b), similar results would occur. However, the physical model is required to have an impressed voltage of 440 Vac which can differ from the original machine voltage. Additionally, to arrive at practical model components, other power parameters might require scaling from the original values used for deriving the model. Such changes will not affect the validity of the polyphase induction motor equivalent circuit presented in Figure 1 but may significantly alter results if Figure 3b is used. With the foregoing as input, the next task is to determine when the model will yield valid and meaningful results.

The parallel shunt of Figure 1 is most affected by changes in the terminal voltage (V). Since the current flowing through the shunt accounts for 35 to 50 percent of the terminal current, significant errors can be introduced by combining it with the rotor and stator impedances then computing an equivalent impedance as was done for Figure 3b.

If the machine utilization voltage is not above ten percent of the rated voltage, it can be assumed that the motor is not magnetically saturated. In this case the model will be valid over a range of voltages below actual utilization. This is due to the linearity of the exciting current with voltage until saturation is approached. These conditions are satisfied for all the component specifications given later in the report.

The stator and rotor impedances do not present any significant problems when lumped together with the exception of r_2/s. Again, this quantity relates the converted mechanical power at the shaft to rotor circuit copper losses for a given per unit slip. It will not change linearly with impressed voltage, but the variance will not significantly modify the results.

SUMMARY

As has been shown, the model can consist basically of the equivalent resistance and reactance of the motors utilized in each operation mode. It has been developed by considering the mining machine as a "black box" with given terminal characteristics then calculating an equivalent impedance. Although the process results in a simplification of the general equivalent circuit for a polyphase induction motor, the facsimile provides accurate and meaningful results when its use is restricted to the areas previously discussed.

CONSTRUCTION AND APPLICATION

Appendix I contains the specifications for the model components. It may be difficult in some cases to purchase the actual values listed and, if a different value is necessary, errors can be introduced. Furthermore, considering that all components have tolerances, more deviation can be added to the model. To aid in the economical component selection to match these specifications, the following equations are derived to compute the total error.

The total differential change in current to a differential change in resistance, inductance, and capacitance (dR, dL, and dC) can be determined by:

$$dI = \frac{\partial I}{\partial R} dR + \frac{\partial I}{\partial L} dL + \frac{\partial I}{\partial C} dC \qquad (23)$$

The current in the equivalent circuit is

$$I = \frac{V}{Z} = V(R^2 + W^2L^2 + W^{-2}C^{-2} - 2LC^{-1})^{-1/2} \qquad (24)$$

Therefore, the partial differentials of current with respect to each circuit component is

$$\frac{\partial I}{\partial R} = -\frac{1}{2}V(R^2 + W^2L^2 + W^{-2}C^{-2} - 2LC^{-1})^{-3/2}(2R)$$

$$\frac{\partial I}{\partial R} = -VR\,(R^2 + W^2L^2 + W^{-2}C^{-2} - 2LC^{-1})^{-3/2} \qquad (25)$$

$$\frac{\partial I}{\partial L} = -\frac{1}{2}\,V\,(R^2 + W^2L^2 + W^{-2}C^{-2} - 2LC^{-1})^{-3/2}(2W^2L - 2C^{-1})$$

$$\frac{\partial I}{\partial L} = -V\,(W^2L - C^{-1})\,(R^2 + W^2L^2 + W^{-2}C^{-2} - 2LC^{-1})^{-3/2} \qquad (26)$$

$$\frac{\partial I}{\partial C} = -\frac{1}{2}\,V\,(R^2 + W^2L^2 + W^{-2}C^{-2} - 2LC^{-1})^{-3/2}(-2W^{-2}C^{-3} + 2LC^{-2})$$

$$\frac{\partial I}{\partial C} = +V\,(W^{-2}C^{-3} - LC^{-2})\,(R^2 + W^2L^2 + W^{-2}C^{-2} - 2LC^{-1})^{-3/2} \qquad (27)$$

Substituting equations (25), (26), and (27) into (23) yields

$$\begin{aligned} dI = \frac{-VRdR}{(R^2 + W^2L^2 + W^{-2}C^{-2} - 2LC^{-1})^{3/2}} - \frac{V(W^2L-C^{-1})\ dL}{(R^2 + W^2L^2 + W^{-2}C^{-2} - 2LC^{-1})^{3/2}} \\ + \frac{V(W^{-2}C^{-3} - LC^{-2})\ dC}{(R^2 + W^2L^2 + W^{-2}C^{-2} - 2LC^{-1})^{3/2}} \qquad (28) \end{aligned}$$

Simplifying equation (28) and replacing the differentials with finite differences,

$$\begin{aligned} \Delta I = \frac{V}{(R^2 + W^2L^2 + W^{-2}C^{-2} - 2LC^{-1})^{3/2}} \Big\{ -R\Delta R - (W^2L-C^{-1})\ \Delta L \\ + (W^{-2}C^{-3} - LC^{-2})\ C \Big\} \qquad (29) \end{aligned}$$

where

ΔI = change in current due to a change in resistance, inductance, and capacitance.

In equation (29), ΔR, ΔL, and ΔC consist of two parts each. One is the component deviation from the model specifications, and the other is the tolerance (or deviation) of the chosen component value. The amount of error for the first is restricted by the components commercially available with the second error restricted by the cost of components with nominal tolerances. If the capacitor is not included, equation (29) reduces to:

$$I = \frac{V}{(R^2 + W^2L^2)^{3/2}} \left\{ -R\Delta R - W^2L\Delta L \right\} \qquad (30)$$

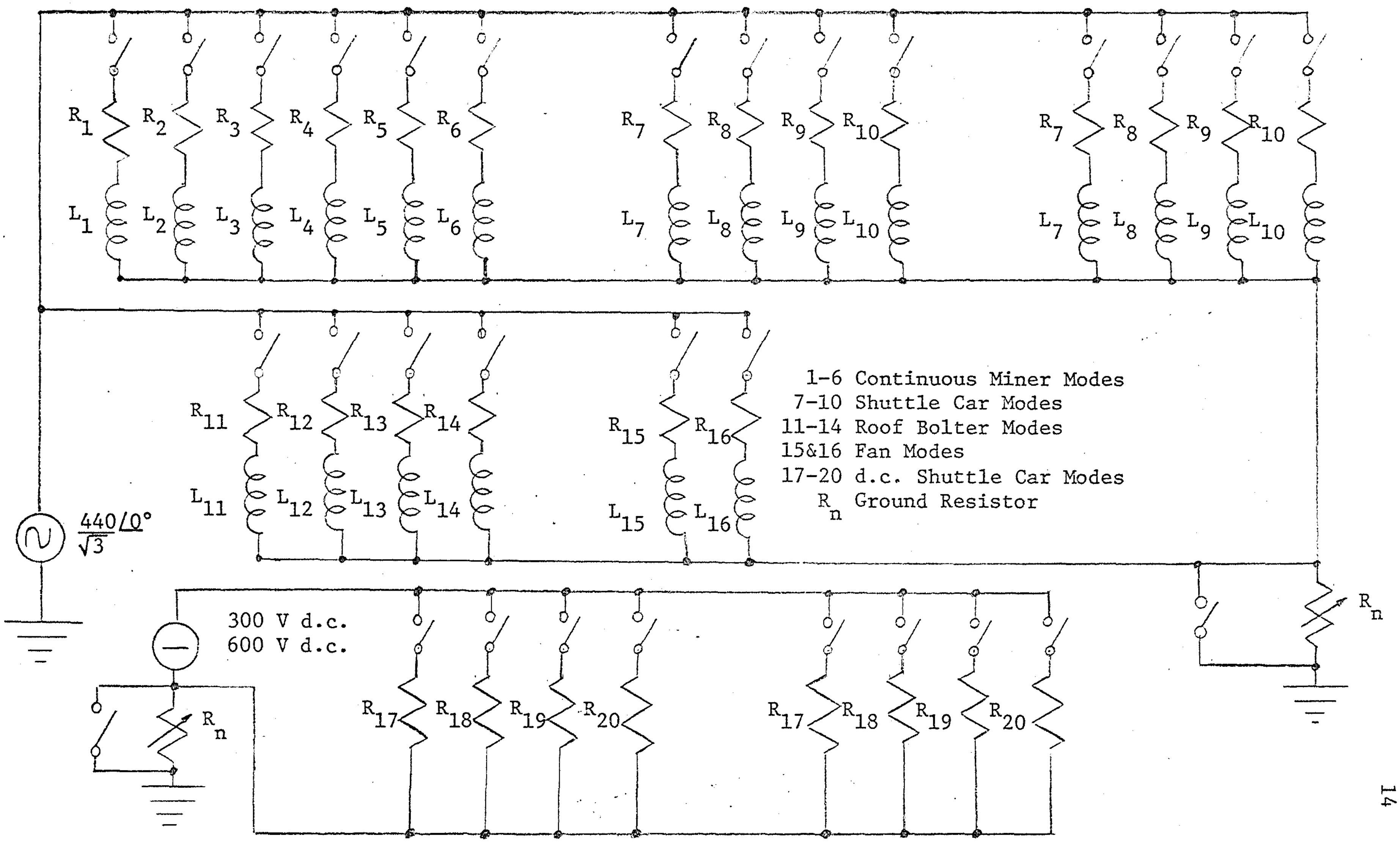


Figure 4 - Model Schematic

MODEL APPLICATION

Attention has been given to the model validity but primarily with respect to the equivalent circuit. As mentioned before, the model's applicability to any given situation, must be carefully examined. Various cases could be considered where the model could be correctly applied with an equal number where it would be useless. Such a compilation would be voluminous. However, a brief discussion of what the model is really simulating is necessary.

The loading of each motor basically determines its terminal characteristics. This loading (the consumed power compared with the motor's rated power) is affected by four principle factors:

1. mechanical,
2. geological,
3. geometrical, and
4. operational.

The mechanical factor includes the condition of the motors and the condition of the machine. Geological factors cover (to name a few) the hardness of the coal, the extent of inclusions, and the floor conditions. The angle of inclination which the shuttle cars must traverse as well as the width of cut to depth of cut ratio of a continuous miner are examples of geometrical factors. Operational factors primarily include the efficiency and technical skill of the machine operator. (2)

The measured normal power parameters are a function of all four principle factors. Consequently, if a machine were operated in a different seam or by a different operator, its equivalent circuit would probably deviate from the values provided in Appendix I.

This is a particularly critical point for continuous miner cutting motors. There during the project, a study of this area was initiated. The goal was to correlate loading (hence the power parameters) with the principle factors.

In the past, there have been a few attempts to relate power to the principle factors. Cree in 1956 (3) determined qualitative relationships between power consumption and the cuttability of coals. Kahlon in 1960 (4) applied statistical analysis to the problem of relating geometrical aspects to power consumption per unit of coal. Barrett (5) along with Kahlon (4) identified differences of consumed power with sumping and shearing. Stefanko and Morley (6) quantified this, thereby suggesting a relation between cutting action and rate of generation of loose coal. Round (7) noted differences in cuttability of coal depending on the direction of cut with respect to the cleavage planes of the coal. This was also quantified by Stefanko and Morley in terms of power.

The brief literature search has indicated three things.

1. The relationships developed consider power, not the power parameters.
2. The relationships often consider production or power consumed per unit of coal.
3. The statistical analysis applied is often of questionable value.

Except for the work of Stefanko and Morley, there is no applicable literature. Warner (8) studied the energy requirements for cutting different coals. He developed a "J" factor which is recorded for various rocks, minerals, and coals. Warner's work would be quite valuable here if cutting energy could be easily related to motor terminal characteristics. Bower (9) determined that shale is approximately five times more difficult to cut than coal, but this is also meaningless unless power parameters can be related to cutting ability.

Wilson (2) used regression analysis to determine the influence of the principle factors on rate of production. Power was included as an independent variable in the regression equation. His model explained less than 60 percent of the variance and incorporated a few very dubious assumptions. It was, however, a good approach to the problem.

One mining machine manufacturer has provided numerous test reports which deal primarily with motor performance under various conditions. This data was studied, and attempts were made to correlate power parameters to the principle factors. In all cases there were insufficient data sets to draw conclusions.

Bureau of Mines personnel expressed the need to relate the primary factors to the power parameters so the model could be applied to any mine rather than being restricted to the principle factor conditions inherent in the developed model. The best way to do this (in other words to assure a sufficiently general and valid model) is to record the principle factors along with the normal power parameters. Regression analysis of these data would result in definite relations between the power parameters and the principle factors. Then, the equivalent circuit for each machine and operational mode would include one extra component, the variable resistor r_2/s of Figure 1.

CONCLUSIONS

The specifications listed in Appendix I were calculated on the IBM 370 computer, using the Fortran program of Appendix II. The model, as developed, is valuable for conducting preliminary investigations and studying mine power systems macroscopically. It will provide valid results. Other areas, such as transient behavior and harmonic generation, must be approached cautiously because the equivalent circuit may not react similarly to the system it models due to the equivalent circuit's frequency dependence. As an alternative, fractional horsepower induction motors could be used as loads in the simulated system. Their use would be more logical for frequency domain studies; however, scaling the results could be a difficult task. Detailed transient investigations are more easily accomplished by computer simulation.

A Bureau of Mines request initiated a study to correlate the principle factors with the normal machine power parameters. Although the area is not covered in the grant proposal, considerable effort has been extended, and two conclusions are available.

1. A correlation is imperative to develop a flexible model. All development effort is easily justified when greatly increased applications in coal mine health and safety research are considered.
2. A lack of sufficient data prohibits the model development. Sufficient data for the correlation could be obtained if the following variables were recorded in addition to the normal machine power parameters:
    a. geometrical parameters,

b. geological parameters (for example, Hardgrove grindability index and Proximate Analysis),

c. machine condition, and

d. operator efficiency and skill.

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APPENDIX I

MODEL COAL MINE ELECTRICAL SYSTEM SPECIFICATIONS

Table 1. Alpine F6A Continuous Miner.

OPERATIONAL MODE	RESISTOR	INDUCTOR
Starting Cutting Motors	49Ω, 425 W	0.19073 H, 3.0 A
Cutting and Loading	73Ω, 300 W	0.27781 H, 2.0 A
Tramming	275Ω, 200 W	0.43199 H, 0.8 A

MOTORS

1	Cutting Motor @ 50 h.p.
1	Tramming Motor @ 10 h.p.
2	Conveyor Motor @ 10 h.p.
2	Gathering Motor @ 10 h.p.

Rated Voltage - 440 Vac

Table 2. Joy 8CM Continuous Miner.

OPERATIONAL MODE	RESISTOR	INDUCTOR
Idling Hydraulic Circuit Motors	43Ω, 700 W	0.12272 H, 4.1 A
Cutting and Loading	8Ω, 2500 W	0.03202 H, 18A
Tramming	26Ω, 1050 W	0.08187 H, 6.3 A
Maneuvering	31Ω, 775 W	0.10989 H, 5.0A
Loading, Cutters Off	22Ω, 1075 W	0.07738 H, 7.0A

MOTORS

2	Cutting Motor @ 130 h.p.
1	Pump Motor @ 130 h.p.
1	Loading Motor @ 50 h.p.

Rated Voltage - 440 Vac

Table 3. Joy 10CM Continuous Miner.*

OPERATIONAL MODE	RESISTOR	INDUCTOR
Idling Hydraulic Circuit Motor	38Ω, 275 W	0.23384 H, 2.7 A
Starting Cutting Motors	9Ω, 1600 W	0.04419 H, 13.6 A
Starting Conveyor Motor	16Ω, 1425 W	0.05801 H, 9.4 A
Cutting and Loading	13Ω, 2675 W	0.03198 H, 14.2 A
Tramming	43Ω, 1100 W	0.07283 H, 5.1 A
Maneuvering	36Ω, 950 W	0.09316 H, 5.1 A

MOTORS

2	Cutting Motor @ 100 h.p.
1	Pump Motor @ 100 h.p.
1	Conveyor Motor @ 50 h.p.

Rated Voltage - 440 Vac

*Joy 8CM with cutter head modified to 10 CM.

Table 4. Joy 10CM Continuous Miner.

OPERATIONAL MODE	RESISTOR	INDUCTOR
Idling Hydraulic Circuit Motor	107Ω, 60 W	0.90567 H, 0.8 A
Starting Cutting Motors	32Ω, 600 W	0.13388 H, 4.3 A
Starting Conveyor Motor	25Ω, 475 W	0.14215 H, 4.4 A
Cutting and Loading	25Ω, 550 W	0.13098 H, 4.6 A
Tramming	151Ω, 125 W	0.67479 H, 0.9 A
Maneuvering	150Ω, 125 W	0.68822 H, 0.9 A

MOTORS

2	Cutting Motor @ 175 h.p.
1	Pump Motor @ 135 h.p.
1	Conveyor Motor @ 50 h.p.

Rated Voltage - 950 Vac

Table 5. Joy 18SC Shuttle Car.

OPERATIONAL MODE	RESISTOR	INDUCTOR
Loading	632Ω, 150 W	---
Tramming Loaded	260Ω, 360 W	---
Unloading	578Ω, 175 W	---
Tramming Empty	457Ω, 210 W	---

MOTORS

1 Conveyor Motor @ 10 h.p.
1 Pump Motor @ 15 h.p.
2 Traction Motor @ 15 h.p.

Rated Voltage - 250 Vdc

Table 6. Torkar 48S Shuttle Car.

OPERATIONAL MODE	RESISTOR	INDUCTOR
Loading	146Ω, 425 W	0.12857 H, 1.7 A
Tramming Loaded	39Ω, 350 W	0.20489 H, 3.0 A
Unloading	24Ω, 180 W	0.24686 H, 2.7 A
Tramming Empty	44Ω, 200 W	0.31324 H, 2.1 A

MOTOR

1 60 h.p., with 7 clutch drive torque converter

Rated Voltage - 440 Vac

Table 7. Fletcher LTDO-15 Roof Bolter.

OPERATIONAL MODE	RESISTOR	INDUCTOR
Drilling and Bolting	139Ω, 125 W	0.60672 H, 1.0 A
Tramming	159Ω, 160 W	0.56334 H, 1.0 A

MOTOR

1 40 h.p. motor

Rated Voltage - 440 Vac

Table 8. Galis 300 Roof Bolter.

OPERATIONAL MODE	RESISTOR	INDUCTOR
Idling Motor	94Ω, 160 W	0.48091 H, 1.3 A
Tramming and Maneuvering	103Ω, 210 W	0.40228 H, 1.4 A
Drilling	110Ω, 400 W	0.21169 H, 1.9 A
Bolting	103Ω, 260 W	0.34523 H, 1.6 A

MOTOR

1 40 h.p. motor

Rated Voltage - 440 Vac

Table 9. Galis 320 Roof Bolter.

OPERATIONAL MODE	RESISTOR	INDUCTOR
Idling	85Ω, 125 W	0.53110 H, 1.2 A
Maneuvering	96Ω, 230 W	0.37641 H, 1.5 A
Drilling	97Ω, 260 W	0.33335 H, 1.7 A
Changing Steel	118Ω, 210 W	0.45261 H, 1.3 A
Bolting	85Ω, 125 W	0.53110 H, 1.2 A

MOTOR

1 40 h.p. motor

Rated Voltage - 440 Vac

Table 10. Galis 320A Roof Bolter.

OPERATIONAL MODE	RESISTOR	INDUCTOR
Idling	32Ω, 75 W	0.47021 H, 1.5 A
Tramming	38Ω, 140 W	0.35911 H, 1.9 A
Drilling	38Ω, 270 W	0.24372 H, 2.6 A

MOTOR

1 30 h.p. motor

Rated Voltage - 440 Vac

Table 11. Joy Axivane Fan.

OPERATIONAL MODE	RESISTOR	INDUCTOR
Starting	24Ω, 725 W	.10942 H, 5.5 A
Running	136Ω, 100 W	.8256 H, .8 A

MOTOR

1 25 h.p. motor

Rated Voltage - 460 V

APPENDIX II

COMPUTER PROGRAM FOR COMPUTING THE SPECIFICATIONS

The input parameters as specified by Table 12 are used to compute an equivalent RL or RLC circuit. This program, consisting of two parts, is written in Fortran Watfiv. The first part, consisting of the main program, organizes the data and determines the manner in which it is to be processed. It also formats the output. RLCMOD, the second part, is a subprogram to compute the equivalent circuit from the data supplied by the main program. Control cards are explained with comment cards throughout the program.

MAIN PROGRAM

```
//              'P0245,T=010,R=2500','KOHLER JEFF'
// EXEC FWCG
//SYSIN DD *
      COMMON V,I,PF,FREQ,K
      INTEGER A,B,D
      REAL I,K,L,M,N
C   N IS THE SCALING FACTOR FOR THE MEASURED PHASE CURRENT
      N=20.
C   K IS THE OPTIMIZATION CONSTANT USED WHEN COMPUTING THE INDUCTANCE,L
C   K MUST BE GREATER THAN OR EQUAL TO ONE
C   IF K=1. THE MODEL ASSUMES C=0. AND COMPUTES AN EQUIVALENT RL MODEL
      K=1.
      Y=1.
      WRITE(6,100)
      WRITE(6,110)
```

```
WRITE(6,120)
WRITE(6,130)
WRITE(6,140)
WRITE(6,150)
WRITE(6,160)
WRITE(6,170)
WRITE(6,180)
WRITE(6,190)
WRITE(6,200)
WRITE(6,210)
WRITE(6,220)
WRITE(6,230)
WRITE(6,240)
WRITE(6,250)
WRITE(6,260)
```

```
WRITE(6,270)
WRITE(6,280)
WRITE(6,290)
WRITE(6,300)
WRITE(6,310)
WRITE(6,320)
WRITE(6,330)
WRITE(6,340)
WRITE(6,350)
WRITE(6,360)
WRITE(6,370)
WRITE(6,380)
WRITE(6,15)
DO 5 D=1,45
```

```
C IF L=0.,SUBROUTINE RLCMOD WILL COMPUTE THE INDUCTOR VALUE OF THE EQUIVALENT
C RLC CIRCUIT AND THEN THE CAPACITOR VALUE WILL BE COMPUTED FOR THE CIRCUIT,
C WHICH WILL BE CORRECT FOR THE COMPUTED INDUCTANCE.  IF L IS NOT SET EQUAL
C TO ZERO, THE CAPACITANCE WILL BE COMPUTED USING THE GIVEN INDUCTANCE.  FOR
C THIS CASE L SHOULD BE SPECIFIED IN HENRIES.
      L=0.
C IN THE READ STATEMENT:  A=MACHINE CODE, B=OPERATION CODE,V=MEASURED OUTBY
C LINE TO LINE VOLTAGE IN VOLTS, I=MEASURED PHASE CURRENT IN AMPERES, PF=
C MEASURED POWER FACTOR, FREQ=FORCED FREQUENCY IN HERTZ, Z=MAGNITUDE OF THE
C TOTAL TRAILING CABLE IMPEDANCE IN OHMS
C IF THE MEASURED OUTBY VOLTAGE IS D.C. IT SHOULD BE SPECIFIED AS A LINE TO
C NEUTRAL VOLTAGE, IN VOLTS
      READ,A,B,V,I,PF,FREQ,Z
C I IS THE SCALED CURRENT USED TO COMPUTE THE RLC EQUIVALENT CIRCUIT
      I=I/N
      IF(Y.EQ.A) GO TO 2
```

```
Y=Y+1.
WRITE(6,100)
WRITE(6,110)
WRITE(6,120)
WRITE(6,130)
WRITE(6,140)
WRITE(6,150)
WRITE(6,160)
WRITE(6,170)
WRITE(6,180)
WRITE(6,190)
WRITE(6,200)
WRITE(6,210)
WRITE(6,220)
WRITE(6,230)
```

```
WRITE(6,240)
WRITE(6,250)
WRITE(6,260)
WRITE(6,270)
WRITE(6,280)
WRITE(6,290)
WRITE(6,300)
WRITE(6,310)
WRITE(6,320)
WRITE(6,330)
WRITE(6,340)
WRITE(6,350)
WRITE(6,360)
WRITE(6,370)
WRITE(6,380)
```

```
      WRITE(6,15)
 15   FORMAT('1')
      WRITE(6,14) K
 2    CONTINUE
C  V IS THE COMPUTED INBY LINE TO NEUTRAL VOLTAGE (UTILIZATION VOLTAGE
      IF(FREQ.EQ.0.) GO TO 3
      V=V/1.732-I*Z
      GO TO 4
 3    V=V-I*Z
 4    CONTINUE
            CALL RLCMOD(R,L,C,P,QL,QC,Q,XL,XC,THETA,PHI,DEL)
      C=C*1000000.
      R=R/1000.
 14   FORMAT(' ','K=',F4.2)
      WRITE(6,1)A,B,V,FREQ,N,I,R,L,C
```

```
 1    FORMAT('0',I2,2X,I2,2X,F10.5,' V  ',F6.0,' HZ  ',F6.0,2X,F13.6,
     1' A  ',F15.5,' KOHMS  ',F15.5,' H  ',F15.5,' UF')
C  I IS THE CURRENT WHICH WILL FLOW IN THE RLC MODEL AT AN IMPRESSED VOLTAGE OF
C  440 V LINE TO LINE OF A BALANCED 3-PHASE WYE CONNECTED SOURCE
      IF(FREQ.EQ.0.) GO TO 7
      I=440./(((R*1000.)**2+XL**2+XC**2)**.5)  *.57735
C  P IS THE POWER DISSIPATED IN THE RESISTOR OF THE RLC MODEL.  (I**2R LOSSES)
      P=I**2*R*1000.
 8    CONTINUE
      WRITE(6,16)P,I
 16   FORMAT('0',15X,F10.4,' WATTS',5X,F10.4,' A')
 100  FORMAT('1')
 110  FORMAT(' ','MACHINE CODE',45X,'OPERATION CODE')
 120  FORMAT('+','____________',45X,'______________')
 130  FORMAT('-')
```

```
140  FORMAT('0',2X,'1',2X,'F6A CONTINUOUS MINER',22X,'1',3X,'START HYDR
    1AULIC CIRCUIT MOTOR')
150  FORMAT('0',2X,'2',2X,'JOY 8CM CONTINUOUS MINER',18X,'2',3X,'IDLING
    1 HYDRAULIC CIRCUIT MOTOR')
160  FORMAT('0',2X,'3',2X,'JOY 10CM CONTINUOUS MINER',17X,'3',3X,'START
    1ING CUTTING MOTORS')
170  FORMAT('0',2X,'4',2X,'JOY 10CM CONTINUOUS  MINER',16X,'4',3X,'STAR
    1TING CONVEYOR MOTOR')
180  FORMAT('0',2X,'5',2X,'JOY 18SC SHUTTLE CAR',22X,'5',3X,'CUTTING AN
    1D LOADING')
190  FORMAT('0',2X,'6',2X,'TORKAR 48S SHUTTLE CAR',20X,'6',3X,'TRAMMING
    1')
200  FORMAT('0',2X,'7',2X,'FLETCHER LT00-15 ROOF BOLTER',14X,'7',3X,'MA
    1NEUVERING')
210  FORMAT('0',2X,'8',2X,'GALIS 300 ROOF BOLTER',21X,'8',3X,'TRAMMING
```

```
     1AND MANEUVERING')
220   FORMAT('0',2X,'9',2X,'GALIS 320 ROOF BOLTER',21X,'9',3X,'LOADING,
     1WITH CUTTING MOTORS OFF')
230   FORMAT('0',2X,'10',1X,'GALIS 320A ROOF BOLTER',20X,'10',2X,'STARTI
     1NG MOTOR')
240   FORMAT('0',47X,'11',2X,'DRILLING AND BOLTING')
250   FORMAT('0',47X,'12',2X,'TRAMMING (RB)')
260   FORMAT('0',47X,'13',2X,'TRAMMING EMPTY')
270   FORMAT('0',47X,'14',2X,'TRAMMING LOADED')
280   FORMAT('0',47X,'15',2X,'LOADING')
290   FORMAT('0',47X,'16',2X,'UNLOADING')
300   FORMAT('0',47X,'17',2X,'DRILLING')
310   FORMAT('0',47X,'18',2X,'BOLTING')
320   FORMAT('0',47X,'19',2X,'MANEUVERING (RB)')
330   FORMAT('0',47X,'20',2X,'IDLING MOTOR (RB)')
```

```
340   FORMAT('0',47X,'21',2X,'TRAMMING AND MANEUVERING (RB)')
350   FORMAT('0',47X,'22',2X,'CHANGING STEEL')
360   FORMAT('0',47X,'23',2X,'INSTALLING BOLT')
370   FORMAT('0',47X,'24',2X,'IDLING (RB)')
380   FORMAT('0',47X,'25',2X,'TOURQUE BOLT')
      GO TO 5
7     I=300./(R*1000.)
      P=I**2*R*1000.
      GO TO 8
5     CONTINUE
      STOP
      END
```

SUBPROGAM

```
      SUBROUTINE RLCMOD(R,L,C,P,QL,QC,Q,XL,XC,THETA,PHI,DEL)
C  SUBROUTONE RLCMOD CALCULATES THE EQUIVALENT RLC SERIES CIRCUIT OF A
C  SYSTEM WITH GIVEN VOLTAGE, CURRENT,POWER FACTOR, FREQUENCY.
C IT CAN ALSO RETURN VALUES FOR REAL POWER,P; REACTIVE POWER,Q COMPOSED OF ITS
C  CAPACITIVE AND INDUCTIVE COMPONENTS,QC &QL; INDUCTIVE REACTANCE,XL;
C  CAPACITIVE REACTANCE,XC;PHASE ANGLE, THETA: PHASE ANGLE OF EQUIVALENT
C  CIRCUIT,PHI;THE DIFFERENCE BETWEEN THE MEASURED AND CALCULATED PHASE ANGLE,
C  DEL
      IMPLICIT REAL(A-Z)
      COMMON V,I,PF,FREQ,K
C  CONVERT FORCED FREQUENCY TO ANGULAR FREQUENCY
      FREQ=FREQ*6.2834
      IF(FREQ.EQ.0.) GO TO 15
      R=V/I*PF
      P=I**2*R
      IF(L.NE.0.) GO TO 10
      L=K*V/(FREQ*I)*SQRT(1.-PF**2)
      IF(K.EQ.1.) GO TO 11
```

```
10    C=I/((I*FREQ**2*L)-(FREQ*V*SQRT(1.-PF**2)))
12    CONTINUE
      IF(C.EQ.0.) GO TO 13
      XC=1./(FREQ*C)
14    CONTINUE
      XL=FREQ*L
      QL=I**2*XL
      QC=I**2*XC
      Q=QL+QC
       THETA=ARCOS(PF)*57.3
      PHI=(ATAN((XL-XC)/R))*57.3
      DEL=(THETA-PHI)/THETA*100.
      RETURN
15    R=V/I
      P=I**2*R
```

```
      C=0.
      L=0.
      QL=0.
      QC=0.
      Q=0.
      THETA=0.
      PHI=0.
      DEL=0.
      RETURN
11    C=0.
      GO TO 12
13    XC=0.
      GO TO 14
      END
```

Table 12. Input Data Codes, a and b.

MACHINE CODE

1 F6A Continuous Miner
2 Joy 8CM Continuous Miner
3 Joy 10CM Continuous Miner
4 Joy 10CM Continuous Miner
5 Joy 18SC Shuttle Car
6 Torkar 48S Shuttle Car
7 Fletcher LTDO-15 Roof Bolter
8 Galis 300 Roof Bolter
9 Galis 320 Roof Bolter
10 Galis 320A Roof Bolter

OPERATION CODE

1 Start hydraulic circuit motor
2 Idling hydraulic circuit motor
3 Starting cutting motors
4 Starting conveyor motor
5 Cutting and loading
6 Tramming
7 Maneuvering
8 Tramming and maneuvering
9 Loading, with cutting motors off
10 Starting motor
11 Drilling and bolting
12 Tramming (RB)
13 Tramming empty
14 Tramming loaded
15 Loading
16 Unloading
17 Drilling
18 Bolting
19 Maneuvering (RB)
20 Idling motor (RB)
21 Tramming and maneuvering (RB)
22 Changing steel
23 Installing bolt
24 Idling (RB)
25 Torque bolt

Table 13. Input Data Format

A B V I P.F. F Z

Free formatting is utilized.

A minimum of one blank space must be inserted between each variable.

where: A = Machine code, Integer Field

B = Operation code, Integer Field

V= Measured line to line voltage in volts, Real Field

I = Measured phase current in amperes, Real Field

P.F. = Measured power factor, Real Field

F = Forced system frequency in hertz, Real Field

Z = Total trailing cable impedance from monitoring point to machine in ohms, Real Field

Table 14. Computer Program Input Data

```
1 3 459. 61. .56 60. .0986
1 5 464. 42. .57 60. .0986
1 6 470. 17. .86 60. .0986
2 2 454. 83. .68 60. .06184
2 5 445. 354. .55 60. .06184
2 6 465. 132. .65 60. .06184
2 7 458. 102. .60 60. .06184
2 9 465. 147. .60 60. .06184
3 2 500. 60. .40 60. .03865
3 3 495. 304. .46 60. .03865
3 4 498. 212. .59 60. .03865
3 5 490. 315. .74 60. .03865
  3 6 500. 114. .84 60. .03865
3 7 500. 114. .72 60. .03865
4 2 1085. 35. .30 60. .03865
```

```
4 3 1040. 200. .54 60. .07865
4 4 1060. 207. .42 60. .07865
4 5 1055. 220. .45 60. .07865
4 6 1076. 42. .51 60. .07865
4 7 1090. 42. .50 60. .07865
5 13 320. 14. 0. 0. .1085
5 14 313. 24. 0. 0. .1085
5 15 316. 10. 0. 0. .1085
5 16 318. 11. 0. 0. .1085
6 14 450. 60. .45 60. .1095
6 15 453. 34. .949 60. .1095
6 16 450. 54. .25 60. .1095
6 13 448. 41. .35 60. .1095
7 11 580. 25. .52 60. .1095
7 12 575. 25. .60 60. .1095
```

```
8 20 460. 26. .46 60. .1095
8 18 460. 32. .62 60. .1095
8 17 460. 39. .81 60. .1095
8 21 460. 29. .56 60. .1095
9 17 495. 36. .61 60. .1765
9 17 495. 39. .72 60. .1765
9 19 490. 33. .56 60. .1765
9 22 495. 27.5 .57 60. .1765
9 23 490. 26. .39 60. .1765
9 23 490. 27. .38 60. .1765
9 24 490. 26. .39 60. .1765
10 12 500. 41. .27 60. .2118
10 17 500. 58. .38 60. .2118
10 24 500. 42. .29 60. .2118
10 20 500. 32. .18 60. .2118
```

Table 15. Computer Program Sample Output Format

```
K=1.00

 4   2   626.37540 V     377. HZ  20.          1.750000 A 0.10738 KOHMS 0.90567 H   0.00000 UF

                    54.0890 WATTS        0.7097 A

 4   3   599.67500 V     377. HZ  20.         10.000000 A 0.03238 KOHMS 0.13388 H   0.00000 UF

                   581.1145 WATTS        4.2362 A

 4   4   611.19480 V     377. HZ  20.         10.349990 A 0.02480 KOHMS 0.14215 H   0.00000 UF

                   458.9800 WATTS        4.3018 A

 4   5   608.25680 V     377. HZ  20.         11.000000 A 0.02488 KOHMS 0.13098 H   0.00000 UF

                   525.1726 WATTS        4.5941 A

 4   6   621.08150 V     377. HZ  20.          2.099999 A 0.15083 KOHMS 0.67479 H   0.00000 UF

                   111.2820 WATTS        0.8589 A

 4   7   629.16470 V     377. HZ  20.          2.099999 A 0.14980 KOHMS 0.68822 H   0.00000 UF

                   107.6983 WATTS        0.8479 A
```