SINGLE-PHASE INDUCTION MOTOR

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DESIGN OF A SINGLE-PHASE INDUCTION MOTOR

A THESIS

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Contents.

Design of a single phase motor.

Part 1. Introduction.

Part 2. Specifications.


Part 5. Results of test with curves and tabulated data.
This work is presented with the idea that the design of a split phase motor of large output in relation to size of machine could be accomplished by proper arrangement of parts to bring the greatest possible air circulation in and about those such pieces as are likely to reach limiting temperatures.

The frame of the machine is built up of castings which are not complex and present an easy job for the machine shop. The bearing surfaces are large insuring long life. Lubrication is by a ring dipping into a can of oil, dust is kept out of all oil passages by felt washer on the shaft at either end of bearing housing.
Part 2

Max. rise of t... 16 60. Cent.
Supply: 60 c. plus, 110 volts 1.5.
Speed (full load) 1,600 r.p.m.
Eff. (full load) 75%

Over resistor 75%
The circle diagram can be applied to design of a single-phase motor, but the operating range comes so near the origin that data to be derived from it are subject to too more error than is permissible, hence the design must attempted by other methods. An analysis of how motor action is produced revolves what is called the quadrature field. It is action between the transformer field and quadrature field that produces rotation. The transformer field arises directly from the line current in the stator winding, while the quadrature field arises only after the motor has come up to speed. As the inductors on the rotor cut the main transformer field currents are induced in them due to the impedance of these paths being nearly all reactance, the currents are in time quadrature with the induced e.m.f. This in turn puts the two fields in time and space quadrature. It will be upon the above assumptions that calculations or design will be made together with certain constants of reliable source.
CIRCUIT OF STEEL SECTIONS.

AIR-GAP TURNS FOR THE AIR-GAP.

The expression showing the ampere turns required to send flux across the air-gap is as follows:

\[ AT = 0.0003 B a \]

where \( a \) is the effective length of air-gap and \( B \) is the flux density.

For this calculation, \( a = 0.02 \) in.
\[ B = 10000 \text{ lines per in} \]

\[ AT = 0.0003 \times 10000 \times 0.02 = 0.06 \text{ per pole} \]

AIR-GAP TURNS FOR THE SPEED FIELD.

Theory and practice confirm the fact that at synchronous speed the two fields of a single-phase motor are equal. Below synchronous speed the speed field weakens directly as the slip decreases. Because of the small slip on these machines for figuring the two will be assumed equal.

Hence \( AT \) total for the air-gap:

\[ = 0.06 = 0.0 \text{ per pole} \]
CALCULATIONS.

AIR gap TURNS FOR THE TEETH.

The reluctance of the teeth is a small percentage of the total magnetic circuit and because of the low flux density it is not likely that tooth density will approach saturation. In case any large percentage of the air-gap flux traverses the slots then the ampere turns for this part of the magnetic would have to be taken into account. So that for trial not attempt will be made to ascertain this part.

AIR gap TURNS FOR THE YOKE.

This also is a very small part of the total reluctance of the magnetic circuit and will be neglected as always more material is put into this part of the machine for mechanical strength that would be required for electrical purposes. And as many previous designs bear out this fact it not considered essential that it be known.
At this point it will become necessary to decide the number of slots in the stator laminations. The accompanying drawing shows a satisfactory pattern which can be purchased, all dimensions being given on the drawing.

There being 16 slots the winding can be arranged in pyramid form in four pairs or slots per pole. The factor for four pair of slots to use numerical interpretation of air-gap flux is 0.633.

The total ampere turns for a full pitch winding will have to be increased as given by the following equation:

\[
\text{AT total} = \frac{633}{0.633} \text{ amp. per pole}
\]

The accompanying drawing, Fig. 2, shows the graphical method of determining the winding turns for each pair of slots. Results are tabulated below.

*Gray's Electrical Machine Design.
CALCULATIONS

RUNNING COILS

Since slots are \( \frac{7}{16"}{\times}\frac{7}{4"} \) this area will accommodate 34 turns of \#14 D. C. magnet wire. But to insure less crowding of conductors and lessen the danger of insulation break down \#14 D. C. wire will be used for the running winding.

STARTING COILS

In the space left in pairs of slots i.e. No. 5 and No. 4, is placed the starting coils. It is desirable to have as much phase displacement as possible, and as the current in the starting winding will be of low power factor at the start, the remaining choice is to have the current in the starting winding near unity power factor. By having a preponderance of resistance to the starting winding, the effect of a rotating field will be less.
CALCULATIONS

MENDING DIA.

MENDING COILS: Total turns, 120 to 260 s.s.d.c.

1st slot: 10 turns
2nd slot: 20 turns
3rd slot: 30 turns
4th slot: 15 turns

MENDING COILS: Total turns, 180 to 280 s.s.d.c.

2nd slot: 60 turns
3rd slot: 30 turns

MENDING COILS: Total

\[ T = \varepsilon \varphi \]

\[ I = 7.00 \text{ amp.} \]
Diameter of rotor space 6 in.
length of core 5 in. The torque
to be developed is figured from the
horse power output.

\[
T = \frac{0.20 \times 1200}{1700} \approx 0.15 \text{ ft lb}
\]

The rotor pattern is also shown
in Fig. 2. The force at center line
of rotor bars is wound to be io
rounds.

The force acting on an inductor
carrying current in a field of
strength B is

\[
F = Bli
\]

\[
103800 \times 6000 \times 1200 \times \frac{1}{10}
\]

\[
i = 190
\]

\[
\text{magnetizing field current}
\]

\[
\text{flux density or speed field}
\]

\[
3 \times \frac{2}{10} = 18000 \times \frac{10}{10}
\]
CALCULATIONS

E. M. F. equation for quadrature field inductors as follows:

\[ v = BIV \quad V = \text{peripheral speed} \]

\[ = 13000 \times 400 \times 10 \]

\[ = 520 \text{ volts} \]

Resistance of quadrature field circuit per pole

\[ \frac{L}{1} = \frac{0.875}{130} = 0.006 \text{ ohms} \]

THE INDUCTION OF ROTOR CAGE

The power developed by the motor is in large part dependent on the rotor. Being of the squirrel cage type e.m.f.'s, induced in the rotor conductors are small and in order to make the quadrature field as large as possible a low resistance path is essential.
**CALCULATIONS**

**Length of Quadrature Field Circuit**

Circuit is figured as follows:

- Diameter of rotor, 9 in.
- Length of core, 3 in.
- Quarter circumference of rotor inducer circuit

\[
\frac{\pi \times 1.44}{4} = 4
\]

\[
3 \times 4 + 3 \times 5 = 30
\]

\[
I = \frac{L}{A}
\]

For copper \( I = 10.0 \) A in circular mills

\( L \) in inches.

Since cross in. solder entering into the circuit the value of \( A \) will be increased to 14.0

\[
0.003 = 14\pi \times \frac{15}{100}
\]

\[
A = 20000
\]

This is a conductor whose cross section is one in. in diameter. From Fig. 2 it will be seen that only 4 in. of copper per pole have induced voltage due to rotation, therefore the cross section of the equivalent quadrature field circuit will be subdivided into 4 parts, making the cross section per inducer 0.77
The size of rotor inductor will be as lightly determined

\[
\frac{0.71}{50.9} = 0.0014
\]

This area will be increased to .11 sq. in. This oversize to the rotor bars provides for overload. These three-eighths bars are rolled that till the thickness between parallel races is seven thirtyseconds of an inch. These are also set endwise in the rotor slots as shown in Fig. 2 and not insulated.

The core loss iron curves of frequency and flux density will be about .3 watts per pound weight of laminated iron.

\text{Weight of laminated iron} = 45 \text{ lbs.}

\text{.3} \times 45 = 22.5 \text{ watts}

**Friction and Wearage Losses**

From data obtained iron losses in this loss is taken as 25 lbs.

**Copper Losses. (Stator)**

Two pounds of copper is 2 lbs. wire will be required for the winding of the stator, the resistance of which will be .70 ohms. With full load current of 11 amperes copper loss and the stator will be 30.5 watts.
LOSSES

Quadrature Losses (Rotor)

The current to excite the quadrature field in the rotor forms a constant loss, so that as roughly estimated will be

\[ 190^2 \times 0.014 \]

\[ 0.0000 \times 0.014 = 0.0 \text{ watts} \]

Due to increased size of rotor inductors, the resistances will vary inversely as the cross sections. The constant 0.003 is reduced to 0.0014 as follows:

\[ \frac{0.003}{0.077} = \frac{0.003}{0.0014} \]

\[ 0.003 = \text{final area of quadrature circuit.} \]

The current set up in the rotor due to transformer action is small in this machine due to its small slip and will be roughly estimated as equal to the quadrature field loss.

Total rotor copper loss = 100 watts

Total copper losses = 190.0 "
Friction and Windage Losses = 20 "
Iron Losses = 22.0 "

TOTAL LOSSES = 252.0 "
<table>
<thead>
<tr>
<th>Dimension</th>
<th>Calculated Value</th>
<th>Value As Finally Determined</th>
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</thead>
<tbody>
<tr>
<td>No of Poles</td>
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<td>4</td>
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<td>Speed r.p.m.</td>
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<td>1750</td>
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<tr>
<td>Voltage</td>
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<td>108</td>
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<tr>
<td>Outside Dia. Stator</td>
<td>8&quot;</td>
<td>8&quot;</td>
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<tr>
<td>Inside Dia</td>
<td>5&quot;</td>
<td>5&quot;</td>
</tr>
<tr>
<td>Size Slots</td>
<td>3/6&quot; x 1/2&quot;</td>
<td>7/6 x 3/4&quot;</td>
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<tr>
<td>Slot Opening</td>
<td>1/8&quot;</td>
<td>1/6&quot;</td>
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<tr>
<td>No of Slots</td>
<td>32</td>
<td>32</td>
</tr>
<tr>
<td>Outside Dia. Rotor</td>
<td>5&quot; .050&quot;</td>
<td>5&quot; .030&quot;</td>
</tr>
<tr>
<td>Dia. Rotor Spider</td>
<td>2&quot;</td>
<td>2&quot;</td>
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<tr>
<td>Size Rotor Slots</td>
<td>3/8&quot; D</td>
<td>3/32&quot; x 1/2&quot;</td>
</tr>
<tr>
<td>Slot Opening</td>
<td>1/16&quot;</td>
<td>1/16&quot;</td>
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<tr>
<td>No of Slots</td>
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<td>32</td>
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<tr>
<td>Length of Stator</td>
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<tr>
<td>Length of Rotor</td>
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<td>2.75&quot;</td>
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<td>Size Rotor Bars</td>
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<td>Brass</td>
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<td>End Rings</td>
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<td>End Ring Thickness</td>
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<td>1/4</td>
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<td>Running Coils</td>
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<tr>
<td>Size Wire</td>
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<tr>
<td>No of Turns</td>
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<tr>
<td>Second Slot</td>
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<tr>
<td>Third Slot</td>
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<tr>
<td>Fourth Slot</td>
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<tr>
<td>Starting Coils</td>
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<td>Size Wire</td>
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<tr>
<td>Third Slot</td>
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Winding Diagram Showing Starting and Running Coils
Winding arranged in four pairs of slots
Fig. 1
<table>
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<tr>
<th>VOLTS</th>
<th>AMP.</th>
<th>WATTS INPUT</th>
<th>POWER FACTOR</th>
<th>VOLT AMP.</th>
<th>FRICTION LOSS WATTS</th>
<th>BRAKE I^2R LOSS</th>
<th>PRIMARY I^2R LOSS</th>
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<tr>
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<td>250</td>
<td>.265</td>
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<td>108</td>
<td>7</td>
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<td>49</td>
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<td>100</td>
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<td>155</td>
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<td>630</td>
<td>21</td>
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<td>140</td>
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<td>518</td>
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<td>100</td>
<td>.244</td>
<td>410</td>
<td>21</td>
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<td>25</td>
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<td>50</td>
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<td>21</td>
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<td>25</td>
<td>.415</td>
<td>60</td>
<td>21</td>
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<tr>
<td>Torque</td>
<td>Amperes</td>
<td>Volts</td>
<td>Kilowatts</td>
<td>Horsepower</td>
<td>R.P.M.</td>
<td>Power Factor</td>
<td>Eff. %</td>
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<td>0</td>
<td>7.5</td>
<td>109</td>
<td>.21</td>
<td>0</td>
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<td>.247</td>
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<td>.318</td>
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<td>.26</td>
<td>.104</td>
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<td>1.87</td>
<td>9.2</td>
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<td>.67</td>
<td>.61</td>
<td>1760</td>
<td>.675</td>
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<td>2.93</td>
<td>11.14</td>
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<td>.97</td>
<td>.95</td>
<td>1750</td>
<td>.785</td>
<td>73.0</td>
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<td>3.95</td>
<td>14.1</td>
<td>107.5</td>
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<td>4.98</td>
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